LUMINESCENCE DATING OF COLLUVIUM AND LANDSLIDE DEPOSITS IN HONG KONG
&
TOE SLOPE ANGLE OF NATURAL TERRAIN LANDSLIDES

GEO REPORT No. 134

J.P. King
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A.S.W. Choi, E.K.S. Fung, A.M.H. Law & J.P. King

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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Prepared by:

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

PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering Department (http://www.info.gov.hk/ced/) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

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R.K.S. Chan
Head, Geotechnical Engineering Office
June 2003

EXPLANATORY NOTE

This GEO Report consists of two Technical Notes in two separate research and development projects carried out by the Planning Division in 2001.

They are presented in two separate sections in this Report. Their titles are as follows:

SECTION 1: LUMINESCENCE DATING OF COLLUVIUM AND LANDSLIDE DEPOSITS IN HONG KONG

J.P. King

This report was originally produced in January 2001
as GEO Technical Note No. TN 1/2001

FOREWORD

This Technical Note summarises the basic principles of Luminescence dating and evaluates the newly developed Dose Distribution method of analysis. The results of Luminescence dating of colluvium in Hong Kong are reported and tentative dates ares proposed for a large colluvial lobe at Sham Wat, North Lantau. Recommendations are given for further evaluation of the dating technique.

The report was written by Mr J. King and edited by Dr K.C. Ng. It is mainly based on research by Dr A. Murray of the Nordic Laboratory for Luminescence Dating and Dr S.H. Li from the University of Hong Kong. Figures were prepared by Mr C. So and Mr K.C. Lau under the supervision of Mr K. K. Lau.

H.N. WONG
Chief Geotechnical Engineer/Planning

ABSTRACT

Some colluvial deposits in Hong Kong are believed to have been derived from landslides that were considerably larger than those described in the recent historical record. An understanding of their age and genesis is necessary to assess whether similar landslides could occur in the current environmental regime. This information is important if the risk from such events, and their return periods, need to be considered in engineering design.

Conventionally, recent superficial deposits such as colluvium are dated using radiocarbon (^{14}C) methods, which require the presence of organic matter. However, materials suitable for ^{14}C dating are rare in Hong Kong colluvium and this technique has not been able to provide the necessary dating information for colluvial deposits. The GEO has been investigating other dating methods. Average Response Luminescence Dating is a technique that has been developed in the last few years for establishing the length of time since a sediment was last exposed to sunlight. A more refined statistical technique of Dose Distribution Optically Stimulated Luminescence is currently being developed. The GEO has collaborated with the leading researchers in this field (Dr A. Murray of the Nordic Laboratory for Luminescence Dating and Dr S.H. Li from the University of Hong Kong) by providing samples of colluvium and control samples of recent landslide debris for testing.

This Technical Note summarises the luminescence-dating results obtained from colluvium samples in Hong Kong. These include both the Average Response and Dose Distribution methods and control samples of modern landslide debris. The Dose Distribution dates suggest that a large colluvium lobe (1 million m^3) on North Lantau has been deposited within the last 10,000 years, and may be as young as 2000 years. The results are subject to a certain degree of uncertainty due to the pioneering nature of this technique. To further evaluate the potential of the Dose Distribution method, additional trials should be carried out, and their results compared to dates obtained from other techniques.

CONTENTS

1. INTRODUCTION

Luminescence dating is based on the assessment of when material was last exposed to light. It can be applied to samples up to 500,000 years old. The technique is relatively well established for alluvial material but application to colluvial material is still largely experimental research. In 1996, the GEO commissioned the Aberystwyth Luminescence Laboratory to study the potential for luminescence dating Hong Kong colluvial deposits (Wintle and Duller, 1996). Subsequently the same laboratory carried out a luminescence-testing program that included two colluvial samples (Duller and Wintle, 1996). In 1997, colluvium samples from the Sham Wat Debris Lobe (King, 1998), and recent landslide debris, were sent to the Nordic Laboratory for Luminescence Dating. This testing is now complete and the results are reported in Murray (2000) at Appendix A. In parallel with this testing, other similar samples were dated by Dr S.H. Li of the Radio Isotope Unit of the University of Hong Kong. Some thermoluminescence dates have also been reported by the Guandong Laboratory of Quaternary Dating.

This Technical Note reviews the use of luminescence dating for colluvial and landslide debris deposits in Hong Kong and reports the dating results.

2. LUMINESCENCE DATING

The following account is summarised from Wintle and Duller (1996), Duller and Wintle (1996), Murray (2000) and discussions with Dr S.H. Li.

2.1 Basic Principles

Luminescence dating is based on the principle that when ionising rays from natural environmental radioactivity pass through certain minerals, particularly quartz, electrons are trapped in the mineral. Given a constant rate of environmental radiation, the number of trapped electrons will be time dependent. The electron traps can be "emptied" by exposure to daylight, a process known as bleaching. Thus the population of electrons trapped in a mineral grain indicates the time elapsed since it was last exposed to daylight.

If a mineral is stimulated by light, or raised temperature, some of the trapped electrons give up their stored energy by the processes know as Optically Stimulated Luminescence (OSL) or Thermo Luminescence (TL) respectively. Measurement of the energy released can be used to determine the trapped population and this, combined with measurements of the environmental radioactivity, allows calculation of how long ago the mineral was last exposed to daylight.

2.2 Thermoluminescence and Optically Stimulated Luminescence

Thermoluminescence dating is discussed in Wintle and Duller (1996). It was first used for dating pottery shards where the electron traps had been reset when the pottery was fired and is less sensitive than OSL for measurement of resetting by daylight. In general, OSL measures the most light sensitive signal and so should be more appropriate for dating colluvial sediments.

2.3 Luminescence Dating of Colluvium

Luminescence dating is relatively easy to use for windblown sands, or alluvium transported in shallow clear rivers, where all the mineral grains in a sample would have been well exposed to daylight and thoroughly bleached during transport. The application of this technique is much more difficult for landslide debris, including colluvium. Landslide movement is generally of short duration and may have occurred at night. Furthermore, the transport medium is often muddy slurry and only mineral grains that have remained on the surface of the slurry long enough will have been sufficiently bleached during the transport process. In general, bleaching of clean quartz grains requires exposure to bright daylight for at least 20 seconds and takes longer in less intense light or if coatings obscure the grains. Thus, very few grains in landslide debris are likely to be fully bleached. However, landslide debris will always contain part of the pre-existing land surface and grains at this surface should have been fully bleached. If the buried grains previously exposed at the surface, or bleached during transport, can be identified and dated, this should indicate when the landslide occurred.

2.4 Average Response and Dose Distribution Methods

Conventional luminescence dating techniques measure the luminescence response of single, or multiple samples (aliquots) of the material to be dated (Duller and Wintle 1996). This response will be the average of all the grains in the aliquot (typically many thousands of grains). Where the sample comprises grains that have all been completely bleached then this "average" measurement should give a reasonable representation of the age. However, colluvial samples that are assumed to originate from a landslide are likely to comprise a mixture of grains that may be anything from completely bleached to completely saturated. In this case, the "average" response is not likely to represent the date of the landslide that buried the sample but will depend on the ratio of bleached to unbleached grains in the aliquot.

The dose distribution method aims at solving the problems of poorly bleached materials such as colluvium. This method assumes that if a large number of sub-samples (up to say 200) each containing as few as 50 grains is tested, at least some of these will have a large enough proportion of grains that were bleached in the landslide that their response will reflect this event. The results from these multiple sub-samples can be plotted to show the dose distribution between them. The lowest values in the distribution can be taken as the best estimate of the true dose since the sample was bleached and can be used to calculate the age of this event (Murray, 2000). The dose distribution curves may show more than one peak and these can be interpreted to represent several events in which incomplete bleaching occurred. Such events could be partial exposure to sunlight during movement in a turbulent opaque medium (muddy slurry) or mixing of bleached surface materials with unbleached subsurface materials.

The dose distribution method was used by both Dr Murray and Dr Li to obtain the results given in this report (Appendices A & C). Dr Murray is currently developing a technique to obtain the response from single grains, which appears to be the ultimate development of the method.

3. LUMINESCENCE DATING OF COLLUVIUM IN HONG KONG

Four suites of luminescence dating tests of colluvial samples have been carried out in Hong Kong. The results are summarised in Table 1, where the 22 samples have been given sequential sample numbers for use in this Technical Note. The ages in thousands of years ago (Ka) are given with confidence limits that represent the aggregate of experimental error for each component of the analysis. In discussion of the dates in the text, the nearest whole number will be used for all dates greater than 3000 years.

3.1 Guandong Laboratory of Quaternary Dating

Thermoluminescence dates (TL) for seven samples have been given by the Laboratory of Quaternary Dating, Institute of Geochemistry (Guandong), Chinese Academy of Sciences. The details of the techniques employed were not provided. The results are reported in Fyfe *et al* (2000) and the details are given at Appendix B. Some of the results are listed and briefly discussed in Wintle and Duller (1996). Sample locations are shown on Figures 1, 2 and 3.

3.2 Aberystwyth Luminescence Laboratory

OSL dates for two samples are given in Duller and Wintle (1996). These samples were tested using a multiple aliquot method that measured the average response (OSLA). Sample locations are shown on Figures 2 and 4. The testing of modern analogue samples (recent landslide debris) was recommended to assess the applicability of the technique to colluvial samples.

3.3 Nordic Laboratory for Luminescence Dating

OSL dates for four colluvium samples from the Sham Wat Debris Lobe and two samples of recent landslide debris are given at Appendix A. These samples were tested using the dose distribution method and for each date involved measurements of between 144 and 276 individual sub-samples each comprising 50 to 200 grains. The Sham Wat sample locations are shown on Figure 5. The recent landslide debris was from the 1990 Tsing Shan Debris Flow (King, 1996) and the 1993 Liu Pok Landslide (King, 1997). The Nordic Laboratory is currently pioneering a method of luminescence dating using single grains and is using one of the Sham Wat samples for calibration of the new machine. Preliminary results suggest a similar dose distribution to that obtained using the 50-200 grain samples. (Dr Murray, pers.com.)

3.4 Radio Isotope Unit of the University of Hong Kong

OSL dates for six colluvium samples from the Sham Wat Debris Lobe and one sample of recent landslide debris from Liu Pok have been given by Dr Li of the Radio Isotope Unit of the University of Hong Kong (Appendix C). These samples were tested as part of a PhD study supervised by Dr Li (J. F. Zhang, 2000). The dose distribution method was used and each date involved the measurement of between 16 and 46 individual sub-samples each comprising 100-500 grains. The Sham Wat sample locations are shown on Figure 5.

4. ANALYSIS OF RESULTS

4.1 Thermoluminescence Samples

Seven thermoluminescence dating samples from three locations were tested by the Chinese Academy of Sciences. Sample 1 was taken from the relatively thick colluvial infill to a steep valley below Tai Mo Shan (Figure 1) and gave an age of 19 Ka. Samples 2, 3 and 4 were from the Mid-Levels colluvial lobes and aprons (Figure 2). Samples 3 and 4 are from the proximal part of the colluvial lobes below the Mid-Levels cliffs and gave dates of 27 and 61 Ka respectively. Sample 2 is from a more distal location and gave a younger age (10 Ka) but is located adjacent to Sample 8, which gave the considerably different OSLA date of 196 Ka (Section 4.2 below). Samples 5, 6 and 7 were from much thinner colluvial deposits up to 1.5 m deep on a coastal slope at the Shum Wan Road Landslide site (GEO, 1996; Figure 3). They were described as dense to very dense with mottled red brown and white, highly to moderately decomposed gravel and cobbles (GEO 1996). and gave ages of 35, 44 and 48 Ka.

4.2 Average Response Samples

Only two OSLA dates have been obtained (Duller and Wintle, 1996). One of 196 Ka for Sample 8 in the Mid-Levels mentioned above and one of 38 Ka for Sample 9 which was taken from a colluvial gully fill on the flanks of Fei Ngo Shan. Field descriptions of the colluvium are given at Appendix D. These OSLA results are for large aliquots from materials that probably comprise a mixture of grains that were at different levels of bleaching when they were deposited. It is difficult to assess the validity of these “average” results.

4.3 Modern Analogues

Duller and Wintle (1996) recommended the testing of modern analogue samples to confirm if the basic assumption is satisfied that landslide debris, and by implication colluvium, was exposed to daylight before deposition. This was done as part of the dose distribution OSL studies at the Nordic Laboratory and the University of Hong Kong. Samples 20 and 21 were taken from landslide debris deposits from a small channelized debris flow that occurred during daytime at Liu Pok Village in 1993 (King, 1997) and tested by both Hong Kong University and The Nordic Laboratory. A sample from the Tsing Shan Debris Flow, which occurred at night in 1990 (King, 1996), was also sent to the Nordic Laboratory. The Liu Pok samples gave dates of 600 years ago and 140 years ago respectively and the Tsing Shan Sample gave a date of 400 years ago. The two younger dates are from the Nordic Laboratory which used much larger numbers of sub-samples (190 and 144 as opposed to 20) to obtain the dose distribution. These results are discussed in detail in Appendix A and appear to show that the dose distribution OSL method is suitable for dating colluvial samples derived from landslide debris within a few hundred years. The residual ages recorded for the samples probably represent the current limits to the accuracy of the dose distribution method with confidence limits of up to 600 years. If a large number of sub-samples is used, an accuracy of better than 500 years may be expected.

4.4 Sham Wat Debris Lobe

Ten luminescence dates have been obtained from samples taken at the Sham Wat Debris Lobe. Four of the samples were tested at the Nordic Laboratory (Appendix A) and six at the University of Hong Kong (Appendix C). Both sets of tests were carried out using multiple sub-samples for interpretation using the dose distribution method. The number of sub-samples tested by the Nordic Laboratory was in the order of 200 for each sample while for the HKU tests this was 20 to 40. Thus, the results from the Nordic laboratory provide a better statistical basis for interpretation and selection of the most recent bleaching event(s). The dose distribution graphs for the samples are included in Appendices A and C, and the Nordic Laboratory results are discussed in Appendix A.

The Sham Wat Debris Lobe has been the subject of detailed mapping and ground investigation (King, 1998). From its morphology and materials, it was interpreted to be one of the most recently emplaced large colluvial deposits in Hong Kong. The sample depths and locations are shown on Figures 5 and 6 and geological logs are at Appendix E. All samples are from the colluvium forming the Debris Lobe except for Sample 19 which is from a white clayey sand at the base of the lobe that is interpreted to be of alluvial origin and pre-date the lobe. From interpretation of aerial photographs, a smaller southern part of the lobe appears to post-date the main lobe. Samples 10 and 11 are located in the southern lobe.

Figure 6 shows the interpreted age of the last bleaching event for each sample. The dates for colluvium samples range from 1.4 to 27 Ka. At several locations the age stratigraphy of the samples is reversed with older samples overlying younger samples. Murray (2000) suggests that they could be interpreted by averaging the results for each lobe which gives about 9 Ka (3 samples) for the main lobe and 1.4 Ka (only one sample) for the southern lobe. Using this averaging method and including the dates from HKU, gives about 14 Ka (7 samples) for the main lobe and 3.8 Ka (two samples) for the southern lobe.

Murray (2000) concluded that the best age estimate for the lobe can be obtained by averaging the ages of the interpreted last bleaching event. However, with a close examination of the dose distribution graphs, and consideration of the possible history of the materials in the lobe, the dates are amenable to other possible interpretations. Murray (2000) describes the peak in dose distribution as the last time the sample was significantly bleached. This suggests that the samples may have undergone more than one bleaching event and that such events may not have resulted in complete bleaching. Incomplete or no bleaching may quite understandably have occurred for some of the transported material during the emplacement of a large debris lobe such as Sham Wat. In this case the state of bleaching of any given sample from the lobe may reflect the event that emplaced the lobe or may reflect its previous history. The youngest sample obtained from the lobe would then indicate a maximum age for the lobe while the ages of all other samples indicate the last time in the sample's history that it was exposed to light.

This interpretation implies that the main northern lobe was deposited no more than 2.2 Ka and the southern lobe 1.4 Ka. It also suggests the northern lobe includes materials that were exposed at the surface from 9 to 27 Ka (southern lobe 6.3 Ka), then buried in colluvial or alluvial deposits that became source materials for the lobes. One difficulty with this explanation is that Sample 19 has been interpreted to be alluvial sand that underlies and pre-dates the lobe but gives an age of 18 Ka. Further testing at this location using a greater number, and preferably smaller sub-samples, would be statistically better and may help resolve the difficulty.

If the above interpretation is accepted, the inverted luminescence age stratigraphy provides strong evidence for the possibility that the lobe was emplaced as a single, or series of closely spaced events. Its gradual accumulation over time from more alluvial type of events should have resulted in a clearer age stratigraphy for the data.

5. CONCLUSIONS

5.1 Luminescence Dating

1. Luminescence dating of colluvium samples is possible using the dose distribution method. However, some independent control of the dates obtained is needed to confirm the accuracy of the method.

2. Dose distribution photoluminescence dates from recent landslide debris suggest this method can be used to date landslide debris to within a few hundred years.

3. Average response luminescence methods are most unlikely to give the date of emplacement of colluvium derived from landslide debris.

5.2 Sham Wat Debris Lobe

1. The dose distribution method shows that the last significant transport event at the Sham Wat Debris Lobe might have occurred within the last 10 Ka, possibly as recently as 1500 years ago.

2. The dating results have significant implications with respect to the assessment of risk from large, relict, natural terrain landslide features in Hong Kong. However, the dates are based on the largely experimental Dose Distribution Analysis of Optically Stimulated Photoluminescence data. This method should be further validated by additional trials.

6. RECOMMENDATIONS

6.1 Additional Trials

Additional trials of the dose distribution photoluminescence dating method should be carried out with samples from Sham Wat and other locations. The programme should include use of the newly developed single grain reader and “blind” samples of modern debris. The results should be compared to dates obtained from other techniques.

6.2 Possible Further Sample Sites

Further work should be carried out at the Sham Wat Debris Lobe to build on the work already completed at this site. Other suitable sites would be well-defined old landslides, which could be selected from the Large Landslide Study database and the debris lobes in the Natural Terrain Landslide Inventory. Sites could also be identified by aerial photograph interpretation at areas of thick colluvium deposits shown on geological maps. At large coastal landslides, the offshore deposits might provide some date constraints. Offshore boreholes that encounter colluvial deposits within the Holocene Hang Hau Formation could also be a source of samples. Material from existing cores or mazier samples from these sites could be suitable for dating.

6.3 Dating Techniques

Other dating techniques that may be useful for comparison with photoluminescence dates include use of cosmogenic isotopes, concentrated ^{14}C dating, weathering characteristics and stratigraphic relationships with other deposits.

(a) Cosmogenic isotope analysis gives information about when a surface (rock face or boulder) was first exposed at the ground surface and subject to cosmic radiation.

(b) Concentrated ^{14}C dating only requires very small amounts of carbon that can be concentrated from soil containing diffuse carbon. It may be possible to obtain such weakly carbonaceous material in Hong Kong colluvium.

(c) Weathering characteristics that may indicate age of colluvial deposits include the thickness of weathering rinds developed on clasts and degree of mottling in the matrix.

(d) Stratigraphic relationships between onshore deposits and the much better dated offshore deposits from the last 10,000 years, and comparative geomorphological interpretation from aerial photographs, may yield age relationships between well-defined deposits.

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LIST OF TABLES

Table 1 - Summary of Luminescence Dating of Colluvium Deposits in Hong Kong

No.	Sample No.	Locality	Landform	Laboratory Code	Test Type	Age Thousand Years B.P.
1	HK 11962	Shek Kong	Slope Deposit	IG TL18	TL	19.4 ± 1.6
2	HK 11966	High Street	Slope	IG TL22	TL	10.5 ± 0.9
3	HK 11964	Conduit Road	Slope	IG TL20	TL	26.6 ± 2.0
4	HK 11965	Kotewall Road	Slope	IG TL21	TL	61.0 ± 4.6
5	HK 11860	Shum Wan	Slope	IG TL1	TL	34.8 ± 2.8
6	HK 11942	Shum Wan	Slope	IG TL3	TL	43.6 ± 3.5
7	HK 11941	Shum Wan	Slope	IG TL2	TL	48.2 ± 3.9
8	HK 11981	High Street	Slope	A TP4A	OSLA	196.1 ± 12.6
9	HK 11984	Clearwater Bay Road	Slope	A TP6C	OSLA	37.8 ± 3.6
10	PL8 BH7	Sham Wat South Lobe	Debris Lobe	HK PL8	DD N=216	6.3 ± 1.1
11	PL7 E11	Sham Wat South Lobe	Debris Lobe	R 975001	DD N=276	1.4 ± 0.2
12	PL15 BH5	Sham Wat North Lobe	Debris Lobe	R 975002	DD N=226	2.2 ± 0.3
13	PL2 P1	Sham Wat North Lobe	Debris Lobe	R 985005	DD N=191	9.6 ± 1.5
14	PL12 BH2	Sham Wat North Lobe	Debris Lobe	R 985006	DD N=191	13.9 ± 1.7
15	PL14 BH5	Sham Wat North Lobe	Debris Lobe	HK PL14	DD N=16	9.9 ± 1.7
16	PL16 BH1	Sham Wat North Lobe	Debris Lobe	HK PL16	DD N=30	14.2 ± 1.6
17	PL17 BH1	Sham Wat North Lobe	Debris Lobe	HK PL17	DD N=41	23.3 ± 2.7
18	PL1 BH9	Sham Wat North Lobe	Debris Lobe	HK PL1	DD N=46	27.0 ± 3.2
19	PL2 BH9	Sham Wat North Lobe	Debris Lobe	HK PL2	DD N=46	18.0 ± 1.6
20	LO	Liu Pok	Landslide Debris	HK LO	DD N=20	0.6 ± 0.07
21	LPH	Liu Pok	Landslide Debris	R 985007	DD N=190	0.14 ± 0.005
22	TS3	Tsing Shan	Landslide Debris	R 985008	DD N=144	0.4 ± 0.048

Notes: Laboratory Code
- IG Laboratory of Quaternary Dating, Institute of Geochemistry (Guangzhou) Chinese Academy of Sciences
- A Aberystwyth Luminescence Laboratory
- R Nordic Laboratory for Luminescence Dating
- HK Radio Isotope Unit of the University of Hong Kong

Test Type
- TL Thermoluminescence Dating
- OSLA Optically Stimulated Luminescence "Average Response" Dating
- DD Optically Stimulated Luminescence "Dose Distribution" Dating. N = Number of sub-samples tested

LIST OF FIGURES

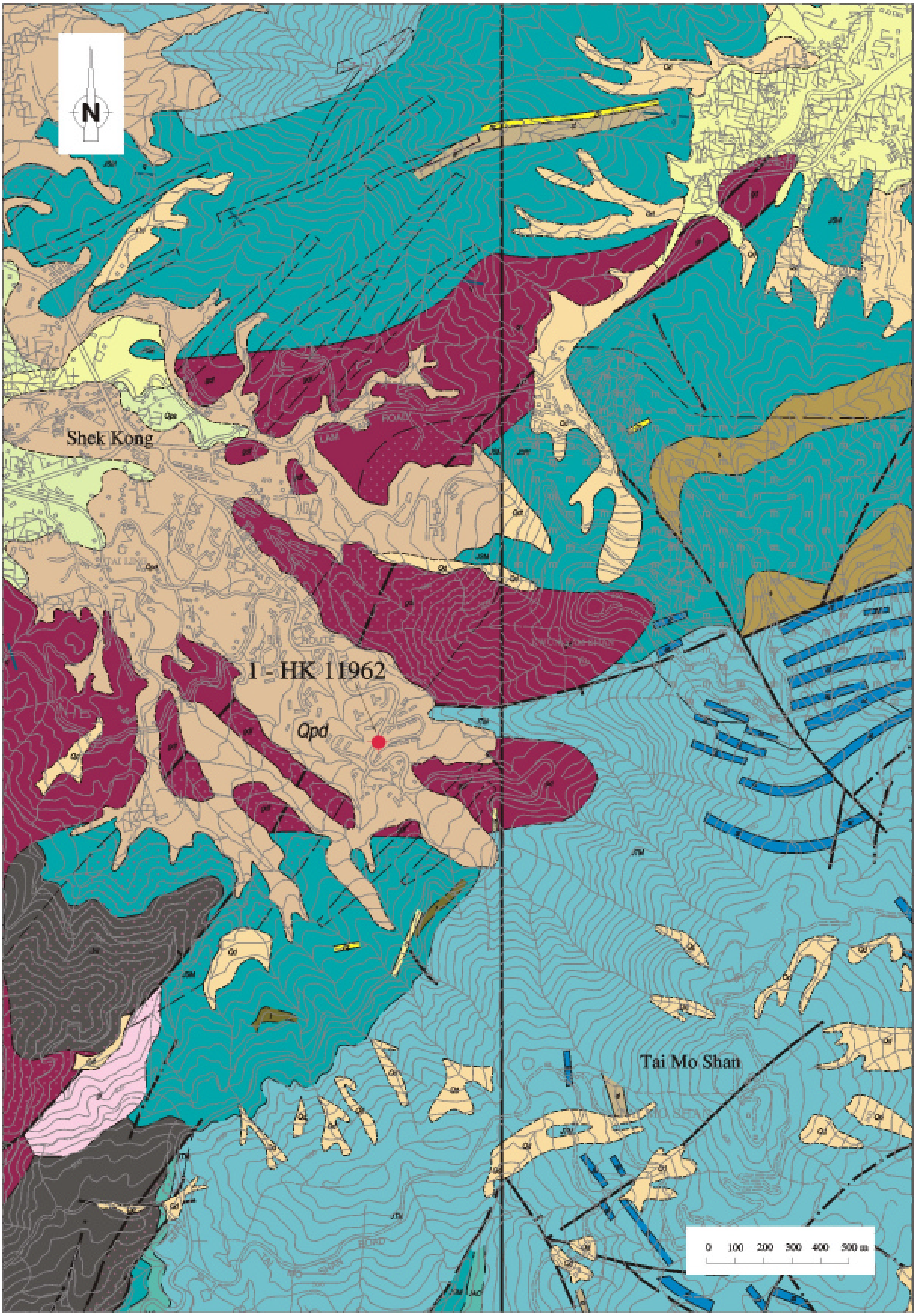

Figure 1 - Location Plan of Luminescence Dating Colluvium Sample 1

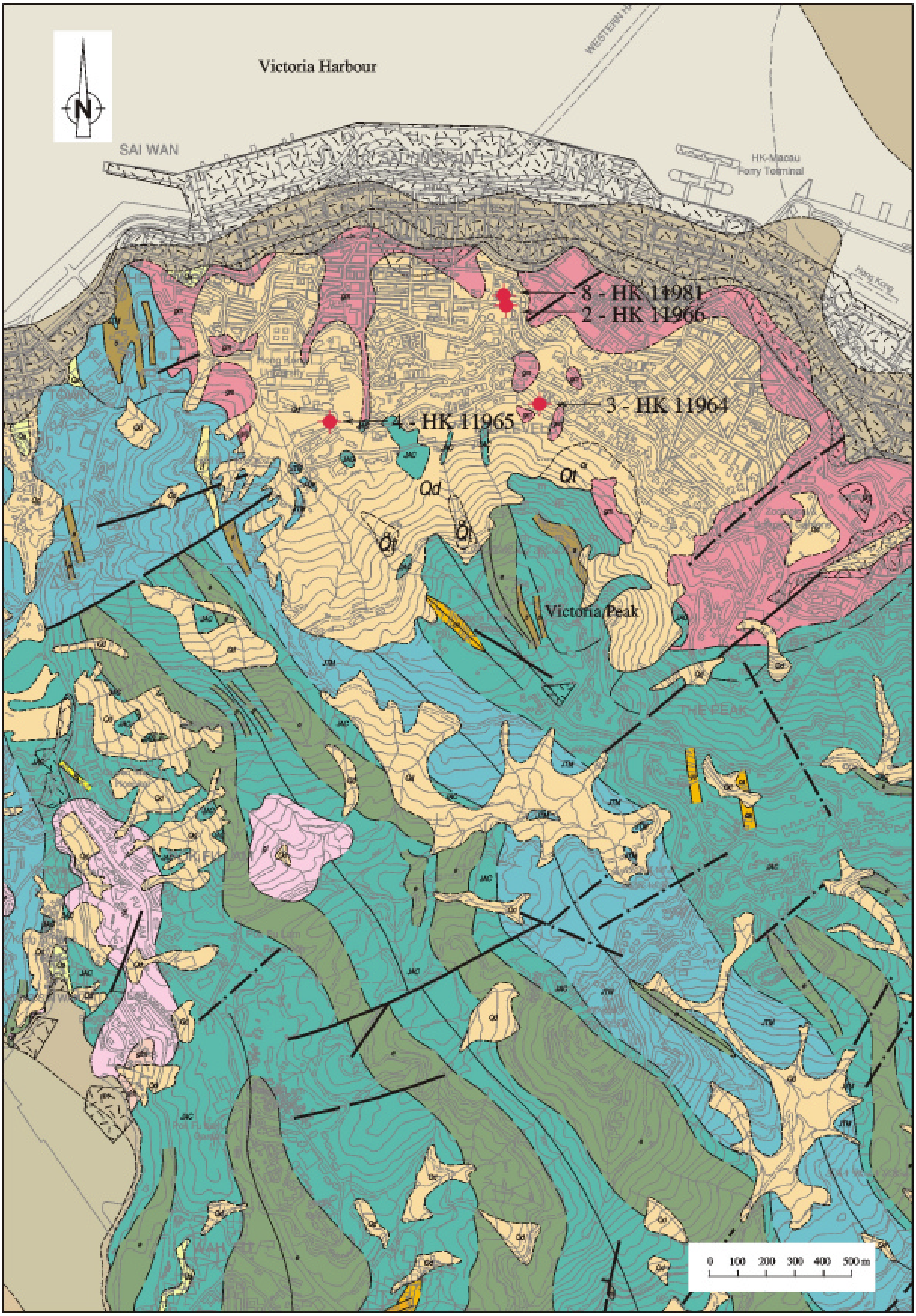

Figure 2 - Location Plan of Luminescence Dating Colluvium Samples 2,3,4,8

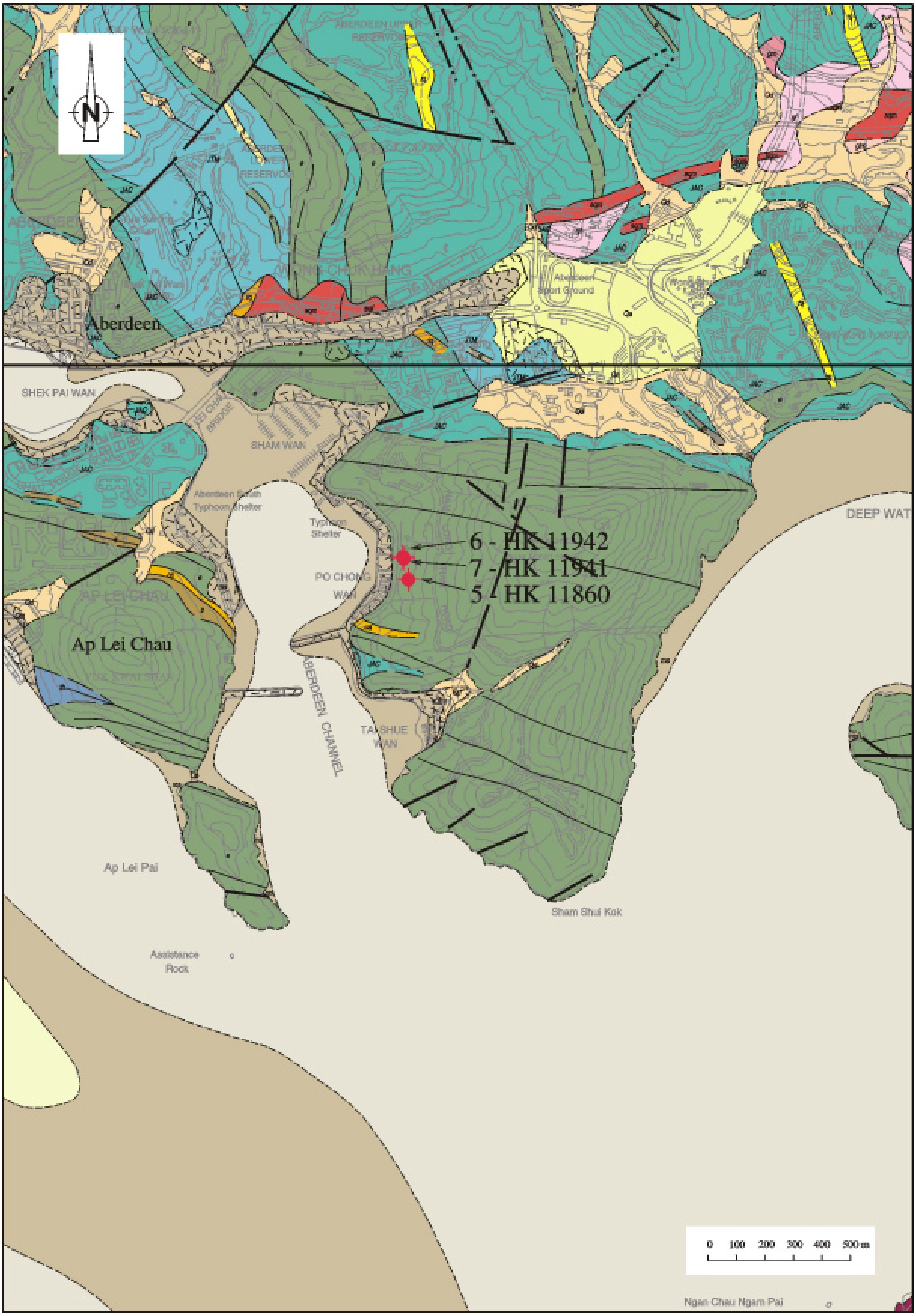

Figure 3 - Location Plan of Luminescence Dating Colluvium Samples 5,6,7

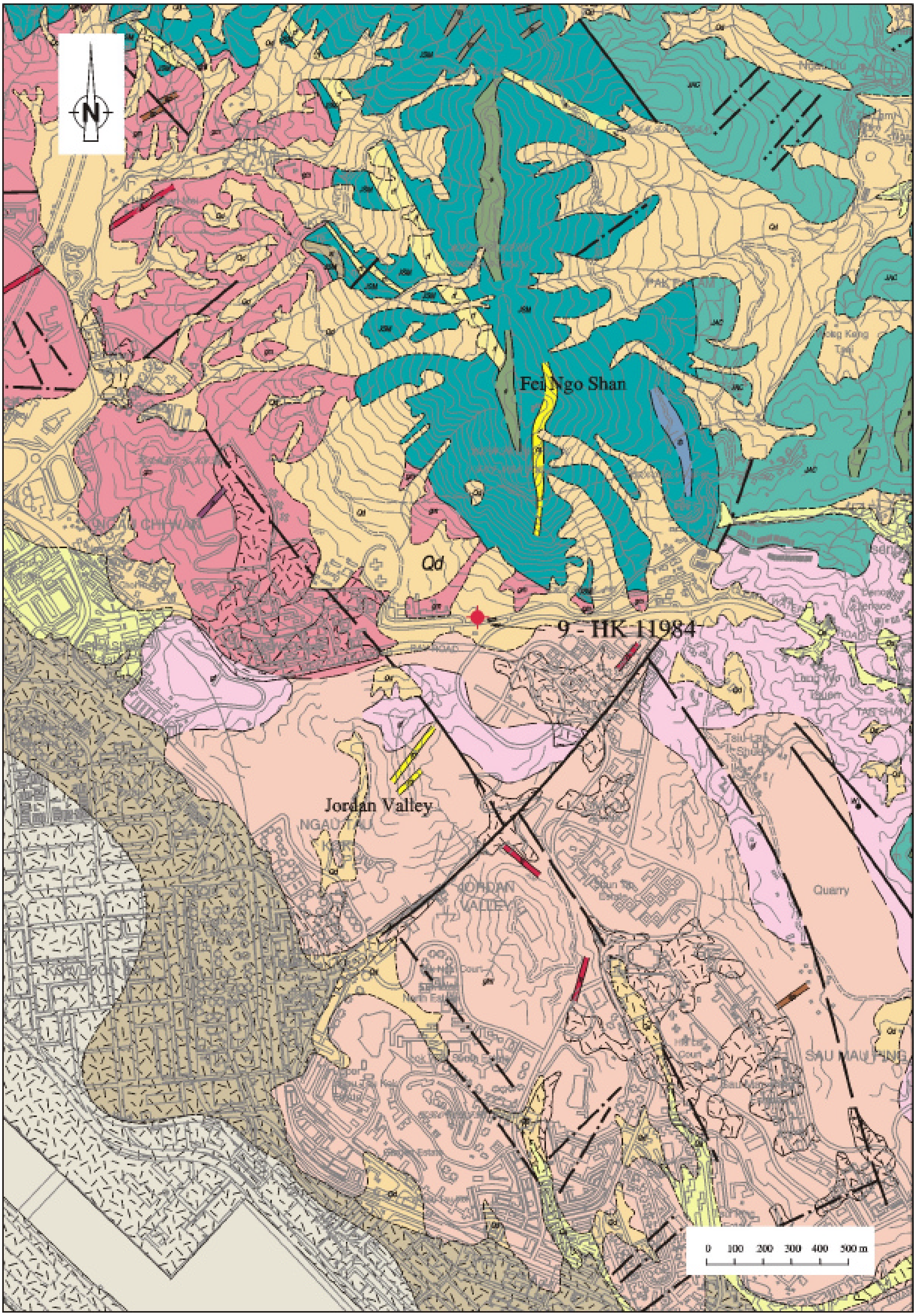

Figure 4 - Location Plan of Luminescence Dating Colluvium Sample 9

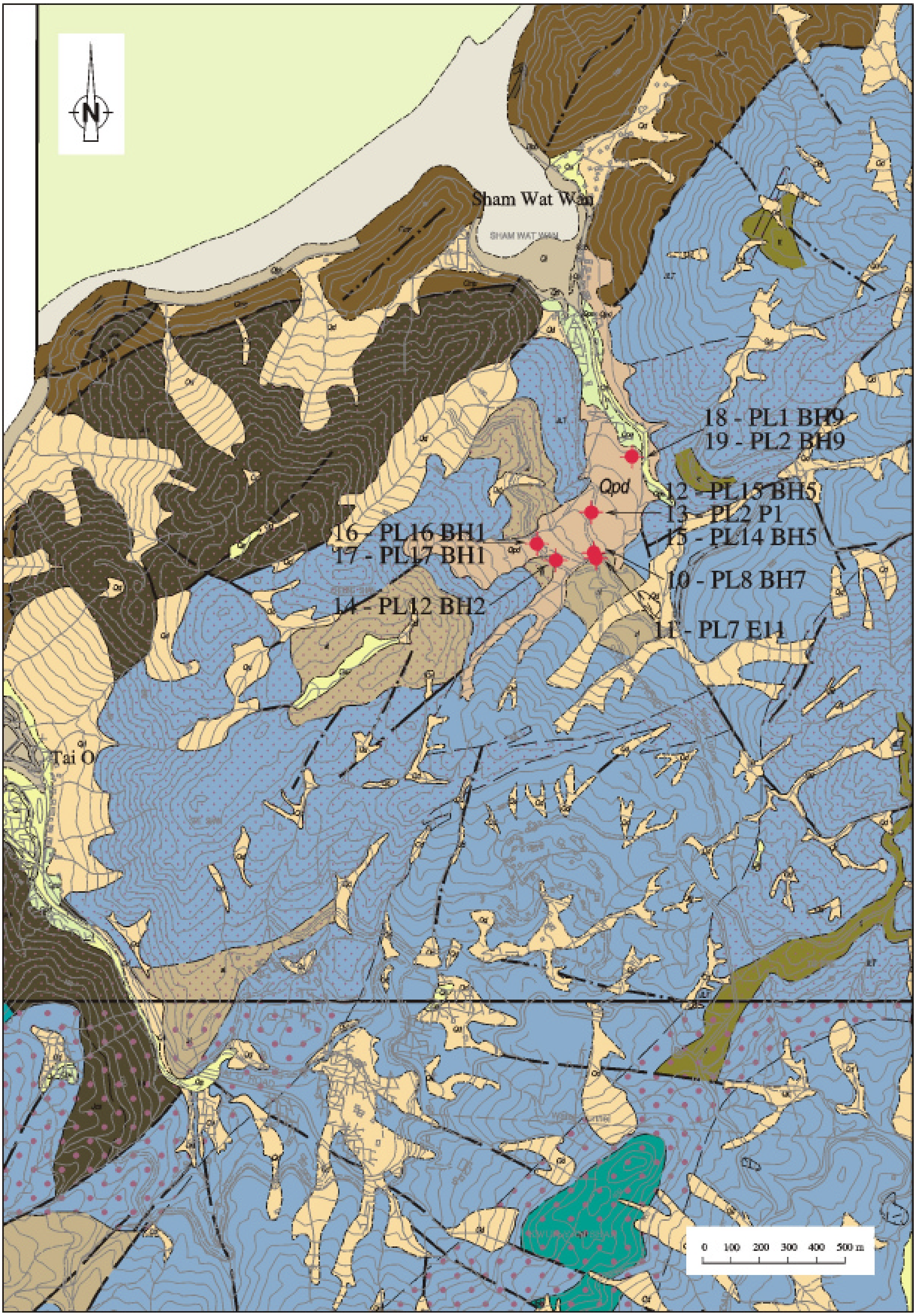

Figure 5 - Location Plan of Luminescence Dating Colluvium Samples 10-19

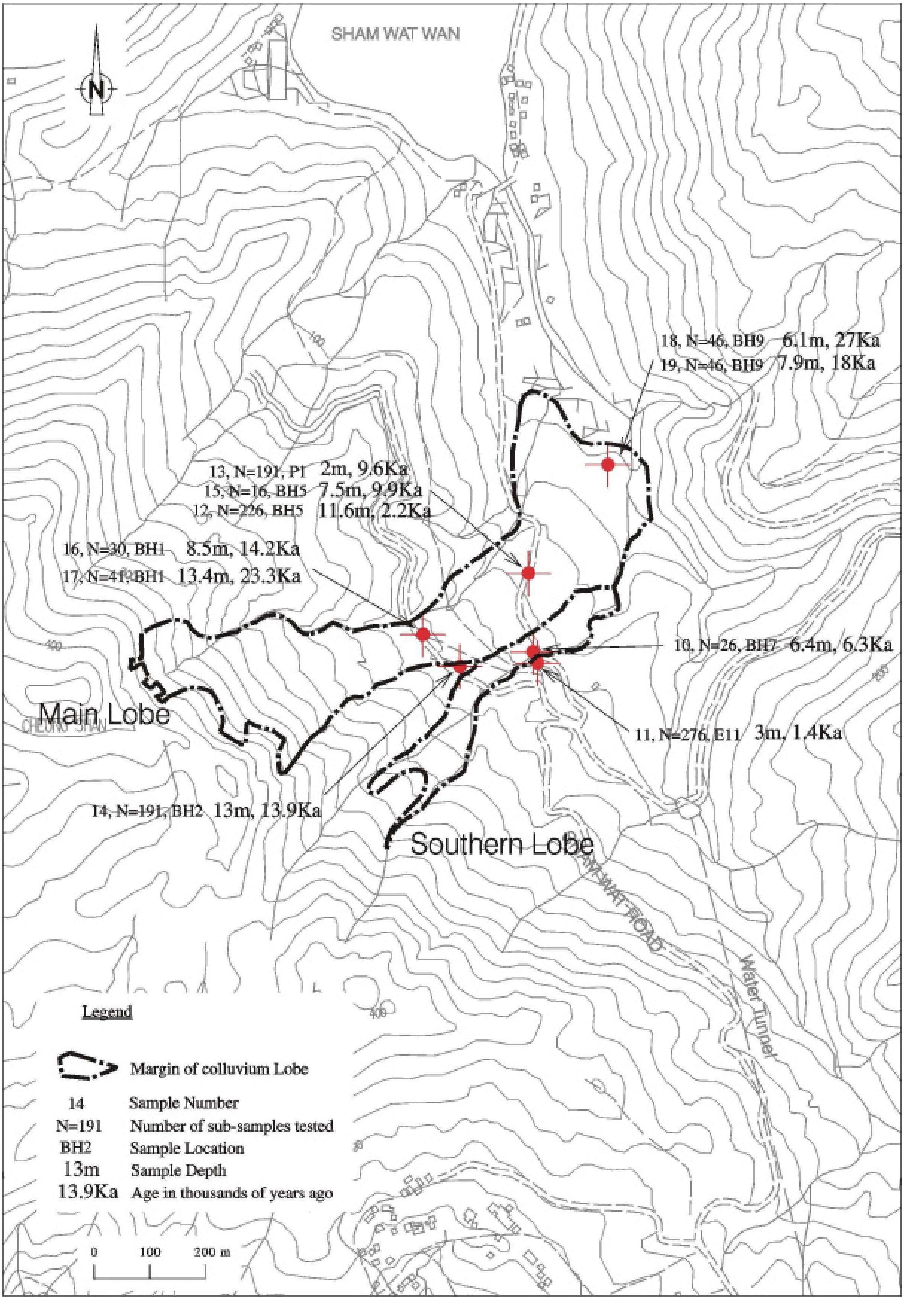

Figure 6 - Luminescence Dates at the Sham Wat Debris Lobe

APPENDIX A

LUMINESCENCE DATING OF A DEBRIS LOBE FROM SHAM WAT HONG KONG
REPORT BY DR A. MURRAY OF THE NORDIC LABORATORY FOR LUMINESCENCE DATING, DENMARK

Luminescence Dating of a Debris Lobe from Sham Wat, Hong Kong

Andrew Murray

Nordic Laboratory For Luminescence Dating, Department of Earth Sciences, Aarhus University, Risø National Laboratory, DK-4000 Roskilde, Denmark

SUMMARY

Four samples taken from a debris lobe at Sham Wat, Lantau Island, Hong Kong, have been examined using the optically stimulated luminescence (OSL) from quartz sand grains extracted from the deposit. OSL can be used to date the last time the sediment was exposed to light. The samples were taken from three locations, and were of unknown age. Two additional samples were taken from smaller modern landslips, one known to have occurred in daylight, and one at night. At the sites of unknown age, the light exposure received during transport was insufficient to completely reset the OSL signal, and so the apparent age (~35 ka) obtained using samples consisting of many thousands of quartz grains is considered to be a gross overestimate of the time since the sediment last moved. Thus the measured signals are the average response of the sediment. Further measurements, on subsamples each made up of only a small number of grains of quartz, were undertaken on all samples to examine the distribution of the quartz OSL signals. This allows the identification of those few grains which were sufficiently exposed to light during transport to be completely reset. Using this method, the apparent age of the modern material was found to be 140 years (moved in daylight) and 400 years (moved at night). These offsets can be compared with apparent ages of up to 2 ka obtained using subsamples containing many thousands of grains; these data demonstrate that the effects of incomplete bleaching can be largely compensated for by examining small subsamples. Results from the samples of unknown age strongly suggest that the debris lobe has moved within the last 10 ka. Furthermore, there may have been at least two distinct transport events, one as recently as 1000 to 2000 years ago.

The principal uncertainty in the application of this novel approach is in the selection of the most appropriate fraction of grains from which to calculate the age. Further measurements are now being undertaken to examine the dose distribution on a grain-by-grain basis, to increase our confidence in the selection of the most appropriate burial dose.

1 INTRODUCTION

This report describes results from the dating of a large debris lobe at Sham Wat, Lantau Island, Hong Kong, and from two smaller Hong Kong debris deposits of known (recent) date. Debris flows and other mass movements are often very difficult to date, especially if they contain little or no carbon. One potential method is based on the phenomenon of luminescence, where visible light is emitted by the sample if appropriately stimulated. This light is derived from electrons trapped in defects in the crystal structure of certain minerals, particularly quartz. The electrons are trapped when ionising rays (from natural radioactivity) pass through the mineral; for a constant environment, the number of trapped electrons is dependent on time. Electron traps can be emptied by exposure to light (a process known as bleaching). In sediments transported during the day and then deposited, the trapped population of electrons begins to build up from the time of deposition. Thus the trapping process provides a 'clock' that can be used to date the time since deposition, which was when the 'clock' was started.

1.1 Dating using optically stimulated luminescence

The trapped electron population is measured by stimulating a sample of quartz using blue/green visible light. This excites the electrons from the traps, and allows them to give up their stored energy during recombination. In the process they emit ultra-violet/blue light, which is measured using a photomultiplier equipped with filters to reject the stimulating light. This signal is known as optically stimulated luminescence (OSL). To convert the OSL signal into a measure of the total energy absorbed by the crystal (the dose), a known dose is given to the sample using a calibrated beta source, and the OSL response derived from this known dose is measured; this gives the sensitivity, χ (OSL/dose). The so-called equivalent dose, D_e, is calculated by dividing the OSL from the natural sample by χ. D_e is the dose equivalent to that which has been accumulated in the sample since burial. The age equation can then be expressed as

$$Age = \frac{D_e}{natural\ dose\ rate} \cdots\cdots (1)$$

The dose rate is calculated by measuring the concentrations of naturally occurring radionuclides, and converting these to dose rates using well-known relationships. A contribution from cosmic radiation is included, and some allowance must be made for the average water content of a sample.

In our context, the most important assumption made in the use of equation 1 is that the sample was completely bleached (i.e. all light sensitive electrons were released from traps) before or during deposition.

1.2 Incomplete bleaching

The assumption of complete bleaching is usually true for wind-blown or beach-washed sand, is less true for fluvial sand, and is usually not valid for any type of mass-movement deposit or slurry. In the latter types of deposit, transport is usually episodic and the concentrations of solids are extremely high. This greatly reduces the opportunity for quartz grains to be exposed to daylight, and so be bleached.

The dating of such poorly bleached deposits is an active research field. It has recently been shown that in marine sand (Lamothe *et al.*, 1994) and fluvial sand (Murray *et al.*, 1995; Olley *et al.*, 1998), the bleaching process is markedly heterogeneous, i.e. different grains are bleached to different degrees, with the majority being well bleached. The latter was considered surprising in the fluvial studies, because the rivers and streams considered were all very turbid and/or the transport distance was very short (about 100 m in one case). It is known that quartz bleaches very quickly when exposed to normal daylight, and so it would appear that the heterogeneity is controlled by the probability that the grain is exposed, rather than the length of time for which it is exposed.

1.3 Single aliquot protocols and dose distributions

Most methods of measuring D_e, the dose equivalent to that received during burial, require the use of several tens of sub-samples (aliquots); it is a necessary assumption underlying all these methods that the aliquots have identical luminescence characteristics. This is clearly not true for heterogeneously poorly-bleached samples. To make reliable measurements on such samples, so-called single aliquot protocols are required, where all measurements are made on a single sub-sample. This aliquot can consist of many thousands of grains, in which case an average dose will be measured which will include any (averaged) residual dose not completely removed before burial. Or the aliquot can contain a very small number of grains, such that there is a high probability that, at least in some aliquots, all the grains will have been adequately bleached before burial. Some recent studies have even been able to look at individual grains (Murray and Roberts, 1997; Roberts *et al.*, 1997, 1998). By looking at many sub-samples (typically one to two hundred) a distribution of D_e in the sample can be built up. The lowest values in this distribution are then taken as the best estimate of the true dose since deposition, and this value of D_e can then be used with more confidence in equation 1.

2 SAMPLES AND ANALYTICAL FACILITIES

2.1 Samples

The samples used in this study were collected by Mr J. King of the Geotechnical Engineering Office, Civil Engineering Department, Hong Kong Government. He has provided a detailed description of the sample sites and a description of the section. Here it is sufficient to identify sample codes as follows:

Table 1: Sample codes and descriptions

Risø code	Sample code	comment (depths are below modern surface)
975001	PL7-E11	3 m, Sham Wat location 1, southern lobe
975002	PL15-BH5	11.57-11.75 m, Sham Wat location 2, northern lobe
985005	PL2-PI	2 m, Sham Wat location 2, northern lobe
985006	PL12-BH2	12.92-13.03 m, Sham Wat location 3, northern lobe
985007	LP4	0.3 m, Liu Pok midday 1993
985008	TS3	0.5 m, Tsing Shan night 1990 (20% hill slope, 80% stream deposits)

On receipt in the laboratory, samples PL2, PL7, LP4 and TS3 were intact inside the steel tubes which had been used to take the samples in the field. About 5 cm of sediment at each end of the tube was removed under low level orange light (photographic safe-light) and discarded, to ensure that no part of the sample had been exposed to daylight during or after sampling. Samples PL12 and PL15 were in the form of sections of core extruded in daylight from the core barrel in Hong Kong, and then wrapped in aluminium foil for shipping; by the time they were received in the laboratory they had dried hard and cracked into separate pieces. Those parts of the sample which had not been exposed to light were recovered by scraping off at least the outer 2 mm of sediment from all surfaces of intact blocks of hardened material. All operations were carried out under the appropriate low level lighting.

Unexposed sample was disaggregated in water, and sieved to recover the 130-300 μm grain size. This material was then washed in 10% HCl, and etched in 45% HF for 45 min. This dissolves all feldspars, and removes the outer surface of the quartz grains (to a depth of about 10 μm). The latter is important because it reduces the dependence of the D_e on the alpha dose from the matrix. (Alpha particles have a very short range (5-10 μm) in quartz). The cleaned quartz grains were checked for feldspar contamination using infrared stimulation

(Spooner and Questiaux, 1989). For measurement, the grains were mounted on 10 mm diameter stainless steel discs using silicone oil. The number of grains on each disc varied between about 50 and several thousand, depending on the type of measurement.

The water content of the discarded material was measured, and the sediment was then prepared for high resolution gamma spectrometry (Murray *et al.*, 1987), to provide radiochemical analyses.

2.2 Analytical facilities

All the OSL measurements reported here were carried out using an automated Risø TL/OSL reader with a green or blue light OSL attachment. The green stimulating light source is a tungsten-halogen lamp filtered using a GG-420 filter in combination with an interference filter to reduce the scattered light reaching the photomultiplier tube (Bøtter-Jensen, 1997). The intensity of light incident on the sample is about 20 mW cm^{-2}. The blue light source is made up of 30 blue (470±30 nm) light emitting diodes, also illuminating the sample through a GG-420 filter (Bøtter-Jensen and Murray, 1999). The light intensity of this source is about 30 mW cm^{-2}.

The background signal recorded by the TL/OSL reader during stimulation, measured using 10 mg of quartz preheated to 800°C for 1 hr (i.e. quartz with no OSL signal), is about 80 counts s^{-1}. The OSL is measured through 7 mm of U-340 filters (Bøtter-Jensen, 1997). All measurements were run under the control of the software package TL/OSL for Windows. The reader is also equipped with a $^{90}Sr/^{90}Y$ beta source delivering about 0.243 Gy s^{-1} to quartz mounted on stainless-steel discs.

3 DOSIMETRY

The results of the gamma spectrometry analyses are summarised in Table 2.

Table 2: Summary of radionuclide concentrations and derived dose rates[1]

Sample	^{238}U Bq kg^{-1}	^{226}Ra Bq kg^{-1}	^{210}Pb Bq kg^{-1}	^{232}Th Bq kg^{-1}	^{40}K Bq kg^{-1}	Beta Gy ka^{-1}	Gamma Gy ka^{-1}	Total[2] Gy ka^{-1}
975001	63±7	40.3±1.3	40±10	183±2	621±24	3.25±0.12	3.10±0.07	5.8±0.2
975002	81±8	65.8±1.5	45±11	188±3	914±30	4.10±0.15	3.45±0.10	6.7±0.3
985005	58±8	63.7±1.5	78±11	213±3	690±25	3.66±0.13	3.62±0.06	6.0±0.4
985006	61±6	52.5±0.7	42±5[3]	139±2	806±14	3.41±0.12	2.73±0.05	5.8±0.7
985007	21±3	21.1±0.5	11±3	42.5±0.7	299±10	1.21±0.05	0.91±0.02	2.08±0.02
995008	112±5	129.0±1.2	103±13[3]	117.6±1.0	1017±16	4.38±0.16	3.17±0.11	6.3±0.4

Note:
1. calculated from concentrations using data provided by Olley *et al.*, (1997)
2. includes the attenuating effects (~8%) of water content, an assumed alpha particle contribution (~2%), and a 0.13 Gy ka^{-1} estimated cosmic ray dose rate.
3. value assumed.

The radionuclide concentrations deserve some comment. Taking the Sham Wat results first, there is some evidence for disequilibrium in the uranium series ($^{238}U > ^{226}Ra$), but given the ages derived later, this is not of significance. The $^{232}Th/^{238}U$ ratio of between 2.5 and 3.3 is noteworthy compared with the world crustal average of about 1; this has been observed before in the Hong Kong area (e.g. Huxtable *et al.*, 1984). Because of the high thorium content, the overall dose rates are atypically high (Duller and Wintle, 1996).

In respect of the two modern slides, it should first be emphasised that these dose rates are not of relevance to the measured doses discussed later, and should not be used to calculate apparent ages. This is because we know that any dose contained in these samples was not accumulated in the present context, but is a residual from some earlier exposure. Nevertheless it is interesting to note that there is no sign of disequilibrium in the uranium series ($^{238}U \sim ^{226}Ra$), and the $^{232}Th/^{238}U$ ratio lies between 1 and 2. Concentrations in sample 985007 are within a factor of two of crustal average, and are typical of sandy deposits, whereas sample 985008 is unusually high in radionuclide activity, and has concentrations that are comparable with the 4 older deposits. J. King (personal communication, 1999) has pointed out that only sample 985007 is largely derived from valley bottom deposits. The other 5 samples are all derived from hill-slope colluvium.

4 MEASUREMENT OF BURIAL DOSE (D_e)

Initial bulk measurements on samples 975001 and 975002 made use of large aliquots (i.e. several thousands of grains in each aliquot). Subsequently small aliquots were used (each consisting of 50-200 grains) for analyses of all samples. The aliquot size was determined by the area of the stainless-steel discs covered in silicone oil, which in turn was dictated by the size of spray-mask used when applying the oil (8 mm diameter for large aliquots, or 3 mm or 1 mm for small aliquots).

4.1 Bulk measurements

OSL investigations began by applying the single-aliquot regeneration protocol (Murray and Roberts, 1998; Murray and Mejdahl, 1999; Strickertsen and Murray, 1999) to large aliquots. This technique has recently been discussed in detail by Murray and Wintle (2000). In a regeneration protocol, the naturally derived OSL signal is measured, and compared with a signal regenerated by a laboratory dose. For the comparison to be valid, either it must be shown that there is no change in OSL per unit dose between the two measurements (no sensitivity change), or any sensitivity changes must be measured and accounted for. Murray and Mejdahl (1999) used the later approach; they measured the OSL response to a small test dose after each of the measurements of the natural and laboratory induced signals. The main OSL signal was then divided by the response to the test dose to provide the sensitivity corrected OSL signal. Figure 1 shows a representative growth curve of this corrected OSL with laboratory dose from a single-aliquot of the sample from location 1, 975001 (not all samples were analysed over such a wide dose range). Note that the laboratory doses were given in increasing order, after the third regeneration dose, the first was repeated (open triangle). This is indistinguishable from the first laboratory signal after correction, and is typical of the reproducibility found with this protocol. The value of D_e interpolated from the region of the growth curve of corrected OSL against dose is 293 Gy, similar to the average of 200±40 Gy for the 5 large aliquot estimates of D_e obtained for this sample. (The uncertainties are one standard error on the mean). The corresponding average for the deeper sample from location 2 (975002) is 230±40 Gy. It is noteworthy that the corrected OSL can be increased well beyond the level observed in the natural sample. This was observed in all aliquots from all samples, and implies that the majority of grains have received significant light exposure in the past. As will be demonstrated later, this was not likely to be the most recent transport event, and presumably represents some much earlier exposure to daylight. If we simply use the average large aliquot estimates of D_e for these samples, and divide by the annual dose-rates of Table 2, this event appears to have occurred about some 35 ka previously. It should also be noted that, even using aliquots made up of several thousand grains, there is a large spread in the observed values of D_e, from 115 up to 330 Gy.

From these data, we must first conclude that it is very unlikely that all grains contribute equally to the OSL signal - had that been the case, even in a poorly bleached sample one would expect to observe a reproducible average from one collection of, say, 8000 grains to another. Secondly, the wide spread in values leads us to conclude that these samples were probably poorly bleached during the most recent deposition, which is to be expected from our understanding of the transport process which put these deposits in place.

4.2 Dose distributions using small aliquots - modern samples

The conclusions drawn above suggest that examination of small aliquots, containing only 100 to 200 grains, would provide a much larger range in doses, because in a small number of grains the probability of obtaining an aliquot which contains only well-bleached, or only poorly bleached, grains is greatly increased. Unfortunately, the conclusion that only a small fraction of grains dominate the OSL signal implies that using small aliquots will also increase the probability of preparing samples from which no OSL signals can be measured, because all the grains are insensitive to dose.

Figure 2 presents the distributions of equivalent dose observed in the two modern landslips, obtained using aliquots of 50 to 200 grains. The distributions are skewed, as would be expected from heterogeneous exposure of the sediment to light, although not strongly so. Neither distribution contains aliquots close to saturation (i.e. doses above about 800 Gy, see Figure 1), from which we can conclude that both sediments must have received significant light exposure. Since one of these slides moved at night, it is likely that at least in that case, the significant light exposure was mainly prior to final emplacement. Nevertheless, it should be noted that the average and maximum doses in sample 985007 (transported in daylight) are 1.64 and 4.4 Gy, respectively. These are nearly ten times less than the corresponding values of 11.9 and 62 Gy in sample 985008 (transported at night). These differences suggest that the final daylight exposure during transport may have contributed significantly to the resetting of the OSL signal. If these sediments had been transported (i.e. exposed to light) and deposited with similar residual doses in the past, and then exposed to the typical dose rates found in the older Sham Wat samples of Table 2, incomplete bleaching would have contributed only about 2 ka (moved at night) and 0.3 ka (moved in daylight) to the average apparent age. However, the average is almost certainly the incorrect value to choose. Olley *et al.* (1998) have examined both modern and known age fluvial deposits (in which bleaching is incomplete, but probably more complete than in these samples), and shown that using the first 5% of such distributions gives the best estimate of the true equivalent dose. In these cases, this calculation would give values of 2.5±0.3 Gy (moved at night) and 0.88±0.03 Gy (moved in daylight), equivalent to age offsets of only 400 and 140 years, respectively.

4.3 Dose distributions using small aliquots - older samples

Figures 3a, 4a, 5 and 6 present the distributions of values of equivalent dose observed in 276 aliquots (975001) and 226 aliquots (975002), using a bin width of 10 Gy, and in 191 aliquots (985005 and 985006), using a bin width of 5 Gy. (From Table 2, a dose of about 6 Gy would be acquired in 1000 years of burial.) Doses are observed extending up to over 600 Gy (Figure 4a), and the mean values of 230 and 220 Gy (975001 and 975002) are consistent with those obtained in the previous section from large aliquots. (Exact agreement should not be expected, because the average of the distribution is essentially independent of OSL signal strength, whereas that from large aliquots is dominated by the brightest grains.) The distributions of samples 975001, 985005 and 985006 all have broad peaks at high doses, although with a pronounced low dose peak in sample 975001. Sample 985005 has a distinct tail to low doses, whereas sample 985006 is slightly skewed to higher doses. Sample 975002 is unlike any of the others; it has no well-defined high-dose peak in the distribution, but a broad tail extending from a low dose peak. (Note that there are no doses consistent with zero in either 975001 or 975002). The two distributions from samples 985005 and 985006 are similar in shape to the modern distributions shown in Figure 2, whereas both the distributions in Figures 3 and 4 have a pronounced peak at low values of D_e.

There are three ways in which such differences in distribution shape could arise:

(i) The first is by incomplete removal of light-exposed sample during the preparation of samples 975002 and 985006 (received in the laboratory as dried and cracked pieces of sediment). There are two arguments against this: (a) there is a strong similarity in shape between sample 985006 (exposed to light before delivery) and 985005 (delivered intact in sampling tube), and also between 985006 and the two modern distributions (985007 and 985008, both delivered in sampling tubes). This argues against any problems with post-sampling light exposure in the grains used for analysis in this sample, and so suggests that laboratory procedures were appropriate. (b) Although the surfaces of both samples must have received significant light exposure during and after extrusion, there is little doubt that the bulk of the samples was not light-exposed during this process (deduced from the surface/volume ratios of the intact pieces of core). If we assume that there was originally a broad peak at high dose in the distribution of sample 975002 prior to sampling, similar to that seen in 975001, 985005 and 985006, it is then very difficult to see how such a distribution could be modified to give the distribution shape of Figure 4, if only a small fraction of the sample was exposed after sampling. Thus although post-sampling exposure cannot be completely ruled out for the grains used for analysis from samples 975002 and 985006, it must be considered very unlikely.

(ii) The second potential cause of the differences in dose distributions is as a result of differential averaging in the laboratory. Olley *et al.* (1999) have shown that as the number of light emitting grains in an aliquot increases, the chances of obtaining a dose estimate far from the average decreases rapidly, and the distribution shape rapidly becomes more symmetric. The four samples discussed here are all of the same geological origin, and in the laboratory all aliquots showed a similar (although very variable) range in dose sensitivities. Given the large differences in shape between Figure 3,4 and 5,6, which all were taken with the same size of aliquot, it is considered unlikely that the differences arise simply because of changes in the number of light emitting grains per aliquot.

(iii) The third potential origin of such distributions is incomplete bleaching during transport. At some point in their history the grains making up these sediments must have been saturated with dose (e.g. prior to undergoing the primary erosion event the grains were probably buried for $>>10^6$ years). During subsequent erosion, this saturated dose must have been substantially removed; no aliquots from any of the samples gave doses higher than 600 Gy and Figure 1 shows that this material is not in saturation until well above this figure. It is presumed that the last time these samples were significantly bleached is reflected by the peak of the distribution in Figure 5 and 6, and probably by the upper peak (at about 260 Gy) in Figure 3a. Two of the samples, 975001 from location 1 (Figure 3) and 975002 from location 2 (Figure 4) clearly then underwent some other bleaching event, the effects of which are very marked in the dose distributions, but which was not sufficient to completely reset the prior burial dose. This was presumably the last transport event, i.e. the landslip. The evidence for two events is much less marked in the remaining two samples, 985005 from at location 2 (Figures 5) and 985006 from location 3 (Figure 6); only the small low dose tail in Figure 5, and the suggestion of a small low dose peak in Figure 6, give any suggestion of a recent bleaching event.

Methods for calculating the best estimate of the most recent burial dose in such distributions are not well known at present [see Galbraith *et al.* (1999) for a discussion]. Given the results described above for the modern distributions, it can be assumed that selecting the first 5% of the data of Figures 5 and 6 will not result in a gross over- or underestimate of the burial age. These values are 57±8 Gy for the 2 m deposit from location 2 (Figure 5) and 80±2 Gy for the 13 m deposit from location 3 (Figure 6).

The modern analogues of Figure 2 clearly do not apply to the shapes shown in Figures 3 and 4, implying that the resetting in these samples was probably less complete. Figures 3b and 4b show the first 100 Gy of these distributions in more detail, using a bin width of 4 Gy. The lowest observed values of D_e are 1.6 Gy (975001) and 2.1 Gy (975002); both are non-zero, implying that the most recent exposure of this material to daylight did not occur within the last few decades. This also helps to rule out post-sampling light-exposure of sample 975002. In the sample from location 1 (975001, Figure 3b), there is a well defined cluster of 24 values centred about 10 Gy. In that from location 2 (975002, Figure 4b) the corresponding cluster (of 30 values) is less well defined, and appears to be centred between 10 and 20 Gy. These clusters contain 9% and 14% of the total in each distribution, respectively. At this stage it is suggested that the best estimates of dose are given by these small low dose peaks, which have mean doses of 8.0±1.0 Gy and 14.7±1.3 Gy respectively. Note that if only the first 5% of the distributions were taken these values would decrease (to about 7 Gy in both cases, i.e. the apparent age would get younger).

5 CALCULATED AGES

As discussed above, the ages derived for samples 975001 (location 1) and 975002 (location 2) using both large aliquots and the averages of the distributions from small aliquots are about 35 ka for both samples, implying that the deposit was derived from a body of material which had been previously transported, and may have been moderately well exposed to light during this process. The corresponding average age for the other two samples 985005 (location 2) and 985006 (location 3) is about 23 ka. All four samples could well be derived from similar parent material, especially if the two samples 9859005 and 985006 are significantly better reset than 975001 and 975002, as suggested above. More recently, this material was moved to its present position, and this process is presumed to give rise to the low doses present in all dose distributions. Using the dose rate data of Table 2 allows us to derive ages for location 1 in the southern lobe of the slide of 1400±200 years (3 m deep) and for the northern lobe at location 2 of 9600±1500 years (2 m deep) and 2200±300 years (11.7 m deep). The age for the sample from the northern lobe at location 3 is 13900±1700 years (13 m deep).

6 DISCUSSION

At this stage in our knowledge, it would be unwise to take the estimates of uncertainty calculated above at face value. Given the very large range in values of D_e present in these samples, it is likely that the largest single source of uncertainty in the apparent times elapsed since last exposure to light arises from uncertainties in the choice of the values of D_e relevant to this event. The part of the samples used for dating are considered to be secure, in the sense that no light exposure is likely to have taken place after sampling. It is certain that this is true for samples 975001, 985005, 985007 and 985008 (all received in intact coring tubes), and it is very likely to be true for the two samples received as pieces of core (975002 and 985006), for the reasons given in Section 4.3 above. The method of calculating the doses in individual aliquots has been extensively tested by comparison with other established techniques (Murray and Roberts, 1997, 1998; Murray and Mejdahl 1999; Strickertsen and Murray, 1999). We can therefore be confident that the apparent dose distribution arose as a result of the last light exposure of this material during transport. This movement could have been postdepositional faunal mixing (bioturbation), but given the poorly sorted nature of the deposit, the observed stratification and the depth of at least the deeper layers, this is considered unlikely. Furthermore, it is unlikely that faunal mixing would have generated an apparently less well bleached layer nearer the surface than at depth (see section 4, and Figures 3 and 4). We therefore conclude that the most likely origin of the dose distributions remains incomplete exposure to light during the last transport event, and that this event occurred much less than 35 ka ago.

There is convincing published evidence from related studies on very young material (<200 years old) that accurate dates, within this century, can be derived from incompletely bleached (fluvial) sediments by selecting the first few percent of the observed dose distribution (Murray *et al.*, 1995; Olley *et al.*, 1998; Olley *et al.*, 1999). This conclusion is supported by the analysis of the modern dose distributions discussed here. The exact fraction that should be selected presumably depends on, *inter alia*, the total fraction of grains that were well bleached, the number of grains in each aliquot, the uncertainties on each dose estimate, and variations in microdosimetry (Murray and Roberts, 1997). Given the recent nature of these studies, there are probably other factors as yet unconsidered. Nevertheless, it would seem unlikely that the true doses acquired since last transport are markedly less than those derived in Section 5. They may be larger, but it is possible to discuss upper limits to the likely range. For instance, using the average of the first half of the distributions (i.e. from the lowest values up to the median) from location 1 gives 132 Gy (corresponding to an age of about 23 ka); from location 2, 80 Gy and 77 Gy (13 ka and 11 ka) for the upper and lower layers, respectively; from location 3, 110 Gy (18 ka). It is considered very unlikely that the true ages are older than these upper limits. Table 3 summarises these conclusions.

Table 3: Summary of sample ages			
Sample	Location and approx. depth	Most probable age, ka	upper limit, ka
975001	Loc 1, 3 m	1.4±0.2	23
985005	Loc 2, 2 m	9.6±1.5	13
975002	Loc 2, 12 m	2.2±0.3	11
985006	Loc 3, 13 m	13.9±1.7	18
Note:	Lower limit is given by uncertainties on most probable age		

On geomorphological grounds, it has been suggested that the samples from the northern lobe (locations 2 and 3) should all be approximately the same age, and that the sample from the southern lobe (location 1) may be younger (J. King, personal communication, 1999). Given that the apparent ages of the two samples from location 2 are inverted with respect to stratigraphy, it is suggested that the best estimate of the age of the northern lobe from these data is the simple average of the three individual values, i.e. 9±3 ka. If sample 975002 is omitted, on the grounds that it might have been exposed to light after sampling (although this is considered unlikely), then the average for the northern lobe becomes 11.5±1.1 ka. The only estimate of the age of the southern lobe is 1.4±0.2 ka.

7 CONCLUSIONS

The luminescence characteristics of four samples taken from the Sham Wat debris lobe have been examined, and it is concluded that they are suitable for OSL dating. The natural radioactivity of the deposit is higher than the world average, but not unusually high for the Hong Kong region. Using standard methods of analysis, the apparent age of the deposit is about 35 ka, but this is certainly a gross overestimate. By looking at sub-samples containing only a small number of quartz grains, the distribution of dose in two modern samples has been examined. Using criteria consistent with those established in related fluvial studies, apparent ages of 140 and 400 years are obtained from material known to have been transported during daylight and at night, respectively; this provides estimates of the likely age offsets in older material when using the same approach to estimating the dose.

Four samples of unknown age, from three locations, have been examined using dose distributions. At the sampling location from the southern lobe of the deposit, the best estimate of age is 1.4±0.2 ka. The apparent age inversion with respect to stratigraphy at one location in the northern lobe suggests that only the average age for the three samples from for this lobe should be considered, i.e. 9±3 ka. In recognition of the fact the methods employed here are new, and that there is no independent age control in our studies, bounds on the ages have been considered, and it is concluded that the southern lobe (location 1) the age is unlikely to be much less than 1000 years, and very unlikely to be more than 23 ka. In the northern lobe (locations 2 and 3) the corresponding age range is from about 2 ka to 11 ka.

Considering all four results together, it seems very likely that the last significant transport event at Sham Wat must have occurred with the last 10 ka, possibly as recently as 1500 years ago. It is also likely that the two lobes were transported at different times, with the southern lobe being the younger.

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Figure 1: Growth curve for 975001, using a large (8 mm) aliquot

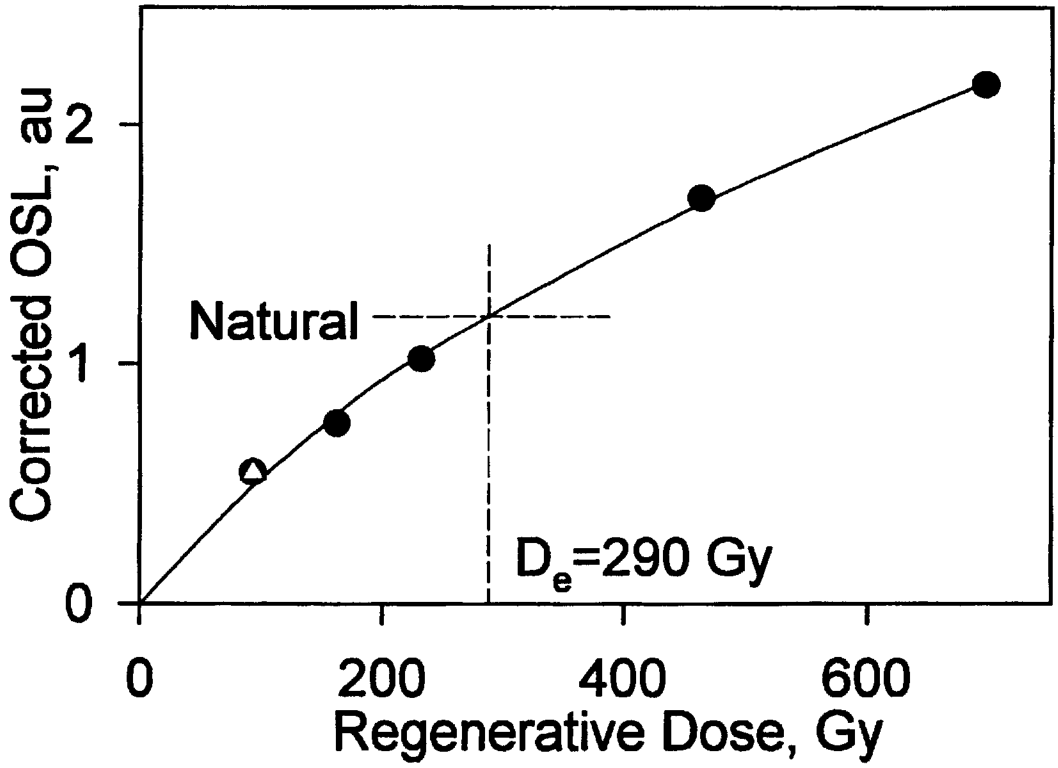


Figure 2: Modern Landslips

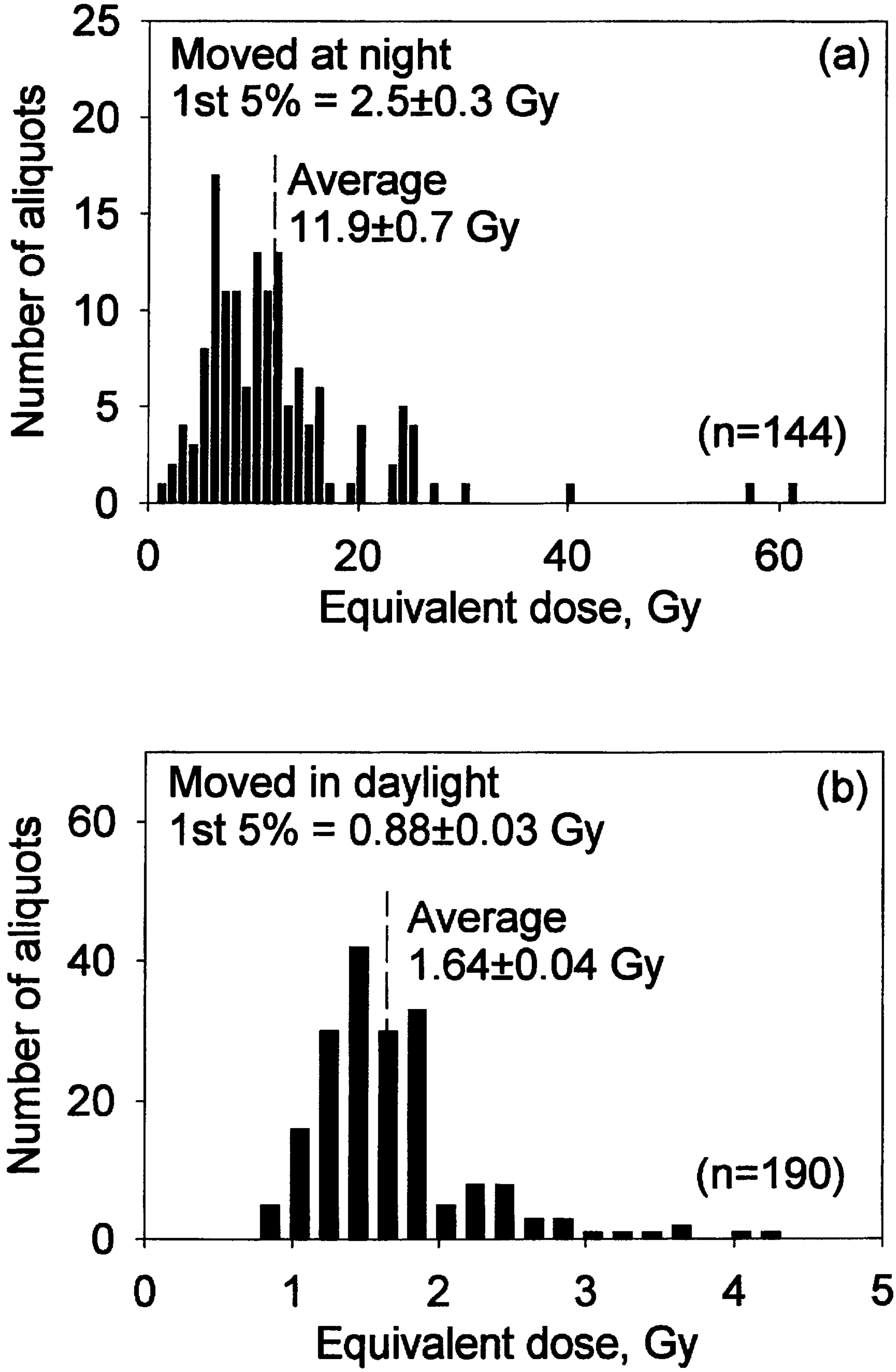
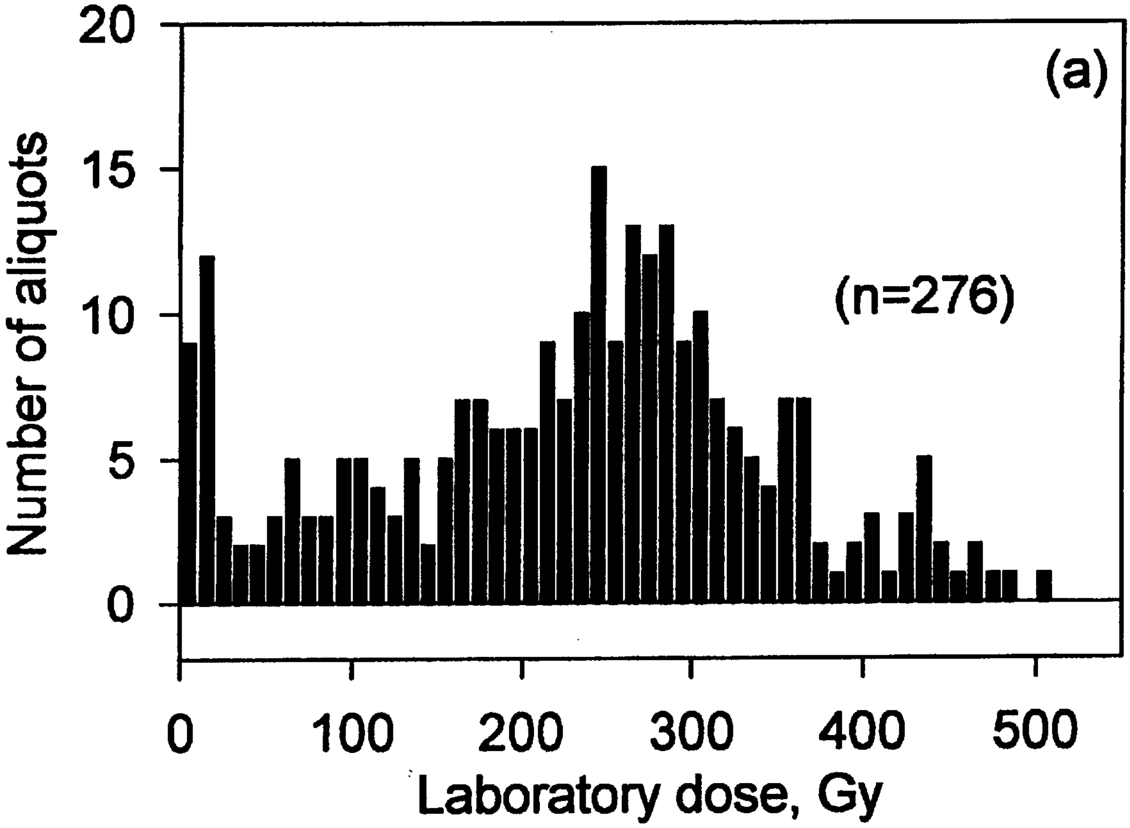


Figure 3: Sham Wat Loc. 1, 3 m deep



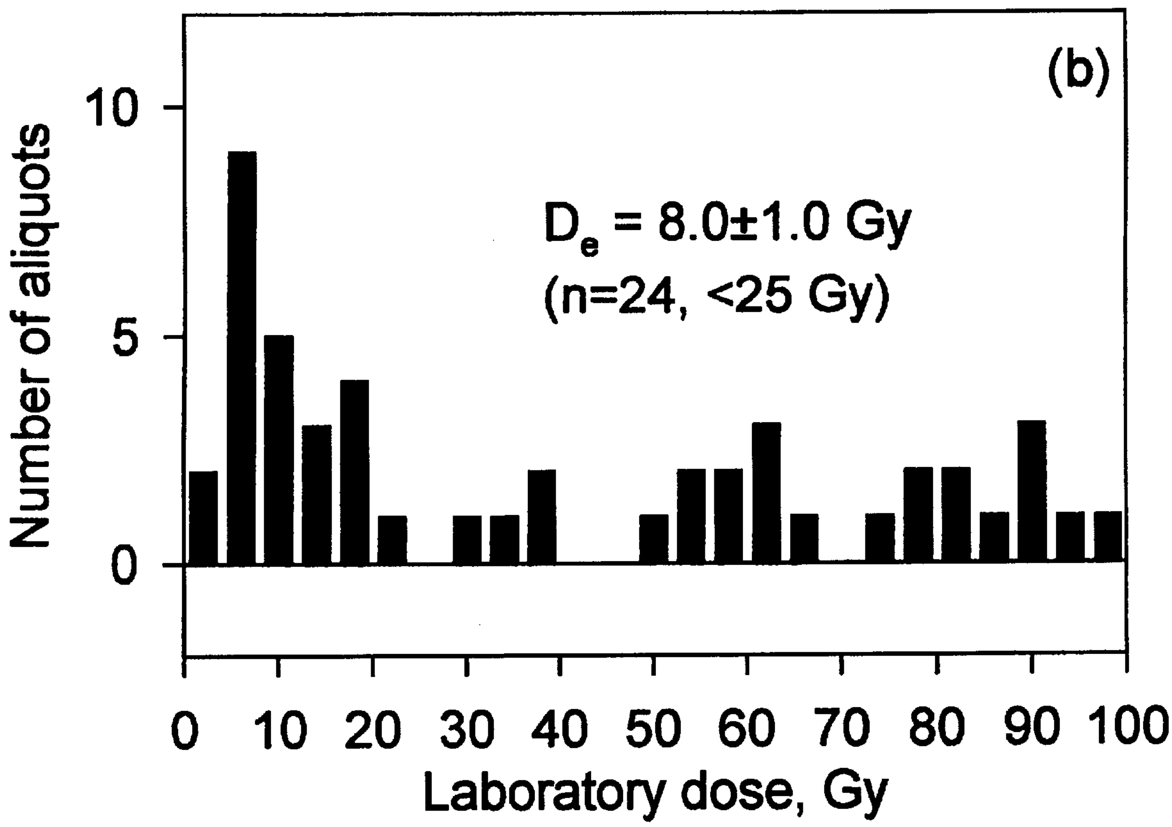
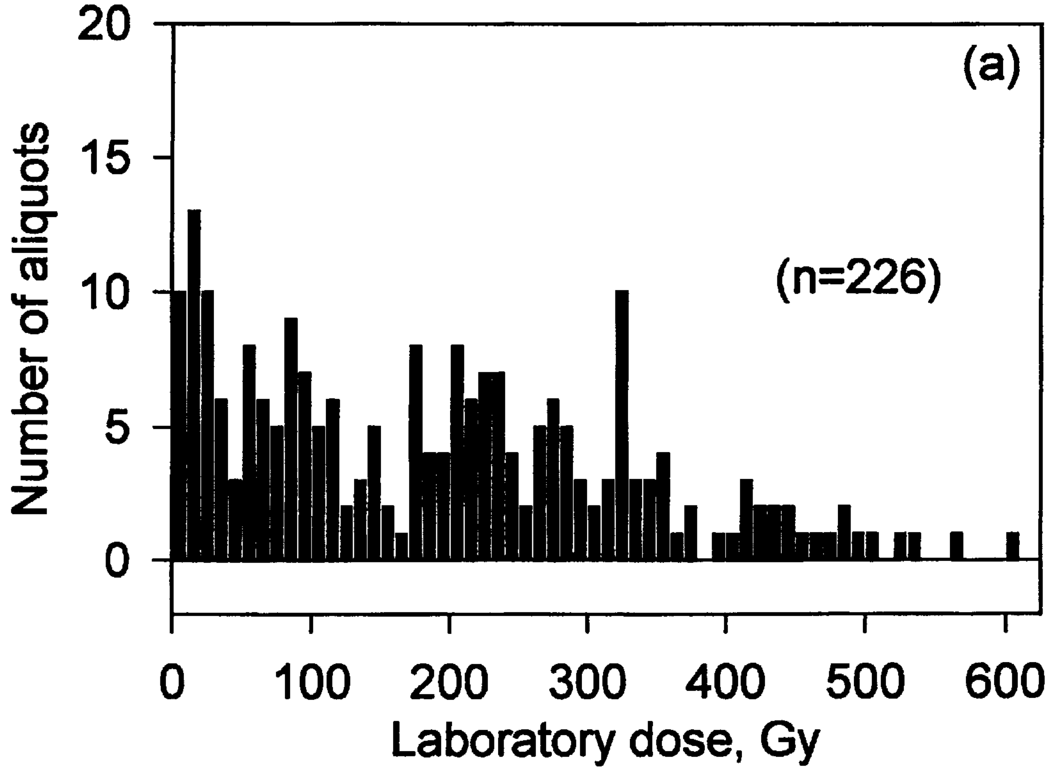


Figure 4: Sham Wat Loc. 1, 11.57-11.75 m deep



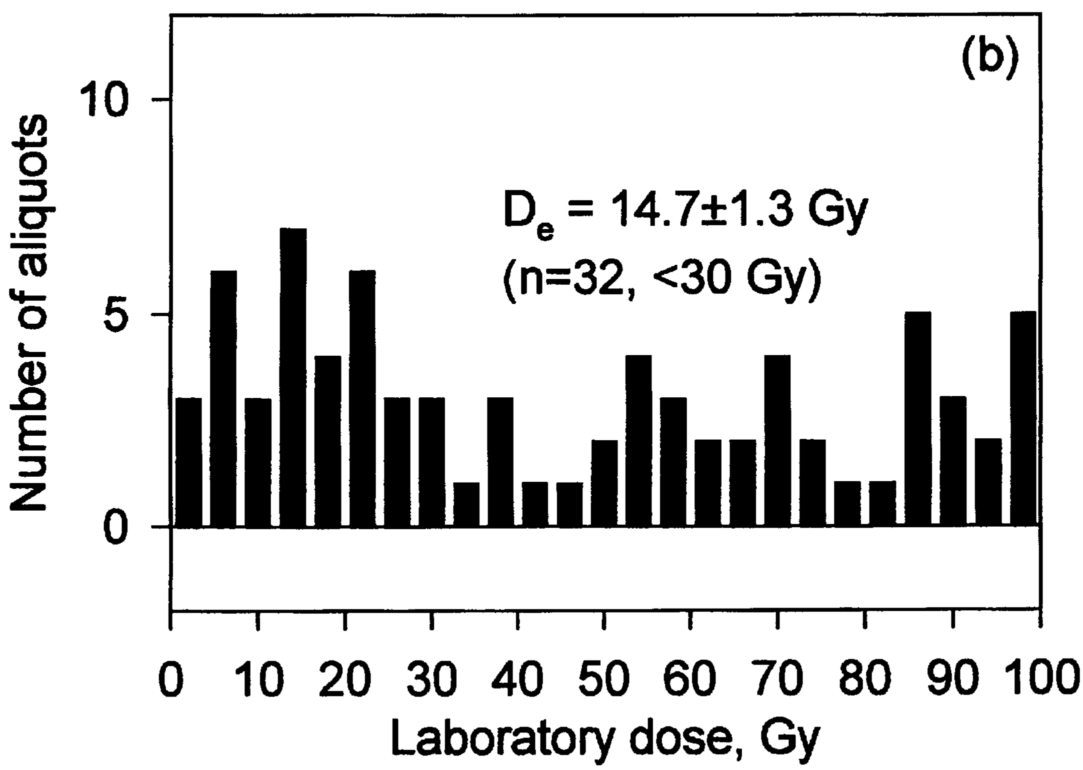


Figure 5: Sham Wat Loc. 2, 2 m deep

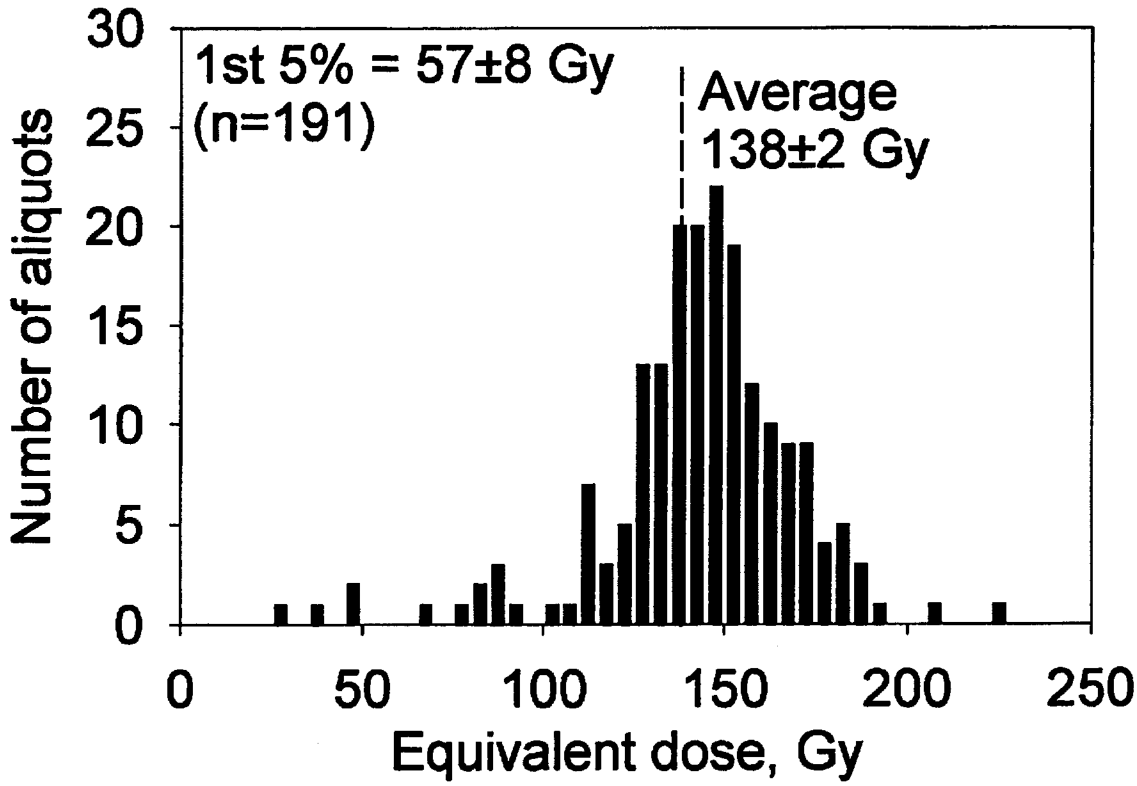
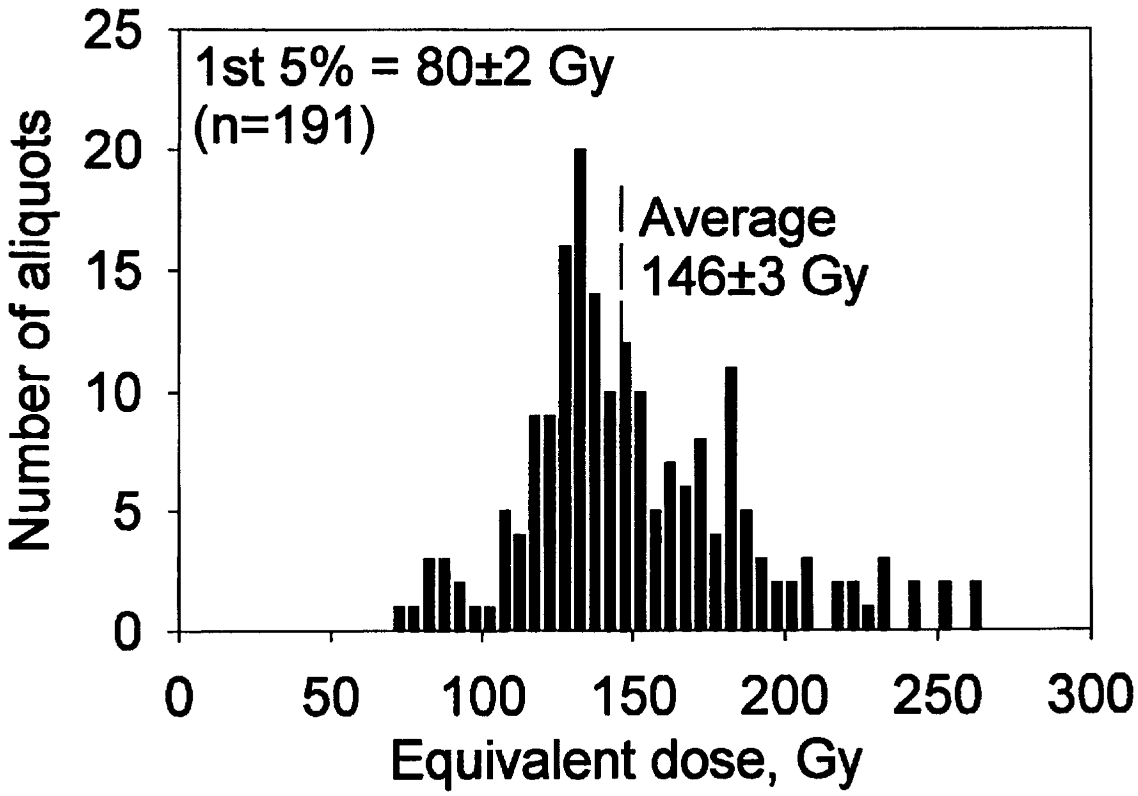


Figure 6: Sham Wat Loc. 2, 12.92-13.03 m deep



APPENDIX B

THERMOLUMINESCENCE DATING RESULT OF SLOPE DEPOSITS OF HONG KONG LABORATORY OF QUARTERNARY DATING, INSTITUTE OF GEOCHEMISTRY (GUANGZHOU) CHINESE ACADEMY OF SCIENCES

Thermoluminescence dating result of slope deposits of Hong Kong

No.	Sample No.	Localities	Co-ordinates		Landform	Soil Type	Sample Type	Depth m	Elevation m PD	Laboratory Code	TL age years BP
			East	North							
1	HK 11966	High Street	833030	816230	Slope	Silty Sand With Cobbles & Boulders	-	0.3	58.0	IG TL22	10,500 ± 900
2	HK 11962	Shek Kong	829565	831420	Slope deposit	Silty Sand With Cobbles	-	0.0	195.0	IG TL18	19,400 ± 1,600
3	HK 11964	Conduit Road	833160	815880	Slope	Silty Sand With Cobbles & Boulders	-	0.3	138.1	IG TL20	26,600 ± 2,000
4	HK 11860	Shum Wan	835223	811246	Slope	Silty Sand With Cobbles	-	0.3	34.1	IG TL1	34,800 ± 2,800
5	HK 11942	Shum Wan	835206	811320	Slope	Silty Sand With Cobbles	-	0.5	19.22	IG TL3	43,600 ± 3,500
6	HK 11941	Shum Wan	835204	811326	Slope	Silty Sand With Cobbles	-	0.5	19.87	IG TL2	48,200 ± 3,900
7	HK 11965	Kotewall Road	832415	815815	Slope	Silty Sand With Cobbles & Boulders	-	0.5	150.0	IG TL21	61,000 ± 4,600

Notes : IG Laboratory of Quarternary Dating, Institute of Geochemistry (Guangzhou) Chinese Academy of Sciences

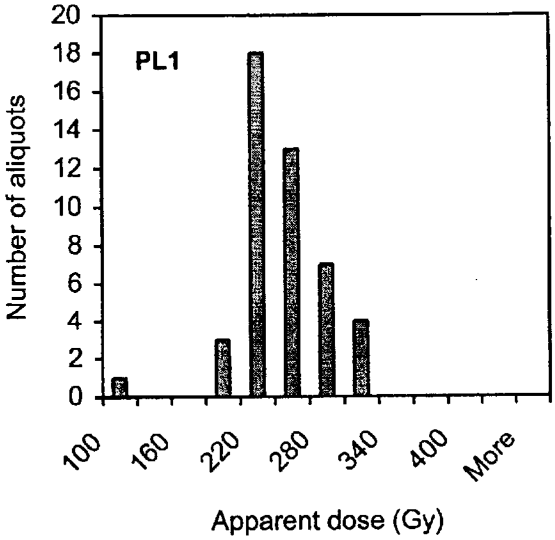
TL Thermoluminescence dating

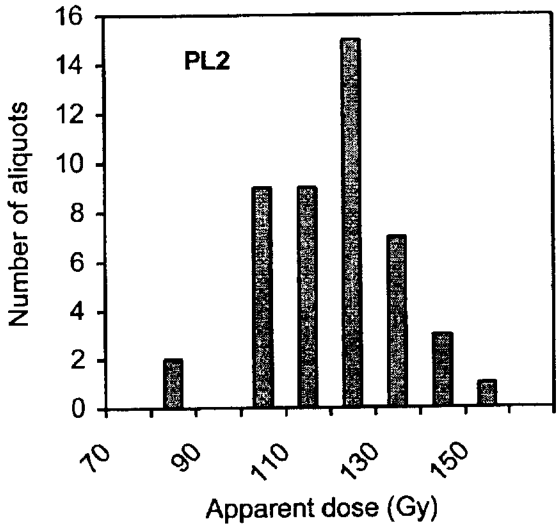
APPENDIX C

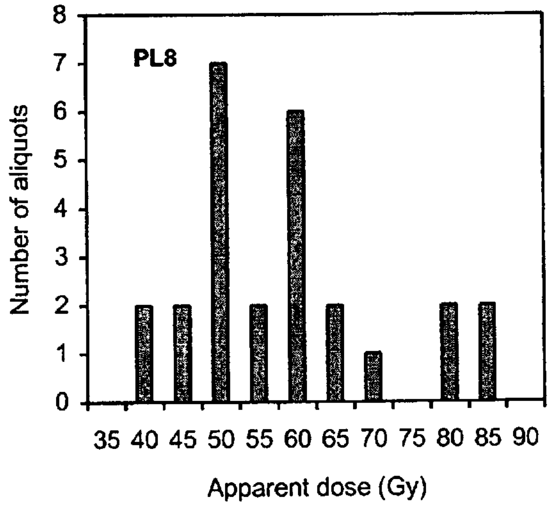
DOSE DISTRIBUTION LUMINESCENCE DATING RESULTS FROM DR S.H. LI, RADIOISOTOPE UNIT, UNIVERSITY OF HONG KONG

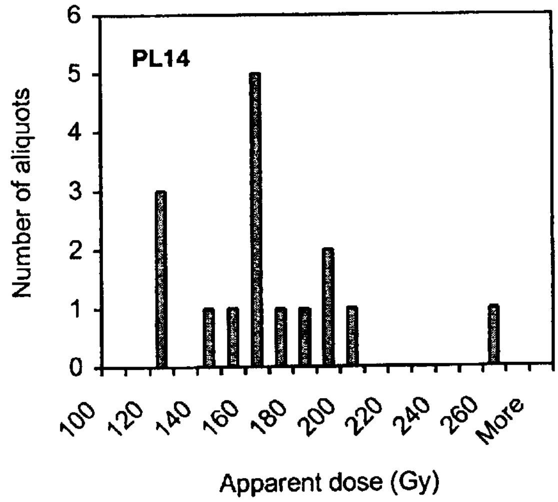
Table Equivlent doses(ED), dose rttes and apparent optical ages

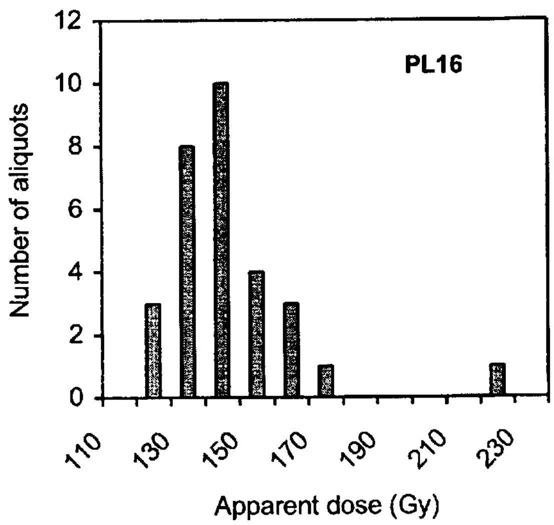
Sample No.	Borehole No.	Depth (m)		ED (Gy)	Dose rate (Gy/ka)	Age (ka)
		From	To			
PL1	BH9	6.1	6.2	195.19±7.05	7.23±0.81	27.0±3,2
PL2	BH9	7.9	7.96	105.65±1.72	5.86±0.51	18.0±1.6
PL8	BH7	6.39	6.73	46.51±0.77	7.37±1.23	6.3±1.1
PL14	BH5	7.47	7.77	115.67±2.52	11.65±2.00	9.9±1.7
PL16	BH1	8.54	8.67	136.67±3.61	9.61±1.07	14.2±1.6
Pl17	BH1	13.42	13.5	185.11±5.97	7.95±0.86	23.3±2.7
Lo	Lo Wu	Surface soil		1.91±0.15	3.20±0.32	0.60±0.07

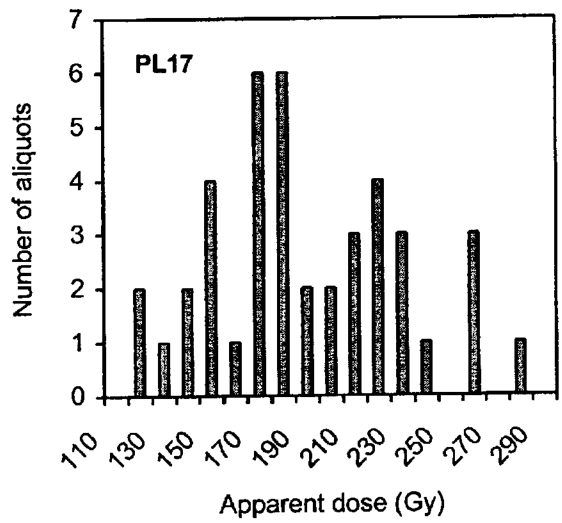

PL1
Number of aliquots
Apparent dose (Gy)
100
160
220
280
340
400
More

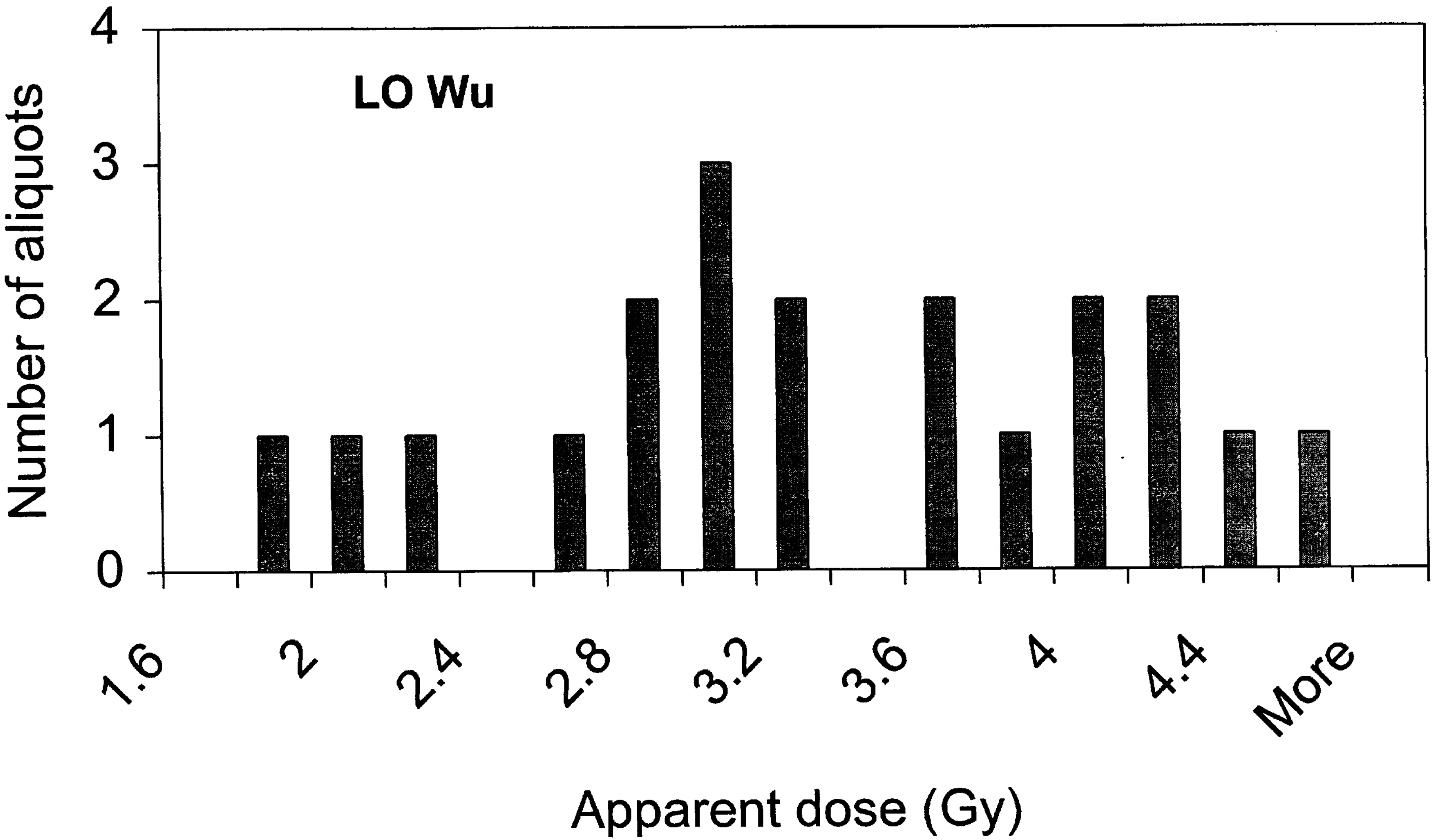

PL2
Number of aliquots
Apparent dose (Gy)
70
90
110
130
150


PL8
Number of aliquots
Apparent dose (Gy)
35 40 45 50 55 60 65 70 75 80 85 90


PL14
Number of aliquots
Apparent dose (Gy)
100
120
140
160
180
200
220
240
260
More

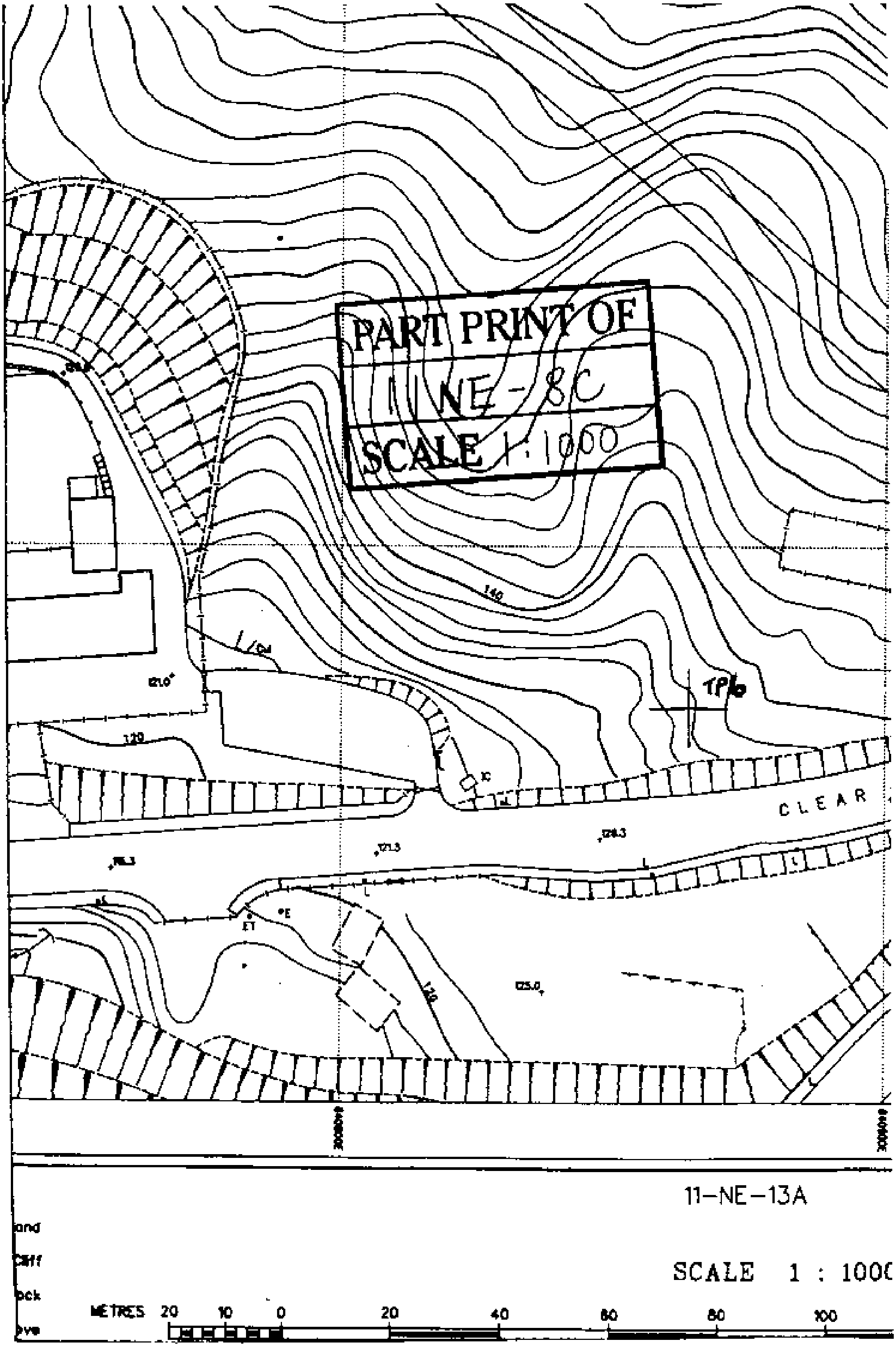

PL16
Number of aliquots
Apparent dose (Gy)
110
130
150
170
190
210
230


PL17
Number of aliquots
Apparent dose (Gy)
110
130
150
170
190
210
230
250
270
290


LO Wu
Number of aliquots
0
1
2
3
4
1.6
2
2.4
2.8
3.2
3.6
4
4.4
More
Apparent dose (Gy)

APPENDIX D

LOCATION MAPS AND GEOLOGICAL LOGS FOR PHOTOLUMINESCENCE DATING SAMPLES 8 AND 9

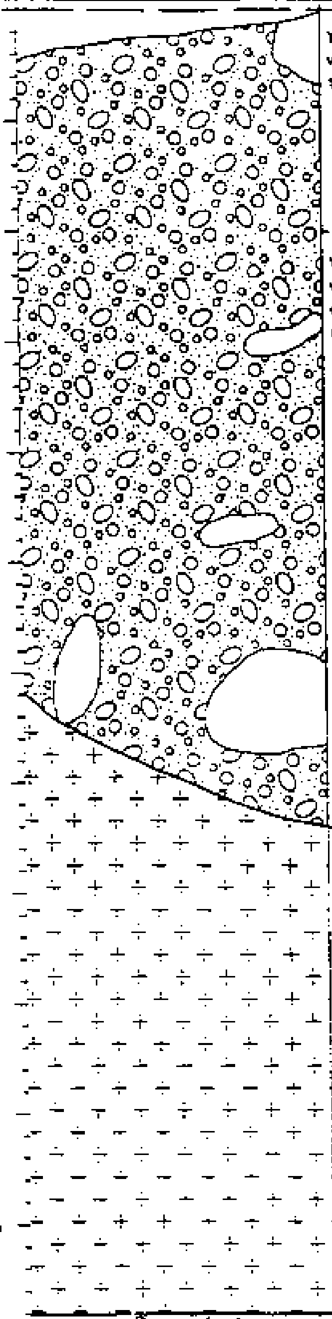

PART PRINT OF
11 NE - 8C
SCALE 1:1000
140
120
121.0
TP16
CLEAR
11-NE-13A
SCALE 1 : 100(
METRES 20 10 0 20 40 60 80 100

Trial Pit no. : TP6

Contractor : Enpack (HK) Ltd

Type of Excavation : Hand-dug | Date Excavated : 21.03.1996 | Date Backfilled : 01.04.1996

Location : Clear Water Bay Road, Kowloon | Ground Level : 135.57 mPD | Co-ordinates : E840864 N821671

Water Conditions	Depth (Sample & Test)	Reduced Level	Depth (m)	Profile of Face B (Width = 1.5 m)	Description	Soil Type
		135.57	0		Yellowish to dark yellowish brown sandy clayey SILT with angular cobbles & boulders. Weathered rind ≤ 10mm thick.	Qc
	1 ●		0.5			
	3 ● 2	134.57	1.0		Very dense, mottled red and yellow clayed sandy SILT with completely to highly decomposed gravel and cobbles of tuff and granite. Boulders up to 660x450mm across with 30mm thick weathered rind.	
	5 ● 4		1.5			
HK11984 Sample (9)	7 ● 6		2.0			
	9 ● 8		2.5			
	10 ●	132.47	3.0			
	11 ●		3.5		COLLUVIUM	
	12 ●		4.0		Reddish brown clayey silty SAND.	gd
	14 ● 13 15 ●		4.5			
	16 ●		5.0			
	18 ● 17 19		5.5		Completely decomposed GRANITE	
	20 ●	129.67	6.0	Base of pit		

● Small disturbed sample

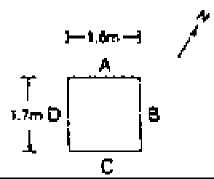
▭ U100 sample

▭ Block sample

Remarks :

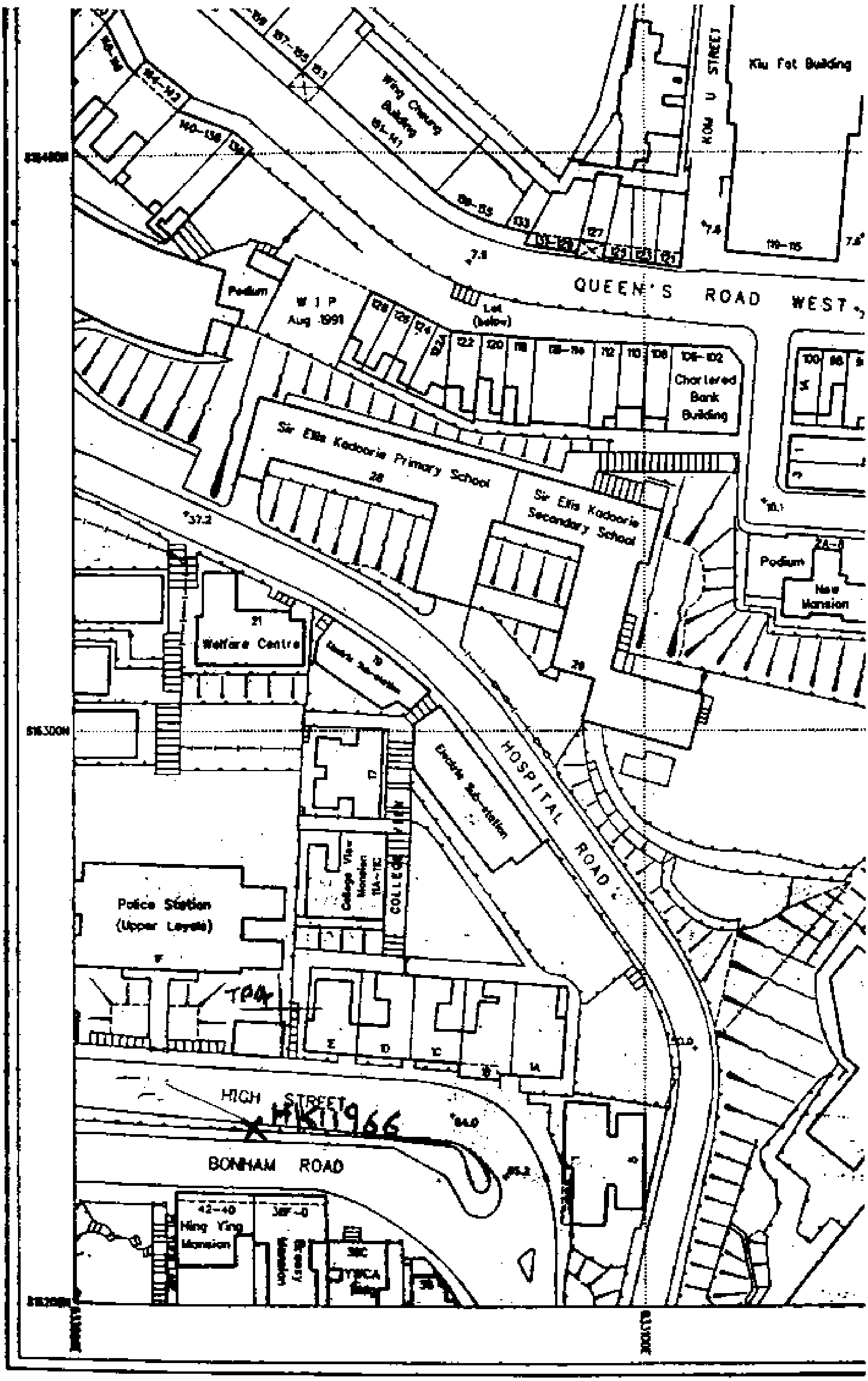
Qc - Colluvium

gd - Completely decomposed Granodiorite



Logged by : KWL

Date : 02.04.1996

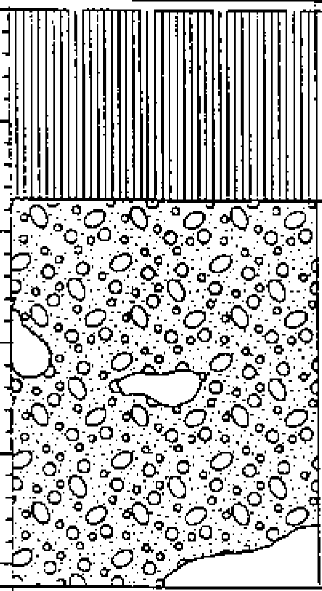

Kiu Fat Building
KOW U STREET
Wing Cheung Building
QUEEN'S ROAD WEST
W I P
Aug 1991
Podium
Lot (below)
Chartered Bank Building
Sir Ellis Kadoorie Primary School
Sir Ellis Kadoorie Secondary School
Podium
New Mansion
Welfare Centre
Electric Sub-station
HOSPITAL ROAD
College View Mansion
COLLEGE VIEW
Police Station
(Upper Levels)
HIGH STREET
BONHAM ROAD
Hing Ying Mansion
YMCA
TPO
HK11966

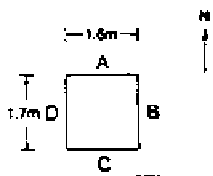
Trial Pit no. : TP4

Contractor : Enpack (HK) Ltd

Type of Excavation : Hand-dug | Date Excavated : 14.03.1996 | Date Backfilled : 21.03.1996

Location : High Street, Hong Kong | Ground Level : 54.92 mPD | Co-ordinates : E833036 N816252

Water Conditions	Depth (Sample & Test)	Reduced Level	Depth (m)	Profile of Face A (Width = 1.75 m)	Description	Soil Type
		54.92	0		Bricks, concrete remains and rootlets FILL	Qf
	2 ●, 1	54.07	0.5, 1.0		Dense to very dense mottled brick red, yellow and white sandy clayey SILT with subangular to subrounded, completely to slightly decomposed gravel, cobbles and boulders Most gravel and cobbles of tuff are highly decomposed. The thickness of weathered rind of boulders varies from 30 to 100mm. COLLUVIUM	Qc
Sample	4 ●, 3		1.5, 2.0, 2.5			
HK1198 (8)	5, 6 ●	29.82		Base of pit		
			3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0			

● Small disturbed sample ▭ U100 sample ▭ Block sample	Remarks : Qf - Fill Qc - Colluvium		Logged by : KWL Date : 22.03.1996

APPENDIX E

GEOLOGICAL LOGS OF TRIAL PITS AND BOREHOLES FOR PHOTOLUMINESCENCE DATING SAMPLES TAKEN FROM THE SHAM WAT DEBRIS LOBE

DRILLHOLE RECORD

lam			
CONTRACT NO. GE/95/12 LG21726/51		HOLE NO.	BH 1
		SHEET	1 OF 3
PROJECT	Natural Terrain Landslide Study at Shum Wat Road, Lantau Island		
METHOD	Rotary	CO-ORDINATES E 806311.42 N 813603.89	W.O. NO. GE/95/12.73
MACHINE & NO.	Longyear D66		DATE : 14/02/97 To 18/02/97
FLUSHING MEDIUM	Air-Foam	ORIENTATION Vertical	GROUND LEVEL 125.47 mPD

Drilling Progress	Casing Size	Water level/ (m) Shift start/ end	TCR%	SCR%	RQD%	FI	Tests	Samples	Reduced Level	Depth (m)	Legend	Grade	Description
14/02/97	Sx	DRY 08:45						INSP. PIT A, B, C		0.50, 1.00, 1.30			Pinkish grey and brownish grey, clayey/silty fine to coarse SAND with some angular and subangular fine to medium gravel sized weak and moderately strong rock fragments (FILL) From 1.30m-1.45m strong, dark grey rock fragments
			100						123.87	1.60			Soft, black slightly organic, clayey sandy SILT with some roots (TOPSOIL) From 1.60m-1.80m with some subangular cobble sized moderately strong rock fragments
			100, 100					1, 2	123.57	1.90, 3.30			Grey and purplish grey angular and subangular fine to coarse GRAVEL and COBBLE sized moderately strong and strong meta-tuff, occasionally meta-mudstone fragments (DEBRIS FLOW DEPOSIT) From 1.95m-2.15m and 2.60m-2.85m boulder sized moderately strong, meta-tuff fragments From 2.20m-3.75m with some soft, light brown, occasionally mottled orangish red, clay and sand matrix
15/02/97		DRY 17:00 3.61m 08:45	100						121.72	3.75			Soft to firm, yellowish grey mottled orangish red, sandy silty CLAY with some subangular fine to coarse gravel sized weak rock fragments (DEBRIS FLOW DEPOSIT)
			100					3	121.09	4.38, 5.30, 6.55, 7.66			Soft to firm, yellowish grey mottled orangish red, sandy silty CLAY with many angular and subangular gravel and cobble sized weak and strong meta-tuff, occasionally meta-mudstone fragments (DEBRIS FLOW DEPOSIT)
17/02/97		6.10m 17:00 DRY 08:45	100										
			100				PL16		117.57	7.90			Soft to firm, light reddish brown mottled light yellow and brownish red, sandy silty CLAY with occasional angular and subangular fine to coarse gravel sized weak and strong rock fragments
			100						116.47	9.00, 9.15			Grey and purplish grey angular and subangular fine to coarse GRAVEL and COBBLE sized meta-tuff, occasionally meta-mudstone fragments with occasional orangish red, clay and sand matrix (DEBRIS
									116.02	9.45			

Depth scale (m): 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Key			
Disturbed Sample	Piston Sample	Standard Penetration Test	In-situ Vane Shear Test
U76 Undisturbed Sample	U100 Undisturbed Sample	Permeability Test	Impression Packer Test
Mazier Sample	SPT Liner Sample	Packer Test	Piezometer Tip
Water Sample		Observation Well Tip	

LOGGED	S.P.Su
DATE	25/02/97
CHECKED	M.D.
DATE	03/03/97

REMARKS

1. Inspection pit excavated to 1.30m depth.

Lam Geotechnics Limited

DRILLHOLE RECORD

lam	CONTRACT NO. GE/95/12 LG21726/51	HOLE NO. BH 1	SHEET 2 OF 3
PROJECT	Natural Terrain Landslide Study at Shum Wat Road, Lantau Island		
METHOD Rotary	CO-ORDINATES E 806311.42 N 813603.89	W.O. NO. GE/95/12.73	
MACHINE & NO. Longyear D66		DATE : 14/02/97 To 18/02/97	
FLUSHING MEDIUM Air-Foam	ORIENTATION Vertical	GROUND LEVEL 125.47 mPD	

Drilling Progress	Casing Size	Water level/ (m) Shift start/ end	TCR%	SCR%	RQD%	FI	Tests	Samples	Reduced Level	Depth (m)	Grade	Description
									115.36	10.11		FLOW DEPOSIT)
			100							10.30		Soft to firm, light reddish brown mottled orangish red, sandy silty CLAY with occasional to some angular and subangular fine to coarse gravel sized weak and moderately weak rock fragments (DEBRIS FLOW DEPOSIT) From 9.80m-10.00m cobble sized strong meta-tuff fragments
		11.53m 17:00	100							10.99		
18/02/97		11.36m 08:45	100							11.82		Purplish grey, subangular COBBLE and BOULDER sized strong meta-tuff fragments
			100				PL17	4	113.00	12.47		Soft to firm, yellowish grey mottled orangish red, sandy silty CLAY with occasional to some subangular fine to coarse gravel, occasionally cobble sized weak and strong meta-tuff fragments (DEBRIS FLOW DEPOSIT) From 13.60m-13.85m and 14.15m-14.69m boulder sized strong meta-tuff fragments
										13.42		
			100						110.62	14.85		Grey and purplish grey BOULDER sized strong meta-tuff fragments with clay and sand matrix (DEBRIS FLOW DEPOSIT)
								5		15.02		
										16.62		
			100	0	0	NA			108.50	16.97		Soft to firm, light yellowish brown mottled orangish red, sandy silty CLAY with occasional to some angular and subangular fine to coarse gravel, occasionally cobble sized weak and strong meta-tuff fragments (DEBRIS FLOW DEPOSIT)
						NI			107.92	17.55	IV	Very weak, dark grey discoloured purplish red, highly decomposed meta-MUDSTONE, highly fractured
			100	60	20	NA			107.47	18.00		
										18.12	V/IV	
						>20			107.17	18.30	IV/III	Extremely weak to very weak, grey discoloured light purplish red, completely to highly decomposed meta-MUDSTONE (Clayey/silty sandy GRAVEL sized weak rock fragments)
						8.7			106.62	18.85	III	Weak to moderately weak, grey discoloured purplish red, highly to moderately
		19.30m 17:00							105.93	19.54		

Depth scale: 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

Key		LOGGED S.P.Su	REMARKS
Disturbed Sample	Standard Penetration Test	DATE 25/02/97	
Piston Sample	In-situ Vane Shear Test	CHECKED M.D.	
U76 Undisturbed Sample	Permeability Test	DATE 03/03/97	
U100 Undisturbed Sample	Impression Packer Test		
Mazier Sample	Packer Test		
SPT Liner Sample	Piezometer Tip		
Water Sample	Observation Well Tip		

DRILLHOLE RECORD

lam	DRILLHOLE RECORD	HOLE NO. BH 2
	CONTRACT NO. GE/95/12 LG21726/51	SHEET 1 OF 2
PROJECT	Natural Terrain Landslide Study at Shum Wat Road, Lantau Island	
METHOD Rotary	CO-ORDINATES E 806333.70 N 813580.18	W.O. NO. GE/95/12.73
MACHINE & NO. Longyear D66		DATE : 01/02/97 To 13/02/97
FLUSHING MEDIUM Air Foam	ORIENTATION Vertical	GROUND LEVEL 124.33 mPD

Drilling Progress	Casing Size	Water level/ (m) Shift start/ end	TCR%	SCR%	RQD%	FI	Tests	Samples	Reduced Level	Depth (m)	Legend	Grade	Description
1/2/97	Sx	DRY 08:45						INSPECTION PIT A	123.83	0.50			Brownish yellow, clayey/silty fine to medium, occasionally coarse SAND with some angular fine to medium gravel (FILL)
								B	123.33	1.00			Soft, dark grey, slightly organic clayey sandy SILT with occasional subangular fine gravel and some roots (TOPSOIL)
			100					1	122.89	1.44			Brownish grey, purplish grey and brownish yellow, clayey/silty sandy angular and subangular fine to coarse GRAVEL and COBBLE sized weak, moderately weak and strong meta-tuff fragments (DEBRIS FLOW DEPOSIT)
		DRY 17:00	100						122.67	1.66			From 1.44m-1.67m, 3.13m-3.40m and 4.65m-5.00m soft, brownish yellow, sandy silty CLAY with occasional to some subangular fine to coarse gravel sized weak rock fragments
3/2/97		1.38m 08:45	100					2		2.37			From 1.67m-2.37m, 2.86m-3.13m and 6.90m-7.10m boulder sized strong meta-tuff fragments
			68							2.78 / 2.88			
								3	121.20	3.13			
			100						120.93	3.40 / 3.56			
			100							4.25			
								4	119.68	4.65			
			100						119.33	5.00			
			100					5		5.59 / 5.89			
		1.60m 17:00	100							6.50			
4/2/97		6.00m 08:50	100					6		7.17			
			100										
			100					7	116.39	7.94 / 8.09			Soft to firm, brownish yellow, sandy silty CLAY with some to many angular to subangular fine to coarse gravel and occasional cobble sized weak, moderately weak and strong meta-tuff fragments (DEBRIS FLOW DEPOSIT)
		8.90m 12:00						8		9.31			From 8.40m-8.60m boulder sized strong meta-tuff fragment
11/2/97		7.62m 08:50	100							9.60			
			100										

Disturbed Sample	Standard Penetration Test	LOGGED S.P.Su	REMARKS
Piston Sample	In-situ Vane Shear Test	DATE 17/02/97	1. Inspection pit excavated to 1.00m depth.
U76 Undisturbed Sample	Permeability Test	CHECKED M.D.	2. 3 Standpipes installed at 5.00m, 11.50m and 15.50m depths
U100 Undisturbed Sample	Impression Packer Test	DATE 25/02/97	
Mazier Sample	Packer Test		
SPT Liner Sample	Piezometer Tip		
Water Sample	Observation Well Tip		

Lam Geotechnics Limited

lam	DRILLHOLE RECORD CONTRACT NO. GE/95/12 LG21726/51	HOLE NO. BH 2 SHEET 2 OF 2
PROJECT	Natural Terrain Landslide Study at Shum Wat Road, Lantau Island	
METHOD Rotary	CO-ORDINATES E 806333.70	W.O. NO. GE/95/12.73
MACHINE & NO. Longyear D66	N 813580.18	DATE : 01/02/97 To 13/02/97
FLUSHING MEDIUM Air Foam	ORIENTATION Vertical	GROUND LEVEL 124.33 mPD

Drilling Progress	Casing Size	Water level/ (m) Shift start/ end	TCR%	SCR%	RQD%	FI	Tests	Samples	Reduced Level	Depth (m)	Legend	Grade	Description
									113.93	10.40			As sheet 1 of 2
12/2/97		8.53m 17:00 9.41m 8:45	100 100 100				PL12	9 10		10.82 12.03 12.82			Purplish grey and brownish yellow, clayey/silty sandy angular and subangular fine to coarse GRAVEL and COBBLE sized weak, moderately weak and strong rock fragments (OLD DEBRIS FLOW DEPOSIT?) From 10.82m-11.25m boulder sized strong meta-tuff fragment with a curved void infilled with brownish and yellowish grey angular and subangular fine to coarse gravel sized clasts of weak meta-tuff, loosely cemented by clay and sand
									110.57	13.76			Dark purplish grey angular fine to coarse GRAVEL and COBBLE sized strong meta-tuff fragments (DEBRIS FLOW DEPOSIT)
		DRY 17:00	100 100	10 43	0 30	>20			110.24	14.09 14.76		III/II	Strong, dark grey discoloured light purple, moderately to slightly decomposed TUFFITE with very closely to closely spaced smooth planar and undulating limonite and manganese oxide stained joints, dipping at subhorizontal to 10°, 45°-50°, 75° and subvertical From 15.09m-15.39m shear zone, dipping at 70°
13/2/97			100	0	0				108.41	15.79 15.92			End of investigation hole at 15.92m

Depth scale: 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

Key		LOGGED S.P.Su	REMARKS
Disturbed Sample	Standard Penetration Test	DATE 17/02/97	
Piston Sample	In-situ Vane Shear Test	CHECKED M.D.	
U76 Undisturbed Sample	Permeability Test	DATE 25/02/97	
U100 Undisturbed Sample	Impression Packer Test		
Mazier Sample	Packer Test		
SPT Liner Sample	Piezometer Tip		
Water Sample	Observation Well Tip		

Lam Geotechnics Limited

DRILLHOLE RECORD

lam

CONTRACT NO. GE/95/12 LG21726/51

HOLE NO.	BH 5
SHEET	1 OF 2
PROJECT	Natural Terrain Landslide Study at Shum Wat Road, Lantau Island
METHOD	Rotary
MACHINE & NO.	Longyear D36
FLUSHING MEDIUM	Air Foam
CO-ORDINATES	E 806502.10, N 813714.32
ORIENTATION	Vertical
W.O. NO.	GE/95/12.73
DATE :	03/02/97 To 13/02/97
GROUND LEVEL	73.38 mPD

Drilling Progress: 3/2/97 (0 – 5.1 m); 4/2/97 (5.1 – 6.4 m); 11/2/97 (6.4 – 7.8 m); 12/2/97 (7.8 – 10 m)

Casing Size: Sx

Water level/(m) Shift start/end: DRY 08:00; 5.10m 17:00; 5.01m 09:00; 6.05m 12:00; 5.50m 09:00; 5.68m 12:00; 7.30m 09:00

TCR%: 100, 100, 90, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, ~~100~~, 100, 100, 75, 100

SCR%: –

RQD%: –

FI: –

Tests: PL14

Samples: I.P. A; 1; GLC (continuous)

Reduced Level: 72.55; 66.73

Depth (m): 0.50, 0.83, 1.33, 1.89, 2.18, 2.98, 3.95, 4.54, 4.85, 5.15, 5.42, 5.75, 6.23, 6.46, 6.65, 6.80, 7.25, 7.70, 8.21, 8.30, 8.77, 9.15, 9.35, 9.85

Grade: –

Reduced Level	Depth (m)	Description
	0.00 – 0.83	Soft, brownish yellow, sandy silty CLAY with occasional subangular fine quartz gravel and fine to medium gravel sized weak meta-tuff fragments (DEBRIS FLOW DEPOSIT)
72.55	0.83 – 6.65	Purplish grey and brownish yellow, clayey/silty sandy angular and subangular fine to coarse GRAVEL and COBBLE sized weak and moderately weak meta-tuff fragments (DEBRIS FLOW DEPOSIT) From 1.12m-1.33m, 4.54m-5.01m, 5.15m-5.61m, 5.75m-5.95m and 5.98m-6.23m boulder sized strong meta-tuff fragments From 1.54m-1.77m and 6.23m-6.40m soft, brownish yellow spotted brownish red, sandy silty CLAY with some angular and subangular fine to medium gravel sized weak rock, occasionally quartz fragments From 1.85m-2.60m and 3.09m-3.25m brownish and yellowish grey spotted brownish red, clayey/silty fine to medium, occasionally coarse SAND with some angular and subangular fine to coarse gravel, occasionally cobble sized moderately weak rock fragments
66.73	6.65 –	Purplish grey subangular GRAVEL, COBBLE and BOULDER sized strong meta-tuff fragments locally with a soft, brownish yellow, sandy silty CLAY matrix (DEBRIS FLOW DEPOSIT) From 7.93m-8.21m, 8.77m-9.15m, 9.55m-10.31m and 11.87m-12.31m boulders sized strong meta-tuff fragments

Key		Key	
Disturbed Sample		Standard Penetration Test	
Piston Sample		In-situ Vane Shear Test	
U76 Undisturbed Sample		Permeability Test	
U100 Undisturbed Sample		Impression Packer Test	
Mazier Sample		Packer Test	
SPT Liner Sample		Piezometer Tip	
Water Sample		Observation Well Tip	

LOGGED	S.P.Su
DATE	15/02/97
CHECKED	M.D.
DATE	27/02/97

REMARKS

1. Inspection pit excavated to 0.60m depth.

Lam Geotechnics Limited

DRILLHOLE RECORD

lam

CONTRACT NO. GE/95/12	LG21726/51	HOLE NO.	BH 5
		SHEET	2 OF 2
PROJECT	Natural Terrain Landslide Study at Shum Wat Road, Lantau Island		
METHOD	Rotary	CO-ORDINATES E 806502.10 N 813714.32	W.O. NO. GE/95/12.73
MACHINE & NO.	Longyear D36		DATE : 03/02/97 To 13/02/97
FLUSHING MEDIUM	Air Foam	ORIENTATION Vertical	GROUND LEVEL 73.38 mPD

Drilling Progress	Casing Size	Water level/ (m) Shift start/ end	TCR%	SCR%	RQD%	FI	Tests	Samples	Reduced Level	Depth (m)	Legend	Grade	Description
			100										As sheet 1 of 2
			100					2		10.75			
			100				PL15			11.75 / 11.85			
			100							12.60			
		8.38m 17:00	100					3	60.26	13.12		V/IV	Extremely weak to very weak, light purple and brownish grey, completely to highly decomposed meta-MUDSTONE? (Silty sandy fine to coarse GRAVEL sized weak rock fragments)
13/2/97		12.38m 09:00	100	0	0	Nl			60.18	13.20 / 13.43		IV	Weak to moderately weak, dark grey discoloured light purplish pink, highly to moderately decomposed meta-MUDSTONE, generally highly fractured. Where intact with very closely to closely spaced smooth planar and undulating limonite and manganese oxide stained joints, dipping at subhorizontal to 10°, 25° and subvertical and with very narrow subhorizontal foliations (original laminae) From 13.20m-13.43m very weak, highly decomposed and highly fractured From 13.91m-14.21m and 14.43m-14.60m moderately weak to moderately strong and moderately decomposed
			100	13	0	>20				13.91		IV/III	
			100	75	30	10				14.31		III	
			100	44	16	>20 / 17.6 / >20						IV/III / III / IV/III	
		13.65m 13:00							58.24	15.14			End of investigation hole at 15.14m

Depth scale: 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

Legend		
Disturbed Sample	Standard Penetration Test	LOGGED S.P.Su
Piston Sample	In-situ Vane Shear Test	DATE 15/02/97
U76 Undisturbed Sample	Permeability Test	CHECKED M.D.
U100 Undisturbed Sample	Impression Packer Test	DATE 27/02/97
Mazier Sample	Packer Test	
SPT Liner Sample	Piezometer Tip	
Water Sample	Observation Well Tip	

REMARKS

Lam Geotechnics Limited

DRILLHOLE RECORD

CONTRACT NO. GE/95/12 LG21726/51

HOLE NO.	BH 7
SHEET	1 OF 2
PROJECT	Natural Terrain Landslide Study at Shum Wat Road, Lantau Island
METHOD	Rotary
MACHINE & NO.	Longyear D66
FLUSHING MEDIUM	Air Foam
CO-ORDINATES	E 806515.16 N 813582.04
ORIENTATION	Vertical
W.O. NO.	GE/95/12.73
DATE :	20/02/97 To 24/02/97
GROUND LEVEL	91.05 mPD

Drilling Progress	Casing Size	Water level/(m) Shift start/end	TCR%	SCR%	RQD%	FI	Tests	Samples	Reduced Level	Depth (m)	Grade	Description
20/02/97	Sx	DRY 08:45						INSP. PIT A, B	90.05	0.50, 1.00		Soft, brownish yellow, occasionally mottled pink, clayey sandy SILT with some subangular fine to medium gravel (DEBRIS FLOW DEPOSIT)
		DRY 17:00	100						87.34	2.28, 3.59, 3.71		Grey, dark grey and purplish grey angular and subangular fine to coarse GRAVEL and COBBLE sized moderately weak, moderately strong and strong meta-tuff, occasionally meta-mudstone fragments with brownish yellow, clay and sand matrix (DEBRIS FLOW DEPOSIT) From 2.06m-2.62m boulder sized strong meta-tuff fragments
21/02/97		DRY 08:45	100					1	87.00	4.05		Brownish and yellowish grey, very clayey/silty fine to medium, occasionally coarse SAND with some angular and subangular fine to coarse gravel, occasionally cobble sized weak and moderately strong, meta-tuff, occasionally meta-mudstone fragments (DEBRIS FLOW DEPOSIT)
			100					2	86.20	4.33, 4.85		Brownish grey subangular COBBLE and BOULDER sized moderately strong to strong meta-tuff fragments (DEBRIS FLOW DEPOSIT)
			100						84.93	5.57, 6.12		Firm, brownish yellow mottled orangish red, clayey sandy SILT with some angular and subangular fine to coarse gravel and cobble sized weak and moderately weak meta-tuff, occasionally meta-mudstone fragments (DEBRIS FLOW DEPOSIT)
			100				PL8		83.55	6.95, 7.50		Brownish grey, COBBLE and BOULDER sized moderately strong to strong meta-tuff fragments with brownish yellow mottled orangish red sandy clayey silt matrix (DEBRIS FLOW DEPOSIT)
		8.95m 17:00	100					3	81.73	7.97, 9.32	V	Extremely weak, grey discoloured brownish yellow mottling orangish red, completely decomposed lapilli bearing coarse ash meta-TUFF (Firm, clayey sandy SILT with occasional fine quartz gravel)
22/02/97		8.95m 08:45	100	81	0			4			V/IV	Extremely weak to very weak, grey discoloured brownish yellow and stained brown, completely to highly decomposed

Key: Disturbed Sample; Piston Sample; U76 Undisturbed Sample; U100 Undisturbed Sample; Mazier Sample; SPT Liner Sample; Water Sample; Standard Penetration Test; In-situ Vane Shear Test; Permeability Test; Impression Packer Test; Packer Test; Piezometer Tip; Observation Well Tip

LOGGED	S.P.Su
DATE	01/03/97
CHECKED	M.D.
DATE	03/03/97

REMARKS

1. Inspection pit excavated to 1.00m depth.

Lam Geotechnics Limited

ENPACK (HONG KONG) LIMITED
Civil Engineers & Contractors

DRILLHOLE RECORD

HOLE NO.	BH 9		
CONTRACT NO.	GE/97/15	SHEET	1 of 2
PROJECT	Natural Terrain Landslide Study Investigation at Sham Wat Road, Lantau Island. Ground Investigation.		
METHOD	W+RC	W.O. No	GE/97/15.69
MACHINE & No.	DR 76	DATE:	18/11/1998 to 25/11/1998
FLUSHING MEDIUM	AIR FOAM	GROUND LEVEL	21.34 mPD
CO-ORDINATES	E 806657.36 N 813914.28	ORIENTATION	VERTICAL

Drilling progress / casing / water level (m) shift start/end

Drilling Progress	Casing size	Water level (m) Shift start/end
18/11	UX (0 – 1.20), SX (from 1.20)	1.98 at 18:00
19/11		2.50 at 08:00; 2.47 at 18:00
20/11		2.73 at 08:00; 2.23 at 18:00
21/11		2.87 at 08:00; 2.11 at 18:00
23/11		3.93 at 08:00; 1.94 at 18:00
24/11		4.45 at 08:00

Core run records

T.C.R.(%)	S.C.R.(%)	R.Q.D.(%)	F.I.
100			
100			
98			
98			
77			
100			
95			
100			
85			
100			
100			
100			
100			
100			
100	100	100	0.9
100	82	72	NI
100	95	95	12.5 / 1.0
100	99	99	

Tests: PL1 (approx. 6.3 m), PL2 (approx. 7.9 m)

Samples (depths, m): 0.00, 1 0.50, 2 0.90, 1.20, 1.95, 2.87, 3.36, 4.27, 4.55, 5.13, 5.64, 6.42, 6.65, 6.90, 7.43, 7.80, 8.04, 8.66, 9.38, 9.75

Reduced Level	Depth (m)	Grade	Description
20.84	0.50		Grey to yellowish grey, subangular COBBLE sized moderately weak to moderately strong tuff fragments. (DEBRIS FLOW DEPOSIT)
20.14	1.20		Soft, reddish yellow (5YR 6/8), slightly sandy, silty CLAY with some to much subangular fine quartz gravel and occasional coarse gravel and cobble sized moderately strong tuff fragments. (DEBRIS FLOW DEPOSIT)
17.63	3.71		Grey to yellowish grey, BOULDER sized strong locally moderately strong tuff fragments with a matrix of soft, yellowish grey, sandy clay. (DEBRIS FLOW DEPOSIT)
14.44	6.90		Yellowish grey locally grey, subangular COBBLE and occasional to some coarse gravel sized moderately weak to moderately strong tuff fragments with a matrix of soft, yellowish grey, silty sandy to very sandy clay. (DEBRIS FLOW DEPOSIT)
13.54	7.80		Grey, strong tuff BOULDERS. (DEBRIS FLOW DEPOSIT)
13.30	8.04		Soft, whitish grey, sandy, silty CLAY with some to much subangular fine quartz gravel. (ALLUVIUM?)
		II, IV/III, II	Strong, grey locally yellowish grey, slightly decomposed, TUFF. Joints are widely occasionally medium spaced, rough, planar, extremely narrow, iron stained, dipping subhorizontally. From 9.17-9.38m : Moderately weak to moderately strong, yellowish grey to reddish yellow, highly to moderately decomposed and highly fractured.

Legend

- Small Disturbed Sample
- Piston Sample
- U76 Undisturbed Sample
- U100 Undisturbed Sample
- Mazier Sample
- SPT Liner Sample
- Water Sample
- Standard Penetration Test
- In-situ Vane Shear Test
- Permeability Test
- Impression Packer Test
- Packer Test
- Piezometer Tip
- Standpipe Tip

LOGGED F.S.Woo
DATE 26/11/1998
CHECKED P. Barry
DATE 30/12/1998

REMARKS
1. Standpipe installed to 10.00m depth.
2. Halcrow buckets installed at 0.50m, 1.00m, 1.50m, 2.50m, 3.00m, 3.50m, 4.00m, 4.50m, 5.00m, 5.50m and 6.00m below Ground Level.

TRIAL PIT RECORD

P 1

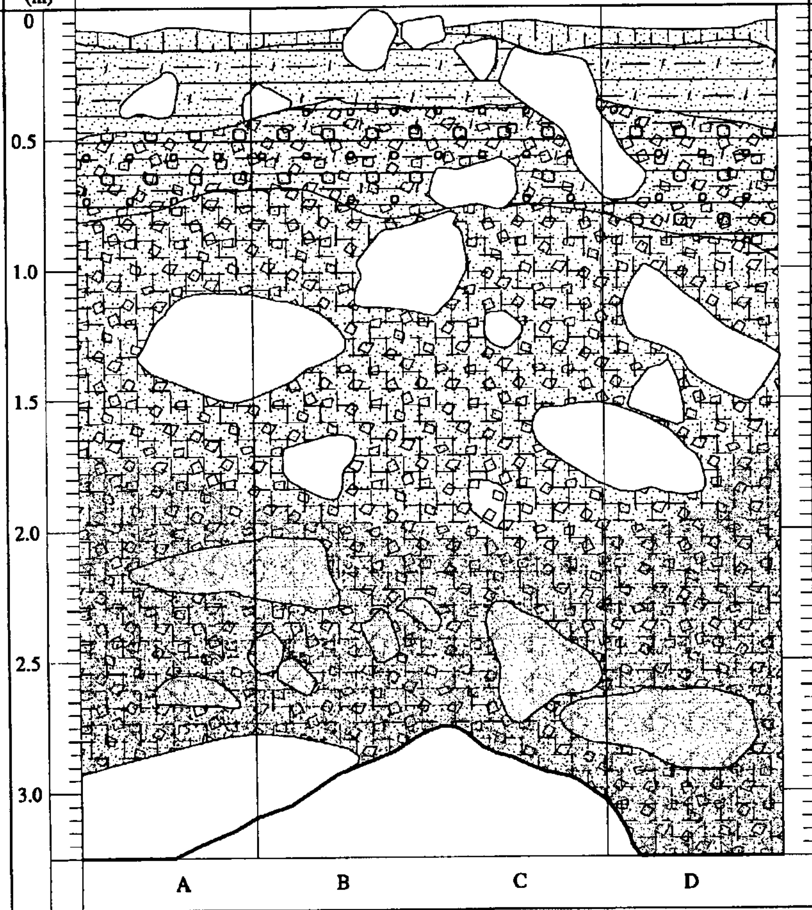
SHEET 1 OF 1

CONTRACTOR : Highways Department	LOGGED BY : JK	DATE : 4/2/97	CO-ORDINATES	PIT No. : P 1
WORKS ORDER No. :	CHECKED BY :	DATE :	EXCAVATION DATES : 31/1/97	LOCATION : Sham Wat

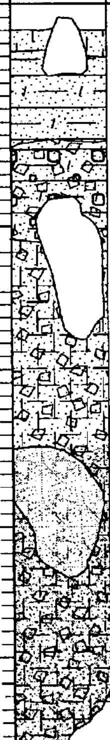
SAMPLES AND TESTS

- ▭— 1.5 - 2.0 kg/cm2
- (PL1)
- ▭— 3.0 to 4.0 kg/cm2
- Level Top BH5
- ▭— >5.0 kg/cm2
- (PL2)

Depth (m)



LEGEND



Light brown silty SAND with roots (TOPSOIL).

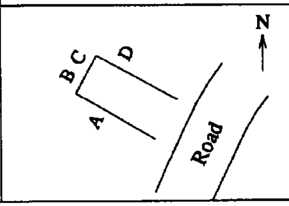
Soft, moist, orange silty, sandy CLAY with occasional subangular to subrounded boulders of strong, fresh to slightly decomposed coarse ash crystal tuff (matrix supported).

Soft to firm, moist, orange silty sandy very gravelly CLAY with many cobbles and boulders. Boulders and most cobbles are subangular to subrounded, strong, fresh to slightly decomposed coarse ash crystal tuff. This material becomes more angular and decomposed when gravel sized. Some angular gravel is composed of grey fresh fine ash tuff and light khaki brown fresh to slightly decomposed siltstone.

Dense, dry, orange brown, silty clayey very sandy GRAVEL with many cobbles and boulders (matrix supported). Locally becoming a gravelly SAND. Boulders are subangular to subrounded strong fresh to slightly decomposed coarse ash crystal tuff. In the cobble and gravel sizes this material is moderately to highly decomposed and some clasts are rounded to sub rounded. Some gravel and cobbles are subangular slightly to moderately decomposed fine ash tuff and occasional gravel clasts are fresh whitish grey angular chert. Below approximately 2 m depth the matrix becomes indistinctly mottled and by 3.5 m depth is clearly mottled orange and brick red.

SECTION (not to scale)

PLAN (not to scale)



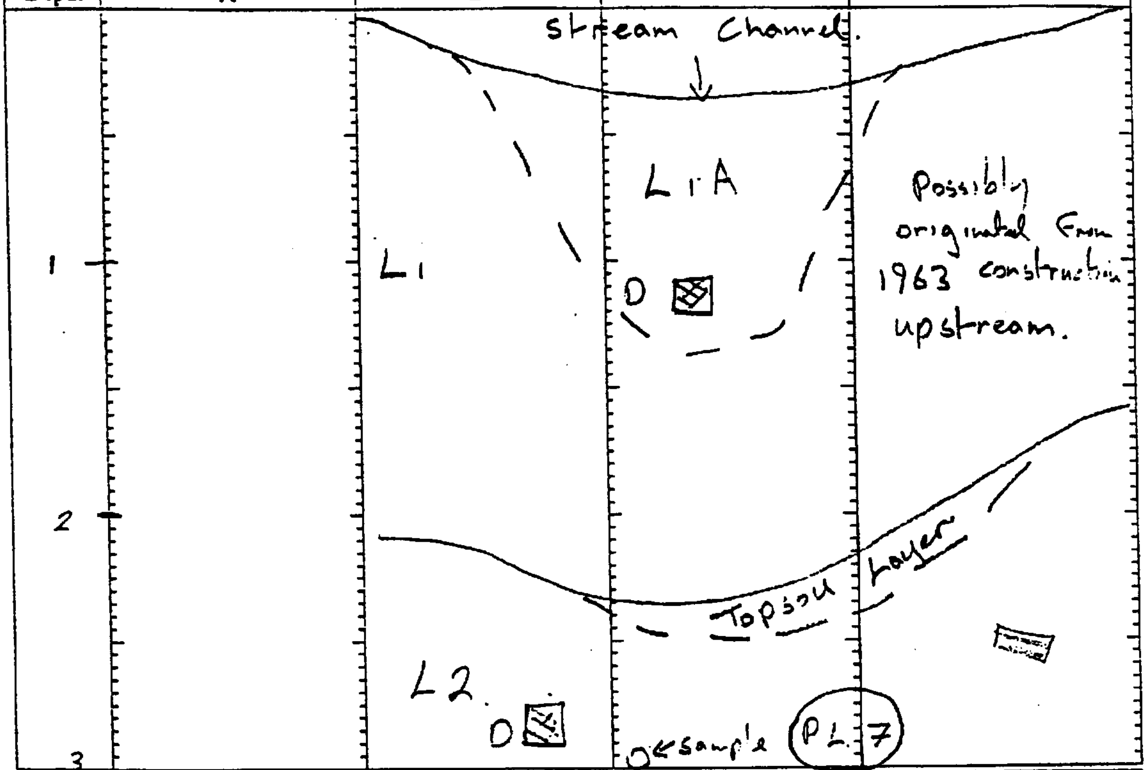
◆ = DISTURBED SAMPLE ▭— PENETROMETER ⊔ SAND INSITU DENSITY TEST

TRIAL PIT LOG (Sketch)

Project	Sham Wai Debris Lobe.		TRIAL PIT No E11
Job No	Date 27/2/97.	Ground Level (m)	Co-Ordinates 0
Contractor	Natural Streambed Exposure.		Sheet 1 of 1.

SKETCH OF FACES SHOWING DEPTH

Depth	A	B	C	D



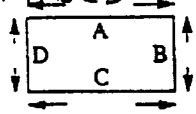
NOTES

3.2 - - - — EOP. — - - - - -

L1 Loose Orangish Brown Very gravelly silty SAND with much cobbles and boulders (L1A has a little cobbles and boulders)

L2 Firm to stiff, Tan mottled Orange, silty very sandy GRAVEL with some cobbles + boulders. Many clasts moderately to highly decomposed - occ Fresh Dk Grey Mudstone.

PLAN ABCD →



Bearing 90°

~~Shoring / Stability~~ O ▨ = Disturbed Sample.

Groundwater: No Seepage.

All dimensions in metres Scale	Client	Plant	Logged By JK

Form A4