Appendix C

Luminescence and Radiocarbon Dating Reports
(in CD ROM)

Report to Geotechnical Engineering Office Civil Engineering and Development Department on

Determination of sediment deposition ages by Luminescence Dating Phase 3A

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Technical Report
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1. INTRODUCTION

Six samples (laboratory code WLL794-799) were submitted for Luminescence Dating by the Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government.

The deposition ages have been determined for these samples using the silt fraction (4-11μm). Dependent on the relative luminescence intensities of feldspars and quartz in the samples, the palaeodose, i.e. the radiation dose accumulated in the sample after the last light exposure (assumed at deposition), was determined either by:

• measuring the blue luminescence output during infrared optical stimulation of the feldspar fraction.

• measuring the ultraviolet luminescence output during bluelight optical stimulation of the quartz fraction.

The doserate was estimated on the basis of a low level gammaspectrometry measurement.

All measurements were done in the Luminescence Dating Laboratory, School of Geography, Environment and Earth Sciences, Victoria University of Wellington.

2. EXPERIMENTAL TECHNIQUES

2.1 LUMINESCENCE MEASUREMENTS

The samples contained a considerable amount of silt, and we decided to apply a so-called fine grain technique, i.e. use the grain size 4-11 μm for dating.

Sample preparation was done under extremely subdued safe orange light in a darkroom. Outer surfaces, which may have seen light during sampling, were removed and discarded. The actual water content and the saturation content were measured using 'fresh' inside material.

The samples were treated with 10%HCl to remove carbonates until the reaction stopped, then carefully rinsed with distilled water. Thereafter, all organic matter was destroyed with 10%H_2O_2 until the reaction stopped, then carefully rinsed with distilled water. By treatment with a solution of sodium citrate, sodium bicarbonate and sodium dithionate iron oxide coatings were removed from the mineral grains and then the sample was carefully rinsed again.

The grain size 4-11μm was extracted from the samples in a water-filled (with added dispersing agent to deflocculate clay) measuring cylinder using Stokes' Law. The other fractions were discarded. The samples then are brought into suspension in pure acetone and deposited evenly in a thin layer on up to 50 aluminum discs (1cm diameter).

Luminescence measurements were done using a standard Riso TL-DA15 measurement system, equipped with

• Schott BG39 + Kopp 5-58 optical filters to select the blue luminescence band of feldspars. Stimulation was done cw at about 40mW/cm^2 with infrared diodes at 880Δ80nm.

• 7.5mm thick Hoya U340 optical filters to select the UV luminescence band of quartz. Stimulation was done cw at about 60mW/cm^2 with blue diodes at 470Δ30nm.

β-irradiations were done by the built in ^{90}Sr,^{90}Y β-irradiator, calibrated against the Riso National Laboratory to about 3% accuracy. α-irradiations were done on a ^{241}Am irradiator supplied and calibrated by ELSEC, Littlemore, UK.

Multiple Aliquot Additive (MA)

For sample WLL794 the Paleodose was estimated by use of the multiple aliquot additive-dose method (with late-light subtraction). After an initial test-measurement, 30 aliquots were β-irradiated in six groups up to five times of the dose result taken from the test. 9 aliquots were α-irradiated in three groups up to three times of the dose result taken from the test. These 39 disks were stored in the dark for four weeks to relax the crystal lattice after irradiation.

After storage, these 39 disks and 9 unirradiated disks were preheated for 5min at 220C to remove unstable signal components, and then measured for 100sec each, resulting in 39 shinedown curves. These curves were then normalized for their luminescence response, using 0.1s shortshine measurements taken before irradiation from all aliquots.

The luminescence growth curve (β-induced luminescence intensity vs added dose) is then constructed by using the initial 10 seconds of the shine down curves and subtracting the average of the last 20 sec, the so called late light which is thought to be a mixture of background and hardly bleachable components. The shine plateau was checked to be flat after this manipulation. Extrapolation of this growth curve to the dose-axis gives the equivalent dose D_e, which is used as an estimate of the Paleodose.

A similar plot for the alpha-irradiated discs allows an estimate of the α-efficiency, the a-value (Luminescence/dose generated by the α-source divided by the luminescence/dose generated by the β-source).

Single Aliquot Regenerative (SAR)

Palaeodoses for samples WLL795-WLL799 were estimated by use of the Single Aliquot Regenerative method (SAR; see Murray and Wintle, 2000). The blue-light stimulation SAR method was chosen because of the extremely low feldspar content (as proven by extremely low or even zero infrared stimulated luminescence signal). Under bluelight stimulation bright UV OSL signals were measured, which together with the shinedown curve shapes and the strong sensitivity changes prove that quartz is the dominant OSL emitting mineral in these samples.

In the SAR method a number of aliquots are subjected to a repetitive cycle of irradiation, preheat and measurement. In the first cycle the natural luminescence output is measured, in all following cycles an artificial dose is applied. Usually four or five of these dose points are used to build the luminescence growth curve (β-induced luminescence intensity vs added dose) and bracket the natural luminescence output. This allows interpolation of the equivalent dose (the β-dose equivalent to the palaeodose). In order to correct for potential sensitivity changes from cycle to cycle, a test dose is applied between the cycles, preheated ('cut heat') and measured.

For the samples reported here 16 aliquots were measured, preheat and cutheat temperature was 260C for 50s, and measurement time 40s (blue stimulation) or 100s (IR stimulation), which resets the luminescence signal to a negligible residual. All quartz measurements were carried out at 120^{o}C, all feldspar measurements at room temperature. Though feldspar luminescence was dim compared to the relatively bright quartz, and thus any contribution from feldspar to the total blue-stimulated OSL signal is basically negligible, nevertheless an infrared bleach (880nm light, 40mW/cm^2, for 40 sec) has been applied before each OSL measurement to erase any feldspar OSL. We thus can safely assume that in the quartz measurements all luminescence signal originated from the quartz fraction.

The measurement of 16 aliquots resulted in 16 equivalent doses, spread over the so called dose distribution. The arithmetic mean of this distribution was interpreted as the best estimate for the equivalent dose, and subsequently used for age calculation.

2.2 GAMMA SPECTROMETRY

The dry, ground and homogenised soil samples were encapsuled in airtight perspex containers and stored for at least 4 weeks. This procedure minimizes the loss of the short-lived noble gas ^{222}Rn and allows ^{226}Ra to reach equilibrium with its daughters ^{214}Pb and ^{214}Bi.

The samples were counted using high resolution gamma spectrometry with a CANBERRA broad energy Ge detector for a minimum time of 24h. The spectra were analysed using GENIE2000 software. The doserate calculation is based on the activity concentration of the nuclides ^{40}K, ^{208}Tl, ^{212}Pb, ^{228}Ac, ^{214}Bi, ^{214}Pb, ^{226}Ra.

3. RESULTS

The radionuclide contents were calculated from the raw gammaspectrometry data. The Uranium and Thorium contents of most samples were quite high, similar to what we've measured in the previous phases of this project reported earlier. Table 2 gives a summary of the radiometric data.

The high radionuclide contents cause high doserates for most samples, compared to 2…3 Gy/ka for what would be an 'average' sample. Owing to the high doserates, some samples showed the onset of saturation of the electron traps, despite being relatively young for the OSL dating technique.

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Table 1 gives sample summaries and calculated cosmic doserates, whereas Table 3 gives a summary of all equivalent doses, doserates and ages.

All errors in this report are stated as 1 sigma errors. A radioactive disequilibrium was considered as significant, if the equivalent Uranium contents do not overlap in a 2 sigma interval.

4. REFERENCES

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Murray A.S. and Wintle A.G. (2000) Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements* 32, 57-73.

Prescott & Hutton (1994), *Radiation Measurements*, Vol. 23.

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Table 1 - Doserate contribution of cosmic radiation

Sample no.	depth below surface (m)	dD_c/dt (Gy/ka)[1]	Field code
WLL794	1.0	0.1524±0.0076	HK13220
WLL795	1.8	0.1366±0.0068	HK13221
WLL796	3.9	0.1040±0.0052	HK13217
WLL797	3.1	0.1151±0.0058	HK13218
WLL798	5.8	0.0825±0.0041	HK13219
WLL799	0.8	0.1567±0.0078	HK13222

[1] Contribution of cosmic radiation to the total doserate, calculated as proposed by Prescott & Hutton (1994), Radiation Measurements, Vol. 23.

Table 2 - Radionuclide and water contents

Sample no.	Water content δ[1]	U (µg/g) from ^{234}Th	U (µg/g)[2] from ^{226}Ra, ^{214}Pb, ^{214}Bi	U (µg/g) from ^{210}Pb	Th (µg/g)[2] from ^{208}Tl, ^{212}Pb, ^{228}Ac	K (%)	Field code
WLL794	1.181	6.22±0.63	7.33±0.40	7.61±0.53	33.3±0.4	2.64±0.06	HK13220
WLL795	1.209	5.02±0.60	5.18±0.33	5.95±0.46	43.7±0.5	1.93±0.05	HK13221
WLL796	1.286	5.38±0.61	6.40±0.36	6.35±0.48	40.0±0.5	1.47±0.04	HK13217
WLL797	1.105	3.45±0.54	3.22±0.28	3.24±0.38	43.3±0.5	2.77±0.06	HK13218
WLL798	1.235	3.80±0.54	3.31±0.28	3.95±0.39	43.2±0.5	2.18±0.05	HK13219
WLL799	1.145	4.97±0.52	3.81±0.27	4.70±0.39	22.2±0.3	1.09±0.03	HK13222

[1] Ratio wet sample to dry sample weight. Errors assumed 50% of (δ-1).
[2] U and Th-content is calculated from the error weighted mean of the isotope equivalent contents

Table3: a-value and equivalent dose, doserate and luminescence age

Sample no.	Method	a-value	D_e (Gy)	dD/dt (Gy/ka)[#]	**OSL-age (ka)**	Field code
WLL794	MA b	0.072±0.012	29.3±2.4	8.39±0.58	**3.49±0.37**	HK13220
WLL795	SAR q	0.06±0.03*	78.9±4.8	7.50±1.01	**10.5±1.6**	HK13221
WLL796	SAR q	0.06±0.03*	199.1±11.6	6.60±0.98	**30.2±4.8**	HK13217
WLL797	SAR q	0.06±0.03*	215.6±17.3	8.42±0.95	**25.6±3.5**	HK13218
WLL798^	SAR q	0.06±0.03*	462.8±137.0	6.86±0.90	**67.5±21.8^**	HK13219
WLL799	SAR q	0.06±0.03*	15.3±0.6	4.64±0.60	**3.30±0.44**	HK13222

[#] The doserate dD/dt was calculated using the conversion factors of Adamiec and Aitken (1998)
[*] The a-values were estimated
^ Maximum age

MA Multiple Aliquot Additive
SAR Single Aliquot Regenerative

b 4-11µm polymineral sample
infrared stimulation (i.e. only feldspars contribute to OSL)
410 nm 'blue' optical OSL filter (measures predominantly K-feldspars)

q 4-11µm polymineral sample
blue light stimulation (i.e. quartz and feldspars contribute to OSL, but in these samples the signal was dominated by quartz as was evident by OSL intensity and shinedown curve shape)
340nm nm UV optical OSL filter

Some comments

• Our standard method is 'MA b', i.e. a multiple aliquot approach focusing on the blue emission band of potassium feldspars. However, all except one sample (WLL794) had very low (or even zero) infrared stimulated luminescence, indicating the absence of feldspars. Thus, SAR was the method of choice. The blue light stimulated OSL signal was very bright, and undoubtedly dominated by quartz.

• Sample WLL798 showed clear signs of partial bleaching, i.e. the OSL clock was not fully reset at the time of deposition. This age must be interpreted as a maximum age.

Report to Geotechnical Engineering Office Civil Engineering Department on Age Determination of Natural Terrain Landslides By Luminescence Dating LPMitP Phase I

by

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OSL results for Batch 1, 20 samples

April 5, 2011
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Summary

Batch 1 included 20 samples from 5 different locations. The samples contained predominantly fine grained material. Coarser grains (90-212μm) have been dated for 2 samples and the ages were compared with the results for fine grains (4-11μm). In both cases the larger grains resulted in higher ages. One possible reason is that coarser grains were bleached to a lesser extent during transport by the landslide. All samples have been dated therefore by extracting fine grained quartz and using a SAR procedure. Some samples were contaminated with feldspar after the extraction procedure. Those samples were measured with a post-IR blue SAR procedure to eliminate contributions from feldspar to the signal.
All samples showed a radioactive disequilibrium in the uranium decay chain.

1. General Principles of Luminescence Dating

Ionizing radiation from natural radioactive isotopes and from cosmic rays liberates charge carriers within silicate mineral grains like quartz and feldspar over geologic time. Charge carriers become localized at crystal defects and lead to the accumulation of a "trapped" charge population. Exposure to solar radiation releases the charges from the trap sites and thereby resets the "luminescence clock." If the mineral grains are then shielded from further solar radiation by burial, the trapped charge population begins to reaccumulate. When the sample is collected at a later time the trapped charge population is representative of the time elapsed since the mineral grains were last exposed to solar radiation, i.e., the time since burial. As the samples are heated or illuminated in the laboratory, the thermal or optical stimulation results in the release of trapped charge, which subsequently undergoes recombination with charge of the opposite sign. The light emitted during this process is called TL (Thermally Stimulated Luminescence) or OSL (Optically Stimulated Luminescence). The intensity of this "natural" luminescence signal is proportional to the radiation dose (in units of Gray, 1 Gy = 1 J/kg) absorbed in the time since burial. The natural equivalent dose is determined by comparing the natural luminescence signal with that obtained after known radiation exposures administered in the laboratory, the dose response. With the dose rate, the rate of natural irradiation of the minerals, the age of the sample (i.e., the burial time) is derived from

$$Age\left[a\right] = \frac{\text{Equivalent Dose}\left[\text{Gy}\right]}{\text{Dose Rate}\left[\text{Gy/a}\right]}.$$

Detailed discussions of luminescence dating methods including equivalent dose and dose rate determination can be found in publications by Aitken (1985, 1998) and by Wintle (1997).

2. Natural Dose-rate

The rate at which the trapped charge population accumulates is proportional to the rate at which energy from ionising radiation is absorbed by the crystal. The ionising radiation originates mainly from the radioactive decays of ^{232}Th, ^{235}U, ^{238}U (and their daughter nuclides), ^{40}K and ^{87}Rb, and to a lesser extent from cosmic radiation. As the energy release of each decay and the half-life of the nuclides are well known, the dose rate (unit: Gy/a) can be determined from the concentration of the nuclides in the soil. The concentration of ^{232}Th, natural uranium, and ^{40}K is measured by means of gamma spectrometry and the dose rate is calculated using the conversion factors given by Adamiec and Aitken (1998).

Water in the pores of the sediment absorbs part of the radiation that would otherwise reach the crystals. Therefore the dose-rate in wet sediment is less than in the same sediment when it is dry. The water content of the sample as found can be measured. Taking into account the type of sediment, its environment, and its pore-structure, assumptions about the average wetness over the burial time span have to be made. Usually the water content *w* is calculated from the mass of the sample before (m_w) and after (m_d) drying: $w = (m_w - m_d)/m_d$.

An effect that also influences the dose rate is the different penetrating power of alpha, beta, and gamma radiation. Gamma-radiation has a range of about 30 cm in sediments, so that the sample taken for the gamma spectrometry must be representative for the whole 30 cm sphere of influence. Beta radiation, with a range of 2-3 mm, does not uniformly penetrate the grains but is attenuated. The beta dose-rate therefore depends on the diameter of the grains, and the effect has to be allowed for by using the attenuation factors calculated by Mejdahl (1979). Alpha radiation only penetrates the outer 10 μm of a grain.

Disequilibria: In most of the samples a disequilibrium in the uranium decay chain has been detected. No information about the possible development of the equilibrium was available. The dose rate was therefore calculated using the average value of two extreme scenarios: (1) equilibrium as indicated by the nuclides of ^{214}Bi and ^{214}Pb for the lower limit and (2) measured concentration of each separate nuclide in the decay chain for the upper limit. As uncertainty we used the difference between the average and the limts.

With the concentrations Th (^{232}Th in ppm; 1 ppm = 1 μg/g), U (natural uranium in ppm) and K (natural element potassium in %), the beta and gamma contribution of the dose rate of the dry sediment can be calculated. Taking into account the water content *w*, the effective dose-rate is determined from the following equation:

$$\dot{D} = \frac{\dot{D}_{\alpha,dry}}{1+1.50\times w} + \frac{\dot{D}_{\beta,dry}}{1+1.25\times w} + \frac{\dot{D}_{\gamma,dry}}{1+1.14\times w} + \dot{D}_{\text{cosm}} = \dot{D}_{\alpha,eff} + \dot{D}_{\beta,eff} + \dot{D}_{\gamma,eff} + \dot{D}_{\text{cosm}} .$$

For coarse grains the outer shell affected by alpha radiation is removed through etching. For those samples the contribution by alpha radiation to the total dose rate is not included.

The fraction of the dose rate caused by cosmic radiation depends on the geographical location of the site and can be calculated as described by Barbouti and Rastin (1983) and Prescott and Stephan (1982).

3. Sample preparation

All samples had a small fraction of coarse grained material (90-212μm), but were predominantly fine grained. In environments where a complete resetting of samples by sunlight is questionable, coarse grains offer the possibility to use small aliquots and thereby detect incomplete bleaching. We initially chose the 2 samples with the largest fraction of coarser material (HK13348, HK13349), and we prepared both coarse grains and fine grain material to compare the results. Quartz bleaches faster than feldspar and is not affected by anomalous fading. For colluvial samples quartz is therefore preferable to feldspar.

Coarse grain preparation (90-150 μm): After sieving, the grains were treated with HCl (concentration 3.75 %) and H_2O_2 to remove carbonates and organic components, respectively. Subsequent treatment with 40 % HF for 50 min etched away the outer surface of the grains (10-20 μm), which had been affected by alpha-radiation, and also removed most feldspar contaminations. Finally the samples were treated with HCl again to remove fluoride precipitates that may have formed during the etching process, rinsed with deionised water, and dried. Density separation was carried out with sodium polytungstate. In a first step, heavy minerals with a density greater than 2.75 g/cm^3 were separated from quartz and feldspar. In a second step quartz with a density greater than 2.62 g/cm^3 was separated from feldspar.

Small aliquots (subsamples) were prepared by fixing the grains on steel cups with silicone spray. We used the grain size fraction with the most material.

Fine grain preparation: After sieving the grains smaller than 63 μm were treated with HCl (concentration 3.75 %) and H_2O_2 to remove carbonates and organic components, respectively. Between each treatment the samples were rinsed three times with deionized water. Grains were allowed to settle for at least 4 hours and the supernatant fluid was carefully decanted. Subsequently grains >11μm were removed with the Stokes method by allowing a suspension of the samples to settle for 20 min. Grains between 4 and 11 μm were subsequently separated with a centrifuge. Finally, quartz separates were prepared by etching for 3 days with Hexafluorosilicic acid. We used a suspension of quartz in water and prepared aliquots by pipetting the suspension on Al disks.

All dosimetry samples were dried at 55 °C, and the wet and dry weight was measured to obtain the water content of the samples. The dry samples were filled in air-tight containers and stored for 4 weeks. The thorium, uranium and potassium concentrations were measured with low level gamma spectrometry.

4. Measurements

Instrumentation:

Measurements were conducted using a Risø TL/OSL-DA-15 reader, Risø National Laboratory, with a bialkali PM tube (Thorn EMI 9635Q B) and Hoya U-340 filters (290-370 nm). The built-in $^{90}Sr/^{90}Y$ beta source gives a dose rate of 100 mGy/s (error 4.1 %). Optical stimulation was carried out with blue LEDs (470 nm), delivering 31 mW/cm^2 to the sample; IR stimulation was from an IR LED array at 875 ± 80 nm with 36 mW/cm^2 power at the sample. The heating rate used was 5 °C/s.

Measurement procedure:

The measurement procedure was based on the single aliquot regenerative-dose (SAR) procedure described by Murray and Wintle (2000) and Wintle and Murray (2006):

1. **Give dose D_i**
2. **Preheat at T for 10 s to remove unstable signals**
3. **Stimulate with blue LEDs for 100 s at 125 °C, measure OSL signal L_i**
4. **Give test dose, 15-20% of expected dose**
5. **Preheat at T-20°C for 10 s to remove unstable signals**
6. **Stimulate with blue LEDs for 100 s at 125 °C, measure OSL signal T_i**
7. **Return to 1**

The doses D_i change in each cycle. For the natural signal $D_0 = 0$ Gy and no dose is administered. The regeneration doses D_1 to D_6 are increasing doses. The repeat doses D_7 (expected equivalent dose) and D_8 (equal to D_1) are administered to check the precision with which a known dose can be recovered with the method. $D_9 = 0$ Gy to check for an unwanted recuperation of the OSL (zero dose signal). A possible contamination of the samples by feldspar inclusions is examined in the last cycle with two equal doses $D_{10} = D_3$. In cycles 0 through 9 all steps are carried out as listed above. In cycle 10 the aliquot is stimulated with IR (60°C for 100 s) between steps 1 and 2 to test for an IR depletion of the OSL signal.
For younger samples only 4 regeneration doses were used.

Determination of the preheat temperature T:
The preheat temperature T was determined with a plateau test for 4 samples from different locations (HK13348, HK13349, HK13354, HK13361). All tests resulted in a preheat temperature of 200°C. This value was therefore used for all samples.

Determination of the equivalent dose for one aliquot:
We determined the luminescence signals L_i and T_i by integrating over the first 0.8 seconds of an OSL decay curve and subtracting an average of the next 4 seconds as background (early background). The signal uncertainty followed from counting statistics. The sensitivity corrected signal is given by $C_i = L_i/T_i$. The dose response of every aliquot was determined by fitting a saturating exponential to the luminescence signals C_1 to C_6 and including the origin. For smaller doses the signals C_1 to C_4 were fitted with a linear fit. The dose D_0, corresponding to the natural sensitivity-corrected luminescence signal C_0, was calculated with the fitting parameters A and B of the exponential or linear fit. All uncertainties were calculated using the Gaussian law of error propagation and Poisson statistics.

Selection of reliable aliquots:
Only aliquots that passed the following criteria were deemed "reliable" and were used to calculate the equivalent dose:

1. Dose recovery of known dose D_7 better than 10%
2. Recycling ratio: $0.9 < C_8/C_1 < 1.1$
3. Recuperation: $C_9/C_0 < 5\%$
4. IR depletion: $C_{10}/C_3 > 0.9$

Only few aliquots had to be discarded for not passing tests 1-3. Several samples however showed a large feldspar contamination. For these samples a post-IR blue sequence was used to measure the equivalent dose. This post-IR blue sequence was similar to the SAR procedure

listed above. Before each OSL measurement (steps 3 and 6) another step was added to deplete the feldspar signal:

Stimulate with IR LEDs for 300 s at 60 °C

Total equivalent dose:

The equivalent dose D_e was determined with the common age model (Galbraith et al., 1999). The weights were the statistical errors. The full uncertainty also includes 4.1% error for the source calibration.

5. Results

A detailed report for each of the 20 samples is provided below. A summary is given in the following table.

HK Rock No.	Location	GI Station	Age (ka)	Error (ka)
HK13345	Queen's Mary Hospital	DH7	10.79	0.60
HK13346	Queen's Mary Hospital	DH7	15.26	0.88
HK13347	Sham Wat	SW-TP1	5.59	0.30
HK13348	Sham Wat	SW-TP2	4.31	0.32
HK13349	Sham Wat	SW-TP5	3.14	0.17
HK13350	Sham Wat	SW-TP6	2.69	0.14
HK13351	Sham Wat	SW-TP10	4.93	0.26
HK13352	Sham Wat	SW-TP14	3.43	0.18
HK13353	Sham Wat	SW-TP15	3.39	0.18
HK13354	HKUST Staff Quarters (GIU51687)	BDH2	10.22	0.69
HK13355	HKUST Staff Quarters (GIU51688)	BDH4	28.40	1.90
HK13356	Nam Chung	NC-TP1	22.70	1.41
HK13357	Nam Chung	NC-TP13	10.44	0.60
HK13358	Nam Chung	NC-TP19	1.34	0.07
HK13359	Nam Chung	NC-TP26	1.02	0.07
HK13360	Nam Chung	NC-TP32	2.30	0.14
HK13361	Nam Chung	NC-TP34	4.26	0.26
HK13362	Nam Chung	NC-TP34	6.97	0.40
HK13363	Nam Chung	NC-TP37	2.73	0.15
HK13364	Tai O East	TOE-TP2	18.27	1.12

6. Discussion and Conclusions

Complete solar resetting of grains in colluvia is often questionable. Coarser grains separated from two samples resulted in larger ages than the fine grain fraction. A radial plot indicated overdispersion, which can be indicative of incomplete bleaching during transport. An attempt to apply the minimum age model (Galbraith et al., 1999) was not successful and simply resulted in the dose value of the aliquot with the lowest dose. Even using this value the calculated age was still larger than the one obtained with fine grains. We therefore used fine grain quartz for all samples. Only one sample (HK13356) showed clear overdispersion in a radial plot of the data, indicating an incomplete resetting of this sample.

All samples also showed radioactive disequilibria in the uranium decay chain.

Measurement of a considerably larger number of small coarse-grain aliquots (> 50 reliable aliquots) would be necessary to clearly detect or exclude incomplete bleaching of the samples. This is however not possible in the tight timeframe of 3 months for 20 samples, particularly given the long irradiation times and the necessity of post-IR blue measurements. For this purpose a minimum of 6 months would be necessary. Another possibility are single-grain measurements (currently not possible at OSU).

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HK13345

DH7, Queen's Mary Hospital

Sample type	latitude	longitude	altitude	depth	Depositional type
Core	22.25260172	113.5801317	183.19	5.10-5.25	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**152.7**	**6.2**	**4.1**
Total Dose rate (Gy/ka)	**14.16**	**0.53**	**3.8**
Age (ka)	**10.79**	**0.60**	**5.5**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	19
Reliable aliquots	17
Regeneration doses (Gy)	10, 20, 40, 70, 120, 230

Observations: feldspar contamination; post-IR blue sequence

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.01	0.01
Th (ppm)	47.57	2.83
K (%)	3.72	0.12
U (ppm):		
weighted mean (all)	7.38	0.52
Th234	11.45	1.02
Ra226	7.89	2.45
Pb214 and Bi214	7.10	0.50
Pb210	12.00	3.73

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	4.72	0.45
beta	5.37	0.25
gamma	3.94	0.15
cosmic	0.1223	0.0061

Effective dose rates

HK13346

DH7, Queen's Mary Hospital

Observations: Core consisted mostly of one solid rock, only 10% of the material consisted of sediment

Sample type	latitude	longitude	altitude	depth	Depositional type
Core	22.25260172	113.5801317	183.19	5.70-5.90	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**169.4**	**7.6**	**4.5**
Total Dose rate (Gy/ka)	**11.10**	**0.40**	**3.6**
Age (ka)	**15.26**	**0.88**	**5.7**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	40
Reliable aliquots	26
Regeneration doses (Gy)	10, 20, 50, 90 150, 250

Observations: feldspar contamination; post-IR blue sequence

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.01	0.01
Th (ppm)	36.16	2.16
K (%)	3.06	0.10
U (ppm):		
weighted mean (all)	5.81	0.41
Th234	8.25	0.73
Ra226	6.17	1.92
Pb214 and Bi214	5.62	0.40
Pb210	9.97	3.10

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	3.62	0.34
beta	4.29	0.18
gamma	3.07	0.11
cosmic	0.1176	0.0059

Effective dose rates

HK13347

SW-TP-1, Sham Wat

Observations: Core consisted mostly of one solid rock, only 10% of the material consisted of sediment

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.16052879	113.531931	17	0.8	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**51.6**	**2.1**	**4.1**
Total Dose rate (Gy/ka)	**9.23**	**0.34**	**3.6**
Age (ka)	**5.59**	**0.30**	**5.5**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	16
Reliable aliquots	16
Regeneration doses (Gy)	5, 10, 20, 35 60, 90

Dose rate measurement:

Observations: Equilibrium in Uranium decay chain

		Error
water content	0.15	0.03
Th (ppm)	35.69	2.13
K (%)	3.07	0.10
U (ppm):		
weighted mean (all)	5.54	0.39
Th234	8.07	0.71
Ra226	5.52	1.72
Pb214 and Bi214	5.40	0.38
Pb210	5.12	1.60

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	2.89	0.27
beta	3.57	0.16
gamma	2.61	0.12
cosmic	0.1606	0.00803

Effective dose rates

HK13348

SW-TP-2, Sham Wat

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.16074219	113.5319258	26.56	0.5	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**43.4**	**2.7**	**6.2**
Total Dose rate (Gy/ka)	**10.08**	**0.40**	**4.0**
Age (ka)	**4.31**	**0.32**	**7.4**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	24
Reliable aliquots	16
Regeneration doses (Gy)	5, 10, 15, 20, 35, 60

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.15	0.03
Th (ppm)	43.51	2.59
K (%)	3.37	0.11
U (ppm):		
weighted mean (all)	4.63	0.33
Th234	8.79	0.78
Ra226	4.70	1.48
Pb214 and Bi214	4.40	0.31
Pb210	3.97	1.25

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	3.15	0.32
beta	3.87	0.19
gamma	2.90	0.14
cosmic	0.1643	0.008215

Effective dose rates

Coarse grain fraction:

For this sample we also measured quartz grains 90-150 µm. An average dose value and minimum dose value were calculated. **The results are listed below for the sake of completeness, but were not used for age calculation of the sample**.

Grain size (µm)	90-150
Aliquots measured	24
Reliable aliquots	22
Regeneration doses (Gy)	5, 10, 20, 40 70, 120

	Effective DR (Gy/ka)	Error
alpha	N.A.	
beta	3.55	0.23
gamma	2.90	0.14
cosmic	0.1643	0.008215

		Error	Error (%)
Equivalent Dose (Gy) (Average value)	**43.4**	**2.7**	**6.2**
Total Dose rate (Gy/ka)	**6.62**	**0.27**	**4.0**
Age (ka)	**6.56**	**0.49**	**7.4**

		Error	Error (%)
Equivalent Dose (Gy) (Minimum value)	**30.9**	**0.96**	**3.1**
Total Dose rate (Gy/ka)	**6.62**	**0.27**	**4.0**
Age (ka)	**4.67**	**0.24**	**5.1**

HK13349

SW-TP-5, Sham Wat

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.16107922	113.5318031	17.44	1.5	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**25.7**	**1.1**	**4.3**
Total Dose rate (Gy/ka)	**8.19**	**0.29**	**3.5**
Age (ka)	**3.14**	**0.17**	**5.5**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	23
Reliable aliquots	21
Regeneration doses (Gy)	5, 10, 15, 20, 35, 60

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.12	0.024
Th (ppm)	29.57	1.77
K (%)	2.98	0.10
U (ppm):		
weighted mean (all)	4.19	0.29
Th234	6.35	0.56
Ra226	4.07	1.25
Pb214 and Bi214	4.08	0.29
Pb210	5.30	1.63

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	2.43	0.23
beta	3.33	0.14
gamma	2.28	0.10
cosmic	0.153	0.00765

Effective dose rates

Coarse grain fraction:

For this sample we also measured quartz grains 90-150 µm. **The results are listed below for the sake of completeness, but were not used for age calculation of the sample**.

Grain size (µm)	90-150
Aliquots measured	35
Reliable aliquots	23
Regeneration doses (Gy)	5, 10, 20, 40 70, 120

	Effective DR (Gy/ka)	Error
alpha	N.A.	
beta	3.08	0.18
gamma	2.28	0.10
cosmic	0.153	0.00765

		Error	Error (%)
Equivalent Dose (Gy)	**25.6**	**1.1**	**4.3**
Total Dose rate (Gy/ka)	**5.51**	**0.20**	**3.7**
Age (ka)	**4.64**	**0.26**	**5.6**

HK13350

SW-TP-6, Sham Wat

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.16137012	113.5319449	50.56	0.8	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**18.94**	**0.8**	**4.2**
Total Dose rate (Gy/ka)	**7.04**	**0.23**	**3.2**
Age (ka)	**2.69**	**0.14**	**5.3**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	25
Reliable aliquots	15
Regeneration doses (Gy)	12, 15, 19, 22

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.08	0.016
Th (ppm)	23.12	1.39
K (%)	2.45	0.08
U (ppm):		
weighted mean (all)	3.77	0.27
Th234	5.32	0.48
Ra226	3.84	1.21
Pb214 and Bi214	3.64	0.26
Pb210	4.51	1.42

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	2.09	0.19
beta	2.86	0.11
gamma	1.93	0.07
cosmic	0.1615	0.008075

Effective dose rates

HK13351

SW-TP-10, Sham Wat

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.1620508	113.5320679	47.2	0.7	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**18.11**	**0.74**	**4.1**
Total Dose rate (Gy/ka)	**3.67**	**0.12**	**3.4**
Age (ka)	**4.93**	**0.26**	**5.3**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	20
Reliable aliquots	19
Regeneration doses (Gy)	14, 16, 20, 22

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.094	0.0188
Th (ppm)	11.54	0.69
K (%)	1.42	0.05
U (ppm):		
weighted mean (all)	1.71	0.12
Th234	2.93	0.27
Ra226	1.75	0.58
Pb214 and Bi214	1.62	0.12
Pb210	2.11	0.70

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	1.00	0.10
beta	1.54	0.07
gamma	0.97	0.04
cosmic	0.1625	0.008125

Effective dose rates

HK13352

SW-TP-14, Sham Wat

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.16232972	113.5324815	60.01	0.7	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**13.81**	**0.56**	**4.1**
Total Dose rate (Gy/ka)	**4.03**	**0.13**	**3.2**
Age (ka)	**3.43**	**0.18**	**5.2**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	21
Reliable aliquots	17
Regeneration doses (Gy)	10, 13, 17, 20

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.11	0.022
Th (ppm)	14.21	0.85
K (%)	1.34	0.04
U (ppm):		
weighted mean (all)	2.18	0.15
Th234	3.14	0.28
Ra226	2.11	0.67
Pb214 and Bi214	2.14	0.15
Pb210	1.70	0.54

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	1.20	0.11
beta	1.56	0.06
gamma	1.11	0.05
cosmic	0.1629	0.008145

Effective dose rates

HK13353

SW-TP-15, Sham Wat

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.16255674	113.5323633	40.95	0.8	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**20.15**	**0.83**	**4.1**
Total Dose rate (Gy/ka)	**5.94**	**0.20**	**3.4**
Age (ka)	**3.39**	**0.18**	**5.4**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	17
Reliable aliquots	17
Regeneration doses (Gy)	16, 18, 22, 24

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.17	0.034
Th (ppm)	17.63	1.06
K (%)	2.81	0.09
U (ppm):		
weighted mean (all)	3.41	0.24
Th234	4.81	0.43
Ra226	3.64	1.15
Pb214 and Bi214	3.29	0.23
Pb210	3.85	1.22

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	1.52	0.14
beta	2.67	0.12
gamma	1.59	0.07
cosmic	0.1612	0.00806

Effective dose rates

HK13354

HKUST Staff Quarters (GIU51687), BDH2

Sample type	latitude	longitude	altitude	depth	Depositional type
Mazier	22.32252551	114.0227887	141.25	2.38-2.52	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**84.9**	**3.8**	**4.5**
Total Dose rate (Gy/ka)	**8.31**	**0.41**	**5.0**
Age (ka)	**10.22**	**0.69**	**6.7**

Equivalent dose measurement:

Observations: feldspar contamination, post-IR blue sequence

Grain size (μm)	fine, 4-11
Aliquots measured	21
Reliable aliquots	16
Regeneration doses (Gy)	10, 20, 50, 80 120, 200

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.24	0.048
Th (ppm)	42.17	2.53
K (%)	1.32	0.06
U (ppm):		
weighted mean (all)	7.23	0.51
Th234	9.94	0.87
Ra226	8.84	2.58
Pb214 and Bi214	6.75	0.48
Pb210	11.26	3.28

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	3.20	0.34
beta	2.53	0.19
gamma	2.43	0.14
cosmic	0.1462	0.00731

Effective dose rates

HK13355

HKUST Staff Quarters (GIU51688), BDH4

Sample type	latitude	longitude	altitude	depth	Depositional type
Mazier	22.32223622	114.02318	167.13	2.5-2.63	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**194.3**	**8.6**	**4.4**
Total Dose rate (Gy/ka)	**6.85**	**0.36**	**5.2**
Age (ka)	**28.35**	**1.94**	**6.8**

Equivalent dose measurement:

Observations: feldspar contamination, post-IR blue sequence

Grain size (μm)	fine, 4-11
Aliquots measured	20
Reliable aliquots	20
Regeneration doses (Gy)	10, 20, 50, 90 150, 250

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.23	0.046
Th (ppm)	35.21	2.10
K (%)	1.20	0.04
U (ppm):		
weighted mean (all)	5.08	0.36
Th234	8.08	0.69
Ra226	5.78	1.67
Pb214 and Bi214	4.80	0.34
Pb210	10.02	2.90

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	2.59	0.29
beta	2.13	0.17
gamma	1.99	0.12
cosmic	0.1455	0.007275

Effective dose rates

HK13356

Nam Chung, NC-TP1

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.14479311	113.5159052	79.85	2	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**191.8**	**8.9**	**4.6**
Total Dose rate (Gy/ka)	**8.45**	**0.35**	**4.1**
Age (ka)	**22.70**	**1.41**	**6.2**

Equivalent dose measurement:

Observations: feldspar contamination, post-IR blue sequence

Overdispersion, sample possibly not fully bleached

Grain size (μm)	fine, 4-11
Aliquots measured	30
Reliable aliquots	20
Regeneration doses (Gy)	10, 20, 50, 90 150, 250

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.15	0.03
Th (ppm)	37.91	2.26
K (%)	2.83	0.09
U (ppm):		
weighted mean (all)	3.36	0.24
Th234	6.78	0.60
Ra226	3.47	1.07
Pb214 and Bi214	3.14	0.22
Pb210	4.42	1.36

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	2.64	0.28
beta	3.23	0.17
gamma	2.44	0.12
cosmic	0.1492	0.00746

Effective dose rates

HK13357

Nam Chung, NC-TP13

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.14413037	113.5152338	130.23	1.1	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**50.9**	**2.3**	**4.5**
Total Dose rate (Gy/ka)	**4.88**	**0.17**	**3.6**
Age (ka)	**10.44**	**0.60**	**5.8**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	20
Reliable aliquots	16
Regeneration doses (Gy)	5, 10, 20, 40, 70

Dose rate measurement:

Observations: Equilibrium in Uranium decay chain

		Error
water content	0.11	0.022
Th (ppm)	14.77	0.89
K (%)	1.14	0.04
U (ppm):		
weighted mean (all)	4.54	0.32
Th234	4.91	0.44
Ra226	4.72	1.45
Pb214 and Bi214	4.49	0.32
Pb210	6.07	1.87

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	1.67	0.15
beta	1.73	0.07
gamma	1.33	0.06
cosmic	0.1601	0.008005

Effective dose rates

HK13358

Nam Chung, NC-TP19

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.14389816	113.5135091	34.12	1.5	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**14.04**	**0.58**	**4.1**
Total Dose rate (Gy/ka)	**10.48**	**0.39**	**3.7**
Age (ka)	**1.34**	**0.07**	**5.6**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	21
Reliable aliquots	21
Regeneration doses (Gy)	12, 15, 19, 22

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.11	0.022
Th (ppm)	24.36	1.46
K (%)	2.51	0.08
U (ppm):		
weighted mean (all)	12.29	0.86
Th234	7.62	0.67
Ra226	11.03	3.33
Pb214 and Bi214	12.85	0.90
Pb210	14.83	4.48

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	3.62	0.33
beta	3.85	0.18
gamma	2.86	0.11
cosmic	0.1534	0.00767

Effective dose rates

HK13359

Nam Chung, NC-TP26

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.14517251	113.5158579	24.52	1.2	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**9.05**	**0.37**	**4.1**
Total Dose rate (Gy/ka)	**7.52**	**0.28**	**3.8**
Age (ka)	**1.20**	**0.07**	**5.6**

Equivalent dose measurement:

Grain size (µm)	fine, 4-11
Aliquots measured	30
Reliable aliquots	19
Regeneration doses (Gy)	5, 7, 11, 13

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.125	0.025
Th (ppm)	28.58	1.71
K (%)	2.20	0.07
U (ppm):		
weighted mean (all)	4.65	0.33
Th234	6.76	0.60
Ra226	4.87	1.51
Pb214 and Bi214	4.49	0.32
Pb210	6.58	2.04

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	2.45	0.23
beta	2.81	0.13
gamma	2.11	0.09
cosmic	0.1564	0.00782

Effective dose rates

HK13360

Nam Chung, NC-TP32

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.14453842	113.514365	30.83	0.9	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**27.8**	**1.2**	**4.3**
Total Dose rate (Gy/ka)	**12.09**	**0.52**	**4.3**
Age (ka)	**2.30**	**0.14**	**6.1**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	16
Reliable aliquots	16
Regeneration doses (Gy)	5, 10, 20, 35 50

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.07	0.014
Th (ppm)	24.66	1.48
K (%)	2.10	0.08
U (ppm):		
weighted mean (all)	16.27	1.14
Th234	11.76	1.05
Ra226	16.21	5.07
Pb214 and Bi214	16.62	1.17
Pb210	9.55	2.99

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	4.51	0.43
beta	4.12	0.27
gamma	3.29	0.12
cosmic	0.1598	0.00799

Effective dose rates

HK13361

Nam Chung, NC-TP34

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.14416302	113.5134085	13.38	0.8	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**38.8**	**1.7**	**4.4**
Total Dose rate (Gy/ka)	**9.11**	**0.39**	**4.2**
Age (ka)	**4.26**	**0.26**	**6.1**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	23
Reliable aliquots	20
Regeneration doses (Gy)	5, 10, 20, 35 60, 90

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.1	0.02
Th (ppm)	35.25	2.10
K (%)	1.28	0.05
U (ppm):		
weighted mean (all)	8.06	0.56
Th234	10.12	0.88
Ra226	10.21	3.05
Pb214 and Bi214	7.62	0.54
Pb210	12.39	3.70

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	3.56	0.33
beta	2.83	0.16
gamma	2.56	0.11
cosmic	0.1605	0.008025

Effective dose rates

HK13362

Nam Chung, NC-TP34

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.14416302	113.5134085	13.38	0.8	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**58.8**	**2.5**	**4.3**
Total Dose rate (Gy/ka)	**8.43**	**0.33**	**4.0**
Age (ka)	**6.97**	**0.40**	**5.8**

Equivalent dose measurement:

Grain size (µm)	fine, 4-11
Aliquots measured	20
Reliable aliquots	20
Regeneration doses (Gy)	5, 10, 20, 35 50, 90

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.1	0.02
Th (ppm)	30.31	1.81
K (%)	2.52	0.08
U (ppm):		
weighted mean (all)	5.00	0.35
Th234	7.25	0.64
Ra226	5.60	1.70
Pb214 and Bi214	4.77	0.34
Pb210	9.86	2.99

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	2.72	0.27
beta	3.23	0.17
gamma	2.33	0.10
cosmic	0.1497	0.007485

Effective dose rates

HK13363

Nam Chung, NC-TP37

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.14408773	113.5144942	77.72	1.3	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**23.48**	**0.97**	**4.1**
Total Dose rate (Gy/ka)	**8.60**	**0.29**	**3.4**
Age (ka)	**2.73**	**0.15**	**5.4**

Equivalent dose measurement:

Grain size (μm)	fine, 4-11
Aliquots measured	19
Reliable aliquots	18
Regeneration doses (Gy)	18, 21, 25, 28

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.1	0.02
Th (ppm)	26.89	1.61
K (%)	2.37	0.08
U (ppm):		
weighted mean (all)	7.05	0.49
Th234	6.72	0.60
Ra226	7.43	2.30
Pb214 and Bi214	7.01	0.49
Pb210	9.34	2.90

Concentrations of Thorium, Potassium and Uranium

	Effective DR (Gy/ka)	Error
alpha	2.84	0.25
beta	3.23	0.12
gamma	2.38	0.10
cosmic	0.1566	0.00783

Effective dose rates

HK13364

Tai O East, TOE-TP2

Sample type	latitude	longitude	altitude	depth	Depositional type
U-100 Sample, horizontal	22.15222095	113.5135359	51.89	1.4	Colluvial

		Error	Error (%)
Equivalent Dose (Gy)	**128.1**	**5.1**	**4.0**
Total Dose rate (Gy/ka)	**7.01**	**0.33**	**4.7**
Age (ka)	**18.27**	**1.12**	**6.1**

Equivalent dose measurement:

Observations: feldspar contamination; post-IR blue sequence

Grain size (μm)	fine, 4-11
Aliquots measured	17
Reliable aliquots	16
Regeneration doses (Gy)	10, 20, 40, 70 120, 200

Dose rate measurement:

Observations: Disequilibrium in Uranium decay chain

		Error
water content	0.145	0.029
Th (ppm)	32.43	1.94
K (%)	0.97	0.04
U (ppm):		
weighted mean (all)	5.29	0.37
Th234	7.54	0.67
Ra226	5.74	1.73
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Pb210	9.65	2.91

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Effective dose rates

Report to Geotechnical Engineering Office Civil Engineering Department on

Determination of sediment deposition ages by Luminescence Dating Phase IVA(part1)

by

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03/3

Technical Report

5th March 2003

CONTENTS

1. INTRODUCTION

Thirty samples (laboratory code WLL~~5~~242-WLL260, WLL265-WLL267, WLL269-WLL276) were submitted for Luminescence Dating by the Geotechnical Engineering Office, Civil Engineering Department, Hong Kong SAR Government. Nine ages are reported in this first part of the batch IVA report. The aim of the study is the absolute dating of relict natural terrain landslides. The deposition ages have been determined for all of these samples using the silt fraction. The palaeodose, i.e. the radiation dose accumulated in the sample after the last light exposure (assumed at deposition), was determined by measuring the blue luminescence output during infrared optical stimulation (which selectively stimulates the feldspar fraction). For one sample, which showed no blue luminescence signal under infrared stimulation, the UV luminescence was measured under green light stimulation (this signal likely originates from the quartz fraction). The doserate was estimated on the basis of a low level gammaspectrometry measurement.

Sample preparation and luminescence measurements were done in the Luminescence Dating Laboratory, School of Earth Sciences, Victoria University of Wellington, and gamma spectrometry by the National Radiation Laboratory (NRL), Christchurch.

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The samples, which were described as being of ~~alluvial~~ colluvial origin by the submitter, consisted mainly of silt. It was decided to use this dominant fraction for dating, using the finegrain technique after Aitken and Xie (1992) and a protocol as described by Lang and Wagner (1997).

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The grain size 4-11μm was extracted from the samples in a water-filled (with added dispersing agent to deflocculate clay) measuring cylinder using Stokes' Law. The other fractions were discarded. The samples then were brought into suspension in pure acetone and deposited evenly in a thin layer on 70 aluminum discs (1cm diameter).

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irradiations were done on a Daybreak 801E $^{90}Sr,^{90}Y$ β-irradiator and the Riso TL-DA15 $^{90}Sr,^{90}Y$ β-irradiator, both calibrated against SFU, Vancouver, Canada to about 3% accuracy. α-irradiations were done on a ^{241}Am irradiator supplied and calibrated by ELSEC, Littlemore, UK. The paleodoses were estimated by use of the multiple aliquot additive-dose method (with late-light subtraction). After an initial test-measurement, 30 aliquots were β-irradiated in six groups up to five times of the dose result taken from the test. Nine aliquots were α-irradiated in three groups up to three times of the dose result taken from the test. These 39 disks were stored in the dark for four weeks to relax the crystal lattice after irradiation.

After storage, these 39 disks and nine unirradiated disks were preheated for 5min at 220ºC to remove unstable signal components, and then measured for 100sec each, resulting in 39 shinedown curves. These curves were then normalized for their luminescence response, using 0.1s shortshine measurements taken before irradiation from all aliquots.

The luminescence growth curve (β-induced luminescence intensity vs added dose) is then constructed by using the initial 10 seconds of the shine down curves and subtracting the average of the last 20 sec, the so called late light which is thought to be a mixture of background and hardly bleachable components. The shine plateau was checked to be flat after this manipulation. Extrapolation of this growth curve to the dose-axis gives the equivalent dose D_e, which is used as an estimate of the paleodose.

A similar plot for the alpha-irradiated discs allows an estimate of the α-efficiency, the a-value (Luminescence/dose generated by the α-source divided by the luminescence/dose generated by the β-source).

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None of the analyzed samples has given an indication of this problem so far, but a routine test must be carried out after six months storage of an irradiated subsample to be sure. Thus, all ages reported below must be seen as preliminary until the fading test has been carried out. The result will be notified as soon as it is available.

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The dry, ground and homogenized soil samples were embedded in a two-part epoxy resin to retain ^{222}Rn within the sample and allowed to set. This casting procedure reduces the radon loss from the sample to less than 0.5% and the ^{226}Ra concentration in these samples can be determined from the emissions of the short lived ^{222}Rn daughters, ^{214}Pb and ^{214}Bi. A waiting period of 30 days is necessary to reach equilibrium between ^{226}Ra and its daughter nuclides before the gamma count.

The samples were counted using high resolution gamma spectrometry with a broad energy Ge detector for a minimum time of 24 hours. The spectra were analysed using GENIE2000 software.

The doserate calculation is based on the activity concentration of the nuclides ^{40}K, ^{208}Tl, ^{212}Pb, ^{228}Ac, ^{210}Pb, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{234}Th, as reported by NRL. The latter five of these isotopes allow, if applicable, an estimate of the degree of radioactive disequilibrium in the Uranium decay chain.

3. RESULTS

The radionuclide contents were calculated from the raw gammaspectrometry data supplied by NRL. The Uranium contents of some samples were quite high, but especially ^{226}Ra and its daughters, which are enriched in most samples. The Thorium contents for most samples are also above 'average'. Table 2 gives a summary of all radiometric data.

A likely explanation for the enrichment of Radium could be the flow of groundwater through the sampled sediment layers, bringing in solved ^{226}Ra from a nearby Uranium-rich source. This must be either ongoing, or have happened within the last few thousand years (^{226}Ra decays with a half life of 1600a). Another possibility would be a massive influx of particle-attached ^{230}Th (half life 75,000a) and maybe solved ^{234}U (half life 240,000a) during sediment deposition. As most samples also show an excess of ^{232}Th (which chemically behaves similar to ^{230}Th) above the average Th/U ratio in the Earth's crust, the latter hypothesis is preferred. These radioactive disequilibria are a source of uncertainty about the reliability of doserate results for the samples affected.

The high radionuclide contents cause high doserates for the samples affected (up to 12 Gy/ka), compared to 2…3 Gy/ka for what would be an 'average' sample. Owing to the high doserates, some samples already showed the onset of saturation of electron traps, despite being relatively young for the OSL dating technique. Nevertheless, the equivalent dose could be determined reliably for the samples. Table 1 gives sample summaries and calculated cosmic doserates, whereas Table 3 gives a summary of all equivalent doses, doserates and ages.

All errors in this report are stated as 1 sigma errors. A radioactive disequilibrium was considered as significant, if the equivalent Uranium contents do not overlap in a 2 sigma interval.

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Prescott & Hutton (1994), *Radiation Measurements*, Vol. 23.

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Table 1 - Doserate contribution of cosmic radiation

Sample no.	depth below surface (m)	D_c (Gy/ka)[1]	Field code
WLL242	1.7	0.1349±0.0067	HK-12445
WLL243	0.8	0.1526±0.0076	HK-12485
WLL244	0.8	0.1526±0.0076	HK-12487
WLL245	3.9	0.1016±0.0051	HK-12466
WLL246	0.9	0.1505±0.0075	HK-12438
WLL247	0.5	0.1591±0.0080	HK-12449
WLL248	0.6	0.1569±0.0078	HK-12477
WLL249	2.5	0.1206±0.0060	HK-12463
WLL250	0.1	0.1683±0.0084	HK-12473

[1] Contribution of cosmic radiation to the total doserate, calculated as proposed by Prescott & Hutton (1994).

Table 2 - Radionuclide and water contents

Sample number	Water content δ[1]	U (µg/g) from ^{234}Th	U (µg/g)[2] from ^{226}Ra, ^{214}Pb, ^{214}Bi	U (µg/g) from ^{210}Pb	Th (µg/g)[2] from ^{208}Tl, ^{212}Pb, ^{228}Ac	K (%)	Field code
WLL242	1.217	1.86 ±0.57	3.90 ±0.13	3.96 ±0.61	42.3 ±1.1	3.56 ±0.13	HK-12445
WLL243	1.195	2.89 ±0.40	4.48 ±0.13	4.13 ±0.61	25.1 ±0.7	2.45 ±0.10	HK-12485
WLL244	1.175	2.49 ±0.38	4.13 ±0.12	3.80 ±0.53	18.8 ±0.6	2.23 ±0.09	HK-12487
WLL245	1.167	4.77 ±1.05	6.87 ±0.17	6.31 ±0.73	41.5 ±1.0	3.13 ±0.12	HK-12466
WLL246	1.269	4.21 ±0.53	7.53 ±0.18	6.71 ±0.73	38.2 ±1.0	1.70 ±0.07	HK-12438
WLL247	1.163	3.16 ±0.44	5.72 ±0.15	4.13 ±0.57	41.7 ±1.0	2.50 ±0.10	HK-12449
WLL248	1.273	2.45 ±0.37	5.76 ±0.31	5.26 ±0.61	20.9 ±0.7	2.79 ±0.11	HK-12477
WLL249	1.178	4.45 ±0.57	25.6 ±0.5	15.7 ±1.5	45.7 ±1.2	3.41 ±0.13	HK-12463
WLL250	1.249	2.99 ±0.65	4.92 ±0.14	4.13 ±0.61	27.5 ±0.7	2.19 ±0.09	HK-12473

[1] Ratio wet sample to dry sample weight. Errors assumed 50% of (δ-1).
[2] U and Th-content is calculated from the error weighted mean of the isotope equivalent contents

Highlighted in red are those radionuclides in the Uranium decay chain, between which a radioactive disequilibrium is significant.

Table 3 - Finegrain Technique
Measured a-value and equivalent dose, doserate and luminescence age

Sample no.	a-value	D_e (Gy)	dD/dt (Gy/ka)[#]	OSL-age (ka)	Field code
[%]WLL242	0.087±0.018	158.2±17.7	*8.77±0.75 (9.03±0.75)	*18.0±2.4 (17.5±2.4)	HK-12445
[%]WLL243	0.054±0.013	82.2±8.2	*5.73±0.44 (5.96±0.44)	*14.4±1.7 (13.8±1.7)	HK-12485
[%]WLL244	0.056±0.014	73.4±7.9	*4.97±0.37 (5.22±0.37)	*14.8±1.8 (14.1±1.8)	HK-12487
[%]WLL245	0.075±0.025	196.3±23.7	9.69±0.97	20.3±3.2	HK-12466
WLL246	0.091±0.017	122.7±19.3	*7.45±0.77 (8.01±0.77)	*16.5±2.8 (15.3±2.8)	HK-12438
WLL247	0.067±0.009	41.4±4.6	*8.00±0.52 (8.59±0.52)	*5.18±0.61 (4.82±0.61)	HK-12449
^WLL248	0.046±0.011	7.05±0.13	*5.27±0.61 (6.30±0.61)	*1.34±0.11 (1.24±0.11)	HK-12477
WLL249	0.077±0.015	54.3±7.8	*12.4±1.4 (16.9±1.4)	*4.38±0.53 (3.21±0.53)	HK-12463
WLL250	0.074±0.009	36.4±3.3	*5.86±0.47 (6.21±0.47)	*6.22±0.69 (5.86±0.69)	HK-12473

[#] The doserate dD/dt was calculated using the conversion factors of Adamiec and Aitken (1998)

[*] These doserates and ages are corrected for the radioactive disequilibrium in the samples. As the correction was done under the assumption that the disequilibrium was in a steady state for the whole time after deposition, the corrected age represents only a better estimate than the equilibrium age and not necessarily the true age. The ages in brackets were calculated under the invalid assumption that the whole U-chain was in equilibrium with ^{226}Ra.

[%] These samples showed insufficient luminescence signal intensity when measured in a narrow 410nm band. Thus the detection window was widened to 330-640nm by the use of a 3mm BG39 optical filter. It is generally assumed that this broadband detection picks up more light from plagioclase feldspars, which often show marked emissions in the yellow and UV spectral regions. As some plagioclase feldspars show strong signal fading, these results must be seen as minimum ages until the fading test (due in July 03, six months after the irradiation) confirms their reliability.

^ This sample did not show any luminescence signal under infrared stimulation, indicating that it does not contain feldspars. However, under green light stimulation a strong ‘quartz shape’ signal was measured in the UV band (9mm U340 optical filter). Thus a SAR protocol was applied, which gave a narrow Gaussian distribution.

Report to Geotechnical Engineering Office Civil Engineering Department on

Determination of sediment deposition ages by Luminescence Dating Phase IVA(part2)

by

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Technical Report

10th May 2003

CONTENTS

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The radionuclide contents were calculated from the raw gammaspectrometry data supplied by NRL. The Uranium contents of some samples were quite high, but especially ^{226}Ra and its daughters, which are enriched in most samples. The Thorium contents for most samples are also above 'average'. Table 2 gives a summary of all radiometric data.

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WLL251	0.5	0.1591±0.0080	HK12452
WLL252	0.3	0.1636±0.0082	HK12453
WLL253	1.15	0.1454±0.0073	HK12442
WLL254	0.1	0.1683±0.0084	HK12479
WLL255	0.8	0.1526±0.0076	HK12489
WLL256	0.8	0.1526±0.0076	HK12451
WLL257	1.0	0.1484±0.0074	HK12480
WLL258	2.2	0.1261±0.0063	HK12433
WLL259	2.58	0.1200±0.0060	HK12443
WLL260	0.8	0.1526±0.0076	HK12455
WLL265	1.8	0.1331±0.0067	HK12440
WLL266	1.2	0.1444±0.0072	HK12434
WLL267	2.34	0.1238±0.0062	HK12490
WLL269	0.7	0.1547±0.0077	HK12471
WLL270	1.0	0.1484±0.0074	HK12447
WLL271	1.1	0.1464±0.0073	HK12458
WLL272	6.17	0.0774±0.0039	HK12468
WLL273	1.0	0.1484±0.0074	HK12461
WLL274	0.8	0.1526±0.0076	HK12474
WLL275	0.3	0.1636±0.0082	HK12483
WLL276	1.5	0.1386±0.0069	HK12437

[1] Contribution of cosmic radiation to the total doserate, calculated as proposed by Prescott & Hutton (1994).

Table 2 - Radionuclide and water contents

Sample number	Water content δ^{1}	U (µg/g) from ^{234}Th	U (µg/g)[2] from ^{226}Ra, ^{214}Pb, ^{214}Bi	U (µg/g) from ^{210}Pb	Th (µg/g)[2] from ^{208}Tl, ^{212}Pb, ^{228}Ac	K (%)	Field code
WLL251	1.195	4.85 ±1.17	8.61 ±0.20	5.99 ±0.73	31.8 ±0.9	3.13 ±0.12	HK12452
WLL252	1.167	3.72 ±1.05	7.42 ±0.18	5.91 ±0.69	41.2 ±1.0	3.60 ±0.14	HK12453
WLL253	1.223	5.82 ±1.46	7.67 ±0.18	6.07 ±0.77	51.0 ±1.2	1.82 ±0.08	HK12442
WLL254	1.202	3.32 ±0.93	2.73 ±0.11	2.91 ±0.57	47.3 ±1.2	3.29 ±0.13	HK12479
WLL255	1.220	4.05 ±1.01	5.12 ±0.14	4.37 ±0.65	23.3 ±0.7	2.88 ±0.11	HK12489
WLL256	1.205	4.29 ±1.09	12.3 ±0.26	7.93 ±0.89	32.4 ±0.9	2.13 ±0.09	HK12451
WLL257	1.260	3.72 ±0.93	4.48 ±0.12	3.56 ±0.69	23.9 ±0.7	2.58 ±0.10	HK12480
WLL258	1.227	4.93 ±1.25	6.51 ±0.17	6.96 ±0.85	43.3 ±1.0	2.73 ±0.11	HK12433
WLL259	1.221	5.02 ±1.25	6.86 ±0.17	6.07 ±0.77	37.6 ±1.0	1.54 ±0.07	HK12443
WLL260	1.177	6.80 ±1.62	8.66 ±0.20	6.55 ±0.86	52.9 ±1.3	3.36 ±0.13	HK12455
WLL265	1.215	5.42 ±1.33	6.46 ±0.16	5.66 ±0.69	26.6 ±0.8	2.30 ±0.09	HK12440
WLL266	1.227	4.61 ±1.13	6.60 ±0.16	5.34 ±0.73	44.2 ±1.1	2.04 ±0.08	HK12434
WLL267	1.107	4.13 ±1.01	4.73 ±0.13	4.61 ±0.81	26.3 ±0.8	2.79 ±0.11	HK12490
WLL269	1.184	3.72 ±0.97	5.83 ±0.16	5.50 ±0.73	37.7 ±0.9	2.74 ±0.11	HK12471
WLL270	1.174	4.13 ±1.01	7.98 ±0.19	6.88 ±0.81	36.4 ±1.0	2.51 ±0.10	HK12447
WLL271	1.158	4.37 ±1.13	6.20 ±0.16	5.50 ±0.73	38.3 ±1.2	3.26 ±0.13	HK12458
WLL272	1.270	9.95 ±2.31	15.3 ±0.31	13.6 ±1.4	56.5 ±1.3	4.08 ±0.15	HK12468

Table 2 – continued

Sample number	Water content δ[1]	U (µg/g) from ^{234}Th	U (µg/g)[2] from ^{226}Ra, ^{214}Pb, ^{214}Bi	U (µg/g) from ^{210}Pb	Th (µg/g)[2] from ^{208}Tl, ^{212}Pb, ^{228}Ac	K (%)	Field code
WLL273	1.152	4.36 ±1.13	6.70 ±0.17	7.28 ±0.85	46.5 ±1.1	3.12 ±0.12	HK12461
WLL274	1.197	3.32 ±0.77	6.00 ±0.16	4.36 ±0.69	27.8 ±0.7	3.46 ±0.13	HK12474
WLL275	1.198	3.32 ±0.89	4.77 ±0.13	3.80 ±0.57	24.7 ±0.7	3.14 ±0.12	HK12483
WLL276	1.178	5.50 ±1.33	7.54 ±0.19	5.82 ±0.77	37.2 ±1.0	3.00 ±0.12	HK12437

[1] Ratio wet sample to dry sample weight. Errors assumed 50% of (δ-1).
[2] U and Th-content is calculated from the error weighted mean of the isotope equivalent contents

Highlighted in red are those radionuclides in the Uranium decay chain, between which a radioactive disequilibrium is significant.

Table 3 - Finegrain Technique
Measured a-value and equivalent dose, doserate and luminescence age

Sample no.	a-value	D_e (Gy)	dD/dt (Gy/ka)[#]	OSL-age (ka)	Field code
WLL251	0.080±0.016	28.1±2.4	*8.28±0.73 (9.23±0.73)	*3.39±0.35 (3.05±0.35)	HK12452
[%]WLL252	0.074±0.008	49.4±2.6	*9.56±0.60 (10.30±0.60)	*5.17±0.38 (4.79±0.38)	HK12453
WLL253	0.076±0.004	65.8±2.3	9.34±0.62	7.04±0.53	HK12442
[%]WLL254	0.130±0.014	29.0±6.0	10.28±0.74	2.82±0.62	HK12479
[%]WLL255	0.074±0.020	77.7±11.0	6.61±0.58	11.8±2.0	HK12489
[%]WLL256	0.095±0.010	11.1±0.4	*8.23±0.72 (10.15±0.72)	*1.35±0.09 (1.09±0.09)	HK12451
[%]WLL257	0.063±0.007	20.6±0.9	5.77±0.44	3.57±0.32	HK12480
[%]WLL258	0.056±0.010	111.5±12.2	8.28±0.63	13.5±1.8	HK12433
[%]WLL259	0.057±0.009	168.2±11.9	6.92±0.52	24.3±2.5	HK12443
[%]WLL260	0.099±0.022	10.4±1.6	12.66±1.15	0.821±0.147	HK12455
WLL265	0.062±0.010	48.3±2.1	6.62±0.48	7.30±0.62	HK12440
WLL266	0.049±0.006	68.0±6.4	7.60±0.53	8.95±1.05	HK12434
[&]WLL267	-	-	-	-	HK12490
WLL269	0.090±0.024	124.1±12.6	8.92±0.86	13.9±1.9	HK12471
WLL270	0.065±0.015	36.6±4.3	*7.99±0.67 (8.65±0.67)	*4.58±0.60 (4.23±0.60)	HK12447
[%]WLL271	0.095±0.028	11.1±1.2	9.99±1.00	1.11±0.16	HK12458
[%]WLL272	0.050±0.004	237.8±19.0	*11.56±0.96 (12.35±0.96)	*20.6±2.1 (19.3±2.1)	HK12468
[%]WLL273	0.082±0.014	45.2±2.5	10.61±0.72	4.26±0.37	HK12461
[%]WLL274	0.051±0.005	54.9±3.7	*6.92±0.47 (7.47±0.47)	*7.93±0.68 (7.35±0.68)	HK12474
[%]WLL275	0.085±0.014	11.9±1.0	7.24±0.52	1.65±0.18	HK12483
WLL276	0.050±0.006	47.3±1.9	8.49±0.51	5.57±0.40	HK12437

[#] The doserate dD/dt was calculated using the conversion factors of Adamiec and Aitken (1998)

[*] These doserates and ages are corrected for the radioactive disequilibrium in the samples. As the correction was done under the assumption that the disequilibrium was in a steady state for the whole time after deposition, the corrected age represents only a better estimate than the equilibrium age and not necessarily the true age. The ages in brackets were calculated under the invalid assumption that the whole U-chain was in equilibrium with ^{226}Ra.

[%] These samples showed insufficient luminescence signal intensity when measured in a narrow 410nm band. Thus the detection window was widened to 330-640nm by the use of a 3mm BG39 optical filter. It is generally assumed that this broadband detection picks up more light from

plagioclase feldspars, which often show marked emissions in the yellow and UV spectral regions. As some plagioclase feldspars show strong signal fading, these results must be seen as minimum ages until the fading test (due in July 03, six months after the irradiation) confirms their reliability.

[&] It was not possible so far to obtain a dose estimate for sample WLL267. The sample may be undatable at all, given its coarse, lumpy, appearance, and the difficulties we experienced in sample preparation and fixing the material to sample discs. Nevertheless, we will give it a second try and report the results in an addendum to this report.

Report to Geotechnical Engineering Office Civil Engineering Department on

Determination of sediment deposition ages by Luminescence Dating Phase IVB

by

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CONTENTS

1. INTRODUCTION

Eleven samples (laboratory code WLL242, WLL247, WLL250-252, WLL254, WLL256+257, WLL271, WLL273, WLL275) were submitted for Luminescence Dating by the Geotechnical Engineering Office, Civil Engineering Department, Hong Kong SAR Government. The aim of the study is the absolute dating of relict natural terrain landslides. The deposition ages have been determined for these samples using the sand fraction (90-200μm). The palaeodose, i.e. the radiation dose accumulated in the sample after the last light exposure (assumed at deposition), was determined by measuring the ultraviolet luminescence output during greenlight optical stimulation of the quartz fraction. The doserate was estimated on the basis of a low level gammaspectrometry measurement.

Sample preparation and luminescence measurements were done in the Luminescence Dating Laboratory, School of Earth Sciences, Victoria University of Wellington, and gamma spectrometry by the National Radiation Laboratory (NRL), Christchurch.

2. EXPERIMENTAL TECHNIQUES

2.1 LUMINESCENCE MEASUREMENTS

The samples, which were described as being of colluvial origin by the submitter, consisted mainly of silt. It was requested by the submitter that the quartz coarse fraction was used for a Single Aliquot Regenerative (SAR) dating attempt in order to determine if there was a partial bleaching event, caused by recent sediment movement. The relatively new SAR technique is described by Murray and Wintle (2000).

Sample preparation was done under extremely subdued safe orange light in a darkroom. Outer surfaces, which may have seen light during sampling, were removed and discarded. The actual water content and the saturation content were measured using 'fresh' inside material.

The samples were treated with 10%HCl to remove carbonates until the reaction stopped, then carefully rinsed with distilled water. Thereafter, all organic matter was destroyed with 10%H_2O_2 until the reaction stopped, then carefully rinsed with distilled water.

The grain size 90-200μm was extracted from the samples by sieving, in some cases by wet sieving. The other fractions were discarded, except the 4-11μm fraction which was used for finegrain dating (see report phase IIA). Then heavy liquid separation was carried out in Lithium-polytungstate to obtain a quartz enriched fraction (2.58-2.65g/cm^3). Though relatively pure, this density fraction still may contain minor amounts of plagioclase feldspars. These were destroyed by subsequent HF (40%) etching and washing. The HF etching also removed the outer 10μm of the quartz grains, which may have stored a dose from alpha-radiation. Then the grain size fraction 90-125μm was obtained by a final sieving, and the quartz grains were fixed on 1cm aluminum discs with silicon oil.

Luminescence measurements were done using a standard Riso TL-DA15 measurement system, equipped with 3 Hoya U340 optical filters (stack thickness ~9mm) to select the ultraviolet luminescence band centered around 340nm. Stimulation was done by a green halogen light source (420-575nm), β-irradiations were done on the Riso TL-DA15 ^{90}Sr,^{90}Y β-irradiator, calibrated against the Risø National Laboratory, Denmark, to about 3% accuracy.

The palaeodoses were estimated by use of the Single Aliquot Regenerative method (SAR). In the SAR method a number of aliquots are subjected to a repetitive cycle of irradiation, preheat and measurement. In the first cycle the natural luminescence output is measured, in all following cycles an artificial dose is applied. Usually four or five of these dose points are used to build the luminescence growth curve (β-induced luminescence intensity vs added dose) and bracket the natural luminescence output. This allows interpolation of the equivalent dose (the β-dose equivalent to the palaeodose). In order to correct for potential sensitivity changes from cycle to cycle, a test dose is applied between the cycles, preheated ('cut heat') and measured.

For the samples reported here 30 aliquots were measured, preheat temperature was 260C for 10s, cut heat was 220C for 10s, and measurement time 150s (which resets the luminescence signal to a negligible residual).

The measurement of 30 aliquots resulted in 30 equivalent doses, spread over the so called dose distribution. The extreme scatter within this distribution is usually attributed to partial bleaching of the mineral grains (see e.g. Olley *et al*, 1998), i.e. those aliquots with high equivalent doses contain quartz grains which have not seen light during sediment deposition. The interpretation of these dose distributions is a major cause of uncertainty in the SAR technique, and much research effort is put into a better understanding.

2.2 GAMMA SPECTROMETRY

The dry, ground and homogenized soil samples were embedded in a two-part epoxy resin to retain ^{222}Rn within the sample and allowed to set. This casting procedure reduces the radon loss from the sample to less than 0.5% and the ^{226}Ra concentration in these samples can be determined from the emissions of the short lived ^{222}Rn daughters, ^{214}Pb and ^{214}Bi. A waiting period of 30 days is necessary to reach equilibrium between ^{226}Ra and its daughter nuclides before the gamma count.

The samples were counted using high resolution gamma spectrometry with a broad energy Ge detector for a minimum time of 24 hours. The spectra were analysed using GENIE2000 software.

The doserate calculation is based on the activity concentration of the nuclides ^{40}K, ^{208}Tl, ^{212}Pb, ^{228}Ac, ^{210}Pb, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{234}Th, as reported by NRL. The latter five of these isotopes allow, if applicable, an estimate of the degree of radioactive disequilibrium in the Uranium decay chain.

3. RESULTS

The radionuclide contents were calculated from the raw gammaspectrometry data supplied by NRL. The Uranium contents of the samples were quite high, but especially ^{226}Ra and its daughters, which was enriched in several samples. Thorium and Potassium contents for most samples are also above ‘average’. Table 2 gives a summary of the radiometric data.

A likely explanation for the enrichment of Radium could be the flow of groundwater through the sampled sediment layers, bringing in solved ^{226}Ra from a nearby Uranium-rich source. This must be either ongoing, or have happened within the last few thousand years (^{226}Ra decays with a half life of 1600a). This radioactive disequilibrium is a source of uncertainty about the reliability of the doserate result for the sample.

The high radionuclide contents cause relatively high doserates for all samples (up to 7.3 Gy/ka), compared to 2…3 Gy/ka for what would be an ‘average’ sample. Owing to the high

doserates, some samples already showed the onset of saturation of electron traps, despite being relatively young for the OSL dating technique.

Table 1 gives sample summaries and calculated cosmic doserates, whereas Table 3 gives a summary of all equivalent doses, doserates and ages.

All errors in this report are stated as 1 sigma errors. A radioactive disequilibrium was considered as significant, if the equivalent Uranium contents do not overlap in a 2 sigma interval.

The interpretation of the SAR dose distributions is rather complex. The samples showed, as it is very common, extreme scatter between aliquots. Usually two ages are reported:

(a) The 'mean age', calculated using the arithmetic mean and standard deviation of the distribution. This is thought to give the best age estimate if the scatter is not caused by incomplete bleaching during deposition. The error is usually given as the error of the mean, assuming that the mean will follow a normal distribution even if the data does not.

(b) The 'leading edge age', calculated using only the lowest 5% of the dose distribution (see Olley et al, 1998). This is thought to give the best age estimate only if incomplete bleaching is causing the scatter.

Recent research done by me and E.C.G. Smith, Prof of Geophysics at Victoria University, suggests that there is an alternative method for the interpretation of the distributions. An explanation can be found in Annex III of the batch IIB report. As this research is still ongoing, please see the arguments in Annex III as preliminary. The 'lognormal' approach was developed for the situation where the scatter is not caused by incomplete bleaching, but an inhomogeneous distribution of radioactivity in the sediment. We believe this is the most likely explanation for the scatter in the samples reported here.

Please find in Table 3 the age results for all three different analysis methods. We strongly recommend that you use the 'lognormal' results for your interpretations.

It must be noted that 'leading edge' ages are statistically more unsafe than 'mean' ages. The interpretation of the lowest 5% tail of the dose distribution would be precise only if the whole distribution is known. As the number of discs measured to determine the distribution is necessarily limited, this tail consists of very few data points. For the samples in this study the lowest 3 data points were used in an attempt to balance between the data scatter and the wish to calculate the edge of the tail. So the given 'leading edge' age is based on the arithmetic average of only 3 discs, while the 'mean' and 'lognormal' ages are based on all 30 discs.

4. REFERENCES

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Olley J., Caitcheon G. and Murray A.S. (1998) The distribution of apparent dose as determined by optically stimulated luminescence in small aliquots of fluvial quartz: Implications for dating young sediments. *Quaternary Geochronology* 17, 1033-1040.

Prescott & Hutton (1994), *Radiation Measurements*, Vol. 23.

LIST OF TABLES

Table 1 - Doserate contribution of cosmic radiation

Sample no.	depth below surface (m)	D_c (Gy/ka)[1]	Field code
WLL242	1.7	0.1349±0.0067	HK12445
WLL247	0.5	0.1591±0.0080	HK12449
WLL250	0.1	0.1683±0.0084	HK12473
WLL251	0.5	0.1591±0.0080	HK12452
WLL252	0.3	0.1636±0.0082	HK12453
WLL254	0.1	0.1683±0.0084	HK12479
WLL256	0.8	0.1526±0.0076	HK12451
WLL257	1.0	0.1484±0.0074	HK12480
WLL271	1.1	0.1464±0.0073	HK12458
WLL273	1.0	0.1484±0.0074	HK12461
WLL275	0.3	0.1636±0.0082	HK12483

[1] Contribution of cosmic radiation to the total doserate, calculated as proposed by Prescott & Hutton (1994).

Table 2 - Radionuclide and water contents

Sample number	Water content δ[1]	U (µg/g) from ^{234}Th	U (µg/g)[2] from ^{226}Ra, ^{214}Pb, ^{214}Bi	U (µg/g) from ^{210}Pb	Th (µg/g)[2] from ^{208}Tl, ^{212}Pb, ^{228}Ac	K (%)	Field code
WLL242	1.217	1.86 ±0.57	3.90 ±0.13	3.96 ±0.61	42.3 ±1.1	3.56 ±0.13	HK12445
WLL247	1.163	3.16 ±0.44	5.72 ±0.15	4.13 ±0.57	41.7 ±1.0	2.50 ±0.10	HK12449
WLL250	1.249	2.99 ±0.65	4.92 ±0.14	4.13 ±0.61	27.5 ±0.7	2.19 ±0.09	HK12473
WLL251	1.195	4.85 ±1.17	8.61 ±0.20	5.99 ±0.73	31.8 ±0.9	3.13 ±0.12	HK12452
WLL252	1.167	3.72 ±1.05	7.42 ±0.18	5.91 ±0.69	41.2 ±1.0	3.60 ±0.14	HK12453
WLL254	1.202	3.32 ±0.93	2.73 ±0.11	2.91 ±0.57	47.3 ±1.2	3.29 ±0.13	HK12479
WLL256	1.205	4.29 ±1.09	12.3 ±0.26	7.93 ±0.89	32.4 ±0.9	2.13 ±0.09	HK12451
WLL257	1.260	3.72 ±0.93	4.48 ±0.12	3.56 ±0.69	23.9 ±0.7	2.58 ±0.10	HK12480
WLL271	1.158	4.37 ±1.13	6.20 ±0.16	5.50 ±0.73	38.3 ±1.2	3.26 ±0.13	HK12458
WLL273	1.152	4.36 ±1.13	6.70 ±0.17	7.28 ±0.85	46.5 ±1.1	3.12 ±0.12	HK12461
WLL275	1.198	3.32 ±0.89	4.77 ±0.13	3.80 ±0.57	24.7 ±0.7	3.14 ±0.12	HK12483

[1] Ratio wet sample to dry sample weight. Errors assumed 50% of (δ-1).
[2] U and Th-content is calculated from the error weighted mean of the isotope equivalent contents

Highlighted in red are those radionuclides in the Uranium decay chain, between which a radioactive disequilibrium is significant.

Table 3 – quartz SAR Technique
Measured equivalent dose, doserate and luminescence age

Sample no.	dD/dt (Gy/ka)[#]	D_e (Gy) & OSL-age (ka) 'leading edge'	D_e (Gy) & OSL-age (ka) 'lognormal model'	D_e (Gy) & OSL-age (ka) 'mean'	Field code
WLL242	*6.290±0.474	36.9±4.5Gy	100.2±7.2Gy	99.0±8.2Gy	HK12445
		5.87±0.82ka	15.9±1.6ka	15.7±1.7ka	
WLL247	*5.845±0.364	18.3±1.9Gy	33.6±0.9Gy	32.5±1.7Gy	HK12449
		3.13±0.35ka	5.74±0.35ka	5.56±0.41ka	
WLL250	*4.277±0.359	6.86±0.43Gy	11.7±0.8Gy	15.7±2.5Gy	HK12473
		1.60±0.16ka	2.74±0.28ka	3.67±0.62ka	
WLL251	*5.958±0.439	4.57±0.23Gy	6.96±0.37Gy	11.2±2.7Gy	HK12452
		0.77±0.06ka	1.17±0.09ka	1.88±0.43ka	
WLL252	*7.016±0.447	3.57±0.51Gy	8.01±0.86Gy	8.98±0.92Gy	HK12453
		0.51±0.07ka	1.14±0.13ka	1.28±0.14ka	
WLL254	6.412±0.446	2.29±0.05Gy	5.09±0.55Gy	6.64±1.22Gy	HK12479
		0.36±0.03ka	0.79±0.10ka	1.04±0.20ka	
WLL256	*5.334±0.440	1.44±0.05Gy	1.88±0.09Gy	2.31±0.26Gy	HK12451
		0.27±0.02ka	0.35±0.03ka	0.43±0.05ka	
WLL257	4.438±0.374	6.76±0.38Gy	11.8±0.9Gy	13.5±1.9Gy	HK12480
		1.52±0.15ka	2.66±0.30ka	3.04±0.50ka	
WLL271	6.762±0.393	5.69±0.19Gy	6.87±0.16Gy	7.38±0.34Gy	HK12458
		0.84±0.06ka	1.02±0.07ka	1.09±0.08ka	
WLL273	7.320±0.407	4.4±0.5Gy	11.3±1.3Gy	14.8±2.3Gy	HK12461
		0.60±0.08ka	1.54±0.20ka	2.02±0.33ka	
WLL275	5.291±0.368	20.8±5.5Gy	60.8±2.2Gy	^67.9±6.97Gy	HK12483
		3.93±1.08ka	11.5±0.9ka	^12.8±1.6ka	

[#] The doserate dD/dt was calculated using the conversion factors of Adamiec and Aitken (1998)

[*] This doserate and the age are corrected for the radioactive disequilibrium in the sample. As the correction was done under the assumption that the disequilibrium was in a steady state for the whole time after deposition, the corrected age represents only a better estimate than the equilibrium age and not necessarily the true age. The doserate calculated under the invalid assumption that the whole U-chain was in equilibrium with ^{226}Ra would be (the impact on ages is shown in brackets): WLL242 6.431±0.474Gy/ka (age –2%), WLL247 6.201±0.364 (age –6%), WLL250 4.486±0.359 (age –5%), WLL251 6.492±0.439 (age –8%), WLL252 7.449±0.447 (age –6%), WLL256 6.343±0.440 (age –16%).

^ Six high dose outlyers (saturated aliquots) were removed for this calculation.

ANNEX

COMPARISON OF
FINEGRAIN AND COARSE GRAIN RESULTS

COMPARISON OF SAR AGES WITH FINEGRAIN AGES

The following table shows a comparison of dating results for the samples reported in batch IVA and IVB. This work was carried out to allow a quality assurance of the ages reported, and a comparison with the previous work by A. Murray.

The question remains if these samples have had a recent transport event (i.e. the 'leading edge' is the best age estimate) or not. As already pointed out earlier (see the results chapter), we cannot see any evidence for incomplete bleaching in the SAR measurements. Furthermore, the finegrain dating technique did not yield a 'rising plateau', which would indicate a partial bleaching event. So for all four samples we conclude that the 'leading edge age' is very likely an underestimate.

For reasons outlined in Annex III (report IIB) we prefer the 'lognormal' model compared to the 'mean'. As the logarithmic distribution is of Gaussian type, the error can be reduced to the standard deviation of the mean. As the non-logarithmic dose distribution is not normal, the error calculation for the 'mean age' is only valid under the additional assumption that the mean of the dose distribution is normally distributed.

sample	SAR age 'leading edge' (ka)	SAR age 'lognormal model' (ka)	SAR age 'mean' (ka)	*finegrain age (ka)
WLL242	5.87±0.82	15.9±1.6	15.7±1.7	18.0±2.4
WLL247	3.13±0.35	5.74±0.35	5.56±0.41	5.18±0.61
WLL250	1.60±0.16	2.74±0.28	3.67±0.62	6.22±0.69
WLL251	0.77±0.06	1.17±0.09	1.88±0.43	3.39±0.35
WLL252	0.51±0.07	1.14±0.13	1.28±0.14	5.17±0.38
WLL254	0.36±0.03	0.79±0.10	1.04±0.20	2.82±0.62
WLL256	0.27±0.02	0.35±0.03	0.43±0.05	1.35±0.09
WLL257	1.52±0.15	2.66±0.30	3.04±0.50	3.57±0.32
WLL271	0.84±0.06	1.02±0.07	1.09±0.08	1.11±0.16
WLL273	0.60±0.08	1.54±0.20	2.02±0.33	4.26±0.37
WLL275	3.93±1.08	11.5±0.9	^12.8±1.6	1.65±0.18

* These finegrain ages were reported previously in the Phase IVA report (part1 & part2).
^ Six high dose outlyers (saturated aliquots) were removed for this calculation.

While for some samples the agreement of fine- and SAR-ages is good, we note that a number of SAR dates are significantly younger than their counterparts. Though it is difficult to judge whether one method is better than the other, I'm inclined to give the SAR (lognormal) ages a preference. The reason is that most of the fine ages in question had very dim signals, indicating low potassium feldspar content (the feldspar preferred for dating), while the SAR dose distributions did not show abnormalities. A common reason for age overestimation of silt fractions is the fluvial transport of the grains in larger aggregates, so that some grains within the aggregates do not get enough light exposure to reset the luminescence clock.

One sample (WLL275) has a higher SAR- than finegrain-age. Age overestimates of sandy samples can happen if the large grains creep on the ground of a turbid waterflow. Age

underestimates of finegrain feldspar ages are usually attributed to anomalous fading. It is not possible to decide between the two possibilities without further measurements.

Given the time pressure of this project, supplementary measurements have not been carried out. It would be recommendable to try SAR on quartz finegrains for the samples with marked age discrepancies between both methods. That would at least detect if the problem is caused by some kind of strange feldspar measured in the finegrain sample. You might have other evidence of course, from radiocarbon or cosmogenic dating, which points towards the right method. We would most value if you could give us feedback on this.

Report No. 1/12

Luminescence Dating Technical Report

Luminescence Dating Laboratory

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CONTENTS

1. INTRODUCTION

Eleven samples (laboratory code WLL949-959) were submitted for Luminescence Dating by the Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government.

The deposition ages have been determined for these samples using the silt fraction (4-11μm). Dependent on the relative luminescence intensities of feldspars, the palaeodose, i.e. the radiation dose accumulated in the sample after the last light exposure (assumed at deposition), was determined by measuring the broadband luminescence output during infrared optical stimulation of the feldspar fraction.

The dose rate was estimated on the basis of a low level gamma spectrometry measurement.

All measurements were done in the Luminescence Dating Laboratory, School of Geography, Environment and Earth Sciences, Victoria University of Wellington.

2. EXPERIMENTAL WORK

2.1 Sample Preparation

The samples contained a considerable amount of silt, and we decided to apply a so-called fine grain technique, i.e. use the grain size 4-11 μm for dating.

Sample preparation was done under extremely subdued safe orange light in a darkroom. Outer surfaces, which may have seen light during sampling, were removed and discarded. The actual water content and the saturation content were measured using 'fresh' inside material.

The samples were treated with 10%HCl to remove carbonates until the reaction stopped, then carefully rinsed with distilled water. Thereafter, all organic matter was destroyed with 10%H_2O_2 until the reaction stopped, then carefully rinsed with distilled water. By treatment with a solution of sodium citrate, sodium bicarbonate and sodium dithionate iron oxide coatings were removed from the mineral grains and then the sample was carefully rinsed again.

The grain size 4-11μm was extracted from the samples in a water-filled (with added dispersing agent to deflocculate clay) measuring cylinder using Stokes' Law. The other fractions were discarded. The samples then are brought into suspension in pure acetone and deposited evenly in a thin layer on up to 50 aluminum discs (1cm diameter).

Luminescence measurements were done using a standard Riso TL-DA15 measurement system, equipped with
• Schott BG39 + L40 optical filters to select the board luminescence band of feldspars. Stimulation was done cw at about 40mW/cm^2 with infrared diodes at 880Δ80nm.

β-irradiations were done by the built in $^{90}Sr,^{90}Y$ β-irradiator, calibrated against the Riso National Laboratory to about 3% accuracy. α-irradiations were done on a ^{241}Am irradiator supplied and calibrated by ELSEC, Littlemore, UK.

2.2 Luminescence Measurements

Multiple Aliquot Additive Method (MAAD)

For sample WLL949-952 and WLL954-WLL958, the Paleodose was estimated by use of the multiple aliquot additive-dose method (with late-light subtraction). After an initial test-measurement, 30 aliquots were β-irradiated in six groups up to five times of the dose result taken from the test. 9 aliquots were α-irradiated in three groups up to three times of the dose result taken from the test. These 39 disks were stored in the dark for four weeks to relax the crystal lattice after irradiation.

After storage, these 39 disks and 9 unirradiated disks were preheated for 5mins at 220^0C to remove unstable signal components, and then measured for 100 seconds under IR stimulation, resulting in 48 shinedown curves. These curves were then normalized for their luminescence response, using 0.1s shortshine measurements taken before irradiation from all aliquots.

The luminescence growth curve (β-induced luminescence intensity vs added dose) is then constructed by using the initial 10 seconds of the shine down curves and subtracting the average of the last 20 seconds, the so called late light which is thought to be a mixture of background and hardly bleachable components. The shine plateau was checked to be flat after this manipulation. Extrapolation of this growth curve to the dose-axis gives the equivalent dose D_e, which is used as an estimate of the Paleodose.

A similar plot for the alpha-irradiated disks allows an estimate of the α-efficiency, the a-value (Luminescence/dose generated by the α-source divided by the luminescence/dose generated by the β-source).

Single Aliquot Regenerative Method (SAR)

Palaeodoses for samples WLL953 and WLL959 were estimated by use of the Single Aliquot Regenerative Method (SAR; see Murray and Wintle, 2000) under IR stimulation as the growth curves of the two samples are near saturation, using SAR method can improve curves' positions.

In the SAR method a number of aliquots are subjected to a repetitive cycle of irradiation, preheat and measurement. In the first cycle the natural luminescence output is measured, in all following cycles an artificial dose is applied. Usually four or five of these dose points are used to build the luminescence growth curve (β-induced luminescence intensity vs added dose) and bracket the natural luminescence output. This allows interpolation of the equivalent dose (the β-dose equivalent to the palaeodose). In order to correct for potential sensitivity changes from cycle to cycle, a test dose is applied between the cycles, preheated ('cut heat') and measured.

For the samples reported here 10 aliquots were measured, preheat and cutheat temperature was 260^0C for 20s, and measurement time 100s (IR stimulation), which resets the luminescence signal to a negligible residual. All feldspar measurements at room temperature.

The measurement of 10 aliquots resulted in 10 equivalent doses (D_es). The D_es were accepted within 10% recycling ratio, which spread over the so called dose distribution. The arithmetic mean of this distribution was interpreted as the best estimate for the equivalent dose, and subsequently used for age calculation. A dose recovery test and a zero dose were checked no anomalies.

2.3 Gamma Spectrometry

The dry, ground and homogenised soil samples were encapsuled in airtight perspex containers and stored for at least 4 weeks. This procedure minimizes the loss of the short-lived noble gas ^{222}Rn and allows ^{226}Ra to reach equilibrium with its daughters ^{214}Pb and ^{214}Bi.

The samples were counted using high resolution gamma spectrometry with a CANBERRA broad energy Ge detector for a minimum time of 24h. The spectra were analysed using GENIE2000 software. The doserate calculation is based on the activity concentration of the nuclides ^{40}K, ^{208}Tl, ^{212}Pb, ^{228}Ac, ^{214}Bi, ^{214}Pb, ^{226}Ra.

3. RESULTS

The radionuclide contents were calculated from the raw gammaspectrometry data. The Uranium and Thorium contents of most samples were quite high, similar to what we've measured in the previous phases of this project reported earlier. Table 2 gives a summary of the radiometric data.

The high radionuclide contents cause high doserates for most samples, compared to 2…3 Gy/ka for what would be an 'average' sample. Owing to the high doserates, some samples showed the onset of saturation of the electron traps, despite being relatively young for the OSL dating technique.

Table 1 gives sample summaries and calculated cosmic doserates, whereas Table 3 gives a summary of all equivalent doses, doserates and ages.

All errors in this report are stated as 1 sigma errors. A radioactive disequilibrium was considered as significant, if the equivalent Uranium contents do not overlap in a 2 sigma interval.

4. REFERENCES

Adamiec G. and Aitken M. (1998) Dose-rate conversion factors: update. *Ancient TL* 16, 37-50.

Murray A.S. and Wintle A.G. (2000) Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements* 32, 57-73.

Prescott & Hutton (1994), *Radiation Measurements*, Vol. 23.

LIST OF TABLES

Table 1 - Doserate contribution of cosmic radiation

Sample no.	depth below surface (m)	dD_c/dt (Gy/ka)[1]	Field code
WLL949	1.7	0.1579±0.0079	HK13459
WLL950	3.3	0.1279±0.0064	HK13460
WLL951	0.9	0.1795±0.0090	HK13461
WLL952	2.2	0.1504±0.0075	HK13462
WLL953	0.4	0.1890±0.0095	HK13463
WLL954	1.2	0.1691±0.0085	HK13464
WLL955	2.3	0.1458±0.0073	HK13465
WLL956	1.6	0.1601±0.0080	HK13466
WLL957	2.7	0.1407±0.0070	HK13467
WLL958	0.2	0.1978±0.0099	HK13468
WLL959	1	0.1769±0.0088	HK13469

[1] Contribution of cosmic radiation to the total doserate, calculated as proposed by Prescott & Hutton (1994), Radiation Measurements, Vol. 23.

Table 2 - Radionuclide and water contents

Sample no.	Water content (%)δ[1]	U (μg/g) from ^{234}Th	U (μg/g)[2] from ^{226}Ra, ^{214}Pb, ^{214}Bi	U (μg/g) from ^{210}Pb	Th (μg/g)[2] from ^{208}Tl, ^{212}Pb, ^{228}Ac	K (%)	Field code
WLL949	11.3	4.11±0.45	4.60±0.27	4.24±0.35	37.28±0.39	2.51±0.05	HK13459
WLL950	18.5	4.70±0.49	5.30±0.30	6.41±0.42	37.37±0.39	2.59±0.06	HK13460
WLL951	10.1	5.10±0.44	5.80±0.27	5.21±0.34	49.14±0.47	2.62±0.05	HK13461
WLL952	14.0	5.57±0.55	5.36±0.32	4.88±0.41	43.07±0.45	2.47±0.05	HK13462
WLL953	20.4	4.80±0.56	4.54±0.32	4.76±0.43	38.76±0.42	2.88±0.06	HK13463
WLL954	23.5	5.72±0.50	5.43±0.29	5.92±0.41	24.20±0.29	2.23±0.05	HK13464
WLL955	16.2	5.13±0.48	4.51±0.27	4.01±0.36	30.49±0.33	2.68±0.06	HK13465
WLL956	13.5	4.74±0.34	4.29±0.20	4.16±0.26	20.01±0.21	2.16±0.04	HK13466
WLL957	18.9	4.80±0.40	5.07±0.24	5.54±0.33	39.30±0.39	2.50±0.05	HK13467
WLL958	13.0	4.90±0.45	5.08±0.27	5.56±0.37	25.16±0.28	1.78±0.04	HK13468
WLL959	15.9	6.52±0.59	5.75±0.33	6.37±0.45	42.98±0.45	2.72±0.06	HK13469

[1] Errors assumed 25% of (δ).
[2] U and Th-content are calculated from the error weighted mean of the isotope equivalent contents.

Table3: a-value and equivalent dose, doserate and luminescence age

Sample no.	Method	a-value	D_e (Gy)	dD/dt (Gy/ka)[#]	**OSL-age (ka)**	Field code
WLL949	MAAD	0.07±0.03*	9.96±2.74	7.93±0.89	**1.3±0.4**	HK13459
WLL950	MAAD	0.07±0.01	43.11±5.48	7.63±0.30	**5.6±0.8**	HK13460
WLL951	MAAD	0.06±0.01	126.49±19.46	9.46±0.49	**13.4±2.2**	HK13461
WLL952	MAAD	0.07±0.03*	25.81±3.71	8.50±1.01	**3.0±0.6**	HK13462
WLL953	SAR	0.05±0.03*	305.25±33.92	7.16±0.78	**42.6±6.6**	HK13463
WLL954	MAAD	0.07±0.03*	6.48±0.47	5.87±0.68	**1.1±0.2**	HK13464
WLL955	MAAD	0.06±0.04	130.0±17.3	6.75±0.96	**19.3±3.8**	HK13465
WLL956	MAAD	0.07±0.03*	5.01±0.55	5.60±0.57	**0.9±0.1**	HK13466
WLL957	MAAD	0.06±0.01	136.8±15.2	7.37±0.46	**18.6±2.4**	HK13467
WLL958	MAAD	0.07±0.03*	9.3±0.6	6.12±0.70	**1.5±0.2**	HK13468
WLL959	SAR	0.05±0.03*	227.66±18.85	8.08±0.94	**28.2±4.0**	HK13469

[#] The doserate dD/dt was calculated using the conversion factors of Adamiec and Aitken (1998)
[*] The a-values were estimated
MAAD Multiple Aliquot Additive Method
SAR Single Aliquot Regenerative Method

Some comments

- Our standard method is 'MAAD', i.e. a multiple aliquot approach focusing on the blue emission band of potassium feldspars (410nm). However, all samples had very low blue luminescence under infrared stimulation. Thus, we decided to detect broad band luminescence (400-660nm) by using BG39+L40 filters, to increase signal intensity.

- Samples WLL949, WLL954 and WLL958 contained traces of artificial ^{137}Cs , which likely results from atmospheric atomic bomb tests in the 1960s.

Report No. 5/12

Luminescence Dating Technical Report

Luminescence Dating Laboratory

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CONTENTS

1. INTRODUCTION

Ten samples (laboratory code WLL976-985) were submitted to Luminescence Dating by the Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government.

The deposition ages have been determined for these samples using the silt fraction (4-11μm). Dependent on the relative luminescence intensities of feldspars and quartz in the samples, the palaeodose, i.e. the radiation dose accumulated in the sample after the last light exposure (assumed at deposition), was determined either by:

- measuring the broadband luminescence output from feldspar fraction during infrared optical stimulation
- measuring the ultraviolet luminescence output from quartz fraction during blue light optical stimulation.

The dose rate was estimated on the basis of a low level gamma spectrometry measurement.

All measurements were done in the Luminescence Dating Laboratory, School of Geography, Environment and Earth Sciences, Victoria University of Wellington.

2. EXPERIMENTAL WORK

2.1 Sample Preparation

The samples contained a considerable amount of silt, and we decided to apply a so-called fine grain technique, i.e. use the grain size 4-11 μm for dating.

Sample preparation was done under extremely subdued safe orange light in a darkroom. Outer surfaces, which may have seen light during sampling, were removed and discarded. The actual water content and the saturation content were measured using 'fresh' inside material.

The samples were treated with 10%HCl to remove carbonates until the reaction stopped, then carefully rinsed with distilled water. Thereafter, all organic matter was destroyed with 10%H_2O_2 until the reaction stopped, then carefully rinsed with distilled water. By treatment with a solution of sodium citrate, sodium bicarbonate and sodium dithionate iron oxide coatings were removed from the mineral grains and then the sample was carefully rinsed again.

The grain size 4-11μm was extracted from the samples in a water-filled (with added dispersing agent to deflocculate clay) measuring cylinder using Stokes' Law. The other fractions were discarded. The samples then are brought into suspension in pure acetone and deposited evenly in a thin layer on up to 50 aluminum discs (1cm diameter).

2.2 Luminescence Measurements

Luminescence measurements were done using a standard Riso TL-DA15 measurement system, equipped with

• Schott BG39 + L40 optical filters to select the broad band luminescence of feldspars. Stimulation was done cw at about 40mW/cm^2 with infrared diodes at 880Δ80nm.

• 7.5mm thick Hoya U340 optical filters to select the UV luminescence band of quartz. Stimulation was done cw at about 60mW/cm^2 with blue diodes at 470Δ30nm.

β-irradiations were done by the built in ^{90}Sr,^{90}Y β-irradiator, calibrated against the Riso National Laboratory to about 3% accuracy. α-irradiations were done on a ^{241}Am irradiator supplied and calibrated by ELSEC, Littlemore, UK.

Multiple Aliquot Additive Method (MAAD)

For sample WLL984, the Paleodose was estimated by use of the multiple aliquot additive-dose method (with late-light subtraction) by measuring the broadband luminescence under IR Stimulation. After an initial test-measurement, 30 aliquots were β-irradiated in six groups up to five times of the dose result taken from the test. 9 aliquots were α-irradiated in three groups up to three times of the dose result taken from the test. These 39 disks were stored in the dark for four weeks to relax the crystal lattice after irradiation.

After storage, these 39 disks and 9 unirradiated disks were preheated for 5mins at 220^{0}C to remove unstable signal components, and then measured for 100 seconds under IR stimulation, resulting in 48 shinedown curves. These curves were then normalized for their luminescence response, using 0.1s shortshine measurements taken before irradiation from all aliquots.

The luminescence growth curve (β-induced luminescence intensity vs added dose) is then constructed by using the initial 10 seconds of the shine down curves and subtracting the average of the last 20 seconds, the so called late light which is thought to be a mixture of background and hardly bleachable components. The shine plateau was checked to be flat after this manipulation. Extrapolation of this growth curve to the dose-axis gives the equivalent dose D_e, which is used as an estimate of the Paleodose.

A similar plot for the alpha-irradiated disks allows an estimate of the α-efficiency, the a-value (Luminescence/dose generated by the α-source divided by the luminescence/dose generated by the β-source).

Single Aliquot Regenerative Method (SAR)

Palaeodoses of other samples (except WLL984) were estimated by the use of the Single Aliquot Regenerative Method (SAR; see Murray and Wintle, 2000). As the growth curves of the samples were near saturation, using SAR method can improve curves' positions. The two types of luminescence were measured for the following two groups.

- Broadband luminescence of WLL977-WLL981 and WLL985 were measured under IR stimulation.

- UV luminescence of WLL976, WLL982 and WLL983 were measured under blue stimulation as the three samples had no broadband luminescence under IR stimulation.

In the SAR method a number of aliquots are subjected to a repetitive cycle of irradiation, preheat and measurement. In the first cycle the natural luminescence output is measured, in all following cycles an artificial dose is applied. Usually four or five of these dose points are used to build the luminescence growth curve (β-induced luminescence intensity vs added dose) and bracket the natural luminescence output. This allows interpolation of the equivalent dose (the β-dose equivalent to the palaeodose). In order to correct for potential sensitivity changes from cycle to cycle, a test dose is applied between the cycles, preheated ('cut heat') and measured.

For the samples reported here, ten aliquots for each sample were measured. For IR stimulation, preheat and cutheat temperature was 260^0C for 20s, and measurement time was 100s at the room temperature for all feldspar, which resets the luminescence signal to a negligible residual. For blue light stimulation, preheat and cutheat temperature was 240^0C for 10s, and measurement time was 40s at 125^0C for all quartz. Each UV luminescence from quartz was recorded under blue stimulation after IR bleach 100s to erase any feldspar OSL which was basically negligible residual.

The measurement of 10 aliquots resulted in 10 equivalent doses (D_es). The D_es were accepted within 10% recycling ratio, which spread over the so called dose distribution. The arithmetic mean of this distribution was interpreted as the best estimate for the equivalent dose, and subsequently used for age calculation. A dose recovery test and a zero dose were checked no anomalies.

2.3 Gamma Spectrometry

The dry, ground and homogenised soil samples were encapsuled in airtight perspex containers and stored for at least 4 weeks. This procedure minimizes the loss of the short-lived noble gas ^{222}Rn and allows ^{226}Ra to reach equilibrium with its daughters ^{214}Pb and ^{214}Bi.

The samples were counted using high resolution gamma spectrometry with a CANBERRA broad energy Ge detector for a minimum time of 24h. The spectra were analysed using GENIE2000 software. The doserate calculation is based on the activity concentration of the nuclides ^{40}K, ^{208}Tl, ^{212}Pb, ^{228}Ac, ^{214}Bi, ^{214}Pb, ^{226}Ra.

3. RESULTS

The radionuclide contents were calculated from the raw gammaspectrometry data. The Uranium and Thorium contents of most samples were quite high, similar to what we've measured in the previous phases of Hong Kong project reported earlier. Table 2 gives a summary of the radiometric data.

The high radionuclide contents cause high doserates for all samples, compared to 2-3 Gy/ka for what would be an 'average' sample. Owing to the high doserates, some samples showed the onset of saturation of the electron traps, despite being relatively young for the OSL dating technique.

Table 1 gives sample summaries and calculated cosmic doserates, whereas Table 3 gives a summary of all equivalent doses, doserates and ages.

All errors in this report are stated as 1 sigma errors. A radioactive disequilibrium was considered as significant, if the equivalent Uranium contents do not overlap in a 2 sigma interval.

4. REFERENCES

Guérin, G., Mercier, N., Adamiec, G. 2011: Dose- rate conversion factors: update. *Ancient TL*, Vol.29, No.1, 5-8.

Murray A.S. and Wintle A.G. (2000) Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements* 32, 57-73.

Prescott & Hutton (1994), *Radiation Measurements*, Vol. 23.

LIST OF TABLES

Table 1 - Doserate contribution of cosmic radiation

Laboratory Code	Depth Below the Surface(m)	Cosmic Dose Rate (Gy/ka)	Field Code
WLL976	7.2	0.0808±0.0040	HK13552
WLL977	8.75	0.0687±0.0034	HK13553
WLL978	6.44	0.0878±0.0044	HK13554
WLL979	8.4	0.0711±0.0036	HK13555
WLL980	8.15	0.0730±0.0037	HK13556
WLL981	3.49	0.1249±0.0062	HK13557
WLL982	5.15	0.1019±0.0051	HK13558
WLL983	7	0.0826±0.0041	HK13559
WLL984	6.7	0.0855±0.0043	HK13560
WLL985	8.45	0.0709±0.0035	HK13561

[1] Contribution of cosmic radiation to the total doserate, calculated as proposed by Prescott & Hutton (1994), Radiation Measurements, Vol.

Table 2 - Radionuclide and water contents

Laboratory Code	Water content (%)	U(ppm) from ^{234}Th	U(ppm) from ^{226}Ra, ^{214}Pb, ^{214} Bi	U(ppm) from ^{210}Pb	Th(ppm) From ^{208}Tl ^{212} Pb ^{228} Ac	K(%)	Field Code
WLL976	12.08	5.29±0.36	4.49±0.21	3.77±0.25	47.59±0.45	2.72±0.05	HK13552
WLL977	3.6	5.50±0.53	5.07±0.30	4.51±0.39	45.66±0.46	3.07±0.06	HK13553
WLL978	11.42	5.64±0.51	5.05±0.30	4.45±0.37	46.10±0.46	2.53±0.05	HK13554
WLL979	16.08	5.31±0.61	5.53±0.35	5.53±0.45	48.47±0.51	2.62±0.06	HK13555
WLL980	17.08	5.80±0.62	5.24±0.35	5.32±0.46	56.78±0.57	2.98±0.07	HK13556

WLL981	14.05	4.98±0.34	4.74±0.21	4.94±0.27	36.78±0.35	2.30±0.05	HK13557
WLL982	14.0	5.85±0.52	4.67±0.29	4.82±0.39	38.16±0.40	2.68±0.06	HK13558
WLL983	15.57	5.36±0.58	4.79±0.32	4.76±0.43	51.42±0.52	2.88±0.06	HK13559
WLL984	12.27	5.83±0.55	4.96±0.31	4.36±0.40	48.93±0.50	3.17±0.07	HK13560
WLL985*	16.2	6.28±0.61	9.80±0.42	12.64±0.64	43.96±0.46	2.86±0.06	HK13561

[1] Errors assumed 25% of (δ).
[2] U and Th-content are calculated from the error weighted mean of the isotope equivalent contents.
*WLL 985 was observed disequilibrium of U decay chains.

Table3: a-value and equivalent dose, dose rate and luminescence age

Laboratory Code	Method	a-value*	D_e(Gy)	Dose Rate(Gy/ka)	**Luminescence Age(ka)**	Field Code
WLL976	SAR q	0.05±0.03	401.96±34.64	8.46±1.06	**47.5±7.2 (minimum age)**	HK13552
WLL977	SAR bd	0.05±0.03	248.00±37.77	9.68±1.16	**25.6±5.0**	HK13553
WLL978	SAR bd	0.05±0.03	227.32±25.72	8.40±1.08	**27.1±4.6**	HK13554
WLL979	SAR bd	0.05±0.03	329.54±71.17	8.41±1.10	**39.2±9.9**	HK13555
WLL980	SAR bd	0.05±0.03	328.15±53.53	9.29±1.20	**35.3±7.4**	HK13556
WLL981	SAR bd	0.05±0.03	164.92±29.42	7.04±0.89	**23.4±5.1**	HK13557
WLL982	SAR q	0.05±0.03	355.70±50.07	7.47±0.92	**47.6±8.9**	HK13558
WLL983	SAR q	0.05±0.03	458.51±66.60	8.74±1.12	**52.5±10.2**	HK13559
WLL984	MAAD bd	0.06±0.01	180.40±22.55	9.50±0.48	**19.0±2.6**	HK13560
WLL985	SAR bd	0.05±0.03	312.19±50.70	9.52±1.27	**32.8±6.9**	HK13561

[*] The a-values were estimated (except WLL984).
MAAD Multiple Aliquot Additive Method
SAR Single Aliquot Regenerative Method
bd 4-11 µm polymineral sample
infrared stimulation (i.e. only feldspars contribution to OSL)
broad band optical OSL filters

q 4-11μm polymineral sample
blue light stimulation(i.e quatz and feldspars contribute to OSL, but these samples the signal was dominated by quartz as the evident by OSL intensity after IR bleach and shinedown caves shape)
340nm UV optical filter

Some comments

- Our standard method is 'MAAD', i.e. a multiple aliquot approach focusing on the blue emission band of potassium feldspars (410nm). However, all samples had very low blue luminescence under infrared stimulation. Thus, we decided to detect broad band luminescence (400-660nm) by using BG39+L40 filters, to increase signal intensity. But samples of WLL976, WLL982 and WLL983 had no broad band luminescence, therefore we decided to detect UV luminescence by using UV340 filter under blue stimulation.

- WLL985 displays disequilibrium in the uranium chains, however the affect on age is very small if consideration of the osl age uncertainty and the doserate mainly dominated by thoruim's contribution in this case, the effect is negligible.

- The age of WLL976 is considered as a minimum age because the growth curves were near saturation, reached curves' limitation. This is best estimated age we obtained.

- Some laboratories would report the error of OSL age as the standard deviation of the mean, i.e. Sm=S/sqrt(n) [S standard deviation; n number of aliquots]. While results look more precise, they may be an underestimate.

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Radiocarbon Dating Laboratory

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email c14@waikato.ac.nz
Head: Dr Alan Hogg

Report on Radiocarbon Age Determination for Wk- 11893

(AMS measurement by IGNS [NZA-16576])

Submitter	R.J. Sewell
Submitter's Code	HK12458
Site & Location	Tai O, Hong Kong
Sample Material	Charcoal
Physical Pretreatment	Possible contaminants were removed. Washed in ultrasonic bath.
Chemical Pretreatment	Sample washed in hot 10% HCl, rinsed and treated with hot 0.5% NaOH. The NaOH insoluble fraction was treated with hot 10% HCl, filtered, rinsed and dried.

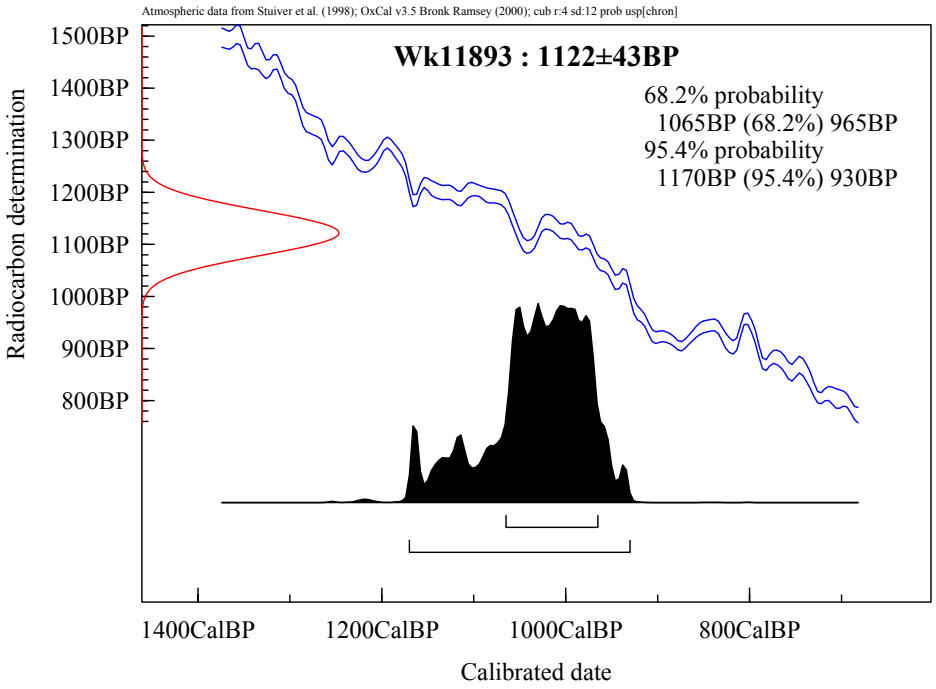
$d^{14}C$	-130.2 ± 4.6	‰
$\delta^{13}C$	-26.8 ± 0.2	‰
$D^{14}C$	-130.3 ± 4.7	‰
% Modern	87.0 ± 0.5	%
Result	**1122 ± 43 BP**	

Comments

Alt Hogg

23/02/03

- Result is *Conventional Age or % Modern* as per Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier of 1 .
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB.
- Results are reported as *% Modern* when the conventional age is younger than 200 yr BP.


Atmospheric data from Stuiver et al. (1998); OxCal v3.5 Bronk Ramsey (2000); cub r:4 sd:12 prob usp[chron]
Wk11893 : 1122±43BP
68.2% probability
1065BP (68.2%) 965BP
95.4% probability
1170BP (95.4%) 930BP
Radiocarbon determination
1500BP
1400BP
1300BP
1200BP
1100BP
1000BP
900BP
800BP
1400CalBP
1200CalBP
1000CalBP
800CalBP
Calibrated date

The University of Waikato

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Report on Radiocarbon Age Determination for Wk- 11894

(AMS measurement by IGNS [NZA-16577])

Submitter R.J. Sewell

Submitter's Code HK12461

Site & Location Tai O, Hong Kong

Sample Material Charcoal

Physical Pretreatment Possible contaminants were removed. Washed in ultrasonic bath.

Chemical Pretreatment Sample washed in hot 10% HCl, rinsed and treated with hot 0.5% NaOH. The NaOH insoluble fraction was treated with hot 10% HCl, filtered, rinsed and dried.

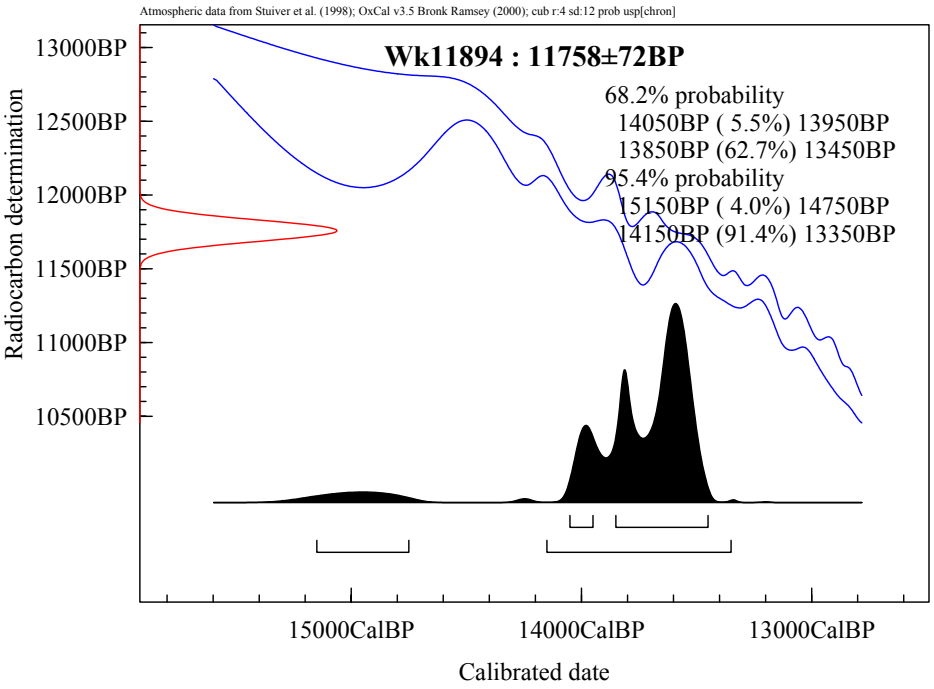
$d^{14}C$	-766.9 ± 1.9	‰
$\delta^{13}C$	-28.3 ± 0.2	‰
$D^{14}C$	-768.6 ± 2.0	‰
% Modern	23.1 ± 0.2	%
Result	**11,758 ± 72 BP**	

Comments

Alt Hogg

23/02/03

- Result is *Conventional Age or % Modern* as per Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier of 1 .
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB.
- Results are reported as *% Modern* when the conventional age is younger than 200 yr BP.


Atmospheric data from Stuiver et al. (1998); OxCal v3.5 Bronk Ramsey (2000); cub r:4 sd:12 prob usp[chron]
Wk11894 : 11758±72BP
68.2% probability
14050BP (5.5%) 13950BP
13850BP (62.7%) 13450BP
95.4% probability
15150BP (4.0%) 14750BP
14150BP (91.4%) 13350BP
13000BP
12500BP
12000BP
11500BP
11000BP
10500BP
Radiocarbon determination
15000CalBP
14000CalBP
13000CalBP
Calibrated date

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Report on Radiocarbon Age Determination for Wk- 11898

(AMS measurement by IGNS [NZA-16581])

Submitter R.J. Sewell

Submitter's Code HK12480

Site & Location Sai Tso Wan, Hong Kong

Sample Material Charcoal

Physical Pretreatment Possible contaminants were removed. Washed in ultrasonic bath.

Chemical Pretreatment Sample washed in hot 10% HCl, rinsed and treated with hot 0.5% NaOH. The NaOH insoluble fraction was treated with hot 10% HCl, filtered, rinsed and dried.

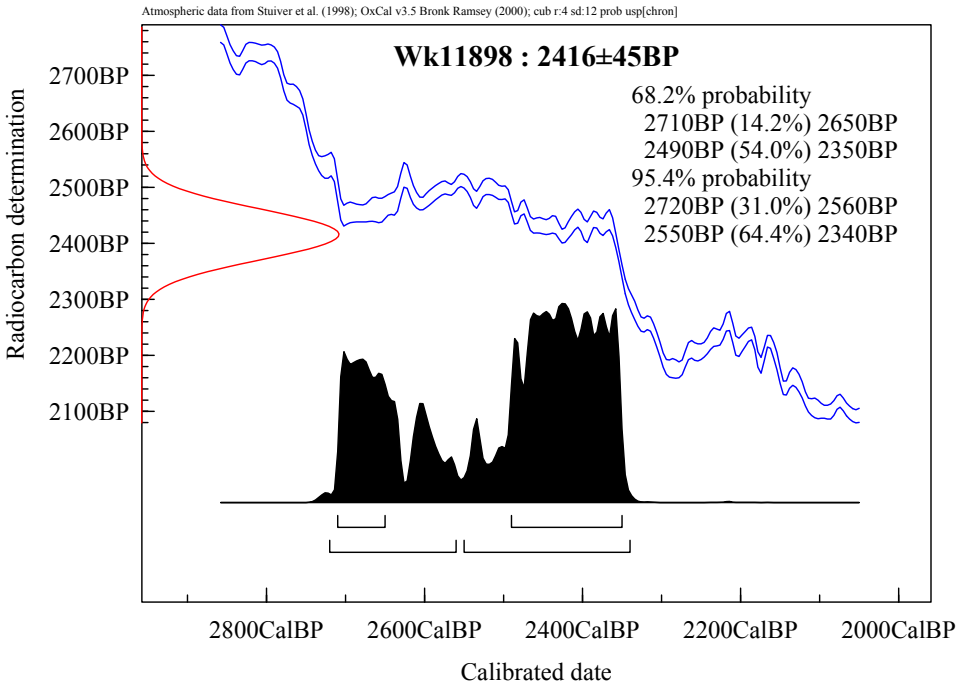
$d^{14}C$	-259.9 ± 4.0	‰
$\delta^{13}C$	-27.3 ± 0.2	‰
$D^{14}C$	-259.8 ± 4.1	‰
% Modern	74.0 ± 0.4	%
Result	**2416 ± 45 BP**	

Comments

Alt Hogg

23/02/03

- Result is *Conventional Age or % Modern* as per Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier of 1 .
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB.
- Results are reported as *% Modern* when the conventional age is younger than 200 yr BP.


Atmospheric data from Stuiver et al. (1998); OxCal v3.5 Bronk Ramsey (2000); cub r:4 sd:12 prob usp[chron]
Wk11898 : 2416±45BP
68.2% probability
2710BP (14.2%) 2650BP
2490BP (54.0%) 2350BP
95.4% probability
2720BP (31.0%) 2560BP
2550BP (64.4%) 2340BP
Radiocarbon determination
2700BP
2600BP
2500BP
2400BP
2300BP
2200BP
2100BP
2800CalBP
2600CalBP
2400CalBP
2200CalBP
2000CalBP
Calibrated date

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Report on Radiocarbon Age Determination for Wk- 11900

(AMS measurement by IGNS [NZA-16641])

Submitter	R.J. Sewell
Submitter's Code	HK12490
Site & Location	Sai Tso Wan, Hong Kong
Sample Material	Charcoal
Physical Pretreatment	Possible contaminants were removed. Washed in ultrasonic bath.
Chemical Pretreatment	Sample washed in hot 10% HCl, rinsed and treated with hot 0.5% NaOH. The NaOH insoluble fraction was treated with hot 10% HCl, filtered, rinsed and dried.

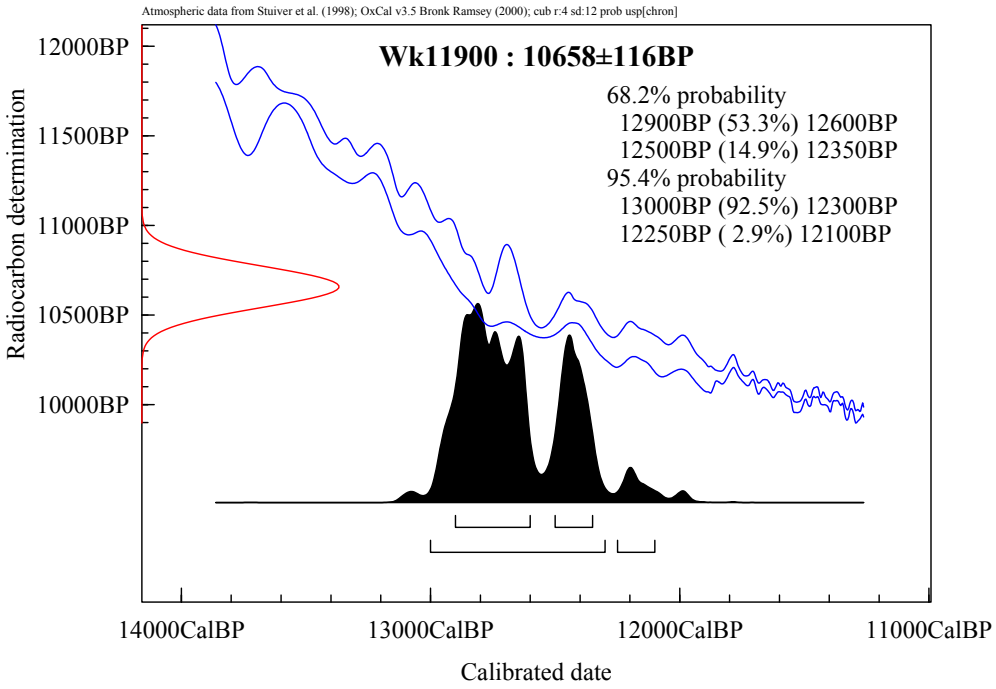
$d^{14}C$	-734.7 ± 3.8	‰
$\delta^{13}C$	-25.0 ± 0.2	‰
$D^{14}C$	-734.7 ± 3.8	‰
% Modern	26.5 ± 0.4	%
Result	**10,658 ± 116 BP**	

Comments

Alt Hogg

23/02/03

- Result is *Conventional Age or % Modern* as per Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier of 1 .
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB.
- Results are reported as *% Modern* when the conventional age is younger than 200 yr BP.


Atmospheric data from Stuiver et al. (1998); OxCal v3.5 Bronk Ramsey (2000); cub r:4 sd:12 prob usp[chron]
Wk11900 : 10658±116BP
68.2% probability
12900BP (53.3%) 12600BP
12500BP (14.9%) 12350BP
95.4% probability
13000BP (92.5%) 12300BP
12250BP (2.9%) 12100BP
12000BP
11500BP
11000BP
10500BP
10000BP
Radiocarbon determination
14000CalBP
13000CalBP
12000CalBP
11000CalBP
Calibrated date

BETA ANALYTIC INC.
DR. M.A. TAMERS and MR. D.G. HOOD
4985 S.W. 74 COURT
MIAMI, FLORIDA, USA 33155
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beta@radiocarbon.com

REPORT OF RADIOCARBON DATING ANALYSES

Dr. Kevin W.F. So

Report Date: 6/17/2013

Civil Engineering and Development Department

Material Received: 6/6/2013

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 350526	3120 +/- 30 BP	-25.6 o/oo	3110 +/- 30 BP
SAMPLE : HK13462 (A)			
ANALYSIS : AMS-Standard delivery			
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid			
2 SIGMA CALIBRATION : Cal BC 1430 to 1370 (Cal BP 3380 to 3320) AND Cal BC 1360 to 1310 (Cal BP 3310 to 3260)			
Beta - 350527	240 +/- 30 BP	-26.7 o/oo	210 +/- 30 BP
SAMPLE : HK13827			
ANALYSIS : AMS-Standard delivery			
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid			
2 SIGMA CALIBRATION : Cal AD 1650 to 1680 (Cal BP 300 to 270) AND Cal AD 1730 to 1810 (Cal BP 220 to 140) Cal AD 1930 to post 1950 (Cal BP 20 to post 1950)			
Beta - 350528	7950 +/- 40 BP	-25.4 o/oo	7940 +/- 40 BP
SAMPLE : HK13834			
ANALYSIS : AMS-Standard delivery			
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid			
2 SIGMA CALIBRATION : Cal BC 7040 to 6680 (Cal BP 8990 to 8630) AND Cal BC 6660 to 6660 (Cal BP 8610 to 8610)			

Dates are reported as RCYBP (radiocarbon years before present, "present" = AD 1950). By international convention, the modern reference standard was 95% the 14C activity of the National Institute of Standards and Technology (NIST) Oxalic Acid (SRM 4990C) and calculated using the Libby 14C half-life (5568 years). Quoted errors represent 1 relative standard deviation statistics (68% probability) counting errors based on the combined measurements of the sample, background, and modern reference standards. Measured 13C/12C ratios (delta 13C) were calculated relative to the PDB-1 standard.

The Conventional Radiocarbon Age represents the Measured Radiocarbon Age corrected for isotopic fractionation, calculated using the delta 13C. On rare occasion where the Conventional Radiocarbon Age was calculated using an assumed delta 13C, the ratio and the Conventional Radiocarbon Age will be followed by "*". The Conventional Radiocarbon Age is not calendar calibrated. When available, the Calendar Calibrated result is calculated from the Conventional Radiocarbon Age and is listed as the "Two Sigma Calibrated Result" for each sample.

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-25.6:lab. mult=1)

Laboratory number: **Beta-350526**

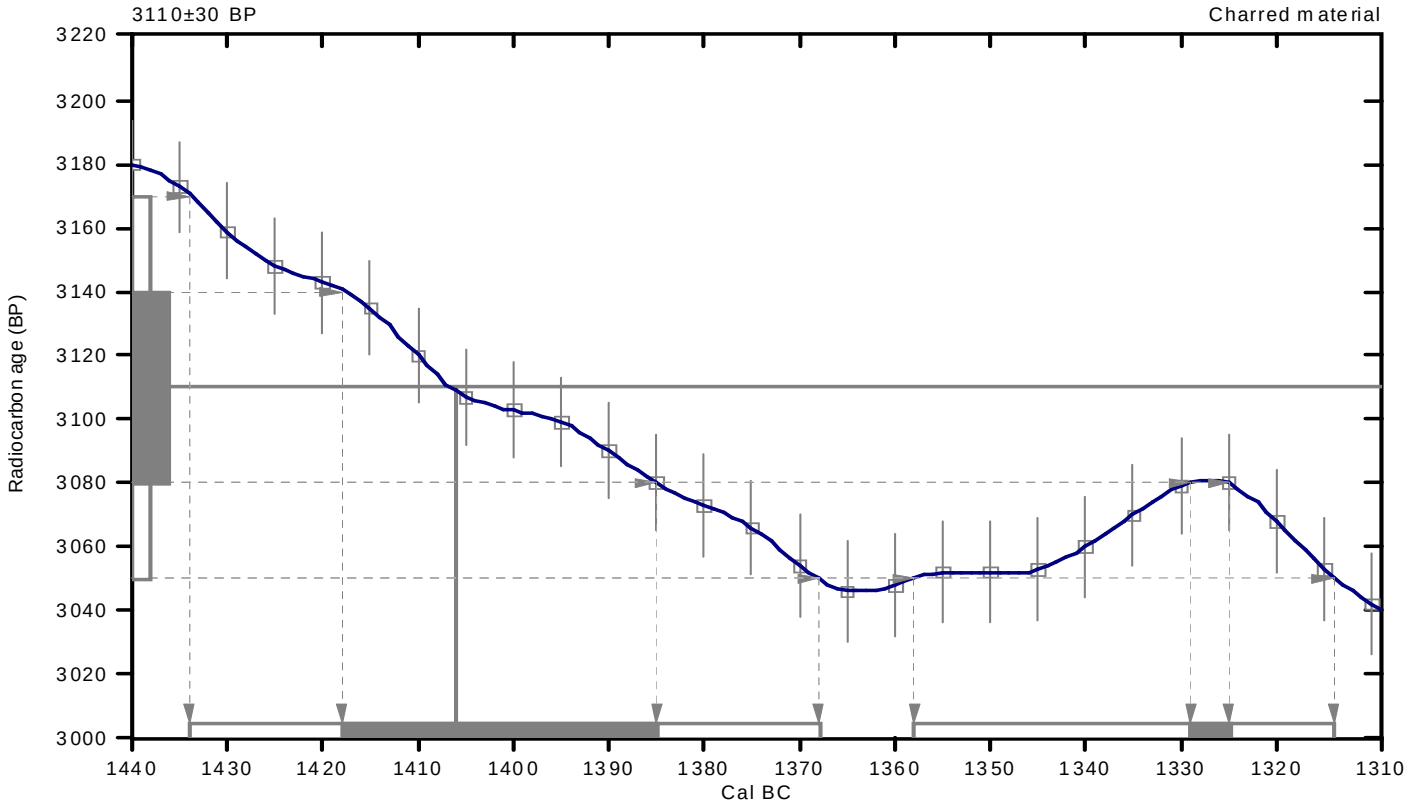
Conventional radiocarbon age: **3110±30 BP**

2 Sigma calibrated results: **Cal BC 1430 to 1370 (Cal BP 3380 to 3320) and**
(95% probability) **Cal BC 1360 to 1310 (Cal BP 3310 to 3260)**

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 1410 (Cal BP 3360)

1 Sigma calibrated results: Cal BC 1420 to 1380 (Cal BP 3370 to 3340) and
(68% probability) Cal BC 1330 to 1320 (Cal BP 3280 to 3280)



References:

Database used

INTCAL09

References to INTCAL09 database

Heaton,et.al.,2009, Radiocarbon 51(4):1151-1164, Reimer,et.al, 2009, Radiocarbon 51(4):1111-1150, Stuiver,et.al,1993, Radiocarbon 35(1):137-189, Oeschger,et.al.,1975,Tellus 27:168-192

Mathematics used for calibration scenario

A Simplified Approach to Calibrating C14 Dates
Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2):317-322

Beta Analytic Radiocarbon Dating Laboratory

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-26.7:lab. mult=1)

Laboratory number: **Beta-350527**

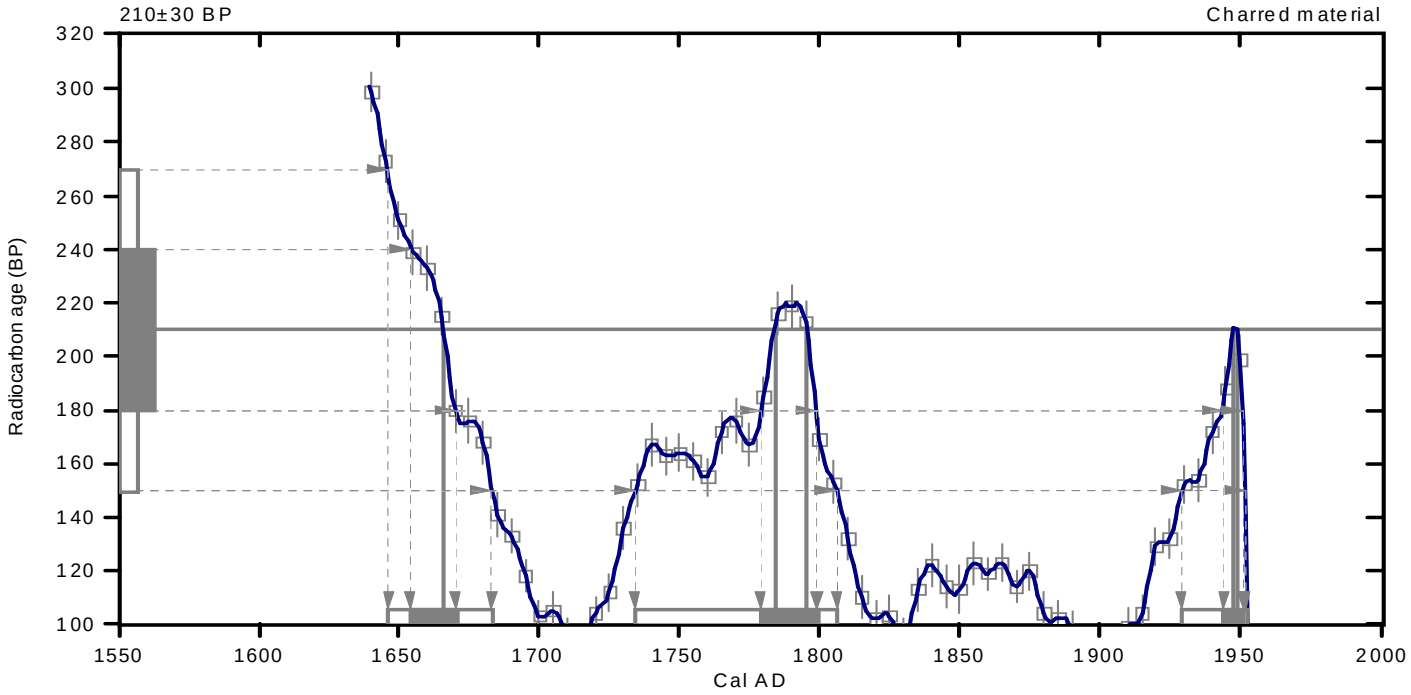
Conventional radiocarbon age: **210±30 BP**

2 Sigma calibrated results: **Cal AD 1650 to 1680 (Cal BP 300 to 270) and**
(95% probability) **Cal AD 1730 to 1810 (Cal BP 220 to 140) and**
Cal AD 1930 to post 1950 (Cal BP 20 to post 1950)

Intercept data

Intercepts of radiocarbon age with calibration curve: Cal AD 1670 (Cal BP 280) and
Cal AD 1780 (Cal BP 170) and
Cal AD 1800 (Cal BP 160) and
Cal AD 1950 (Cal BP 0) and
Cal AD 1950 (Cal BP 0)

1 Sigma calibrated results: Cal AD 1650 to 1670 (Cal BP 300 to 280) and
(68% probability) Cal AD 1780 to 1800 (Cal BP 170 to 150) and
Cal AD 1940 to post 1950 (Cal BP 10 to post 1950)



References:

Database used

INTCAL09

References to INTCAL09 database

Heaton,et.al.,2009, Radiocarbon 51(4):1151-1164, Reimer,et.al, 2009, Radiocarbon 51(4):1111-1150, Stuiver,et.al,1993, Radiocarbon 35(1):1-244, Oeschger,et.al.,1975,Tellus 27:168-192

Mathematics used for calibration scenario

A Simplified Approach to Calibrating C14 Dates
Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2):317-322

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-25.4:lab. mult=1)

Laboratory number: **Beta-350528**

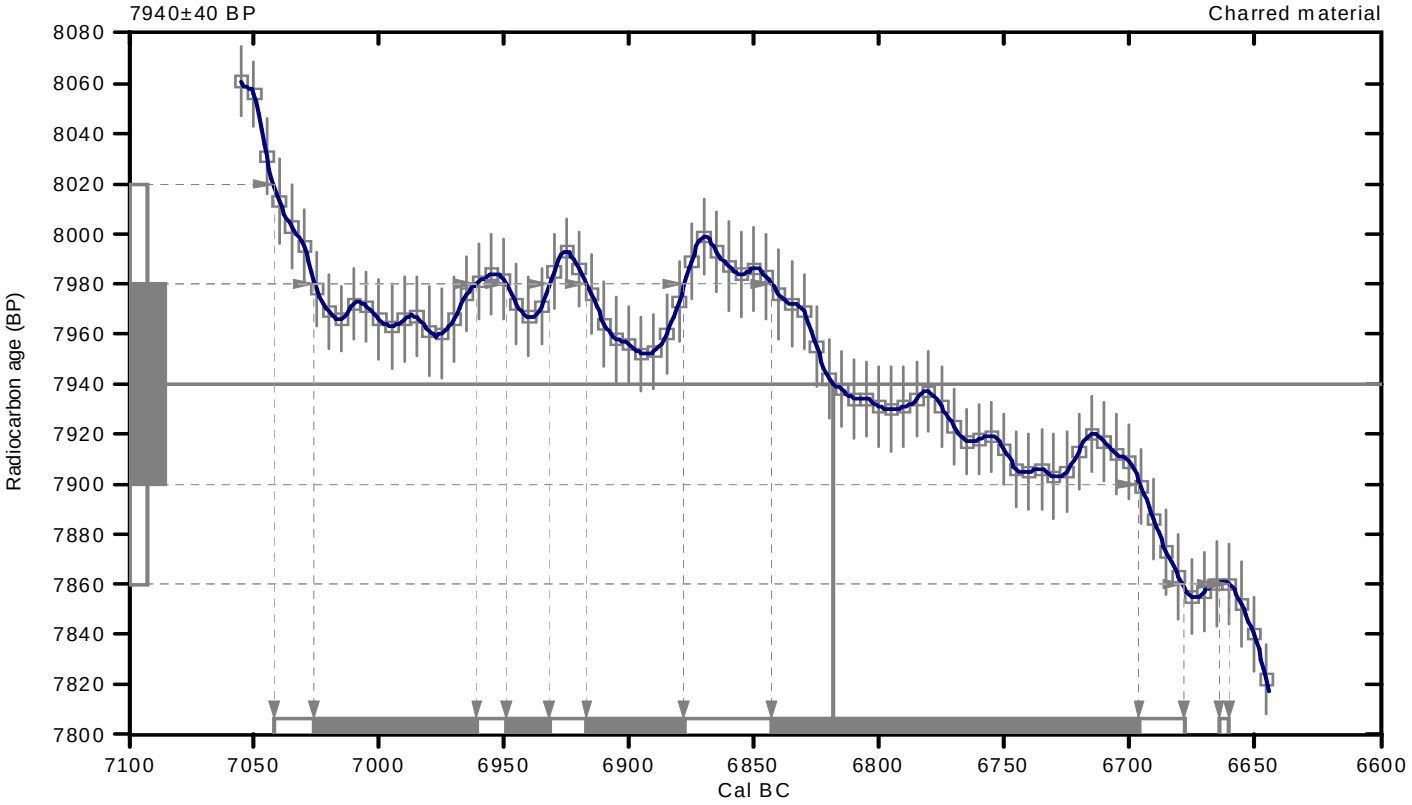
Conventional radiocarbon age: **7940±40 BP**

2 Sigma calibrated results: **Cal BC 7040 to 6680 (Cal BP 8990 to 8630) and**
(95% probability) **Cal BC 6660 to 6660 (Cal BP 8610 to 8610)**

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 6820 (Cal BP 8770)

1 Sigma calibrated results: Cal BC 7030 to 6960 (Cal BP 8980 to 8910) and
(68% probability) Cal BC 6950 to 6930 (Cal BP 8900 to 8880) and
Cal BC 6920 to 6880 (Cal BP 8870 to 8830) and
Cal BC 6840 to 6700 (Cal BP 8790 to 8650)



References:

Database used

INTCAL09

References to INTCAL09 database

Heaton,et.al.,2009, Radiocarbon 51(4):1151-1164, Reimer,et.al, 2009, Radiocarbon 51(4):1111-1150, Stuiver,et.al,1993, Radiocarbon 35(1):137-189, Oeschger,et.al.,1975,Tellus 27:168-192

Mathematics used for calibration scenario

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Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2):317-322

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電子郵件: florenceko@cedd.gov.hk

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

GEOTECHNICAL MANUALS

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

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

GEOSPECS

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

GEO PUBLICATIONS

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

GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents