

GEOTECHNICAL PROPERTIES OF COLLUVIAL AND ALLUVIAL DEPOSITS IN HONG KONG

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ABSTRACT

The Hong Kong colluvial and alluvial deposits have been divided into three classes which can be identified in the field by their colour, decomposition degree of cobbles and boulders, density of matrix, stratigraphic relationship and geological age. Each class of those soils was deposited under particular palaeoclimatic and palaeoenvironmental conditions during the Quaternary period. Recently, a number of geochronological dating results have been conducted by new technique. Consequentially, it might be more accurate and reliable to be classified into Middle Pleistocene, Late Pleistocene and Holocene respectively with each class exhibiting different geotechnical properties.

KEYWORDS

Colluvium, alluvium, dating, Middle Pleistocene, Late Pleistocene, Holocene.

INTRODUCTION

Colluvial deposits are accumulations of soil and rock debris transported by water-mobilised, gravitational processes. Colluvium is not one kind of soil, rather they are a group of soils relating to slopes. Their grain sizes vary from big boulder to clay. The alluvium consists of unconsolidated detrital rock material deposited in the bed of a stream, or on a floodplain or delta. The Hong Kong Geotechnical Engineering Office (GEO) has completed systematic mapping at a scale of 1:20,000 and has done much work related to the age dating of Quaternary superficial deposits. The dating techniques include radiocarbon dating (^{14}C), thermoluminescence (TL) optically stimulated luminescence (OSL), uranium series dating, surface exposure dating (^{10}Be , ^{26}Al and ^{36}Cl) as well as spore-pollen and foraminifera analysis. The testing results were published in GEO (2000), Sewell & Campbell (2005 & 2001) and Lai (1997 & 1998). Meanwhile Wang *et al* (1996) studied the laterite of South China in detail. These have provided the opportunity to recognize the characteristics and to re-assess the classification of Quaternary superficial deposits. Based on the geological age and in relation to their stratigraphy sequence and engineering properties, it is suggested that the colluvial and alluvial deposits of Hong Kong can be divided into three classes: Middle Pleistocene, Late Pleistocene and Holocene age.

PRINCIPLES OF CLASSIFICATION IN HONG KONG

The following characteristics of colluviums and alluvium might aid in their classification:

- Geological age, dating results, stratigraphic sequence, contact relationship;
- Weathering grade, weathering characteristics of soil matrix and coarse clast, thickness of patina;
- Colour, indicator of palaeoclimate;
- Grain size, percentage of soil matrix to cobbles and boulders; and
- Density, resistance to erosion, strength properties, permeability and piping.

QUATERNARY COLLUVIAL DEPOSITS

Middle Pleistocene Colluvial Deposits – Po Chu Tam Formation

The Po Chu Tam Formation crops out at foothills or in gentle mid slopes. Excellent exposures are present on the coast of Po Chu Tam, north of Tai O (Figs 1 & 2), in cut slopes along Clear Water Bay Road, south of Fei Ngo Shan, at So Uk Estate (Fig. 5), on the south flank of Tsim Shan (Eagle's Nest), Kowloon, at Mid-levels area, north of Hong Kong Island and on the west coast of south Sha Chau Island. The main soil type is stiff to very stiff, mottled colour with red, yellow and white streaks or veinlets, slightly clayey sandy silt with 30% to 70% highly to completely decomposed, subangular to subrounded cobbles and boulders. The big boulders of granite and volcanic rocks contain a thick weathered patina more than 100 mm, but the quartzitic sandstone may be less than that size. The thickness of the colluvial deposits varies from 2m to 8m with a maximum thickness of 16.5m on the southern flank of Victoria Peak. The OSL age ranges from $126,100 \pm 10,100$ to $196,100 \pm 12,000$ years BP (Table 1).

On the south coast of Po Chu Tam, the Middle Pleistocene colluvium occurs in the west foothill of Cheung Shan. The deposit is very stiff, mottled colour with brick red, yellow and white streaks, slightly clayey sandy silt with 70% subrounded gravel and cobbles of highly decomposed sandstone and tuff, some of them are moderately decomposed. Since the matrix contains ferric material, the colluvium has been observed to remain stable on steep slopes over considerable periods. The thickness of colluvium is ranging from 1m to 2m. The OSL age is $126,100 \pm 10,100$ years BP. It is overlain by the Late Pleistocene colluvium and underlain by the sandstone and siltstone of Jurassic Tai O Formation.

In the east end of High Street, on the south flank of Che Kei Shan (Victoria Peak), the drillhole H4 and trial pit TP4 revealed the Middle Pleistocene colluvium. The soil is stiff to very stiff, mottled brick red, yellow and white, clayey sandy silt with more than 30% subangular to subrounded highly to completely decomposed cobbles and boulders of tuff. The thickness of the colluvium is 3 m to 5 m. It is underlain by volcanic tuff. A dating sample was collected from the trial pit TP4 and the OSL age is $196,100 \pm 12,600$ years BP.

Another excellent outcrop is present on the west coast of south Sha Chau Island, 4km northwest of Chek Lap Kok (Fig. 3). The soil profile is developed from Middle Pleistocene to Holocene colluviums up to 10m thick. The colluvium of Middle Pleistocene is similar to those at Po Chu Tam. It is also very stiff mottled brick red, yellow and white, clayey sandy silt with a thickness of 3m, but the cobble and boulder content is more than 60%. The same class of colluvium also occurs in cuttings along Clear Water Bay Road. The soil comprises more cobbles and boulders up to 70% including a 4.5m diameter boulder of highly decomposed granite. The cuttings are 5m to 7m high with steep angle nearly 60° which has stood unsupported for more than 50 years prior to being cover with shotcrete.

The mottled colour of this colluvium in south Guangdong has been studied in detail by Wang *et al* (1996). The chemical composition of different colour is as follows:

Red streak	SiO ₂	45.23	Fe ₂ O ₃	8.91	Foe	0.74	Al ₂ O ₃	32.2
White streak	SiO ₂	46.95	Fe ₂ O ₃	3.58	FeO	0.31	Al ₂ O ₃	35.04.

The chemical composition of the red streak mainly contains hematite, Fe₂O₃, whilst the yellow streak is mainly limonite Fe₂O₃.nH₂O and the white streak is mainly kaolinite. Al₄[Si₄O₁₀](OH)₈. (Figure 5)

Late Pleistocene Colluvial Deposits – Shum Wan Formation

This deposit consists of firm to stiff, slightly clayey sandy silt with subangular to subround highly to completely decomposed gravel and cobbles. The large boulder exhibits a weathered patina up to 60mm thick. The matrix is reddish to orange brown, dark yellowish brown and slightly mottled. The thickness of this deposit varies from 2m to 10m and the maximum thickness is up to 36m, near the junction of Robinson Road and Castle Steps. This colluvium is widespread at Shum Wan and Aberdeen Country Park, Mid-levels area, north flank of Che Kei Shan, south slope of Fei Ngo Shan and at Lion Rock. The TL age of Shum Wan colluvium is 34,800±2,800 to 48,200±3,900 years BP. The OSL age of Shum Wat, north Lantau Island is 13,900±1,900 to 54,200±5,200 years BP. A sample containing carbonaceous material in borehole BGS 12 at Tin Shui Wai gave a ¹⁴C age of 26,000 to 27,000 years BP. Some large boulder outcrops with diameter greater than 3m in Fei Ngo Shan have been dated by surface exposure dating method with a ¹⁰Be age of 57,700 to 60, 400 years BP. A depositional break occurred between the Pleistocene and Holocene colluviums. The colour and density of both layers are quite different (Figure 11).

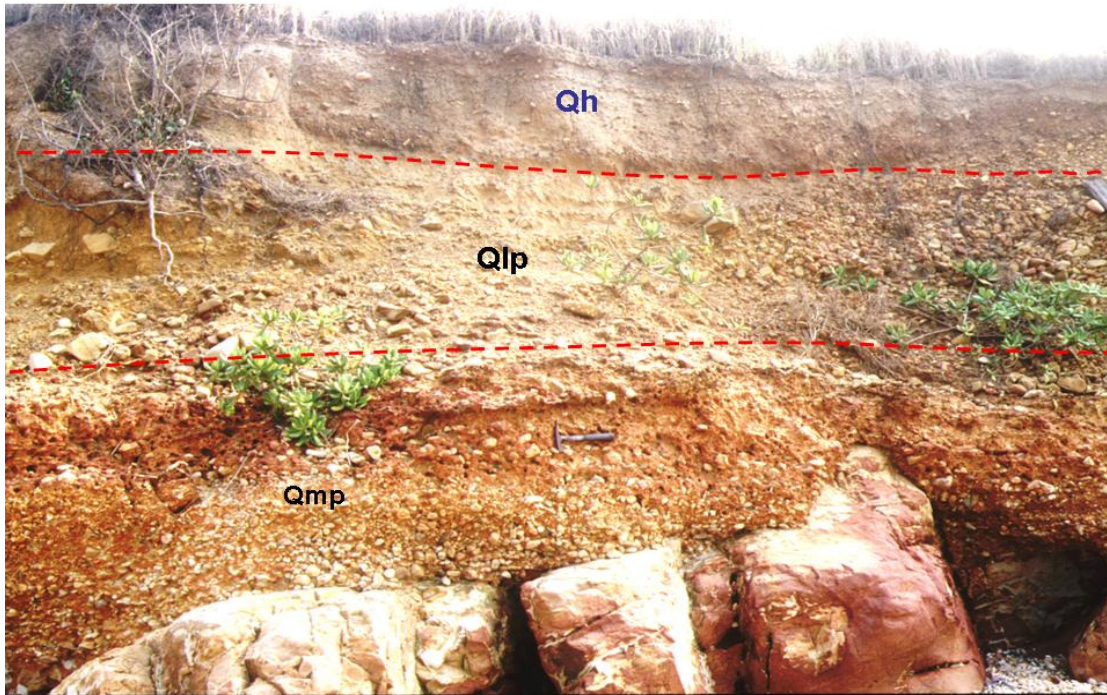


Figure 1 Middle Pleistocene to Holocene colluvium of Po Chu Tam, Tai O

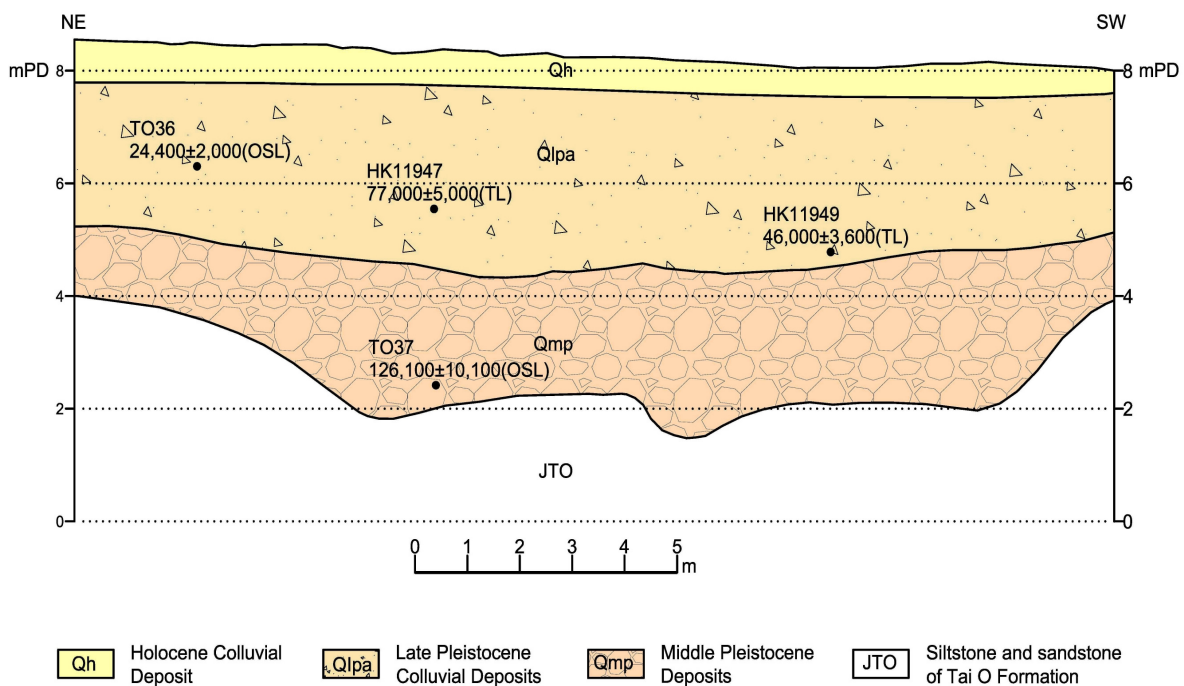


Figure 2 Geological section of Middle Pleistocene to Holocene colluvium of Po Chu Tam, Tai O

Holocene Colluvial Deposits

This deposit is soft to firm, light yellowish brown to yellowish grey clayey sandy silt to silty fine sand. The gravel and cobbles are angular to subangular, moderately to slightly decomposed with a percentage less than 30%. The weathered patina on large boulders is only a few mm thick. This colluvium generally has a thickness of 1m to 3m, but a maximum thickness up to 12 m has been identified. It is always formed by rock fall below steep slopes. The OSL age of this colluvium in the Tsing Shan area is $9,440 \pm 700$ years BP. This deposit can be observed on most hillslopes such as Yu Tung Road, Tung Chung. (Fig. 14). It overlies the Late Pleistocene colluvial and alluvial deposits

Disconformities in Colluvial deposits

Two disconformities expose in the colluvium between Middle /Late Pleistocene and Late Pleistocene/ Holocene deposits in Po Chu Tam and Sha Chau. The disconformity represents a depositional break during that time the lower layer was subjected to erosion and weathering. Borehole logs in the Tai O Bay and the offshore seabed reveal two layers of marine mud. They are deposits of Late Pleistocene Shum Wat Formation and Holocene Hang Hau Formation which were the products of deposition break (Figs 4, 11 & 12). The evidences of erosion are very clear on the disconformity. A thin layer of brick red iron pan represents the intensive erosion and weathering for a long period. The colour, composition, particle size, density and strength properties are quite different between the lower and upper colluvial layers.

QUATERNARY ALLUVIAL DEPOSITS

Middle Pleistocene Alluvial Deposits - Wong Kong Shan Formation

The Wong Kong Shan Formation occurs on the second fluvial terrace of Lam Tsuen River from Kam Tin to Fan Ling Plain at elevation between 80 mPD and 7.4 mPD. A typical section is at Wong Kong Shan (Figs 6, 7 and 9)

0.0m --4.6m	Late Pleistocene alluvial deposit
4.6m – 4.8m	Grey silty medium SAND with subrounded 30 mm to 170 mm gravel and cobble of fresh vein quartz and slightly to moderately decomposed tuff
4.8m—5.0m	Light grey silty medium to coarse SAND with gravel
5.0m—6.0m	Yellowish grey to grey silty medium SAND with subangular to subrounded gravel and cobbles of fresh vein quartz and slightly decomposed tuff with 20mm to 120 mm across. OSL age $157,500 \pm 36,300$ years BP
6.0m –7.0m	Dense silty sandy subangular to subrounded cobbles and boulders of moderately to completely decomposed tuff and fresh vein quartz
> 7.0m	Completely decomposed TUFF

The second fluvial terrace was formed from Middle Pleistocene to Late Pleistocene

Late Pleistocene Alluvial Deposits - Shan Ha Tsuen Formation

A typical section is located 600 m northwest of Yuen Long (Fig 8). A 10 m thick layer of this formation is exposed at the first fluvial terrace. It consist predominantly of yellowish brown gravelly silty fine to medium sand interbedded with dark to black organic-rich silty mud.

- 0 0m - 0.4 m Holocene slope deposit
- 0.4m - 8.6 m Dark yellowish to yellowish brown with pale red and yellow mottling, clayey silty gravelly SAND interbedded with five layers from 0.2m to 0.8m thick dark grey to black organic MUD
- 8.6m -10.4m Yellowish to orange brown silty SAND interbedded with yellowish brown silty gravelly sand
- >10.4m Middle Pleistocene dark yellowish brown, clayey silty SAND.

Pollen analyses of five layers of organic mud revealed a sporo-pollen assemblage including *Alnus*, *Quercus Cyclobalanopsis*, *Artemisia*, and *Pinus* indicating Late Pleistocene age (Li and Lai 1998). Radiocarbon dating of organic mud gave ages from $16,289 \pm 831$ to $32,500 \pm 490$ years BP. TL dating of silty sand layer gave ages from $23,800 \pm 2,000$ to $79,000 \pm 6,300$ years BP and OSL ages from $30,400 \pm 8,000$ to $81,000 \pm 13,500$ years BP.

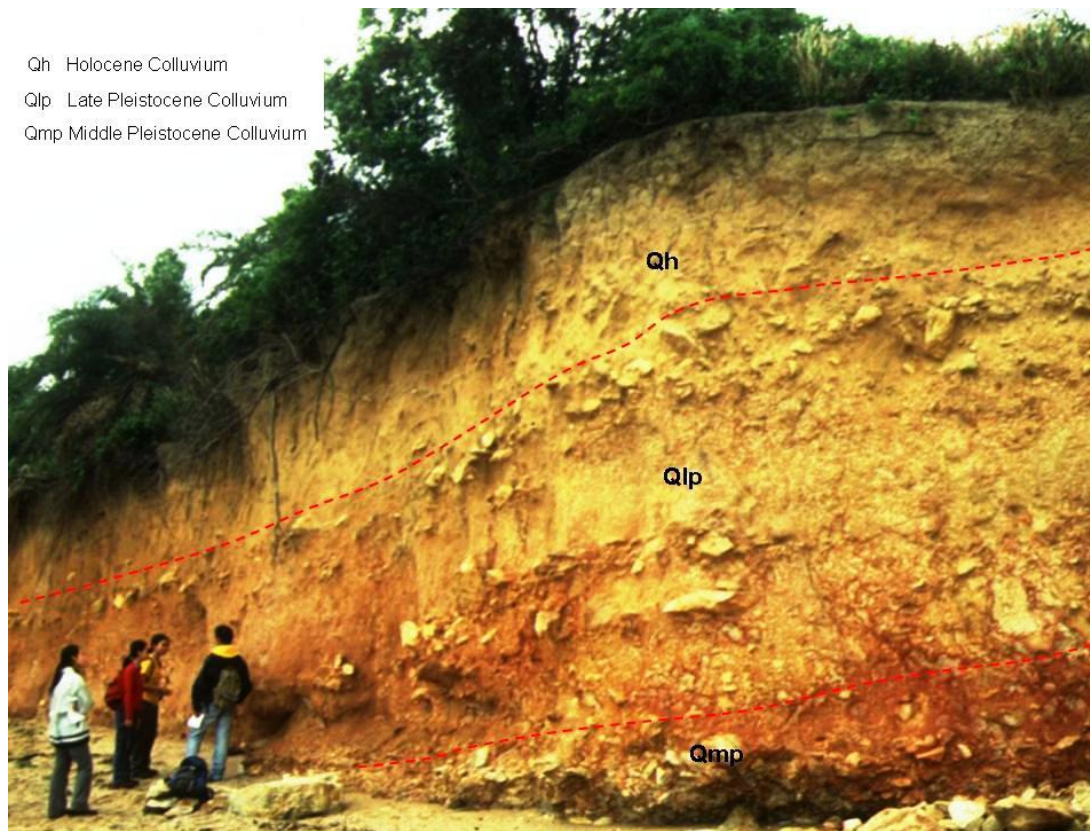


Figure 3 Middle Pleistocene to Holocene colluvium of Sha Chau Island

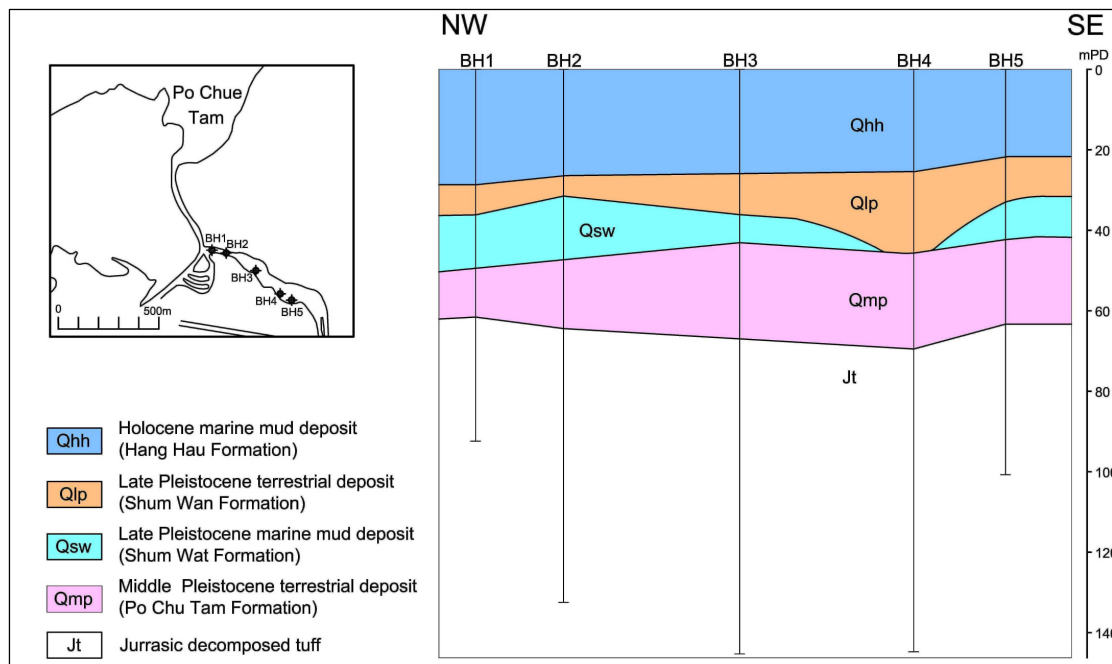


Figure 4 The relation between terrestrial and marine deposits in offshore area of Tai O, Depositional breaks expose on the top of terrestrial deposits

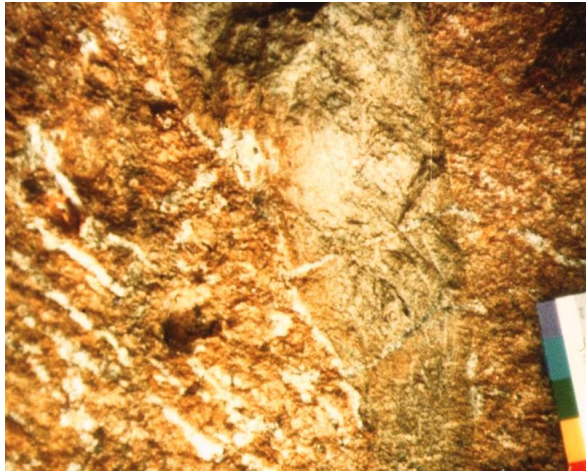


Figure 5 Mottled colour of Middle Pleistocene colluvium, So Uk Estate



Figure 6 Second river terrace alluvial deposits at Wai Tau Tsuen, Tai Po

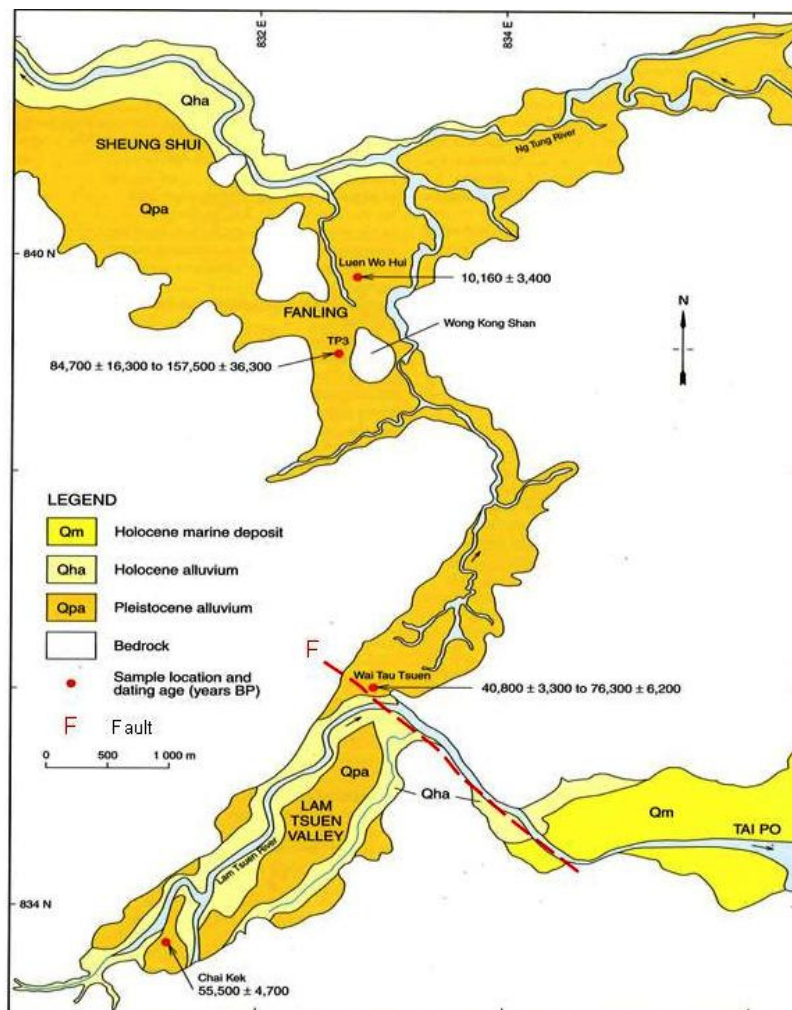


Figure 7 Quaternary geology of the Lam Tsuen Valley area. The river capture formed by a fault between Middle and Late Pleistocene age

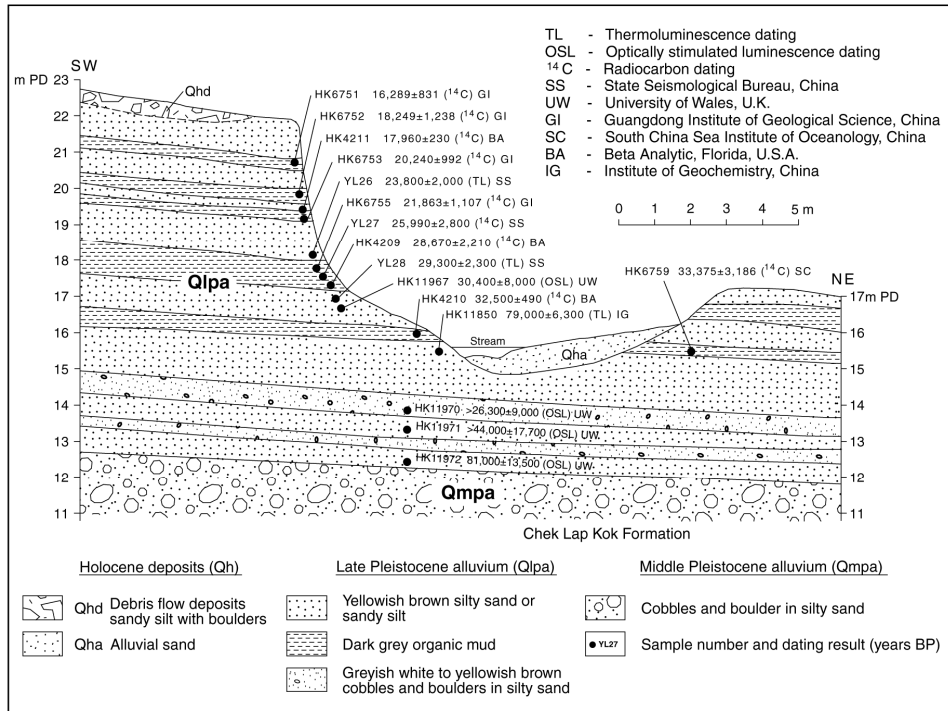


Figure 8 First river terrace alluvium of Late Pleistocene at Shan Ha Tsuen, Yuen Long

Holocene Alluvial Deposits – Fan Ling Formation

Holocene alluvium occurs mainly along narrow stream course which have been incised into the Pleistocene fluvial terraces. The depth of incision varies from 0.5m to 21m. The Fan Ling Formation (Fig.10) comprises pale yellowish brown clayey silty sand with thin layer of organic mud . The ¹⁴C ages range from 520±112 to 6.700±700 years BP.

GEOTECHNICAL PROPERTIES OF COLLUVIAL AND ALLUVIAL DEPOSITS

After comparing the properties of colluvium and alluvium in different classes the following trends become apparent. The colour of the soil matrix becomes paler, from brick red and brown to pale yellowish brown, and mottling becomes less common. The consistency decreases from very stiff to soft while the dry density also decreases at a similar trend. Table 2 shows the test results of in-situ density of granitic colluviums. The average dry density of the Middle Pleistocene, Late Pleistocene and Holocene granite colluviums is found to be 1.75, 1.61 and 1.32 t/m³ respectively (Table 2), indicating that, in general the greater the age, the higher the density. The soil of Middle Pleistocene is most resistant to erosion, the Late Pleistocene soil tends to have moderate erosion, whilst the Holocene soil is most susceptible to extensive erosion. It appears that the shear strength of those soils increases correspondingly with age.

The mottled red colour is considered to be due to extensive oxidation during a long period of weathering under a hotter and wetter climate than at present. Zhang *et al* (1976) suggested that in South China the mean temperature may have been as much as about 5.5°C above that of the present.

Geotechnical Engineering Office (1993) carried out a study and laboratory test on the effect of the coarse fractions on the shear strength of colluvium which proved that shear strength increased with increasing coarse fraction content. No practical increase in the shear strength occurs up to a coarse fraction content of about 20%, only a small increase in the shear strength between about 20% and 30% coarse fraction content but it starts to increase sharply beyond about 30% coarse fraction content. The colluvium always contains a considerable number of boulder and cobble, it is very important to observe and quantify the coarse fraction in field.

CONCLUSIONS

Table 1 Age Data of Hong Kong Colluvial and Alluvial Deposits

No	Sample	Lab no.	Location	Depth (m)	Feature	Test Method	Age (ka)
1	TO36	SS242	Po Chu Tam	1.	Foot hill	TL	24.4 ± 2
2	HK11949	IG13	Po Chu Tam	3	Foot hill	TL	46.0 ± 3
3	HK11947	IG11	Po Chu Tam	2	Foot hill	TL	77.0 ± 5
4	TO37	SS243	Po Chu Tam	4	Foot hill	TL	126.1 ± 10
5	HK11944	IG8	Fui Yue Ha	3	Channelized	TL	45.0 ± 3.8
6	HK11986	UW11	Fui Yue Ha	3.76	debris flow	OSL	107.4 ± 10.7
7	HK 11850	IG4	Shan Ha Tsuen	7.3	Ist Fluvial Terrace	TL	79,000±6,300
8	HK11972	UW4	Shan Ha Tsuen	10.4	Ist Fluvial Terrace	OSL	81,000±13,500
9	HK11978	UW6	Wong Kong Shan	4.3	1 st Fluvial Terrace	OSL	84,700±16,300
10	HK11980	UW8	Wong Kong Shan	5.5	2 nd fluvial Terrace	OSL	157,500±14,000
11	HK11981	UW9	Mid Levels	3.05	Mid slope	OSL	196.1 ± 12
12	SW1	SS01	Shum Wan	0.5	Open hillslope	TL	34.8 ± 2.8
13	SW2	SS02	Shum Wan	1	Open hillslope	TL	48.2 ± 3.9
14	HK12473	WLL250	Shum Wat	0.1	Main lobe	OSL	6.2 ± 0.69
15	HK12471	WLL269	Shum Wat	0.7	Main lobe	OSL	13.9 ± 1.9
16	HK17960	WLL156	Shum Wat	8	Main lobe	OSL	54.2 ± 5.2
17	HK12388	WLL228	Tsing Shan	3.1	Main lobe	OSL	9.44 ± 0.7
18	HK12377	WLL222	Tsing Shan	0.5	Main lobe	OSL	9.8 ± 1
19	HK12386	WLL226	Tsing Shan	2.4	Main lobe	OSL	62 ± 7.7
20	HK12385	WLL225	Tsing Shan	1.7	Main lobe	OSL	63.3 ± 8.7
21	HK12354	FNS-03	Fei Ngo Shan	0	Rock Fall	Cosmogenic ¹⁰ Be	54.7 ± 4.8
22	HK12351	LR03	Lion Rock	0	Rock Fall	Cosmogenic ¹⁰ Be	2.3 ± 0.4
23	Hk12349	LR01	Lion Rock	0	Rock Fall	Cosmogenic ¹⁰ Be	3.7 ± 0.4

Table 2 Test results of in-situ density of granite colluvium

classification of colluvium	Location	No. of samples	Depth m	Dry density t/m ³	Bulk density t/m ³	Test type	Moisture content %
Holocene	Kau Wa Keng	4	1.0--2.0	1.38	1.55	W	12.08
	Shek Lei	6	1.0--2.5	1.26	1.52	W	20.32
Late Pleistocene	Ho Man Tin	2	1.5--2.0	1.60	1.83	V	14.60
	Li Cheng Uk	3	1.5--2.5	1.61	1.89	W	18.28
	Mt. Butler Road	6	2.4--6.5	1.58	--	W	-
	Shun Lee Estate	6	1.0--5.5	1.66	--	W	--
Middle Pleistocene	Wang Tau Hum	3	1.2--2.2	1.63	--	W	--
		7	6.4--14.4	1.72	--	W	--
	Tai Wo Ping	3	3.0--3.9	1.60	-	W	--
		12	3.0--10.1	1.84	-	W	--
	So Uk Estate	2	2.2--2.5	1.81	2.12	W	17.05
		2	0.3--1.2	1.89	-	W	---

Notes : W- Washington densometer V-Volumeter



Figure 9 Yellowish orange with pale grey silty fine sand of second river terrace alluvium, Wong Kong Shan



Figure 10 Holocene alluvial deposit in the river bed of Fan Ling

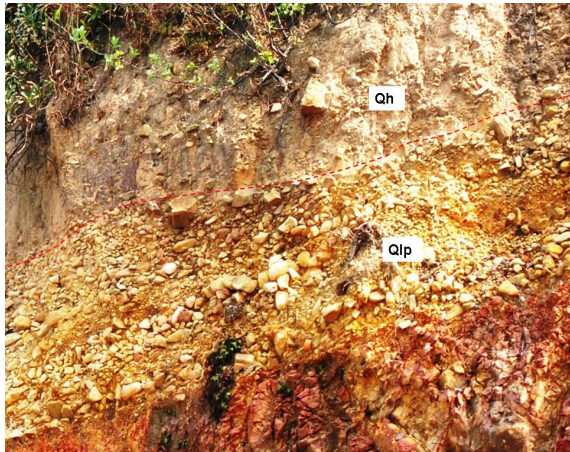


Figure 11 Holocene colluvium (Qh) overlying on the Late Pleistocene (Qlp) colluvium



Figure 12 Marine deposit overlying on the Late Pleistocene alluvium, NW of Yuen Long



Figure 13 Late Pleistocene colluvial deposit of Sham Wan



Figure 14 Holocene colluvium at Yu Tung Road, Tung Chung

Based on the geological mapping result of Hong Kong Geological Survey, Hong Kong geologists have done much work to study the age dating of Quaternary superficial deposits. The colluvial and alluvial deposits have been divided into Middle Pleistocene, Late Pleistocene and Holocene age. The result is more accurate and reliable which is useful to recognize their geotechnical properties.

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