土木工程拓展署
土力工程處
Geotechnical Engineering Office
Civil Engineering and
Development Department

地質與地景導論
INTRODUCTION TO GEOLOGY AND LANDSCAPE

地質與地景 1
GEOLOGY AND LANDSCAPE

前言

教育局於2005年公布，三年新高中學制將於2009年9月在中四級實施。地理科是其中一個重點的選修科目。

新高中地理科課程是根據2005年教育局出版的一份文件和課程發展議會《高中課程指引》(2007)的建議而制訂。在此課程中，地理被視為一門學科讓學生可以從空間的角度了解自身所處的地球。

土木工程拓展署轄下的土力工程處應教育局的請求，在天然災害及地球科學兩個新高中地理科課程內容上製備了一份「教學支援教材套」。其中有關香港岩石及礦物的資料亦適用於部份化學科的課程。

「教學支援教材套」包括了14本小書冊、4張海報、3片光碟及其他一些補充資料。此教材套在香港的斜坡安全、山泥傾瀉、地質及地貌等課題上提供了合適及最新的資料並同時符合新高中地理科課程的水平。

土力工程處的「香港地質調查組」負責編寫有關香港地質及地貌方面的內容，而「斜坡安全部」則負責香港斜坡安全及山泥傾瀉的部份，「斜坡安全部」的同事亦負責整個項目的策劃與安排。我謹向各位參與這項工作的同事致謝。

我相信這教材套對各位負責新高中地理科目的老師在擬備教材時能提供合適的參考。此教材套亦給予有興趣於這些課題的廣大讀者一些有用的資料。

陳健碩

陳健碩
土木工程拓展署
土力工程處處長
2008年12月

Foreword

In 2005, the Education Bureau (EDB) announced that a three-year New Senior Secondary (NSS) curriculum would be implemented at Secondary 4 in September 2009. Geography is one of the elective subjects under the NSS curriculum.

The NSS curriculum has been developed on the basis of the recommendations made by an EDB document in 2005 and a Senior Secondary Curriculum Guide of 2007. Within the curriculum, geography is seen as a key educational discipline that provides students with a spatial understanding of the Earth on which we live and work.

At the request of the EDB, the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department have prepared support teaching materials for the NSS Geography curriculum under the topics of Natural Hazards and Earth Science. The materials written on rocks, minerals and ores in Hong Kong are also suitable for part of the Chemistry curriculum.

The "Teaching Support Materials Kit" consists of 14 booklets, 4 posters, 3 CDs and other supplementary information sheets. This teaching kit contains pertinent and up-to-date information on slope safety, landslides, geology and geomorphology in Hong Kong, written at a level that is suitable for the NSS Geography curriculum.

Hong Kong Geological Survey of GEO have compiled the teaching materials that describe the geology and geomorphology of Hong Kong. The Slope Safety Division of GEO have prepared the teaching materials on Hong Kong slope safety and landslides. Colleagues in the Slope Safety Division are also responsible for the overall planning and coordination of this project. Their contributions are gratefully acknowledged.

I am confident that, for years to come, secondary school geography teachers will find the kit invaluable for preparing their classroom teaching materials. The contents will also be of interest to the more general readers who may wish to learn more about these topics.

Raymond K S Chan
Head, Geotechnical Engineering Office
Civil Engineering and Development Department
December 2008

引言
Introduction

我們的地球是一個由大氣圈、水文圈、生物圈及岩石圈四個主要部份組成的動力體系。這四個部份在漫長的地球歷史中，持續互相影響。地質學為一門研究岩石圈的科學，並且包含岩石圈與其他三個部份相互作用的研究。

地形學是指對地貌的性質及成因的研究，特別是在大氣圈及水文圈中的風化及侵蝕過程。這些過程不斷改變地球表面形狀**(地質與地景之一)**，並且產生岩石循環中的沉積物。地形是岩石圈、大氣圈及水文圈互動產生的結果**(地質與地景之二)**。香港的天然地景是基於地質及地貌作用而形成，並多見於香港的郊野公園**(地質與地景之三)**。人為活動例如填海及築建水塘等，都改變了天然的地貌。

Our Earth is a dynamic system that comprises four main components: the atmosphere, the hydrosphere, the biosphere and the geosphere. These four components have been continuously interacting throughout the Earth's long history. Geology is the science that studies the geosphere, and encompasses the interactions between the geosphere and the other three components.

Geomorphology is the study of the nature and origin of landforms, particularly of the formative processes of weathering and erosion that occur in the atmosphere and hydrosphere. These processes continually shape the Earth's surface **(Geology and Landscape 1)**, and generate the sediments in the Rock Cycle. Landforms are the result of the interactions among the geosphere, atmosphere and hydrosphere **(Geology and Landscape 2)**. The natural landscapes of Hong Kong, displayed in many of the Country Parks, are determined by the underlying geology and geomorphological processes **(Geology and Landscape 3)**. Human activities, such as reclamation and the construction of reservoirs, have considerably modified the original landscapes.

內容
Contents

前言 Foreword i-ii

引言 Introduction 2

風化與侵蝕 Weathering and Erosion 4-13

- 風化作用 Weathering Processes 4-5
- 控制風化 Weathering Controls 4-7
- 風化的產物 Weathering Products 8-9
- 侵蝕作用 Erosion Processes 10-11
- 控制侵蝕 Erosion Controls 10-12
- 侵蝕的產物 Erosion Products 12-13

何謂山崩？ What are Landslides? 12-15

- 天然斜坡 Natural Slopes 12-15
- 人造斜坡 Man-made Slopes 14-15

風化與侵蝕

風化作用是指岩石礦物及岩體暴露在大氣圈下的蝕變及分解作用。

風化作用發生於*原地*，意即同一地點，並沒有涉及主要的岩石物質遷移。

侵蝕是指把風化後的岩石物質移離(搬運)，由上而下，遠離其風化形成的地方。

侵蝕作用主要由重力推動，並由流動媒體輔助，例如水(例如河流)和冰(例如冰川)，又或是單單由重力推動(例如落石)，風也可以移走風化物質(例如風蝕)。

風化作用

風化是一項全球性的基本作用。

風化作用將岩石從堅硬的狀態變為較軟及較脆弱，令它們更容易受到侵蝕。例如它們更可能形成山泥傾瀉。

風化作用主要有兩大類別，而第三類別則為次要：

- **物理風化**：指岩石經過機械性干擾(例如粒狀崩解、鱗剝作用、節理岩塊拆解，或因溫度及壓力改變而成的碎裂)而產生的風化作用，例子有冰楔及礦物體積的改變。
- **化學風化**：指岩石中的礦物受水、氣溫、氧氣、氫氣及弱酸的作用(例如溶解、水合、氧化及碳酸化)，而導致的分解。
- **生物風化**：指由於植物的出現，或較小程度上動物的介入，而造成或協助的風化作用，當中包括樹根造成的楔劈及動植物產生的有機酸。

在任何特定地點發生的風化作用，其類別主要取決於氣候：

- **物理風化**：機械性作用，多出現於較寒冷及乾燥的氣候。
- **化學風化**：礦物分解作用，多出現於較溫暖及潮濕的氣候。
- **生物風化**：植物及動物普遍傾向出現於溫暖及潮濕的氣候。

控制風化

風化的類別、速度與牽涉程度受多個控制因素影響：

- **氣候**：主導風化作用的類別，大都根據風化作用時所存在的水量及氣溫來決定(化學反應在溫度較高的環境，有較快的反應，冰楔作用則發生於較寒冷的氣候)。
- **岩石種類**：決定岩石在特定環境中對抗風化的能力。

Weathering and Erosion

Weathering is the alteration and breakdown of rock minerals and rock masses when they are exposed to the atmosphere.

Weathering processes occur *in situ*, that is in the same place, with no major movement of rock materials involved.

Erosion is the removal (transport) of weathered rock materials downslope, and away, from their original site of weathering.

Erosion processes are driven primarily by the force of gravity, which may be aided by a flowing medium such as water (*e.g.* rivers), and ice (*e.g.* glaciers), or gravity may act alone (*e.g.* rockfalls). Wind can also remove weathered materials (*e.g.* deflation).

Weathering Processes

Weathering is a fundamental Earth process.

Weathering changes rocks from a hard state, to become much softer and weaker, making them more easily eroded. For example, they become more susceptible to landsliding.

Two main groups of weathering processes are identified, with a third supporting group:

- **Physical weathering:** the group of processes, such as frost wedging and volume changes of minerals, that result in the mechanical disruption of rocks (*e.g.* granular disintegration, exfoliation, joint block separation, shattering by changes in temperature or pressure).
- **Chemical weathering:** the decay of rock forming minerals caused by water, temperature, oxygen, hydrogen and mild acids (*e.g.* solution, hydration, oxidation, carbonation).
- **Biological weathering:** the group of processes that are caused by, or assisted by, the presence of vegetation, or to a lesser extent animals, including root wedging and the production of organic acids.

The type of weathering processes that occur at any particular location depend predominantly upon the climate:

- **Physical weathering:** mechanical processes dominate in colder and drier climates.
- **Chemical weathering:** processes of mineral decay dominate in warmer and wetter climates.
- **Biological weathering:** vegetation, and animals, tend to be more active in warmer and wetter climates.

Weathering Controls

The type, rate and extent of weathering depends upon several controlling factors:

- **Climate:** dictates the type of weathering processes that operate, largely by determining the amount of water available and the temperature at which the processes occur (chemical reactions are faster at higher temperatures, frost wedging occurs in colder climates).
- **Rock Type:** determines the resistance of the rock to the weathering processes that operate in that particular environment.

- **岩石構造：**有強烈節理或斷裂的岩石呈現多個軟弱面，容許風化媒介(例如水)滲入岩體內(圖1及2)。

圖1. 花崗岩中的垂直節理受風化而變寬。
Figure 1. Vertical joints in granite widened by weathering.

- **地形：**斜坡的傾斜角度控制水流途經岩體的速度，決定風化作用的力量。一般來說，位於較高或構造運動活躍地區的陡峭斜坡，風化作用較為活躍，而平原的風化作用則較緩慢。

- **侵蝕：**侵蝕作用的動力及效率控制風化物質被移離的速度、未風化岩石露出受風化的頻度、以及風化層能否得以保存。

- **時間：**同類型的風化作用維持的時段，期間風化作用未被氣候轉變、地質運動及其他因素干擾，決定岩石受風化影響的程度及深度。

每類岩石各自由一套獨特的礦物組成，礦物透過結晶，化學結合及膠結物連結起來。

三大主要岩石種類(火成岩、沉積岩及變質岩)根據不同的形成環境分類，舉例如下：

- **火成岩：**源自岩漿，在地球深處(例如花崗岩)、或流出在地球表面(例如玄武岩熔岩)、或自猛烈的火山爆發(例如凝灰岩)而形成。

- **沉積岩：**源自岩石物質受風化及搬運後積聚而成，於海底深處(例如頁岩)、亞熱帶淺水瀉湖(例如石灰岩)、湖底(例如泥岩)、河川(例如砂岩)或懸崖之下(例如角礫岩)等環境形成。

- **變質岩：**當其他岩石受斷層或褶皺影響，期間產生的熱力或壓力而形成(例如片岩及片麻岩)。

當地殼板塊營力將這些岩石移離其形成的環境，並暴露於太陽及雨水中，風化作用便於此時開始。

- **Rock Structure:** highly jointed or faulted rocks present many planes of weakness along which weathering agents (*e.g.* water) can penetrate into the rock mass (Figures 1 & 2).

- **Topography:** the slope angle determines the energy of the weathering system by controlling the rate at which water passes through the rock mass. Generally, higher, tectonically active areas with steeper slopes have more dynamic weathering systems, whereas flat plains have slower weathering systems.

- **Erosion:** the dynamism and efficiency of erosion determines how rapidly any weathered material is removed, how frequently fresh rock is exposed to weathering, and if deeply weathered profiles are preserved.

- **Time:** the duration of the period that the same type of weathering has been operating, uninterrupted by climatic change, earth movements, and other factors, determines the degree and depth to which the rocks have been weathered.

Each rock type is composed of a particular set of minerals, which are joined together by crystallisation, chemical bonding or cementing.

Three major rock groups (igneous, sedimentary and metamorphic) are recognised, which are further classified depending upon the different environments in which they formed, for example:

- **Igneous Rocks:** formed from molten magma deep below the surface of the earth (*e.g.* granite), from molten magma poured out at the surface of the earth (*e.g.* basalt lava), from violent volcanic explosions (*e.g.* fine ash tuff), *etc*.

- **Sedimentary Rocks:** formed by the deposition of weathered and transported rock materials deep under the sea (*e.g.* shales), in shallow tropical lagoons (*e.g.* limestones), on lake beds (*e.g.* mudstones), in large rivers (*e.g.* sandstones), below cliff faces (*e.g.* breccias), *etc*.

- **Metamorphic Rocks:** formed by the heat and pressure generated during the faulting and folding of other rocks (*e.g.* schists and gneisses).

When the forces of plate tectonics move these rocks from the environment in which they formed and expose them to the atmosphere they begin to weather.

圖2. 風化作用使凝灰岩的節理更為明顯。
Figure 2. Weathering of tuff highlighting the joint pattern.

風化的產物

風化作用逐漸使岩石變弱，最終形成於新環境更穩定的地質物質(岩石碎塊、沙粒、粉砂及黏土)。

一般來說，風化作用產生較幼細及疏鬆的岩石物質，以及較弱和多孔滲水的岩體。

在熱帶及亞熱帶地區，由於受炎熱及潮濕氣候影響，劇烈的風化作用形成厚厚的風化層，其厚度可達100米或以上。

風化作用滲透至岩體的不連續面(軟弱面)，例如岩石的斷層及節理，並攻擊岩石面，滲入岩體(圖3)。

圖3. 火山岩受到不均勻的風化，突顯其節理及成份。
Figure 3. Differential weathering of a volcanic rock, emphasising the joint pattern and components.

風化作用傾向侵襲岩石節理的角位及邊緣，使岩石變得渾圓。這風化作用受助於壓力釋放，岩石形成彎曲的片狀碎塊並且剝落，稱為鱗剝作用(圖4)。

圖4. 風化石英二長岩中，渾圓的岩石核有彎曲的鱗剝外殼。
Figure 4. Rounded corestones with curved exfoliation shells in a weathered quartz monzonite.

某些岩石(例如花崗岩及粗粒凝灰岩)經過風化後，會形成厚厚的風化層，其特色是在含有粉砂、黏土及沙粒物質結集成的弱風化土中，出現圓形的巨礫(岩石核)。這含有岩石核的風化層是香港島及九龍市區多個削坡的顯著特徵(圖5)。

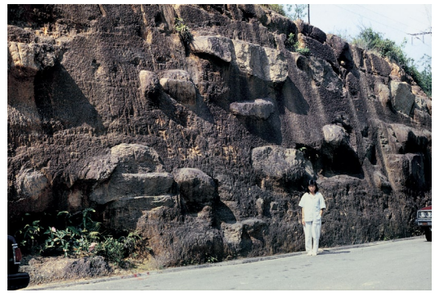

圖5. 中粒花崗岩的風化層中，板長狀的岩石核。
Figure 5. Tabular corestones in a weathered profile in medium-grained granite.

風化的下限界線可能呈不規則及分散，但在多個個案中，風化的下限均終止於一個鮮明的水平界線上(圖6)。地形學家稱這界線為風化基面，而工程師則稱之為基岩(圖7)。

Weathering Products

Weathering gradually weakens rocks, and eventually produces new geological materials (rock fragments, sands, silts and clays) that are more stable in the new environment.

Weathering generally produces finer and less dense rock materials, and weaker, more porous and permeable rock masses.

In the tropics and subtropics, intense weathering in the hot and humid conditions produces thick weathered profiles, which may be up to 100 metres, or more, thick.

Weathering processes penetrate down discontinuities (planes of weakness), such as faults and joints, in the rock mass and then attack the faces of the joint-bounded blocks, penetrating the solid blocks (Figure 3).

Weathering preferentially attacks the corners and edges of the joint blocks, causing them to become rounded. This action is assisted by stress release, which causes the rock to flake into curved shells in a process termed exfoliation (Figure 4).

Weathering of some rock types, such as the granitic rocks and the coarse ash tuffs, results in the development of thick weathered profiles that are characterised by rounded boulders (corestones) set in a matrix of weak, silty, clayey, sandy material. These corestone-bearing profiles are a distinctive feature of many cut-slopes in the urban areas of Hong Kong Island and Kowloon (Figure 5).

The downward limit of weathering may be irregular and diffuse, but in many cases terminates abruptly at a well-defined horizon (Figure 6). This boundary is termed the weathering front by geomorphologists, or rockhead by engineers (Figure 7).

圖6. 火山岩中截然而呈平面的風化基面。
Figure 6. An abrupt, planar weathering front in volcanic rock.

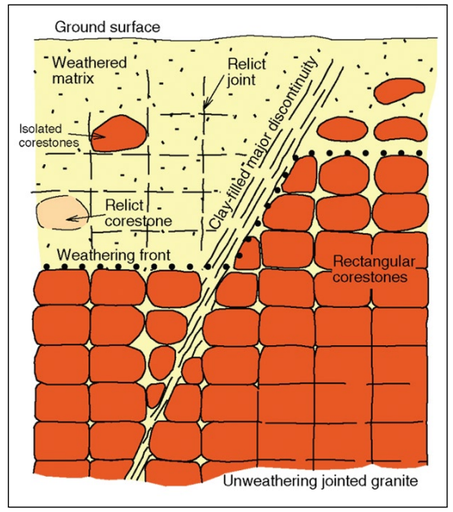

圖7. 典型具有岩石核的花崗岩類的風化層。
Figure 7. The components of a typical corestone-bearing weathered profile in granitic rocks.

侵蝕作用

在運送過程中，流動的角形的粒子會磨滑(磨擦或沖涮)經過的表面，並磨蝕岩石。

因此，山崩的碎石可能會侵蝕沿途的斜坡或河道，河流的沉積物會侵蝕河床的岩石部分，而冰川中的岩石碎塊會侵蝕山谷底部。

侵蝕作用通常分為下列四大類別：

- **塊體崩移：**指受重力影響在山坡發生的侵蝕作用，水可能有部份的影響，但並非主要的運輸媒介。塊體崩移或山崩(見下文)的侵蝕作用在香港非常重要(圖8)。

圖8. 沿溝泥石流只於陡斜而狹窄的季節性河流出現。
Figure 8. Channelised debris flows confined to steep and narrow seasonal stream channels.

- **河流：**指涉及水流的侵蝕作用，可發生在土壤中(例如泥土管涌)，地面(例如細溝及沖溝(圖9))，或於季節性或常流河道。河流作用在香港非常重要。

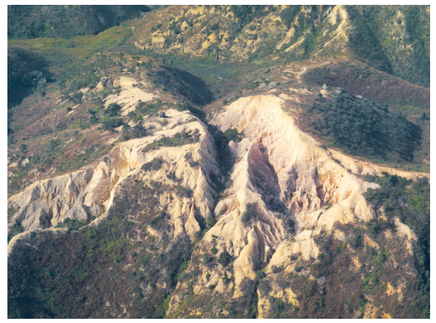

圖9. 深的蝕溝切割着受深度風化的花崗岩的山脊。
Figure 9. Deep erosion gullies dissecting narrow ridges in deeply weathered granite.

- **風力：**指涉及氣流於乾燥地方迅速移動的侵蝕作用，地點可以是寒冷或炎熱的沙漠。風力侵蝕在香港影響不大。

- **冰川：**指涉及冰的侵蝕作用，冰或是存在於泥土中(例如土石緩滑)，或作為搬運媒體(例如冰川)。冰川作用並沒有直接影響香港。

控制侵蝕

侵蝕的類別及程度決定於多個因素，包括：

- **氣候：**氣候基本上控制地區內的侵蝕類別及速度，因為氣候決定水量(雨量)及其季節性分佈、溫度(熱帶、寒帶及兩極)，以及日照時數、風力及風向等。

- **地形：**高山地區的地勢較高，潛在力量較低地為高。結合陡峭的斜坡，高地侵蝕作用的動力較周邊平原大。

Erosion Processes

During transportation of the weathered rock materials, the angular particles commonly abrade (rub or scour) the surfaces over which they pass, wearing away and lowering the rocks.

Thus, landslide debris may erode the slope or channel along its course, the sediments in rivers erode the rocky sections of their beds, and the rock fragments in glaciers erode the valley floor.

Erosion processes are usually considered under four distinct categories:

- **Mass Wasting:** the processes that occur on slopes, under the influence of gravity, in which water may play a part, although water is not the main transporting medium. Mass wasting, or landsliding (see below), processes are very important in Hong Kong (Figure 8).

- **Fluvial:** the processes that involve flowing water, which can occur within the soil mass (*e.g.* soil piping), over the land surface (*e.g.* rills and gullies (Figure 9)), or in seasonal or permanent channels (*e.g.* seasonal streams and rivers). Fluvial processes are very important in Hong Kong.

- **Wind:** the processes that involve the action of rapidly moving air streams in dry areas, which can be cold or hot deserts. The erosional effects of wind play only a small role in Hong Kong.

- **Glacial:** the processes that involve the presence of ice, either in the soil (*e.g.* solifluction), or as the transporting medium (*e.g.* glaciers). Glacial processes do not directly affect Hong Kong.

Erosion Controls

The type and magnitude of erosion depends upon several factors including:

- **Climate:** exerts a fundamental control on the types and rates of erosion in an area, because climate determines the amount and seasonal distribution of water (rainfall), the temperature (tropical, temperate or polar), and factors such as the sunshine hours, the wind strengths, and wind patterns.

- **Topography:** mountain areas have a higher elevation and thus greater potential energy than the lowlands. This, combined with the steeper slope angles, results in more dynamic erosion in upland areas than on the surrounding plains.

- **Rock Type:** the type of rock determines how susceptible an area is to erosion. Within the same climatic regime, each rock type responds differently to weathering and erosion, exhibiting a characteristic resistance or weakness to the prevailing conditions. Thus, some rocks are relatively resistant and form higher ground, whereas others are less-resistant and form valleys and lowlands.

- **Rock Structure:** highly jointed or faulted rocks are usually more intensely weathered along the lines of weakness in the rock mass. Consequently, these softer weathered materials are more easily eroded out, with the result that river valleys are usually located along the line of a major fault or joint set.

- **岩石類別**：岩石的類別決定地區內受侵蝕影響的程度。在同一氣候環境，每種岩石對風化及侵蝕作用的反應各異。根據當時情況，各種岩石展示其獨特的抵抗能力及弱點。抵抗力較強的岩石形成高地，而相對較弱的則形成山谷及低地。

- **岩石結構**：風化作用沿節理或受斷層影響的岩石的弱紋，通常較嚴重。由於這些風化後的物質較易被侵蝕，河流山谷大多出現於主要斷層或節理沿線。

侵蝕的產物

經侵蝕作用而剝落的岩石物質，最終將沉積於海底，儘管途中可能短暫停留於其他地方，如懸崖之下(例如山石堆)、山邊(例如坡積物(圖10))、河道兩旁(例如氾濫平原)、湖(例如三角洲)，或沙漠(例如沙丘)。

過去千億年間，一個地區的地形經由侵蝕作用雕刻而成，由原來被抬升的岩體，變成複雜的山峰、交錯的山谷及圍繞的平原。

重力造成山崩、流水侵蝕水溝及淺水河道(圖11)，節理岩塊從懸崖剝落形成山石堆。在下游地帶，河流勾劃出山谷，沉積物堆積形成氾濫平原。而在地面以下，可溶解的岩石(例如石灰岩)經過水的侵蝕，形成通道、洞穴及豎井。

圖10. 在天然山坡上常見受侵蝕的岩石碎屑層(坡積物)。
Figure 10. A layer of eroded debris (colluvium) is common on most natural hillsides.

侵蝕的最終結果是將高山、山脊及高地變為平原(稱為準平原)，從陸地逐步傾斜伸延至大海。

何謂山崩?

山崩，或稱邊坡坍塌，一般是指由重力操控的塊體崩移過程，影響全球山坡。

天然斜坡

在正常情況下，天然斜坡(指未被人類活動大量改造的斜坡)達到準平衡狀態。即是說，就岩石的種類、結構、泥土種類及厚度、植被的範圍及類別，地表及地下水文，以及當時的氣候情況而看，山坡被侵蝕至一個相對穩定的角度。

風化作用持續在山坡進行，削弱埋藏的岩石。地下水將部分風化物質從岩石節理或覆蓋的泥土中沖走，而山旁的溪水將山澗加深。

山坡上的岩石和泥土不斷被削弱及更不穩定，導致山坡定期透過塌毀(山崩)重新調節至一個較穩定的狀態。

Erosion Products

The rock and soil materials transported by erosion processes are eventually deposited in the sea, although they may be temporarily deposited in other locations such as below cliff faces (*e.g.* as screens), on hillsides (*e.g.* as colluvium (Figure 10)) beside rivers (*e.g.* as flood plains), in lakes (*e.g.* as deltas), or on desert plains (*e.g.* sand dunes).

Over the millennia, the topography of an area is sculptured by the processes of erosion, from an original mass of folded or uplifted rocks into a complex of mountain summits, intervening valleys, and surrounding plains.

Gravity causes landslides on hillsides, flowing water erodes gullies and shallow stream courses (Figure 11), and joint-bounded blocks of rock fall from cliff faces building up screes. On lower ground, rivers carve valleys and deposit floodplain sediments. Below the ground surface, in soluble rocks such as limestone, water erodes passages, caves and shafts.

The ultimate result of erosion is to reduce all mountains, ridges, and high ground to a flat plain (termed a peneplain) that slopes very gently from the centre of a landmass to the sea.

圖11. 紳蛇尖陡斜的山坡受甚多河流侵蝕。
Figure 11. Numerous stream channels erode the steep flanks of Sharp Peak.

What are Landslides?

Landsliding, or slope failure, is a general term that encompasses the gravity-controlled, mass wasting processes that affects hillslopes throughout the world.

Natural Slopes

Under normal circumstances, natural terrain slopes (*i.e.* slopes that are largely unmodified by human activities) reach a state of quasi-equilibrium, in which the slope is eroded to an angle that is relatively stable with regard to the underlying rock type and structure, the soil type and thickness, the extent and type of the vegetation cover, the surface and subsurface hydrology, and the prevailing climatic conditions and local weather patterns.

Weathering processes continually act upon the slopes, weakening the underlying rocks. Groundwater flushes-out some of the weathered materials from the joints in the rocks and from the overlying soils, and hillside streams deepen their channels.

The rocks and soils of the slope progressively become weaker and less stable, so sections of the slope periodically readjust to a more stable profile by failing (landsliding).

Importantly, if one or other of the factors on the slope changes, such as the tree cover is removed by fire or forestry, or an exceptionally heavy rainfall occurs, then large areas of a hillside may be subject to erosion, including failure (landsliding).

重要的是，若其中一個或其他山坡相關因素有所改變，例如當地的樹木被燒毀或伐木所移走，又或遇到反常豪雨，則大規模山坡可能遭侵蝕，包括塌毀(山崩)。

此外，陡峭的溪道在豪雨期間會帶走大量表層物質，這些水份連同土石嚴重地侵蝕河道，令溪流兩岸邊坡不穩，引至斜坡塌毀。

在極端的情況下，地震可能會搖動整個地區，令大量土地鬆脫，造成山崩。

香港大部分天然斜坡的崩塌，源於兩個主要地點的其中一個。

- **開闊斜坡崩塌：**指當一幅鬆脫的物質，從廣闊而相對平坦斜坡上脫落及移動。雖然在大多數的個案中，山泥沒有從源頭移動得太遠，但也可進入溪道，並沿着溪道流動。

- **沿溪道崩塌：**於豪雨期間，發生在溪道源頭的崩塌，山泥隨大量雨水湧進河道(圖12)。

圖12. 由淺層滑坡聚合而成的沿溝泥石崩瀉。
Figure 12. Coalescing channelised debris avalanches originating from shallow failure scars.

人造斜坡

許多在香港市區週圍的山邊，都已遭改動為築建樓房的平台以及公路的台階。此過程造成陡峭的人造削坡，改變了原來斜坡的形態，影響地下水的組織，並將岩石中不利的節理面或其他軟弱線暴露出來。

人造斜坡一般較大多數的天然斜坡陡峭，以及「地質上較年輕」。它們經過挖掘，失去了原來山坡的天然平衡特質，因此通常需要進行一些穩固工程。

工程師在策劃及設計這些人造削坡時，需引用以下技術以盡量令斜坡安全：

- **支撐斜坡：**例如岩層錨杆、裝設土釘及擋土牆 。

- **表面保護：**例如砌石護坡及噴射混凝土。

- **斜坡疏水渠道：**例如排水孔、排水斜管、U 型渠道及梯級渠 。

部分被削至岩石部份的人造斜坡，當發生山崩時，基本上會沿着岩石的節理面塌毀。在香港，這些節理面常見有黏土填充，形成了在岩石中的弱線。當節理面的磨擦力降低或本來支撐斜坡的物料被移走時，泥石便沿着節理脫落。

人造斜坡塌毀的後果比天然斜坡崩塌的較明顯，因為它們直接影響道路及人口稠密的地區。

In addition, steep stream courses carry considerable amounts of surface runoff during heavy rainstorms. This water, and the included debris, can severely erode the stream channel, destabilising the stream banks and the adjacent slopes, triggering slope failures.

In extreme circumstances, earthquakes may shake an area and loosen large masses of material, causing landslides or disturbing the previous equilibrium.

Most natural terrain landslides in Hong Kong originate in one of two main locations:

- **Open slope failures:** occur when a sheet of loose material on a wide, relatively planar slope is detached and displaced. Although, in most cases, the debris does not travel very far from the source, it may enter a stream channel, and become channelised.

- **Channelised failures:** commonly occur near the head of stream channels during heavy rainfall, the debris travelling down the channel accompanied by large volumes of water (Figure 12).

Man-made Slopes

Many of the hillsides adjacent to urban areas in Hong Kong have been modified to create platforms for buildings and benches for roads. This process creates a very steep cutting (a cut slope), which changes the geometry of the original slope, affects the groundwater regime, and may expose unfavourably oriented joint planes or other lines of weakness within the rock.

Man-made slopes are, by their very nature, steeper than most natural slopes and, being "geologically young", they are not in a natural equilibrium with the profile of the original hillside into which they are excavated. Consequently, some form of engineering stabilisation works are normally required.

Engineers plan and design these cut slopes, or man-made slopes, to make them as safe as possible by using techniques such as:

- **Slope support :** *e.g.* rock bolting, soil nailing, and retaining walls.

- **Surface protection:** *e.g.* stone pitching and shotcreting.

- **Slope drainage:** *e.g.* weepholes, raking drains, U-channels, stepped channels.

Failures of man-made slopes primarily occur along joint planes in fresh rock, and along relict joint planes in weathered rock. These discontinuities, which are commonly clay-filled in Hong Kong, present lines of weakness that allow blocks of material to become detached from the slope when the friction on the plane is overcome, or when the material that originally supported the toe of the slope is removed.

The consequences of failures of man-made slopes are usually more immediately apparent than those on natural terrain, because they directly affect roads and populated areas.

香港九龍公主道一零一號
土木工程拓展署大樓
土木工程拓展署 土力工程處

網址：http://www.cedd.gov.hk
香港斜坡安全網頁: http://hkss.cedd.gov.hk

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

Internet homepage : http://www.cedd.gov.hk
Hong Kong Slope Safety Website : http://hkss.cedd.gov.hk