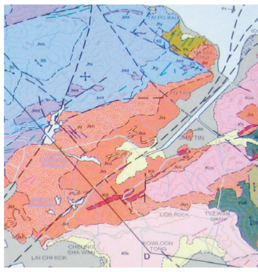
土木工程拓展署
土力工程處
Geotechnical Engineering Office
Civil Engineering and
Development Department

地 質 圖 導 論
INTRODUCTION TO GEOLOGICAL MAPS

地 質 圖 GEOLOGICAL MAPS 1



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。

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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.

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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。

簡單而言，地質圖展示岩石在某地區的分佈形勢。然而，要全面了解地質圖，就必須熟悉一些地質學的基本原則，包括地層學定律、地質年代**(地質圖之一)**及地質構造。對於具經驗的人來説，地質圖反映區內岩石三維分佈的情況，同時，亦能展現該區的地質發展史**(地質圖之二)**。香港備有一系列地質及相關地圖**(地質圖之三)**，為市區規劃、地質資源分佈及地質災害的確認提供有用的資訊。

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.

In simple terms, a geological map shows the surface distribution of rocks in an area. However, in order to fully understand a geological map, it is necessary to be familiar with several basic geological principles, including the laws of stratigraphy, geological age **(Geological Maps 1)**, and geological structures. To the experienced eye, a geological map reflects the three-dimensional distribution of rocks in an area, and also serves as a visual guide to the geological history of that area **(Geological Maps 2)**. A range of geological and related maps is available in Hong Kong **(Geological Maps 3)**. These maps provide useful information for urban planning, locating resources, and identifying geohazards.

內容
Contents

沉積物(礦物顆粒與碎石)在地表受風化而形成，它們受侵蝕過程搬運，並在其他地方沉積下來，形成沉積層。沉積物隨著時間加厚，由於重量及壓力增加，沉積物最終被壓縮及岩化成為沉積岩。

有關岩石循環，見岩石與礦物之二；而風化及侵蝕則請參閱地質與地景之一。

十八世紀科學家詹姆士赫頓被譽為現代地質學之父。他經過觀察沉積物現代的沉積速度，推論出今天看見厚厚的沉積岩層，須經過一段漫長時間形成。他更得出結論指類似現今的地質作用，從前必定已經發生。從此結論並引伸成為**均變說**理論。均變說指所有古老的岩石及地質特徵，均能夠以現今的地質作用解構。**均變說**通常被形容為「**現在是開啟過去的鑰匙**」。

研究保留在岩層內的地質記錄稱為**地層學**(圖1)。

地層學的原理

地層學是基於以下兩個先決原則：

- **地層層序定律**於1699年由尼古拉史德諾創立。他認識到當沉積物按水平狀態順序形成地層時，最老的地層在下面，而最年輕的地層則在上面，組成地層層序。
- **化石層序規律**是由英國礦產地質學家威廉史密夫創立。他觀察後指出，個別的岩層或地層的排列方式，在任何地方皆可預計得到。重要的是，含有相近化石類別(化石組合)的岩層組，會出現在同樣的層位(時代)，這點使分佈在不同地方的岩層能相互連繫，並讓威廉史密夫於1815年製作出首張全國的地質圖。

圖1. 於美國大峽谷國家公園露出的晚古生代(三億一千五百萬至二億八千五百萬年)沉積岩岩層(地層)(相片由美國地質調查局提供)。
Figure 1. Late Palaeozoic (315-285 million years) layered sedimentary rocks (strata) exposed in Grand Canyon National Park, the U.S.A. (photo by courtesy of US Geological Survey).

Sediments (mineral grains and fragments of rock) are produced by weathering at the Earth's surface. They are removed by erosion and deposited elsewhere as layers, which thicken over time and, as the weight and pressure increases, they are eventually compressed and lithified to form sedimentary rock.

Refer to Rocks and Minerals 2 for a discussion of the rock cycle and to Geology and Landscape 1 on weathering and erosion.

The father of modern geology was James Hutton, an eighteenth century scientist. After observing modern rates of sediment accumulation, Hutton concluded that long periods of time were required to build up the thick layers of sedimentary rock strata seen today. Hutton also concluded that geological processes similar to those today must have operated in the past. This led to the theory of **Uniformitarianism**, which states that all ancient rocks and geological features can be explained by observing the operation of modern-day processes. **Uniformitarianism** is usually referred to by the more explanatory phrase **"the present is the key to the past"**.

The study of rock layers preserved in the geological record is called **stratigraphy** (Figure 1).

Principles of Stratigraphy

Stratigraphy is based on two underlying principles:

- **The Law of Superposition** was introduced by Nicolas Steno in 1699, after recognizing that successive beds of sediments laid down in horizontal layers have the oldest beds at the base, and the youngest beds at the top, forming a stratigraphical sequence.
- **The Law of Fossil Assemblages** was introduced by William Smith, a mining geologist in England. Smith observed that, in any one area, the individual rock layers, or strata, were arranged in a predictable pattern. Importantly, groups of strata containing similar types of fossils (fossil assemblages) always occurred in the same relative stratigraphical (age) position. This fact enables groups of strata in different areas to be correlated, and allowed Smith to produce the first national geological map in 1815.

相對年齡

這兩個地層學原理，有助根據岩層的層序推斷岩層的相對年齡。相對年齡是指在岩層序列之中，哪一岩層較其他岩層年長(或是較年輕)。不過，這並沒有指出岩石的確切年紀(即絕對年齡)。

參考圖2，根據地層層序定律，砂岩、粉砂岩、泥岩、石灰岩、火山灰及礫岩的沉積物按次順序沉積，砂岩是最老的岩石，而礫岩則是最年輕。

另外兩個可以協助推斷岩石及地質事件的相對年齡的原則是：

- **相互切割關係原則**是指任何地質特徵(例如岩牆)切過現有的岩石，這地質特徵一定較現有的岩石年輕。
- **包含碎塊原則**是指任何含有其他岩石碎塊的岩石，一定較該碎塊的岩石年輕。

圖2所示，在花崗岩內發現泥岩的碎塊(包含碎石原則)，花崗岩一定在泥岩形成之後侵入。再者，岩牆切過砂岩、粉砂岩、泥岩、石灰岩、火山灰及花崗岩體內，但並沒有觸及礫岩。此關係確定岩牆侵入的時間在砂岩、粉砂岩、泥岩、石灰岩、火山灰及花崗岩形成之後，但在礫岩形成之前。

最後，正斷層錯動整個岩石層序，使到右側的岩層向下位移。

因此，從圖2所見，可以就這些地質歷史事件作出以下摘要：

1. 砂岩沉積
2. 粉砂岩沉積
3. 泥岩沉積
4. 石灰岩沉積
5. 火山灰沉積
6. 花崗岩侵入
7. 岩牆侵入
8. 侵蝕作用
9. 礫岩沉積
10. 正斷層錯動
11. 風化及侵蝕形成現今地貌

Relative Age

The two principles of stratigraphy allow the relative age of rocks in a stratigraphical sequence to be determined. Relative age refers to whether a rock layer in a sequence is older (or younger) than other layers in the sequence. There is, however, no implication of the true age (*i.e.* absolute age) of the rock.

Consider Figure 2. According to the Law of Superposition, the sediments of sandstone, siltstone, mudstone, limestone, volcanic ash and conglomerate were deposited in a sequence. Sandstone is the oldest rock, and conglomerate is the youngest.

Two other principles enable the relative age of rocks and geological events to be inferred, namely:

- **The Principle of Cross-cutting Relationships**, which states that any geological feature (such as a dyke) that cuts across an existing rock unit must be younger than that unit.
- **The Principle of Included Fragments**, which states that any rock containing fragments of another rock body must be younger than the rock body from which the included fragments are derived.

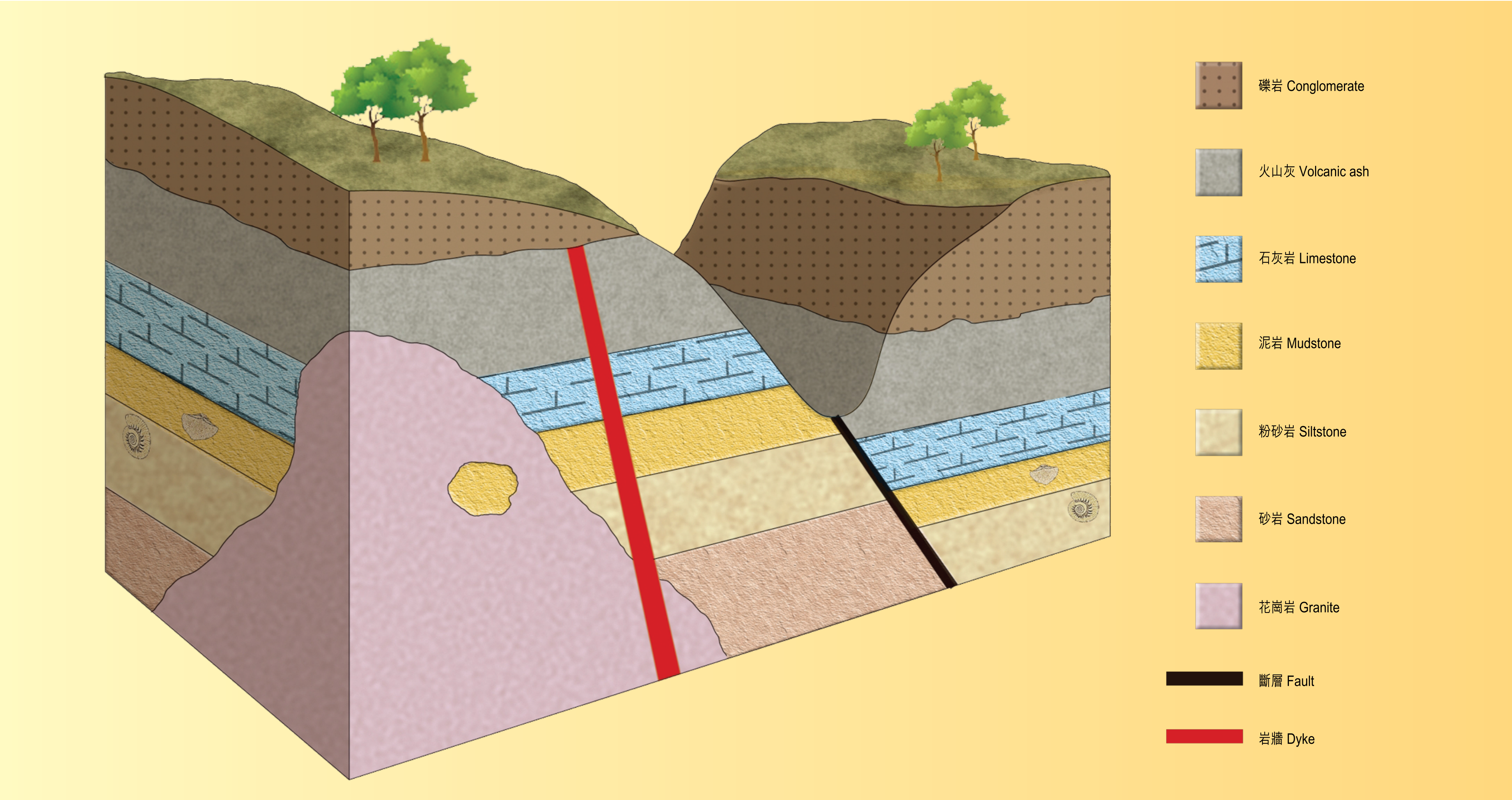

圖2. 沉積岩與火成岩的相對年齡關係。
Figure 2. Relative age relationship of sedimentary and igneous rocks.

從層序所見到的岩層不一定代表完整的沉積歷程。有些沉積物或岩層可能受風化侵蝕，部分剝落並被移走，或是長時期沒有沉積作用發生，甚至可能有些岩層遭侵蝕後全部被移走，以致該地區缺失了整個時期的地質記錄。事實上，缺失的地質事件可能較現在倖存於岩層中能找到線索的還要多。

一個地區的地質史是按照岩層層位關係而編定，之後可從岩層中的化石，而斷定不同岩層的相對年齡。儘管沉積環境因在不同的地域而改變，至使化石不一定出現於相同的岩石之中，遠距離分隔的岩層層序可引用**化石層序規律**來確定相對層位。斷定遠距離關係最為有用的化石，是那些常見、普遍而又快速進化的物種。

地質時代

地質圖顯示不同類型的岩石在地面的分佈情況、構造特徵及其相對年齡的關係。

最初的地質圖只有簡單地顯示含有相似化石組合的岩石的地層關係。後來，隨著有更多地方的地質圖完成及知識的增加，地質時代表根據廣泛的岩石及化石種類為基礎發展而成。期後制定了**地質時代單位**，即是將個別岩石及化石組別歸類至相對的年代。不少的地質時代單位，是按該地層首次在英國被描述的地區而命名(例如泥盆紀)。

自五億四千二百萬年前至今，稱為顯生元(意謂「展現生命」)。在這期間，地球上出現非常豐富、能夠確認而且不斷演化的植物及動物生態，因此地質時代表中，顯生元出現最多的分組。顯生元時期之地質時代單位的界線，通常以物種廣泛絕跡的化石記錄，以及反應了全球性地質事件的不整合來劃分，如主要的岩漿活動或隕石撞擊等事故，例子包括：在二疊紀及白堊紀末期，全球有大量岩漿湧出，以及於白堊紀末期的隕石撞擊。

有關香港地質圖之討論，見地質圖之三。

In Figure 2, because fragments of mudstone are found within the granite body (The Principle of Included Fragments), the granite intrusion must be younger than (post-date) the formation of limestone and mudstone. Furthermore, the dyke cuts across the layers of sandstone, siltstone, mudstone, limestone and volcanic ash, and also the granite body, but not the conglomerate. This relationship confirms that the intrusion of the dyke post-dated the formation of sandstone, siltstone, mudstone, limestone, volcanic ash and granite, but pre-dated the deposition of conglomerate.

Finally, a normal fault has displaced the rock sequence so that the right hand side has been downthrown.

Therefore, a brief history of the geological events shown in Figure 2 can be summarised below:

1. Deposition of the sandstone
2. Deposition of the siltstone
3. Deposition of the mudstone
4. Deposition of the limestone
5. Deposition of the volcanic ash
6. Intrusion of the granite
7. Intrusion of the dyke
8. Erosion
9. Deposition of the conglomerate
10. Normal faulting
11. Weathering and erosion to form the present day topography

It is very important to be aware that the rock layers observed in a particular stratigraphical sequence may not be a complete record of the history of deposition. Some sediments or rock layers within the sequence may have been weathered and partly removed by erosion. There may have been long periods with no deposition. There may even be other rock layers that have been completely removed by erosion, with the result that an entire period of the geological history of the area is missing. In fact, more geological events are probably missing from the geological record than are recorded by the surviving rock sequences.

Having established the geological history of a particular locality from the stratigraphical relationships, the relative ages of the different sedimentary rock layers can be determined by examining the fossil content. Rock sequences that are separated by long distances can then be correlated by applying **the Law of Fossil Assemblages**, even though the fossils may not occur in the same rock type due to changes in sedimentary environment across an ancient ocean or landmass. The most useful fossils for long-distance correlation are those that are common, widespread and evolved rapidly over time.

岩石年齡

直至二十世紀初，沒有任何科學方法可以推斷岩石的確切(絕對)年齡。因此，地質時代單位只代表相對年齡。一直以來有多個有關地球年歲的理論面世。以宗教角度估計，地球相當年輕，即使早期的地質學家早已認定沉積岩的龐大厚度，需要很長的時間始能形成。英國物理學家凱爾文勳爵於1846年根據岩漿在地球表層冷卻估計所需的時間為基礎，推算出地球的年齡約二至三千萬年。

二十世紀初，岩石具有天然放射性的同位素，被確認可用作紀錄岩石的年齡。這個發展有助為地質時代單元編排年歲，從而建立**地質時代表**(圖3)。由於定年法的技術不斷改良，地質時代表的框架目前仍在發展中。

首個地質時代表於1913年由英國地質學家亞瑟霍爾姆斯(1890-1965)發表。國際地層學協會定期根據新加入的數據，調整地質時代單位的分界線，並由國際地質科學會確證，最近一次的修正於2008年完成及發放。

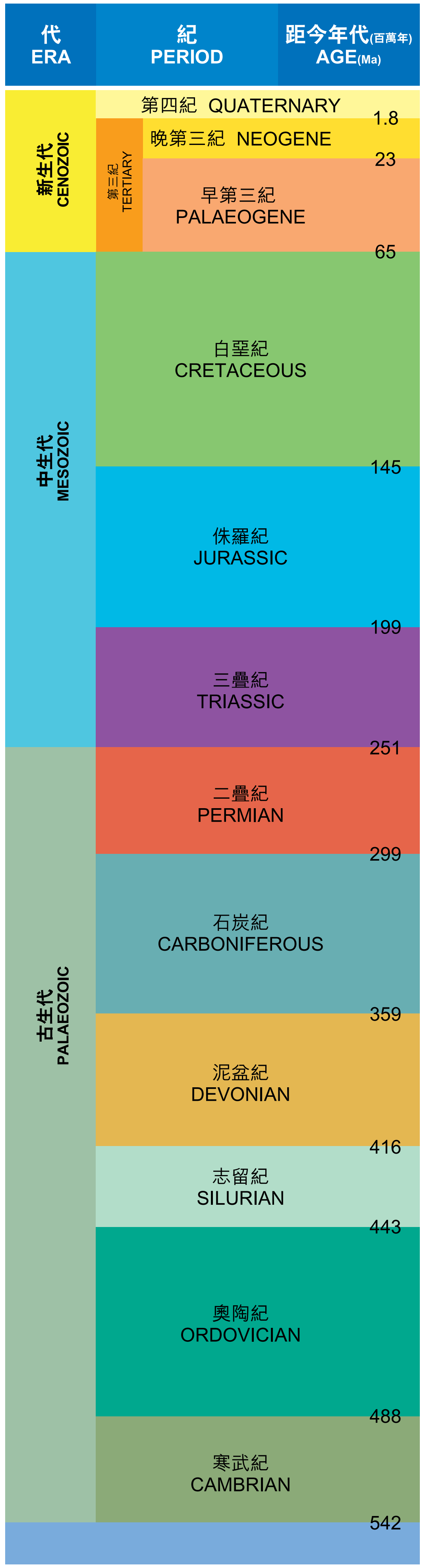

圖3. 地質時代表。
Figure 3. Geological time scale.

Geological Time

A **geological map** shows the surface distribution of different rock types, their structural features, and their age relationships.

The first geological maps simply showed the relative stratigraphical positions of groups of rocks that contained similar fossil assemblages. Over time, as more areas were mapped and knowledge increased, the geological time-scale was developed, based on a wide range of rock and fossil occurrences. **Geological Time Units** were subsequently devised, which placed particular groups of rocks and fossils into relative age categories. Many of these time units are named after groups of strata that were first described from type localities in the British countryside (*e.g.* the Devonian).

The last 542 million years to the present is known as the Phanerozoic (meaning "life presence") era. It contains the most subdivisions in the geological time scale because this period in Earth history was teeming with recognisable and evolving plant and animal life. The boundaries between geological time units of the Phanerozoic era are marked by widespread extinctions in the fossil record and by major unconformities in the rock sequence that signify global events, such as major magmatic episodes and meteorite impacts events. Examples include the voluminous global outpourings of magma at the end of the Permian and Cretaceous periods, and a meteorite impact at the end of the Cretaceous.

Refer to Geological Maps 3 for a discussion of the Geological Maps of Hong Kong.

Rock Ages

Until the beginning of the twentieth century, there were no scientific methods available for determining the true (absolute) age of rocks. Thus, the Geological Time Units represented only relative ages. Over the years, various theories had been proposed for the age of the Earth. Theological estimates suggested that the Earth was very young, but even the early geologists recognised that long periods of time were required to accumulate the vast thicknesses of sedimentary rocks. Based on estimates of the time needed for the exterior of the Earth to cool from a molten state, the British physicist Lord Kelvin calculated, in 1846, that the Earth was about 20 to 30 million years old.

In the early twentieth century, it was recognized that the natural radioactivity inherent in rocks could be used to date rocks in the geological record. This development enabled ages to be assigned to the Geological Time Units, and led to the establishment of the **Geological Time Scale** (Figure 3), a framework that is still being refined as age-dating techniques are developed and improved.

The first geological time scale was proposed in 1913 by Arthur Holmes (1890 - 1965), a British geologist. Periodically, as new data becomes available, the ages of the boundaries between geological time units are revised by the International Commission on Stratigraphy, and ratified by the International Union of Geological Sciences. The latest revision was completed and promulgated in 2008.

絕對年齡

放射性同位素(「藏於岩石內的時鐘」)用來確定岩石的絕對(或數字)年齡，把岩石的絕對年齡計算成一個具體的數字年歲(例如一億四千二百萬年)。

簡單而言，同位素元素的存在，是由於某些元素的原子核內擁有不同數目的中子，但具有相同數目的電子和質子。其中有些同位素(母同位素)不太穩定(指具放射性)，並經由釋放能量而轉化至另一個較穩定的同位素(子同位數)。從母同位素轉化至子同位素的衰減速度是固定的，而個別的同位素的衰減速度均獨一無二。

許多礦物皆含有放射性同位素。當礦物形成後，礦物中的母同位素便開始衰減而轉化至子同位素。理論上，礦物的年齡(自形成後的時間)可從計算礦物中的母及子同位素的比率來判斷。礦物的年歲等同在礦物內，產生出的子同位素數量所需的時間。根據已知的同位素衰減速度，即可計算出該所需時間。

地球年歲

地球上已知最古老的岩石約有四十二億八千萬年歲。然而由於板塊運動的關係，這些最早的岩石於板塊運動的過程中被循環再生及破壞，以致未能憑此計算出地球可靠的歲數。取而代之，估計地球歲數最準確的方法是利用隕石的放射性定年法。隕石相信是太陽系形成時遺留的物質，最古老而又進入地球的含鐵隕石，所含有的礦物的年齡是四十五億七千萬年，這年齡被視為目前地球年歲的最佳估計。

有關板塊邊緣之活動情況，見板塊運動之一。

Absolute Age

Radioactive isotopes ("the clocks in rocks") are used to determine the absolute (or numerical) age of a rock. The absolute age of a rock is calculated as a specific number of years (*e.g.* 142 million years).

In simple terms, isotopes of an element exist when the same element has a different number of neutrons in the nucleus, but the same number of electrons and protons. Some of these isotopes (the parent isotope) are unstable (*i.e.* radioactive), and decay to a more stable isotope (the daughter isotope) by releasing energy. The rate of decay from parent to daughter isotope is constant, and is unique for each particular isotope.

Many minerals contain radioactive isotopes. Once a mineral is formed, the parent isotope in the mineral begins to decay to produce a daughter isotope. In theory, the age (time since formation) of these minerals, and thus the age of the rock bearing them, can be determined by counting the ratio of parent to daughter isotopes in the mineral. The age of the mineral is the length of time that is required to produce the quantity of daughter isotope that has accumulated in the mineral. This length of time required can be calculated using the known decay rate for the isotope.

Age of the Earth

It is now known that the oldest dated rocks on the Earth are about 4.28 billion years old. However, since these original rocks have been recycled and destroyed during the process of plate tectonic movements, they do not provide a reliable age for the Earth. Instead, the most reliable estimate of the age of the Earth is based on the radiometric dating of meteorites. Meteorites are believed to be material left over from the formation of the Solar System. The age of the oldest minerals contained in iron meteorites that have entered the earth's atmosphere is about 4.57 billion years, which is currently regarded as being the best estimate for the age of the Earth.

Refer to Plate Tectonics 1 for further information about the processes occurring at plate boundaries.

繪畫地質圖的工具

傳統上，地質圖是根據地質學家在調查範圍內盡量行經的地方，記錄所見的岩石(**露頭**)、岩石種類(**岩性學**)、地質構造、風化程度，以及其他有用的特徵。全部觀察所得的資料均記錄在**地勢圖**上，並且利用**磁極羅盤**及**傾斜儀**等作量度儀器。**航空照片**亦協助地質學家認出目標地質特徵。

地形圖利用等高線顯示區內的地形，包括河流、湖泊、水塘、道路、建築物、步行徑等。地形圖以不同的比例繪畫，香港最常用的地圖比例有：1:50,000、1:20,000、1:10,000、1:5,000及1:1,000。例如1:10,000比例的地圖指地圖上每一厘米代表實地的10,000厘米(即100米)。選用的比例視乎勘察目的，即地圖上所需記錄的地質資料的多寡而定。

航空照片是從飛機於空中離地面固定的高度拍攝。一對相鄰的航空照片，若有66%的重疊範圍，則可用於塑造地形的三維視象，對偵察性勘察甚有用處。如能掌握拍攝航空照片的飛行高度及鏡頭焦點距離的資料，即可確定航空照片的比例。香港備有少量攝於1924至1963年間，有限地區的航空照片。自1963年開始，每年均有系統地於全港進行黑白航空照片的拍攝。於1985年起，每年進行兩次黑白照片拍攝工作，而到了1993年則定期每年拍攝兩次彩色照片。

磁極羅盤是用來判斷北磁極方向的工具。它的原理是基於地球深處的地核形成有如一個巨型磁石，兩端代表(正負兩極)地理上的南北兩極附近的位置。磁極羅盤具有一支可自由360°旋轉的磁針，讓觀察者能確定其位置與北極間的方位。然而，磁極與地理上的南北兩極出現最多1,167千米的偏差，而這偏差按年轉變。在香港，北磁極與地理上的北極均指向同一方位。然而在世界別的地方，出現的差異，可能須從羅盤讀數作出約30°的加減調整。

傾斜儀是用來量度地面的傾斜度，例如岩層的傾角。它採用水平尺(將液體注入密封玻璃管內)或鐘擺分別來判定水平或垂直的傾斜度。傾斜儀上刻有半圓形度數表，指示一平面的傾角。

Geological Mapping Tools

Traditionally, geological maps are made by geologists who walk over as much of the map area as possible, noting where rocks can be seen (**outcrops**), the rock types (**lithology**), their structure, degree of weathering, and any other features that might be useful. All observations are marked upon a **topographical base map**, and measurements are taken using a **magnetic compass** and **clinometer**. **Aerial photographs** may help the geologist to identify target features in the field.

Topographical base maps show the landscape of an area in the form of contours (lines of equal height), rivers, lakes, reservoirs, roads, buildings, footpaths, *etc.* Topographical maps are drawn at various scales, the most common scales in Hong Kong being 1:50,000, 1:20,000, 1:10,000, and 1:5000, with 1:1,000 scale maps also available. This means, for example, that on a 1:10,000 scale map, 1 centimetre on the map represents 10,000 centimetres (100 metres) on the ground. The scale of the topographical base map selected depends upon the survey objectives, *i.e.* the amount of geological detail required on the finished map.

Aerial photographs are taken from aircraft flying at fixed heights above the ground. Adjacent pairs of aerial photographs with 66% overlap can be used under a stereoscope to provide a three-dimensional image of the landscape, which is useful for reconnaissance surveys. The scale of the aerial photograph can be determined if the flying height and the focal length of the camera lens are known. Aerial photographs of limited areas of Hong Kong are available for some years between 1924 and 1963. Systematic, annual, territory-wide black and white aerial photographic coverage began in 1963, twice-annual black and white photography began in 1985, and routine, twice-annual colour photography began in 1993.

Magnetic compasses are instruments used to determine the direction of the magnetic north pole. They work on the principle that the molten core of the earth causes the earth to act like a giant magnet, with the ends (positive and negative poles) of the magnet located in the vicinity of the north and south geographical poles. A magnetic compass, which has a magnetised needle that pivots freely over a 360° graduated dial, is used to determine the direction of the north pole from the position of the observer. However, the magnetic north pole migrates up to about 1,167 kilometres from the geographical north pole, a value that varies annually. In Hong Kong, the magnetic north pole and the geographical north pole are in the same relative direction. In other parts of the world, this difference must be compensated for by adding, or subtracting, an angle of up to about 30° (the magnetic declination) from the compass reading.

Clinometers are used to measure the angle of inclination of a surface, such as the angle of dip of rock strata. They employ a spirit level (a bubble of air in a liquid enclosed in a glass tube) or a pendulum to determine the horizontal and vertical respectively. Clinometers are equipped with graduated half circles from which the angle of dip of a surface from the horizontal can be read.

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