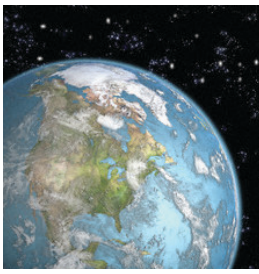
土木工程拓展署
土力工程處
Geotechnical Engineering Office
Civil Engineering and
Development Department

板塊運動導論
INTRODUCTION TO PLATE TECTONICS

板塊運動 1
PLATE TECTONICS



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.

Raymond K S Chan
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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。

板塊運動是指在岩石圈推動地質作用的基本機制。板塊運動理論是基於對地球內部結構，不同類型板塊和板塊邊緣，以及板塊活動推動力的了解**(板塊運動之一)**。板塊運動理論扼要地闡釋地震及火山的產生、不同種類岩石的分佈、岩石循環、以及山脈的形成、大陸張裂和海洋擴張等地質現象**(板塊運動之二)**。褶皺及斷層是地質構造，是岩石以及板塊受壓而作出的反應**(板塊運動之二)**。詳細研究香港的岩石，有助解釋本港的地質歷史及板塊構造環境的演變**(板塊運動之三)**。

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.

Plate tectonics is the fundamental mechanism that drives geological processes in the geosphere. Plate tectonic theory is based on an understanding of the Earth's internal structure, the different types of tectonic plates and plate boundaries, and the driving forces of plate movements **(Plate Tectonics 1)**. The occurrence of earthquakes and volcanoes, the distribution of different rock types, and the Rock Cycle, as well as the processes of mountain building, continental rifting and seafloor spreading, can be concisely explained by plate tectonic processes **(Plate Tectonics 2)**. Folds and faults are geological structures that result from the response of rocks to tectonic stresses **(Plate Tectonics 2)**. Detailed studies of the rocks enable the geological history and the evolution of the tectonic setting to be deciphered **(Plate Tectonics 3)**.

內容
Contents

板塊運動是現代地質學原理，解釋海洋盆地和山脈的形成，以及相關的地震和火山活動。

地球結構

地球呈不規則球形，半徑長6,356至6,378千米。地球按化學成份分層，由地球表面至中心，密度漸增，越深密度越高。地球主要分為三層：**地核** (由內核及外核構成)、**地幔**和**地殼**。每層均具獨特的化學成份，而且密度各異 (圖1)。

根據科學家推斷，高密度的地核主要由鐵和鎳兩種重金屬元素組成。地核外層為液態鐵，地球磁場由此而成。

地核受地幔所包圍，地幔密度較低，深達2,900千米，富帶有鐵和鎂的矽酸鹽礦物。

地球最外層稱為地殼，分為**海洋地殼**及**大陸地殼**。一般而言，大陸地殼含矽元素較多，密度則比海洋地殼低。

- **海洋地殼**(厚約10千米)由富鐵、鎂、鈣，和鋁的矽酸鹽礦物組成，通常形成深色、沉重的岩石，稱為玄武岩。
- **大陸地殼**(厚約20-60千米)由富鉀、鈉和鋁的矽酸鹽礦物組成，形成多種岩石，如花崗岩等。

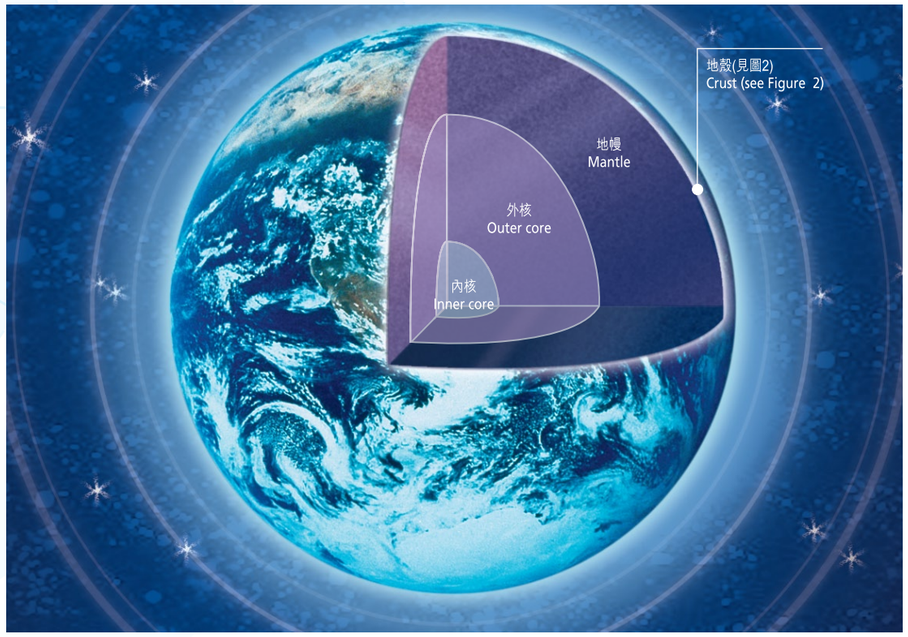

圖1. 地球的基本構造。
Figure 1. Generalised structure of the Earth.

Plate Tectonics is a principle of modern geology that provides a mechanism to explain the formation of ocean basins and mountain ranges, and the associated processes of earthquakes and volcanism.

Structure of the Earth

The Earth is an irregular sphere, with a radius that varies between 6,356 and 6,378 kilometres. This solid sphere is chemically divided into layers that become less dense from the centre towards the surface. Three main layers are recognised: the **core** (which comprises an Inner Core and an Outer Core), the **mantle**, and the **crust**. Each layer has a distinctive chemical composition, and a different density (Figure 1).

Scientists infer that the dense core is primarily composed of the heavy elements iron and nickel. The outer core is made of molten iron, which produces the Earth's magnetic field.

Surrounding the core is the less-dense mantle, which extends to a depth of about 2,900 kilometres. The mantle is rich in iron- and magnesium-bearing silicate minerals.

The outer layer of the Earth is termed the crust, which is divided into **oceanic crust** and **continental crust**. Overall, continental crust is richer in the element silica, and is less dense, than oceanic crust.

- **Oceanic crust** (about 10km thick) is composed of iron-, magnesium-, calcium-, and aluminium-rich silicate minerals that typically form a dark coloured, heavy rock called basalt.
- **Continental crust** (about 20-60km thick) is composed of potassium-, sodium-, and aluminium-rich silicate minerals that form a diverse range of rock types such as granite.

Dynamic Surface of the Earth

The outermost crust and upper part of the mantle of the Earth is further subdivided into the **lithosphere** and the **asthenosphere** (Figure 2). The slow movement of the lithospheric plates over the mobile asthenosphere is known as plate tectonics, a process that maintains the surface of the earth in a dynamic and active state.

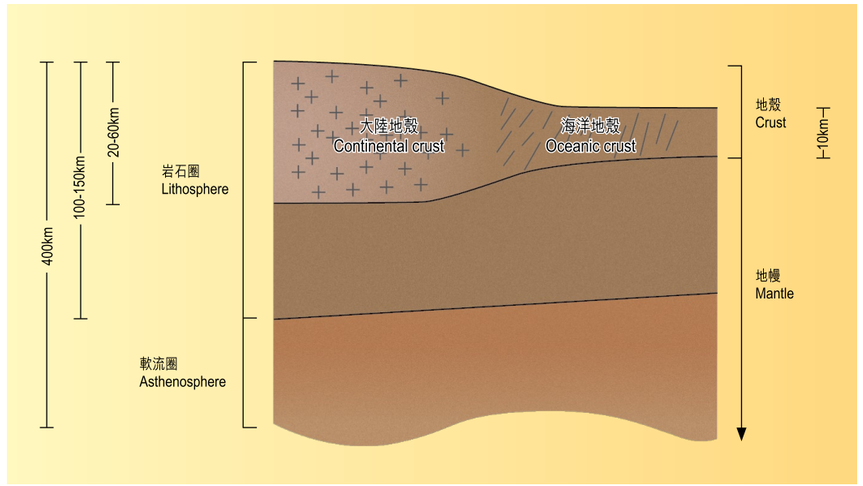

圖2. 地殼及上地幔層的基本構造。
Figure 2. Generalised structure of the crust and upper mantle.

地球的動態表面

地球的地殼最外層和上地幔層可再分為**岩石圈**及**軟流圈**(圖2)。岩石圈板塊在流動的軟流圈上緩慢移動，稱為板塊運動，令地球表面維持在活躍多變的狀態中。

- **岩石圈**非常堅固，深度由約100千米延伸至150千米，包含地殼和部份上地幔層。在地球表面，岩石圈由七塊巨大的板塊及若干較小的板塊組成。板塊邊緣形狀不一，在軟流圈上方移動。

- **軟流圈**結構較弱，深度由約150千米延伸至400千米，岩石圈在上方移動。在軟流圈產生的岩漿形成海洋地殼。地核的熱力在地幔產生環流現象(熱對流)，帶動上面的板塊移動。

板塊運動的動力

板塊運動是由地球內部的熱力產生，它包括地球在最初形成時所產生的餘溫，以及岩石中礦物輻射衰變時產生的熱量。

熱力像**熱流**般由地球下地幔向上升，當到達上地幔層時受冷，熱流向外擴散，再向下降回下地幔(圖3)。

這過程稱為**地幔對流**，它會帶動板塊移動。

雖然地球的熱力帶動地幔對流及板塊活動，但構成地幔的岩石是非常堅固而呈半塑性狀態，因此可轉移物質。

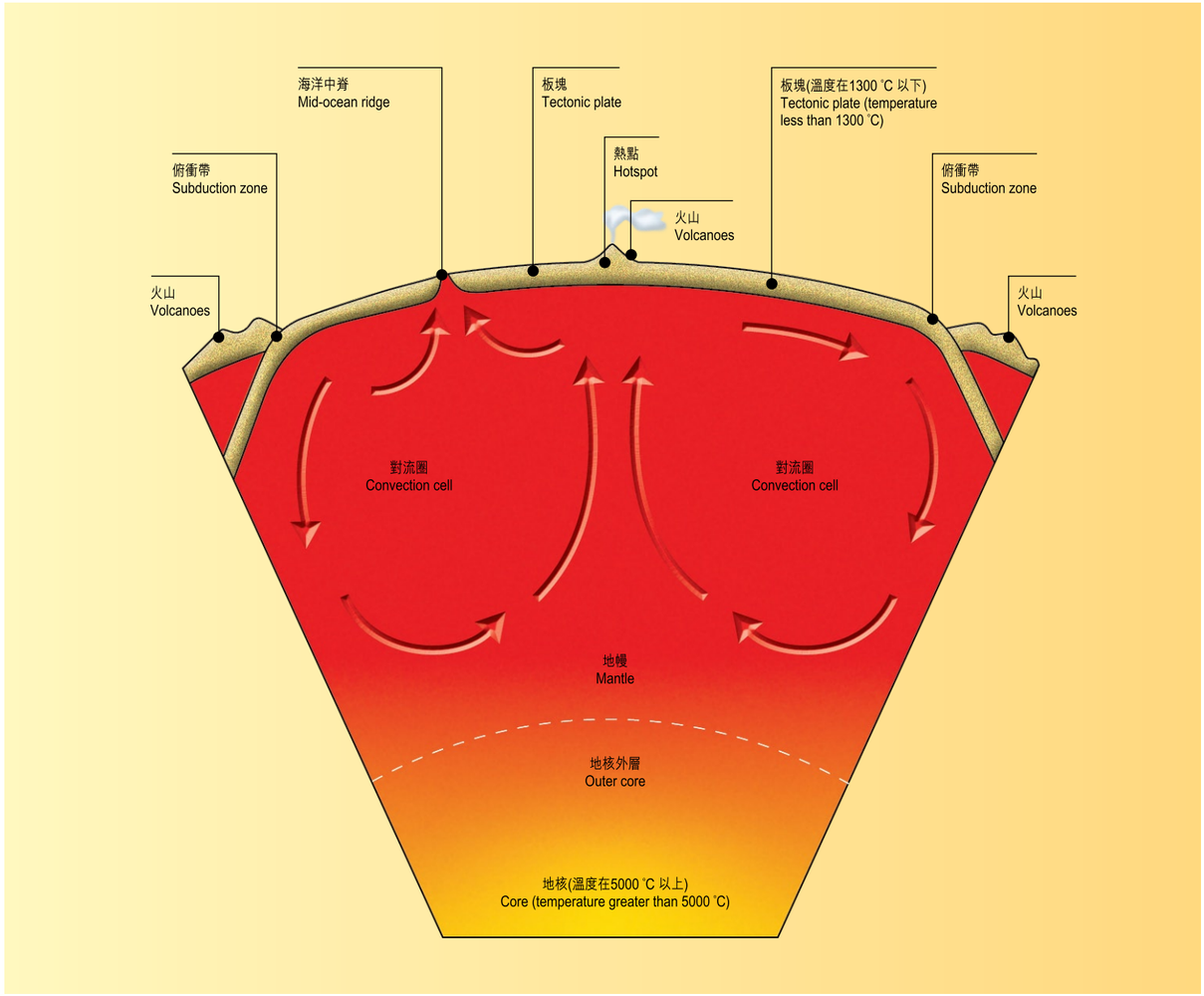

圖3. 地幔對流作為板塊運動的動力。
Figure 3. Mantle convection as the driving force for plate tectonics.

- The **lithosphere** is a strong layer, extending to a depth of 100 to 150 kilometres, that comprises the crust and part of the upper mantle. Over the surface of the earth, the lithosphere is separated into seven large plates, and several smaller plates. These plates, which terminate at different types of plate boundary, move over the underlying asthenosphere.

- The **asthenosphere** is a weaker layer, extending from approximately 150 to 400km depth, upon which the lithospheric plates move, and from which magmas that form the oceanic crust are derived. Heat from the earth's core creates circulation patterns (convection currents) in the mantle that drive the motions of the overlying plates.

What drives Plate Tectonics?

Plate tectonics is driven by the internal heat energy of the Earth. This comprises the heat left over from the initial formation of the Earth, combined with heat from the decay of radioactive minerals contained in the rocks.

Heat from the Earth's lower mantle rises as **plumes** towards the upper mantle where cooling occurs. The plumes spread out, then sink back into the interior (Figure 3).

This process is known as **mantle convection**. These convection currents propel the motion of plates.

Although heat drives mantle convection and the motion of plates, the mantle is mostly solid. The rock forming the mantle, however, behaves in a semi-plastic manner, which enables the slow transfer of materials.

板塊邊緣類型

板塊邊緣分為三大類型：**聚合**、**張裂**及**錯動型板塊邊緣**。

- **張裂型板塊邊緣**(圖4a)：張裂型板塊邊緣就是當岩漿由地幔不斷向上湧，兩塊板塊向兩旁拉張的邊緣。張裂型板塊邊緣的火山活動會形成新的岩石，稱**擴張性山脊**。

- **聚合型板塊邊緣**(圖4b)：聚合型板塊邊緣就是兩塊板塊互相擠壓的邊界，而引至其中一塊板塊推覆到另一板塊之上。下伏的板塊會被推回地幔，並於**俯衝區**被摧毀。地震和火山活動正是在兩塊板塊互相擠壓的過程中，於上覆板塊發生的。

- **錯動型板塊邊緣**(圖4c)：錯動型板塊邊緣就是兩塊板塊擦過的邊緣。當兩塊板塊從旁擦過時，地震便會在板塊邊緣發生。岩石圈受影響較輕微，不會如聚合型板塊邊緣般形成新的岩石，或如張裂型板塊邊緣般摧毀岩石。

板塊運動和地球表面活動

板塊運動令地球表面維持活躍多變，因而帶動下列其他活動：

- **岩漿活動**：岩漿把新元素及物質由地幔送至地殼，是岩石循環的首階段。岩漿由裂縫上湧至地球表面後冷卻成岩石，從而在岩石循環中引入新元素及礦物質。這些岩石會被摧毀(風化)、搬運(侵蝕)、沉澱(沉積)，經埋藏後形成新岩石(岩化)，再迴湧升起，然後風化、被侵蝕及沉積，繼續循環不息。

有關岩石循環，見岩石與礦物之二。

Types of Plate Boundary

There are three types of plate boundary: **convergent**, **divergent**, and **transform plate boundaries**.

- **Divergent plate boundaries** (Figure 4a): occur where two lithospheric plates move away from each other, driven by magma rising from deep within the mantle. Volcanic activity at a divergent plate boundary creates new lithosphere along what is known as a **spreading ridge**.

- **Convergent plate boundaries** (Figure 4b): occur where two lithospheric plates move towards each other, with one plate overriding the other. The overridden plate is driven back into the mantle, and is subsequently destroyed along what is known as a **subduction zone**. During this process, earthquakes and volcanic activity are generated in the overriding plate.

- **Transform plate boundaries** (Figure 4c): occur where two lithospheric plates slide laterally past each other. Earthquakes are generated along this type of plate boundary. Importantly, lithosphere is preserved along transform boundaries, it is not created or destroyed as it is at divergent and convergent plate boundaries.

Plate Tectonics and Earth Surface Processes

Plate tectonics is a process that maintains the surface of the earth in a dynamic and active state. Consequently, it drives such processes as:

- **Magmatism**: the primary way in which new elements and new materials are transported as molten rock (magma) from the mantle to the crust. This is the first stage in the process known as "The Rock Cycle". The molten rock (magma) issuing from cracks in the surface of the Earth cools to create new rocks, and thereby introduces new elements and minerals into the rock cycle. These new rocks are broken down (weathered), transported (eroded), deposited (sedimented), and buried (lithified) to form other rocks, which are subsequently uplifted and then weathered, eroded and deposited in a repeated cycle.

Refer to Rocks and Minerals 2 for a detailed discussion of the rock cycle.

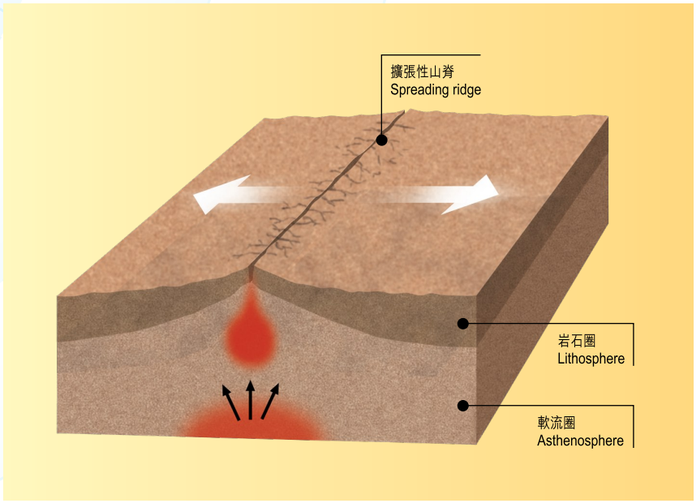

圖4a. 張裂型板塊邊緣的基本結構。
Figure 4a. Generalised structure of a divergent plate boundary.

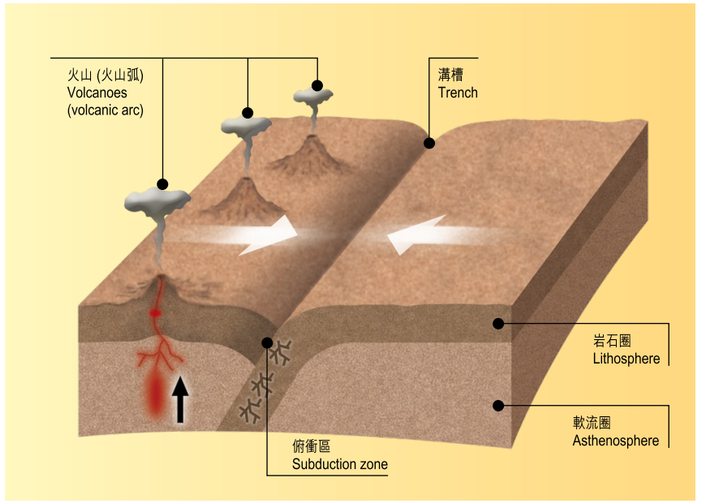

圖4b. 聚合型板塊邊緣的基本結構。
Figure 4b. Generalised structure of a convergent plate boundary.

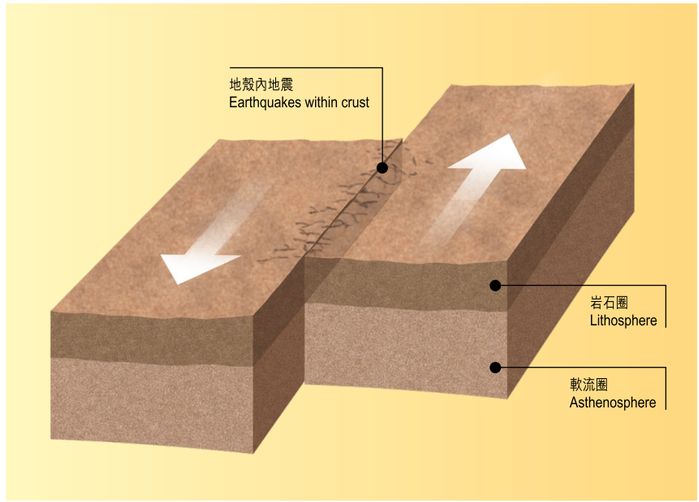

圖4c. 錯動型板塊邊緣的基本結構。
Figure 4c. Generalised structure of a transform plate boundary.

- **深成作用**：大部份岩漿都不能湧到地球表面，這些岩漿在地殼內冷凝結晶，形成深成岩。

- **火山作用**：於特定的板塊邊緣，岩漿及氣體從地殼噴溢到地面，形成火山。猛烈的爆發會產生火山灰，而流出的岩漿則形成熔岩。

- **地震**：由於板塊活動而引起岩石沿着斷層的突然錯動，又或是岩漿從地球表面冒出，都會導致強烈的地震(圖5)。

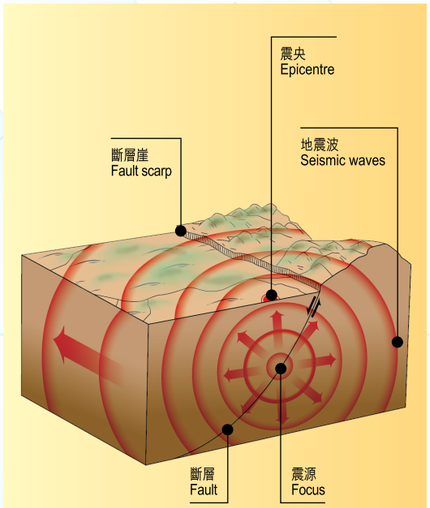

圖5. 沿著地底深處的斷層發生錯動而形成地震波。
Figure 5. Seismic waves generated by movement along a fault deep underground.

- **褶曲及斷層**：板塊活動導致地殼彎曲及斷裂，因而形成岩石褶皺及斷層。

- **造山運動**：沿着聚合型板塊邊緣的岩石受到長期的擠皺，形成山脈及火山(圖6)。

- **海洋盆地和裂谷的形成**：在聚合型板塊邊緣旁的火山帶後，由於板塊拉張引力會增加板塊結構的壓力，發展成**弧後裂谷帶**。新的擴張中心點可能因此形成，造成新海洋地殼(圖7)。

於連綿的大陸地殼地帶，地幔上升導致地殼變薄並發展為裂谷。肯雅的非洲大裂谷便是這類大陸解體的例子。

有關岩漿活動、地震、褶皺及斷層，見板塊運動之二。

- **Plutonism**: a large proportion of the mobile magma never reaches the Earth's surface. This magma accumulates and cools in the crust to form bodies of new rock called plutons.

- **Volcanism**: at certain types of plate boundary, magma and gases escape at the Earth's surface, either explosively, as ash, or effusively, as lava forming volcanoes.

- **Earthquakes**: the sudden displacement of rocks along faults, triggered by plate movements, or by the movement of magma upwards in the crust, causes violent shaking of the Earth (Figure 5).

- **Folding** and **Faulting**: movement of the lithospheric plates bends and fractures the crust, creating folds and faults in the rocks.

- **Mountain Building**: along certain convergent plate margins, prolonged movement of the lithospheric plates causes crumpling of rocks between the plates, which leads to the creation of mountain chains and volcanoes (Figure 6).

- **Opening of Ocean Basins and Rifting**: Behind the chain of volcanoes adjacent to convergent plate margins, tensional tectonic forces develop due to slab pull. This can lead to development of a **back-arc rift zone**. At these sites, a new oceanic spreading centre may develop, leading to formation of new oceanic crust (Figure 7).

Within regions of continuous continental crust, the process of mantle upwelling leads to thinning of the crust and to the development of rift valleys. The Great African Rift Valley in Kenya is an example of this type of continent-continent breakup.

Refer to Plate Tectonics 2 for a detailed discussion of magmatism, earthquakes, folding and faulting.

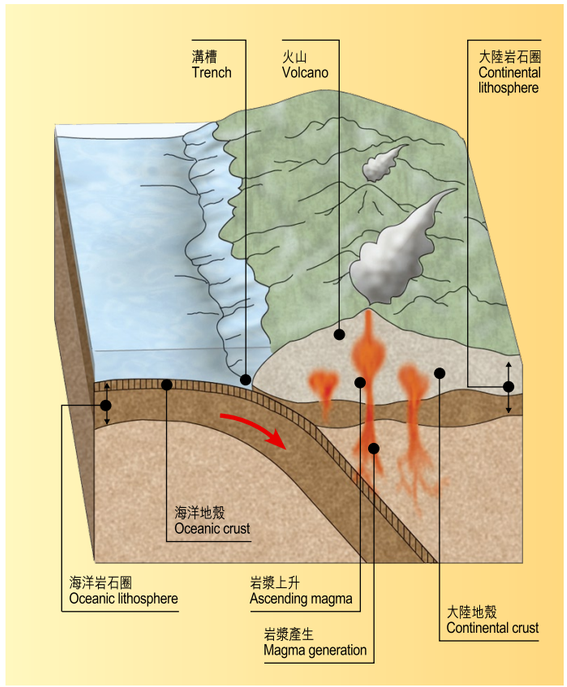

圖6. 火山山脈沿着聚合型板塊邊緣形成。
Figure 6. Creation of a volcanic mountain chain along a convergent plate boundary.

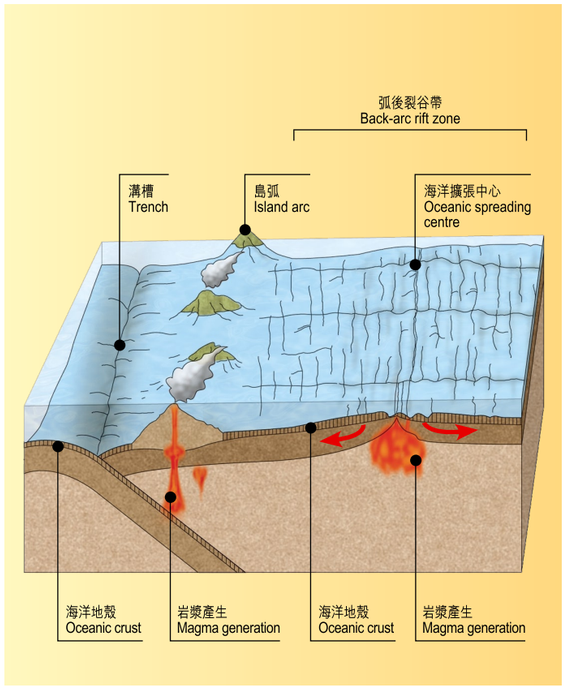

圖7. 弧型裂谷帶在聚合型板塊邊緣旁的火山帶後發展而成。
Figure 7. Development of a back-arc rift zone behind a chain of volcanoes adjacent to a convergent plate boundary.

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