

海洋地質地物探勘(10/15)
板塊構造運動 (10/22)
海洋沈積物與海洋鑽探 (10/29)

海洋科學概論
海洋地質 **MARINE GEOLOGY**

討論區（1分）

請觀看「海洋地質」課程內容中，任何一個影片連結，簡述內容或心得。

文字在50字以內（影片標題+內容或心得）

截止日：11/5（期中考日）

課堂問題（1分）

每週出現一次，每次答對得0.5分，累積至1分。
線上測驗區作答，作答時間，依教公布規定。

研究海床的歷史和結構，是以**地球物理學**、**地球化學**、**沉積學**和**古生物學**方法對海床和海岸進行研究的學科。

海洋地質學的研究提供了**海底擴張學說**和**板塊構造論**的極為關鍵證據。

深海海床是地球上最後的待探索區域，並且軍事（潛艦航行）和經濟（石油與金屬礦）的目的驅使各界進行海洋地質學的研究並製作詳細的海底地圖。

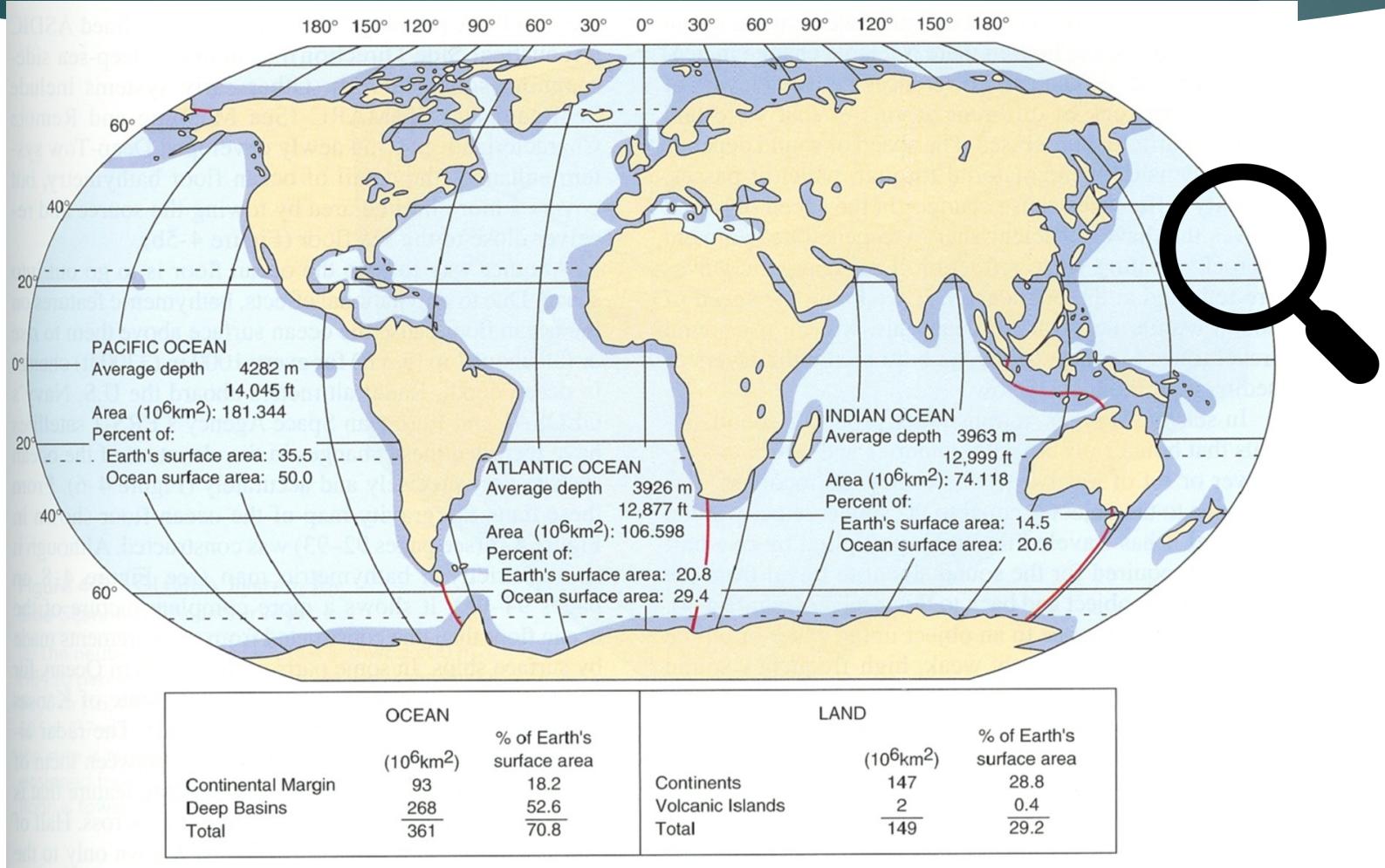
海洋地質 MARINE GEOLOGY

海洋地質地物探勘 海底形貌、海底擴張

王珮玲

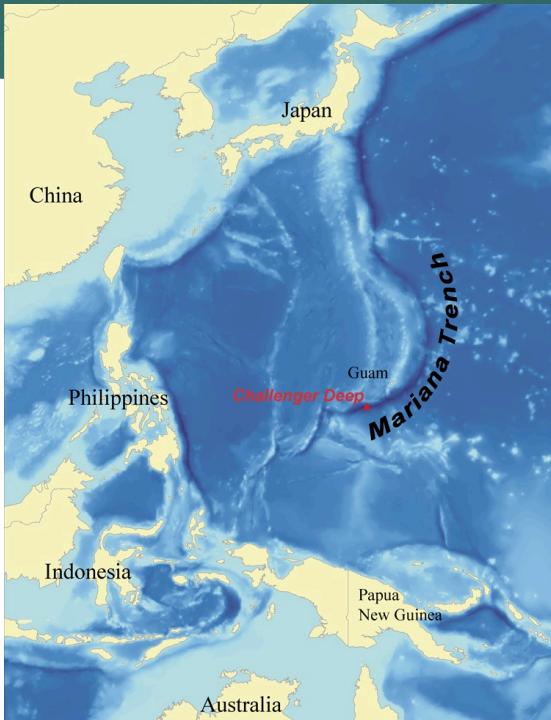
2021/10/15

海陸分佈



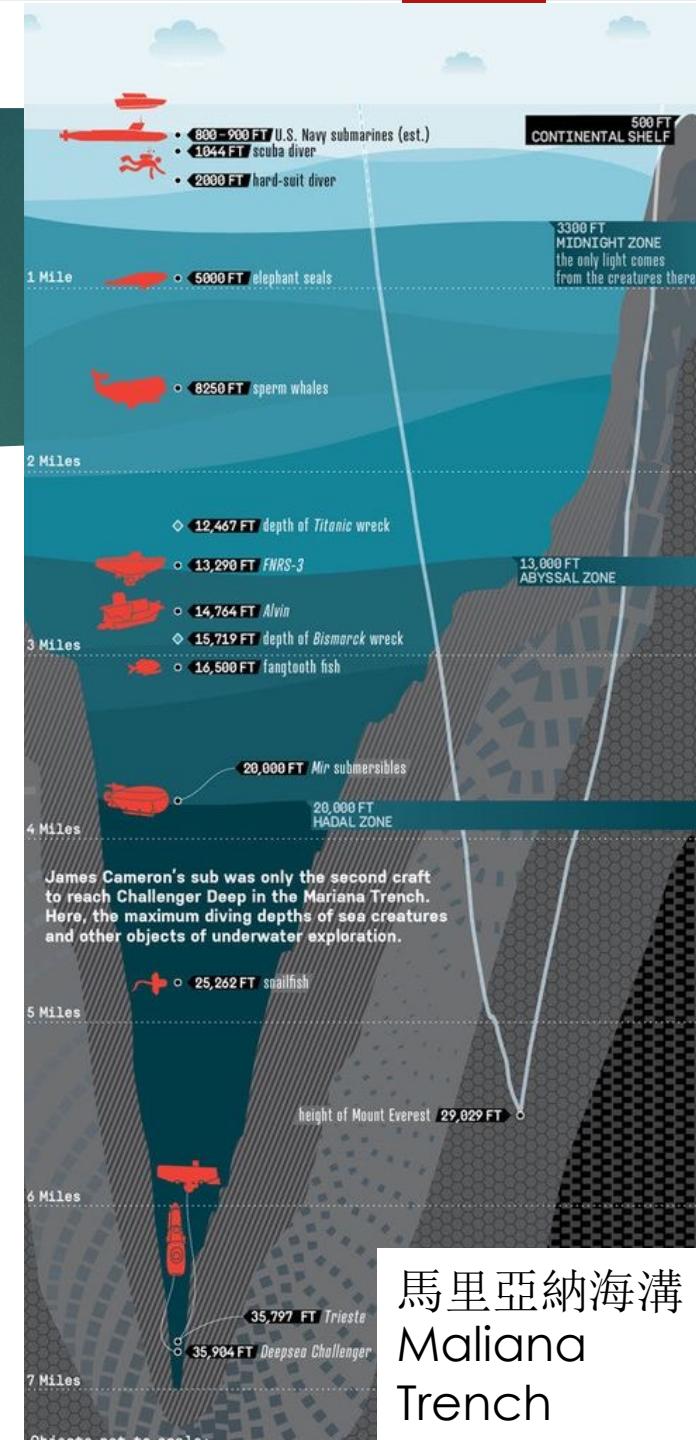
海底探勘：深度的挑戰

馬里亞納海溝為地球目前已知最深的海溝。
海溝地處西北太平洋的海床，位於關島和北馬里亞納群島東部。
海溝平均深度為 8000 m，最深處稱為挑戰者深淵，深度為 11,045 m。



載人潛艇 Human Occupied Vehicle (HOV)

- Trieste 的里雅斯特, USA
- Deepsea Challenger 深海挑戰者, Australia
- DSV Limiting Factor 限制因子, USA



馬里亞納海溝
Mariana Trench

Trieste

的里雅斯特

150 tons

Two pilots

Descent: 4 hours, 48 minutes;
Ascent: 3 hours, 15 minutes

Unable to take photos

20 minutes at the bottom

The first explorers to descend to the deepest part of the oceans were U.S. Navy Lt. **Don Walsh** 唐納德·沃爾什 and Swiss oceanographer and engineer **Jacques Piccard** 雅克·皮卡登。

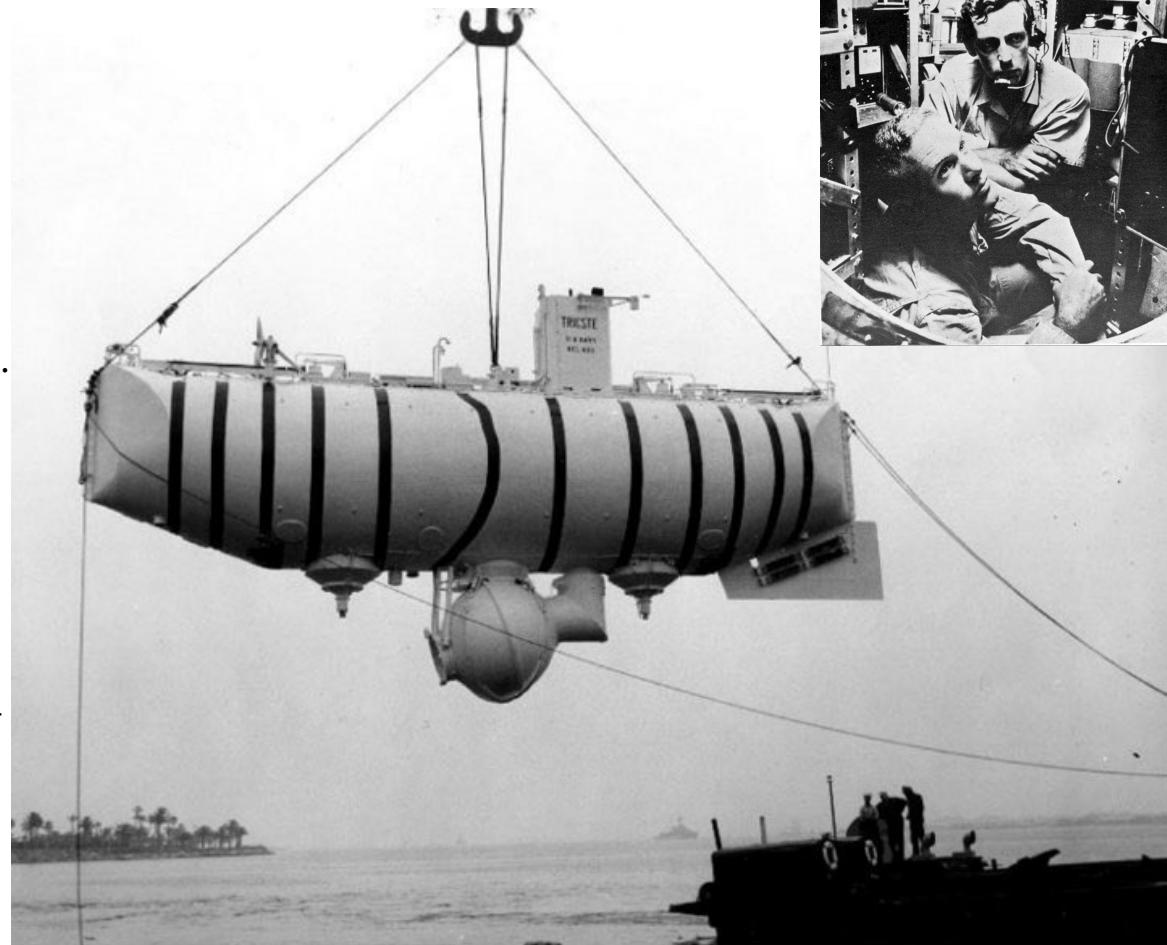
They made their journey on **January 23, 1960**, in the Swiss-designed, Italian-built, United States Navy bathyscaphe *Trieste*. After a descent that took almost five hours, they reached a depth of 35,800 feet (10,912 meters) in the Mariana Trench's Challenger Deep.

The *Trieste*'s Deepest Dive (2:05)

<https://youtu.be/hQ0P5OjE-5w>

The *Trieste*'s Deepest Dive (Extended) (22:38)

<https://youtu.be/AOfS-tzxZAs>



DEEPSEA CHALLENGER

深海挑戰者號

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On 26 March 2012, **James Cameron** 詹姆士·卡麥隆 piloted the craft reaching the Challenger Deep (10,908m).

STAY CONNECTED ▾



JAMES CAMERON'S
DEEPSEA CHALLENGE 3D

11.8 tons

Single pilot

Descent: 2 hour and a half hours; Ascent: 70 minutes

3 hours at the bottom



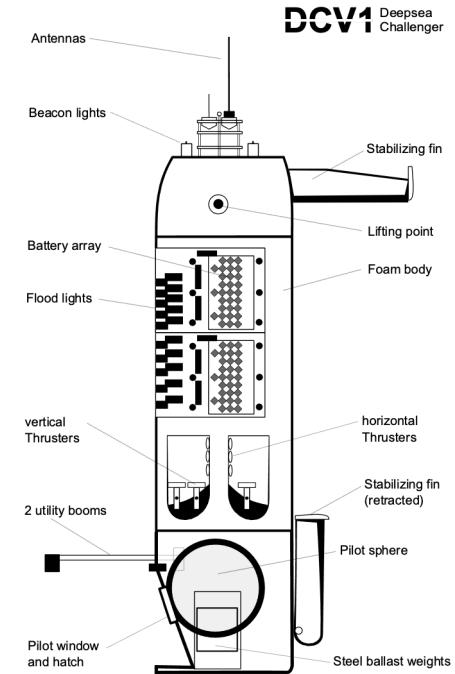
Scripps, U. Hawaii, JPL, Sloan Foundation
www.deepseachallenge.com

Long Way Down: Mariana Trench (2:04min)

<https://youtu.be/Y2tm4ouMhDI>

Cameron Dive First Attempt in Over 50 Years (3:37min)

<https://youtu.be/0mBG0LbAoqk>



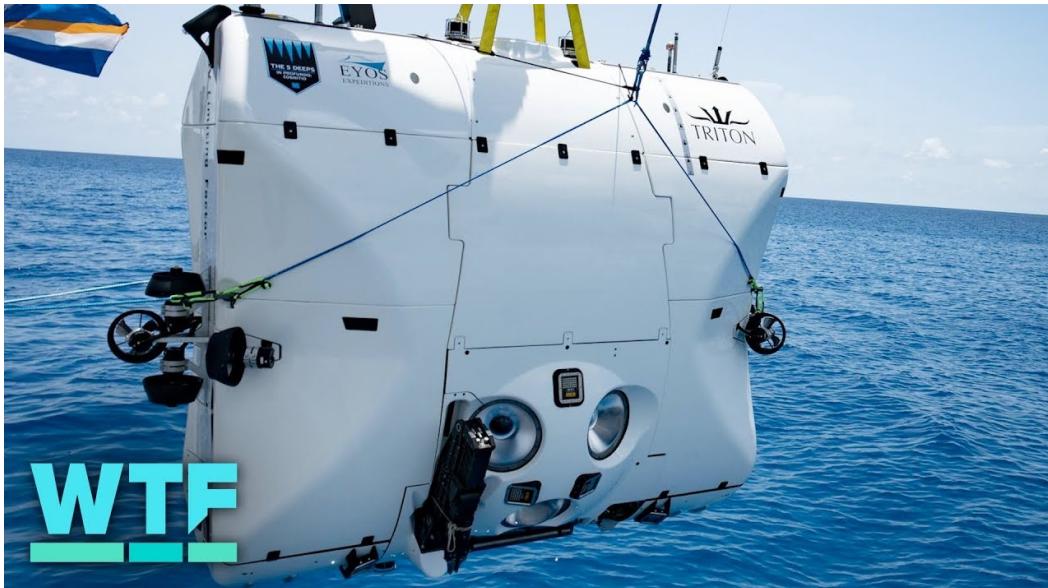
DSV Limiting Factor

限制因子

Five Deeps expedition

The world's first manned expedition to the deepest point in each of the five oceans.

Atlantic Ocean	Dec. '18	Puerto Rico Trench at 8,376 m
Southern Ocean	Feb. '19	South Sandwich Trench at 7,434 m
Indian Ocean	Apr. '19	Java Trench at 7,192 m
Pacific Ocean	May. '19	Mariana Trench at 10,925 m
Arctic Ocean	Aug. '19	Molloy Deep at 5,550 m



<https://fivedeeps.com>

Record-breaking Mariana Trench dive

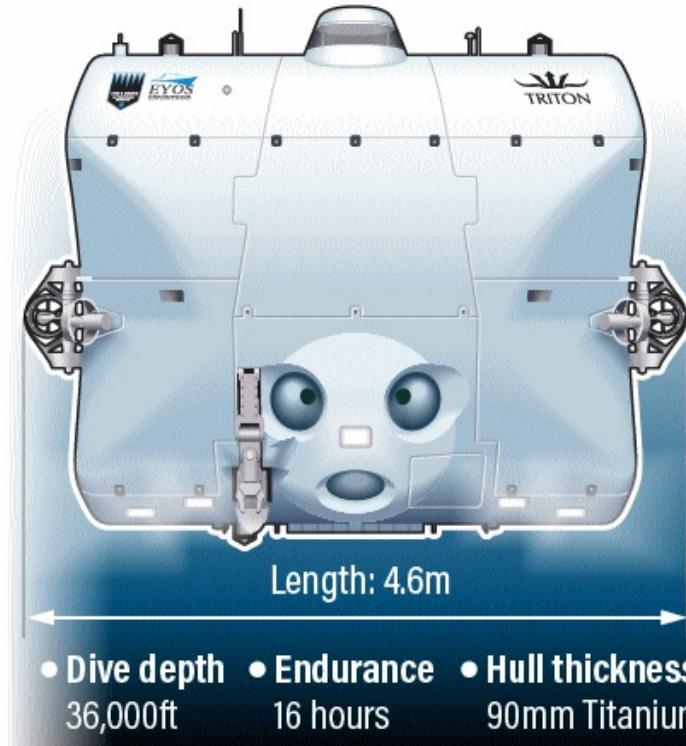
<https://youtu.be/VHEbdotlcFo>

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On Victor Vescovo's 維克多·偉斯柯沃 first dive in the Limiting Factor, he spent four hours at the bottom and found a spot deeper than either previous dive – 10,928 m (35,853 ft) below the surface.

DSV LIMITING FACTOR

Two-man vessel that is capable of diving to full ocean depth. It is the world's first and only manned-submersible



海底探勘：點與線的探索

載人潛艇 Human Occupied Vehicle (HOV)

manned research vehicle

Deep Submergence Vehicle (DSV)

- Alvin (阿爾文) , USA
 - Woods Hole Oceanographic Institution
 - www.whoi.edu/main/hov-alvin
- ShinKai 6500 (深海 6500) , Japan
 - Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
 - www.jamstec.go.jp
- Jiaolong (蛟龍號) , China

Alvin



Since 1964

Alvin enables in-situ data collection and observation by two scientists to depths reaching 4,500 meters, during dives lasting up to ten hours.



Alvin has made more than 5,000 dives, along the way participating in some of the most iconic discoveries in the deep ocean.

Dive Deeper: Alvin Takes You There (~5min)
<https://vimeo.com/album/4261384/video/191864911>

The Alvin Submarine Part 1,2,3 (~3min)
<https://youtu.be/a5aQ4W9GbpU>
<https://youtu.be/dXOQFnU-49k>
https://youtu.be/eUzz_ilxFa0

<https://www.youtube.com/watch?v=B6gG7pfSgao>

6:42min

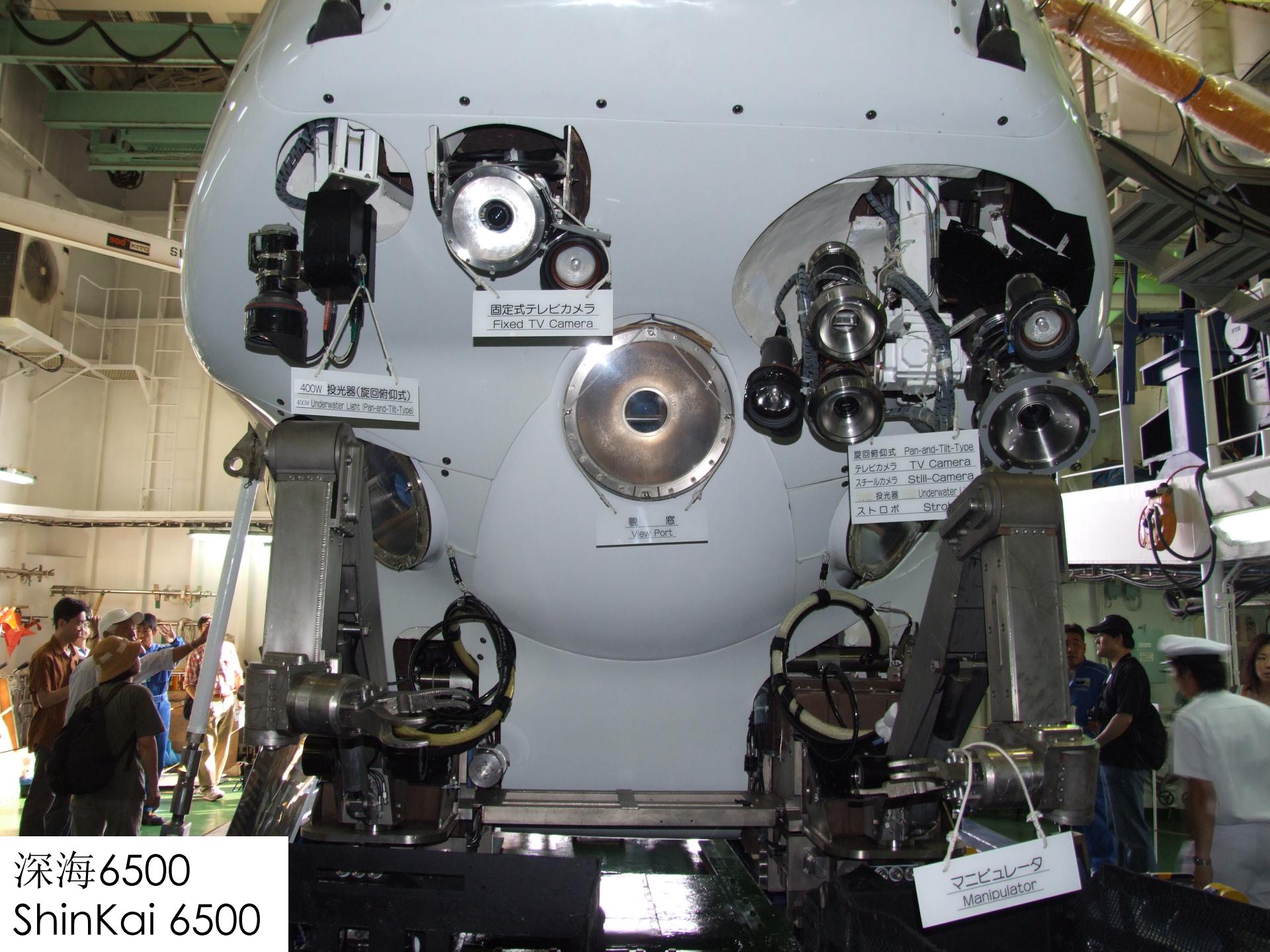


Since 1991

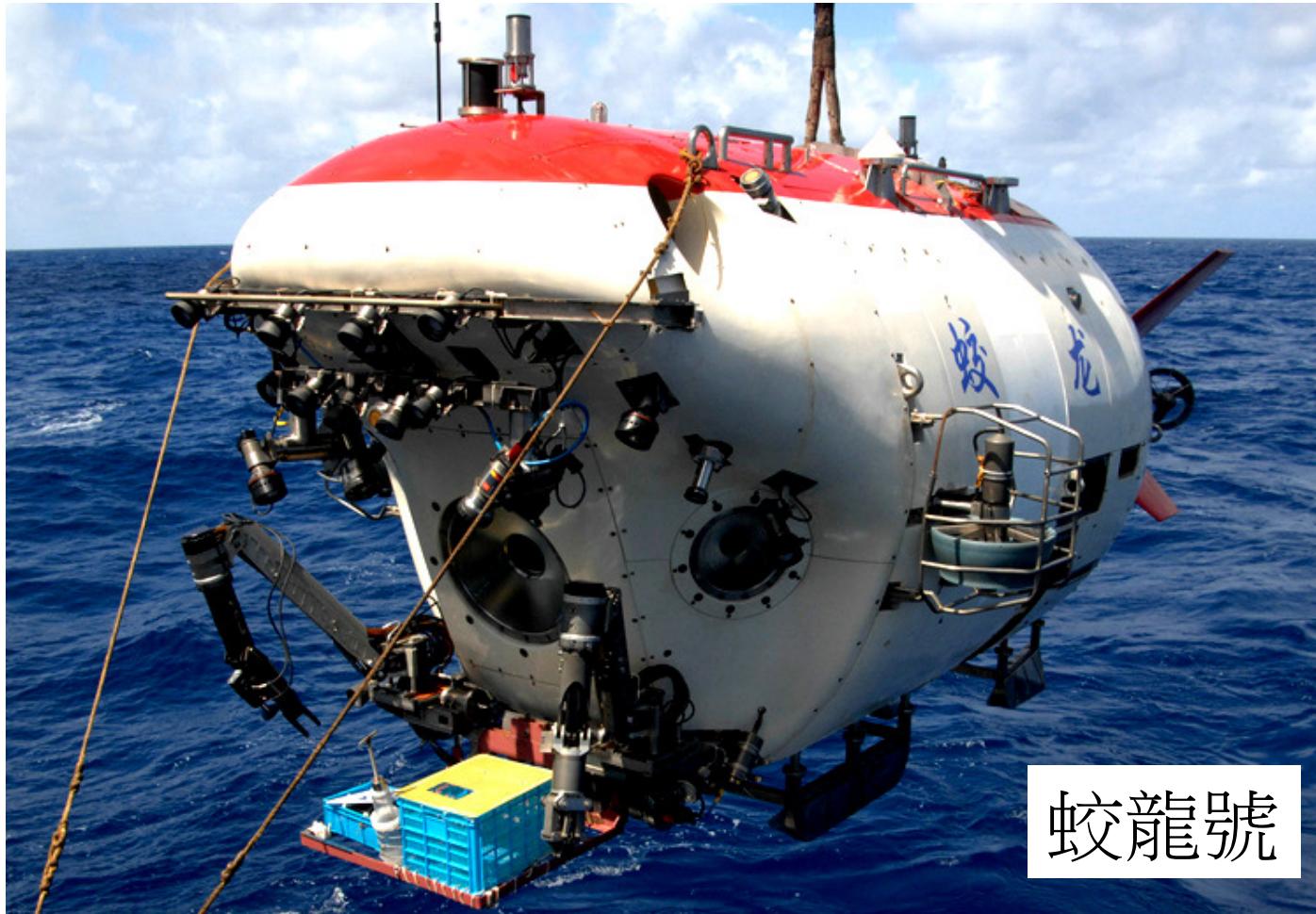
深海6500
ShinKai 6500



JAMSTEC 独立行政法人
海洋研究開発機構
JAPAN AGENCY FOR MARINE-EARTH SCIENCE AND TECHNOLOGY



深海6500
ShinKai 6500

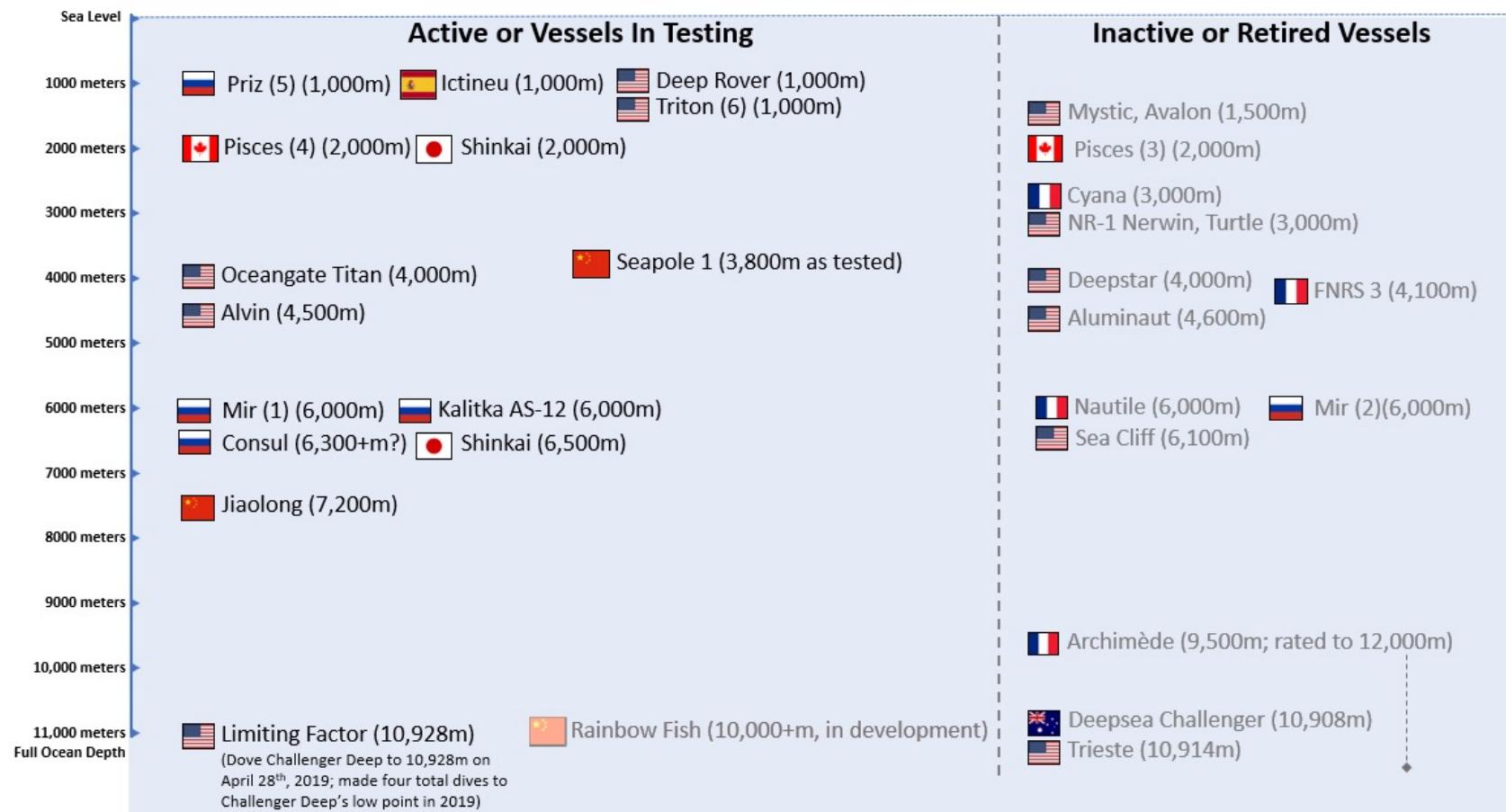


Jiaolong is a Chinese manned deep-sea research submersible that can dive to a depth of over 7000m.

On June 27, 2012, the Jiaolong with two oceanauts reached a depth of 7,062 meters (23,169 feet) in the Mariana Trench in the western Pacific Ocean.



Worldwide Deep Submergence Vehicles (As of May 7, 2019)



Go deeper?

Currently rated to 4,500m, which gives researchers in-person access to about 2/3 of the ocean floor, the most recent upgrade increased the depth rating of many of the vehicle's systems, making it just steps away from having a depth rating of 6,500m, or approximately 98% of the seafloor.

水下無人載具 (ROV, AUV)

- ▶ Remotely Operated underwater Vehicle (ROV) 遙控潛水器
- ▶ Autonomous Underwater Vehicles (AUV)
自主水下載具





遙控潛水器 (Remotely operated underwater vehicles, ROVs)

是一個無人的水下航行器，以電纜連接到母船的人員操作。常搭載水下光源和照相機、攝影機、機械手臂、聲納等。因為具有機械手臂，所以又稱為水下機器人。

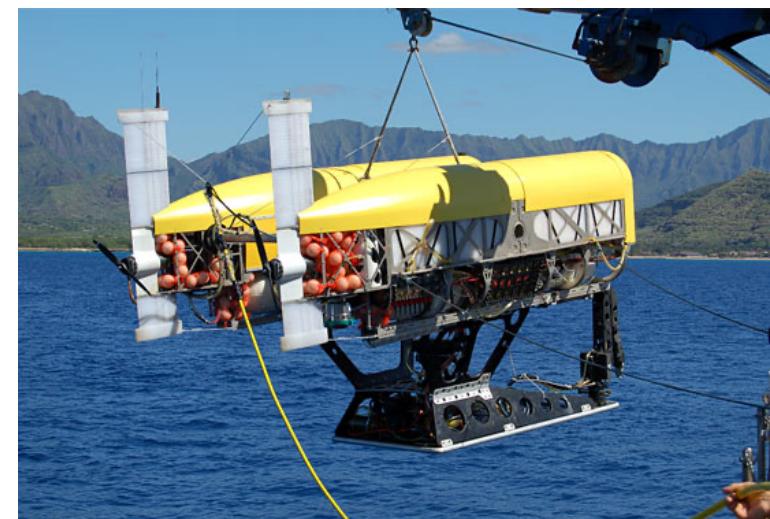
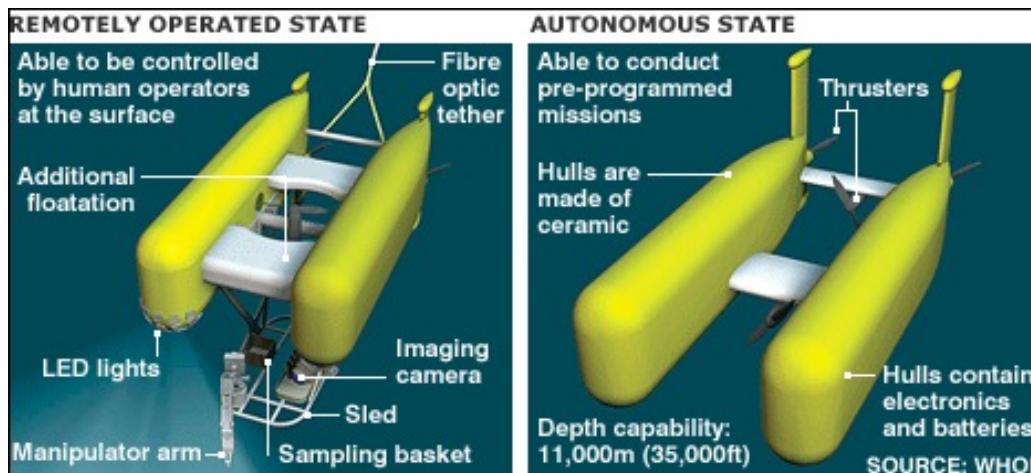
自主水下載具 (Autonomous Underwater Vehicle，縮寫AUV)

是無人水下載具的一種，外型可像一小型潛艇或魚雷，它沒有以電纜連接到母船或外部的操作者，而依據控制器編程以自動執行其任務。

因為所有的工作都是自動的，自主水下載具適合長期性、例行性、或具危險性的工作，例如探索油田、海圖、海洋學研究、排除水雷等。

水下自主載具在科學研究上有很多廣泛的應用，可幫助科學家調查湖、海、海床等大型水域及水下地形。根據不同調查環境與目的，機體可搭載多種傳感器以便量測水中元素、化合物之濃度、光的反射、吸收與微生物生態。另外也可作為運送定置型儀器之底拖載具。

海神號 (Nereus) 是一部由美國伍茲霍爾海洋研究所 (WHOI) 製造的混合型水下機器人 (HROV，遙控潛水器和自主水下載具的混合)。可在水下11,000公尺 (36,000英尺) 進行作業，並探測世界大洋的最深處太平洋馬里亞納海溝挑戰者深淵。海神號是以希臘海神的名字命名的。它於2009年5月開始了它到深海挑戰者深淵的航行，在2009年5月31日到達了最深處。

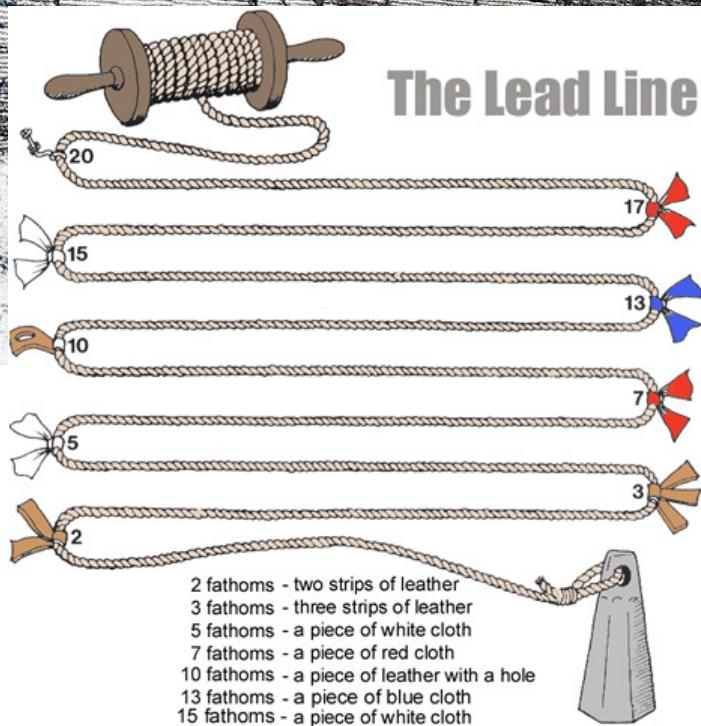
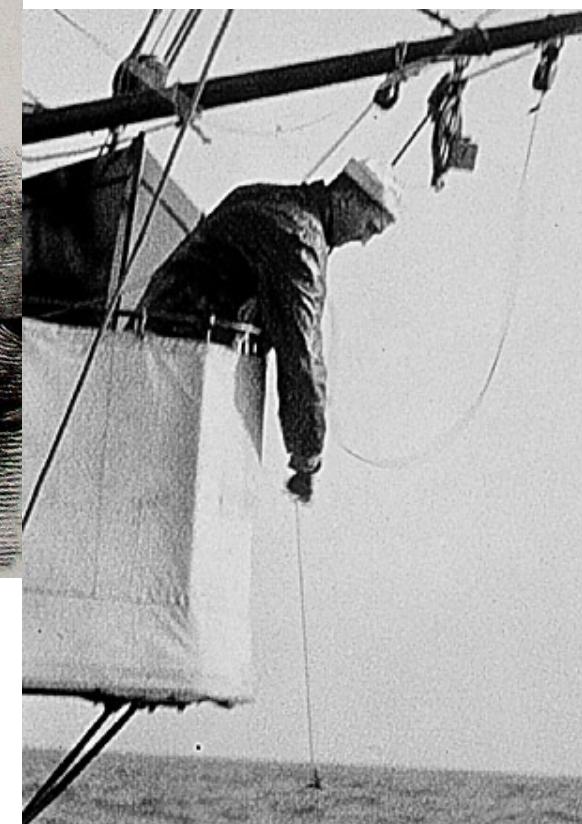


The deep ocean is the final frontier on planet Earth |
The Economist (~15min)
<https://youtu.be/p0G68ORc8uQ>

海深測量 (Bathymetry)

- ▶ 海深測量是量測水面到水下特徵的深度，就像是地形測量是量測陸上特徵的高度。
- ▶ 海深測量技術 (Bathymetric Techniques)
 - ▶ 測深繩 (Sounding Line)
 - ▶ 聲波 (Sonar)
 - ▶ 震波 (Seismic)
 - ▶ 重力 (Gravity)

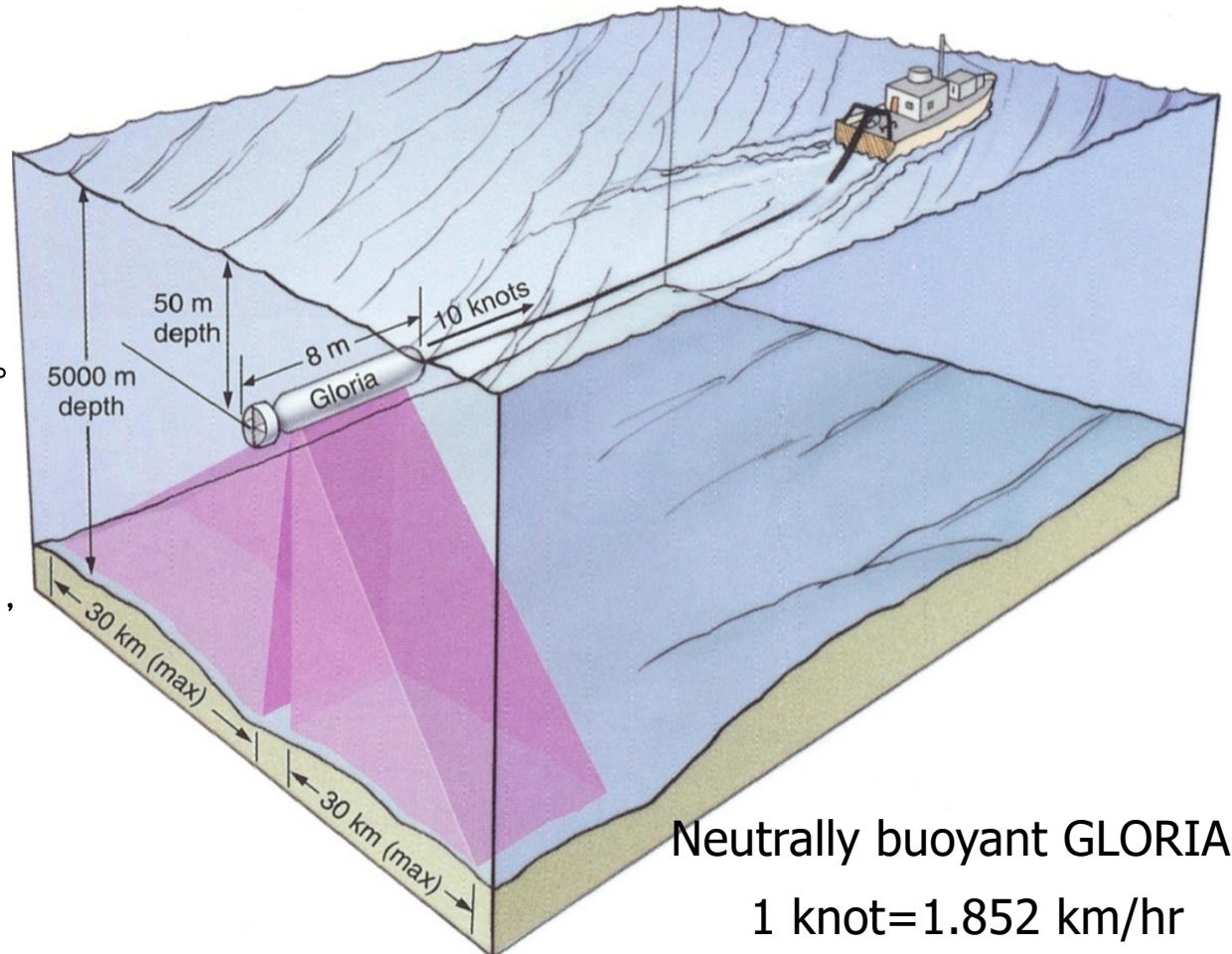
Seaman paying out a sounding line during a hydrographic survey of the East coast of the U.S. in 1916.



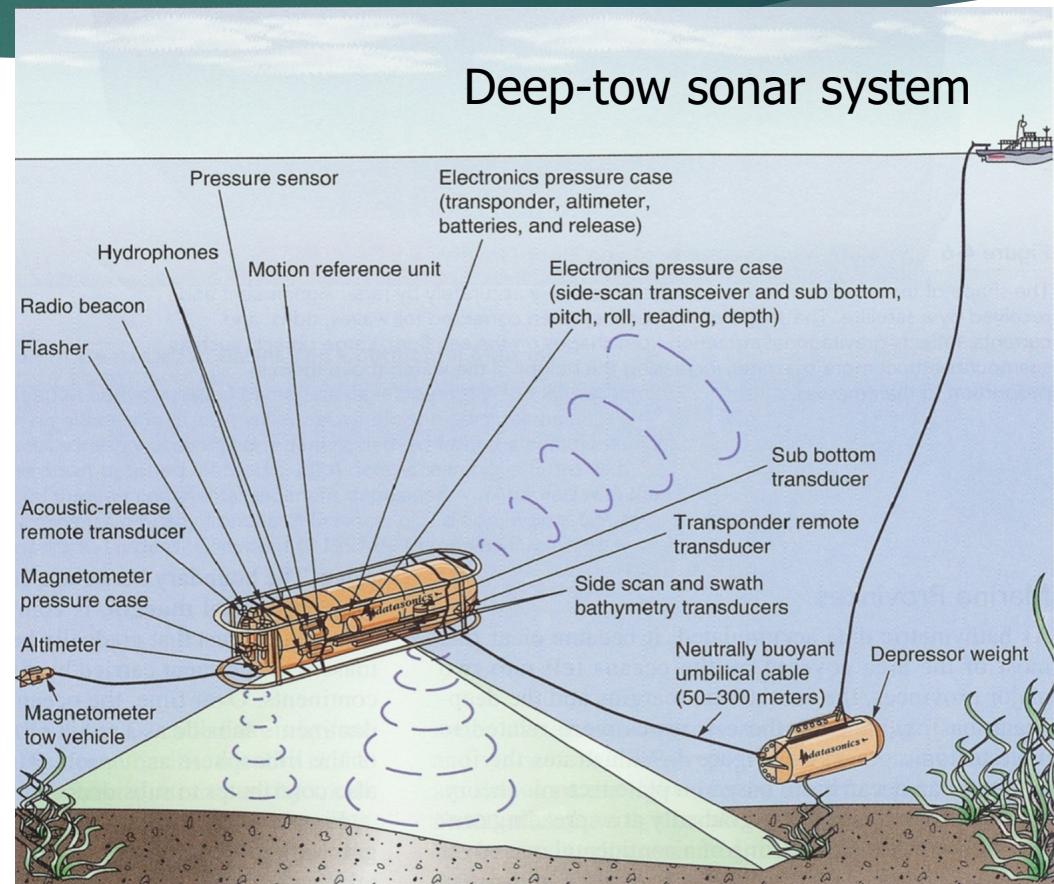
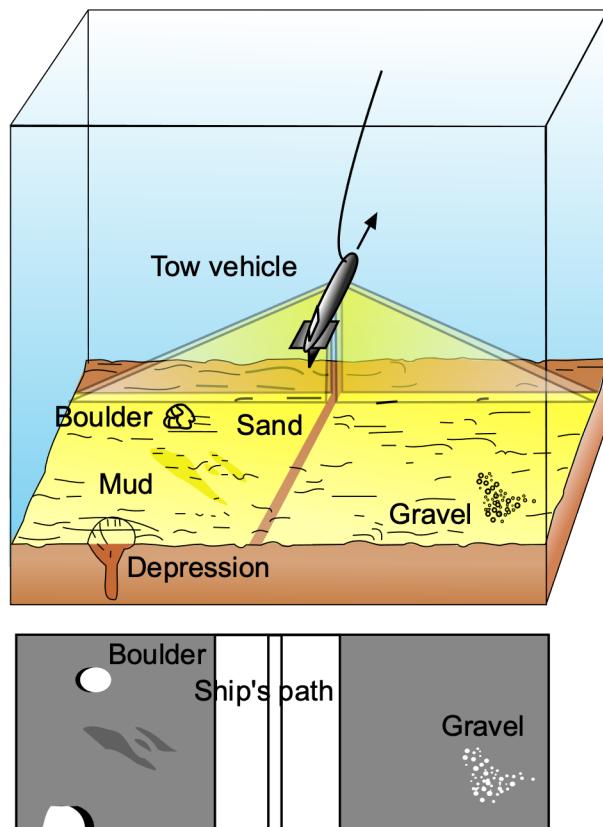
<https://www.e-education.psu.edu/natureofgeoinfo/book/export/html/1840>
https://en.wikipedia.org/wiki/Depth_sounding
<http://oneillseaodyssey.org/navigation/navigationdepth/>

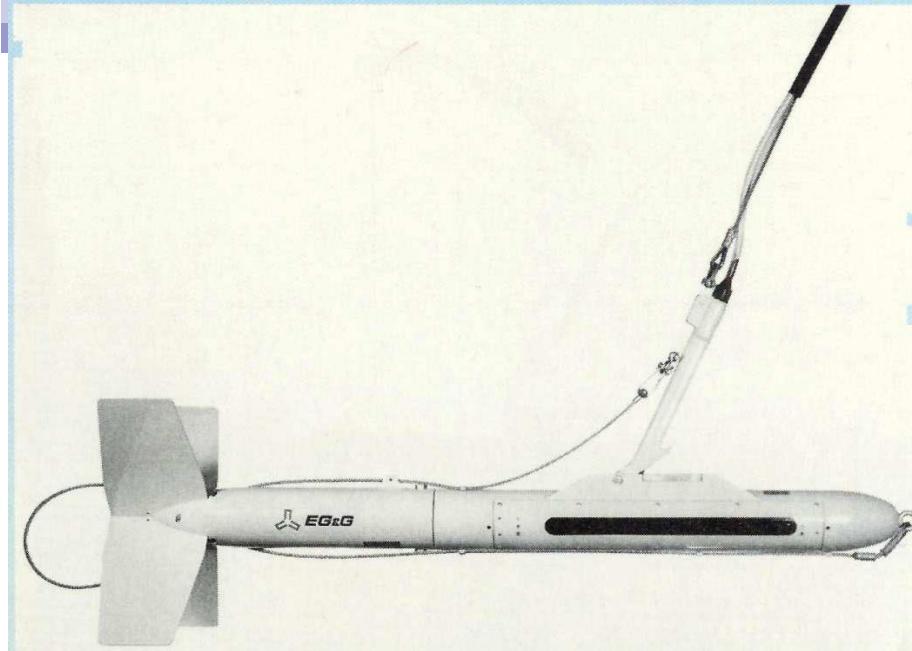
測掃聲納 (Side-Scanning Sonar Surveys)

聲波受到物質間不同密度的影響，而聲速則與其通過物質的密度有關。決定到水下或海床上物體的距離，可以使用測深儀(音響發聲器，sounder)產生的回音中，相對較弱、頻率較高的聲音訊號。

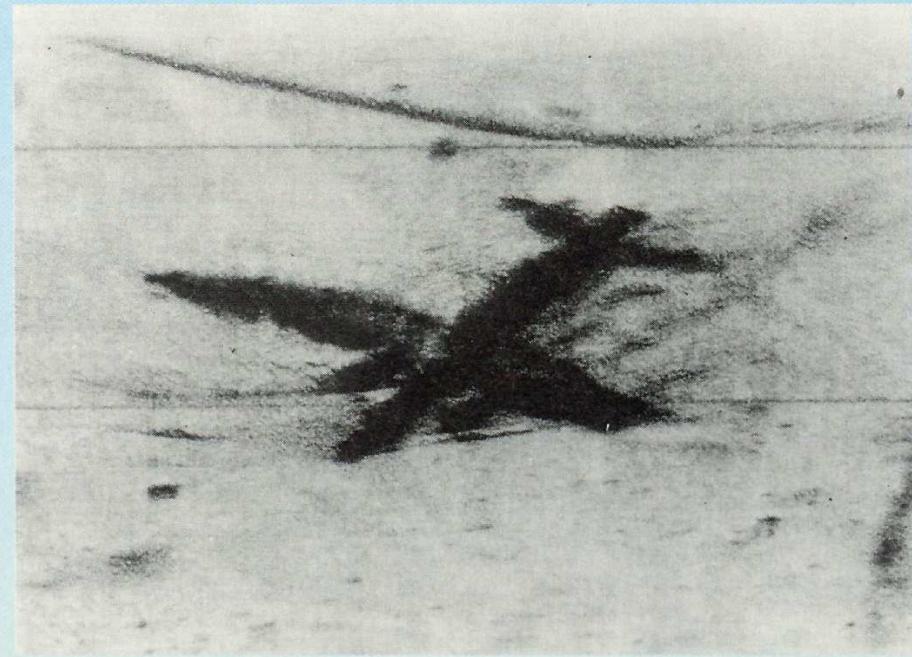


測掃聲納 (Side-Scanning Sonar Surveys)





a



b



c

FIGURE 5 Side-scan sonar device and images.

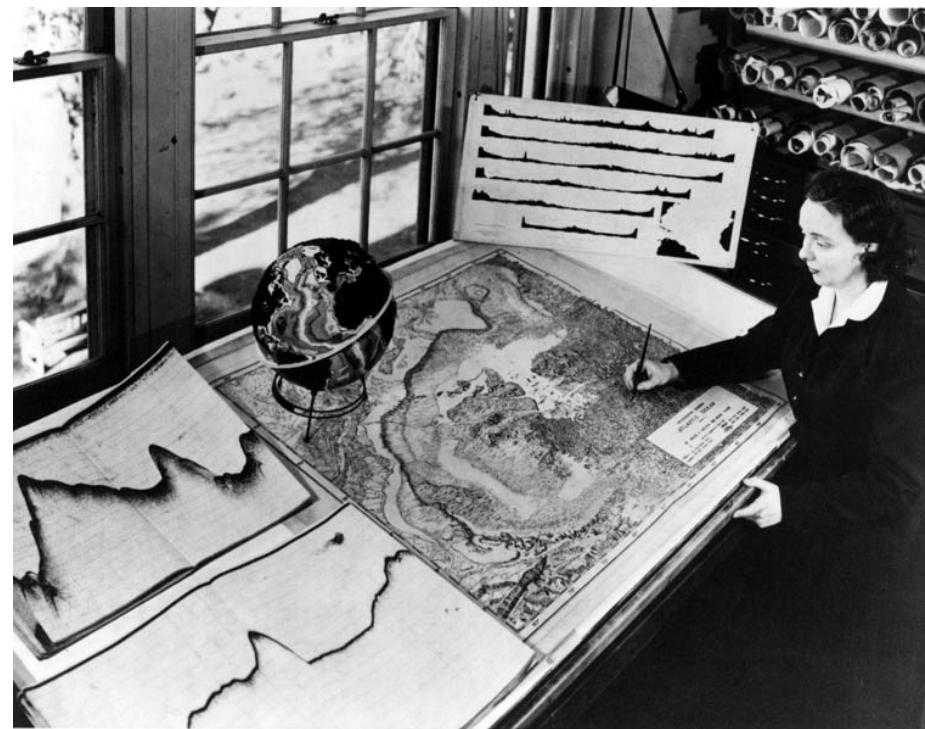
- (a) A towed side-scan sonar device.
- (b) Side-scan sonar record showing an aircraft on the bottom of Loch Ness in Scotland. The device unfortunately did not spot the famous but elusive Loch Ness monster.
- (c) Side-scan sonar record showing an old wooden sailing barge in the Great Lakes. (Photograph (a) courtesy of EG&G Company; photographs (b) and (c) courtesy of Klein Associates, Inc.)

測掃聲納

Marie Tharp & Bruce Heezen

薩普和希森

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Mapping the world ocean floor that
changed the world (1956-1977)

Watch: BBC interview

World Ocean Floor

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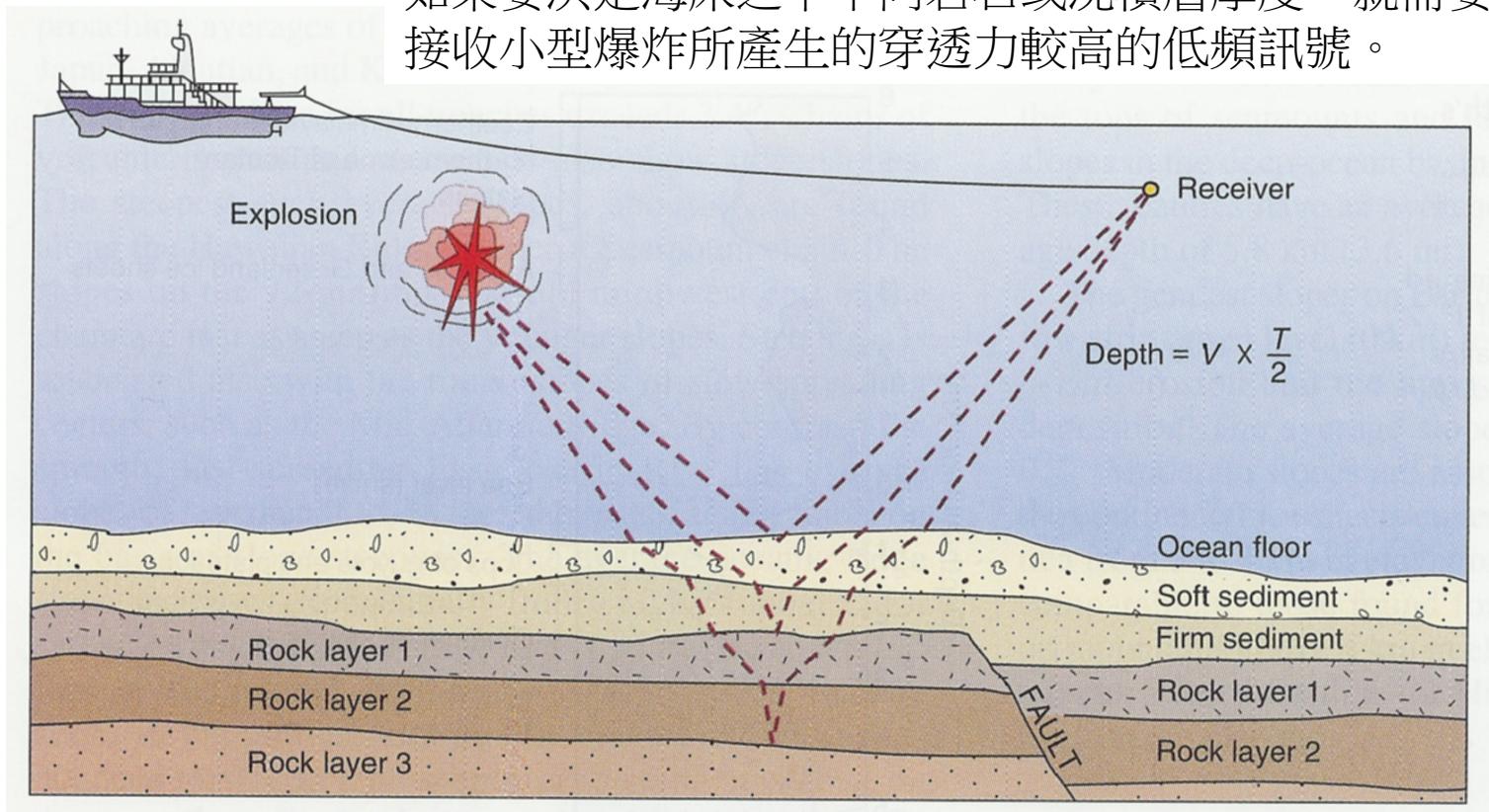


The 1977 World Ocean Floor Map created by Bruce Heezen and Marie Tharp

震測剖面 (Seismic Profiling)

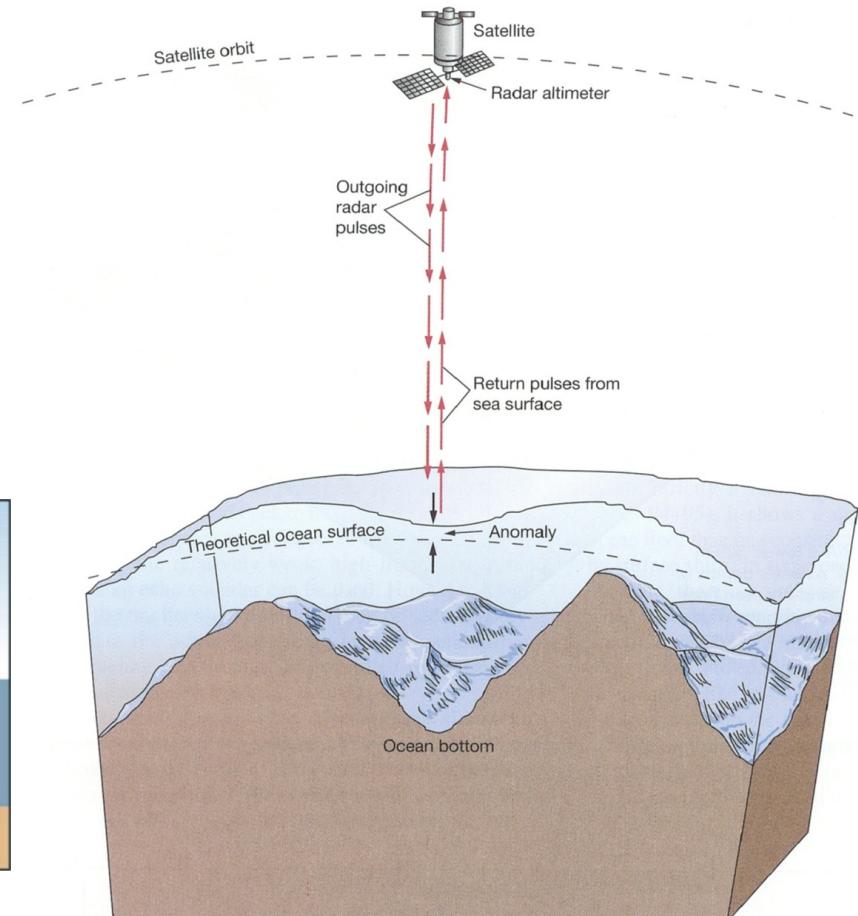
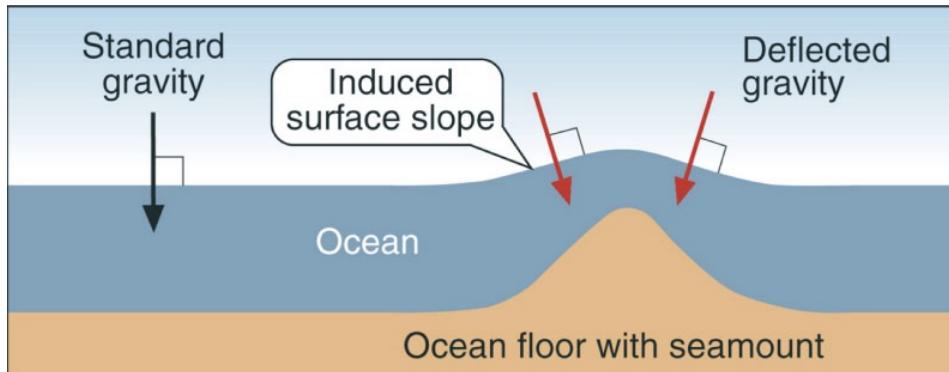
不同種類的震波探測可以用來決定岩石與沈積物界線的位置和形狀。

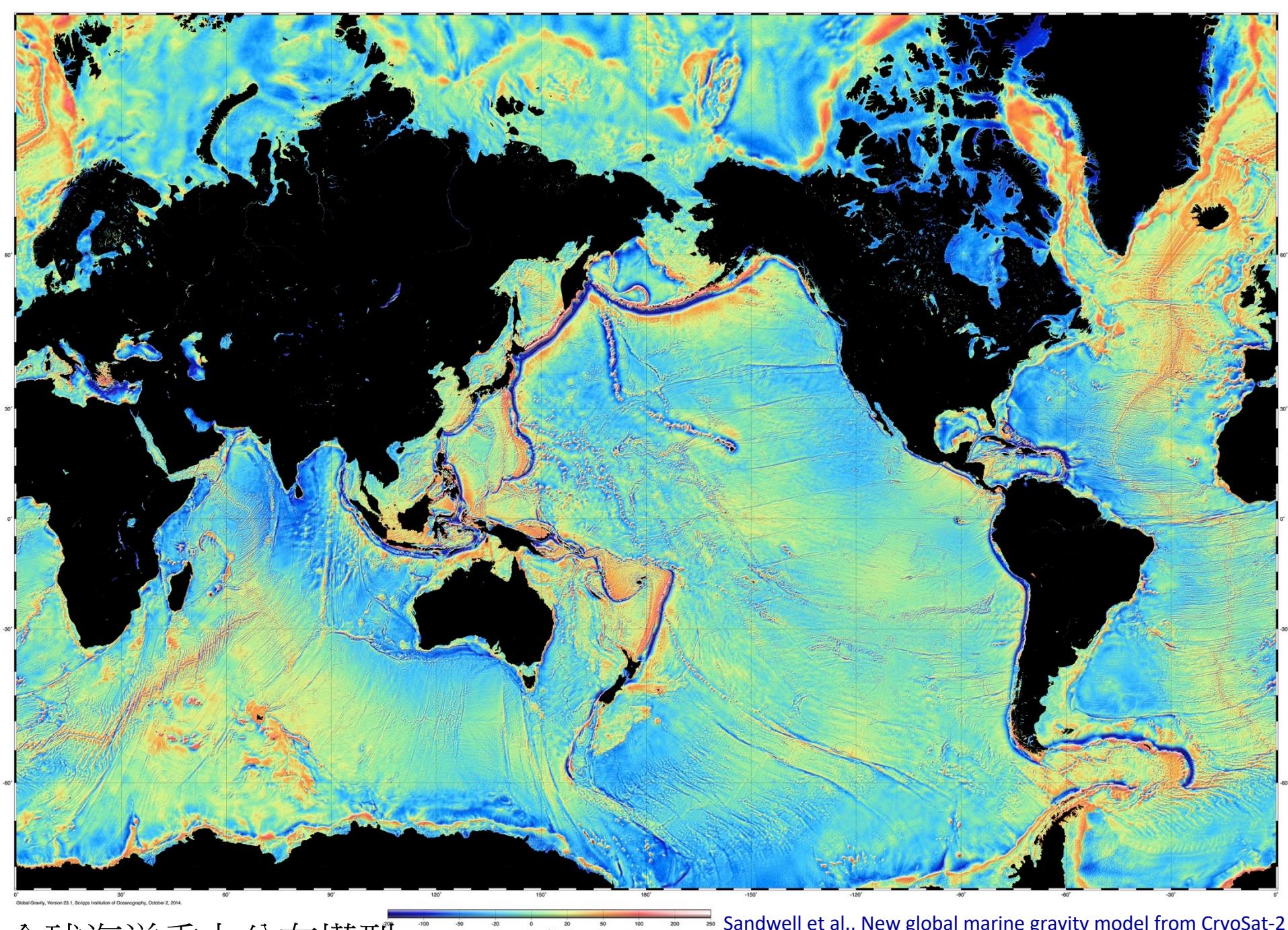
如果要決定海床之下不同岩石或沈積層厚度，就需要設定接收小型爆炸所產生的穿透力較高的低頻訊號。



衛星測量海床重力 (Satellite Measurements of Sea Floor Gravity)

受到重力作用影響，海床的海深測量特徵會造成海水表面約一米的升降。架設在衛星上的雷達測高儀 (radar altimeters) 可以準確又精密的記錄海水表面的高度變化。



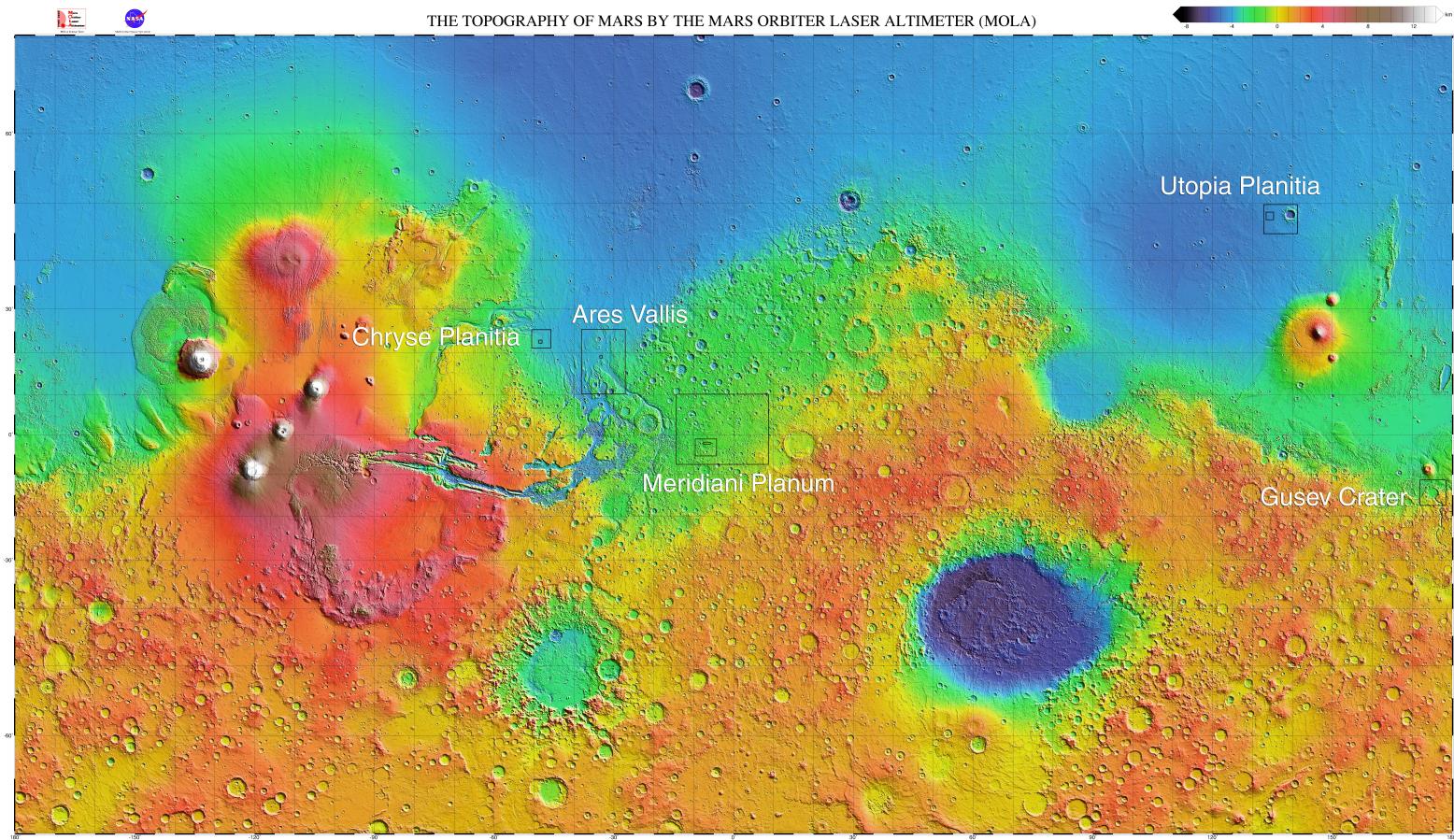


全球海洋重力分布模型

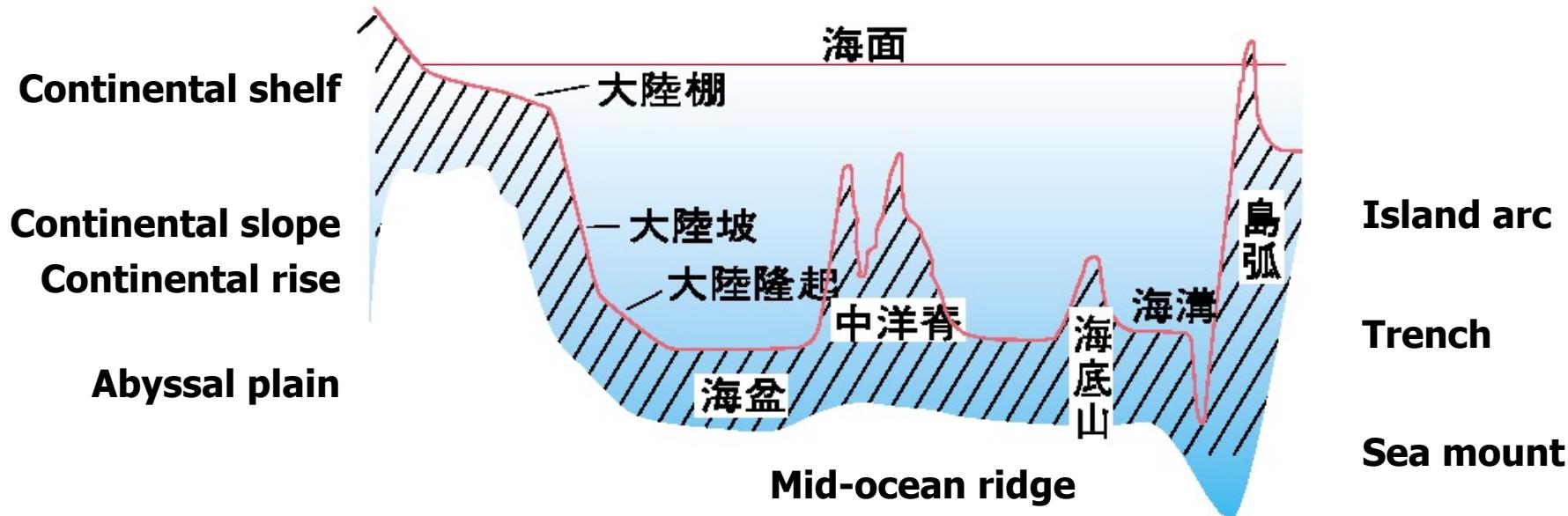
Sandwell et al., New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure, Science, 2014

海底形貌 海盆的形成與演化

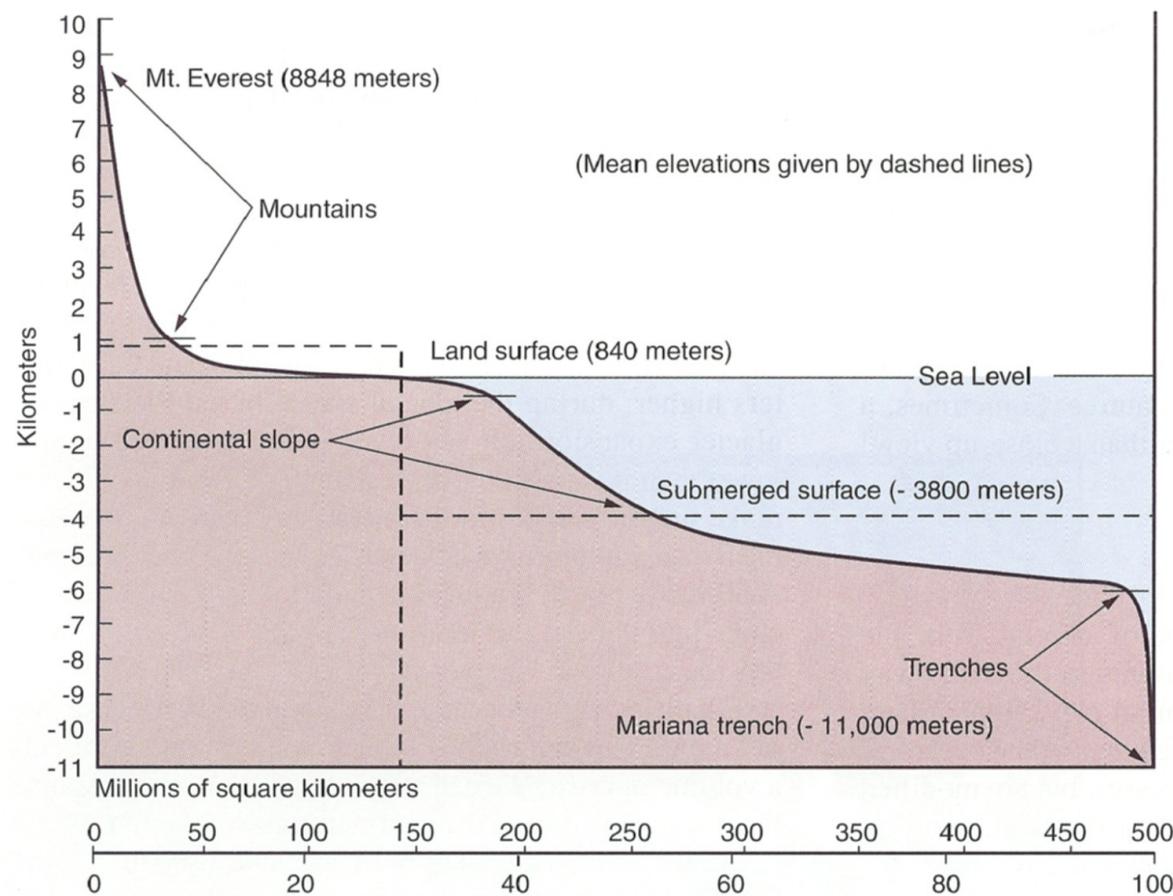
火星的地形 The Topography of Mars



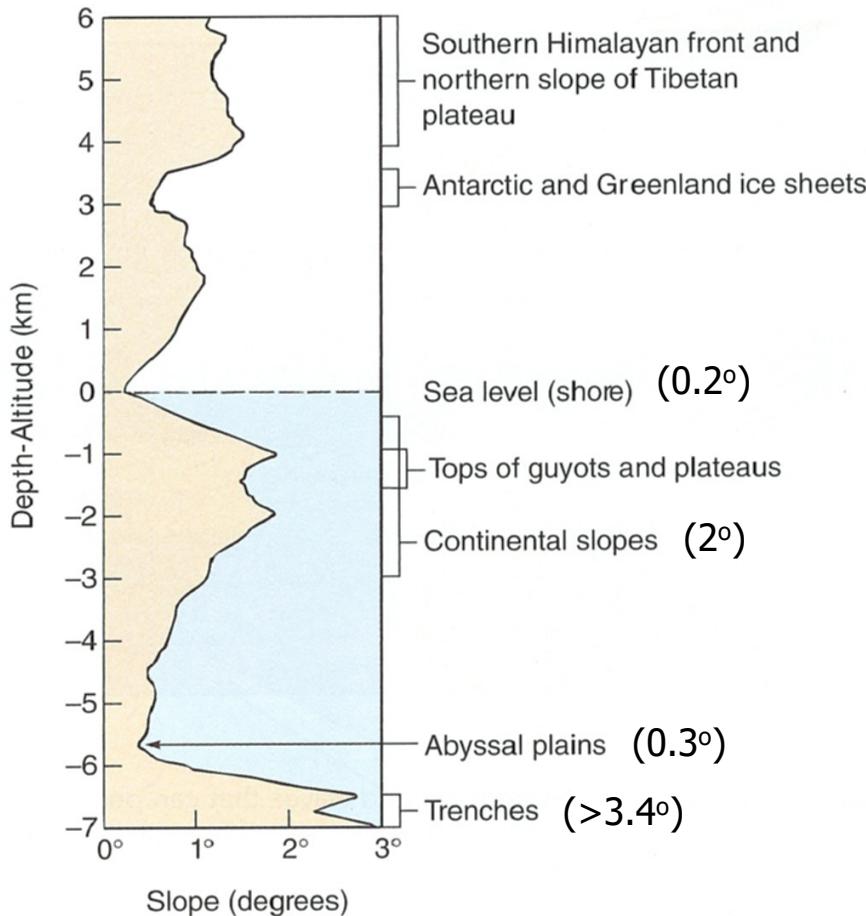
海底主要地形剖面



高度深度分佈曲線 Hypsographic Curve



地表坡度 Slopes on Earth's Surface



海洋中坡度陡的地方出現在海溝、火山和中洋脊等處，而坡度緩的地方則出現在海岸。

坡度變化

海溝內側

約為 **5°**(平均坡度最陡處)。
火山島和海底山

約為 **4°**

中洋脊

分裂速度為 **2-3 cm/yr: 1°**

分裂速度為 **10 cm/yr: 0.1°**

海盆的形成與演化

學說演變的歷程

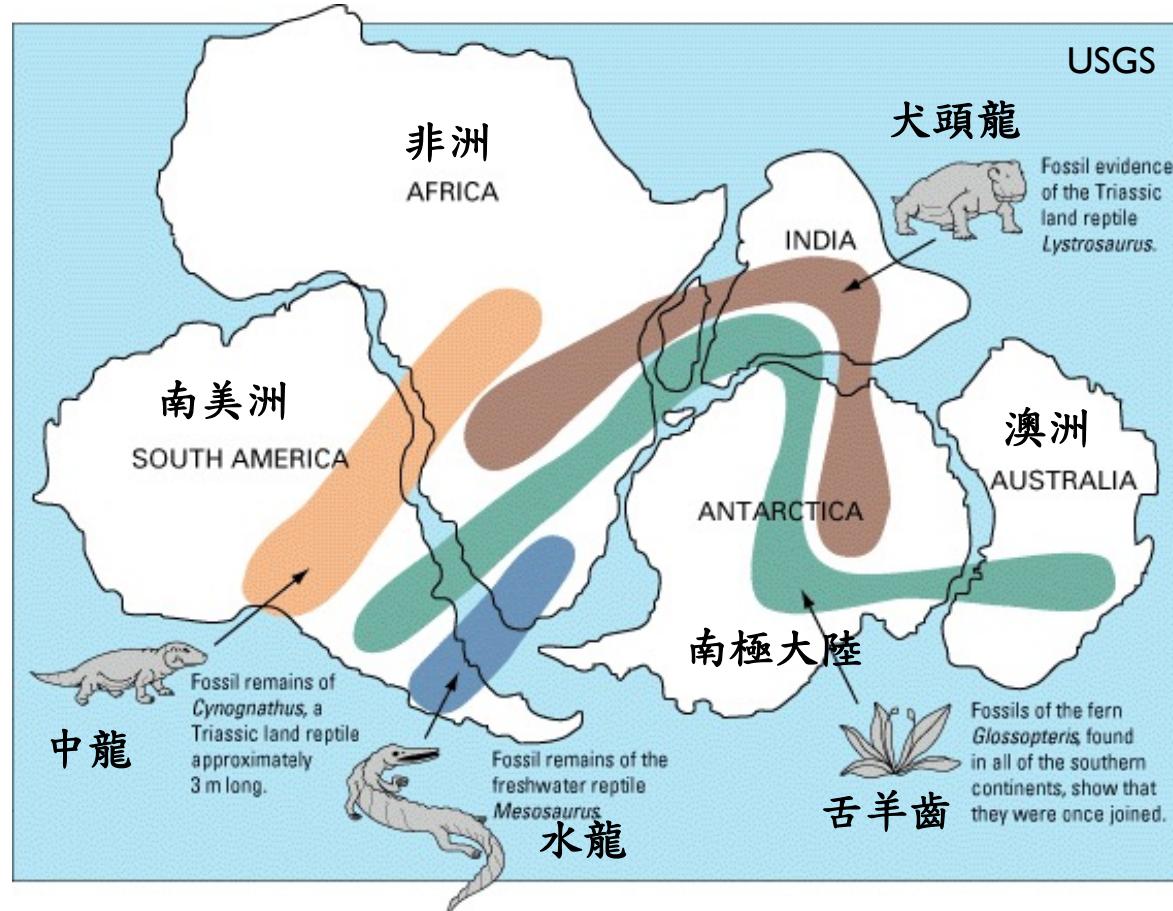
- 大陸漂移學說 Continental drift
- 海底擴張學說 Seafloor spreading
- 板塊構造學說 Plate tectonics

大陸漂移學說 Continental Drift

- ▶ 1921年德國天文、氣象學家韋格納 (Alfred Wegener) 首先提出。
- ▶ 論點：所有的大陸在兩億年前曾結合在一起，成為盤古大陸 (Pangaea)，約在1億8千萬年前開始分裂漂移，而形成目前的形狀。
- ▶ 證據：(1)古生物：爬蟲類、陸生動物（蝸牛、蚯蚓）、羊齒植物(2)古氣候：冰川、沙漠、煤層、珊瑚礁 (3)地質構造

Fossils across the continents

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在非洲、南美洲、印度、南極大陸和澳洲等地，可以找到一些老於兩億年陸生的動植物化石，這些化石目前分布很廣，若將各大陸拼合回去以後，可以發現這些動植物的分布是十分接近且很有規律的。

韋格納 Alfred Wegener

1880-1930



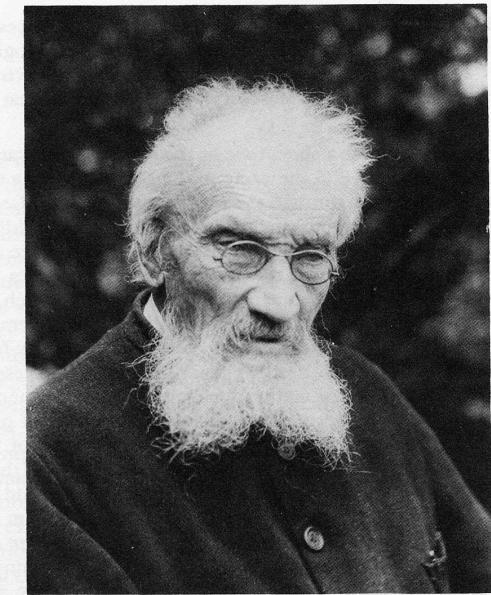
Alfred Wegener in 1910.



1915年韋格納出版《陸地與海洋的起源》
 The Origin of Continents and Oceans
 (1924 translated to English)

1924年韋格納與柯本出版《古氣候學》

柯本 Wladimir Koppen



The well-known climatologist, Wladimir Köppen, Wegener's father-in-law and collaborator, at the age of seventy-eight.

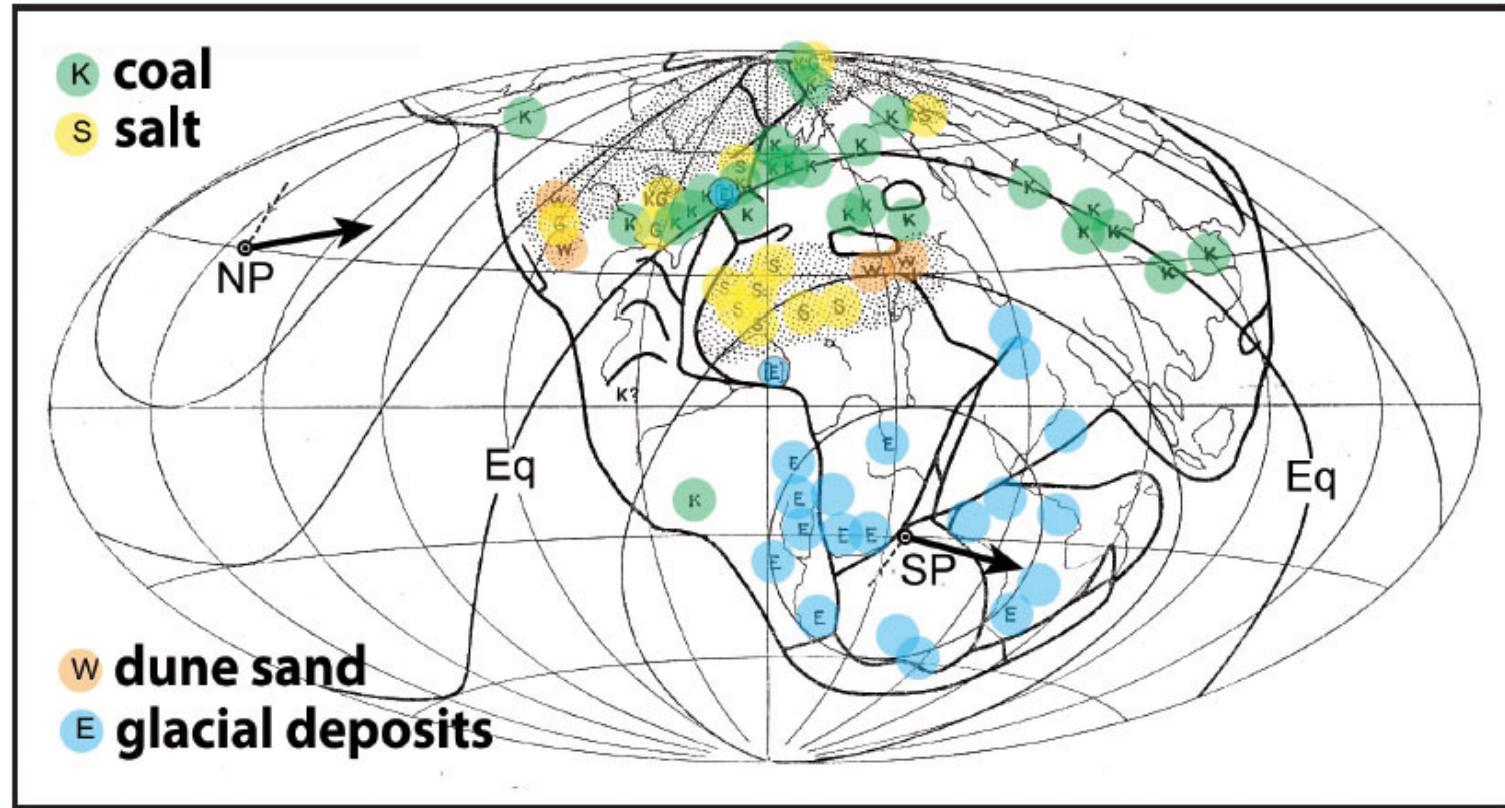
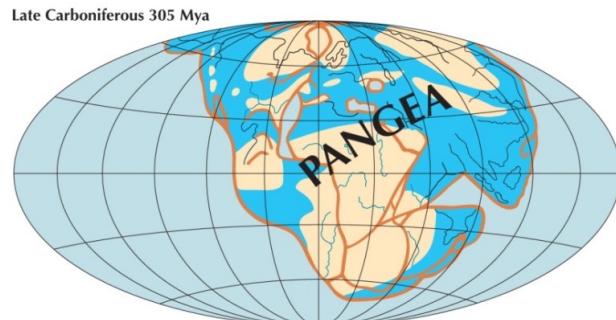


Figure 2. Paleogeographic map for Carboniferous time modified from *Climates of the Geologic Past* by Köppen and Wegener (1924), showing paleoclimate indicators (colour dots added). SP and NP are the south and north poles, with arrows indicating directions of polar wander inferred from eastward younging of glacial deposits. Stipple indicates desert regions. Mid-latitude coals contain trees with annual rings; trees in equatorial coals lack rings. Blue dots without 'E' (Eis) are glacial deposits unknown in Wegener's time. Note the lone blue dot on the paleoequator representing the Squantum Tillite near Boston, Massachusetts, then considered Carboniferous in age. Köppen and Wegener (1924) questioned its age or glacial origin, anticipating its reassignment to the Ediacaran ('Vendian') Period after 1982.

韋格納重建的大陸古地理位置

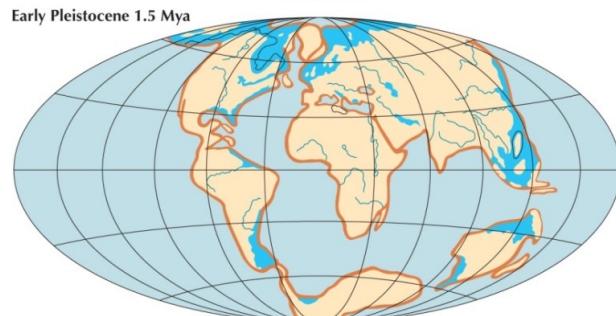
Pangea
盤古大陸



晚石炭紀
Late Carboniferous (about 300 million years ago)



始新世
Eocene (about 50 million years ago)

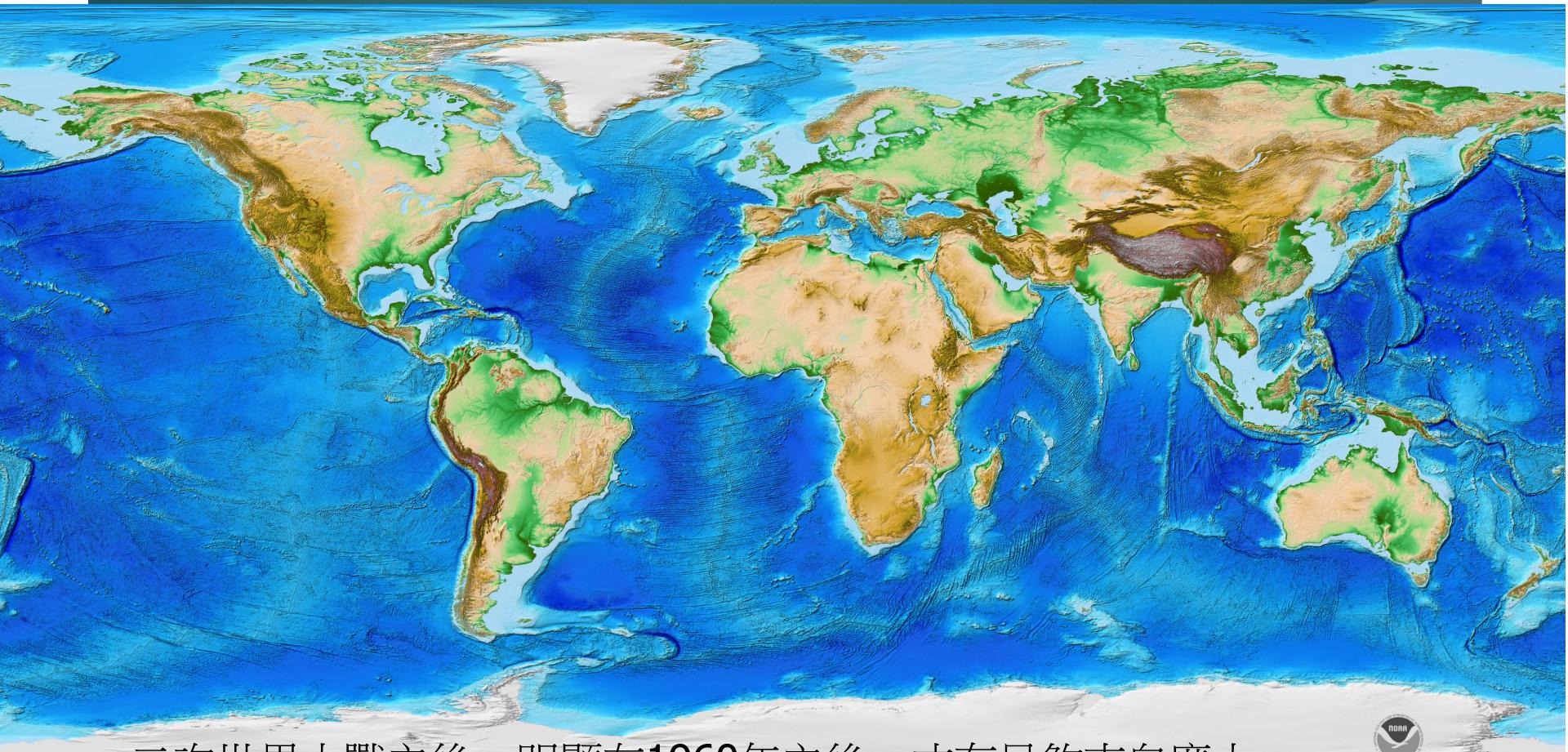


更新世
Pleistocene (about 1 million years ago)

大陸漂移 (Continental Drift)

- ▶ 在兩次世界大戰之間，支持大陸漂移與不支持大陸漂移的學者互相譏斥，但以不支持大陸漂移的學者佔上風。
- ▶ 從最初對韋格納論著質疑到**1960年**之間，關於大陸漂移的文獻其實非常少。
- ▶ 二次世界大戰之前，發展大陸漂移所需要的重要概念都是來自陸地。

海底擴張 (Sea-floor Spreading) 來自海洋的證據



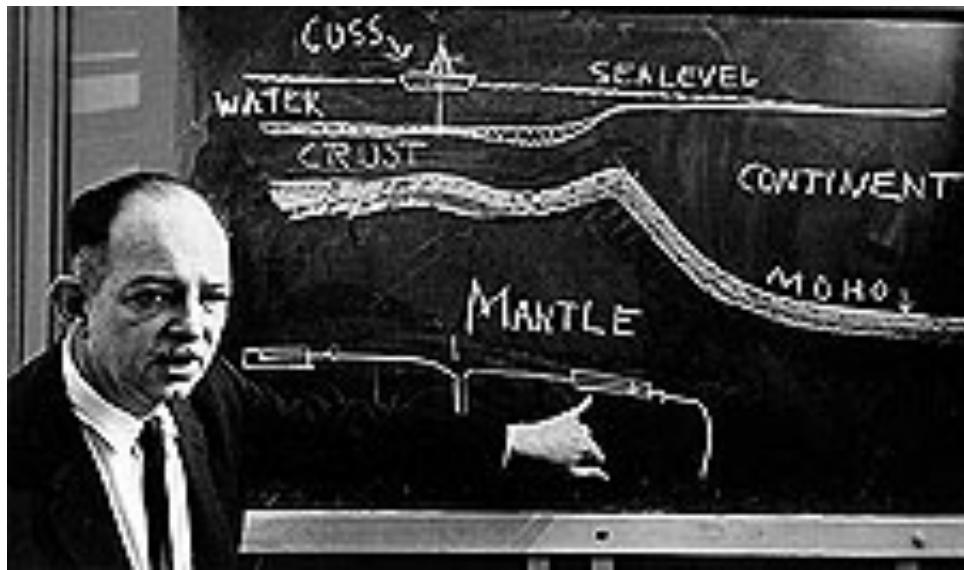
二次世界大戰之後，明顯在1960年之後，才有足夠來自廣大深海區域的資料加入，以瞭解海盆的起源和歷史。



海底擴張說 Sea-floor spreading

- ▶ 提出：1961-2年由美國普林斯頓大學教授海斯 (H. H. Hess) 和美國海岸及大地測量局的迪茲 (R. Dietz) 先後提出。
- ▶ 主要論點：認為推動大陸漂移的動力是由地函對流胞中下沈一邊的流動所帶動地殼產生側向移動，新的海洋地殼在中洋脊出產生，高溫的地函物質所形成的低密度之熱岩石使中洋脊地形隆起，隆起處之表面岩石又被張裡拉開而破裂，其裂口又被地函湧上來的新火山物質填滿，海底則像輸送帶一般向兩側分離，在地函對流胞輻合處海洋地殼被下拉形成海溝。
- ▶ 主要證據：
 - ▶ 1. 磁力異常之證據（地磁條帶狀條紋之建立）
 - ▶ 2. 海洋地殼之定年資料（中洋脊處年輕、海溝處年老）
 - ▶ 3. 沈積物的厚度（中洋脊處薄、離洋脊越遠越厚）

Harry H. Hess
1906-1969

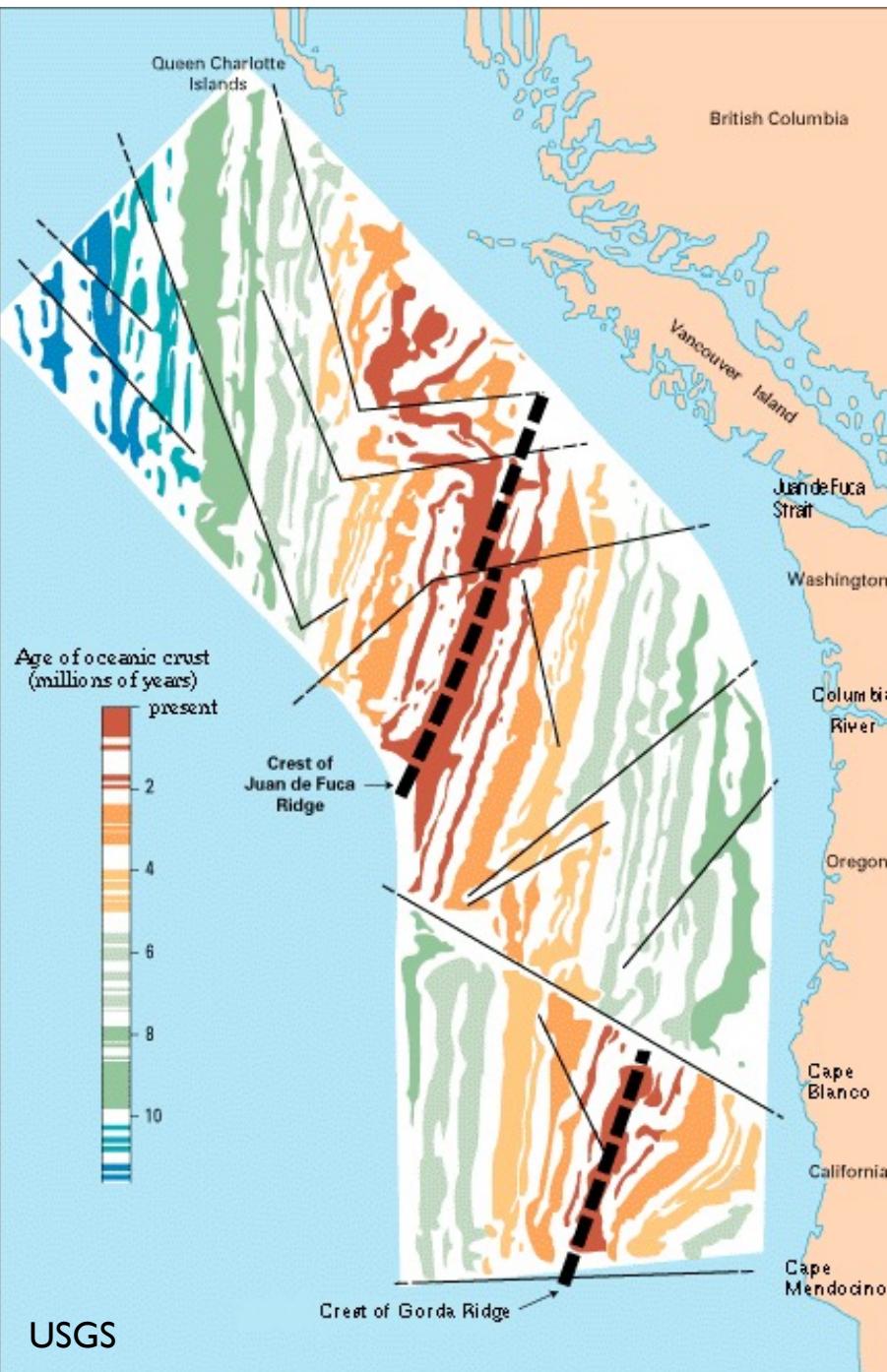


1946 Guyots (平頂海山)
1962 History of Ocean Basins (geopoetry)

Robert S. Dietz
1914-1995



16 December 1966, Volume 154, Number 3755



Spreading of the Ocean Floor: New Evidence

Magnetic anomalies may record histories of the ocean basins and Earth's magnetic field for 2×10^8 years.

F. J. Vine

blocks will be of essentially reversed polarity, and the width and polarity of blocks successively more distant from the central block will depend on the reversal time scale for Earth's field in the past.

Vine and Wilson considered that the bulk of the magnetization resides in a comparatively thin layer, 1 or 2 kilometers of basaltic extrusives and intrusives, coating a main crustal layer of serpentinite (8). If the frequency of extrusion and intrusion of this material is approximately normally distributed about the axis of the ridge (9), all blocks other than the central

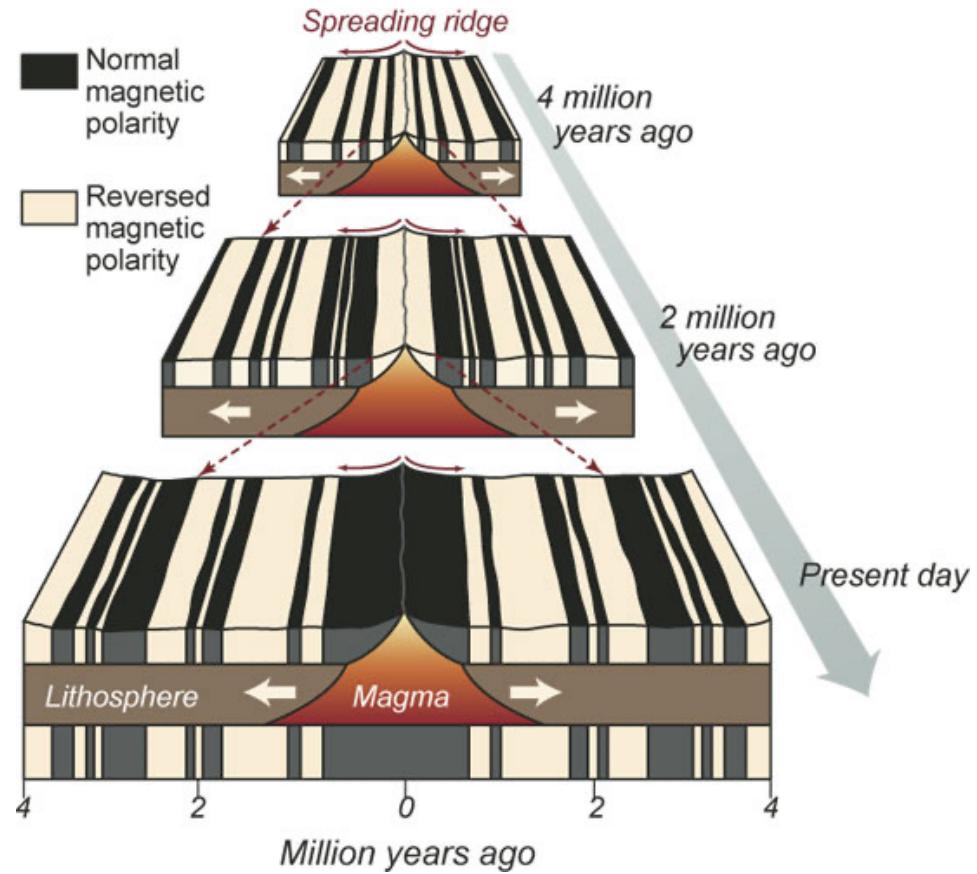
Vine and Matthews, 1963, *Nature*,
“Magnetic Anomalies Over Oceanic
Ridges”
Vine, 1966, *Science*, “Spreading of
the Ocean Floors: New Evidence”

Magnetic anomaly over ocean ridges



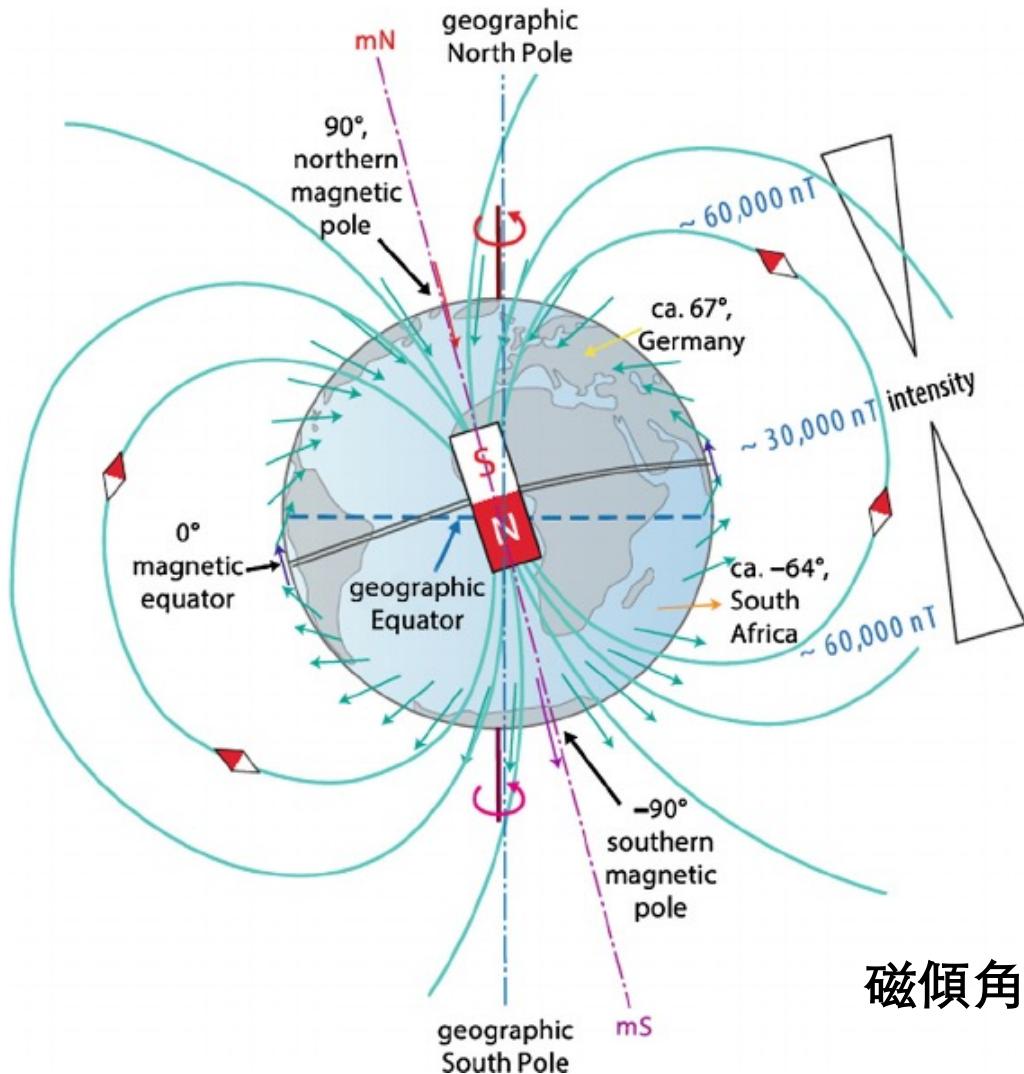
1981 Balzan Prize

Left: D. Matthews (1931 - 1997)
Right: F. Vine (1939 - present)



由中洋脊產生的新海床，記錄了當時的地磁場磁極方向，當海床向兩側擴張時，這些紀錄以中洋脊為中心，向兩側呈對稱排列。

地球具有天然磁場



Paleomagnetism
古地磁學

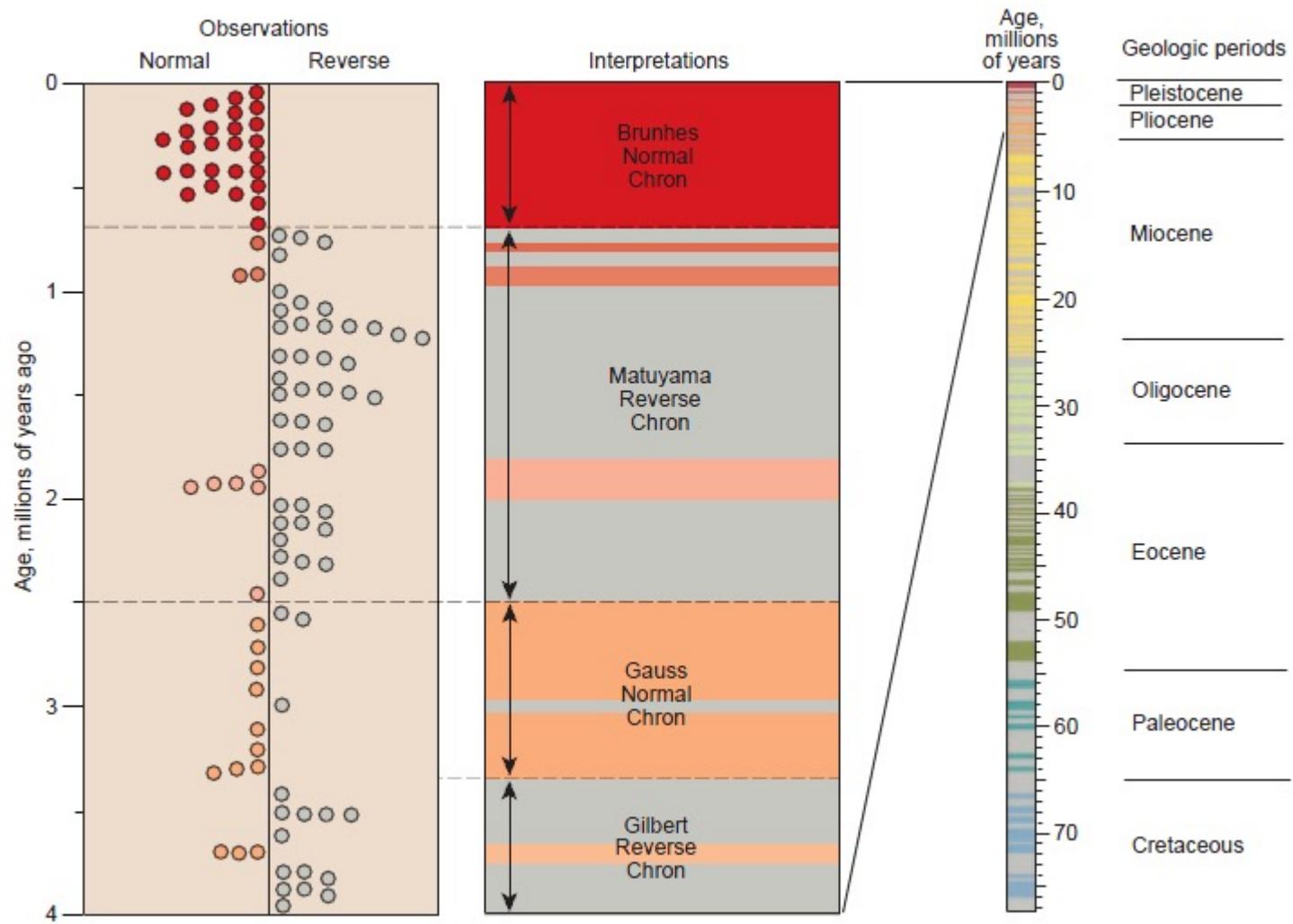
Iron-bearing minerals

In volcanic rocks:
Below Curie point (about 570 °C), Radiometric dating

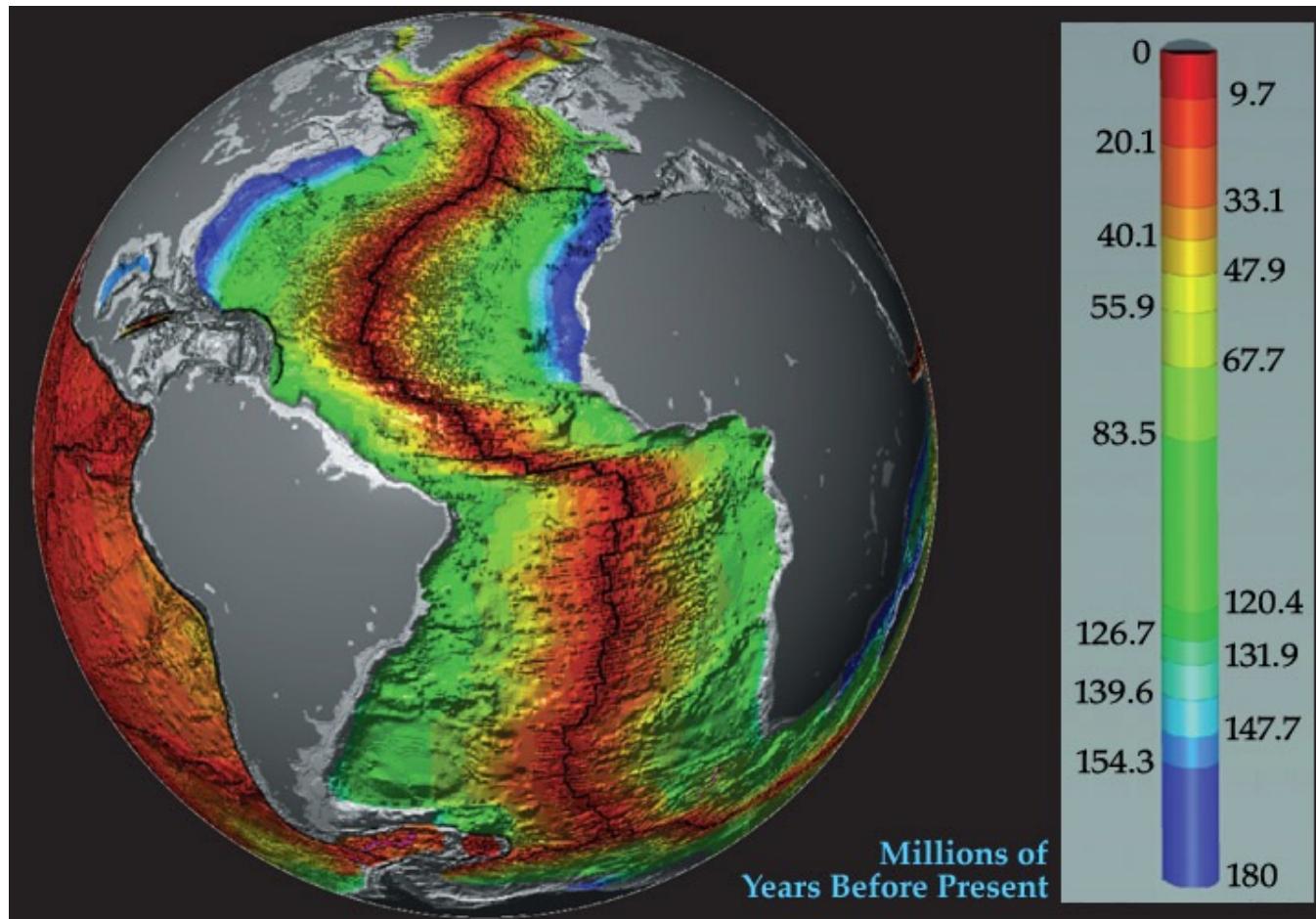
In sedimentary rocks:
During or soon after deposition

磁傾角、磁偏角

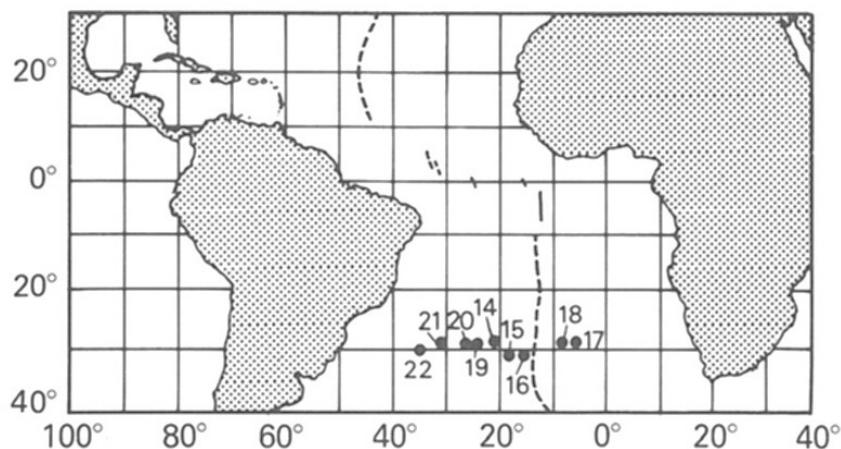
Magnetic Reversals 磁極反轉



Age of Oceanic Crust

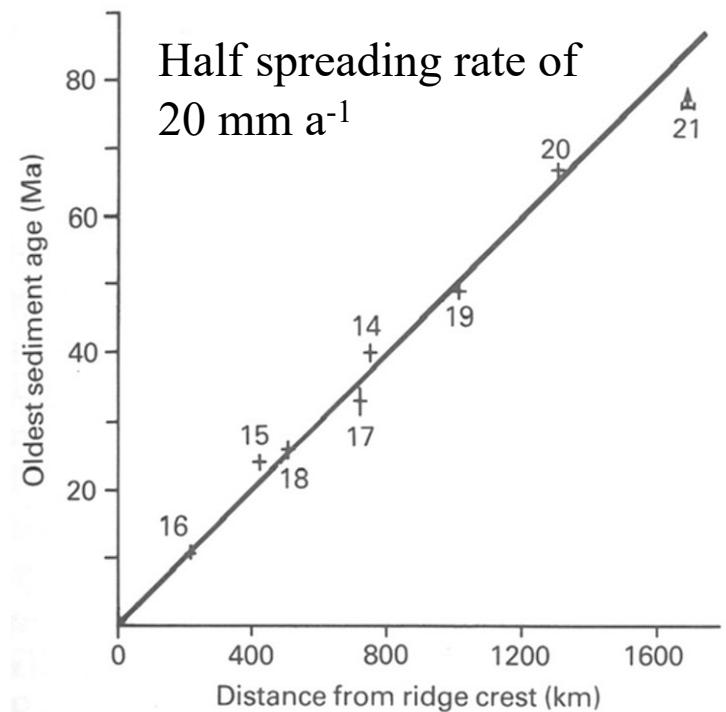


深海鑽探資料



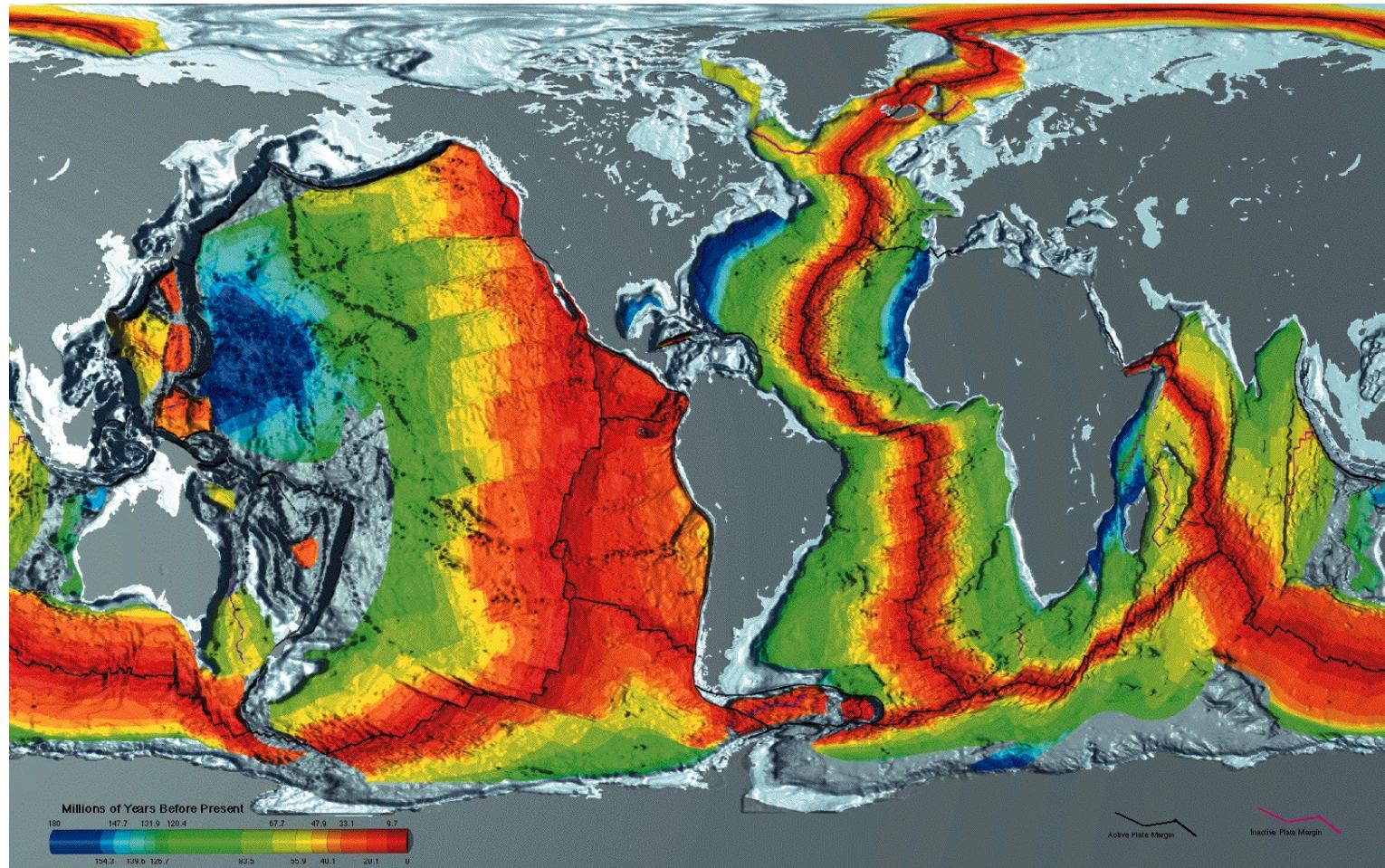
Location map of drilling sites on Leg 3 of the DSDP in the South Atlantic

After Mawell et al., 1970



Relationship between greatest sediment age and distance from the Mid-Atlantic Ridge crest

- ✓ 哪裡的海洋岩石圈最老?
- ✓ 那個中洋脊分裂的速度比較快?
- ✓ 北大西洋 vs. 南大西洋?
- ✓ 印度洋
- ✓ 澳洲 vs. 南極州



https://en.wikipedia.org/wiki/Seafloor_spreading#/media/File:Earth_seafloor_crust_age_1996_-_2.png



海洋地殼年代圖顯示的地質意義

- ▶ 海洋中已知最老的岩層為侏羅紀，出現在西北太平洋。
- ▶ 北大西洋在靠近北美和北非之邊緣存有晚侏羅紀之岩層，但南大西洋則付之闕如，這顯示南大西洋開啟的時間較晚。
- ▶ 現今太平洋的大部分地區都是從東太平洋隆起往西北擴張而形成的。因此中部和西部太平洋的廣大區域是比較老的板塊（白堊紀和晚侏羅紀），而東南太平洋大部分地區則屬新生代。
- ▶ 澳洲和南極洲之間的海底為最後 55 百萬年所形成的，這顯示這兩塊大陸的分裂是岡瓦那古陸之最後的分裂階段。
- ▶ 幾乎所有的印度洋海底都比晚白堊紀年輕，這意味著這個海洋才剛發育不久。

板塊構造學說的誕生

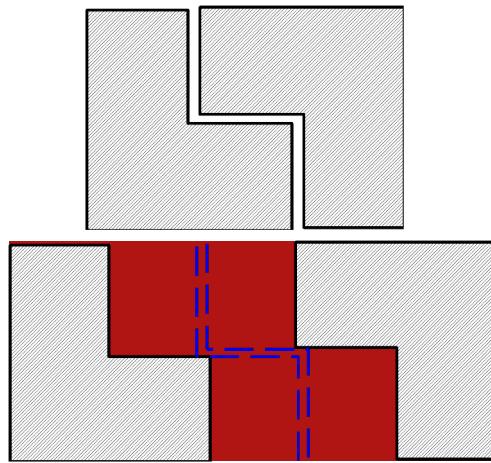
Birth of Plate Tectonic

- ▶ 海床擴張學說在1963-66年間被證實。根據 F.J. Vine 和 D.H. Matthews 認為海床上的磁性條帶可以用海床擴張和古地磁場變化來解釋。
- ▶ 板塊構造學說發展的另一重要觀念，是 J.T. Wilson 在 1965 年定義出新的一種斷層，稱作轉型斷層(transform faults)，轉型斷層連接線性帶到構造活動。
- ▶ D.P. McKenzie, R.L. Parker 和 W.J. Morgan 在 1967-68 年為板塊構造學說加入令人信服的幾何基礎，這也被 B. Isacks, J. Oliver 和 L.R. Sykes 在地震學的工作加以確認。

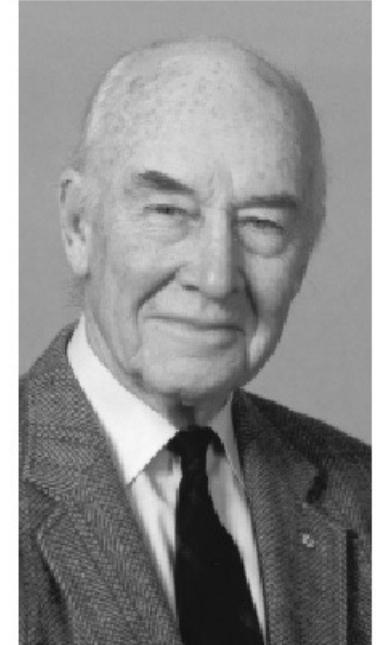
板塊構造學說(Plate Tectonics)

- ▶ 提出：1965年威爾遜 (J. T. Wilson) 有系統地描述一系列洋脊、轉型斷層和隱沒帶所包圍的板塊，正式提出板塊構造的概念。1968年摩根 (W. J. Morgan) 詳細訂出每一板塊的幾何形狀。
- ▶ 主要論點：認為地球表面是由一系列堅硬、不變形且厚度相當薄 (100-150 km) 的板塊所覆蓋，所有板塊都持續移動，不但彼此間在進行相對移動，也同時順著地球旋轉軸而轉動，板塊的相互運動及作用造就了目前地表的形貌，包括目前大陸的形貌和位置，地球上山脈的形成和主要地震帶及火山的分布。
- ▶ 主要證據：地震、火山及山脈之分布及大陸漂移和海底擴張說相關之證據。

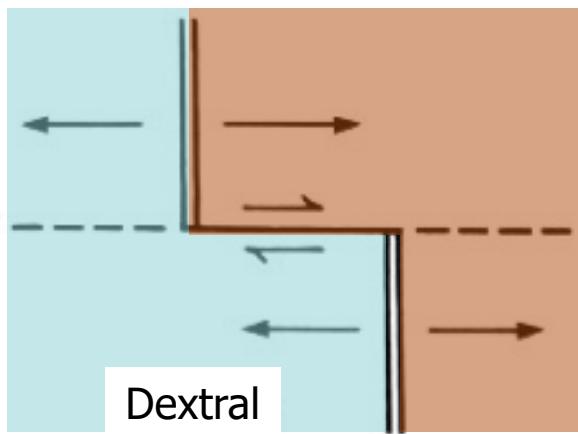
轉形斷層（與平移斷層）



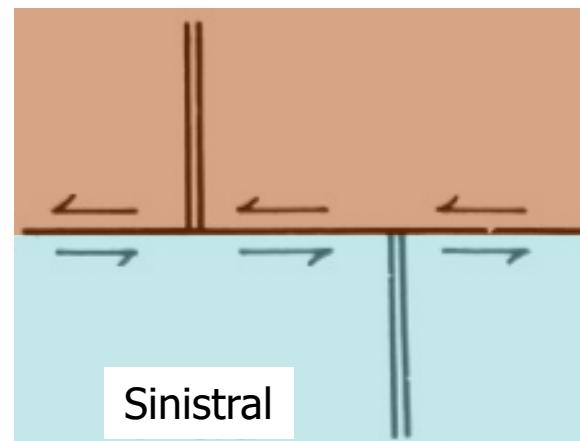
威爾遜
J. Tuzo Wilson
(1908-1993)



J. Tuzo Wilson in his 80s.
Photo courtesy of Delroy Curling.



(a) Transform fault 轉形斷層



(b) Strike-slip fault 平移斷層

全球地震分布(Global Seismicity)

56

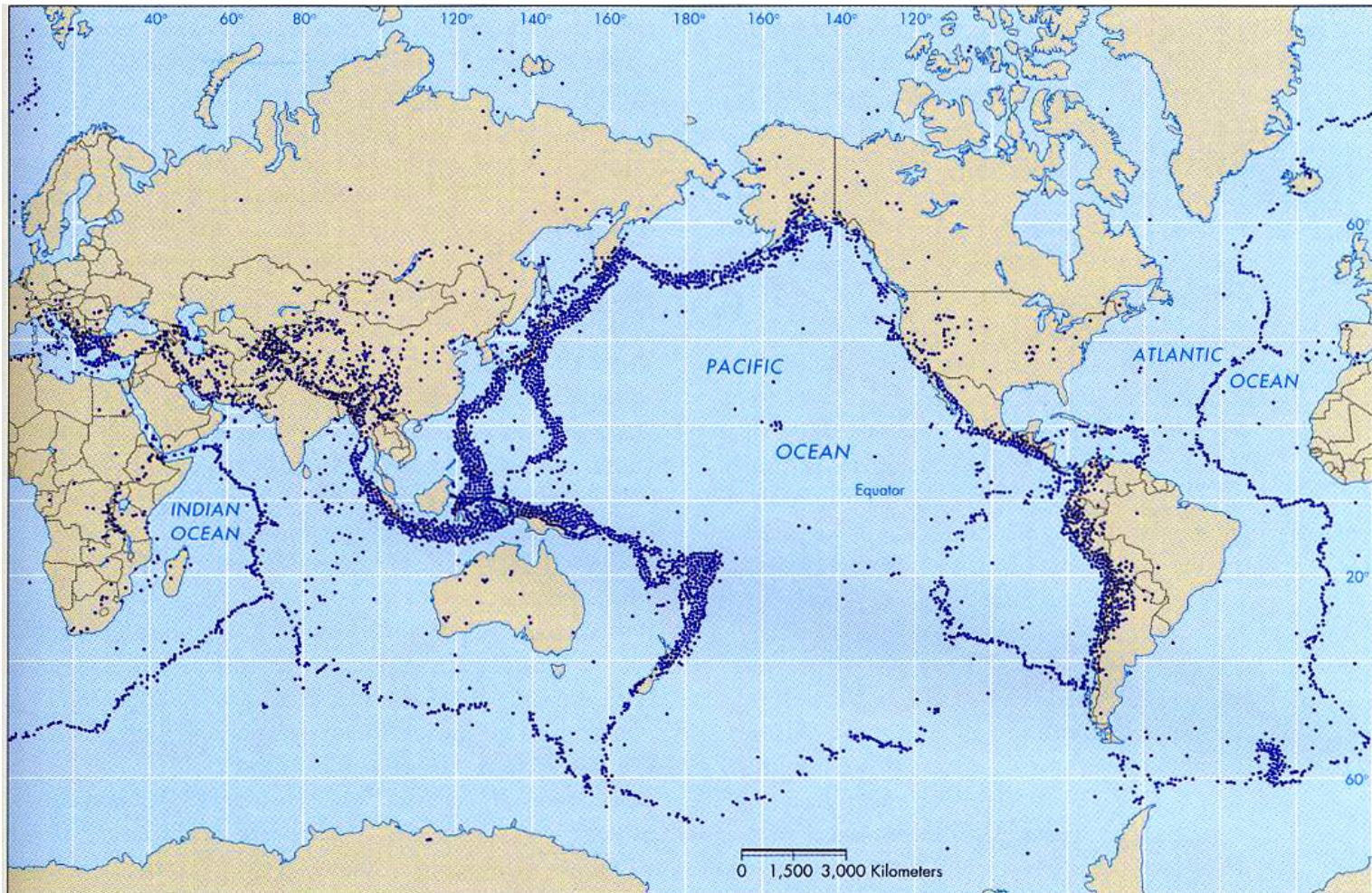


FIGURE 7.2 Map of global seismicity (1963–1988, Richter magnitude [M] = 5+) delineating plate boundaries and earthquake belts shown in Figure 7.3. (Courtesy of National Earthquake Information Center.)

海洋地質地物探勘

海底形貌

探查的工具：載人潛艇、無人載具、聲納....

海底地形：洋脊、海溝、海盆....

海底擴張

大陸漂移：陸地上的證據

海床擴張：海床磁性條帶分布

板塊構造學說（待續）