GP4031台灣地質 (Taiwan Regional Geology)

臺灣周遭海洋地質

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1. 臺灣海域周邊的重要地形特徵與大地構造的關係

2. 熱泉與冷泉系統

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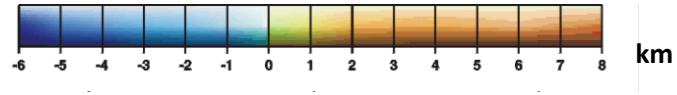
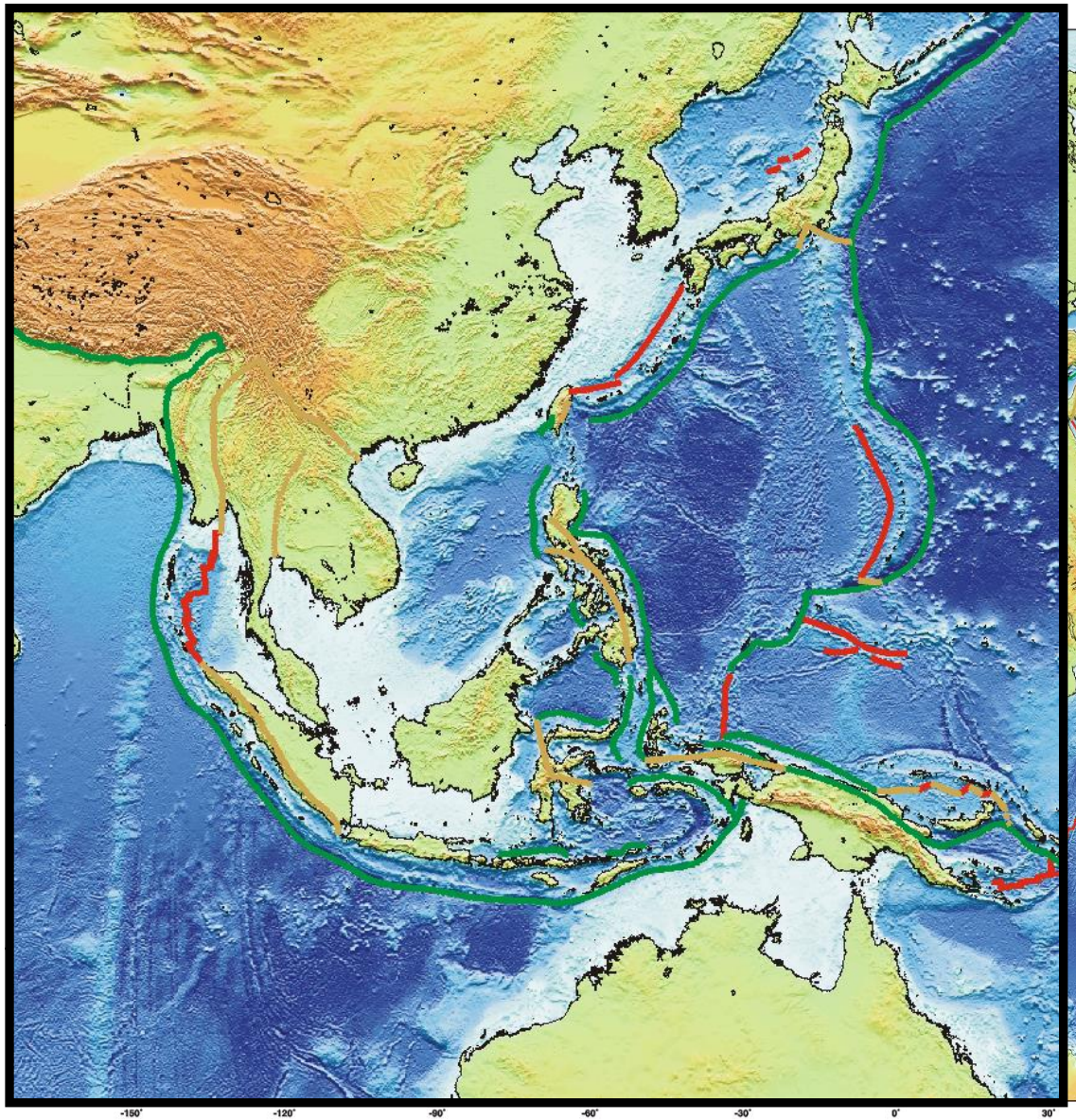
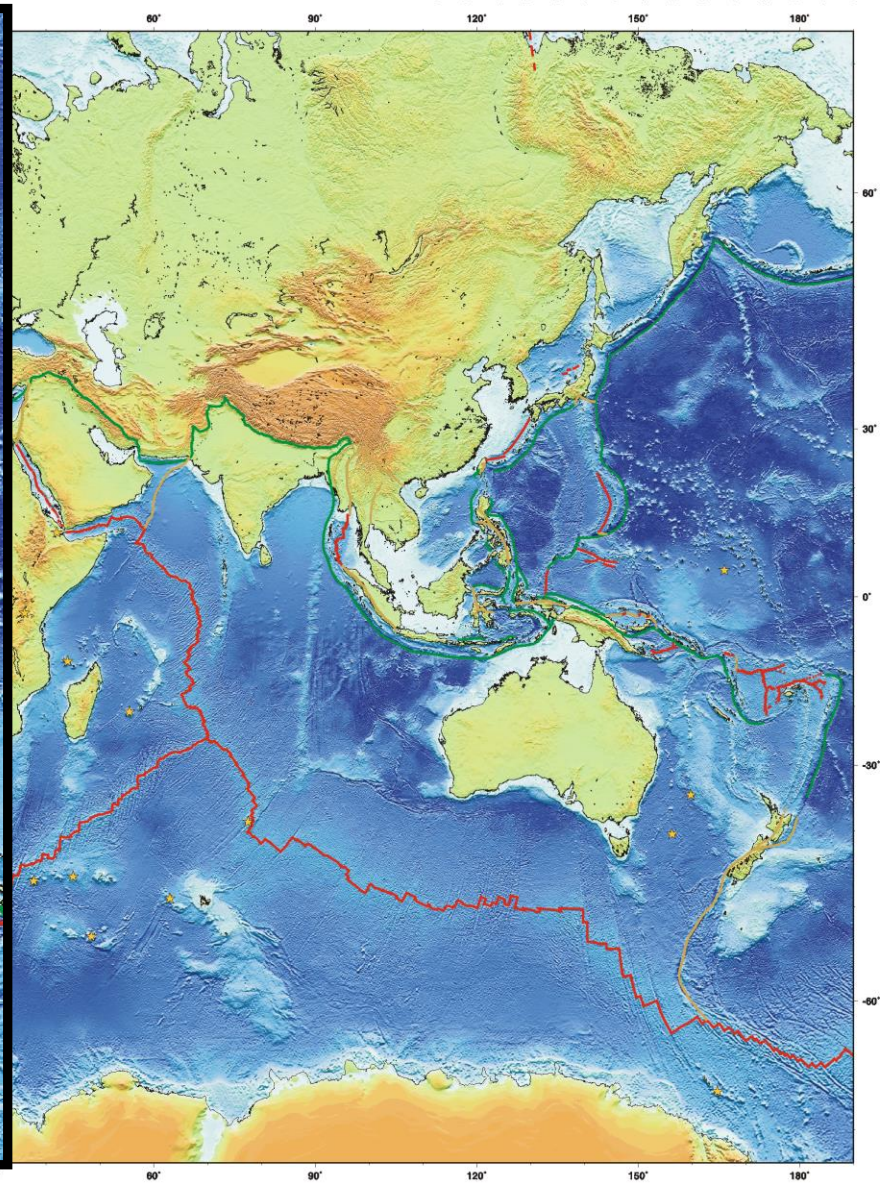
Present-Day Plate Tectonic Features



Tectonic Features are color-coded: Spreading, Conversion, Transform, Hotspot= star





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臺灣海域周邊的重要地形特徵與大地構造的關係

大陸棚

大陸斜坡

海脊

海溝

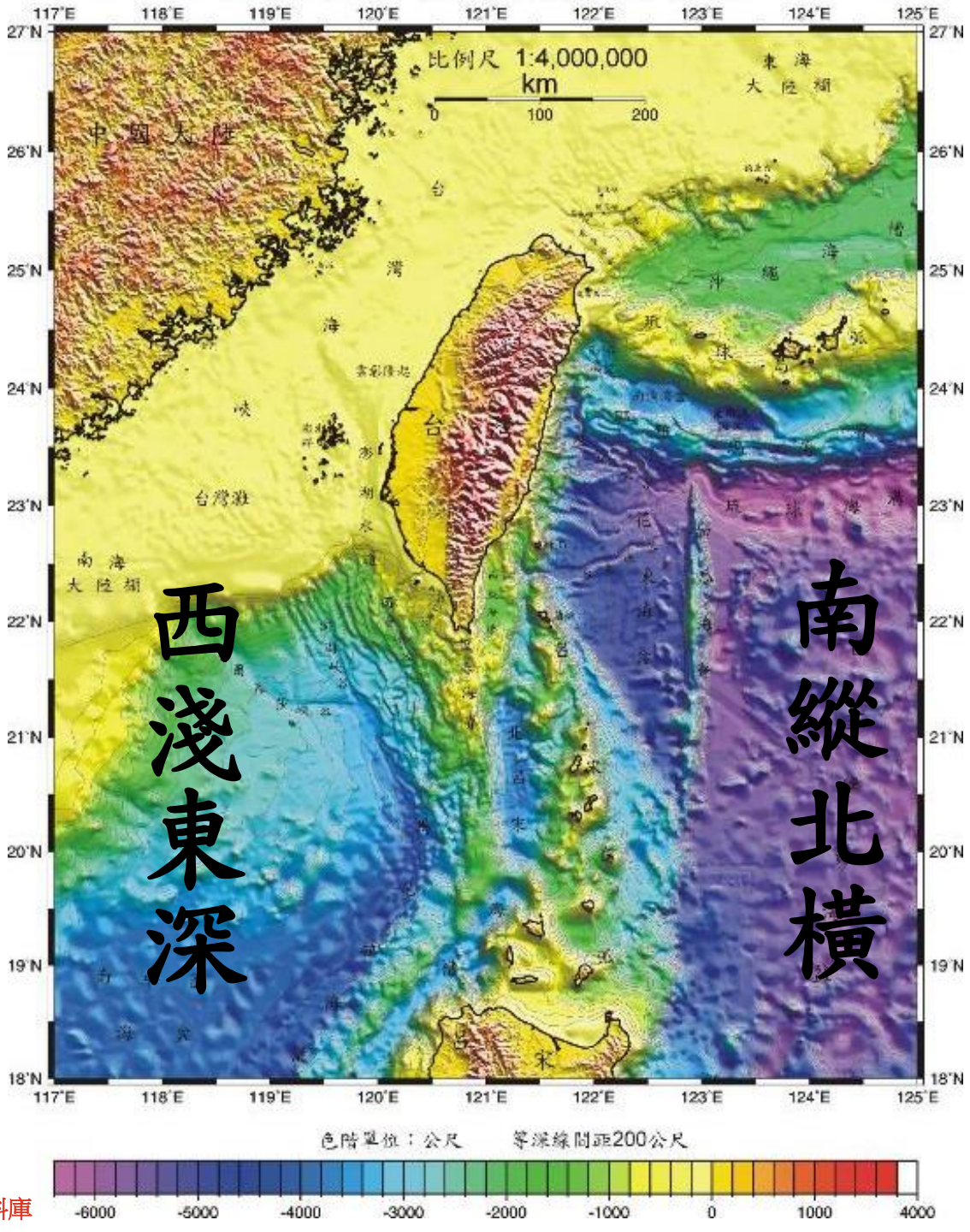
海槽

深海盆地

歐亞板塊中國大陸邊緣

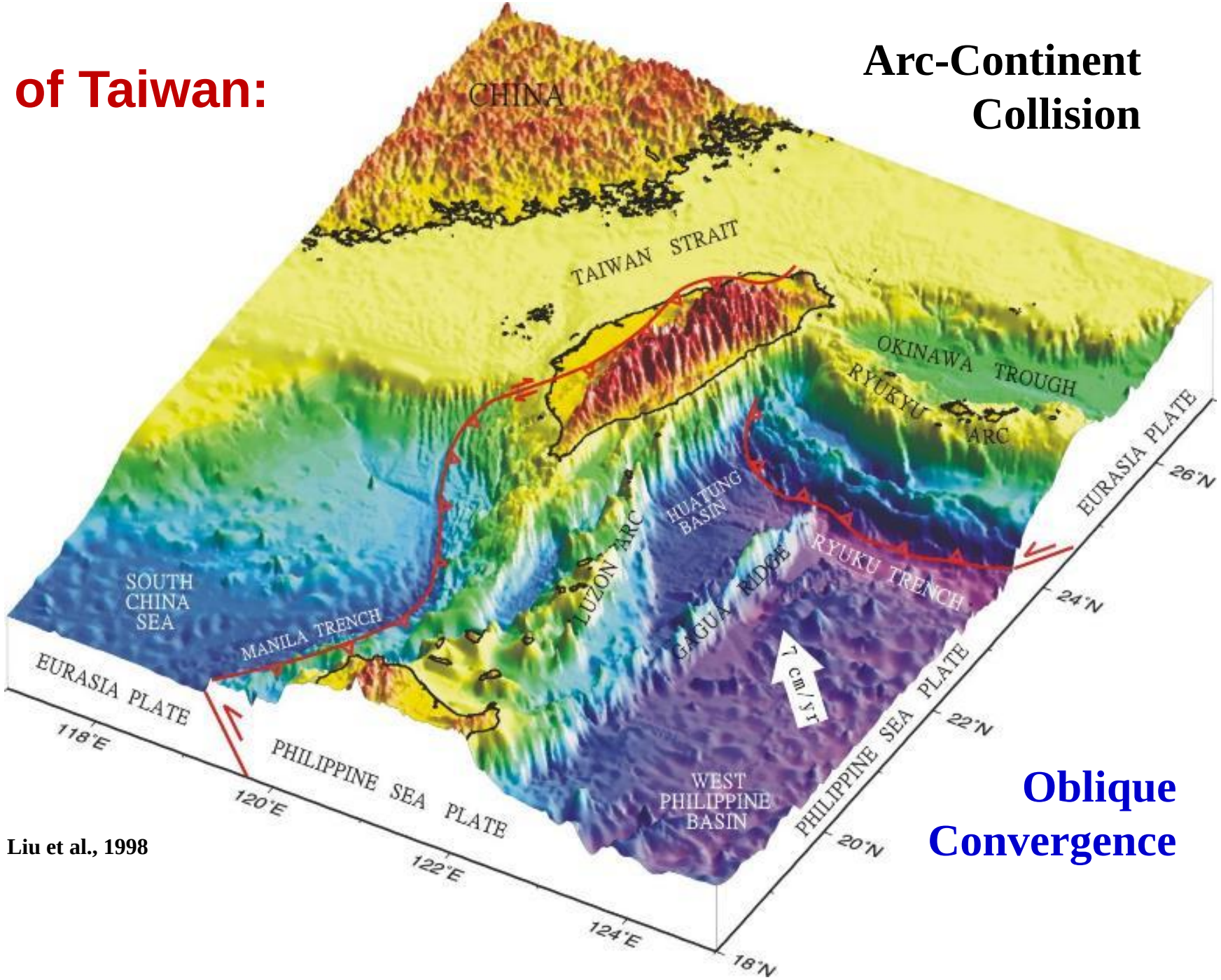
菲律賓海板塊的呂宋島弧

斜向碰撞



Formation of Taiwan:

Arc-Continent Collision



Liu et al., 1998

Oblique Convergence

臺灣海域周邊的重要地形特徵與大地構造的關係

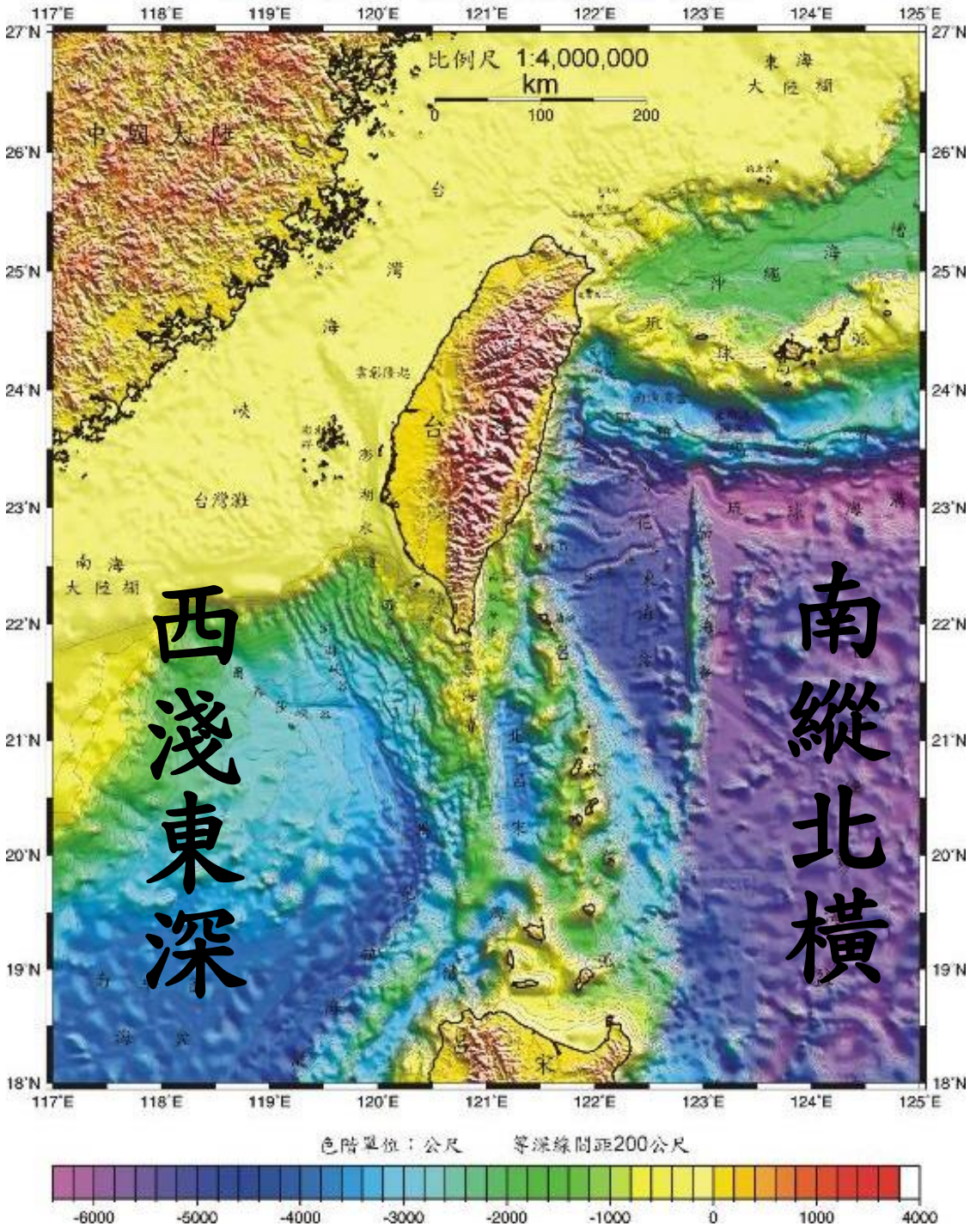
陸棚及陸坡上的淺灘

海底水道

峽谷

海床表層沉積作用

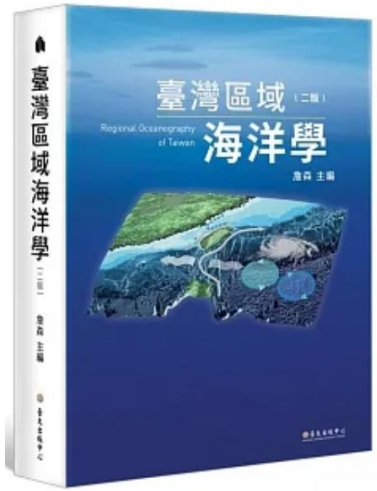
淺層岩石物質的構造影響

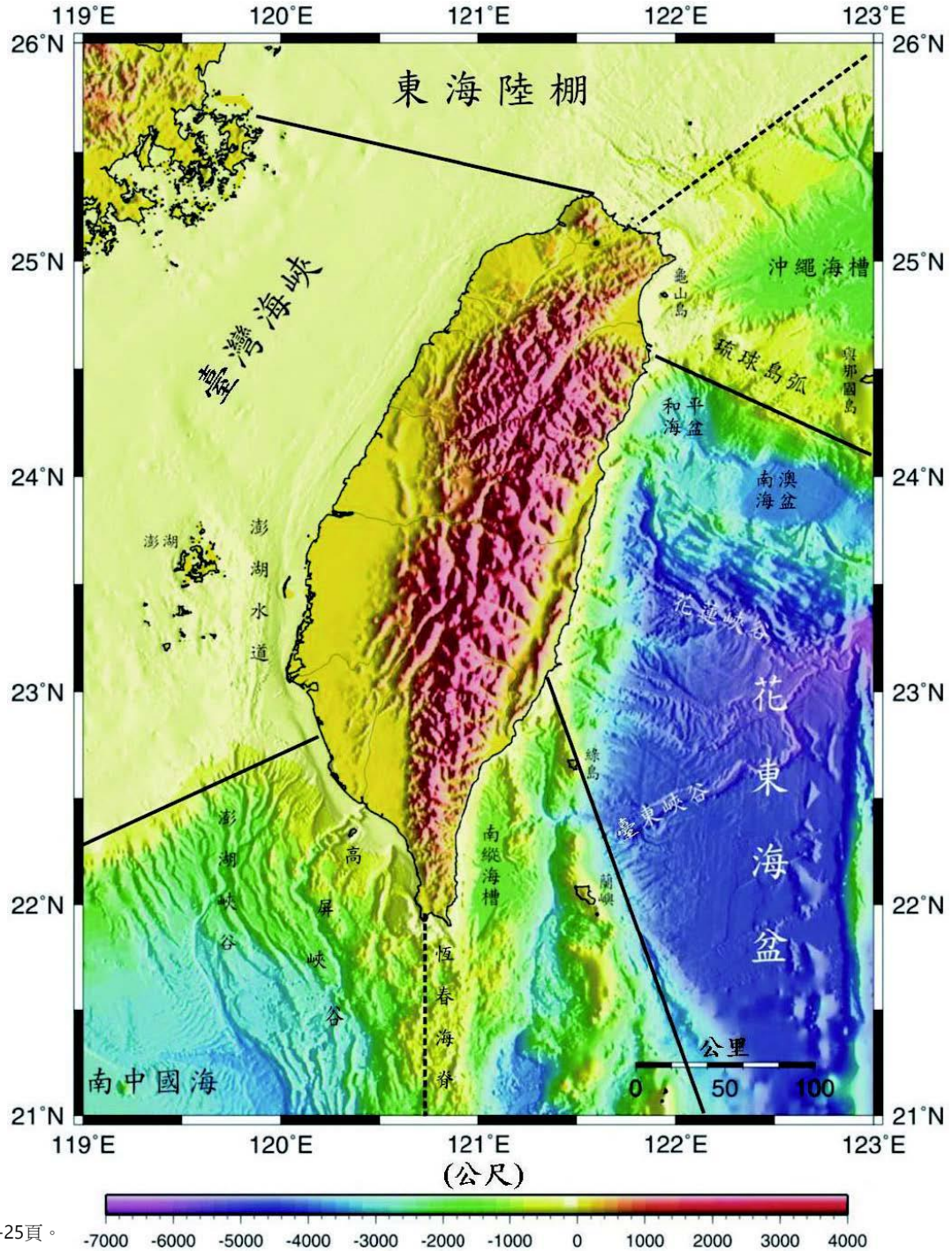


國科會海洋學門資料庫

台灣周遭海域地質分區

- 東海陸棚地質區
- 台灣海峽陸棚地質區
- 高屏斜坡地質區
- 恆春海脊–綠島、蘭嶼地質區
- 花東海盆、加瓜海脊地質區
- 琉球海溝–島弧地質區
- 南沖繩海槽地質區





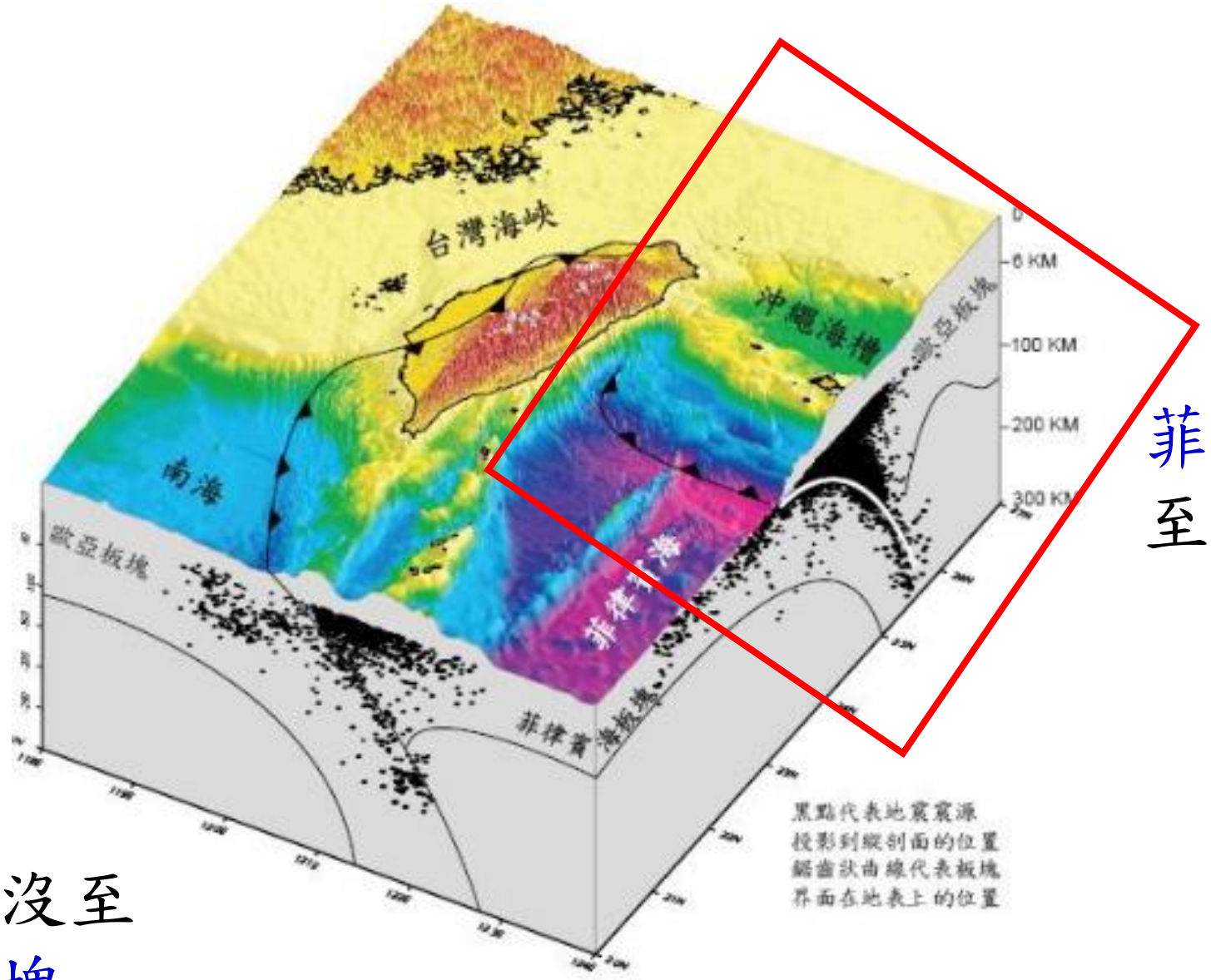
許鶴瀚、劉紹勇、劉家瑄（2010）臺灣附近的海底地形。地質，第29卷，第1期，第22-25頁。

1. 臺灣海域周邊的重要地形特徵與大地構造的關係

2. 熱泉與冷泉系統

板塊構造

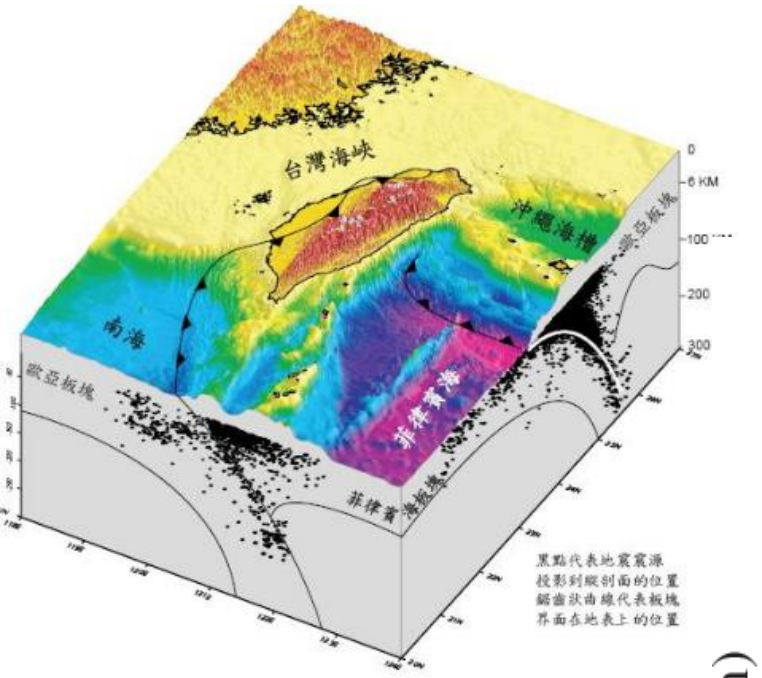
歐亞板塊與菲律賓海板塊交互作用

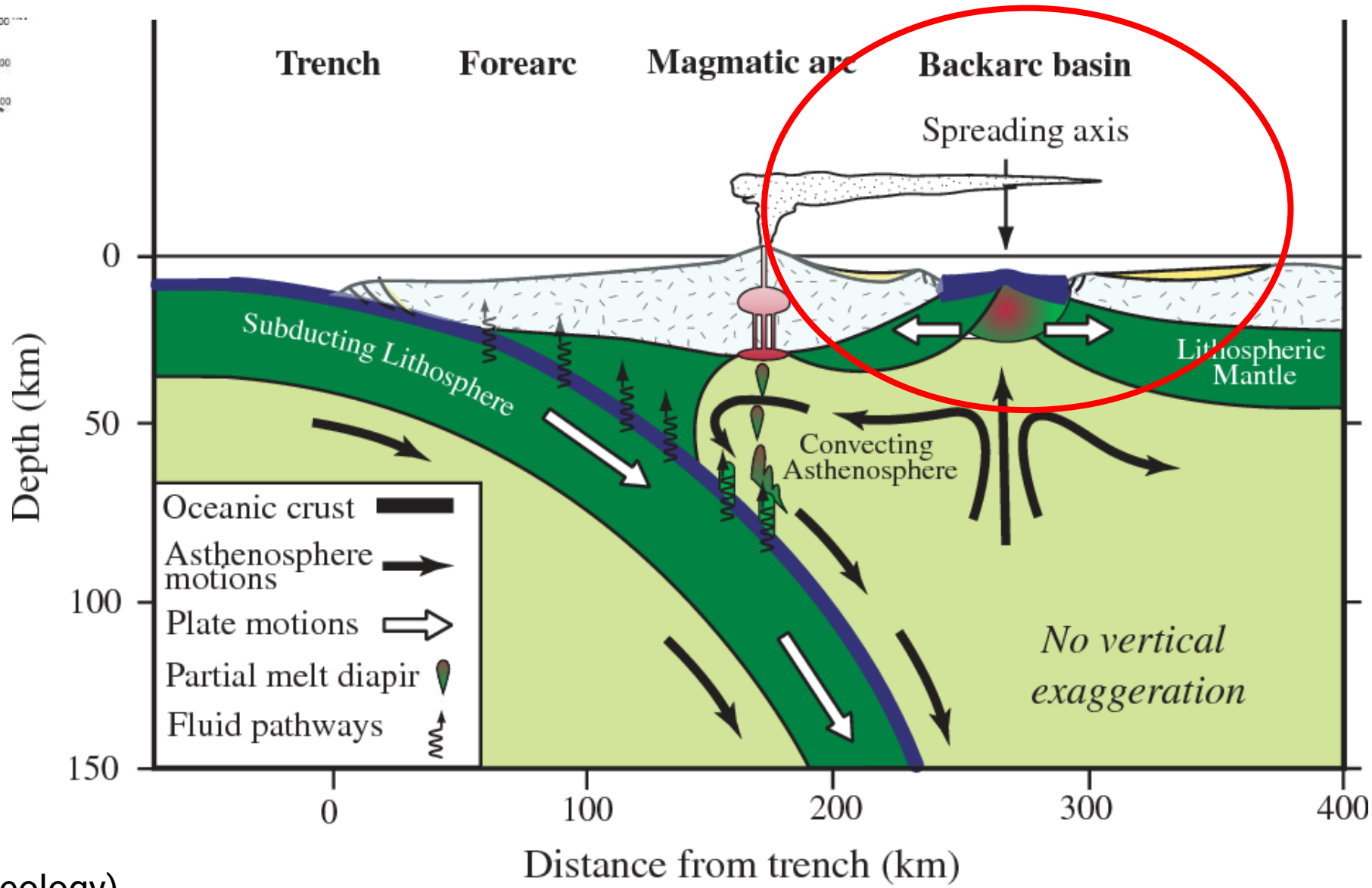


菲律賓海板塊隱沒至歐亞板塊

歐亞板塊隱沒至菲律賓海板塊

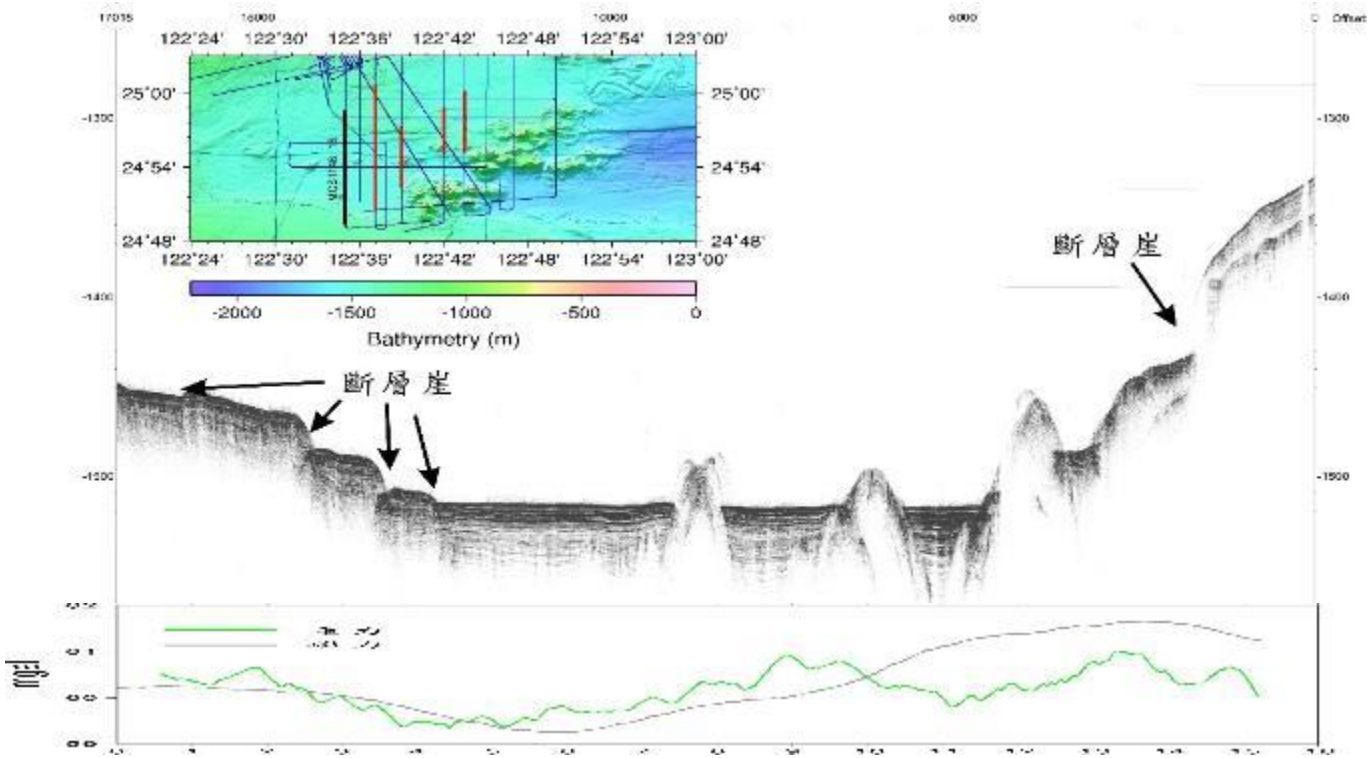
台大海研所劉家瑄教授提供

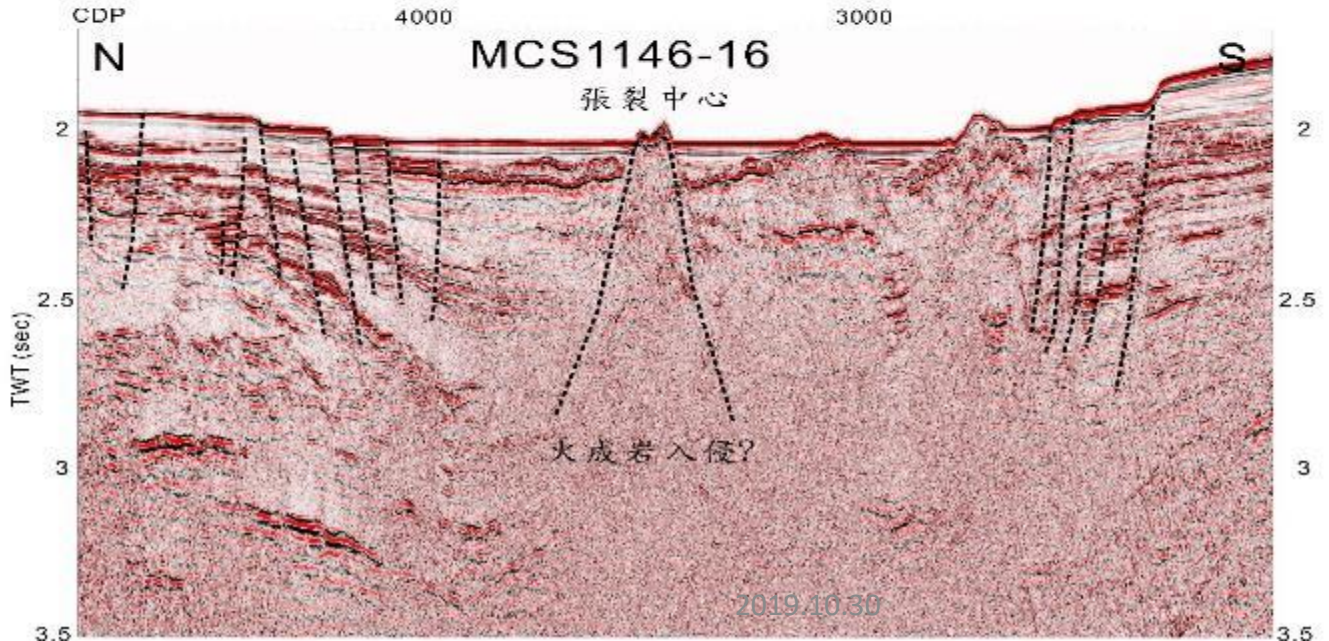




(Stern and Dickinson, 2010, Geology)

弧後擴張形成張裂構造提供熱液循環管道





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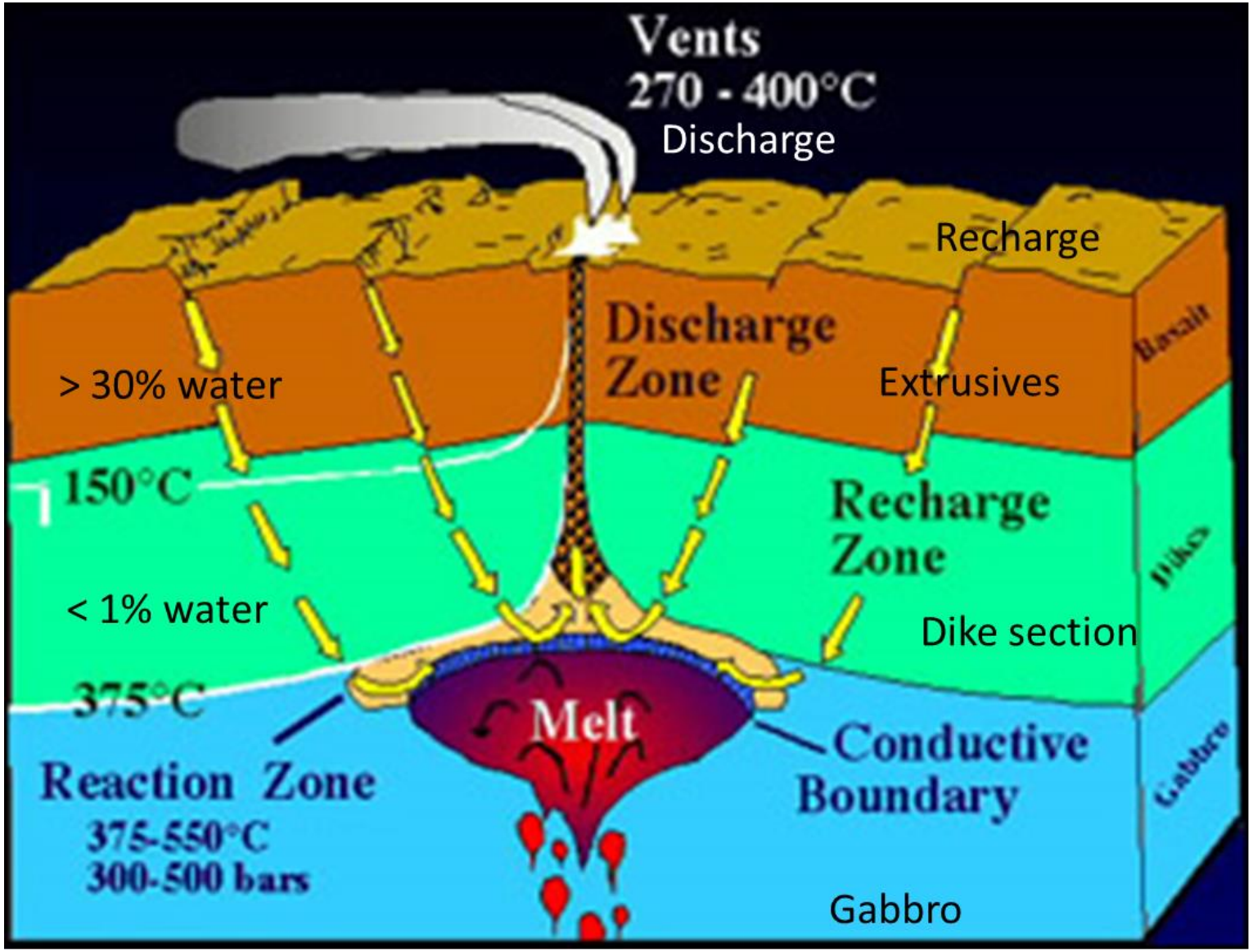
Evolution of hydrothermal fluids / water rock interaction

- **Where do they get their chemical signature?**
- **What processes take place in the subseafloor?**
- **Which factors control the geochemistry of the fluids?**

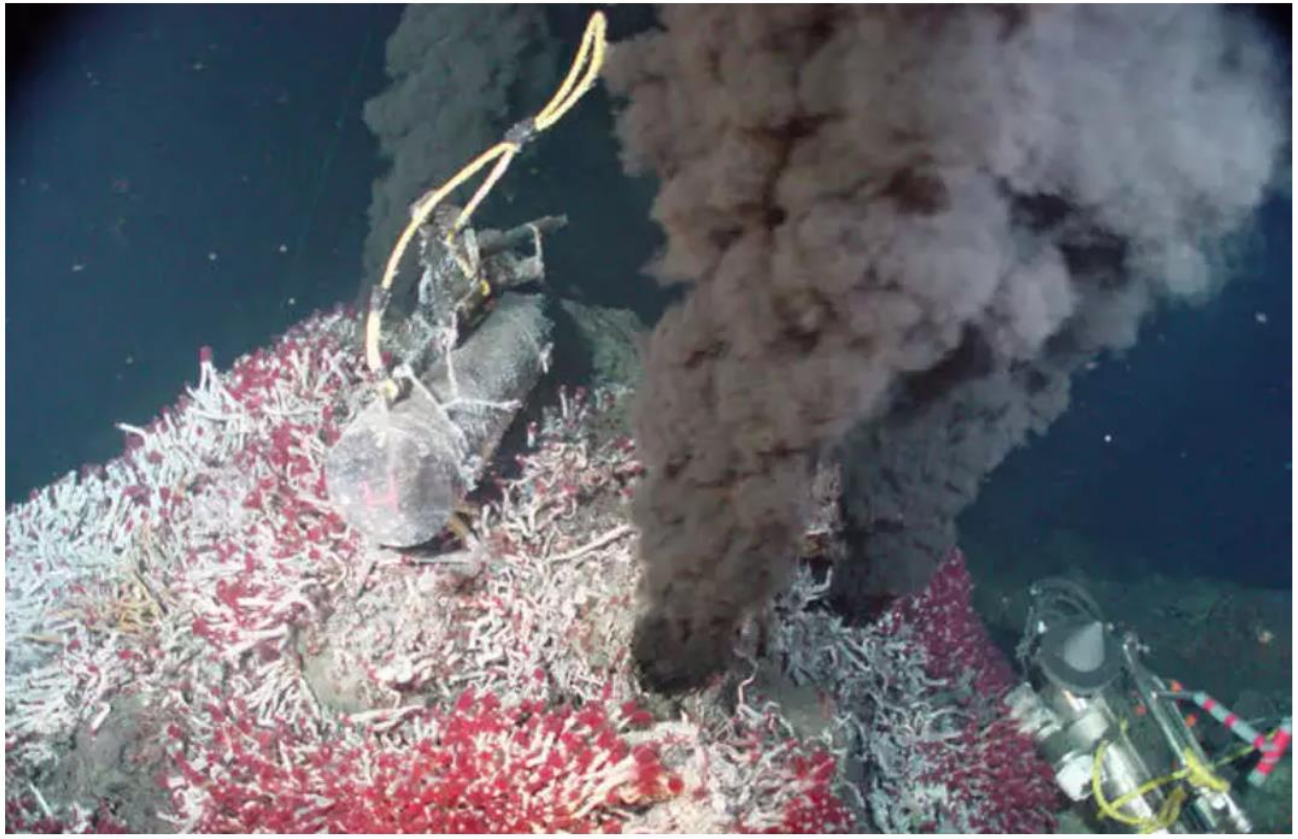
Global marine hydrothermal system



After: http://earthguide.ucsd.edu/mar/dec12.html

Global marine hydrothermal system

- all seawater on Earth circulates through the mid-ocean ridges within ~1 million years
- hydrothermal convection changes the chemistry of seawater on a global scale
- this process results also in the formation of hydrothermal systems and ***massive sulfide deposits*** at the seafloor which are associated with unique faunal communities



NOAA

Global marine hydrothermal system

- all seawater on Earth c
  mid-ocean ridges withi
- hydrothermal convecti
  chemistry of seawater
- this process results als
  hydrotherma' tems
  deposi floo
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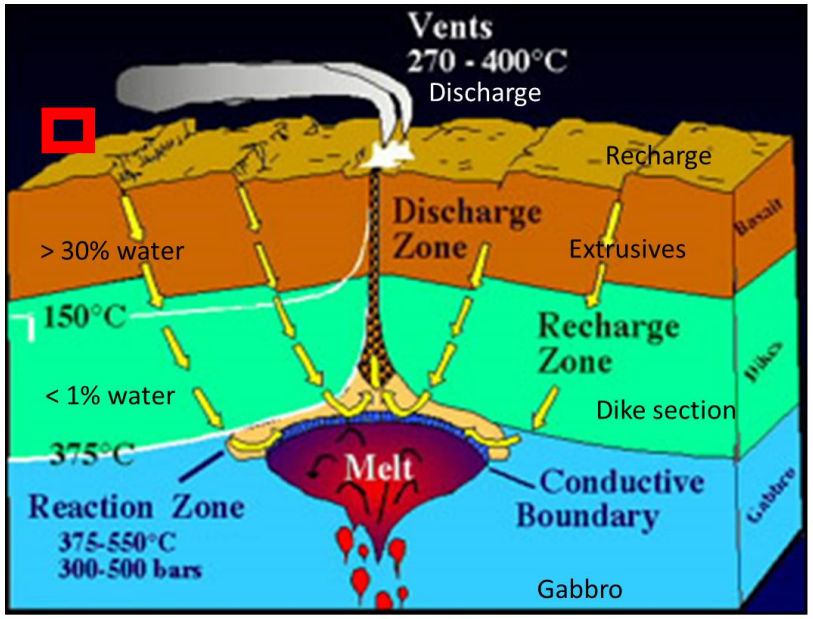
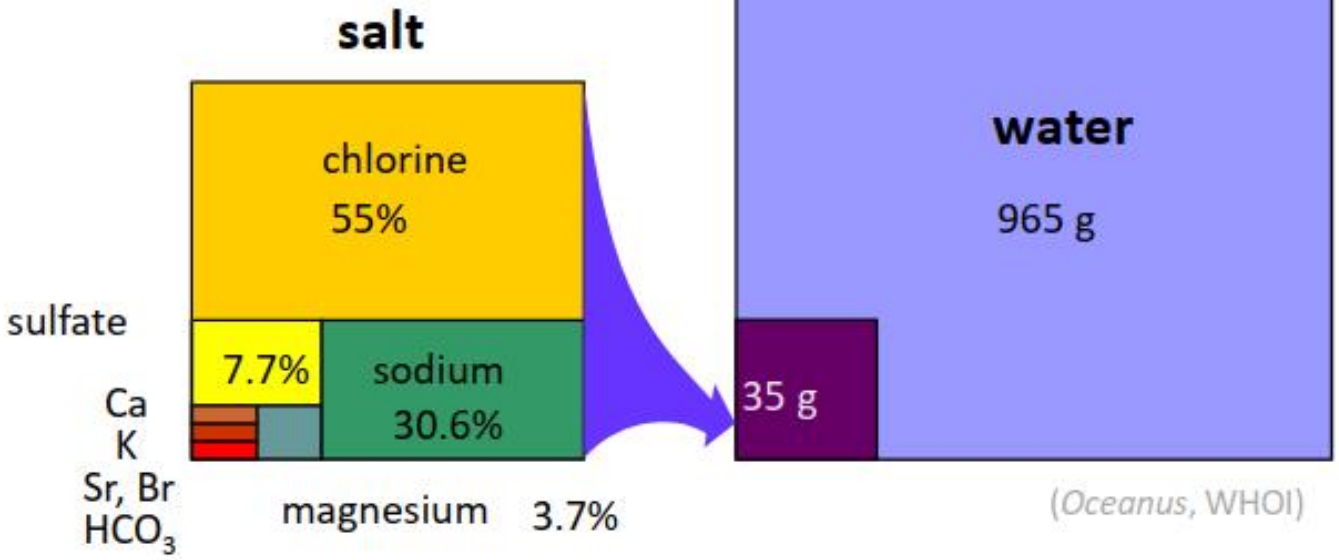
Table 1 | **Anaerobic and aerobic microbial metabolic reactions and potential energy yields in hydrothermal vent environments**

Metabolism	Reaction	$\Delta G^{0\prime}$ (kJ per mole)*	Examples in vent environments
Anaerobic			
Methanogenesis	$4\,H_2 + CO_2 \rightarrow CH_4 + 2\,H_2O$ $CH_3CO_2^- + H_2O \rightarrow CH_4 + HCO_3^-$ $4\,HCOO^- + H^+ \rightarrow 3\,HCO_3^- + CH_4$	−131 −36 −106	*Methanococcus* spp. common in magma-hosted vents; Methanosarcinales at Lost City
S° reduction	$S^\circ + H_2 \rightarrow H_2S$	−45	Lithotrophic and heterotrophic; hyperthermophilic archaea
Anaerobic CH_4 oxidation	$CH_4 + SO_4^{2-} \rightarrow HS^- + HCO_3^- + H_2O$	−21	*Methanosarcina* spp. and epsilonproteobacteria at mud volcanoes and methane seeps
Sulfate reduction	$SO_4^{2-} + H^+ + 4\,H_2 \rightarrow HS^- + 4\,H_2O$	−170	Deltaproteobacteria
Fe reduction	$8\,Fe^{3+} + CH_3CO_2^- + 4\,H_2O \rightarrow 2\,HCO_3^- + 8\,Fe^{2+} + 9\,H^+$	Not calculated‡	Epsilonproteobacteria, thermophilic bacteria and hyperthermophilic Crenarchaeota
Fermentation	$C_6H_{12}O_6 \rightarrow 2\,C_2H_6O + 2\,CO_2$	−300	Many genera of bacteria and archaea
Aerobic			
Sulfide oxidation§	$HS^- + 2\,O_2 \rightarrow SO_4^{2-} + H^+$	−750	Many genera of bacteria; common vent animal symbionts
CH_4 oxidation	$CH_4 + 2\,O_2 \rightarrow HCO_3^- + H^+ + H_2O$	−750	Common in hydrothermal systems; vent animal symbionts
H_2 oxidation	$H_2 + 0.5\,O_2 \rightarrow H_2O$	−230	Common in hydrothermal systems; vent animal symbionts
Fe oxidation	$Fe^{2+} + 0.5\,O_2 + H^+ \rightarrow Fe^{3+} + 0.5\,H_2O$	−65	Common in low-temperature vent fluids; rock-hosted microbial mats
Mn oxidation	$Mn^{2+} + 0.5\,O_2 + H_2O \rightarrow MnO_2 + 2\,H^+$	−50	Common in low-temperature vent fluids; rock-hosted microbial mats; hydrothermal plumes
Respiration	$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$	−2,870	Many genera of bacteria

Evolution of hydrothermal fluids / water rock interaction



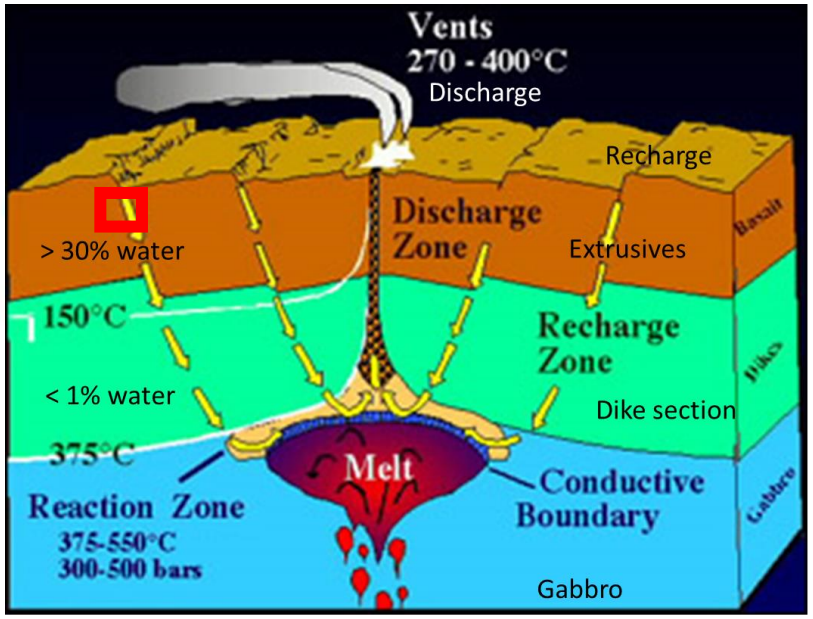


Start

seawater

ca. 2° C		(cold)
pH	= 7.8	(neutral)
oxidizing		(O_2-rich)
Mg	= 1300 ppm	
SO_4	= 2700 ppm	
H_2S	= ~ 0	
Fe	= 0.0003 ppm	
Mn	= 0.0001 ppm	
Zn	= 0.0018 ppm	
Cu	= 0.0002 ppm	

Evolution of hydrothermal fluids / water rock interaction



T < 100° C

basalt is oxidised ⇨ Fe-oxyhydroxide
red-staining of the rocks

seawater **basalt**
K, Rb, Cs, B ⇨ celadonite, nontronite

T > 150° C

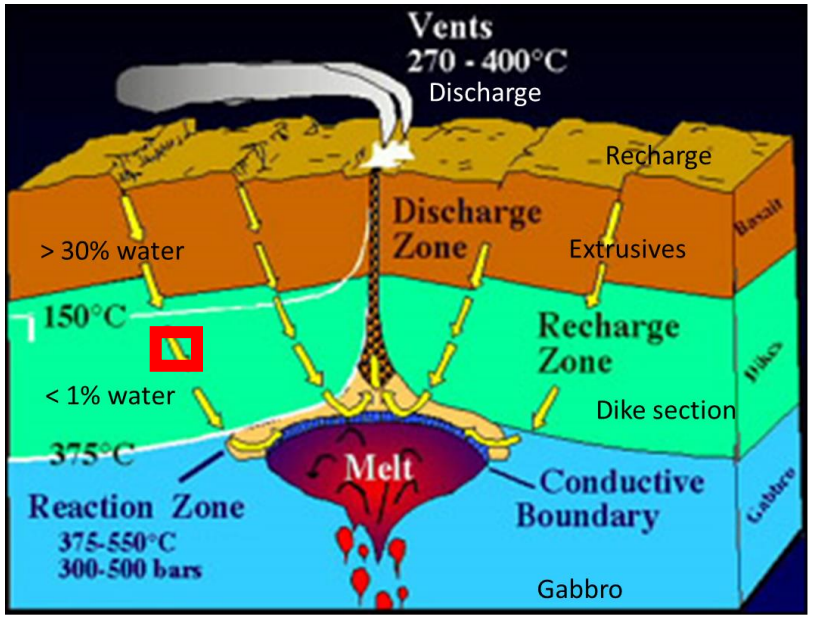
seawater **basalt**
Mg ⇨ smectite/chlorite

Chloritising:

$$4(NaSi)_{0,5}(CaAl)_{0,5}AlSi_2O_8 + 15Mg^+ + 24H_2O \Leftrightarrow 3Mg_5Al_2Si_3O_{10}(OH)_8 + SiO_2 + 2Na^+ + 2Ca^+ + \mathbf{24H^+}$$

albite/anorthite in basalt — chlorite

Evolution of hydrothermal fluids / water rock interaction



T > 150° C

$$H_2O = H^+ + OH^-$$

$$Ca^{2+} + SO_4^{2-} \Leftrightarrow CaSO_4 \text{ (anhydrite)}$$

T > 200° C

seawater basalt

⇦ **Ca**

Albitisation of basalt:

$CaAl_2Si_2O_8 + 2Na^+ + 4SiO_{2(aq)} \Leftrightarrow 2NaAlSi_3O_8 + \mathbf{Ca^{2+}}$

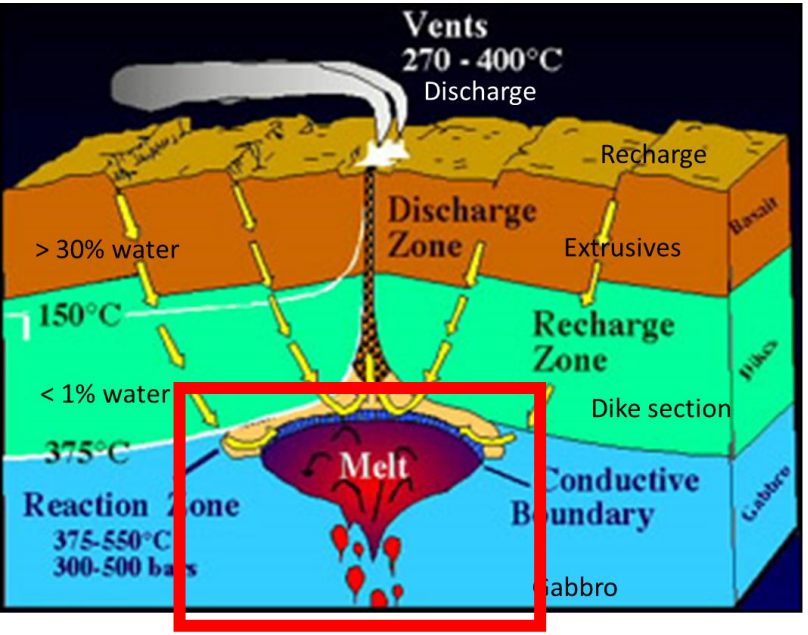
anorthite albite

T > 250° C

reduction of sulfate to H_2S

$$8FeS + 10H^+ + SO_4^{2-} \Leftrightarrow 4FeS_2 + H_2S + 4H_2O + 4Fe^{2+}$$

Evolution of hydrothermal fluids / water rock interaction



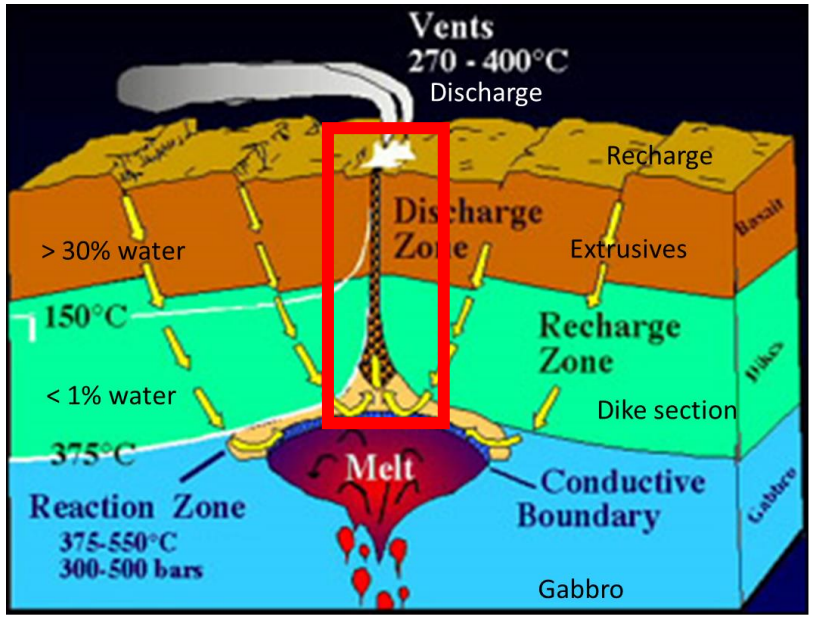
close to a heat source or magma chamber (so called "reaction zone") seawater is heated to temperatures in exess of 400° C. The pressure of the overlying water and rock column prevents boiling.

The hot, acid and reduced fluids are capable to leach Cu, Fe, Zn, Pb, Au, Ag, S, etc. out of the rocks.

- Cu, Fe, Zn, S, Au from primary sulfides
- Zn also from Ti-Oxides
- Au also from silicates
- Pb from feldspar

At these high temperatures the metals are largely transported as chloride-complexes.

Evolution of hydrothermal fluids / water rock interaction



The hot fluids ascend along permeable zones because of their low density.

At the contact with cold oxidized seawater all metals are precipitated as sulfides.

The result are „black smokers“.

Seafloor Massive Sulphides

influx of cold seawater (recharge)

$H_2O = H^+ + OH^-$

$Mg^{2+} + OH^- = Mg(OH)_2$ precipitation

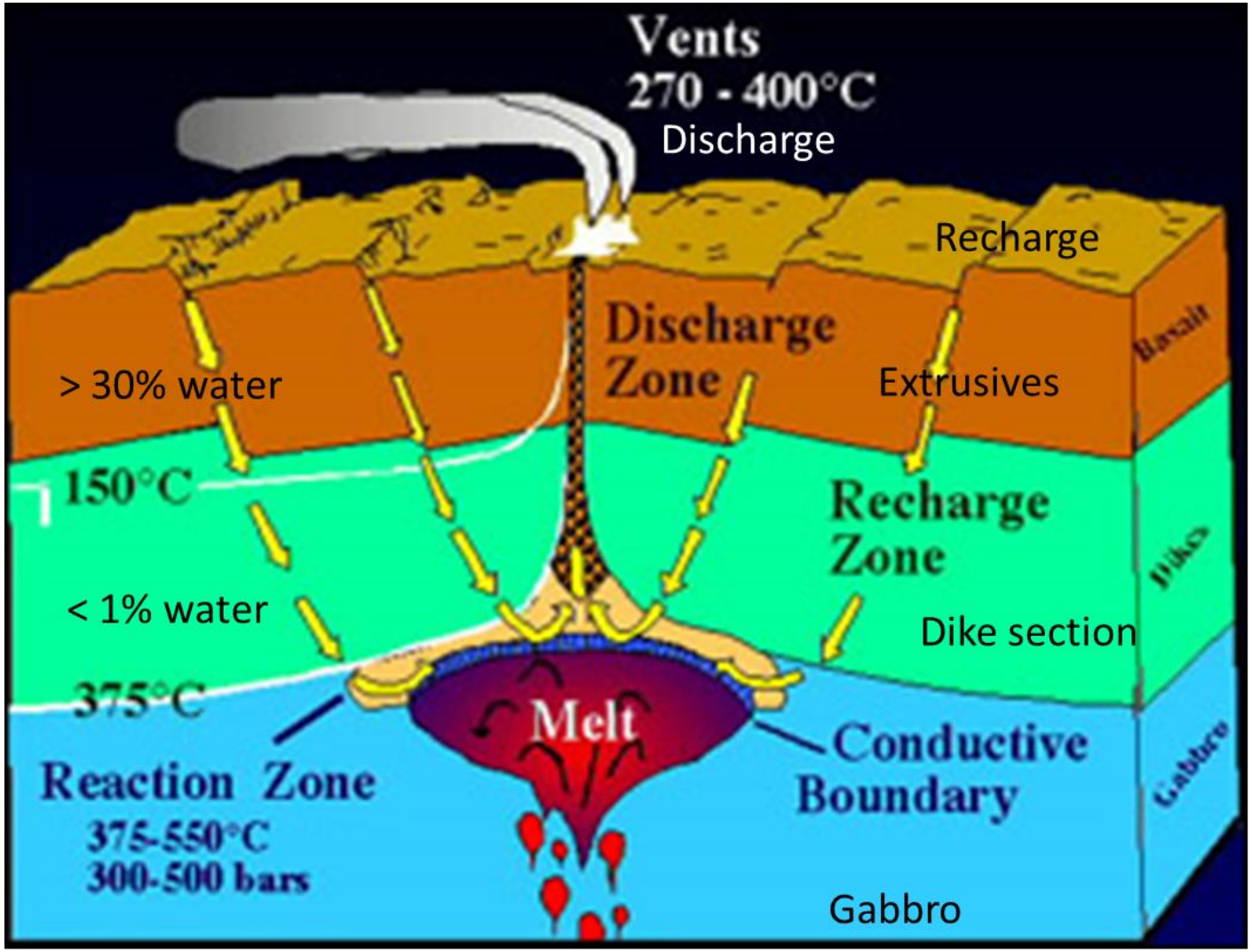
excess H^+ ⇨ pH drop to ~ 4-5

precipitation of seawater SO_4^{2-} as anhydrite, reduction of SO_4^{2-} ⇨ H_2S

heating of seawater to > 400°C leaching of Cu, Zn, Fe, Au, S etc. from the surrounding rock

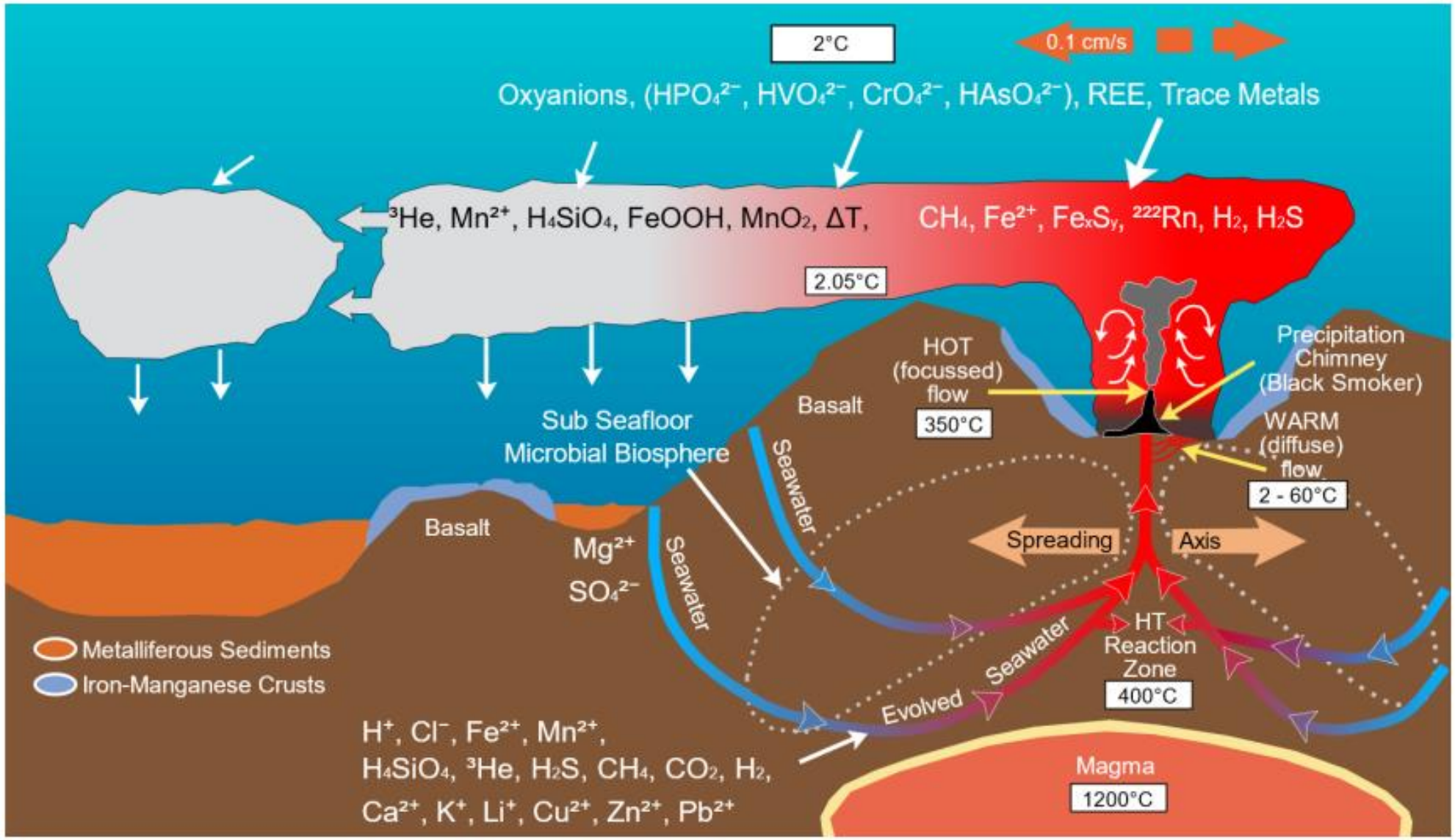
formation of hydrothermal precipitates due to mixing of hot fluid with cold seawater

(± magmatic volatiles and metals)



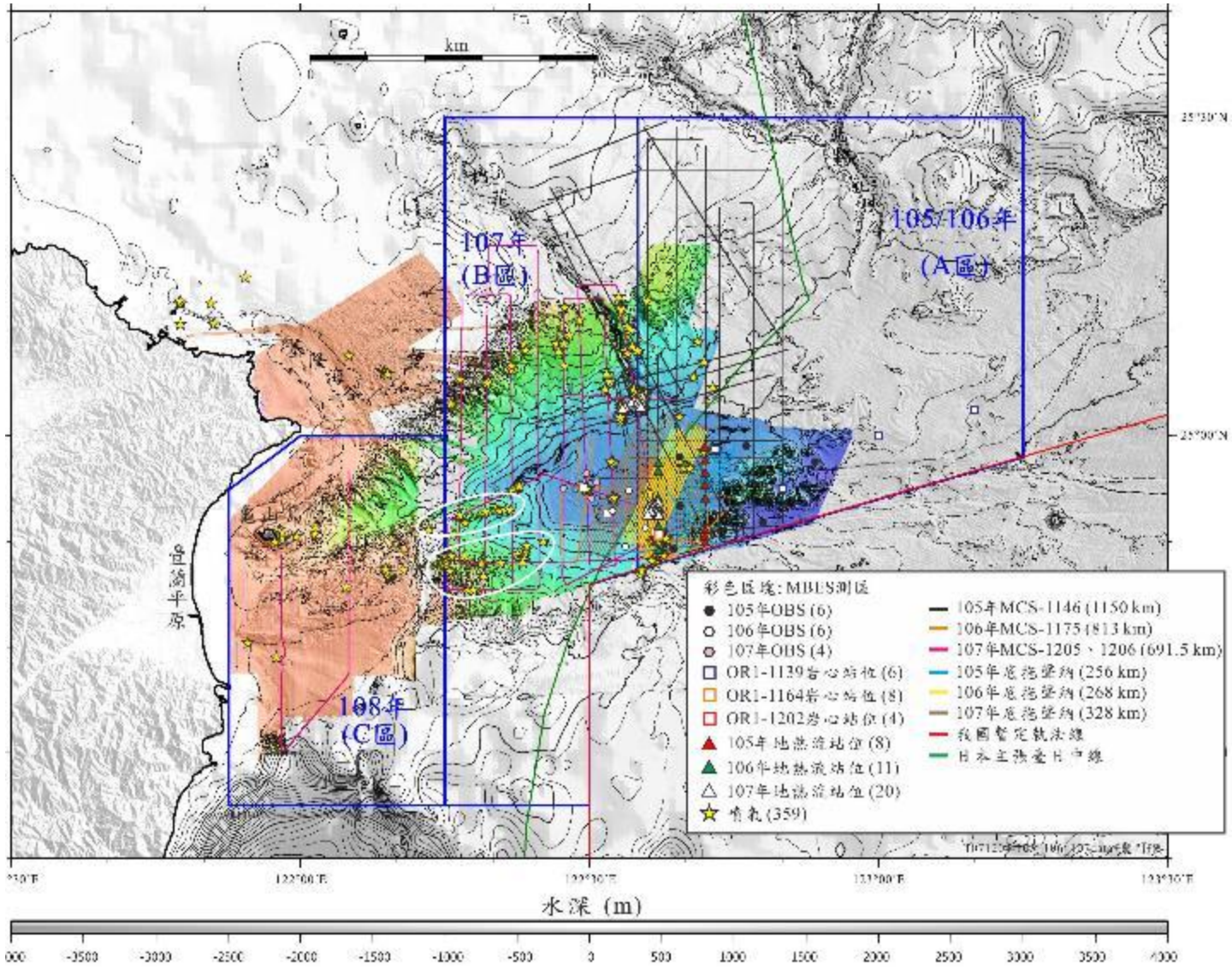
After: http://earthguide.ucsd.edu/mar/dec12.html

Seafloor Massive Sulphides



https://education.nationalgeographic.org/resource/ocean-vent/

臺灣東北海域礦產資源潛能調查



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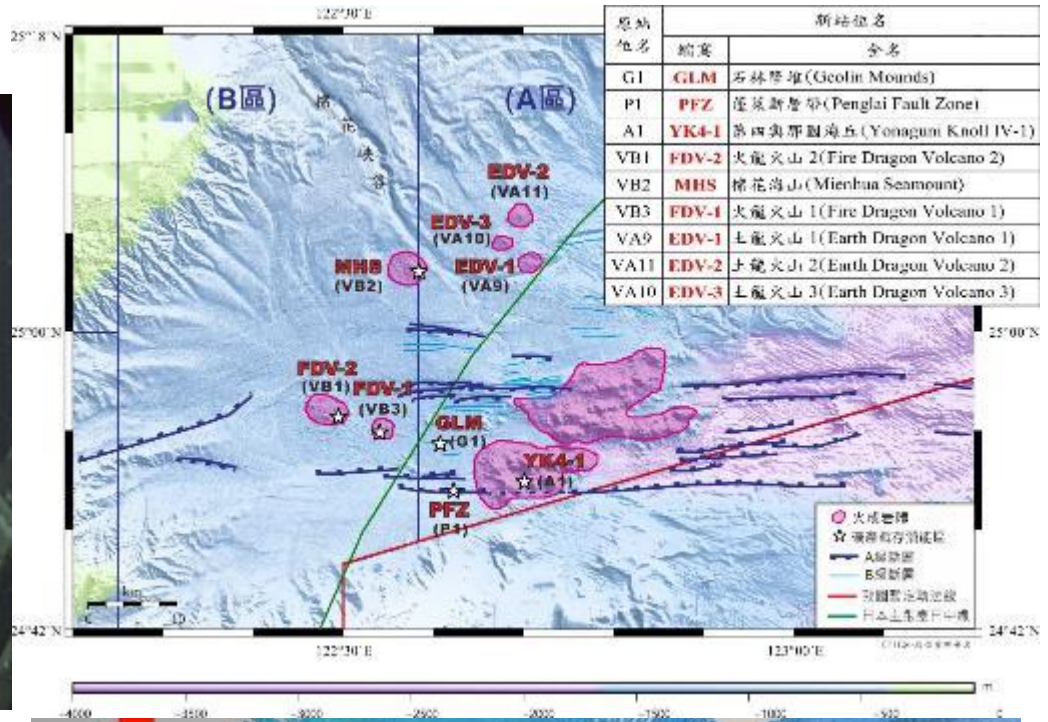
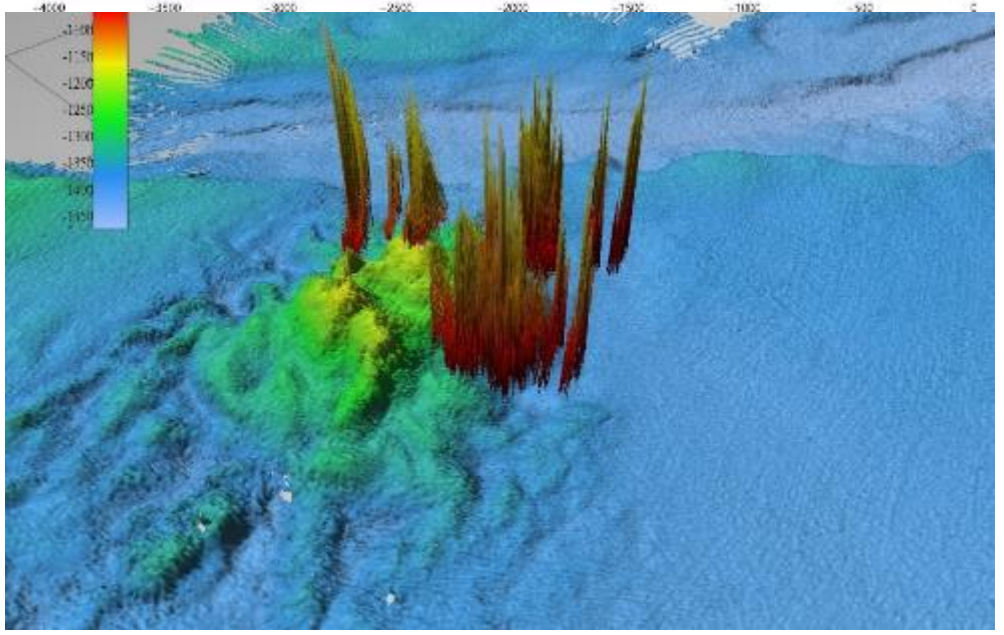
熱液礦床



原熱液名	新站位名	
	縮寫	全名
G1	GLM	石林丘堆(Geolin Mounds)
P1	PFZ	蓬萊斷層帶(Penglai Fault Zone)
A1	YK4-1	第四期鄰園海丘(Yonagun Knoll IV-1)
VB1	FDV-2	火龍火山 2(Fire Dragon Volcano 2)
VB2	MHS	棉花海山(Mienhua Seamount)
VB3	FDV-1	火龍火山 1(Fire Dragon Volcano 1)
VA9	EDV-1	土龍火山 1(Earth Dragon Volcano 1)
VA11	EDV-2	土龍火山 2(Earth Dragon Volcano 2)
VA10	EDV-3	土龍火山 3(Earth Dragon Volcano 3)



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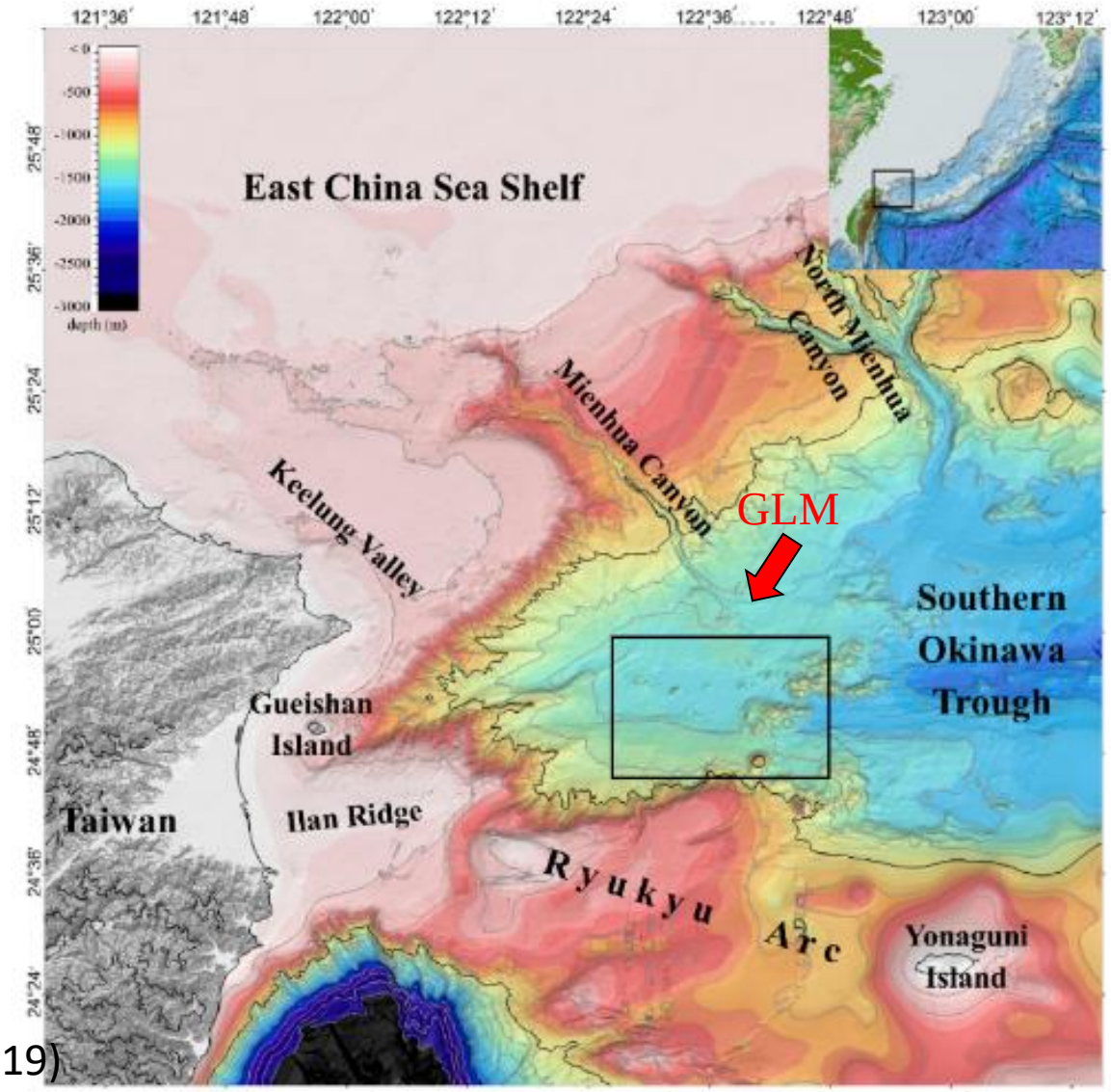
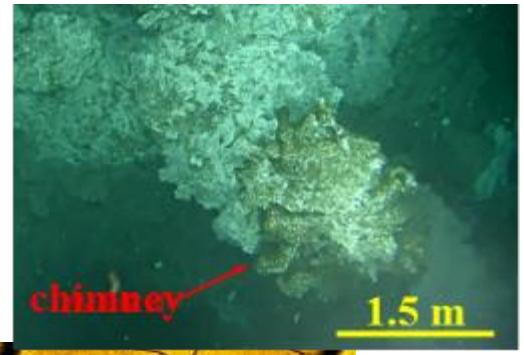
石林隆堆

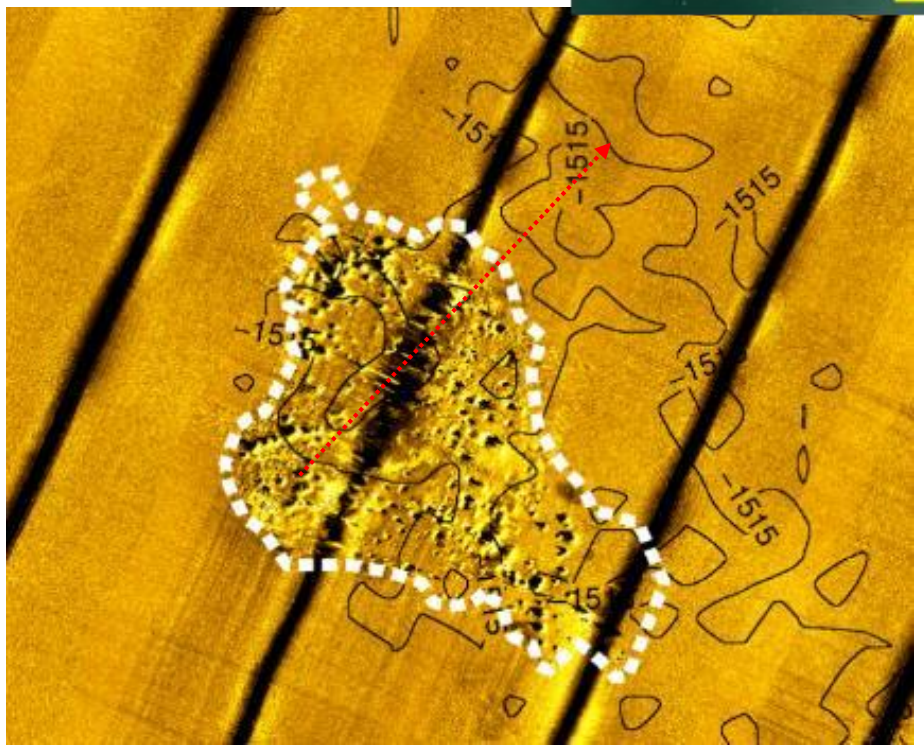
Geolin: 石林 (rock grove) in Taiwanese

- Geolin: rock grove morphological characteristics in Taiwanese
- Several meters high above seafloor



(Hsu et al., 2019)



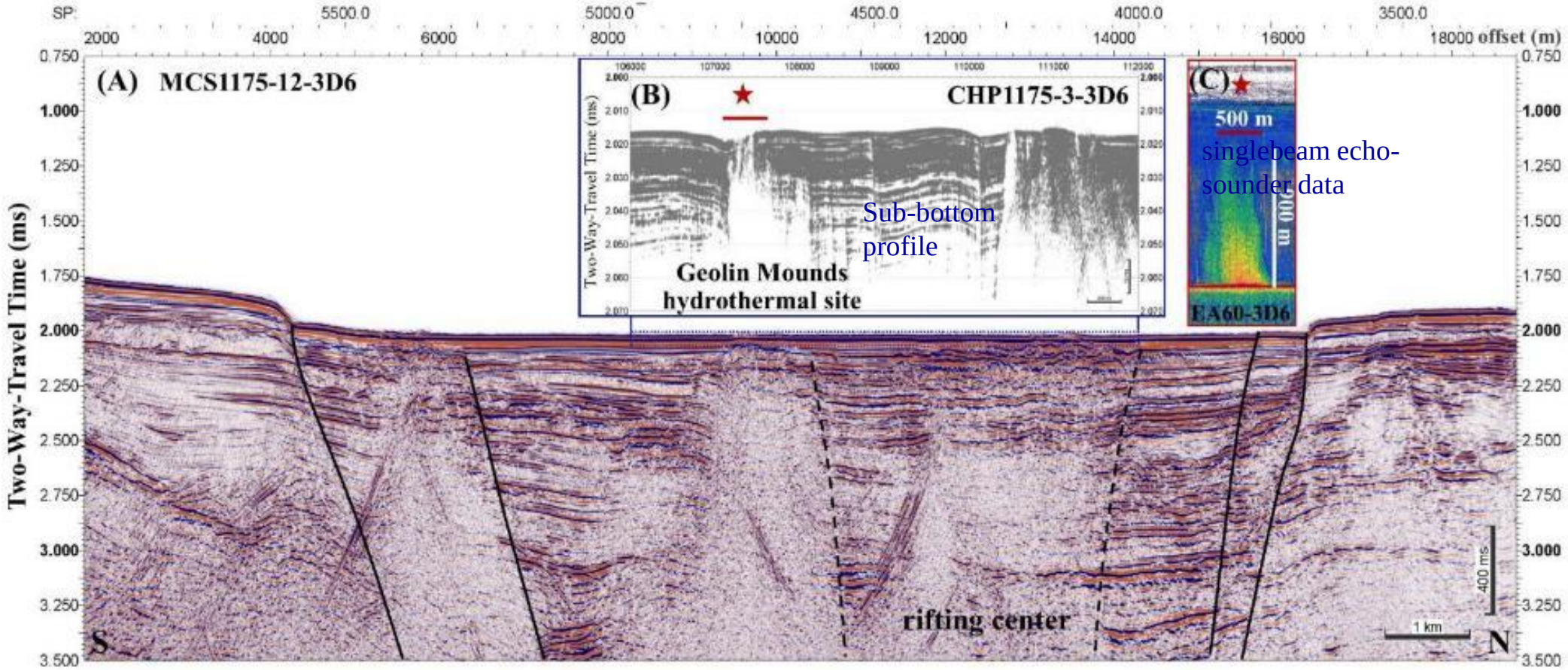


deep-towed side-scan image

2維地球物理資料

- A ~500 m wide and ~900 m high flare is above sea floor.
- Blanking zone (fluid migration feature) is observed.
- Normal faults developed along rifting center of the Southern Okinawa Trough (SOT).

seismic profile



(Hsu et al., 2019)

https://news.pts.org.tw/article/438968

台灣海底黑煙囪

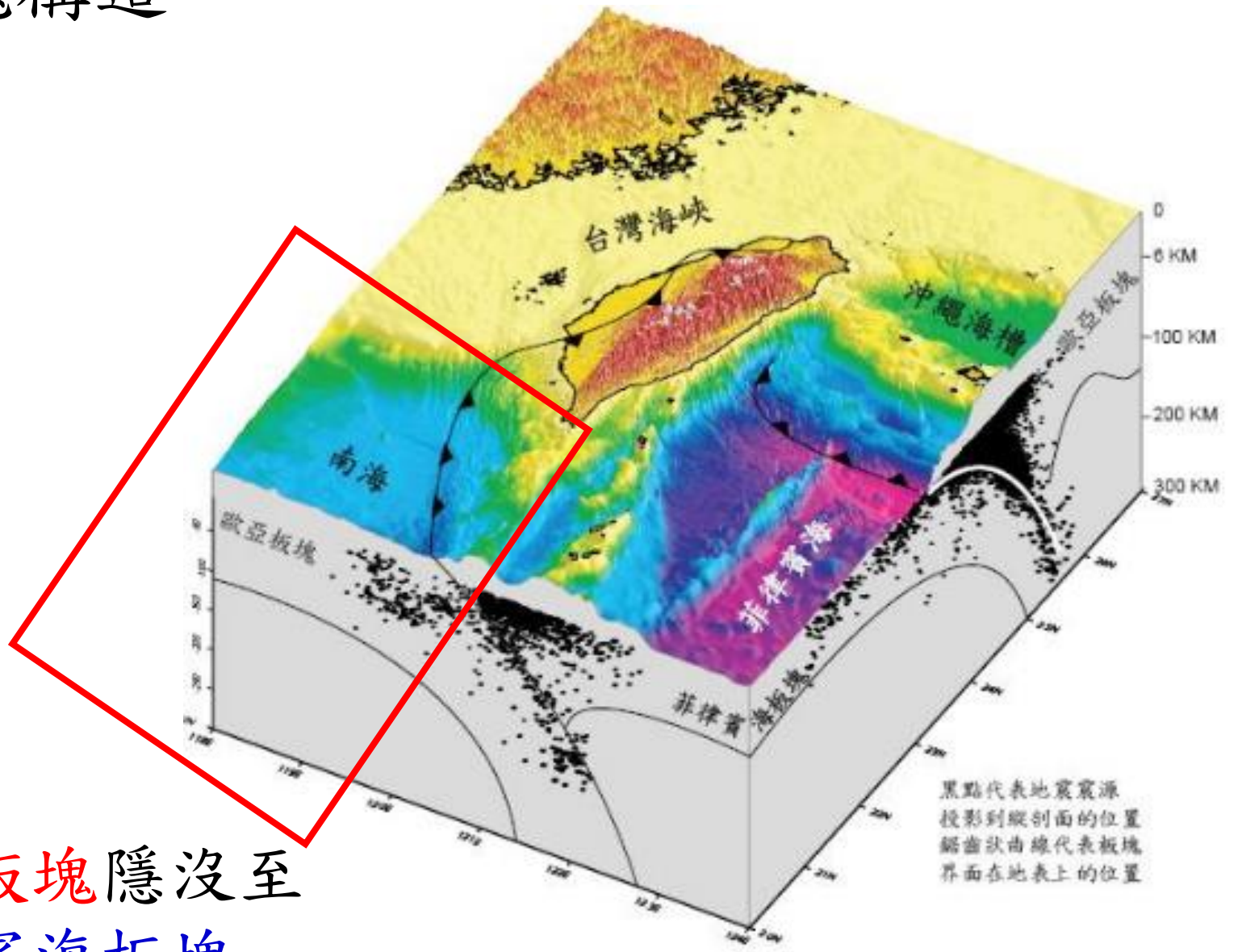
《地球資源大探索》海底聚寶盆：黑煙囪

YouTube

YouTube · 科普一傳十 · May 13, 2020

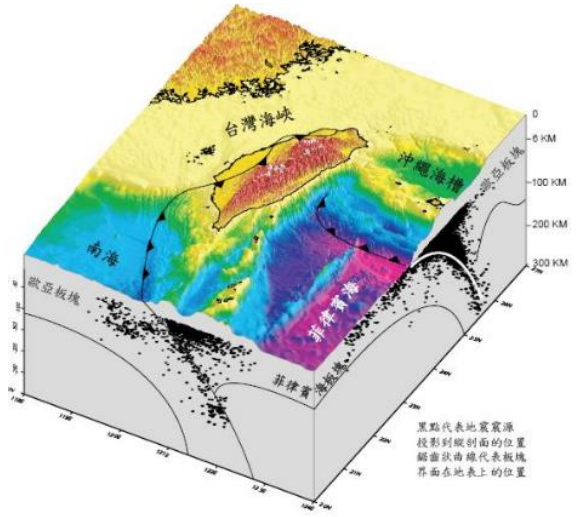
板塊構造

歐亞板塊與菲律賓板塊交互作用



菲律賓海板塊隱沒至歐亞板塊

歐亞板塊隱沒至菲律賓海板塊



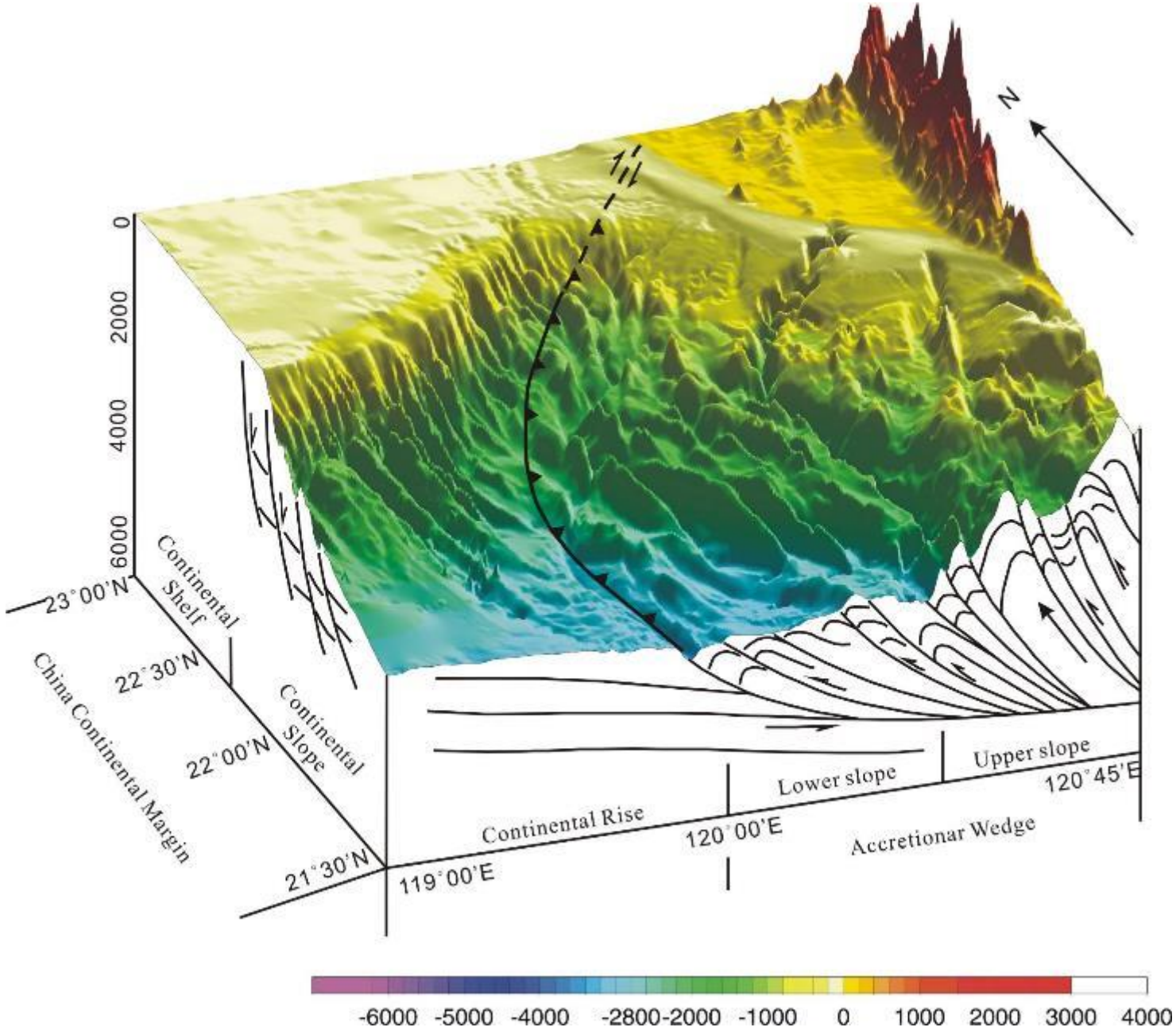
台灣西南海域構造型態

被動大陸邊緣：拉張性正斷層

活動大陸邊緣：增積岩體/造山楔

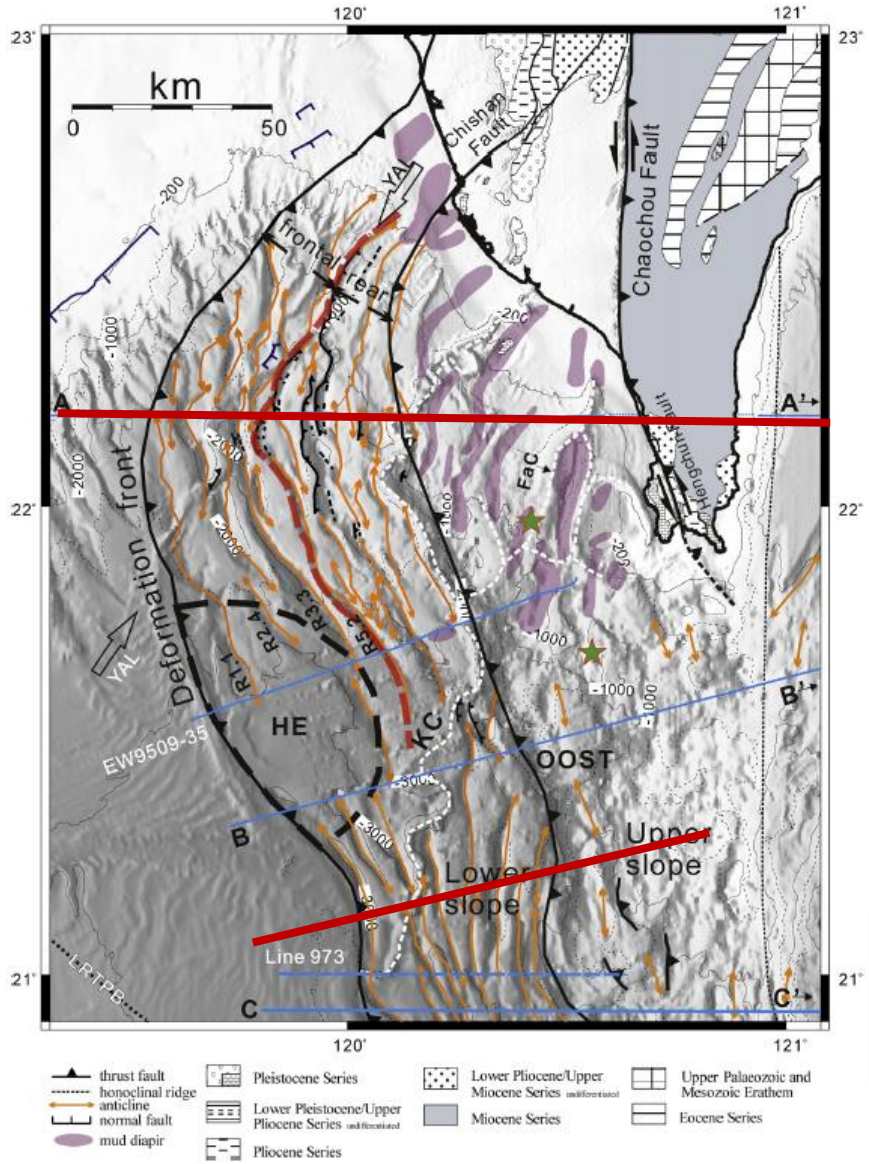
-褶皺與逆衝斷層

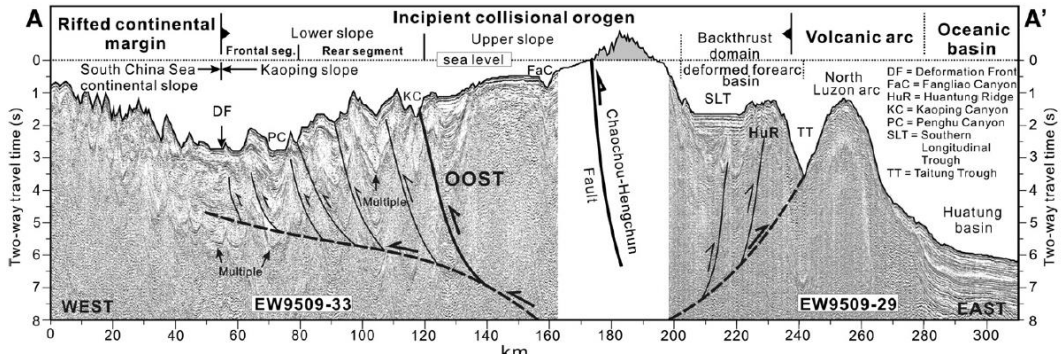
變形前緣分隔兩者

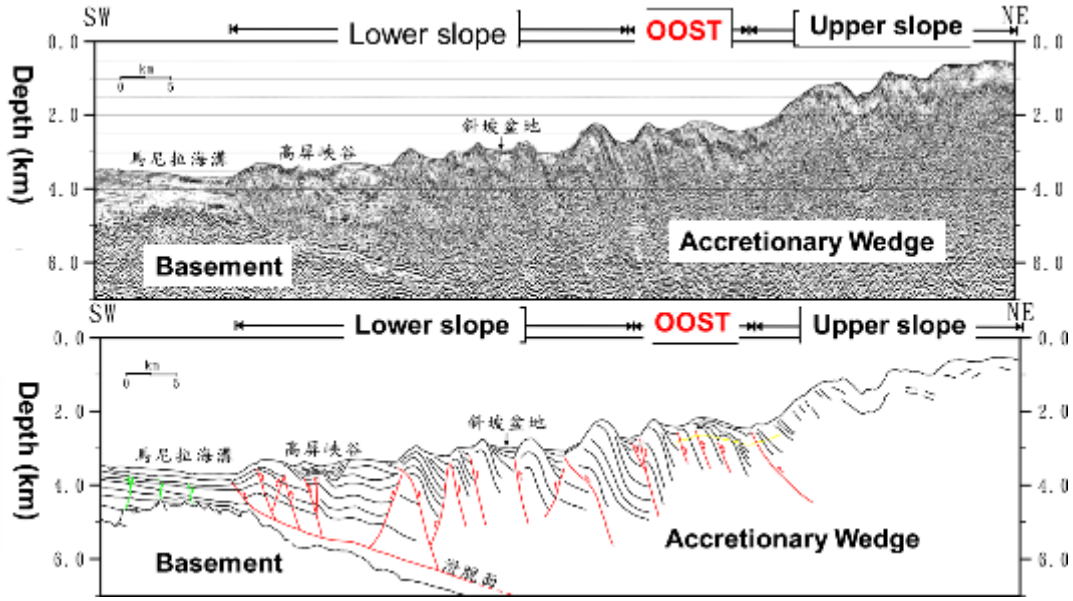


(Liu et al., 1997; 2006)

臺灣南部海域隱沒到碰撞/增積岩體至造山楔構造







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造山活動

高山小河川

大量有機物

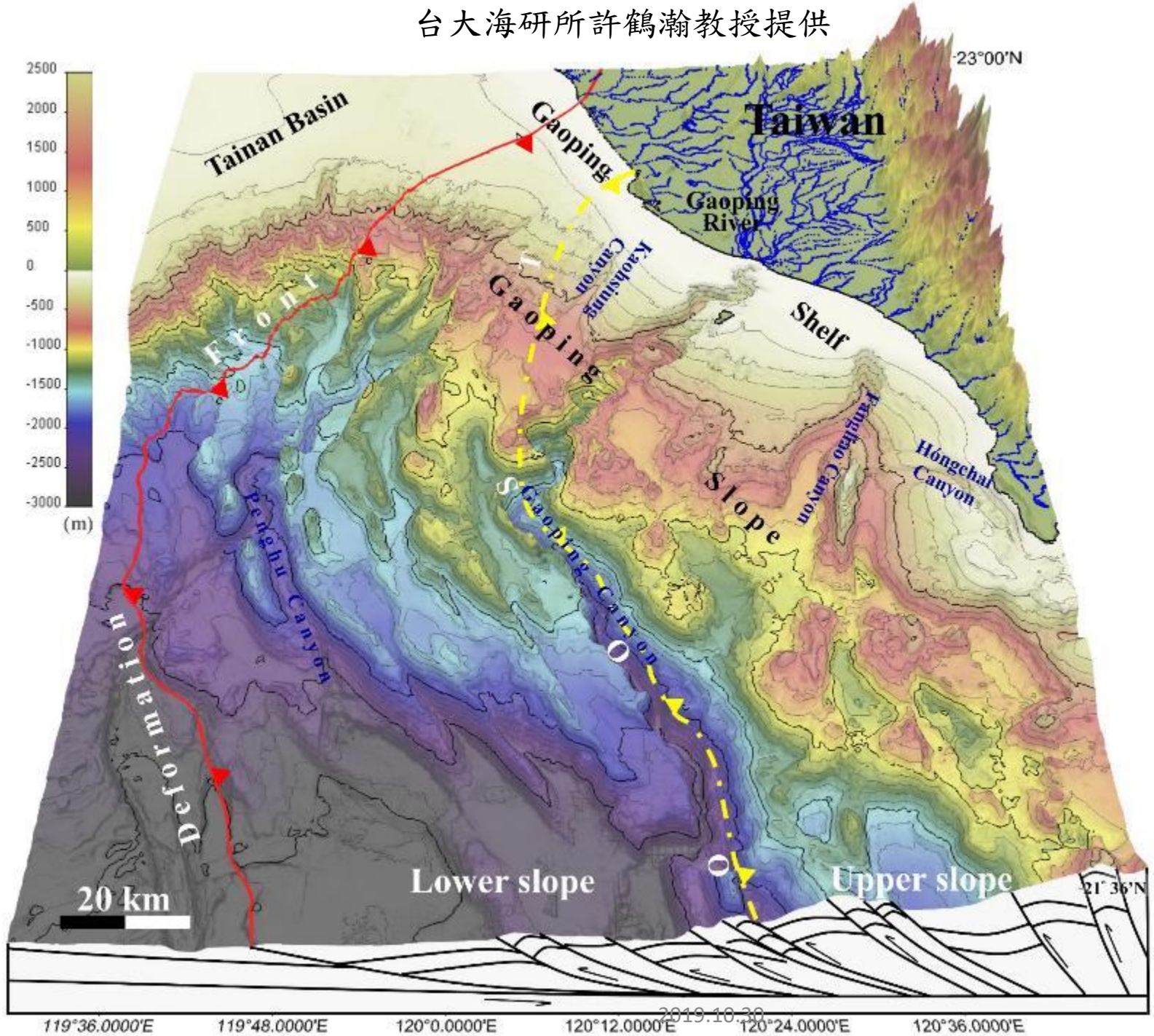
盆地/背斜/
斷層構造/褶皺逆衝斷層帶

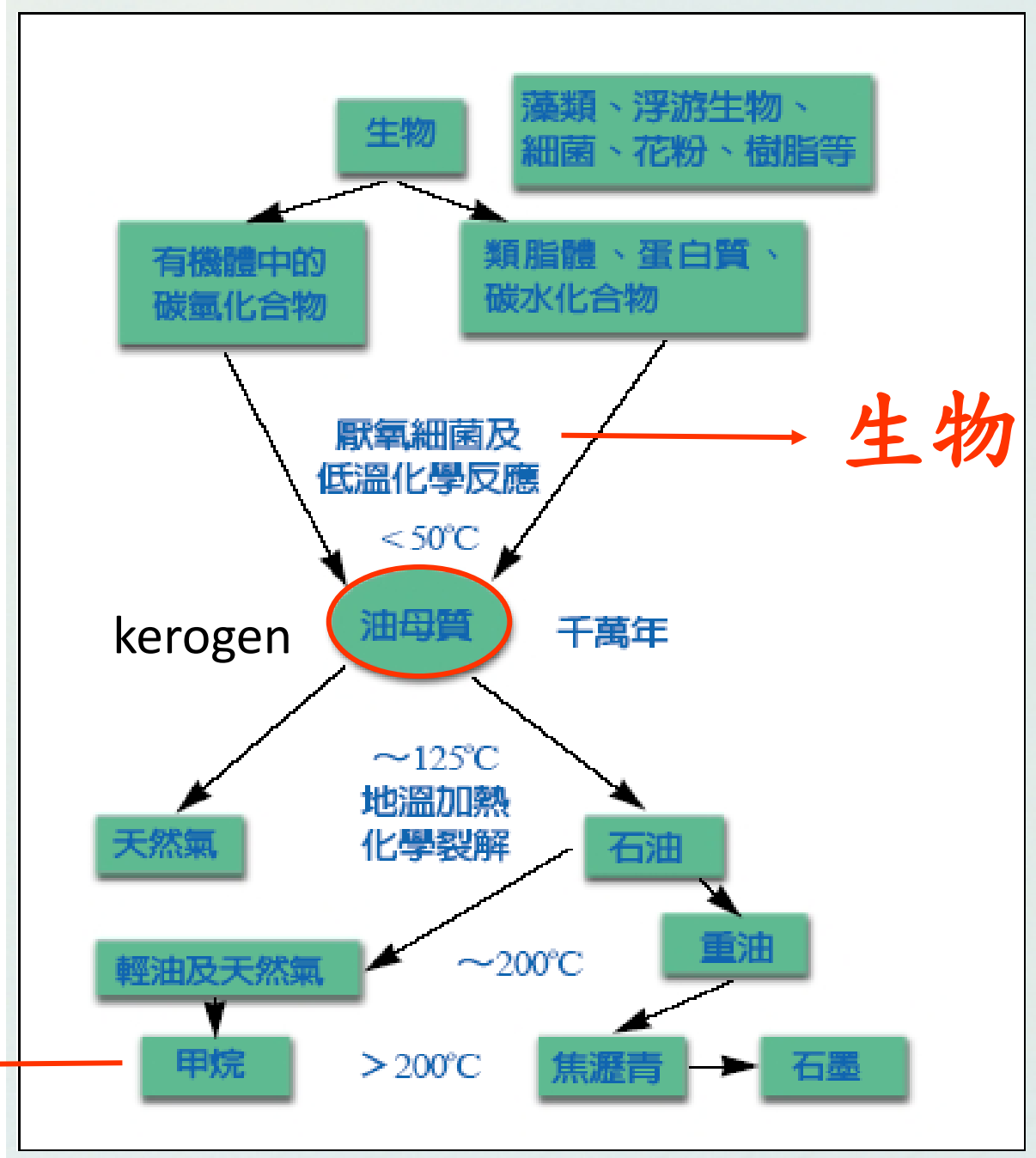
生物源/熱分解來源天然氣

泥火山/泥貫入體/冷泉

天然氣水合物資源

台大海研所許鶴瀚教授提供





生物甲烷

熱分解來源甲烷

After: https://web.fg.tp.edu.tw/~earth/learn/esf/magazine/991203.htm

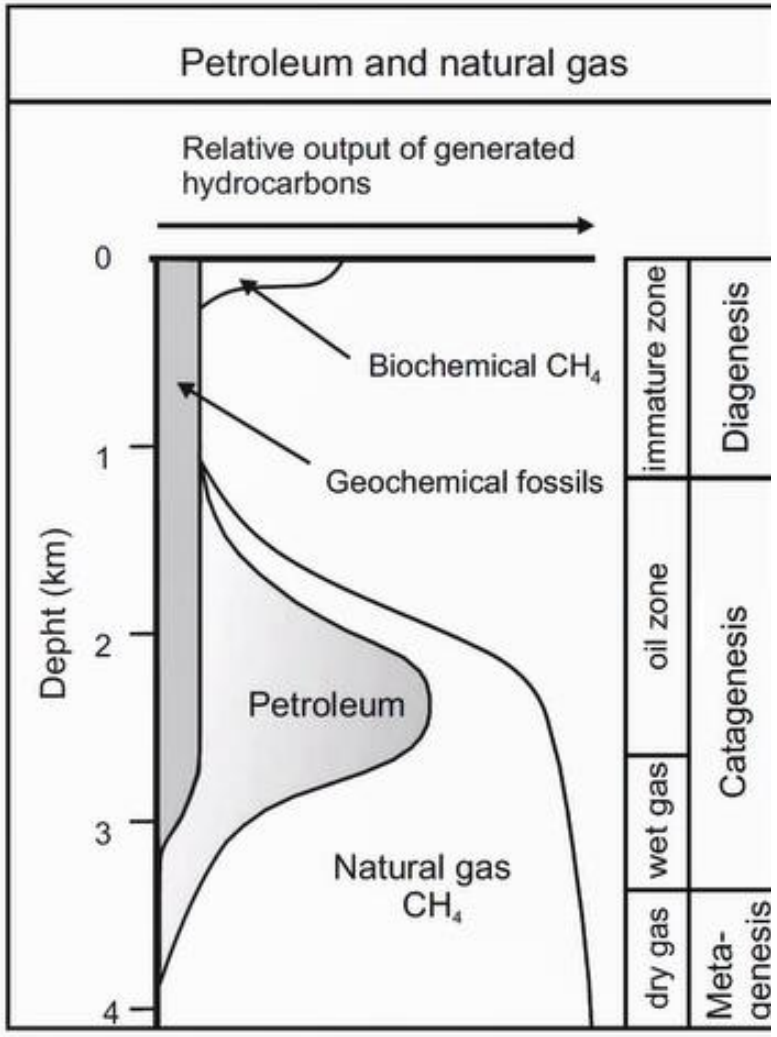


Fig. 4.1. Evolution of organic matter: Diagenetic, catagenetic and metagenetic processes describe the generation of oil and gas and coalification. The picture is from Bahlburg and Breitkreuz (2004). The processes are compared with the relative intensities of light reflected from the coal maceral vitrinite

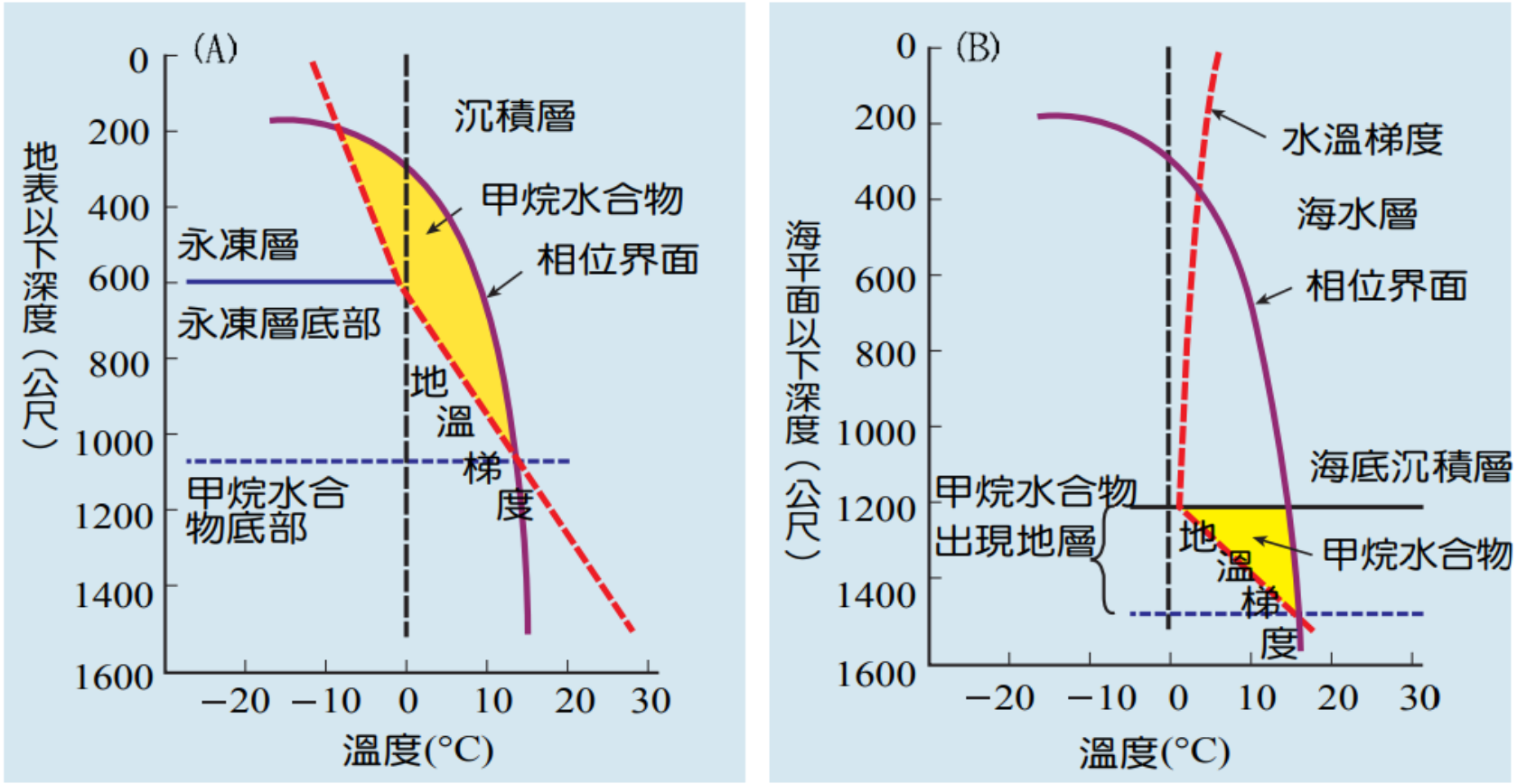
Hantschel & Kutterauf (2009)

- At higher temperature above 80 or 90 degrees, we have thermogenic methane formation.
- Thicker sediments cover 2 to 3 km depths➔ We are able to enter this thermogenic production.

天然氣水合物/甲烷水合物/可燃冰

大自然中甲烷水合物形成的環境

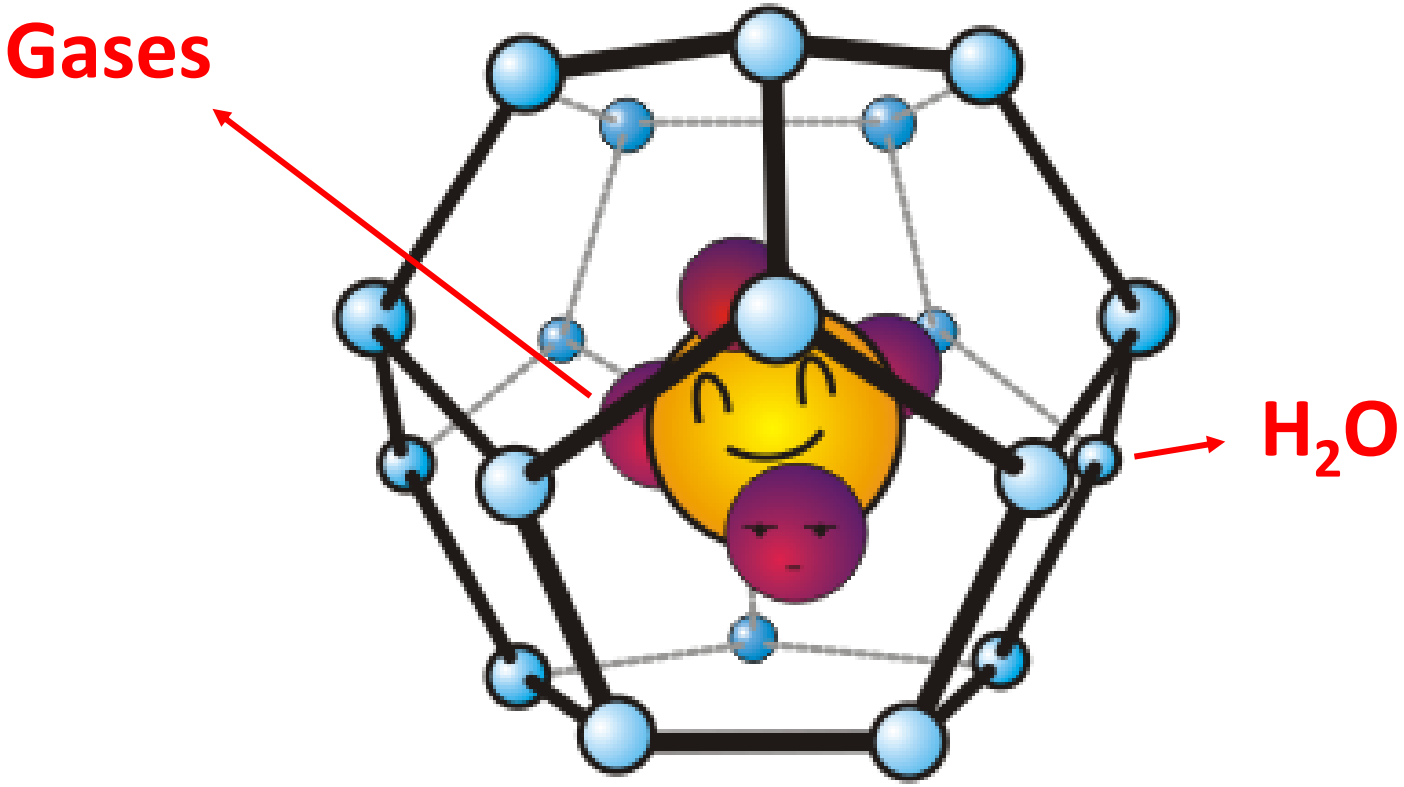
高壓、低溫及足夠甲烷氣



▲圖 2　甲烷水合物在(A)極區永凍層與(B)海域環境下其相位界面和環境溫、壓關係圖。紫色曲線為甲烷水合物相位界面，紅色虛線為溫度變化曲線，黃色區域為甲烷水合物穩定範圍

(劉家瑄, 2002)

What is Gas Hydrate (GH) ?



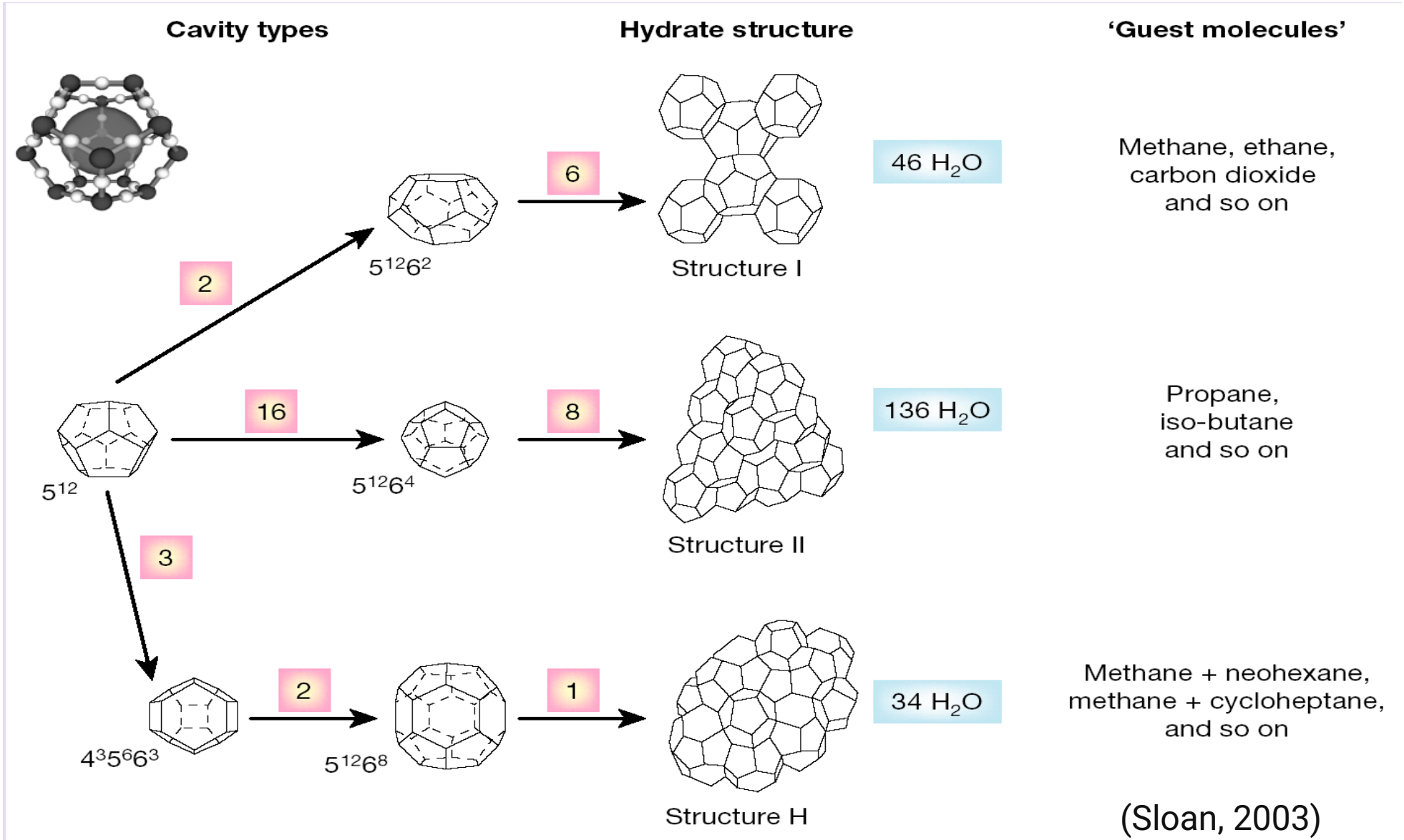
- 1 gas hydrate (L) = 1 water (L) + 168 CH_4 (L) (STP)
- It contains a great volume of methane

Hydrate structure

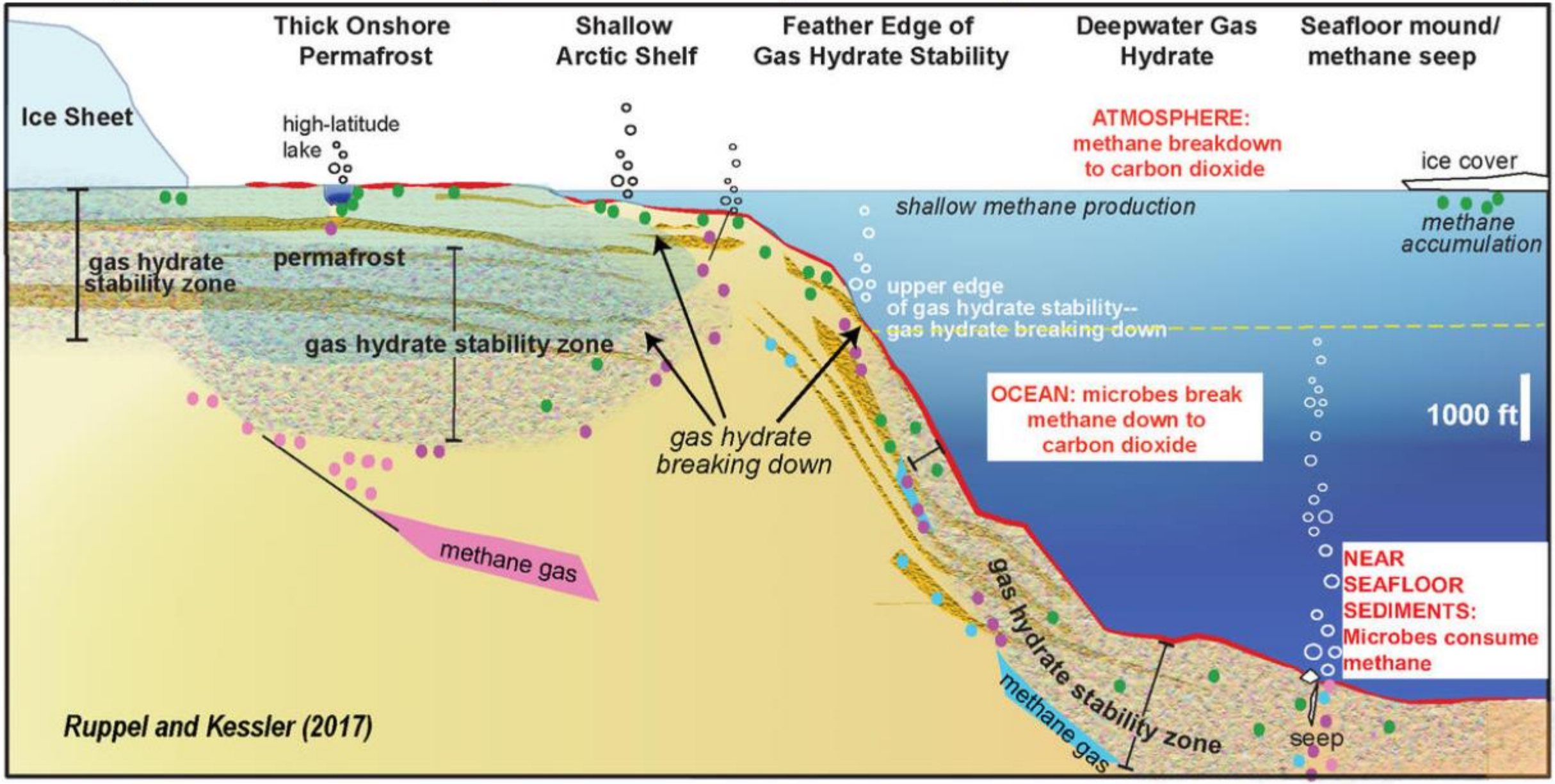
Structure I

Structure II

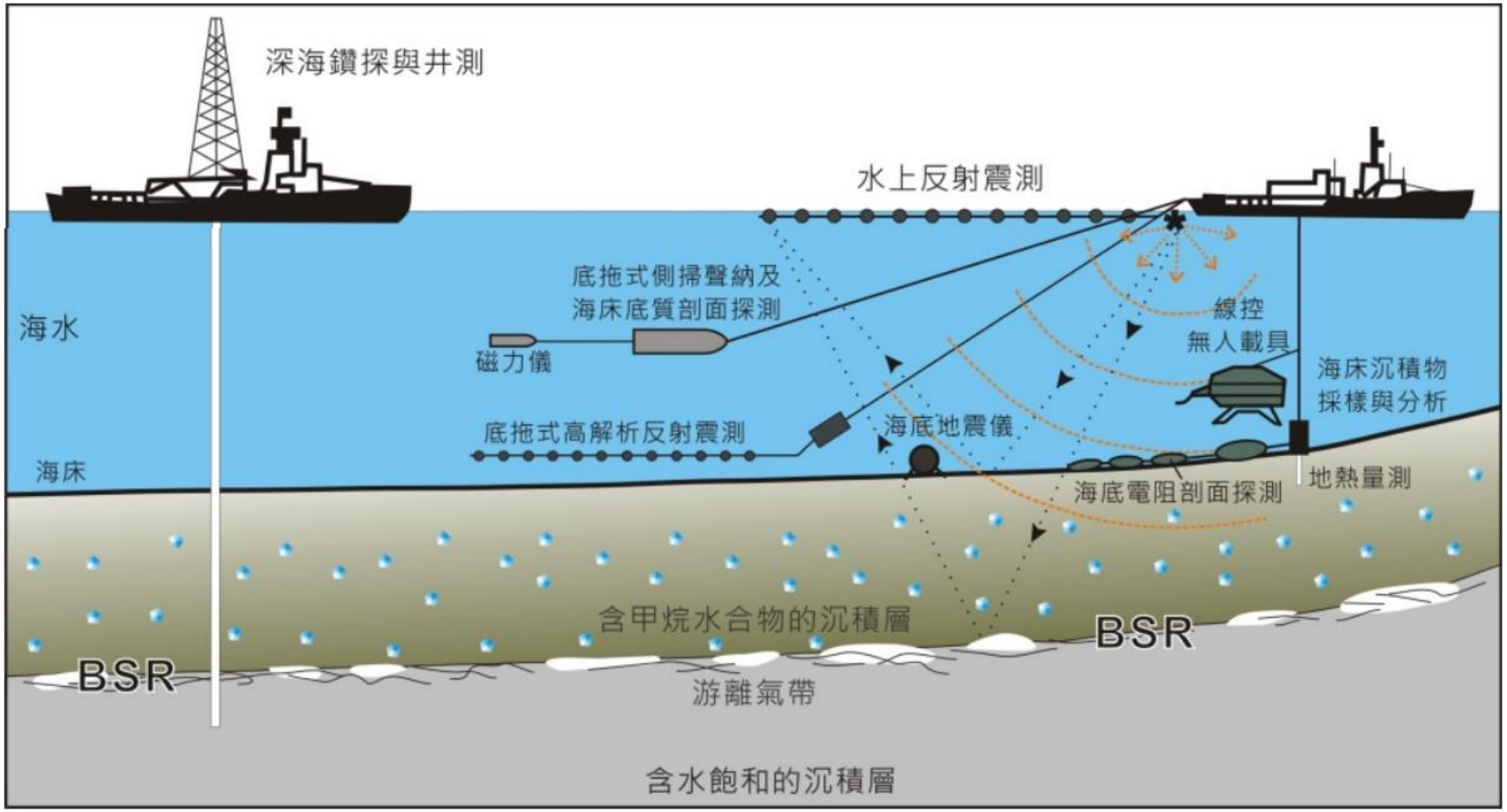
Structure H



(Sloan, 2003)


Thick Onshore Permafrost
Shallow Arctic Shelf
Feather Edge of Gas Hydrate Stability
Deepwater Gas Hydrate
Seafloor mound/ methane seep
Ice Sheet
high-latitude lake
ATMOSPHERE: methane breakdown to carbon dioxide
ice cover
shallow methane production
methane accumulation
gas hydrate stability zone
permafrost
upper edge of gas hydrate stability-- gas hydrate breaking down
gas hydrate stability zone
OCEAN: microbes break methane down to carbon dioxide
1000 ft
gas hydrate breaking down
methane gas
NEAR SEAFLOOR SEDIMENTS: Microbes consume methane
gas hydrate stability zone
methane gas
seep
Ruppel and Kessler (2017)

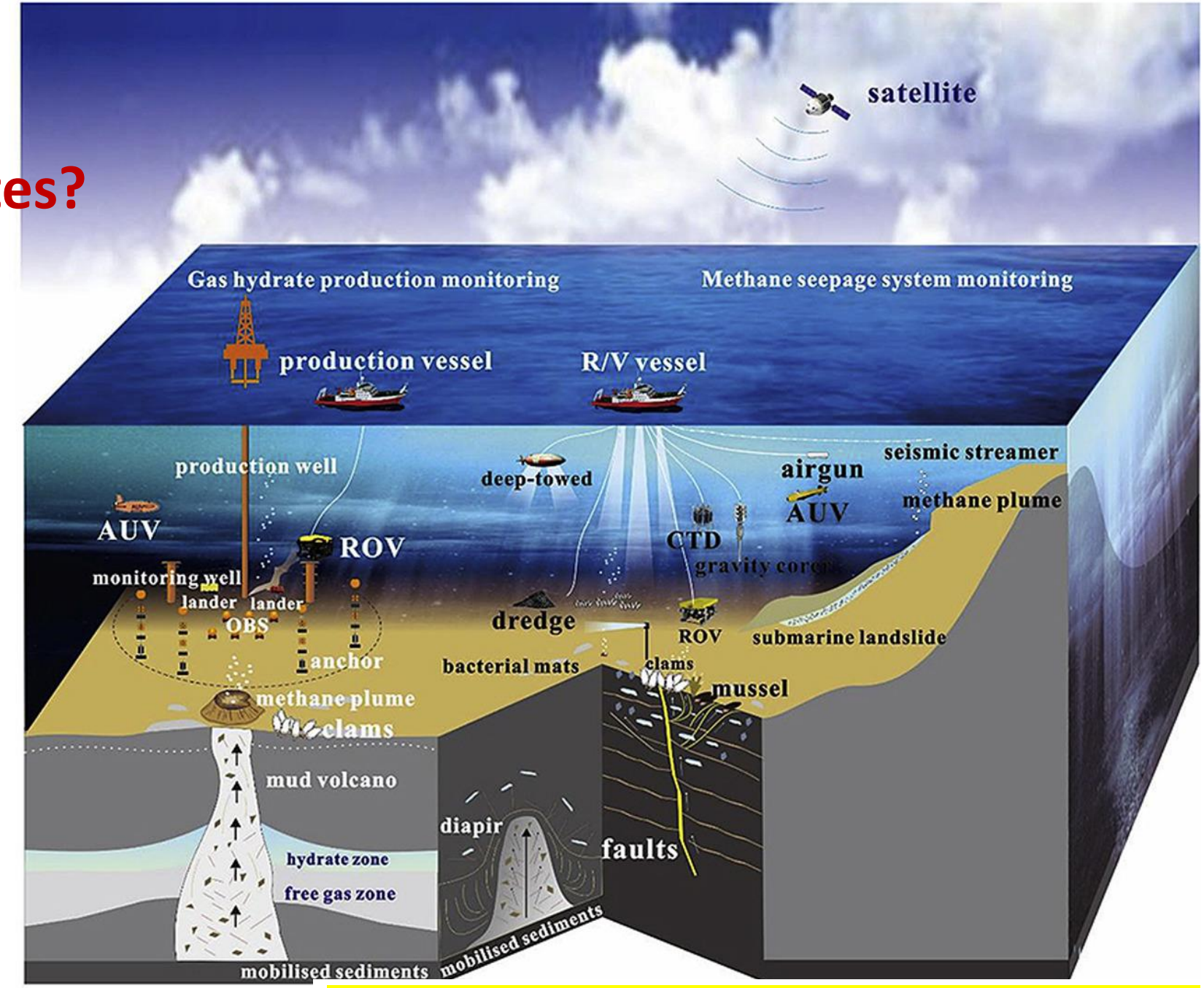
How do scientists investigate gas hydrates?



圖一　海底天然氣水合物的主要調查方法示意圖（改繪自 Hyndman *et al.*, 2001）。

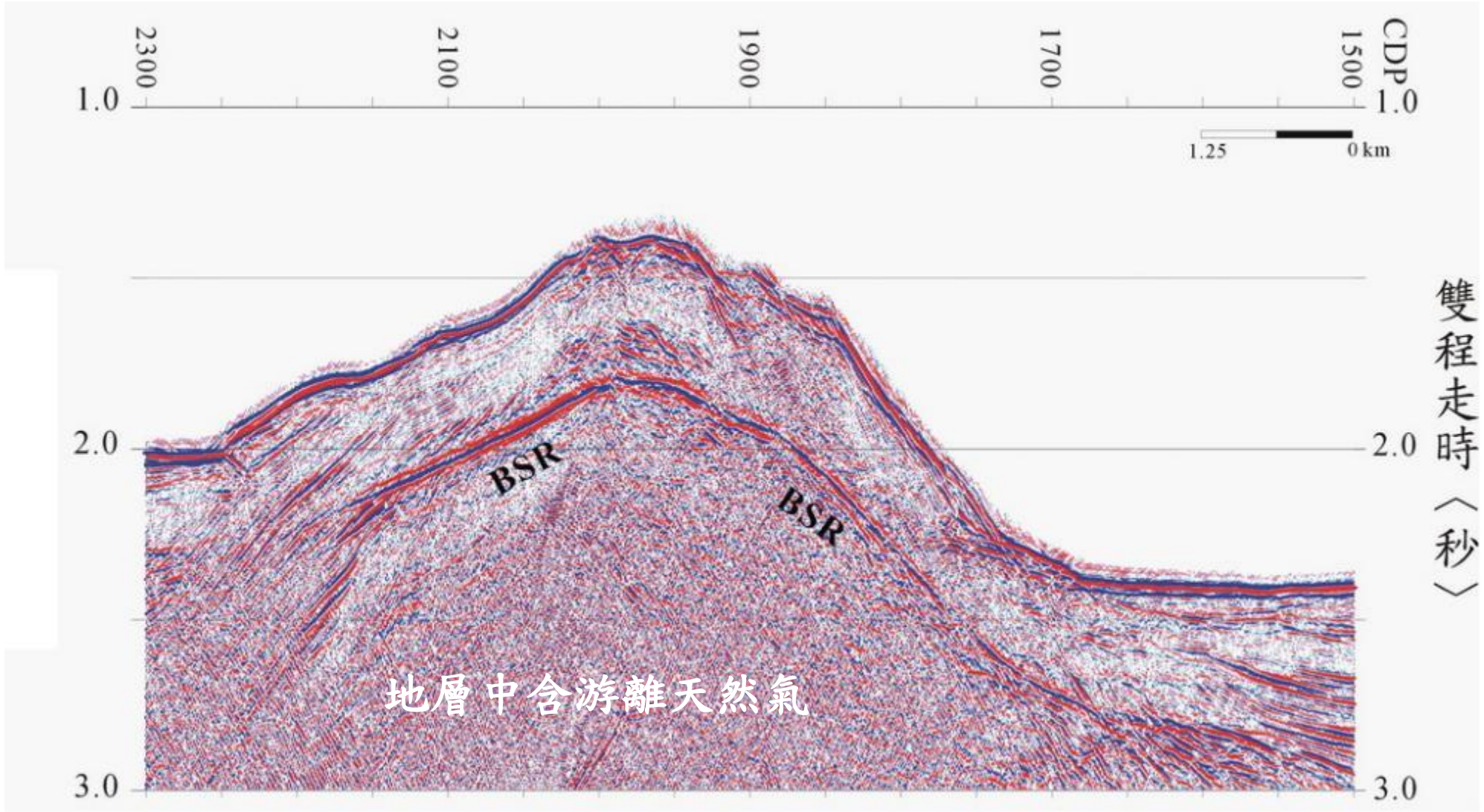
Fig. 1　Investigation methods of marine gas hydrate.

How do scientists investigate gas hydrates?



Liu et al. (2019)(https://doi.org/10.1016/j.jngse.2019.02.007)

海底仿擬反射
BSR: Bottom Simulation Reflector



Liu et al., 2006

海底仿擬反射成因

反射震測剖面

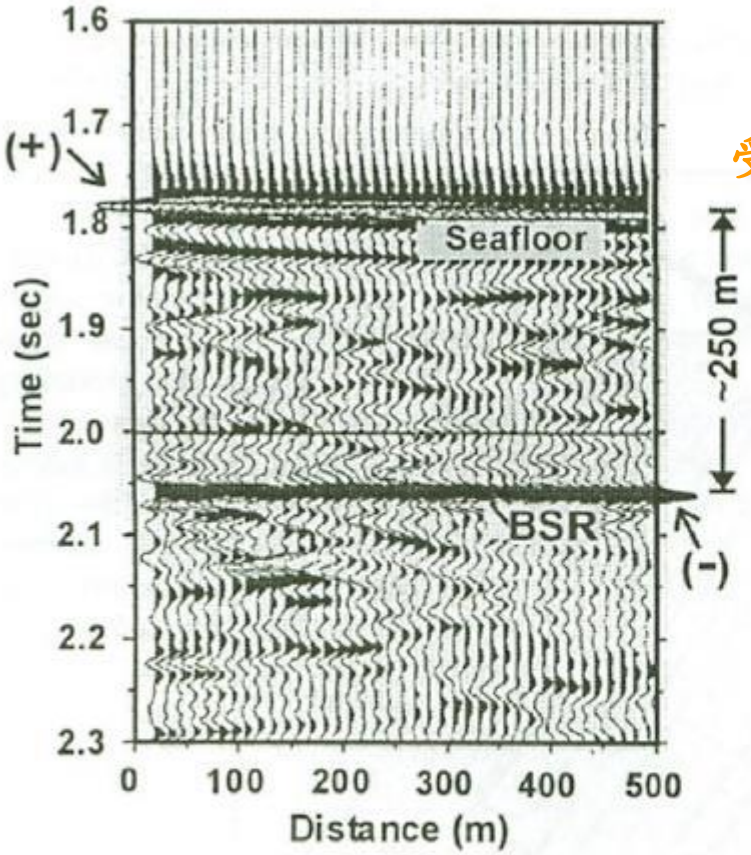


Figure 5. Example of strong BSR near ODP Site 889 showing the simple negative reflection waveform, opposite to that of the seafloor.

特徵

受地溫梯度控制

大致平行海床

信號相位相反

地層聲波阻抗與反射信號

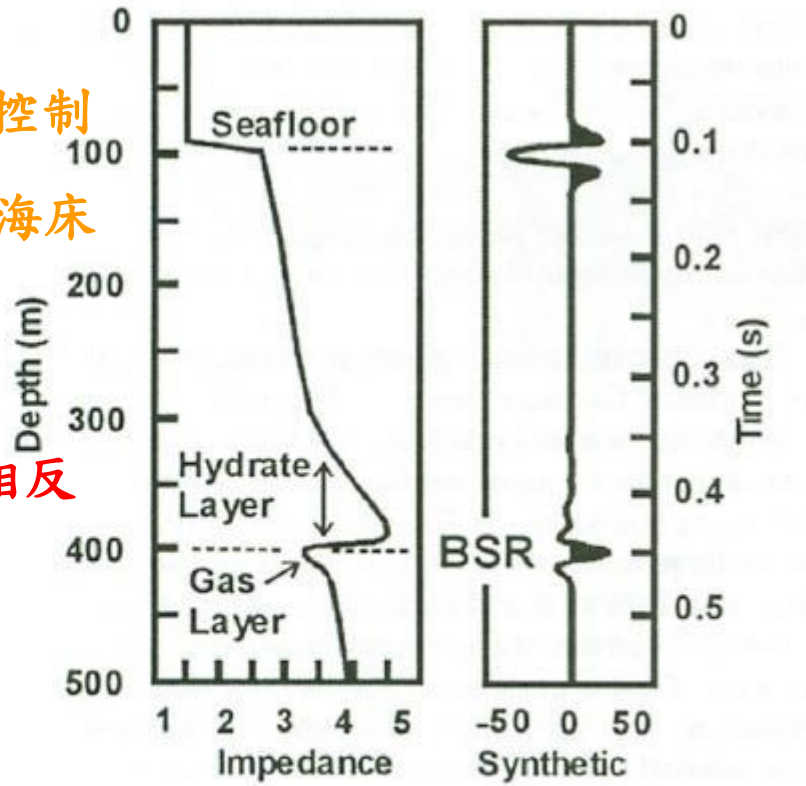
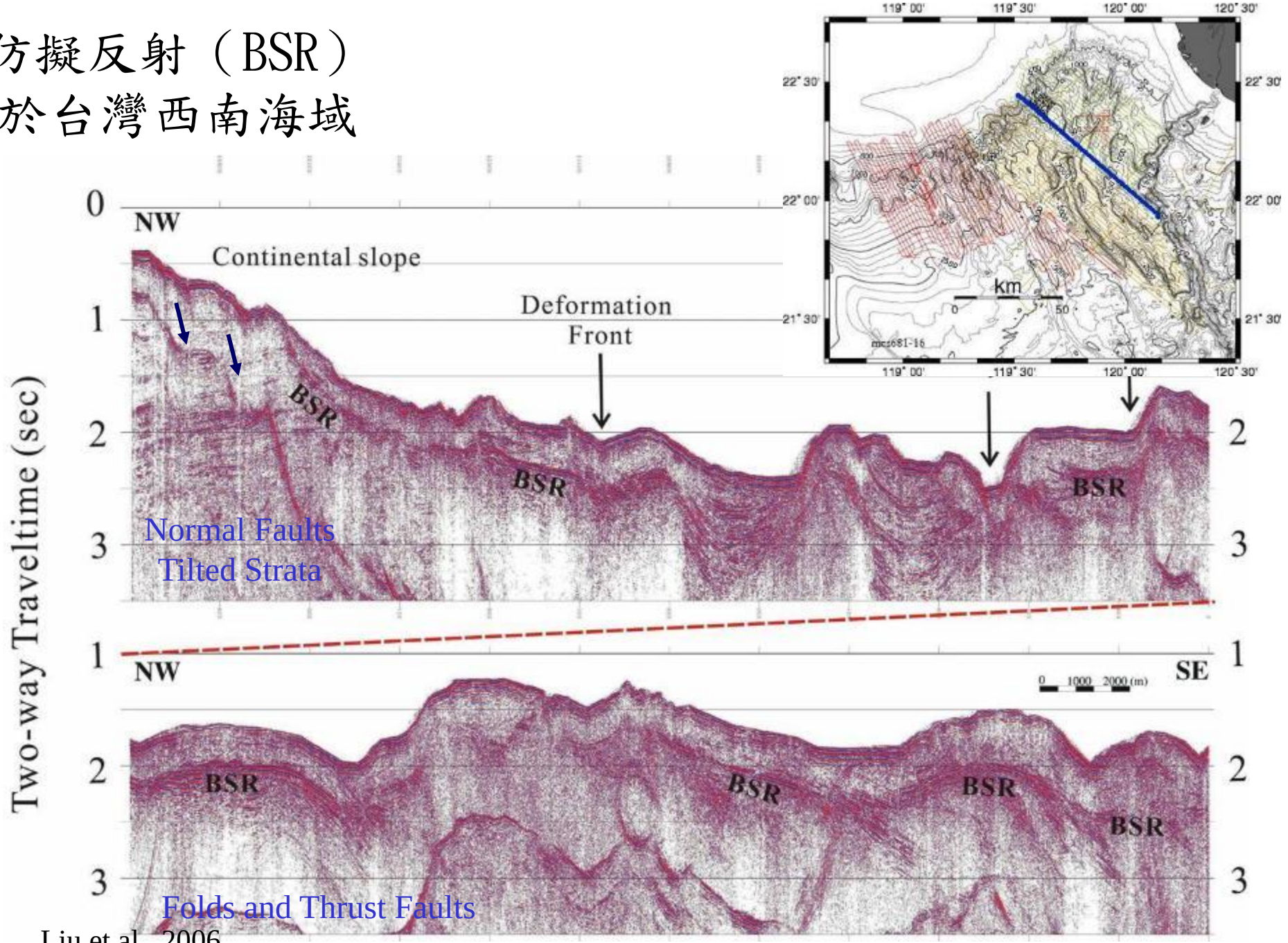


Figure 6. Simple synthetic seismogram that reproduces the main features of the BSRs. The seafloor reflection results mainly from the density contrast and the BSR mainly from the velocity contrast.

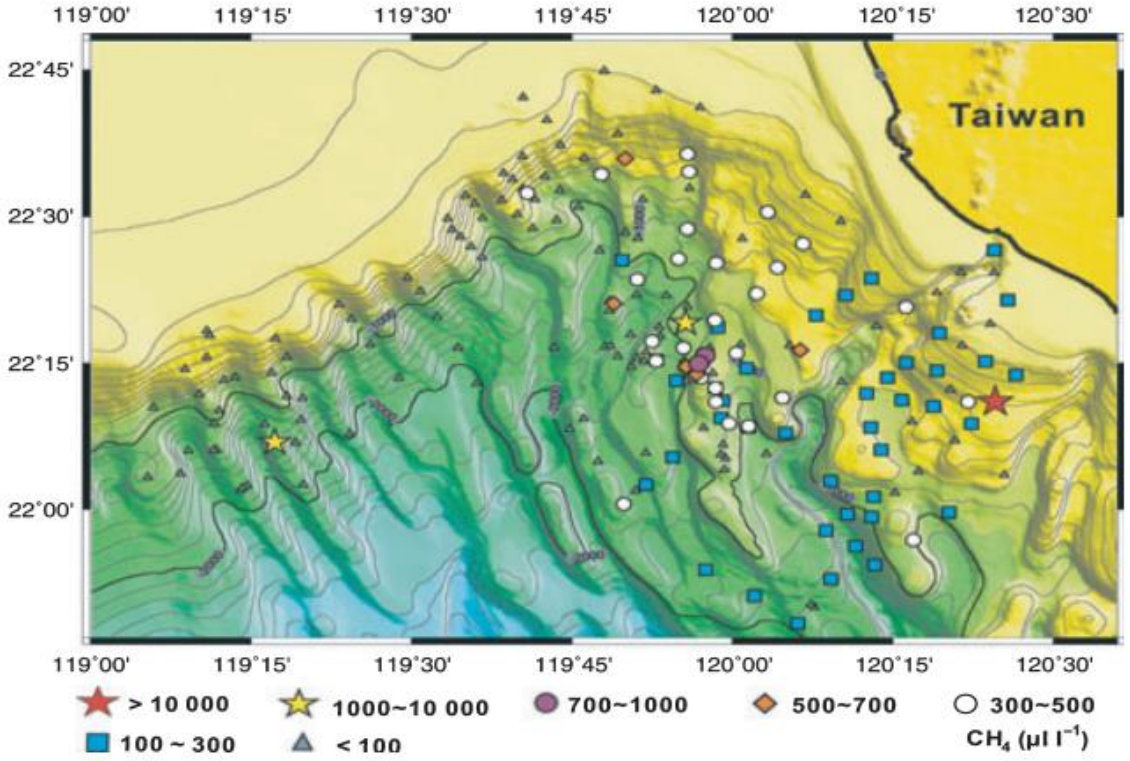
(Dallimore and Hyndman, 2001)

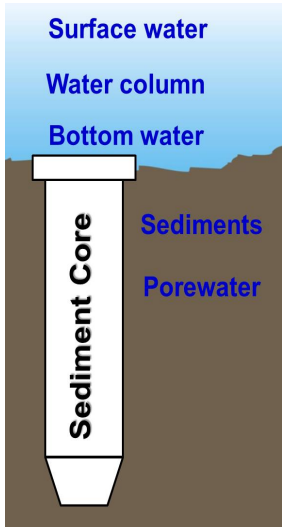
海底仿擬反射（BSR）
廣佈於台灣西南海域



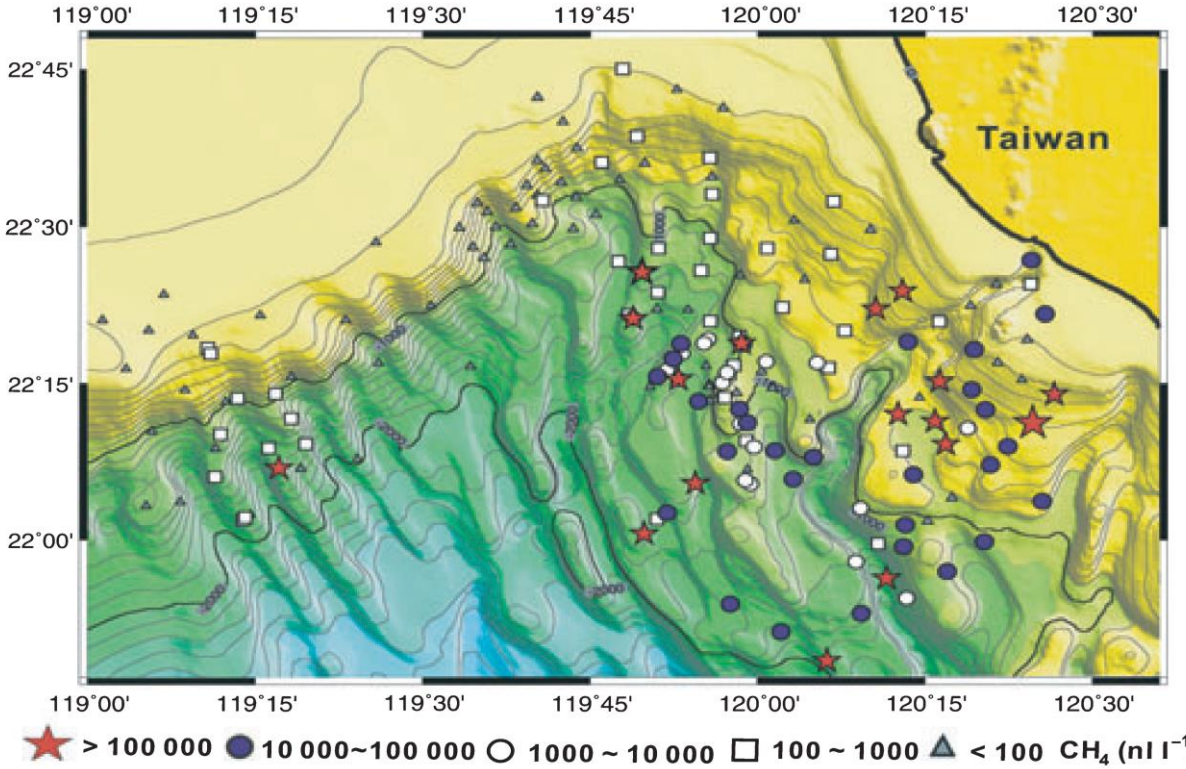
Liu et al., 2006

Dissolved methane concentration in core-top sediments



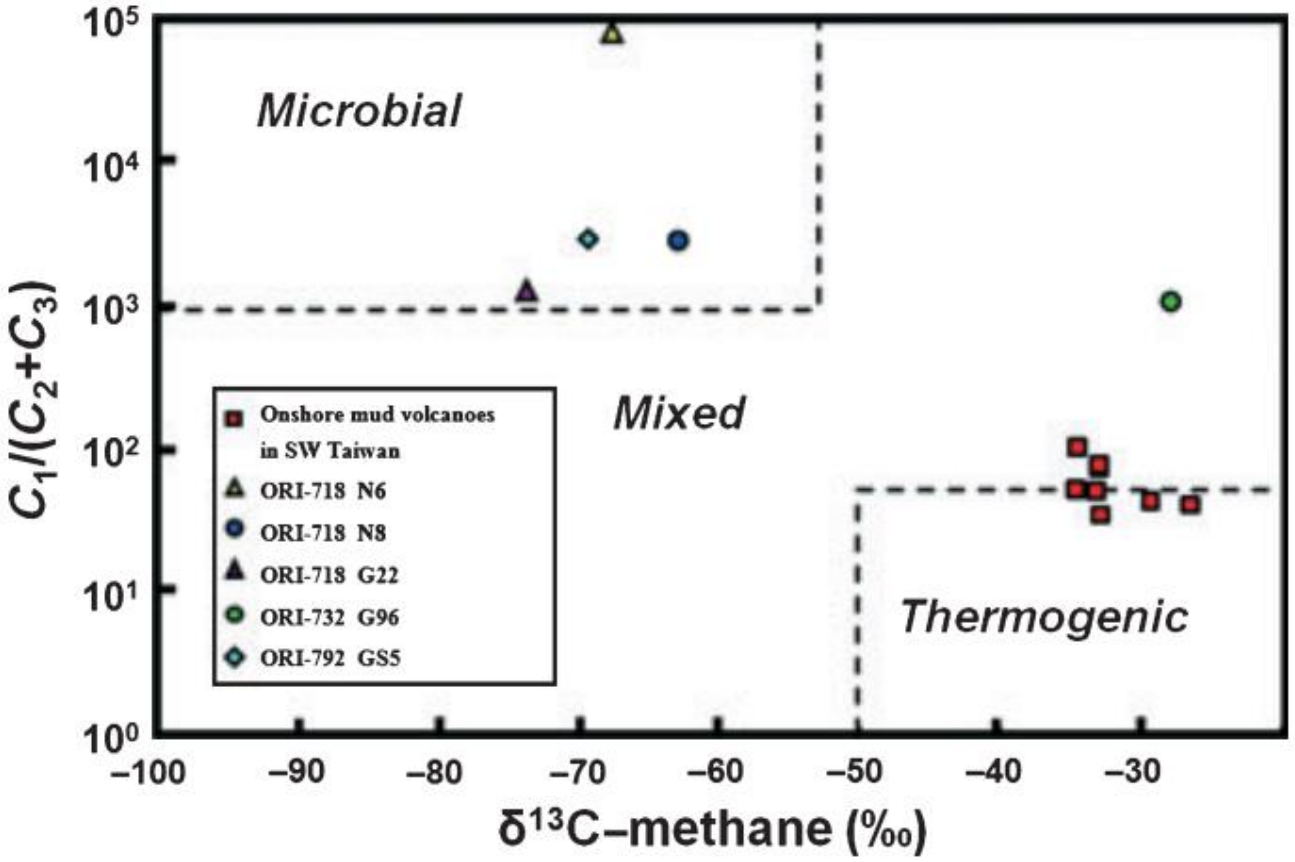


Dissolved methane concentration in bottom water

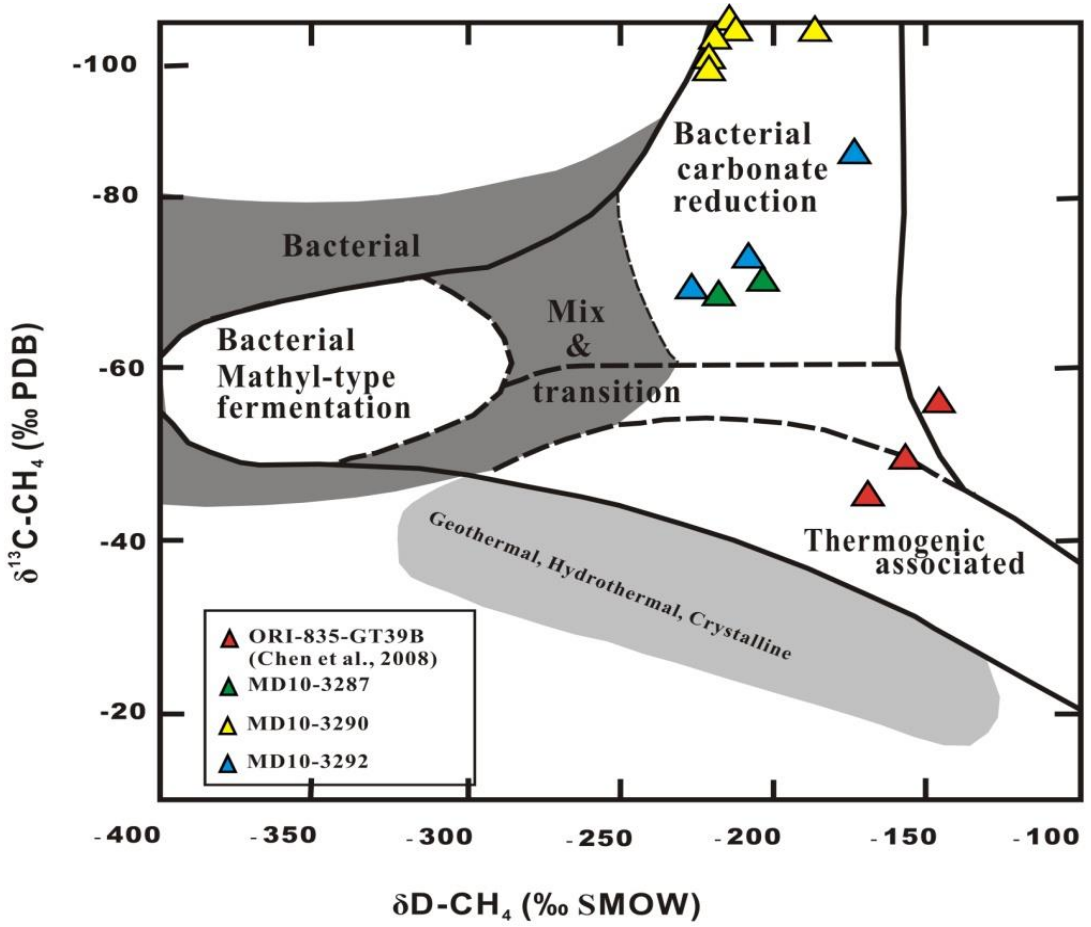


(Chuang et al., 2010)

Tracing methane sources

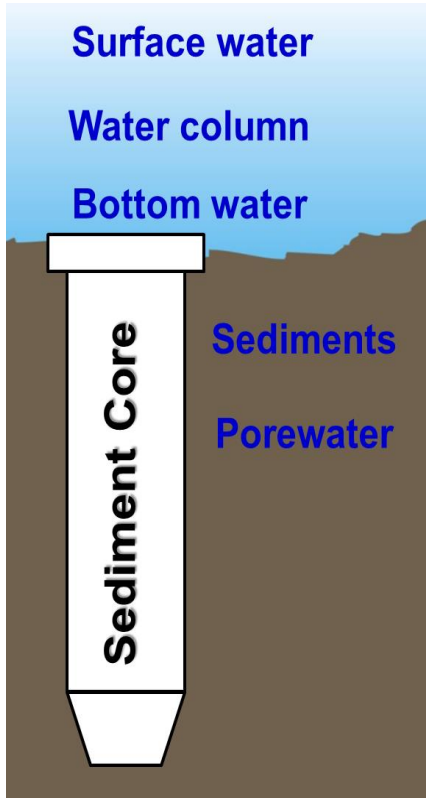


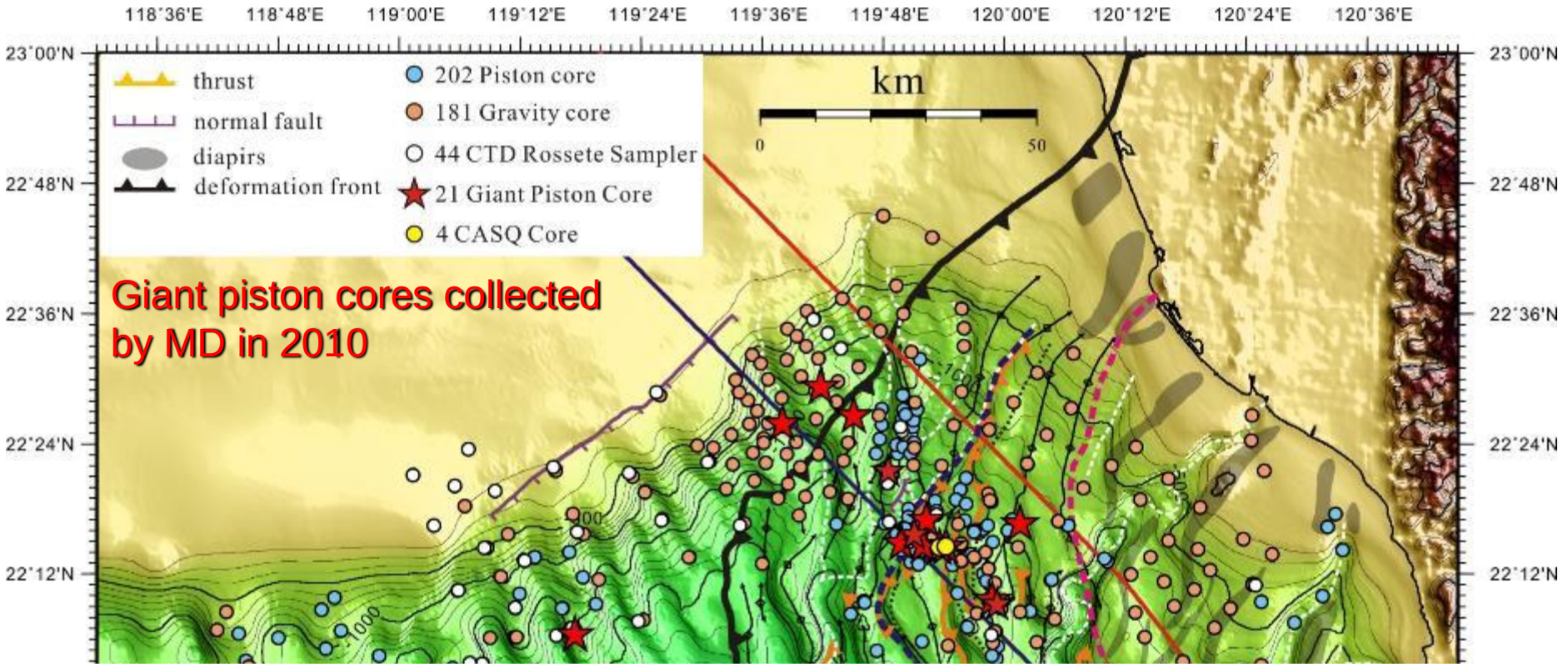
(Chuang et al., 2010)

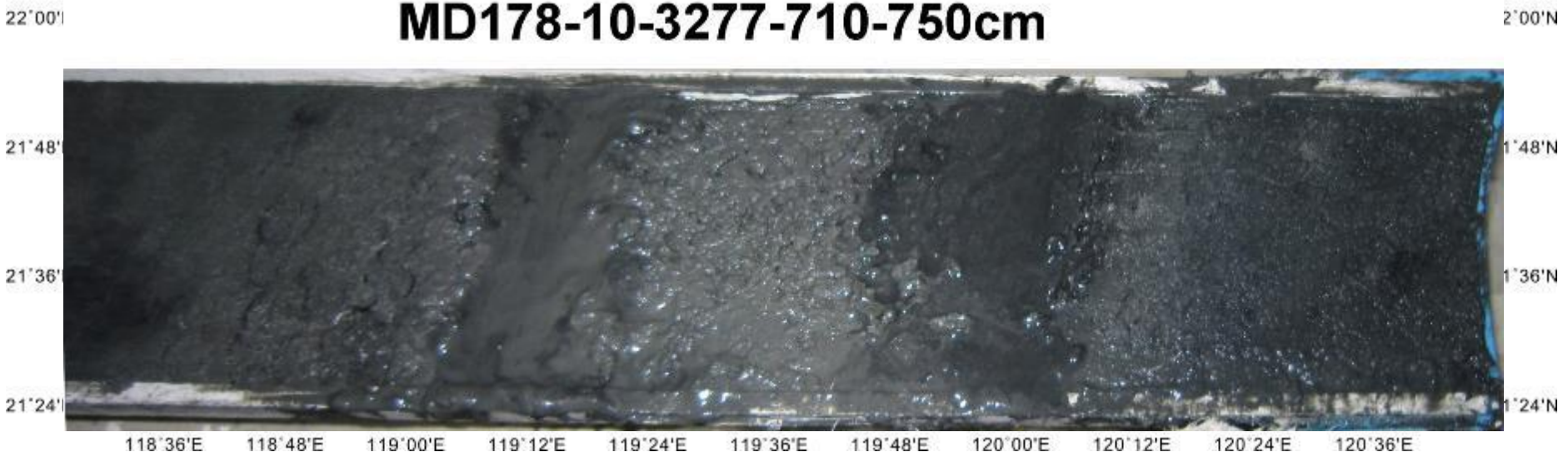


(Yang et al., 2010)

長岩心取樣







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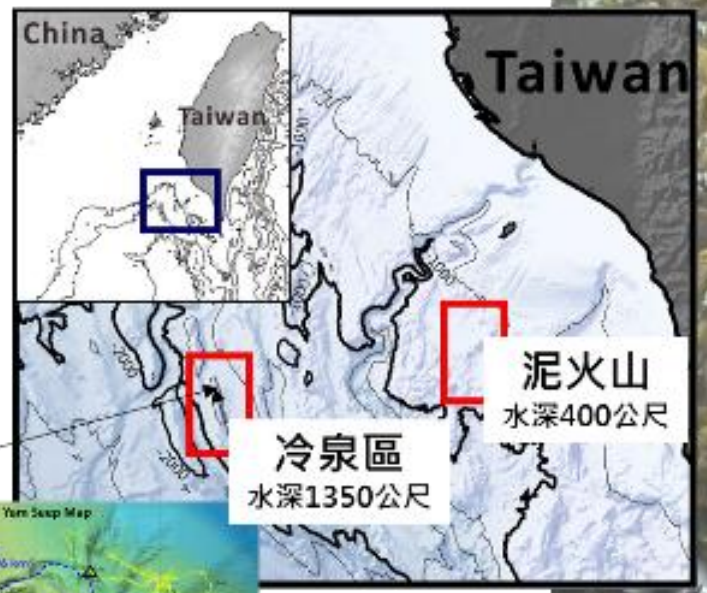
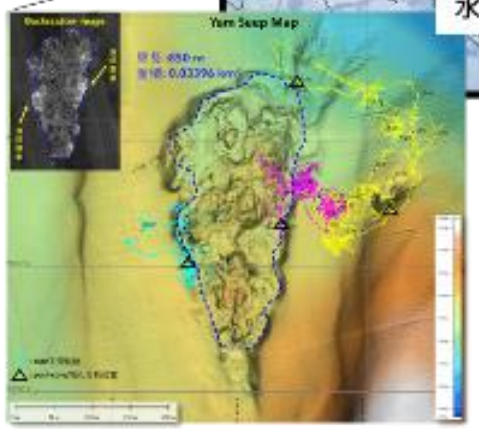
臺灣西南海域
天然氣水合物探勘好景區





研究目的與優勢

-天然氣存藏型態與環境生態的了解

-精準採樣，了解區域底質與生物群聚、地化特性(如:甲烷值)之分布

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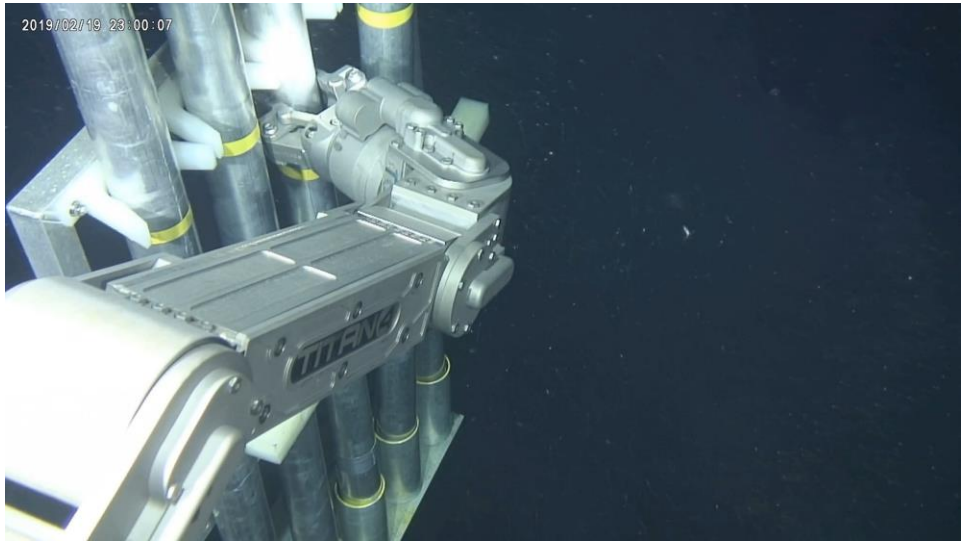
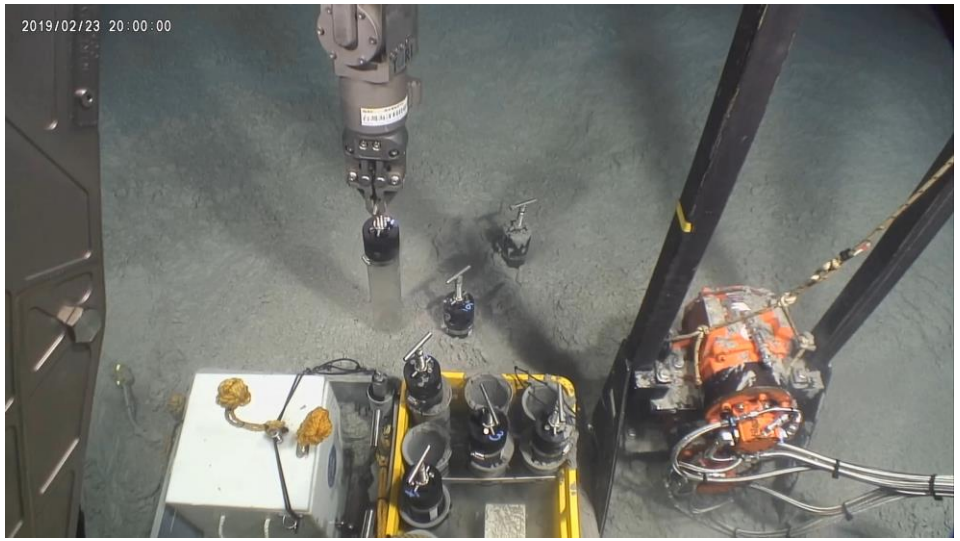
ROV調查

影像觀測



震盪式岩心採集系統



手臂取樣-下壓式岩心採樣

手臂取樣-網子

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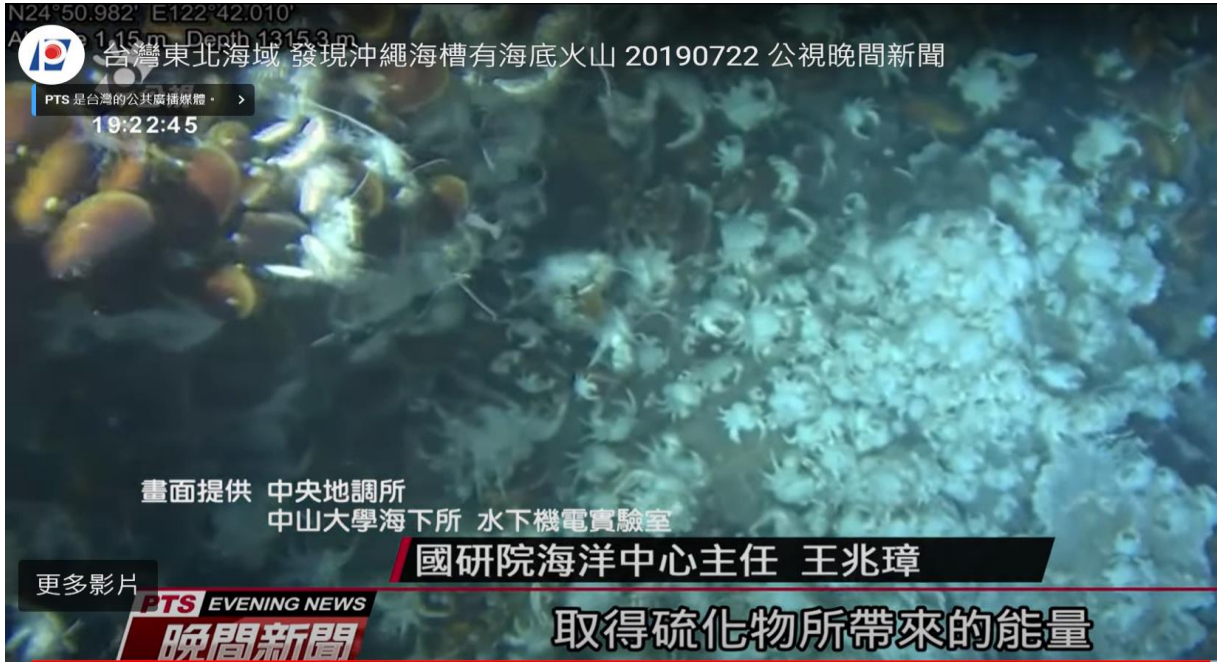
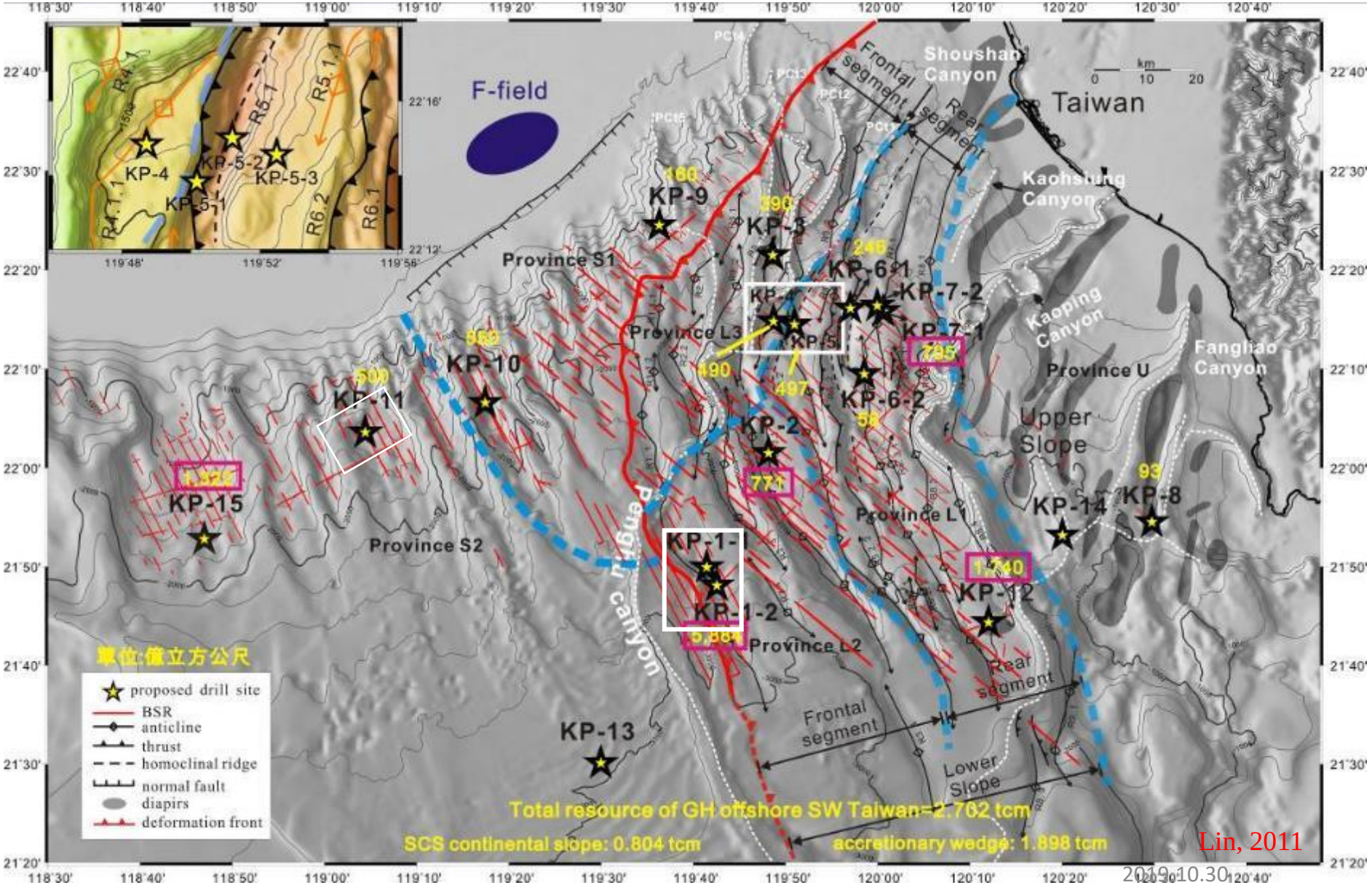


Metabolism	Reaction	$\Delta G^{0\prime}$ (kJ per mole)*
Anaerobic		
Methanogenesis	$4\,H_2 + CO_2 \rightarrow CH_4 + 2\,H_2O$ $CH_3CO_2^- + H_2O \rightarrow CH_4 + HCO_3^-$ $4\,HCOO^- + H^+ \rightarrow 3\,HCO_3^- + CH_4$	−131 −36 −106
S° reduction	$S^\circ + H_2 \rightarrow H_2S$	−45
Anaerobic CH_4 oxidation	$CH_4 + SO_4^{2-} \rightarrow HS^- + HCO_3^- + H_2O$	−21
Sulfate reduction	$SO_4^{2-} + H^+ + 4\,H_2 \rightarrow HS^- + 4\,H_2O$	−170
Fe reduction	$8\,Fe^{3+} + CH_3CO_2^- + 4\,H_2O \rightarrow 2\,HCO_3^- + 8\,Fe^{2+} + 9\,H^+$	Not calculated‡
Fermentation	$C_6H_{12}O_6 \rightarrow 2\,C_2H_6O + 2\,CO_2$	−300
Aerobic		
Sulfide oxidation§	$HS^- + 2\,O_2 \rightarrow SO_4^{2-} + H^+$	−750
CH_4 oxidation	$CH_4 + 2\,O_2 \rightarrow HCO_3^- + H^+ + H_2O$	−750
H_2 oxidation	$H_2 + 0.5\,O_2 \rightarrow H_2O$	−230
Fe oxidation	$Fe^{2+} + 0.5\,O_2 + H^+ \rightarrow Fe^{3+} + 0.5\,H_2O$	−65
Mn oxidation	$Mn^{2+} + 0.5\,O_2 + H_2O \rightarrow MnO_2 + 2\,H^+$	−50
Respiration	$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$	−2,870

天然氣水合物探勘好景區

2.7 兆立方公尺
270年 臺灣用量



天然氣水合物

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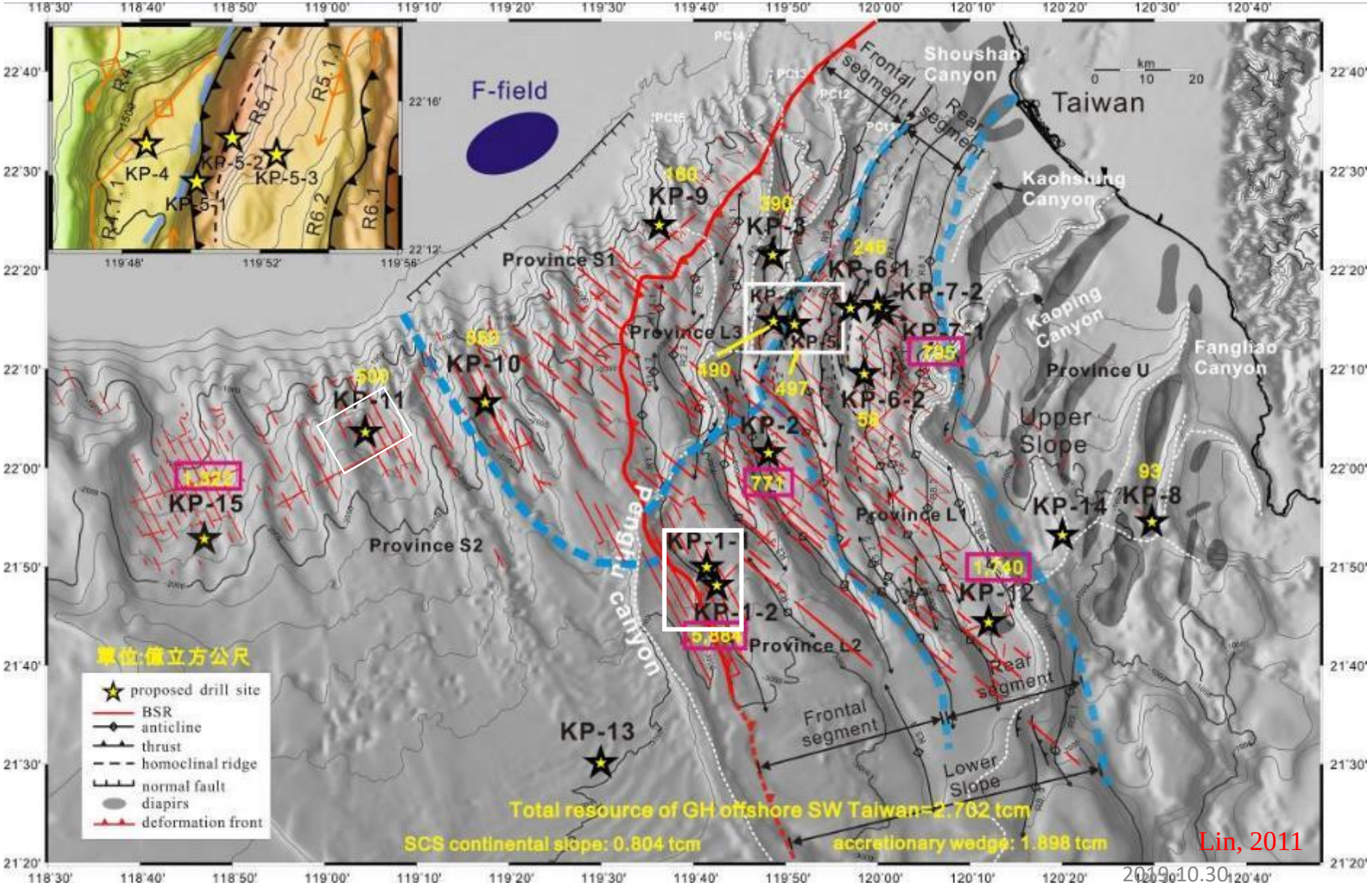
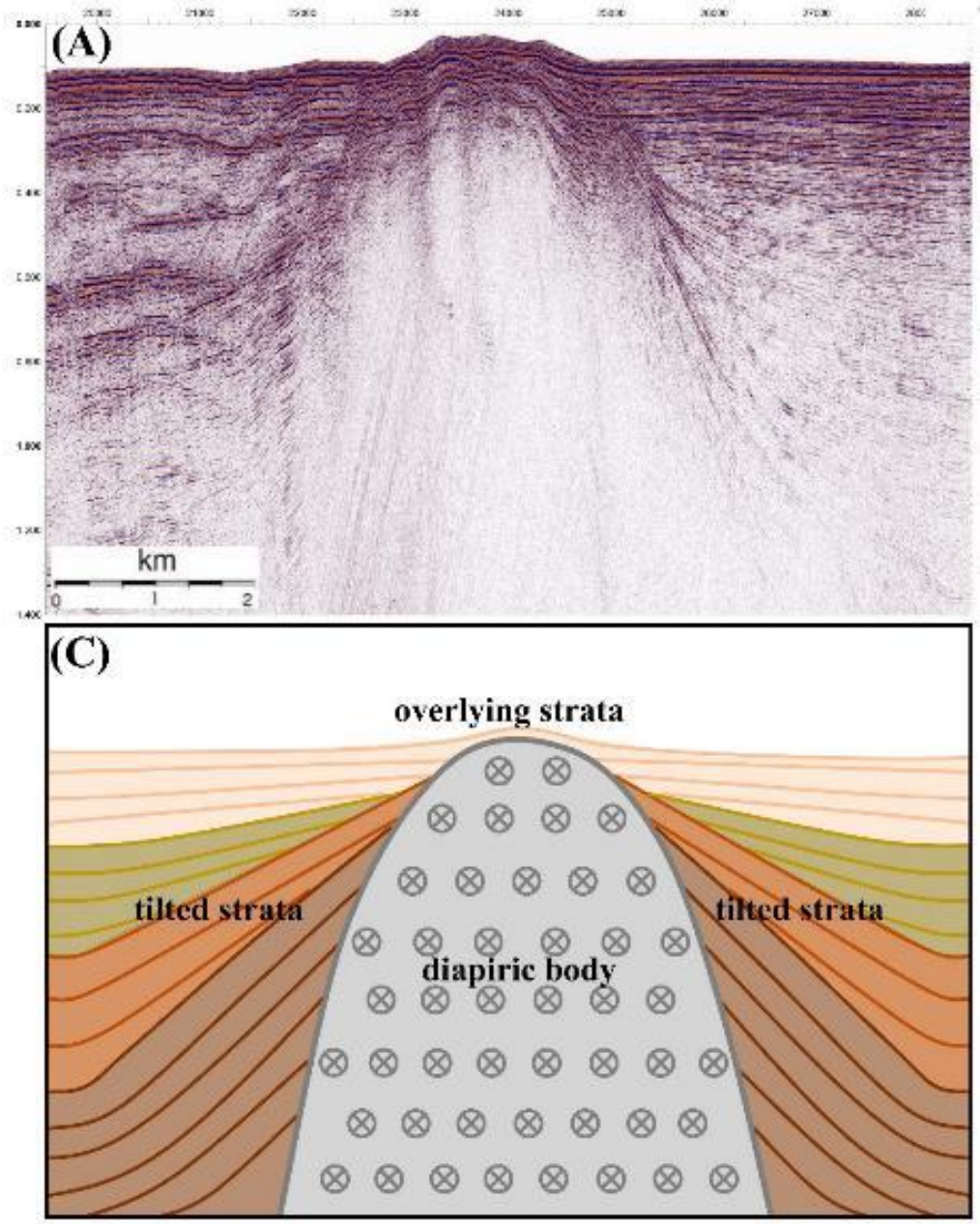
2.7 兆立方公尺
270年 臺灣用量

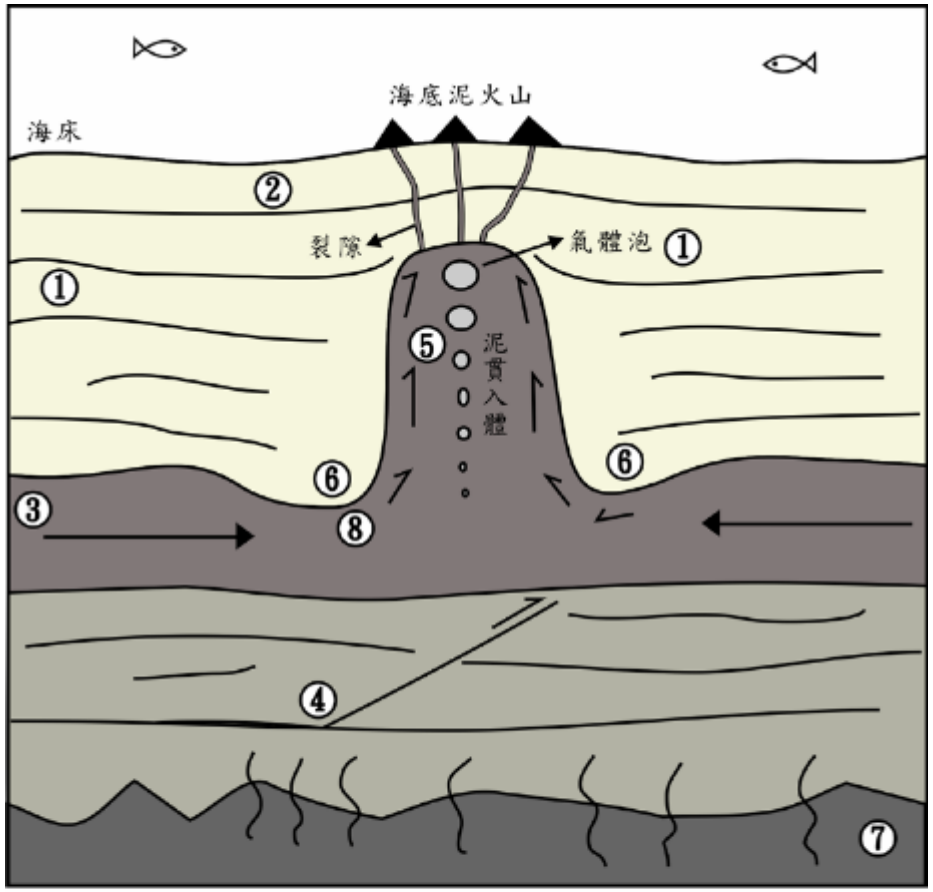


泥貫入體



(Chen et al., 2014)

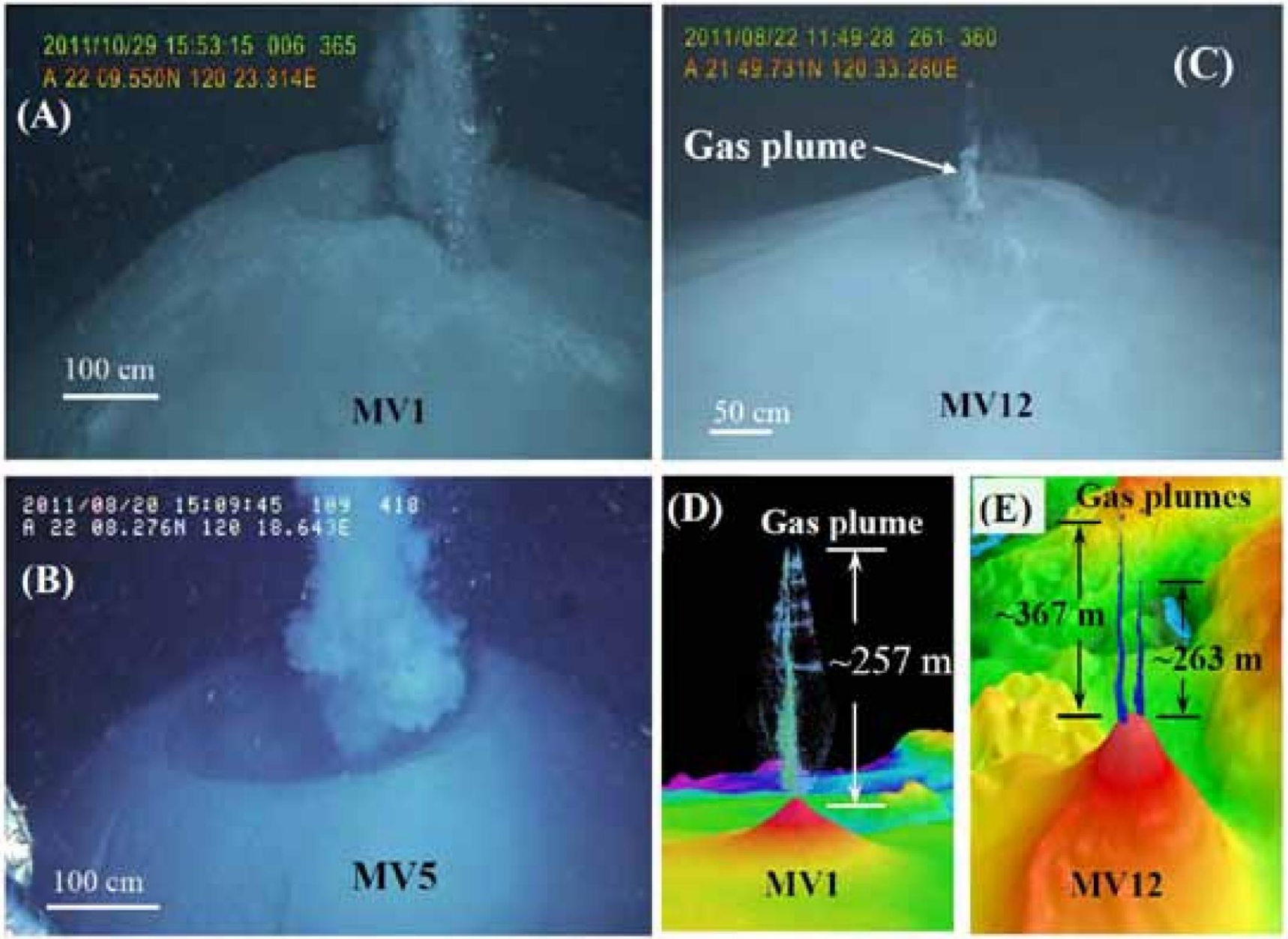
海陸泥火山與泥貫入體



1. 側向擠壓造成孔隙流體排出。
2. 生物源甲烷氣(Biogenic methane)。
3. 來自水平地層或斷層之側向流體流入。
4. 沿深部斷層向上移棲之深部流體來源。
5. 熱成熟來源甲烷氣(Thermogenic methane)。
6. 來自礦物(蛋白石、蒙脫石)脫水作用的流體。
7. 來自地殼岩石置換的熱水流體。
8. 來自貫入作用內部變形之流體來源排出。

雷公火泥火山

(Chen et al., 2014)



https://www.google.com/search?q=%E5%8F%B0%E7%81%A3%E6%B5%B7%E5%BA%95%E5%9C%B0%E5%BD%A2&sca_esv=575810318&rlz=1C1ONGR_zh-TW&tbm=vid&sxsrf=AM9HkKkkvovbcoaQIY7Cay_FcgI806ZdOA:1698074260121&source=lnms&sa=X&ved=2ahUKEwj6mM7Iu4yCAxVObt4KHSbNCC8Q_AUoBHoECAEQBg&biw=1280&bih=601&dpr=1.5#fpstate=ive&vld=cid:85f5e057,vid:cQZ4bxnUM9Q,st:0

(Chen et al., 2014)

冰與火之歌-可燃冰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