



# 蛇绿岩成因研究进展

## ——以扬子克拉通庙湾蛇绿杂岩为例

彭松柏

中国地质大学（武汉）地球科学学院  
二零一五年九月

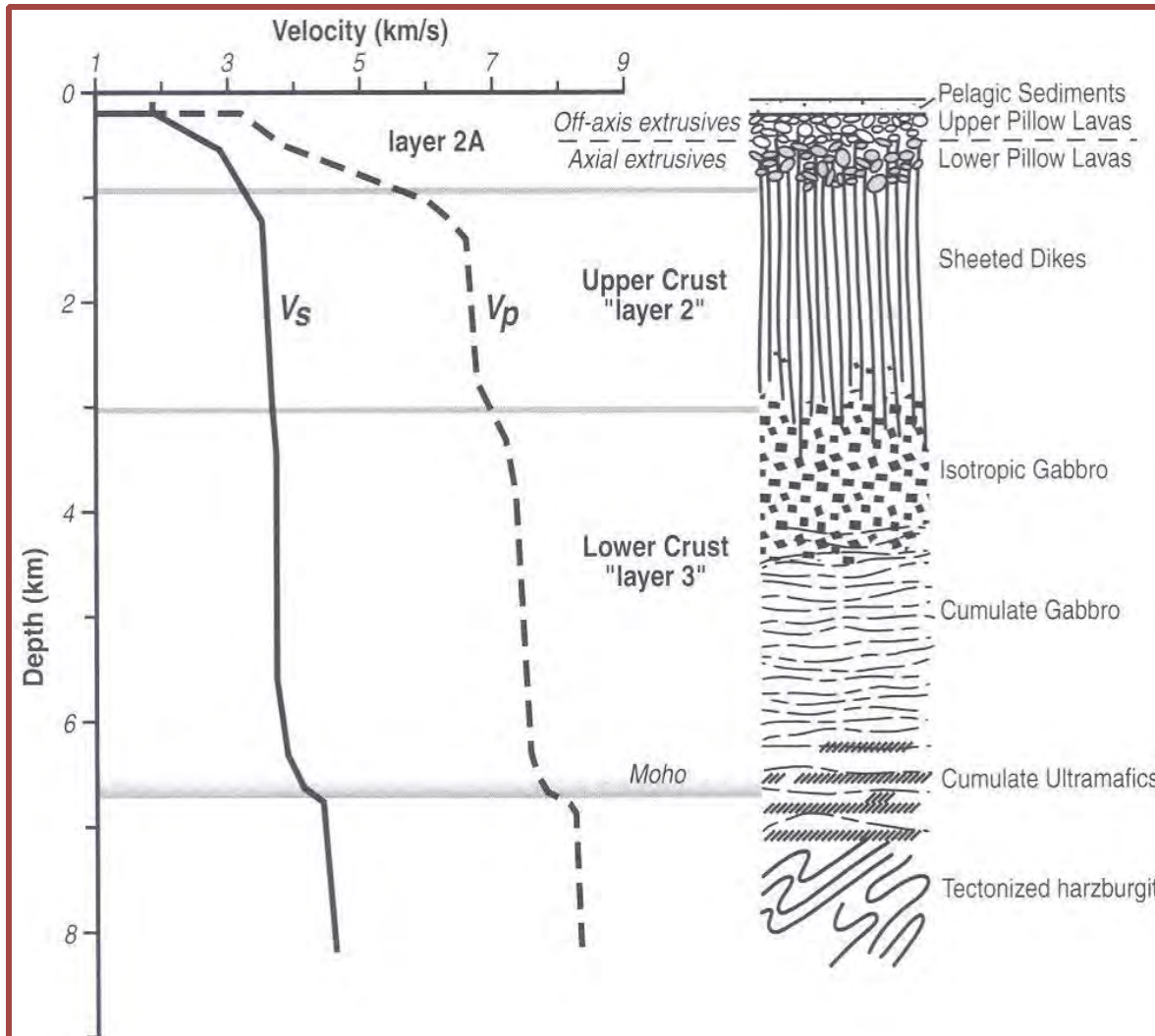
# 提 纲

一、蛇绿岩成因研究进展

三、扬子克拉通庙湾蛇绿杂岩研究

# 一、蛇绿岩成因研究进展

# 经典彭罗斯定义蛇绿岩岩石地层层序 (快速扩张大洋岩石圈)



Layer-cake pseudostratigraphy; Laterally continuous structure & stratigraphy;

Vertical sheeted dike intrusions;

Horizontal contacts;

Moho as a petrological transition zone;

Melt-residua genetic relation between crustal and mantle rocks.



**阿曼Sema i | 蛇绿岩下地壳与上地幔莫霍界面**



阿曼Sema il 蛇绿岩下地壳与上地幔莫霍界面蛇纹石化橄榄岩

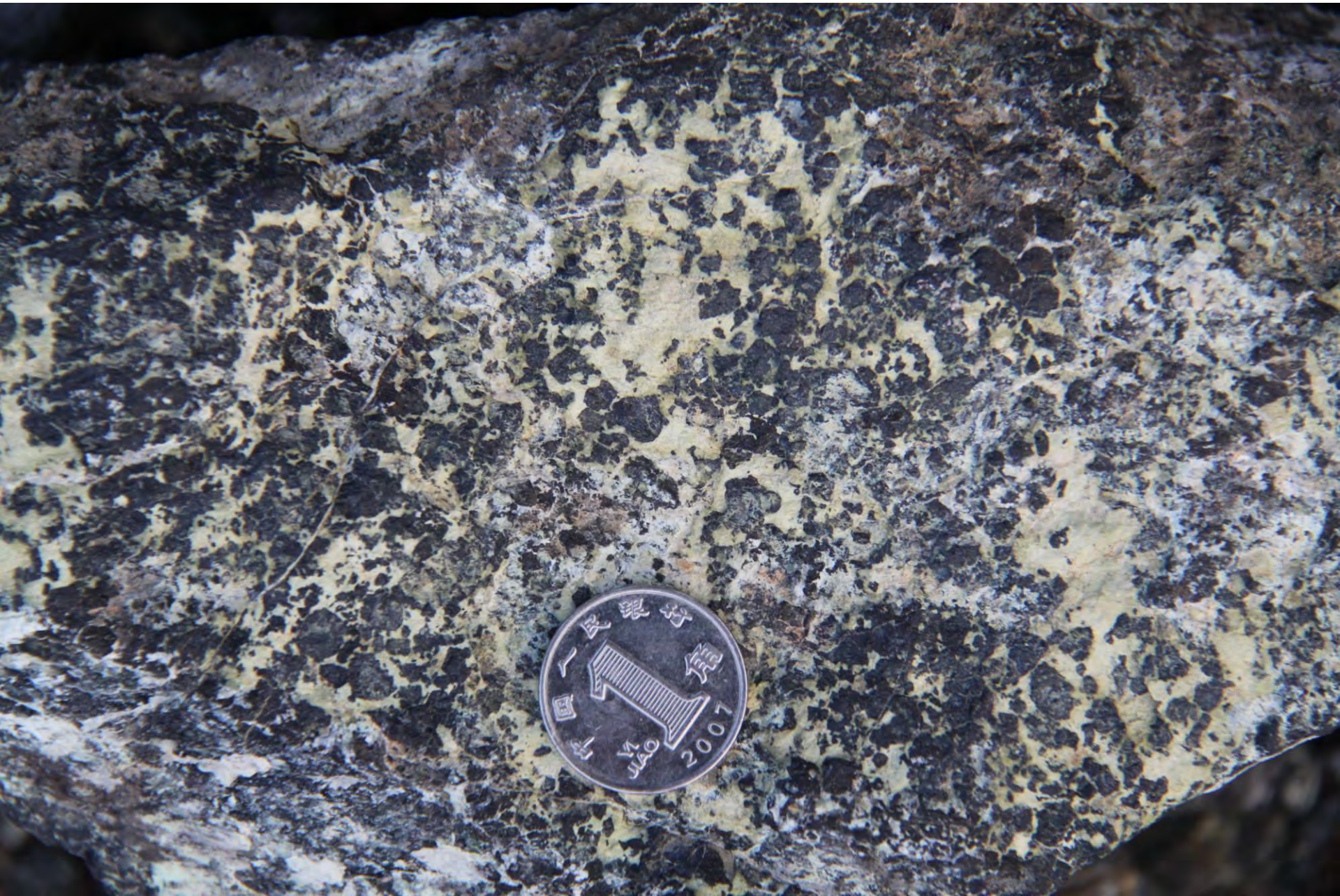


阿曼Sema i | 蛇绿岩下地壳与上地幔莫霍界面橄榄岩与辉长岩互层



阿曼Sema i | 蛇绿岩中块状辉长岩岩脉侵入蛇纹石化橄榄岩





阿曼Sema i | 蛇绿岩中含铬铁矿蛇纹石化纯橄岩



**阿曼Sema i | 蛇绿岩中层状堆晶辉长岩**



阿曼Sema i | 蛇绿岩中层状堆晶辉长岩



阿曼Sema i | 蛇绿岩中席状辉绿岩岩墙



阿曼Sema i | 蛇绿岩中席状辉绿岩岩墙双向和单向冷凝边

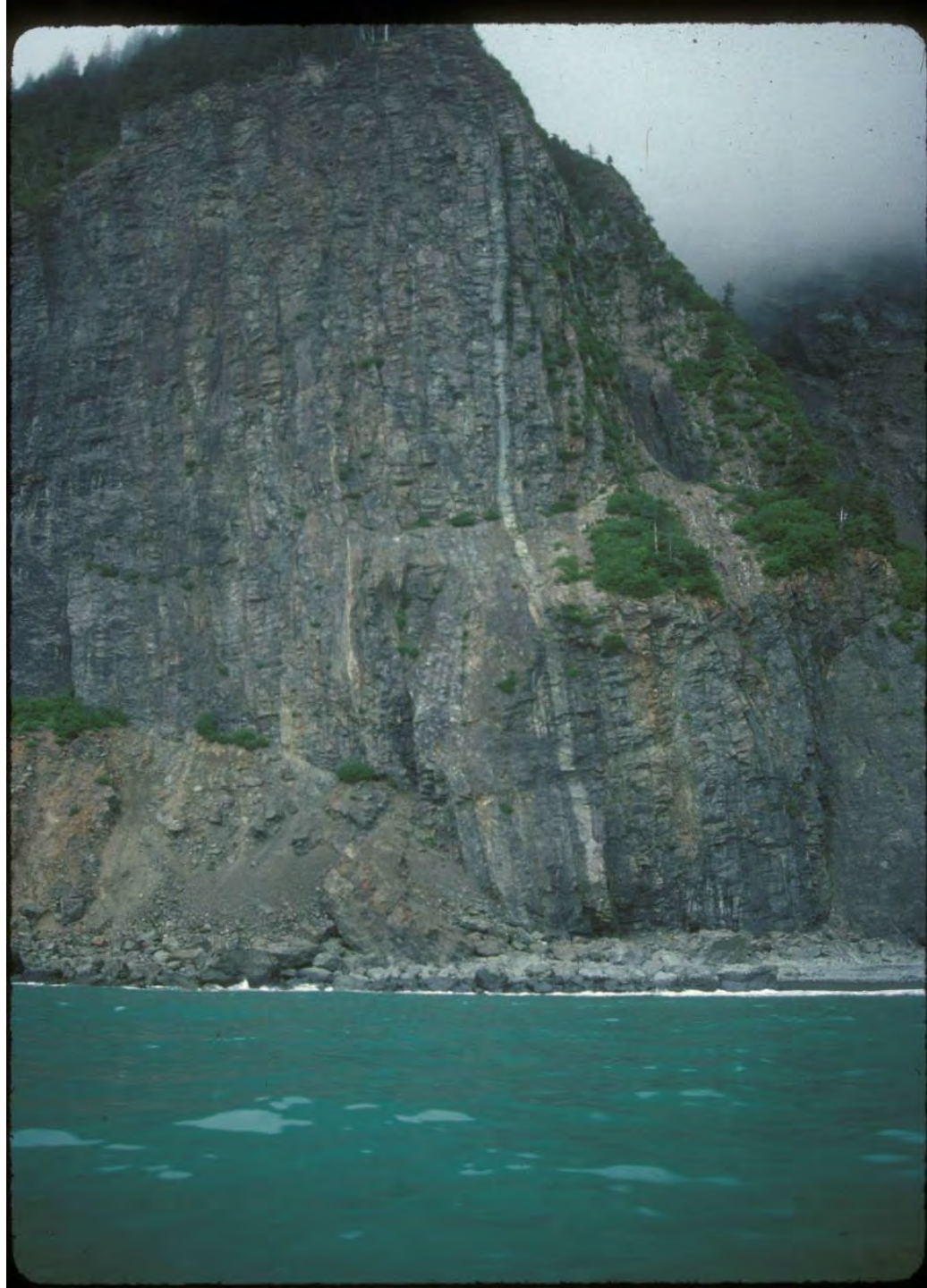


**阿曼Sema i | 蛇绿岩中枕状玄武岩**



**阿曼Sema i | 蛇绿岩中枕状玄武岩**

阿拉斯加Resurrection  
蛇绿岩区席状岩墙杂岩





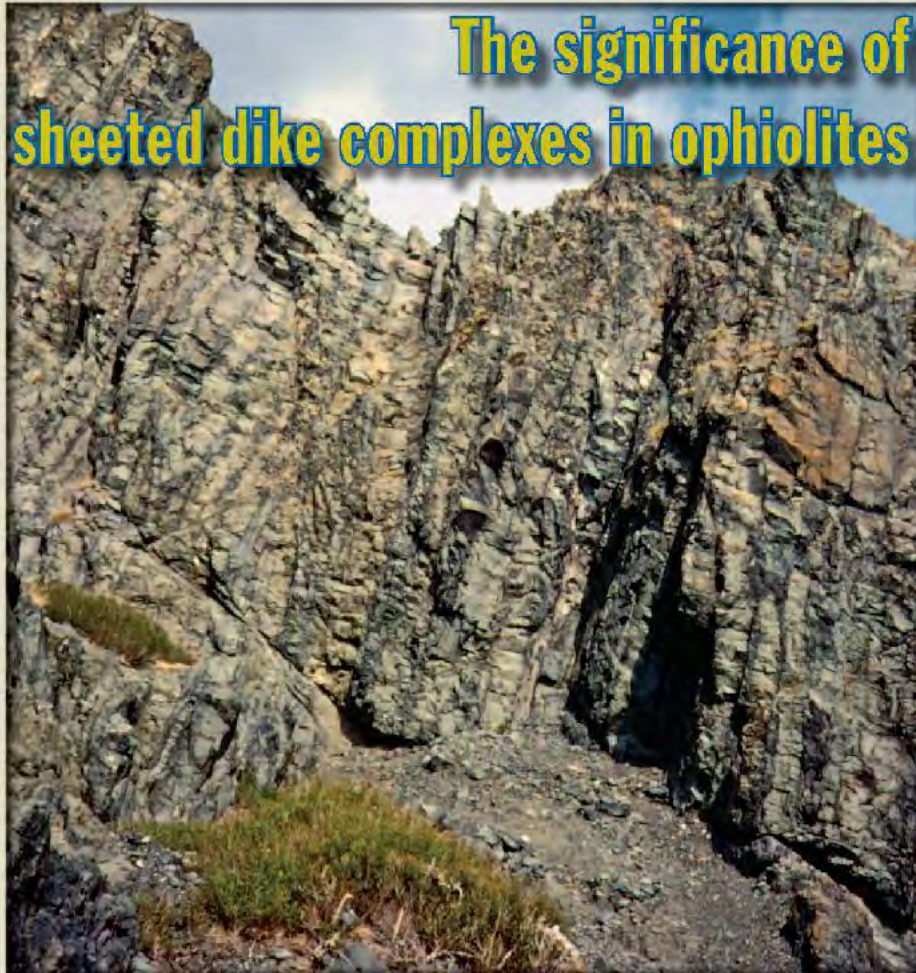
# USA TODAY

VOL. 18, No. 11

A PUBLICATION OF THE GEOLOGICAL SOCIETY OF AMERICA

NOVEMBER 2008

**The significance of  
sheeted dike complexes in ophiolites**

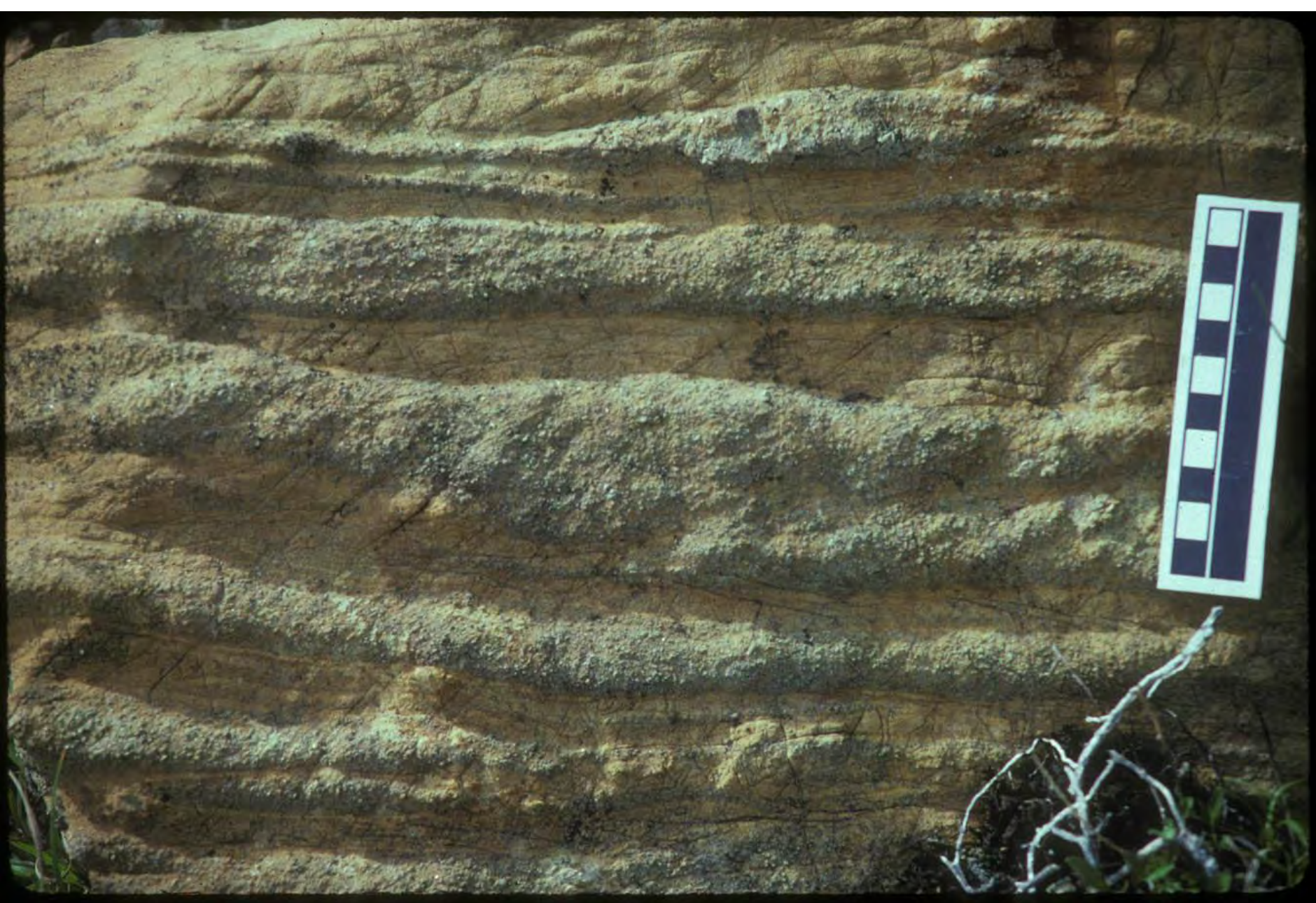


**NOVEMBER 2008**

**Vol. 18, No. 11**

**Page. 4-11**

**Less than 10% of the  
ophiolites in the world  
have sheeted dikes**



阿拉斯加Resurrection蛇绿岩区堆晶辉石岩与辉橄岩互层

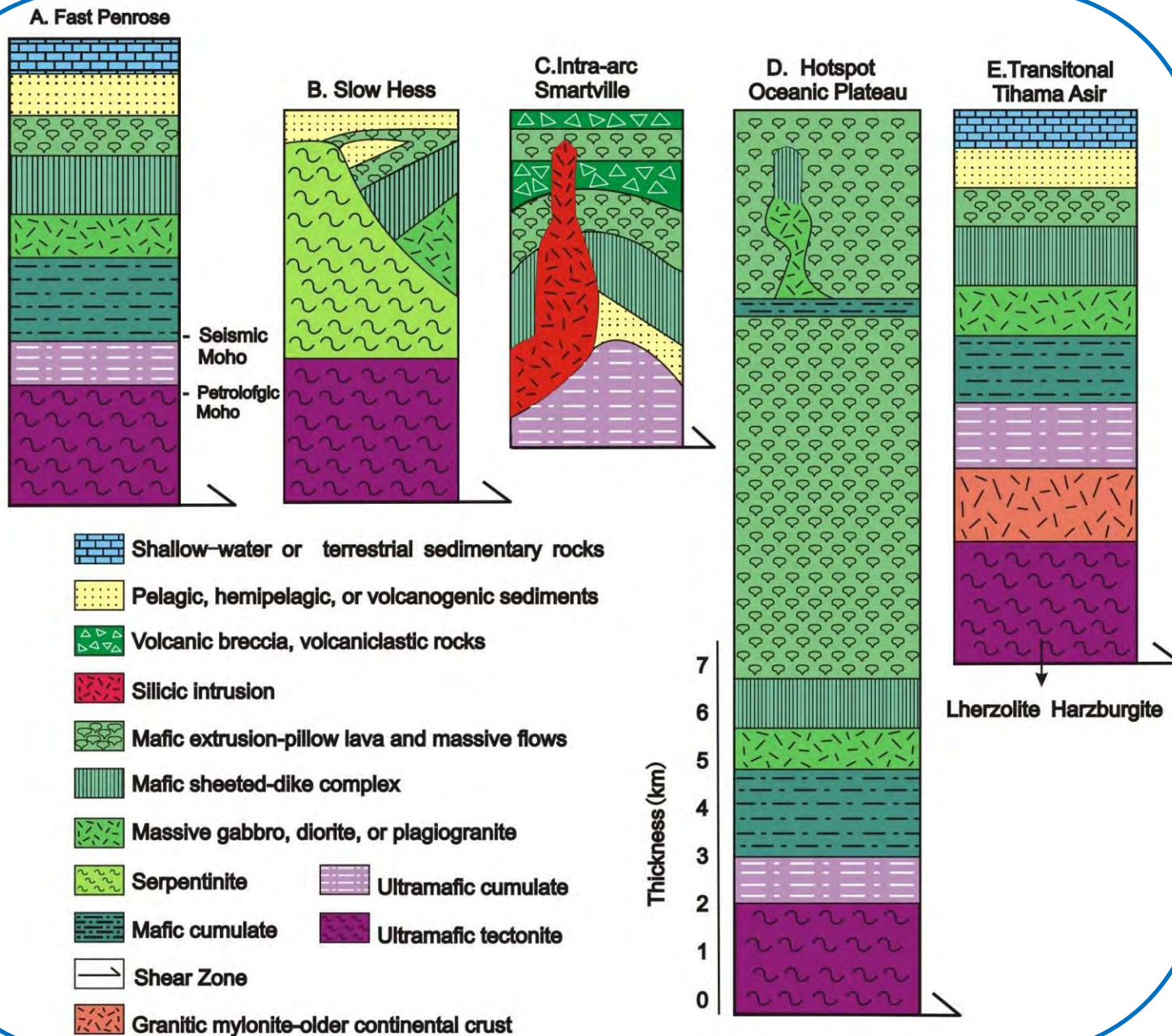


阿拉斯加Resurrection蛇绿岩区纯橄岩中层状变形铬铁矿

# 蛇绿岩定义的扩展

- 地壳结构横向和垂向的不均一性；
- 慢速与快速扩张洋中脊岩石过渡带莫霍面的差异；
- 地幔不均一性对熔体演化的强烈影响；
- 同构造反应和地幔中渗滤作用的影响；
- 多期岩浆抽取和熔融作用事件；
- 不同的岩石地球化学组成和指纹；

# 不同成因类型蛇绿岩岩石地层层序变化



Kusky, et al., 2011, 2013, after Moores, 2002

# 现代蛇绿岩产出的大地构造背景

- 大陆边缘蛇绿岩：**洋盆打开初始阶段的洋壳残片，如阿尔卑斯-亚平宁蛇绿岩；西黎巴嫩大陆边缘蛇绿岩。
- 远离地幔柱的洋中脊蛇绿岩：**大洋中脊地壳残片，如澳大利亚南大洋麦考瑞岛。
- 地幔柱型蛇绿岩：**具大火成岩省 (LIPs) 成因的岩石组合及大洋地壳基底，如危地马拉、哥伦比亚、古巴的蛇绿岩。
- 远离洋中脊-海沟蛇绿岩：**具“硅铝质”地壳成因特征的弧后洋壳残片，如挪威的Solund-Stavfjord、南美的卢卡斯佛得角-智利 (Rocas Verdes-Chile) 蛇绿岩。
- 火山弧蛇绿岩：**具古老洋壳基底的复合岛弧残片，如美国加利福尼亚的内华达山脉山麓、菲律宾、日本岛弧蛇绿岩。
- 俯冲带之上蛇绿岩：**初始弧-弧前洋壳残片（理想彭罗斯蛇绿岩岩石序列），如塞浦路斯的特罗多斯 (Troodos)，阿曼的希曼 (Semail)，阿尔巴尼亚的米尔迪塔 (Mirdita)。

## 蛇绿岩不存在一个唯一模版（多样性）

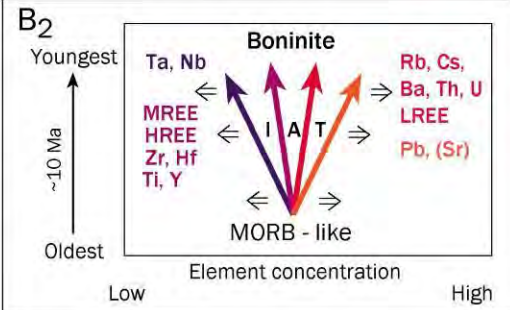
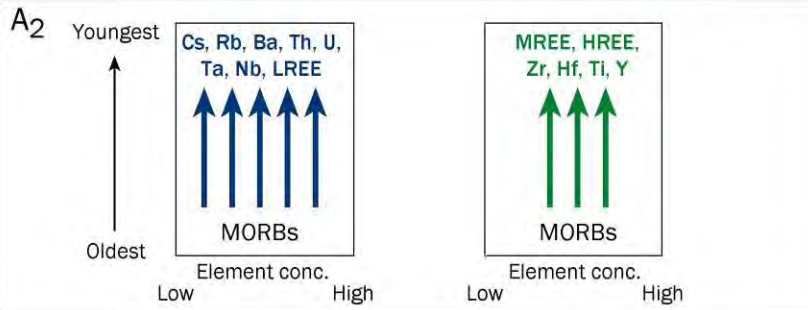
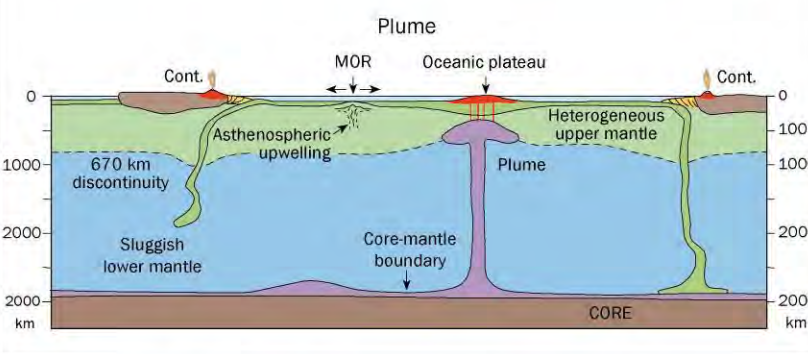
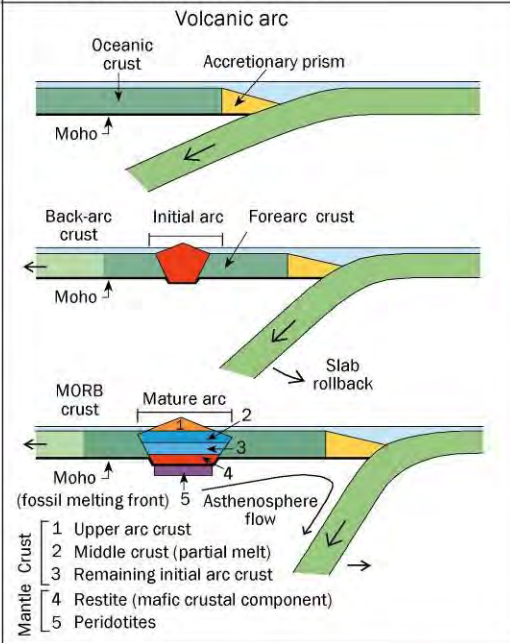
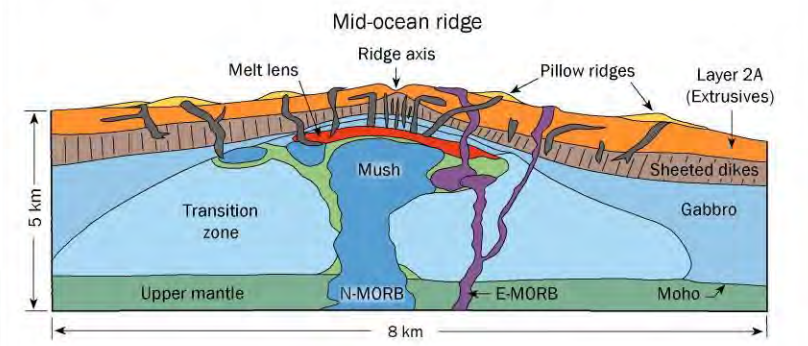
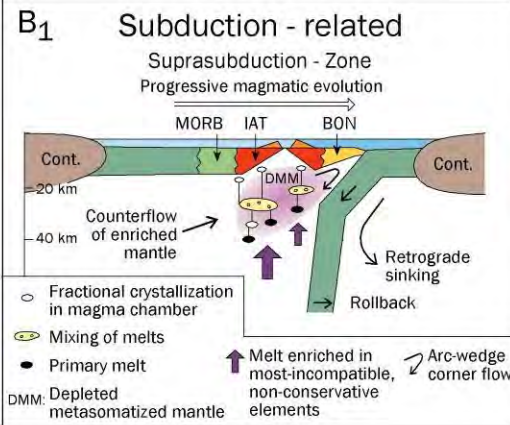
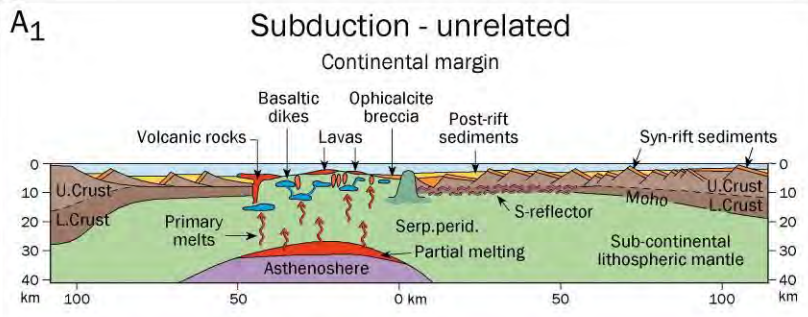
- \* 它们具有不同的内部结构和地球化学组成；
- \* 它们具有不同的地幔熔体来源；
- \* 它们形成于不同的大地构造背景。

# 蛇绿岩的成因分类

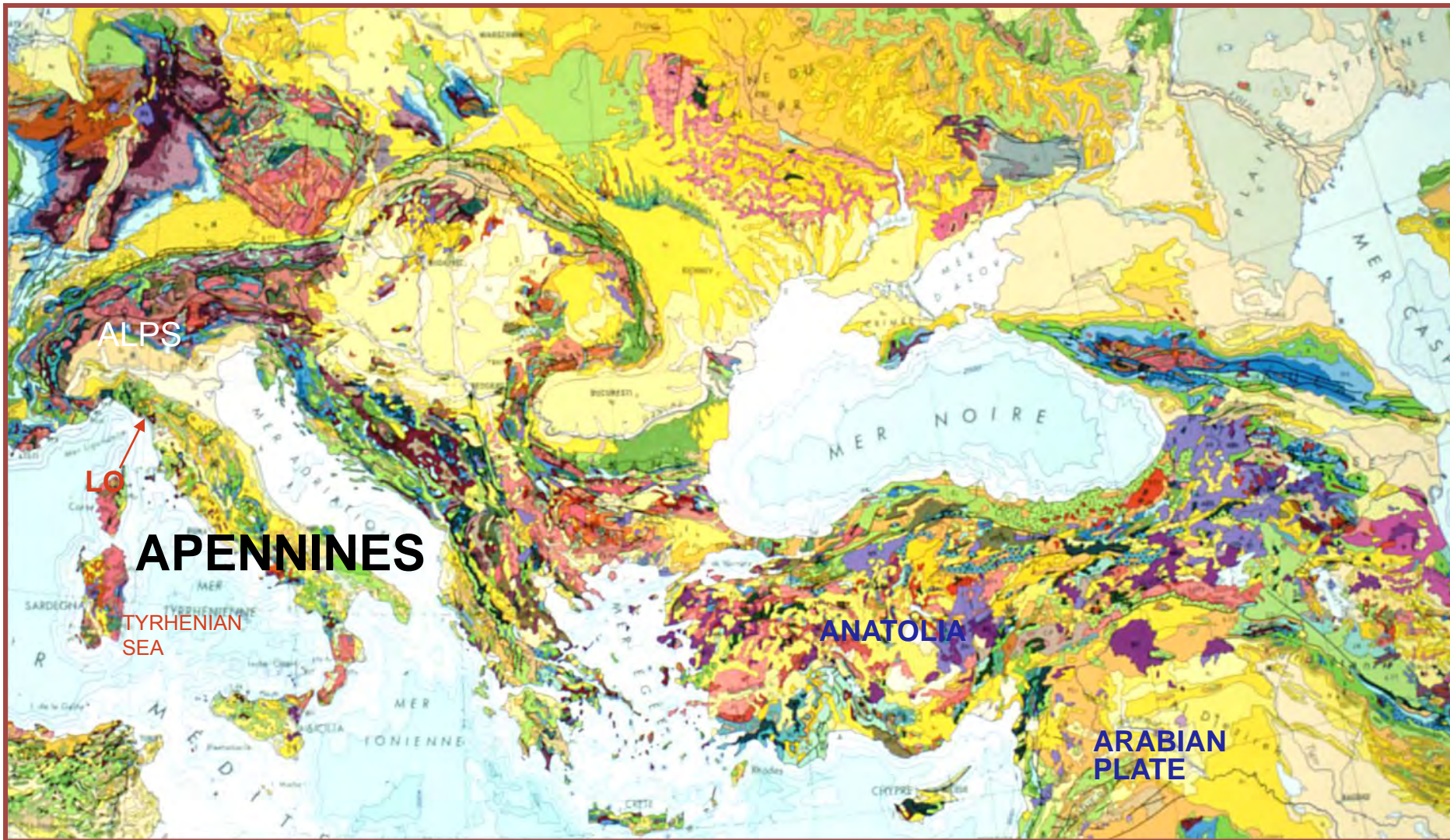
目前，广泛应用的是Pearce (1984) 的洋中脊型 (MOR) 和俯冲带之上型 (SSZ) 蛇绿岩构造成因分类。

最近，Dilek等 (2011) 根据不同蛇绿岩的构造岩石成因特征，将蛇绿岩分为：与俯冲有关的和与俯冲无关的两大类，其中与俯冲无关的蛇绿岩又分为**大陆边缘型、洋中脊型、地幔柱型**三种基本类型，俯冲有关的蛇绿岩又分为**俯冲带之上型、火山弧型**二种基本类型。





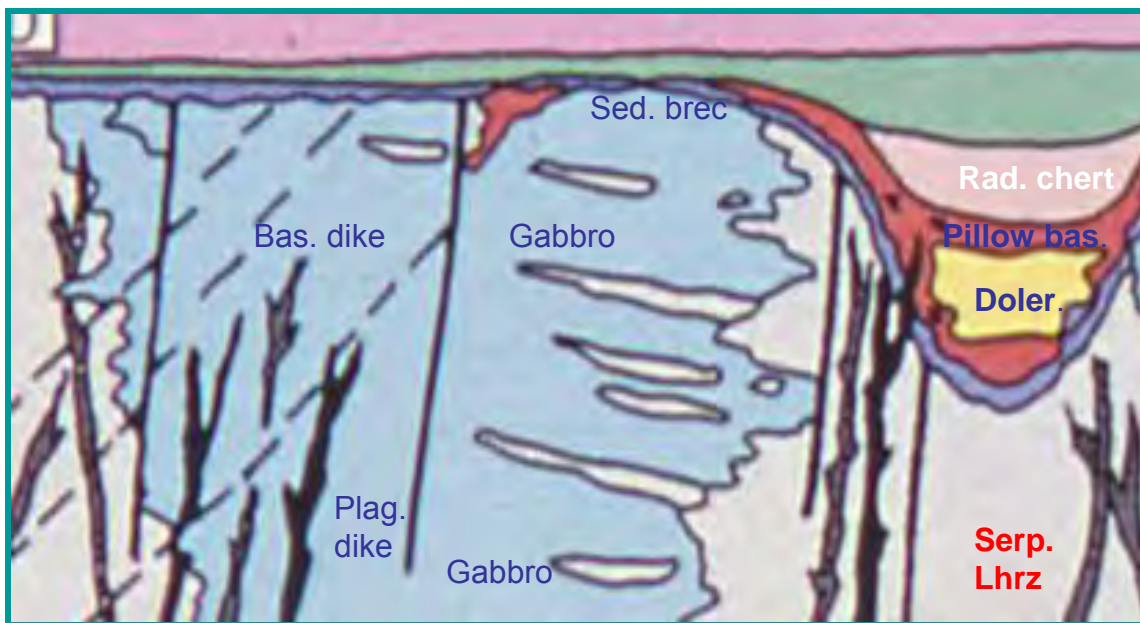
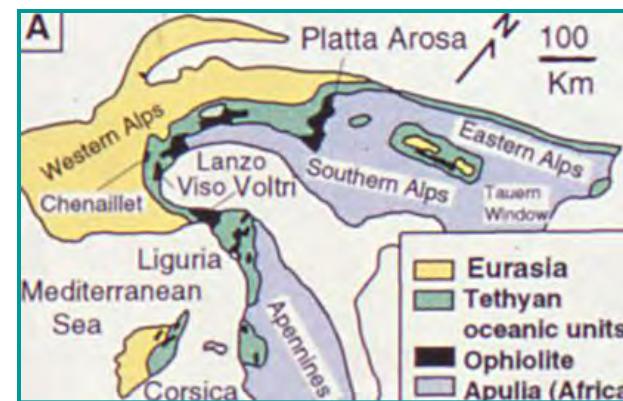
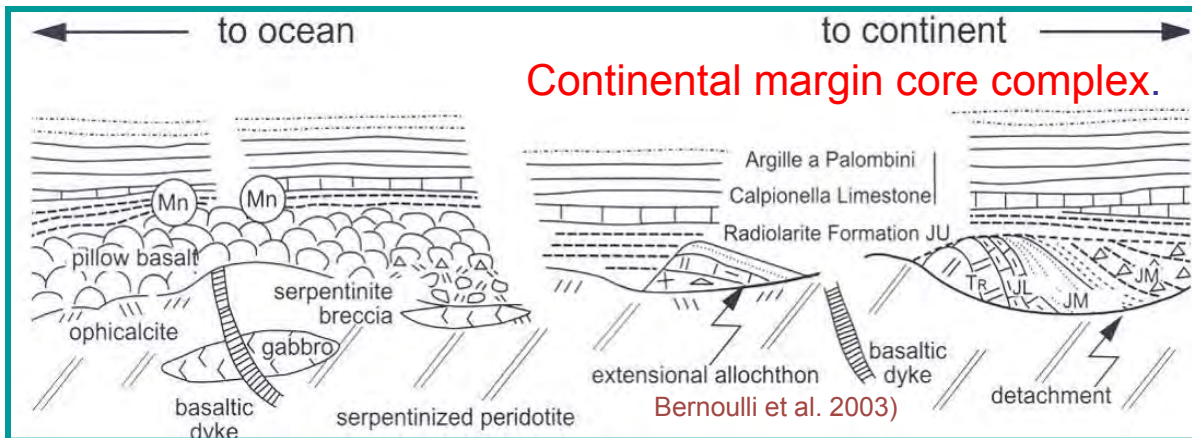
# OPHIOLITE TYPES & TECTO-PETROGENESIS



**ALPINE OROGENIC BELT (亚平宁造山带)**  
**Collision-driven orogen with numerous ophiolites**

# CONTINENTAL MARGIN OPHIOLITE (大陆边缘蛇绿岩) :

W. Alpine & N. Apennine Ophiolites



Hess-type igneous stratigraphy; Peridotites intruded by gabbros and dikes, and overlain by lavas, sed. breccia, ophicalcite, and red. chert.

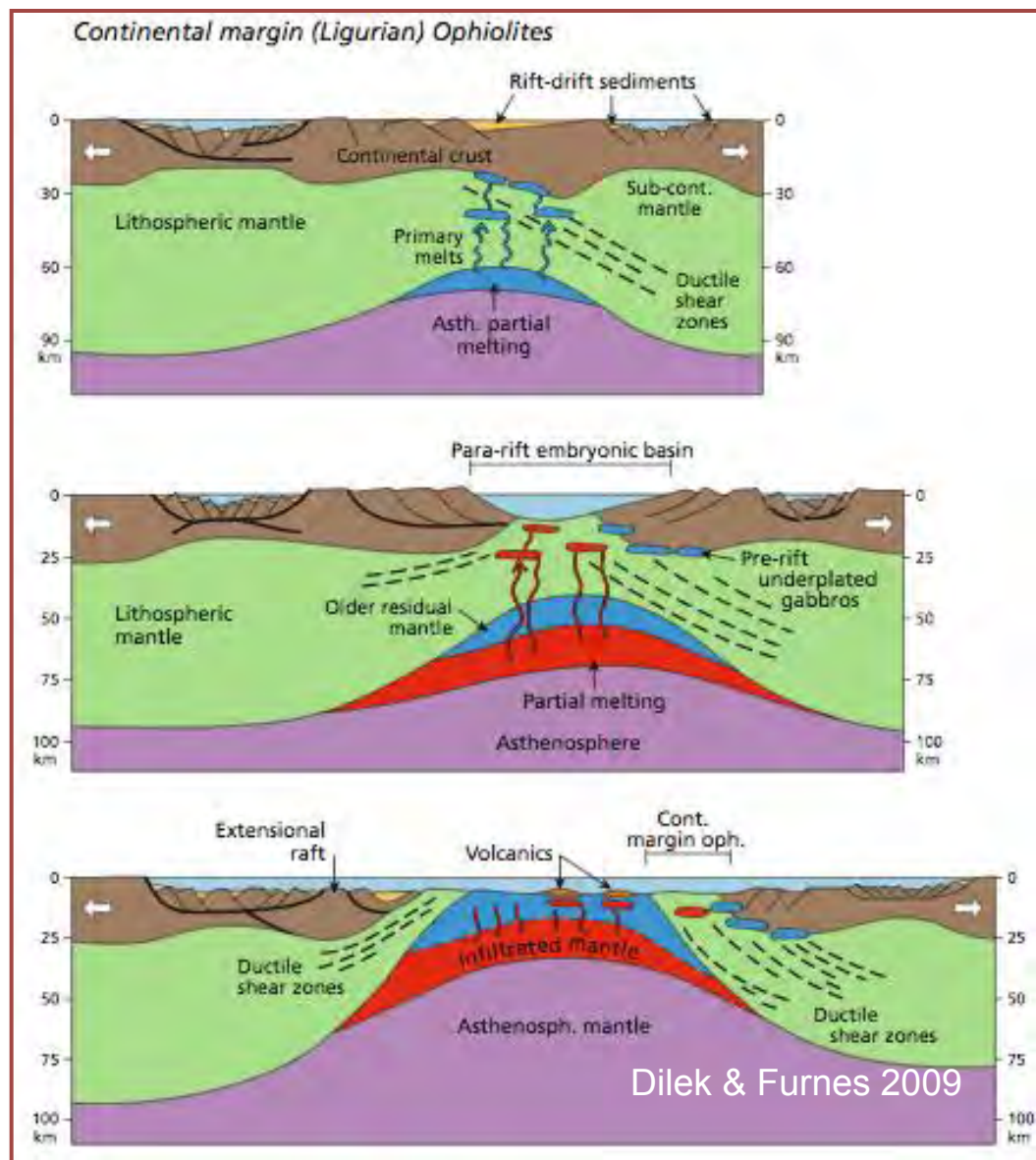
Fertile spinel lherzolites (cont.) to depleted spinel harzburgites, dunites & plag-enriched peridotites.

No melt-residua relationship between the lavas and peridotites.

**Cross-section of an Internal Ligurian ophiolite**

# CONTINENTAL MARGIN OPHIOLITE (大陆边缘蛇绿岩) :

W. Alpine & N. Apennine Ophiolites

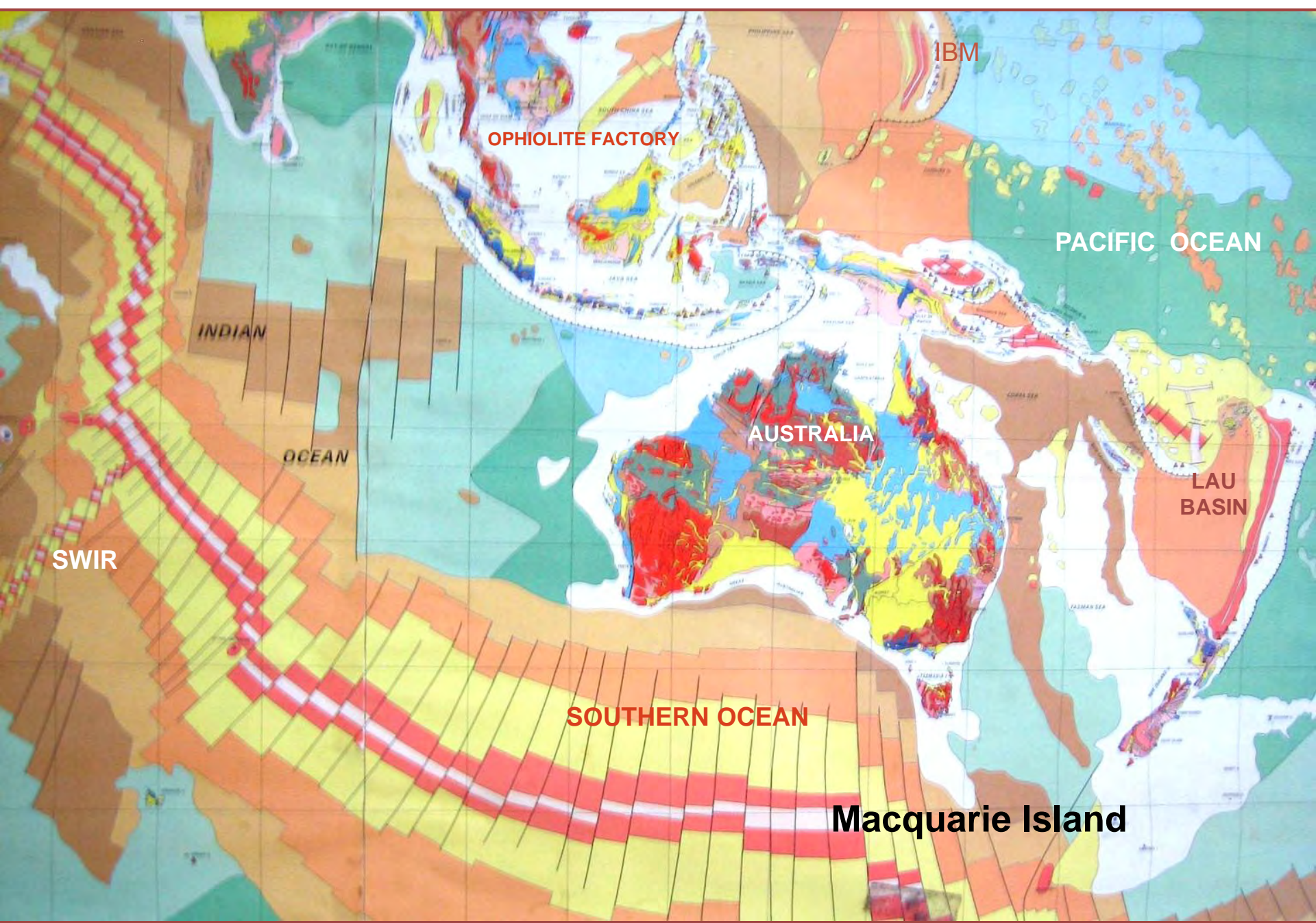


A- Lithospheric extension (岩石圈伸展), asthenospheric upwelling, partial melting of asthenospheric mantle to produce Permian gabbros.

B- Continental breakup (大陆裂解), exhumation of sub-continental lithospheric mantle, more melting of asthenospheric mantle (*External Liguride ophiolites*). "Oceanic core complex"

C- Slow seafloor spreading (慢速海底扩张), exhumation of Permian residual (depleted) mantle on the seafloor, formation of Jurassic MORB lavas (*Internal Liguride ophiolites*).

*Red Sea-type embryonic Ligurian ocean.*



**OPHIOLITE FACTORY**

**IBM**

**PACIFIC OCEAN**

**INDIAN**

**OCEAN**

**AUSTRALIA**

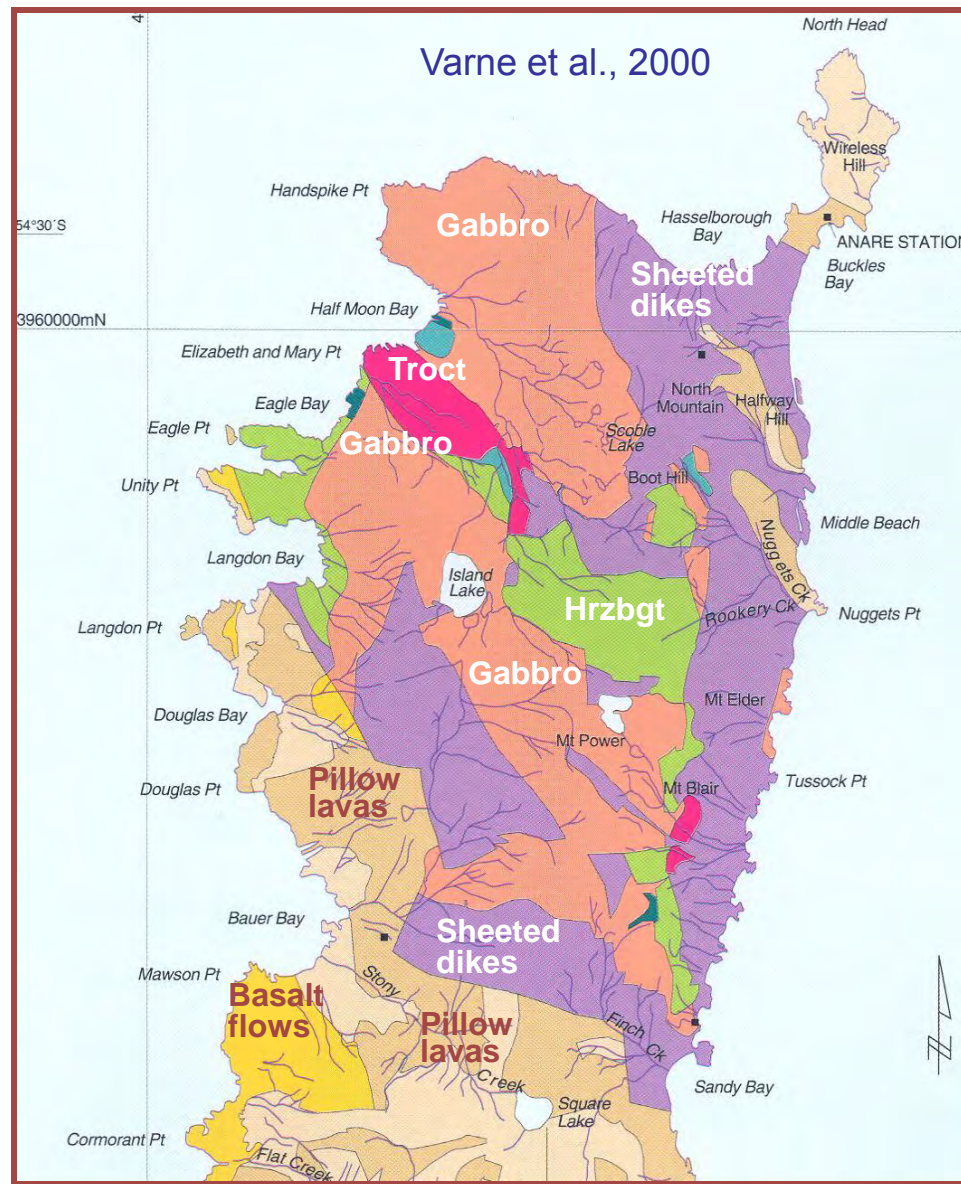
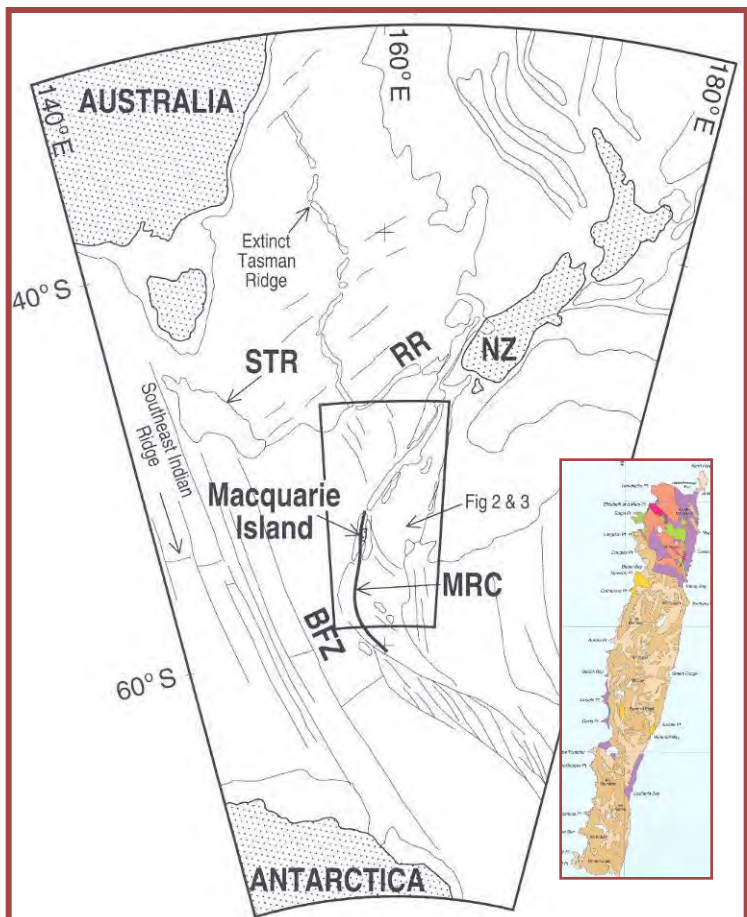
**LAU  
BASIN**

**SWIR**

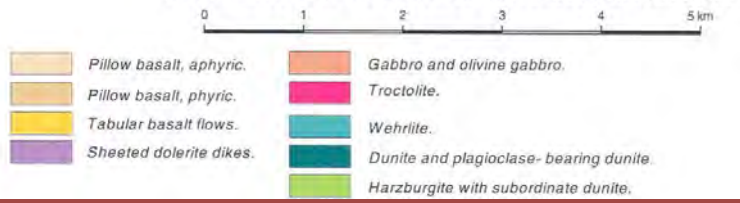
**SOUTHERN OCEAN**

**Macquarie Island**

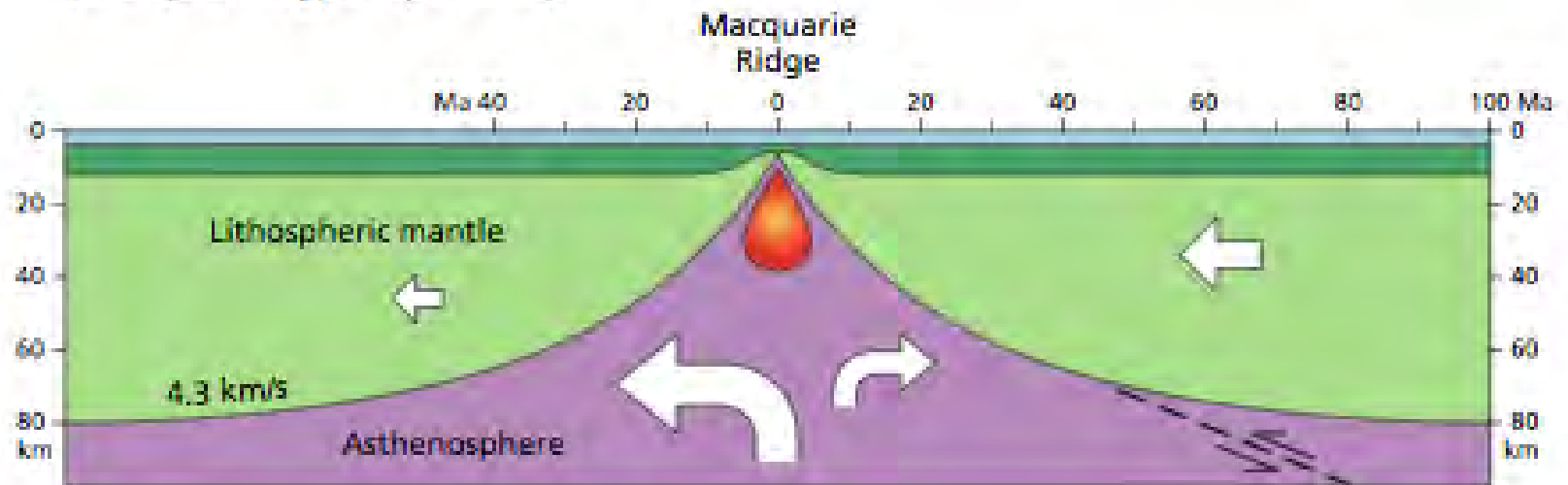
# PLUME-DISTAL MOR OPHIOLITE (远离地幔柱的洋中脊蛇绿岩) : Macquarie Island Ophiolite, Southern Ocean



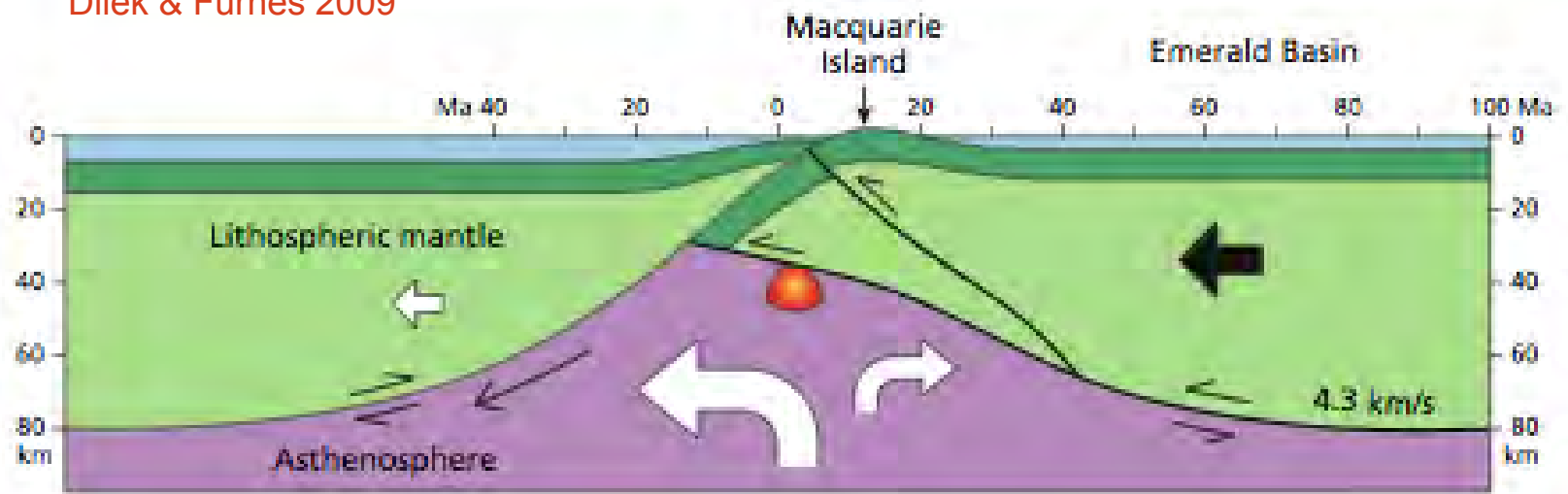
**SCHEMATIC GEOLOGY OF MACQUARIE ISLAND**

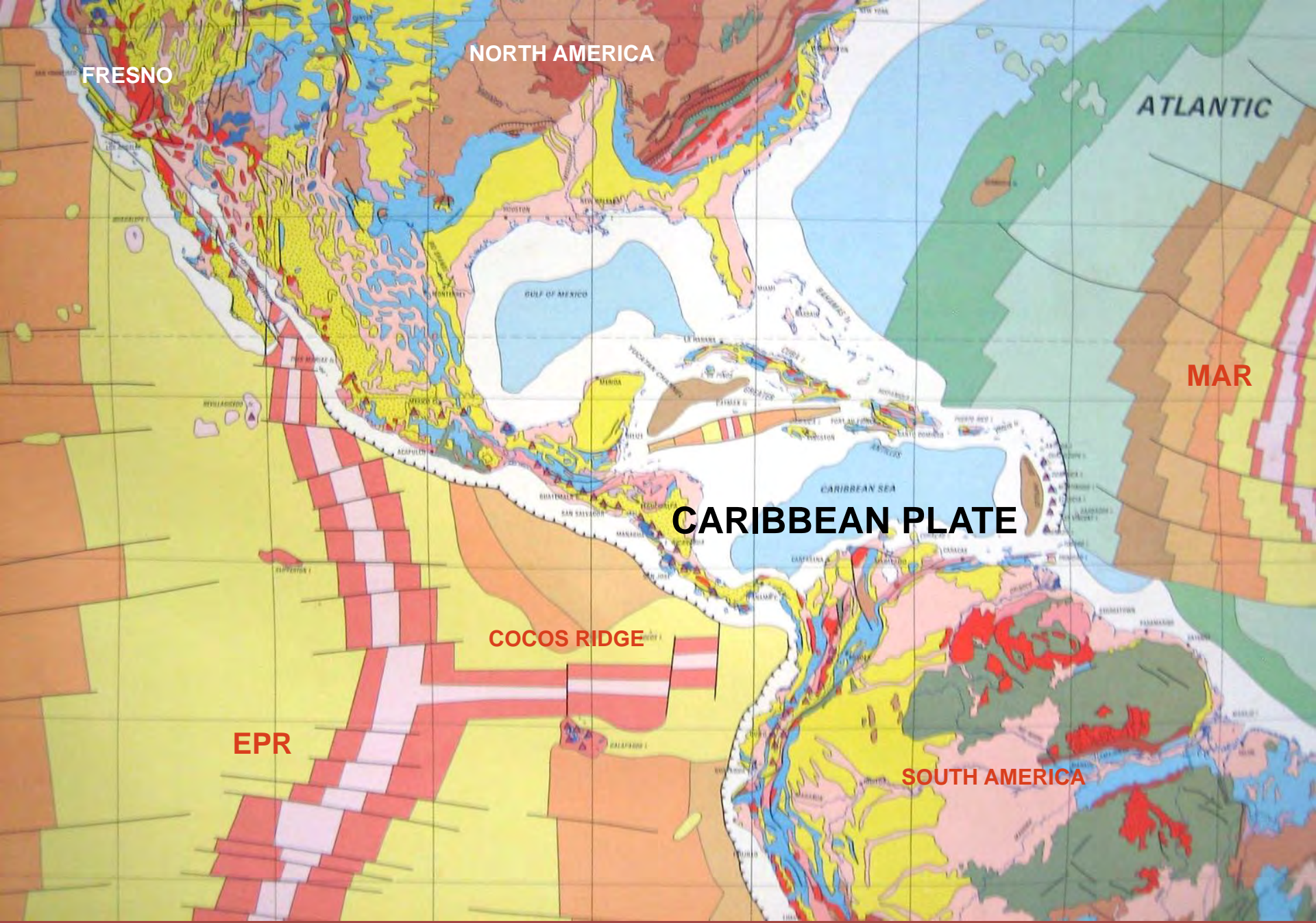


*MOR - Plume distal ophiolite  
(Macquarie-type Ophiolite)*



Dilek & Furnes 2009





FRESNO

NORTH AMERICA

ATLANTIC

MAR

CARIBBEAN PLATE

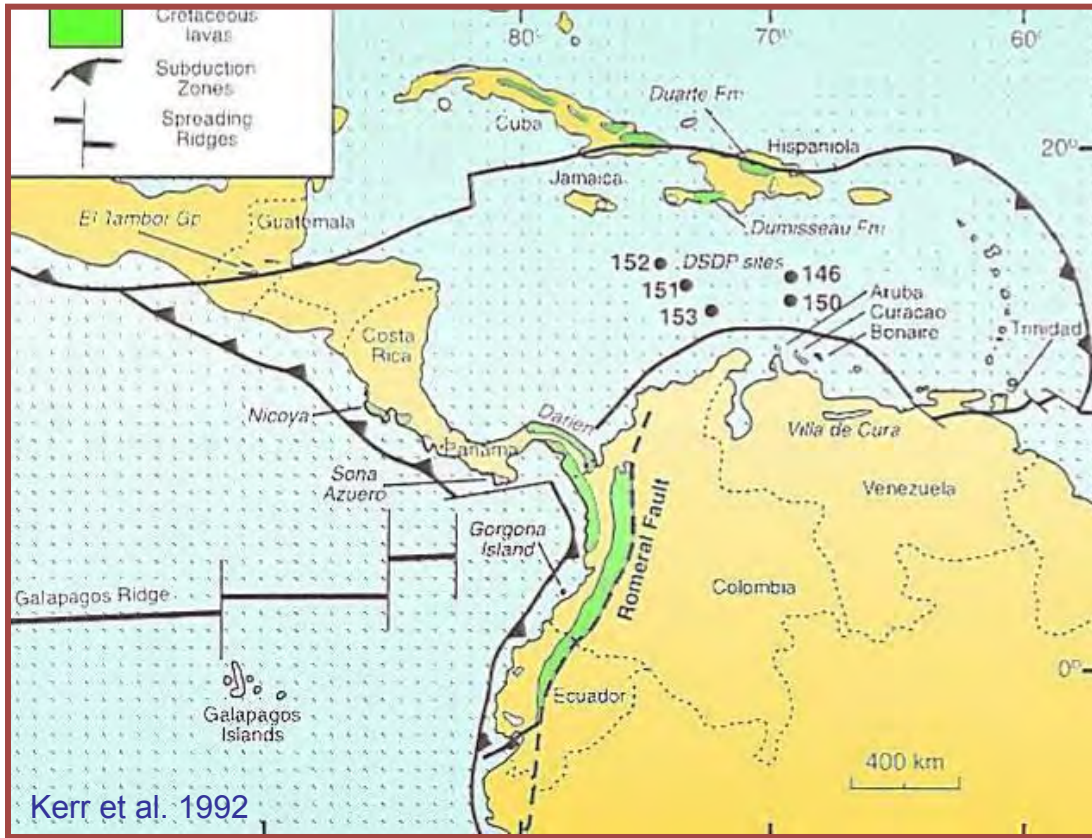
COCOS RIDGE

EPR

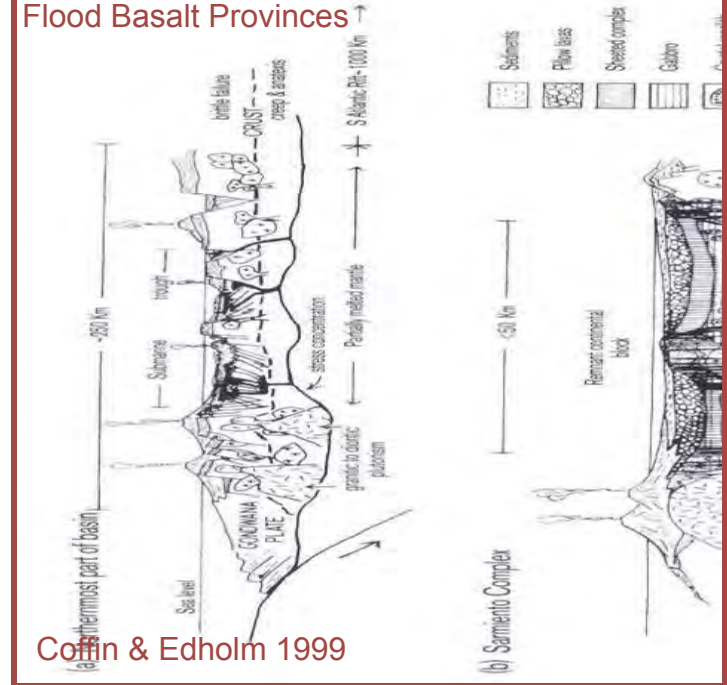
SOUTH AMERICA



# PLUME-TYPE OPHIOLITE (地幔柱型蛇绿岩) : Peri-Caribbean ophiolites



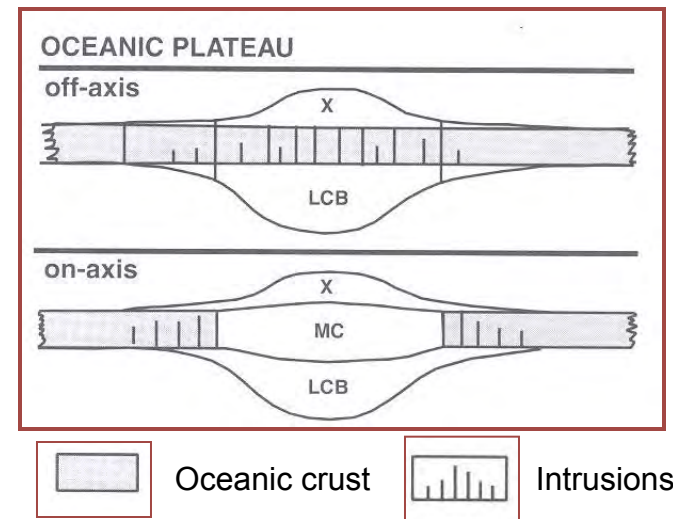
Distribution of Oceanic Plateaus  
Flood Basalt Provinces



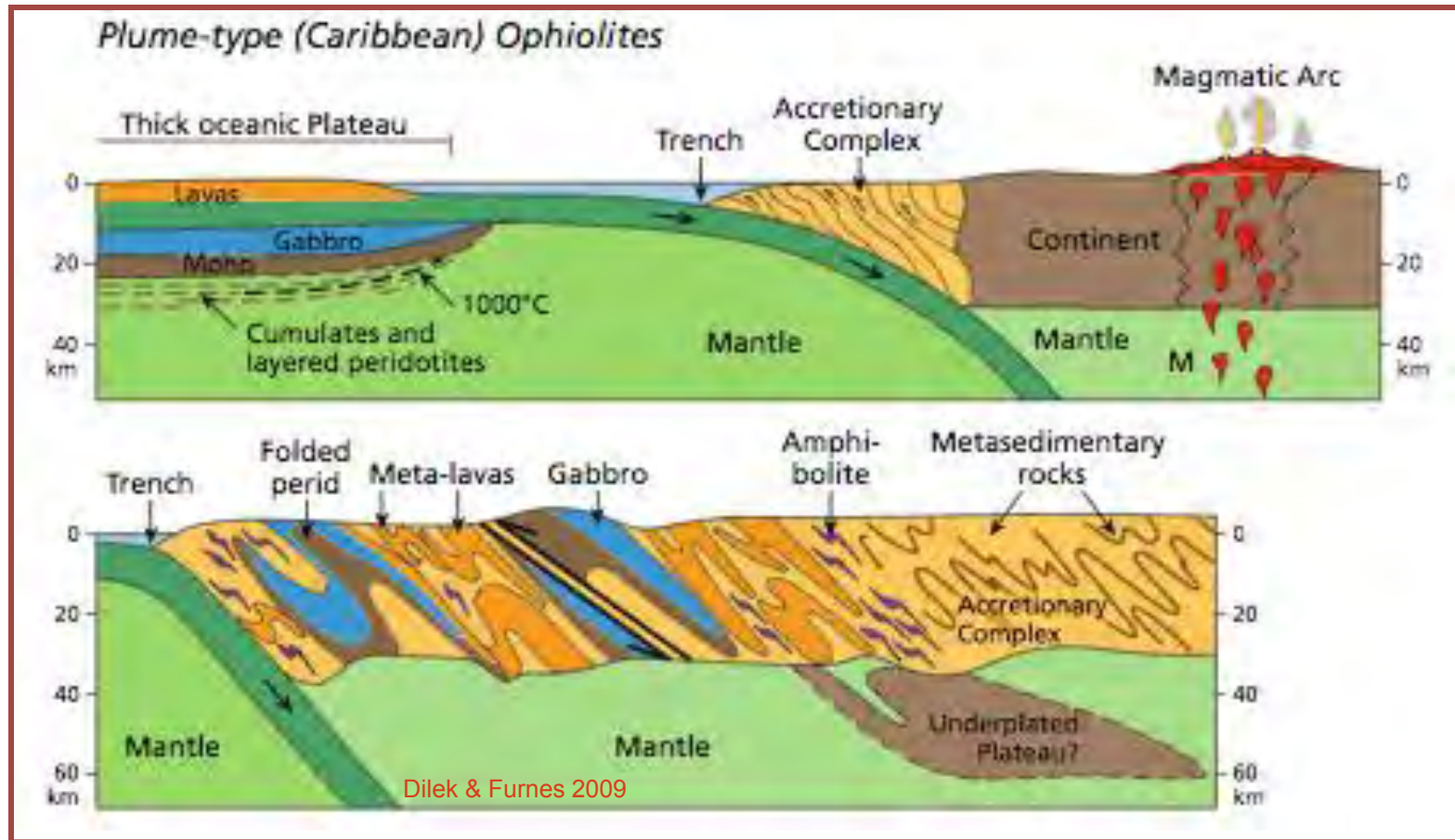
Form in plume-proximal ridges and oceanic plateaus,

Have thick plutonic and volcanic sequences,

Show “komatiitic”, depleted (D-MORB) to enriched basalt (E-MORB) affinities.

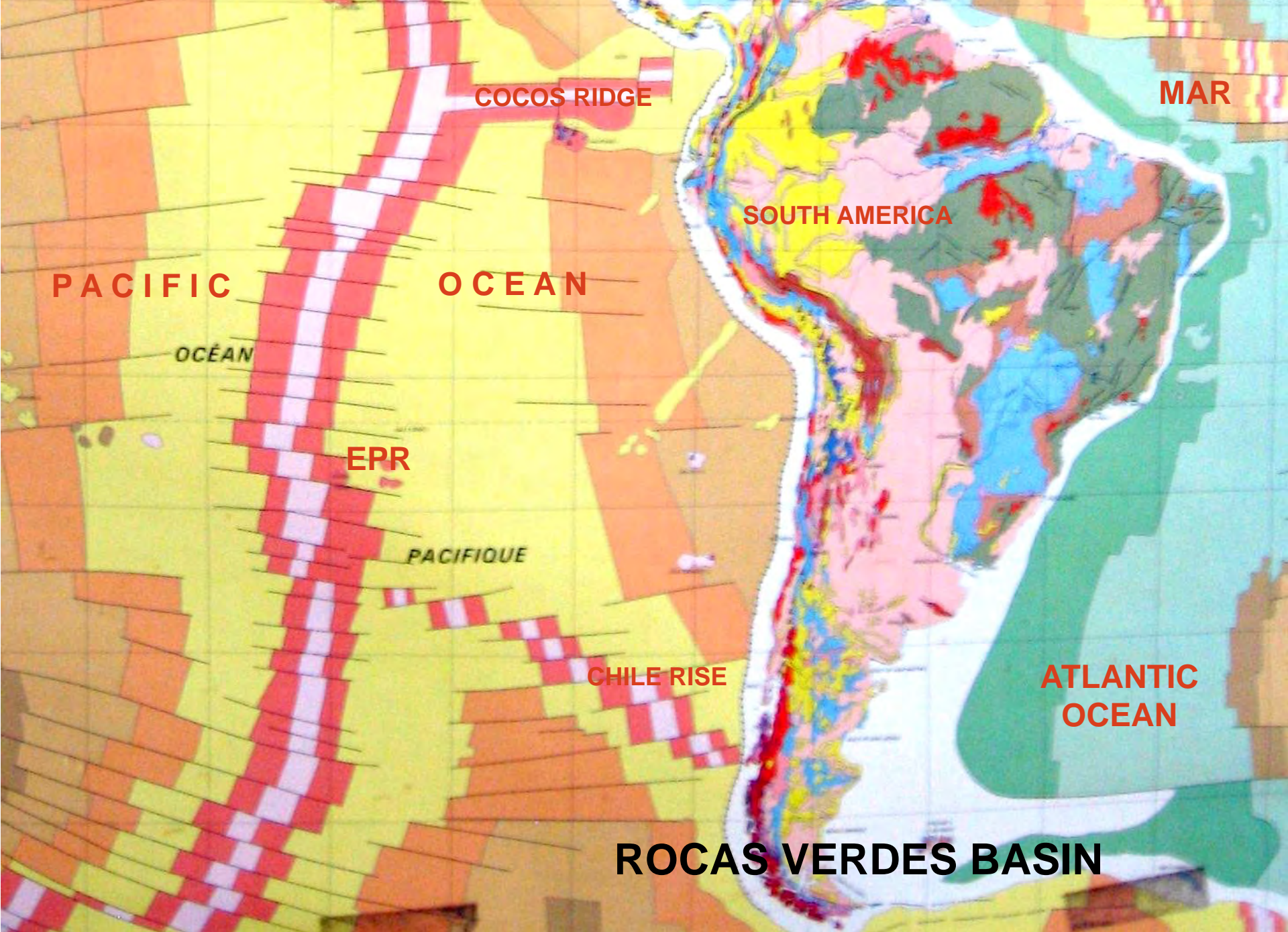


# PLUME-TYPE OPHIOLITE (地幔柱型蛇绿岩) : Peri-Caribbean ophiolites



## Incorporation of plume-type ophiolites and oceanic plateaus into continental margins (地幔柱型蛇绿岩与大洋高原一起进入大陆边缘) :

- Detached mantle continues to subduct,
- Thick volcanic section and lower crust gets accreted in thrust imbricates within the accretionary complex.



PACIFIC

OCEAN

Océan

EPR

PACIFIQUE

CHILE RISE

ROCAS VERDES BASIN

SOUTH AMERICA

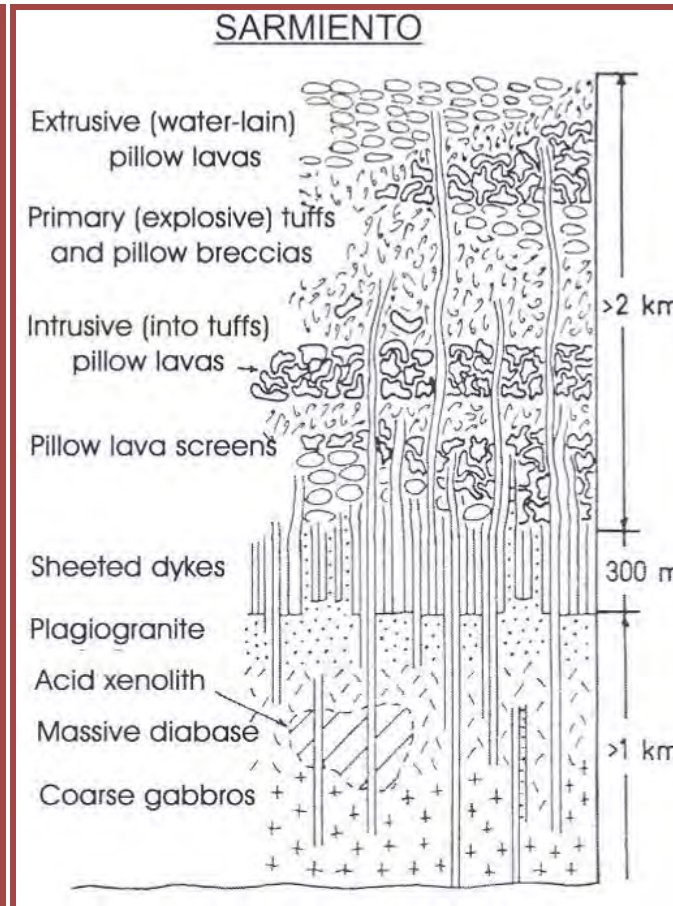
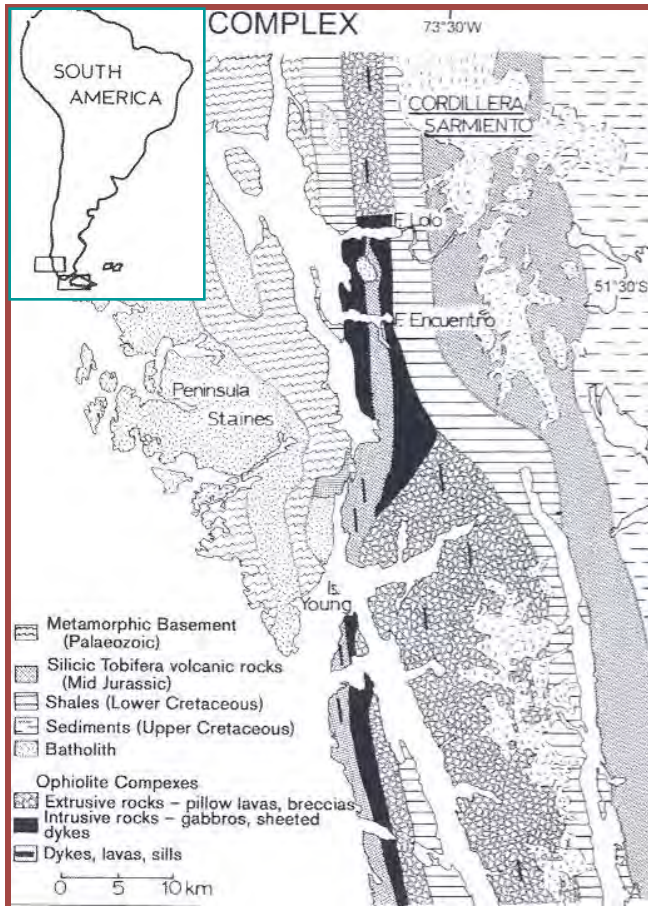
ATLANTIC OCEAN

MAR

COCOS RIDGE

# TRENCH-DISTAL MOR OPHIOLITES (远离海沟-洋中脊蛇绿岩) :

## Sarmiento & Tortuga - Chile



Andean-type, backarc spreading in an ensialic setting;

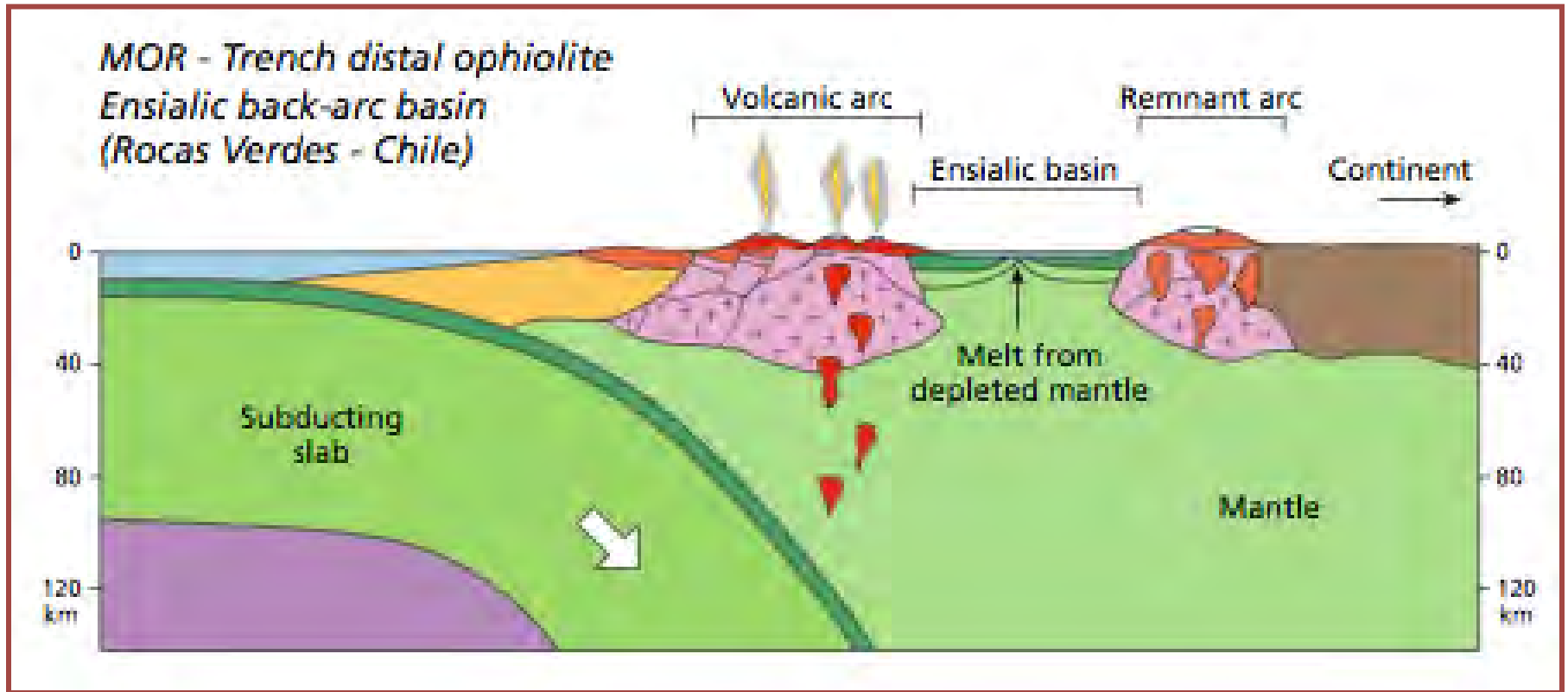
Intrusive relations with the host remnant-arc rocks;

Penrose-type igneous stratigraphy;

Crustally contaminated MORB affinity

# TRENCH-DISTAL MOR OPHIOLITES (远离海沟-洋中脊蛇绿岩) :

Sarmiento & Tortuga - Chile





**NORTH  
AMERICAN  
CRATON**

**JDFR**

**WESTERN US  
CORDILLERA**

**MTR**

**PACIFIC  
OCEAN**

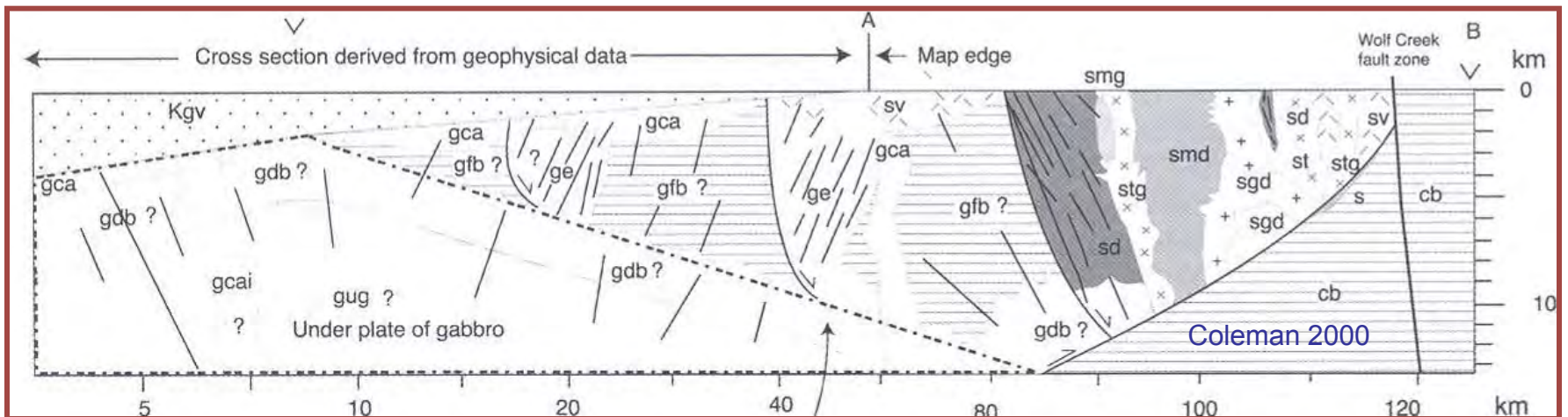
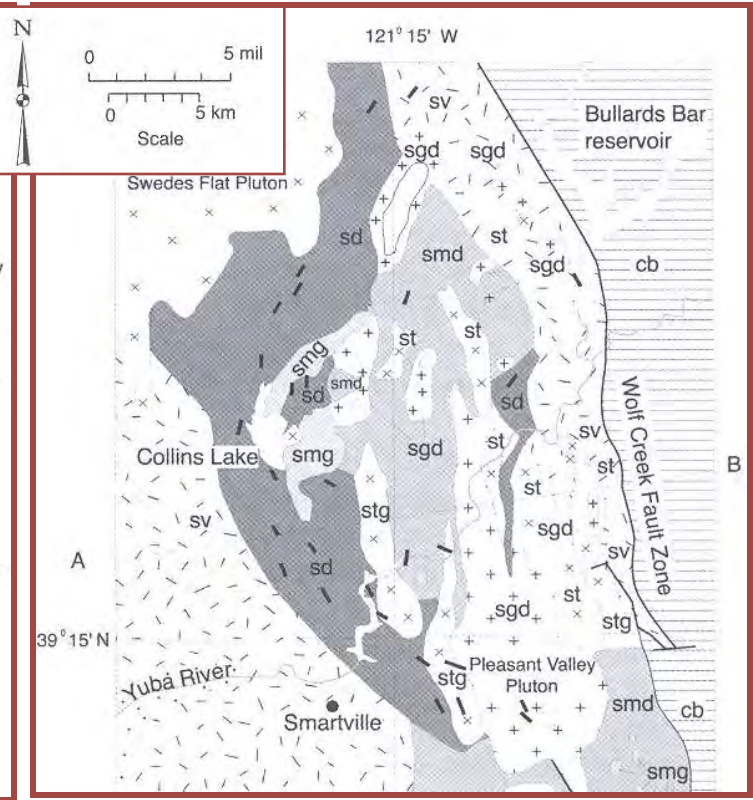
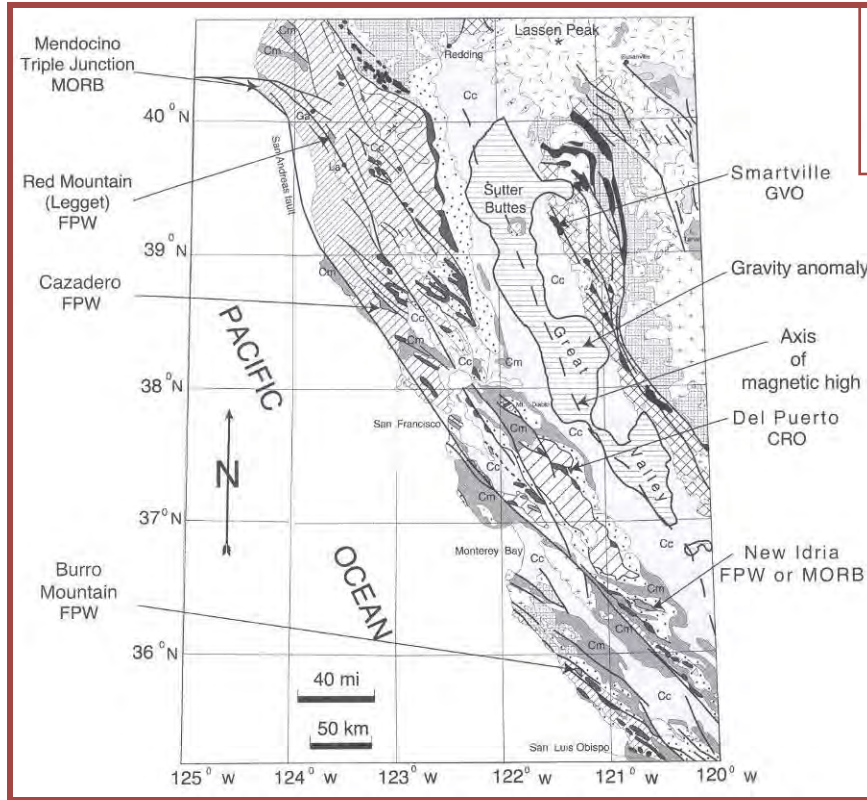
**SIERRA NEVADA**

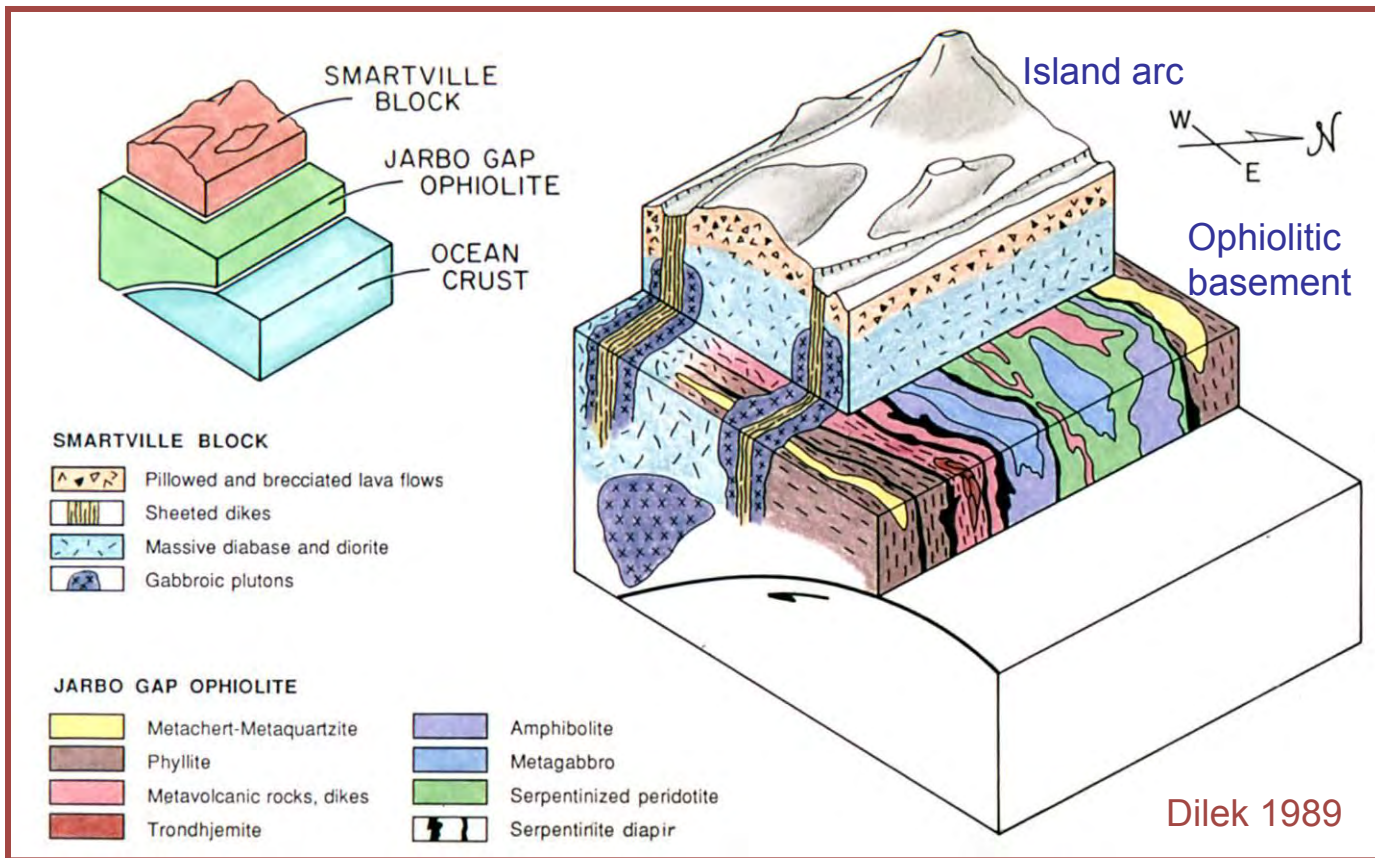
**HAWAII**

**ATLANTIC**

# VOLCANIC ARC OPHIOLITES (火山弧蛇绿岩):

Sierra Nevada Foothills, CA; Smartville Ophiolite; 160-155 Ma





## VOLCANIC ARC OPHIOLITE (火山 弧蛇绿岩)

Polygenetic  
origin in an  
ensimatic arc  
setting

More than 50 m.y.  
of island arc crustal  
accretion

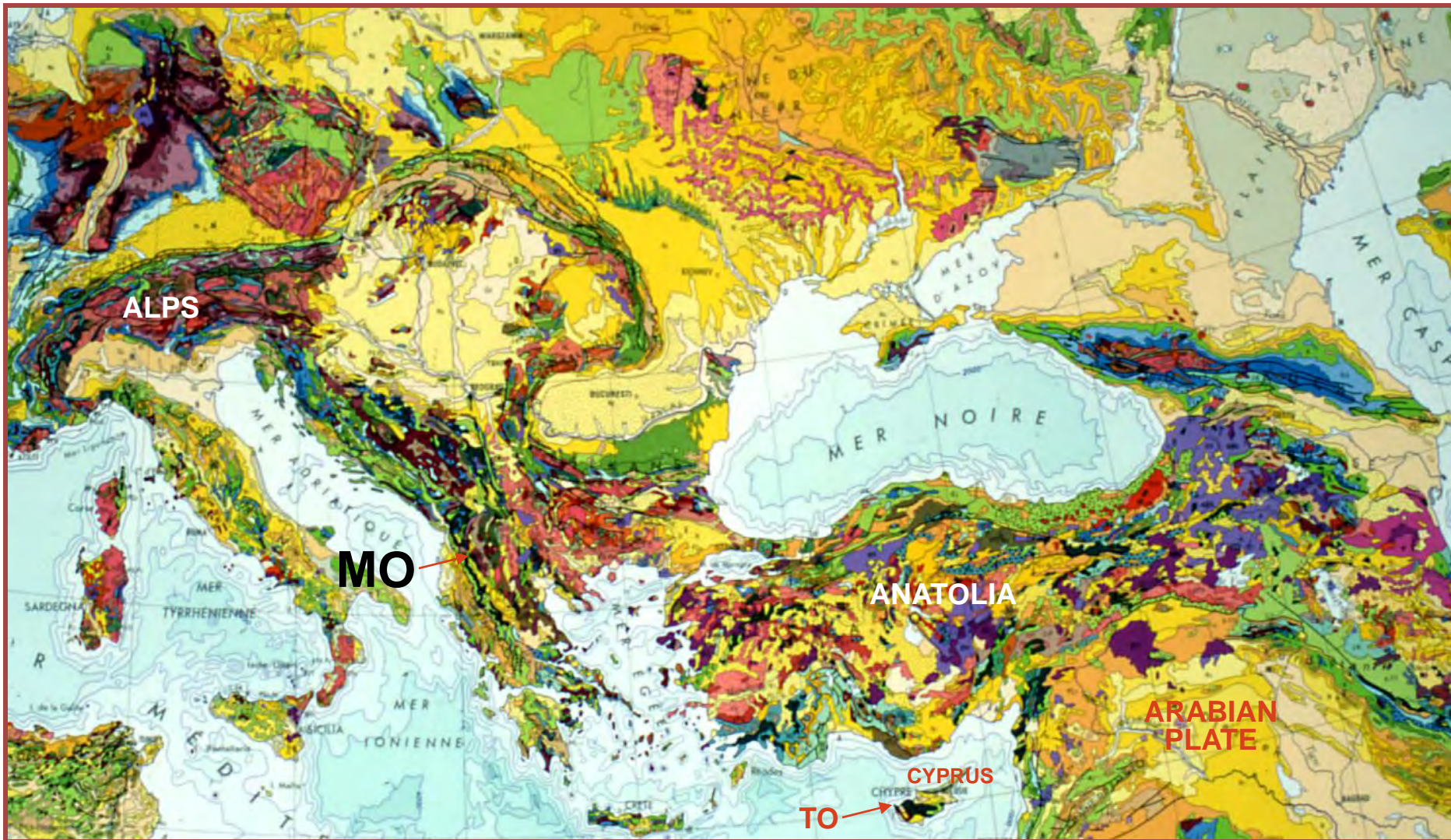
Deformed ophiolitic basement, locally in a mélangé character;

Intruded by basaltic andesite/andesite dikes (as high-Mg andesitic lavas of arc volcanoes; formed by melting of a metasomatized, depleted mantle source during early stages of subduction.

Island arc sequence composed of a plutonic-hypabyssal core, volcanic-volcaniclastic cover, and dike swarms.

Mafic to felsic dike swarms with basaltic compositions following typical calc-alkaline, low-P fractionation trends, compatible with an intra-arc origin.

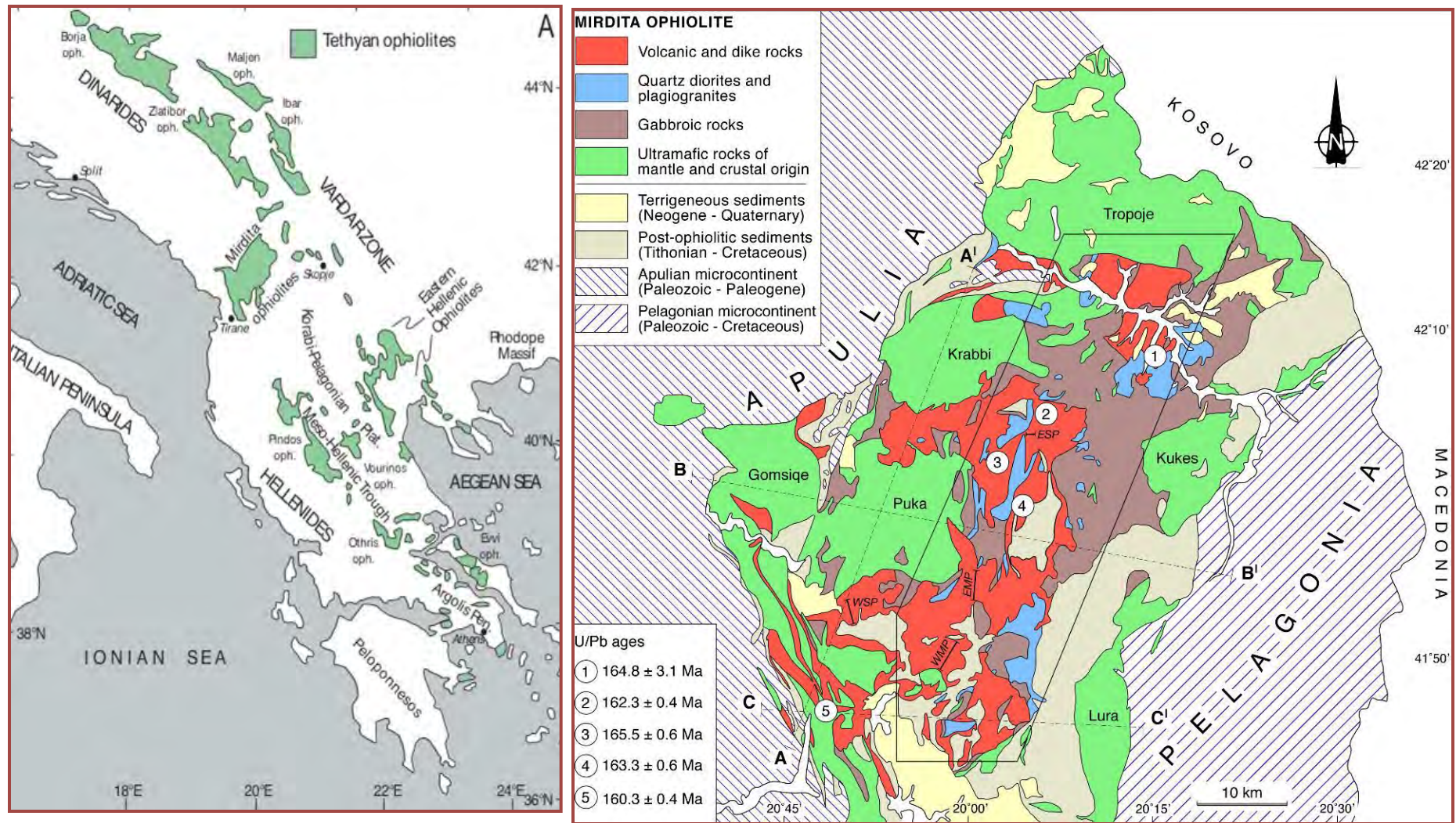




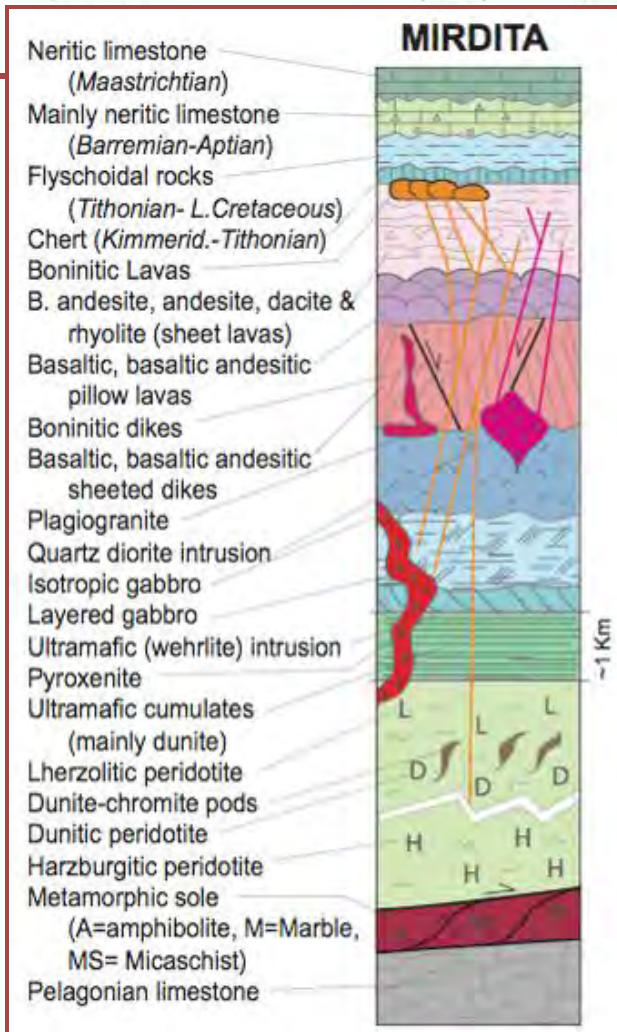
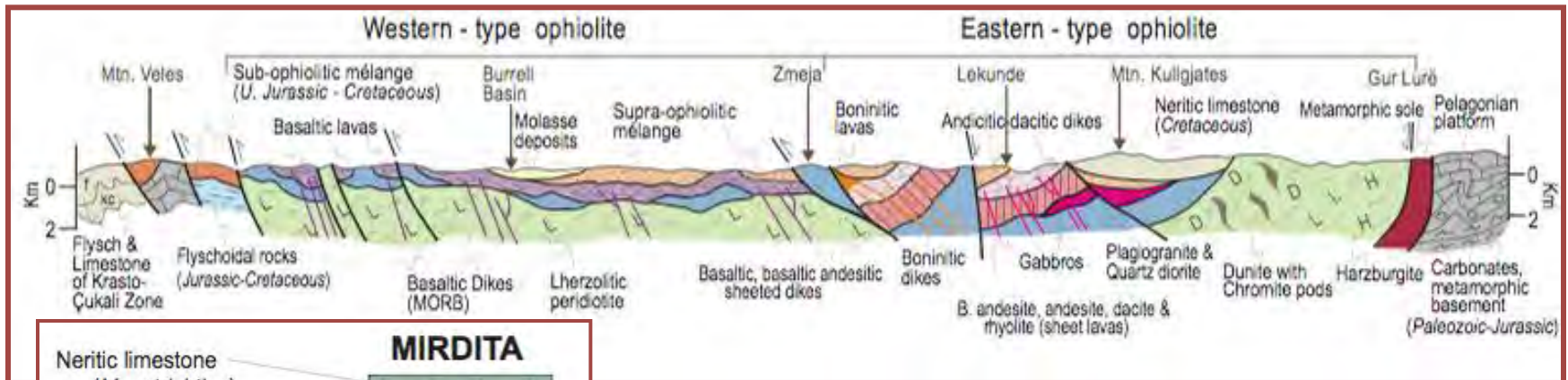
**ALPINE OROGENIC BELT (亚平宁造山带)**  
**Collision-driven orogen with diverse ophiolite occurrences**

# SUPRASUBDUCTION ZONE OPHIOLITE (俯冲带之上的蛇绿岩) :

## Mirdita Ophiolite (Albania)



Dilek et al. 2007



## MIRDITA OPHIOLITE (165 -160 Ma)

Lherzolithic to harzburgitic peridotites

*Hess-type* (West) to *Penrose-type* (East) crust

Geochemical progression from MORB to IAT to boninitic compositions laterally and vertically

Different mantle melt sources that are variably subduction-metasomatized

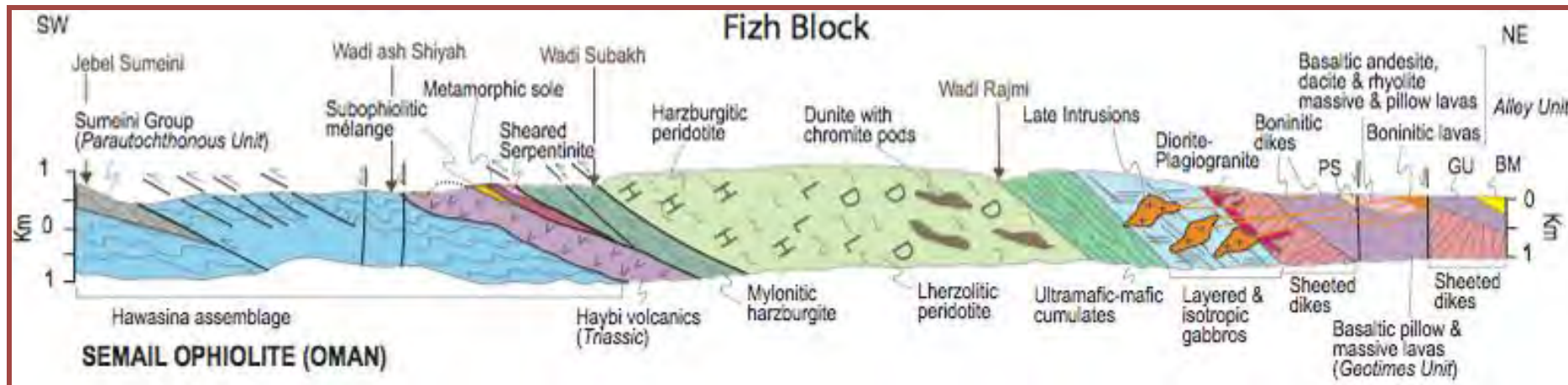
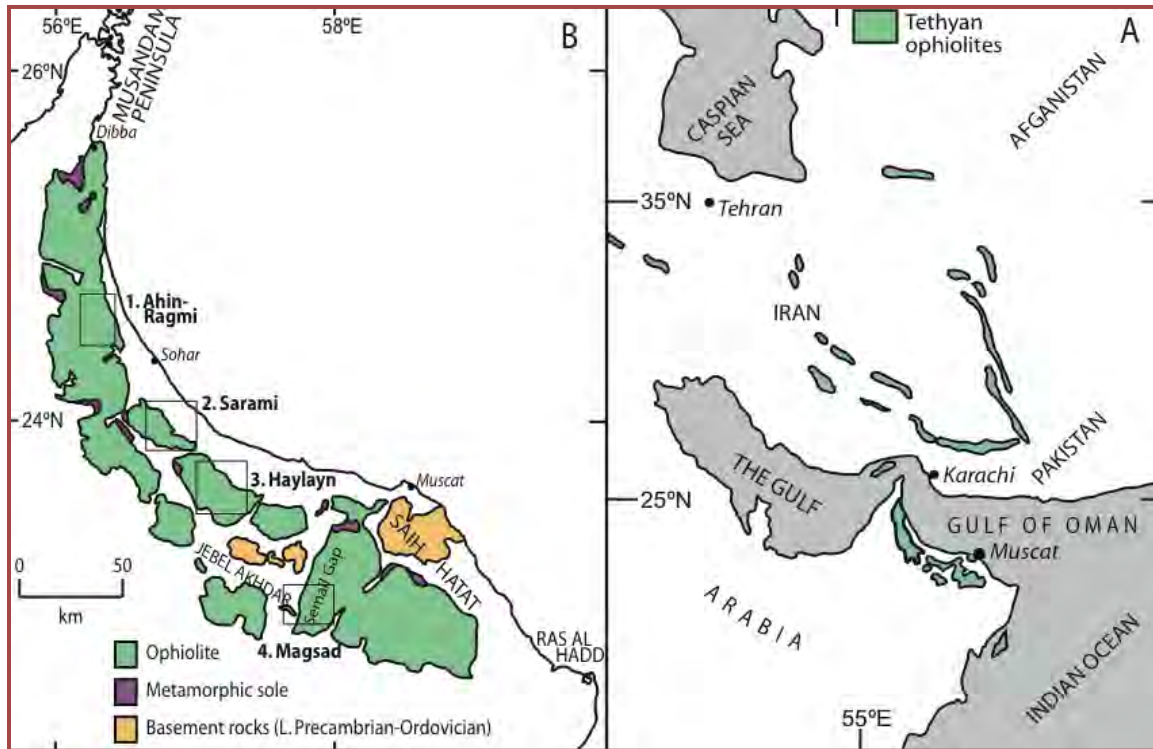
Significant crustal contamination of late-stage melts: increased sediment subduction

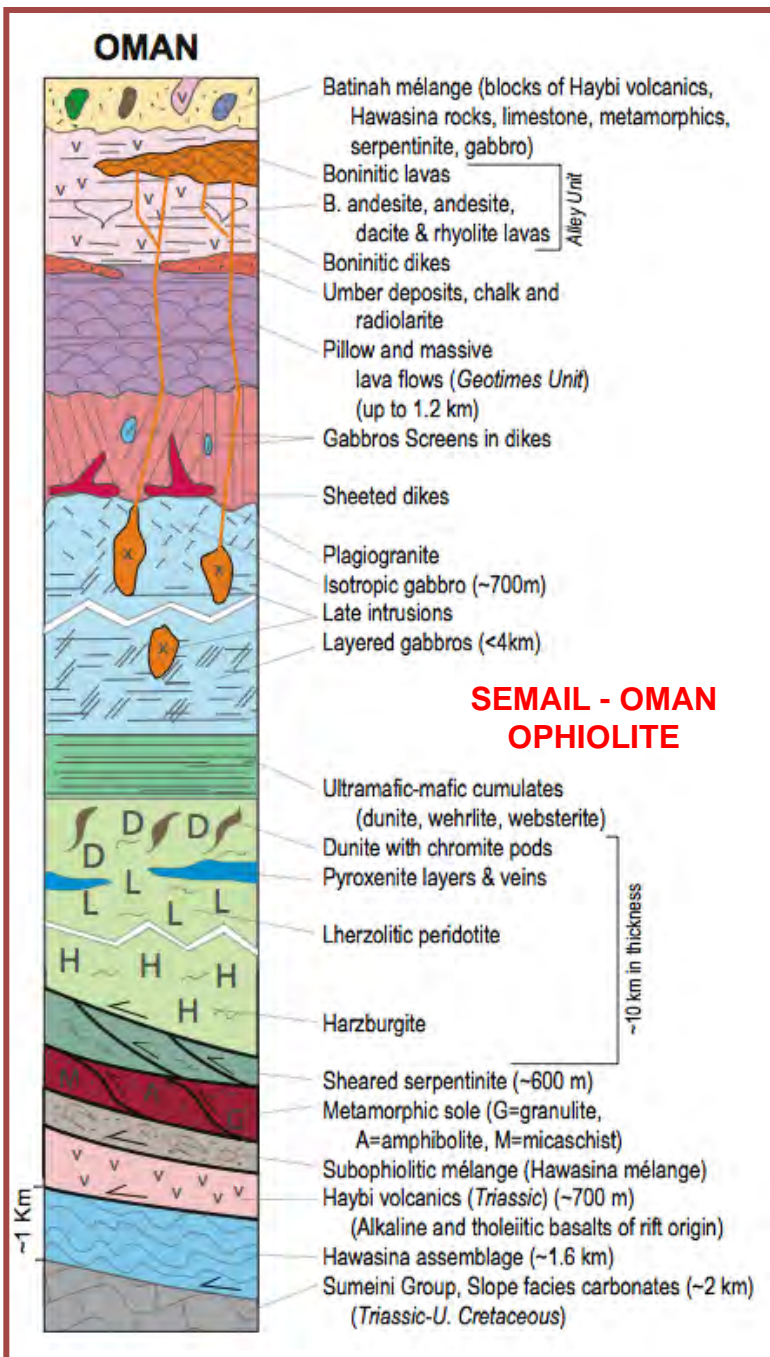
# SEMAIL - OMAN OPHIOLITE (95-92 Ma)

Nearly 12 km thick,

Resting tectonically on  
Triassic rift lavas and  
Arabian passive margin  
sequences,

Penrose-type igneous  
stratigraphy.



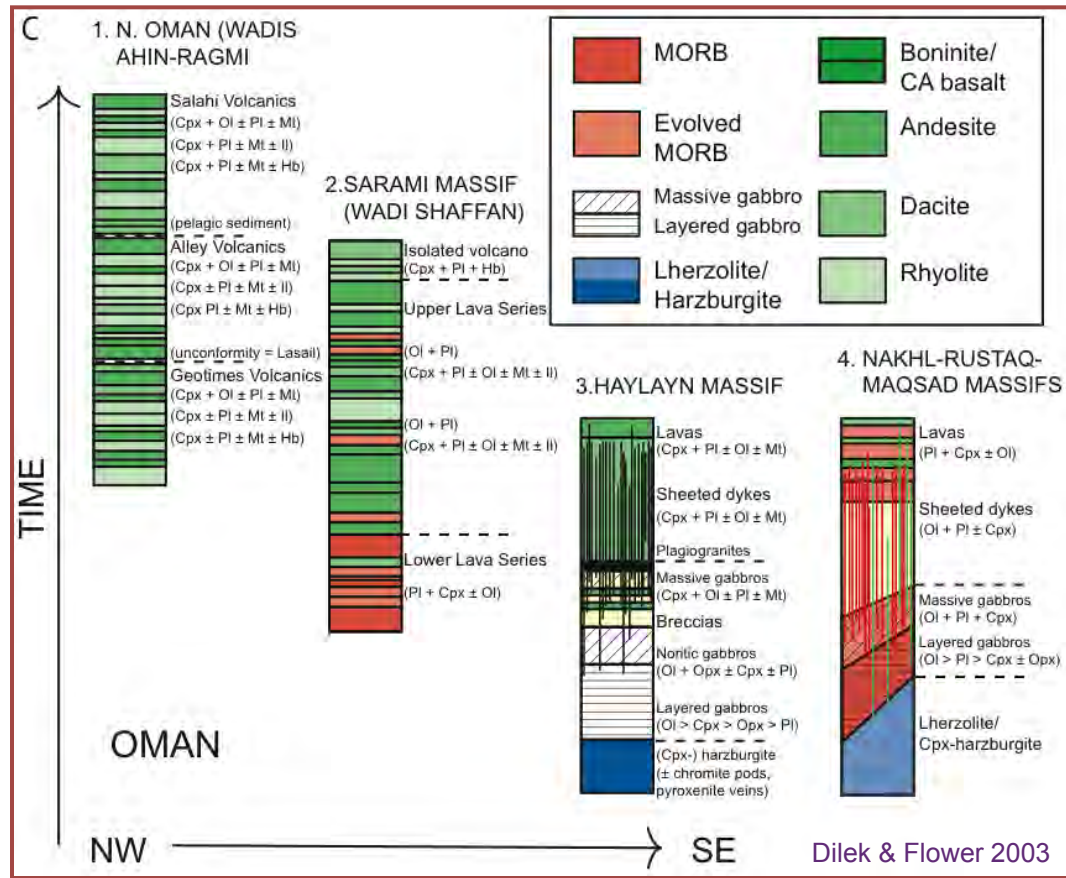


MORB-like gabbroic rocks & lherzolitic peridotites

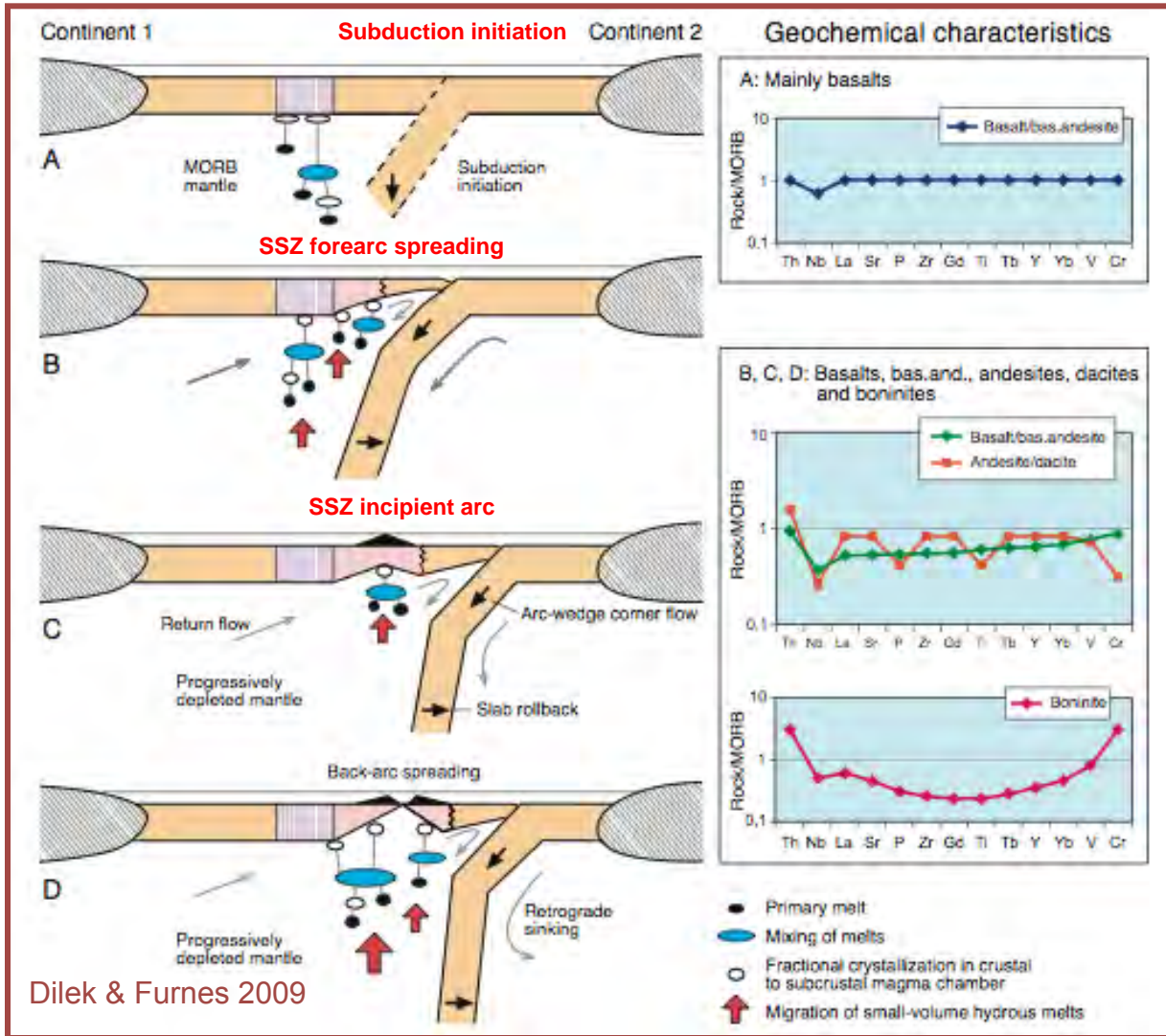
Low-K tholeiitic basalts & sheeted dikes

Calcalkaline plutons and IAT to calcalkaline lavas  
Boninitic dikes and lavas (*Lasail & Alley Units*)

Alkali basalts & dikes (*Salahi*): Off - axis, late-stage magmatism

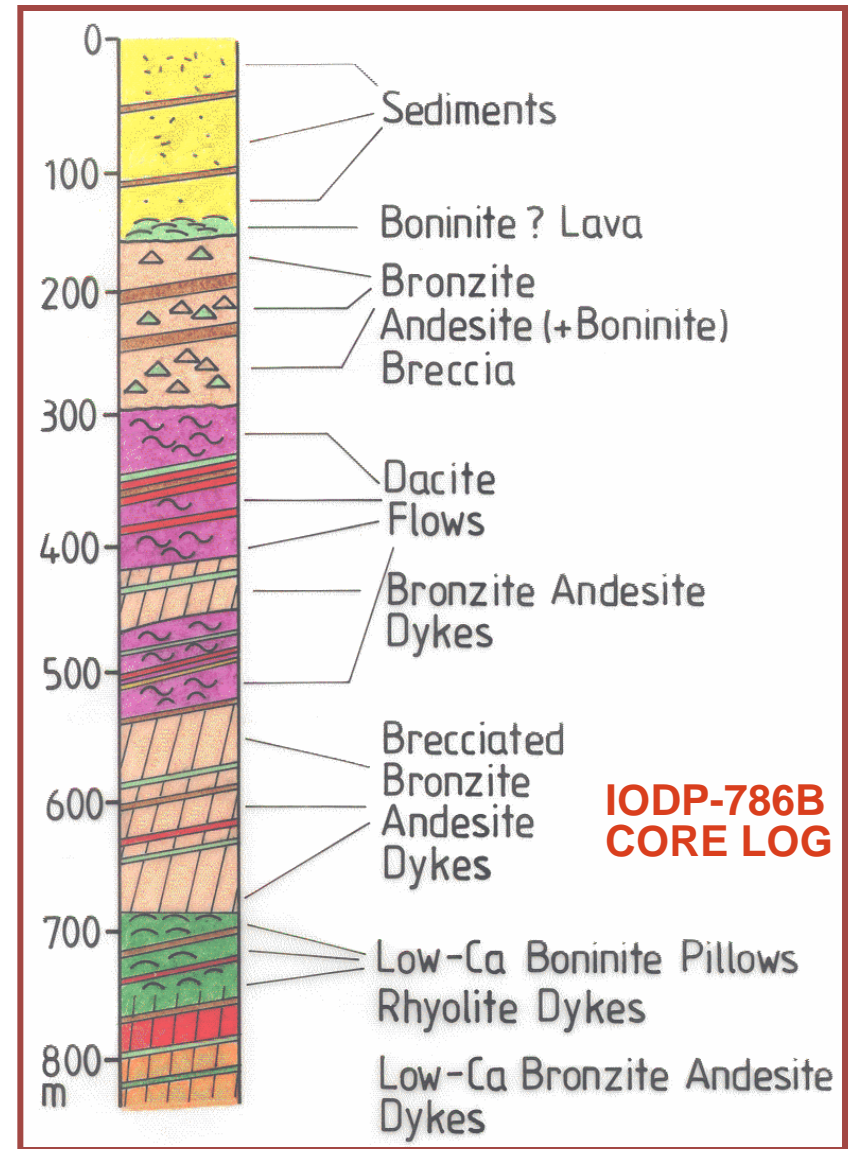
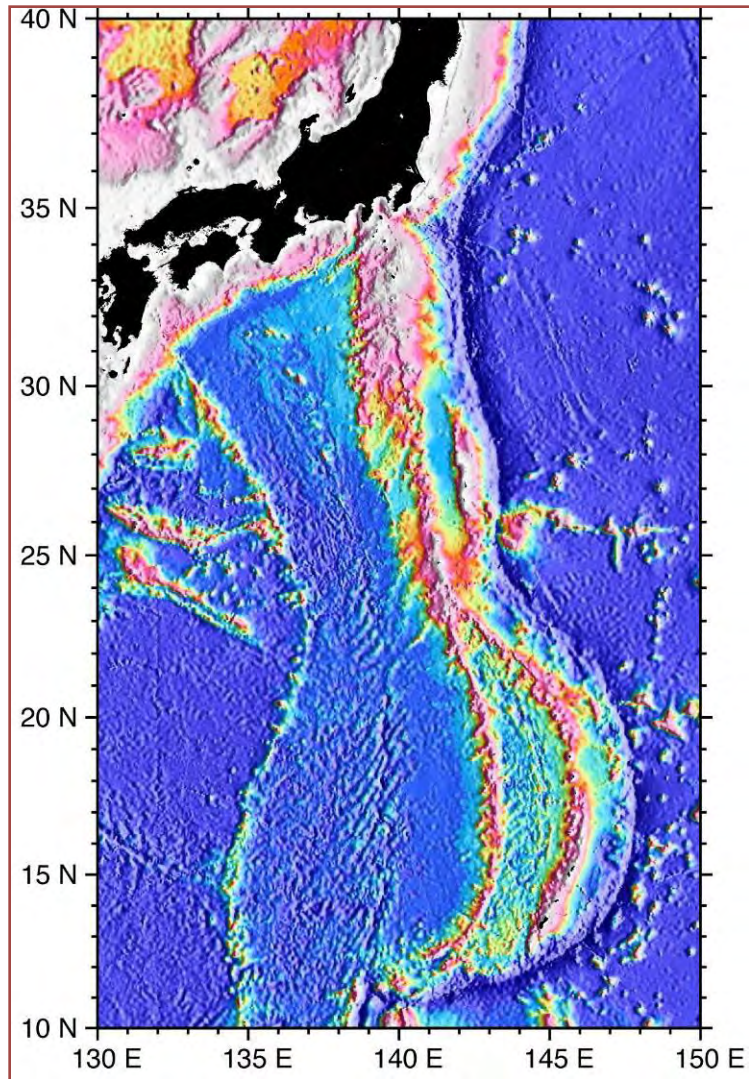


# PETROGENETIC MODEL FOR THE EVOLUTION OF SUPRASUBDUCTION ZONE OPHIOLITES (俯冲带之上蛇绿岩演化成因模式)



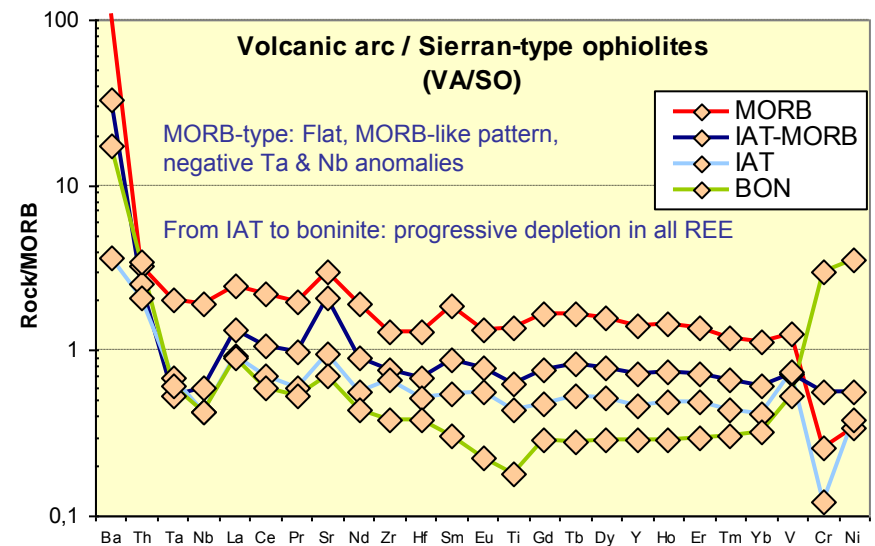
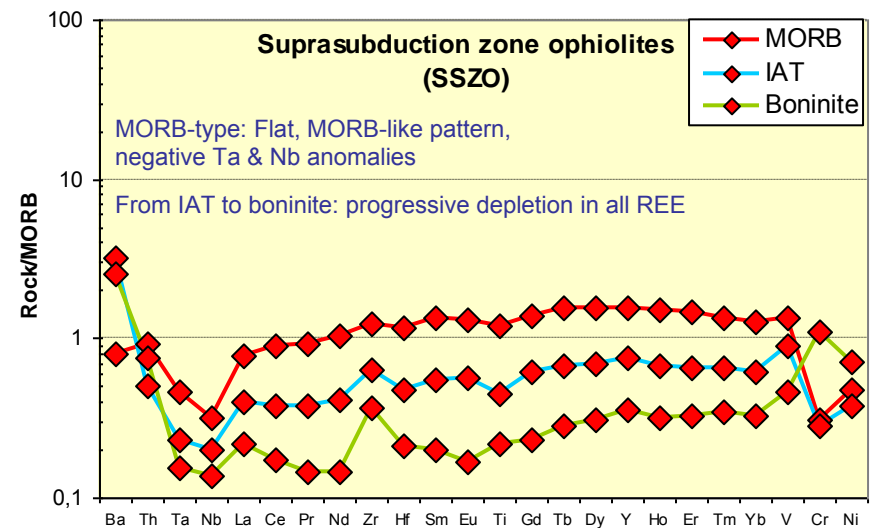
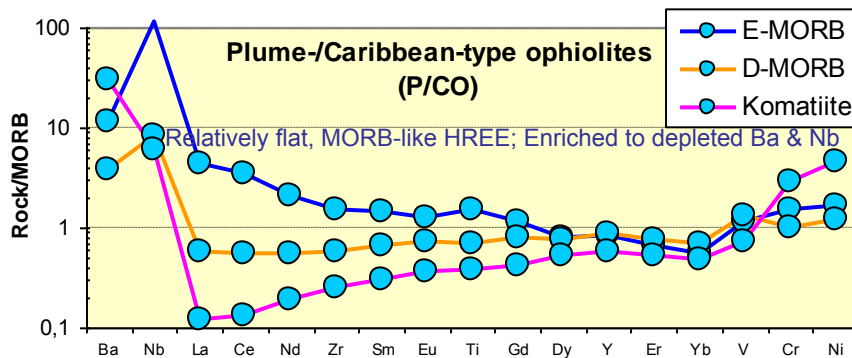
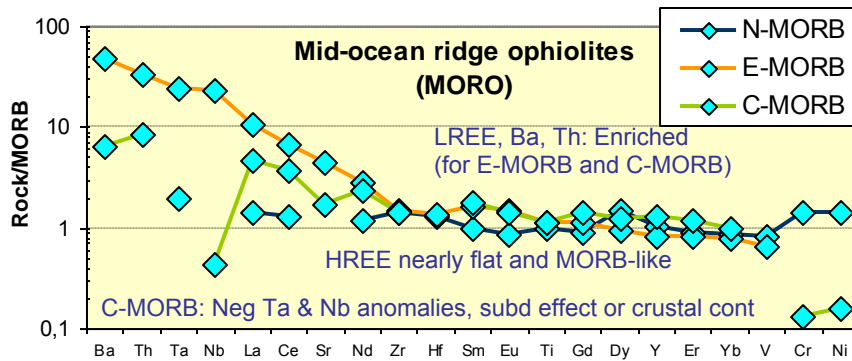
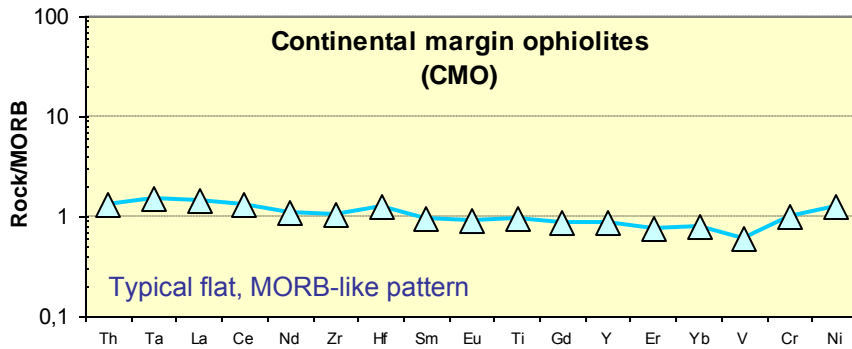
- A. Seafloor spreading & formation of MORB crust; subduction initiation. Formation of basalt to basaltic andesite magmas.**
- B. Corner flow advection & partial melting in hydrated mantle wedge; andesite, dacite & rhyolite formation; mantle becomes depleted.**
- C. Subduction rollback, arc-forearc extension, sheeted dyke formation; highly evolved lavas.**
- D. Rapid mantle advection; hotter mantle wedge; tightly compressed isotherms against the subducting slab; thermal burst to form boninites.**

# IBM Forearc (伊豆-小笠原-马里亚纳海沟弧前) = Ophiolite Nursery



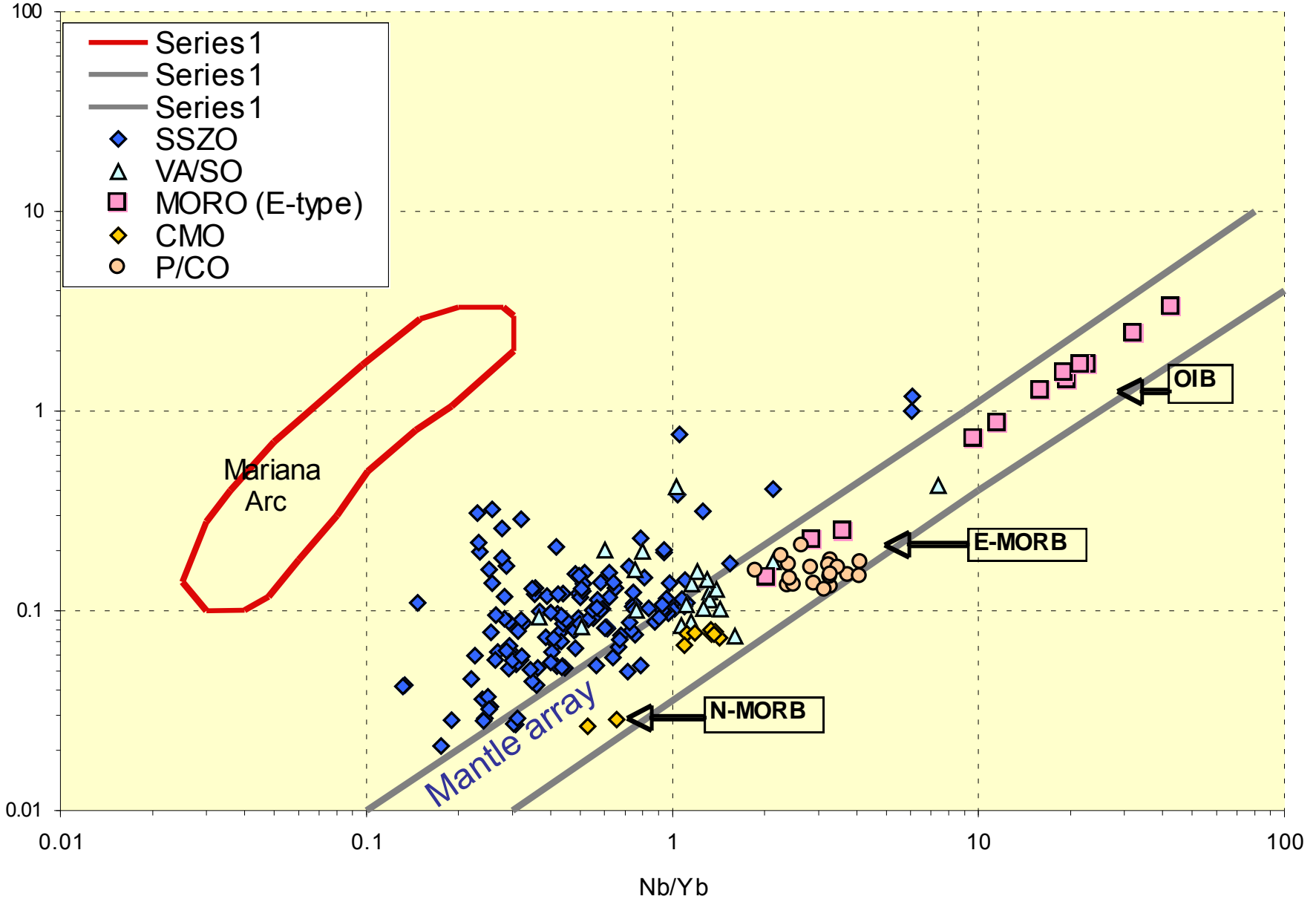
IBM forearc crust was generated during a short (5-10 Ma) “infant arc” episode of forearc spreading, including low-K tholeiite and rhyodacite ± boninite (Courtesy of B. Stern).

# Multielement diagrams for Continental margin, Mid-ocean ridge, Plume-/Caribbean, Suprasubduction zone, Volcanic arc/Sierran-type ophiolites

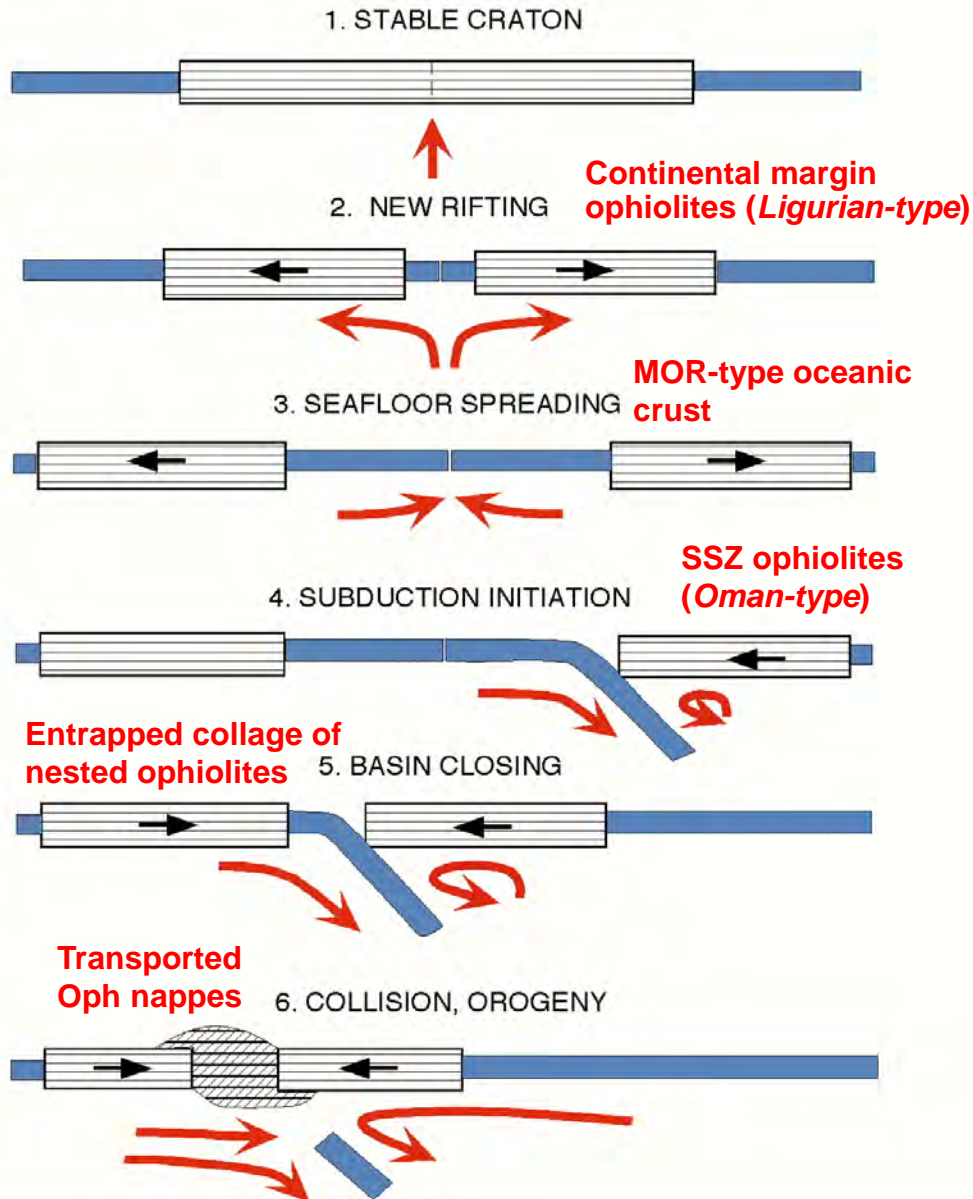




# Th/Yb - Nb/Yb Discriminant Diagram



## WILSON CYCLE

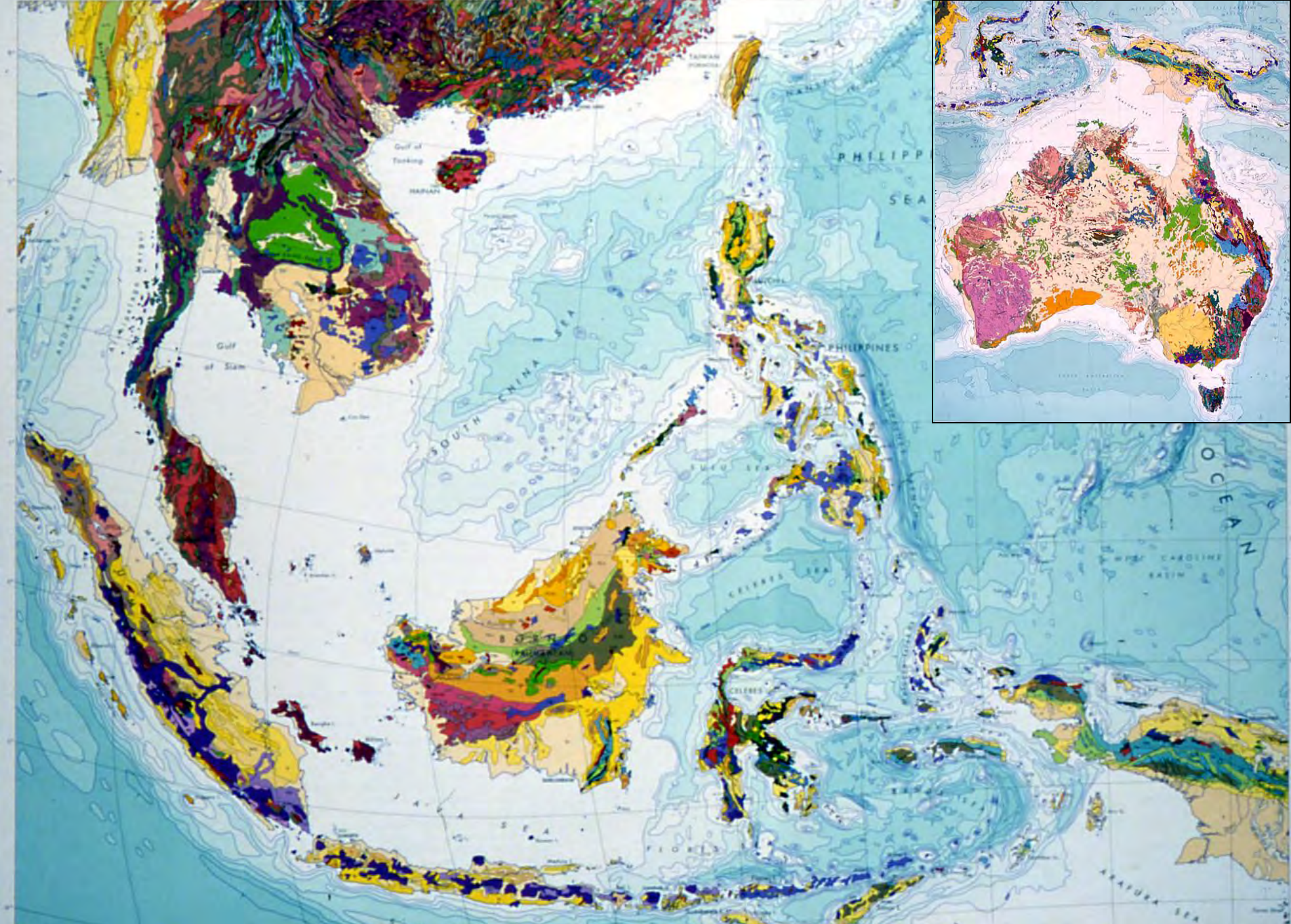


## WILSON CYCLE EVOLUTION OF OCEAN BASINS (大洋盆地威尔逊旋迴演化)

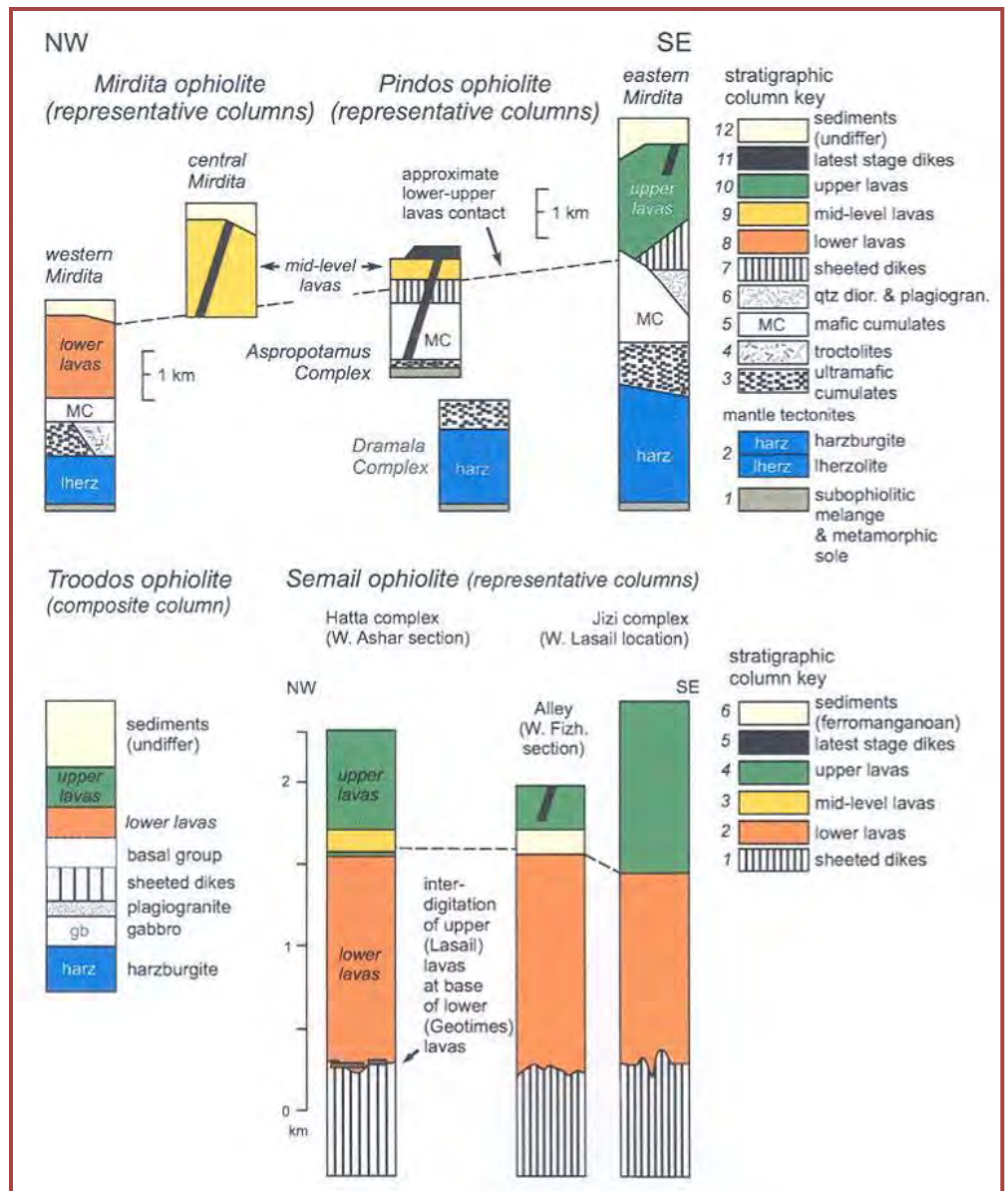
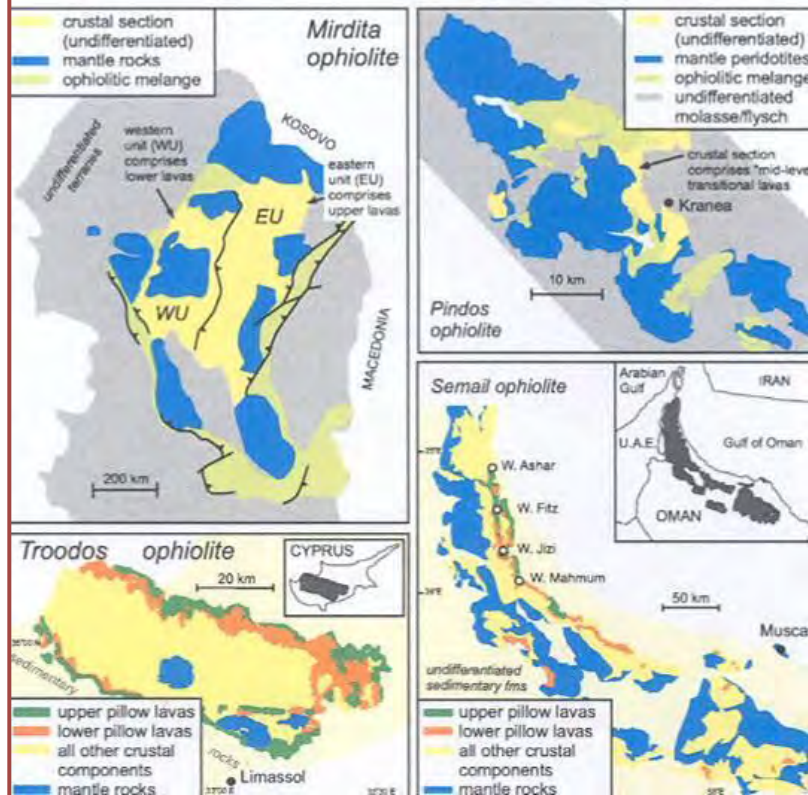
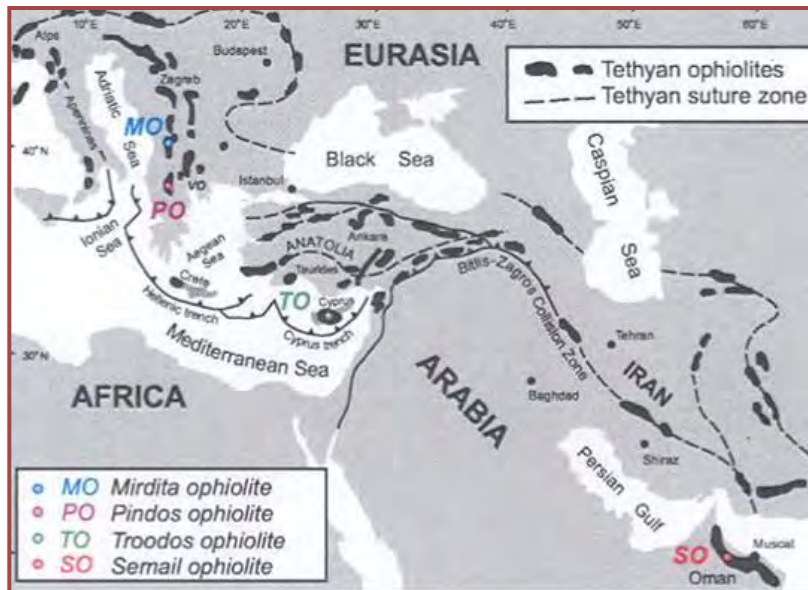
1. Continental breakup in response to asthenospheric upwelling
2. Rifting, development of thin passive margins with the inception of seafloor spreading
3. Continued seafloor spreading and evolution of MORB crust
4. Subduction inception as a result of far-field stresses (i.e. collision) and termination of basin opening
5. Consumption by subduction of remnant oceanic lithosphere and basin collapse
6. Continental collision, orogeny, and eventual exhumation & orogenic collapse of mountain belts

# 研究结论

- 不同蛇绿岩类型代表了古洋盆威尔逊旋迴演化的不同构造阶段；
- 俯冲带之上蛇绿岩形成于边缘盆地闭合作用过程中的俯冲板片后撤作用阶段；
- 边缘（弧后）盆地的形成和俯冲带之上蛇绿岩的产生可能都源于碰撞造山带挤出作用和地幔流变作用；
- 造山带蛇绿岩岩石化学、构造以及年代的差异性是洋中脊-弧/弧前-弧后盆地系统互相嵌入作用遗迹的记录；
- 俯冲带之上蛇绿岩代表了一种与特殊事件相关的特定现象，它在时间和空间上与地球演化过程中的短期快速改变（汇聚边缘的快速板片后撤和俯冲带之上板块的伸展作用）密切相关；



马来西亚-印度尼西亚地区：蛇绿岩加工厂

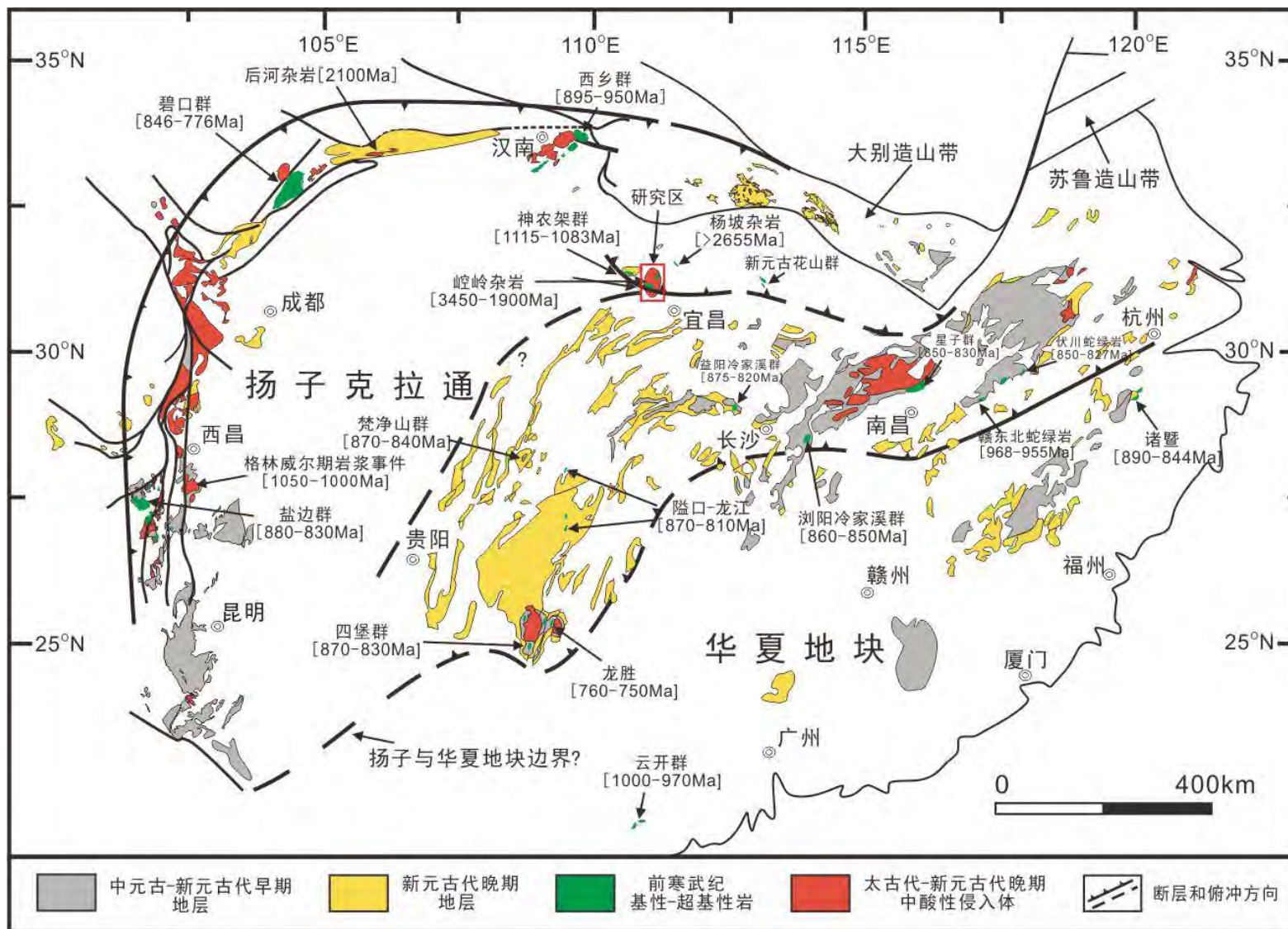


东地中海地区产出的SSZ型特提斯蛇绿岩

## 二、扬子克拉通庙湾蛇绿杂岩 研究

- **研究背景**
- **庙湾蛇绿杂岩地质及岩相学特征**
- **庙湾蛇绿杂岩年代学特征**
- **庙湾蛇绿杂岩地球化学及源区特征**
- **庙湾蛇绿杂岩形成构造环境**
- **结论**

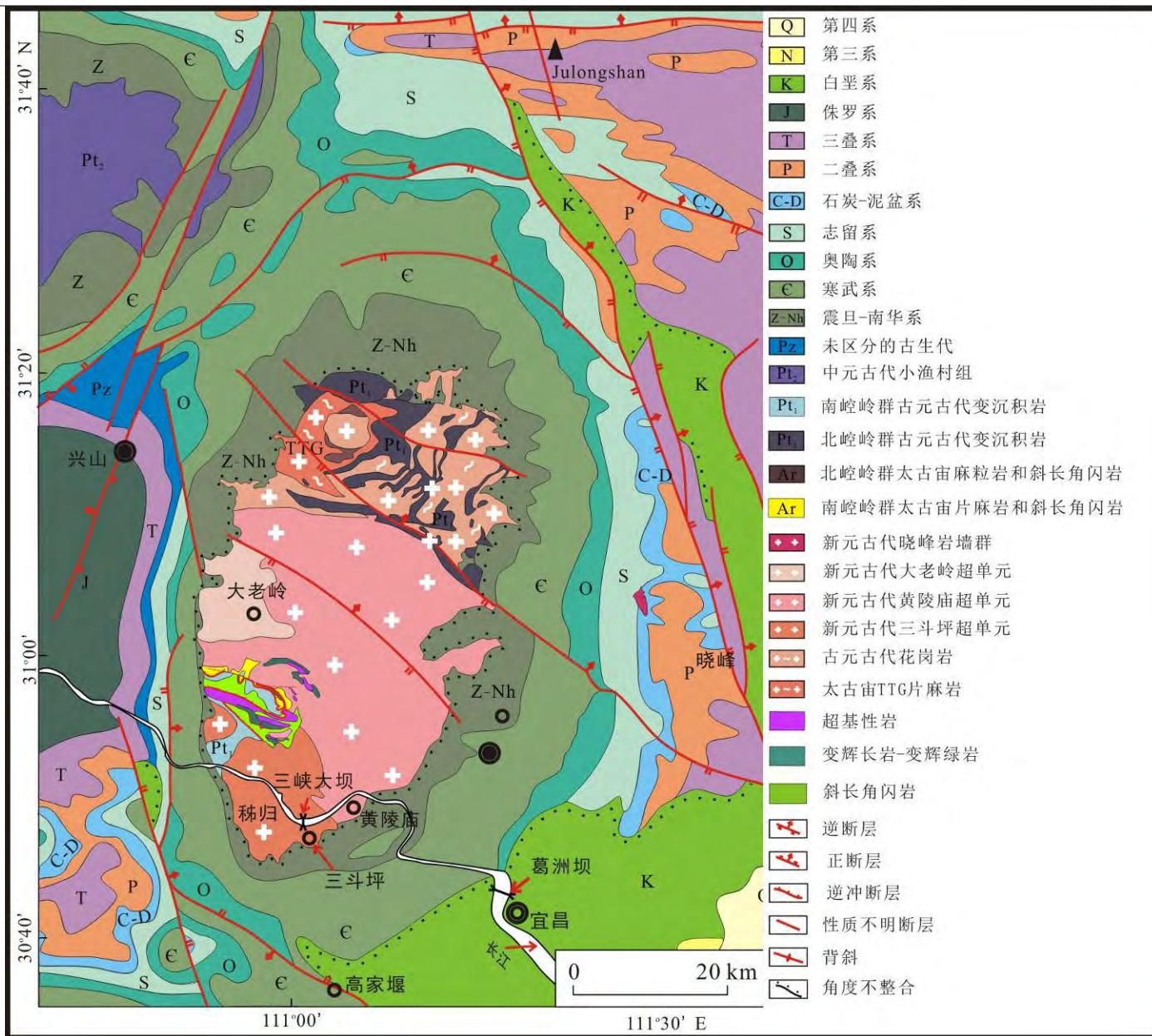
# 研究背景



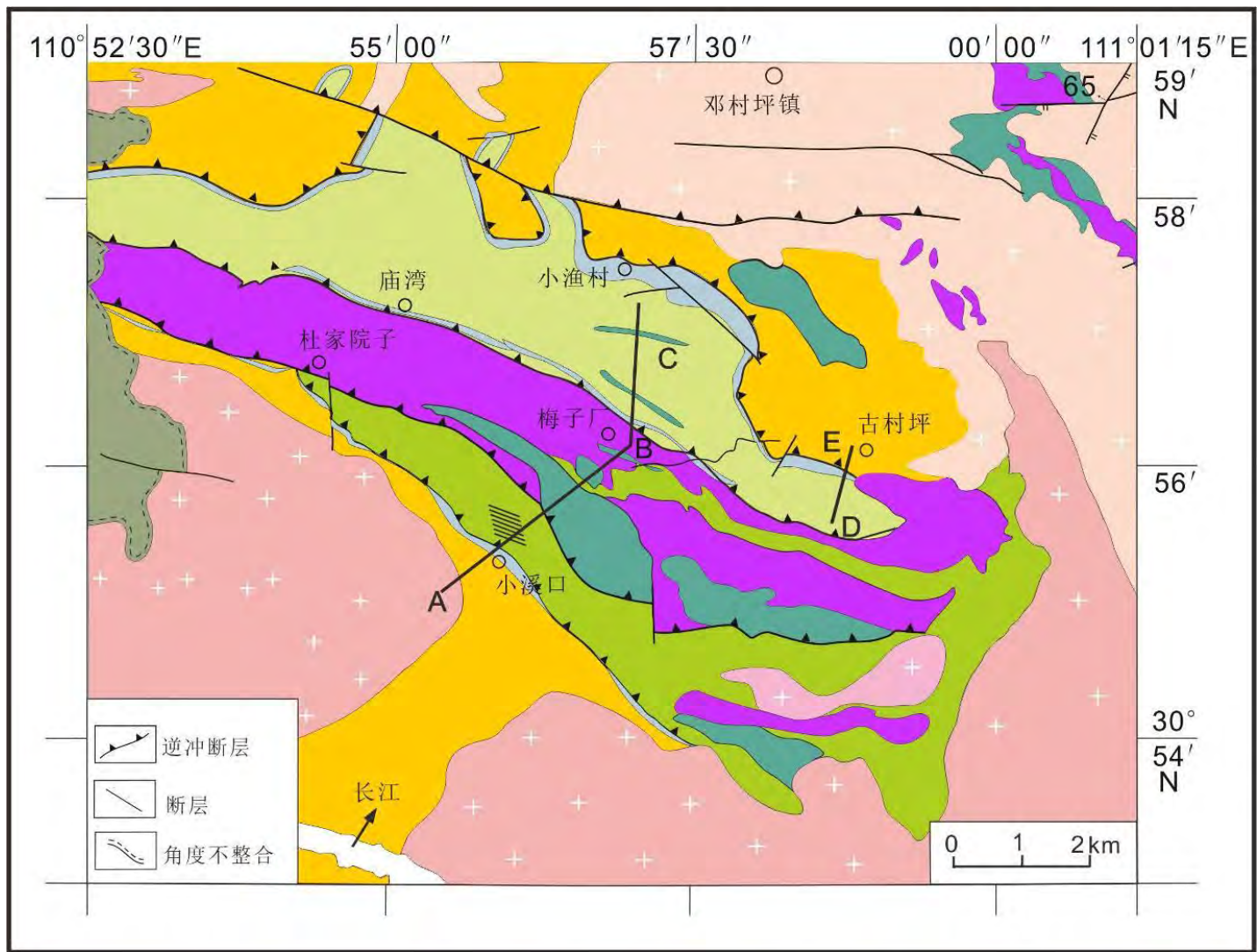
扬子克拉通前南华纪大地构造简图 (据王剑等, 2003, 修编)



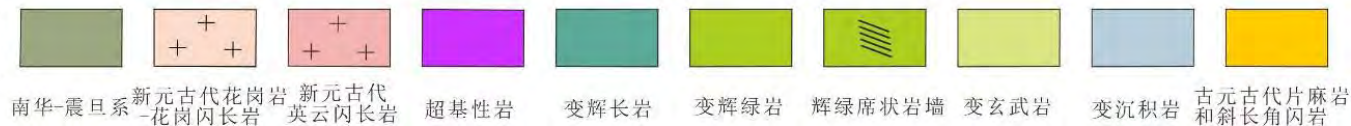
# 研究背景



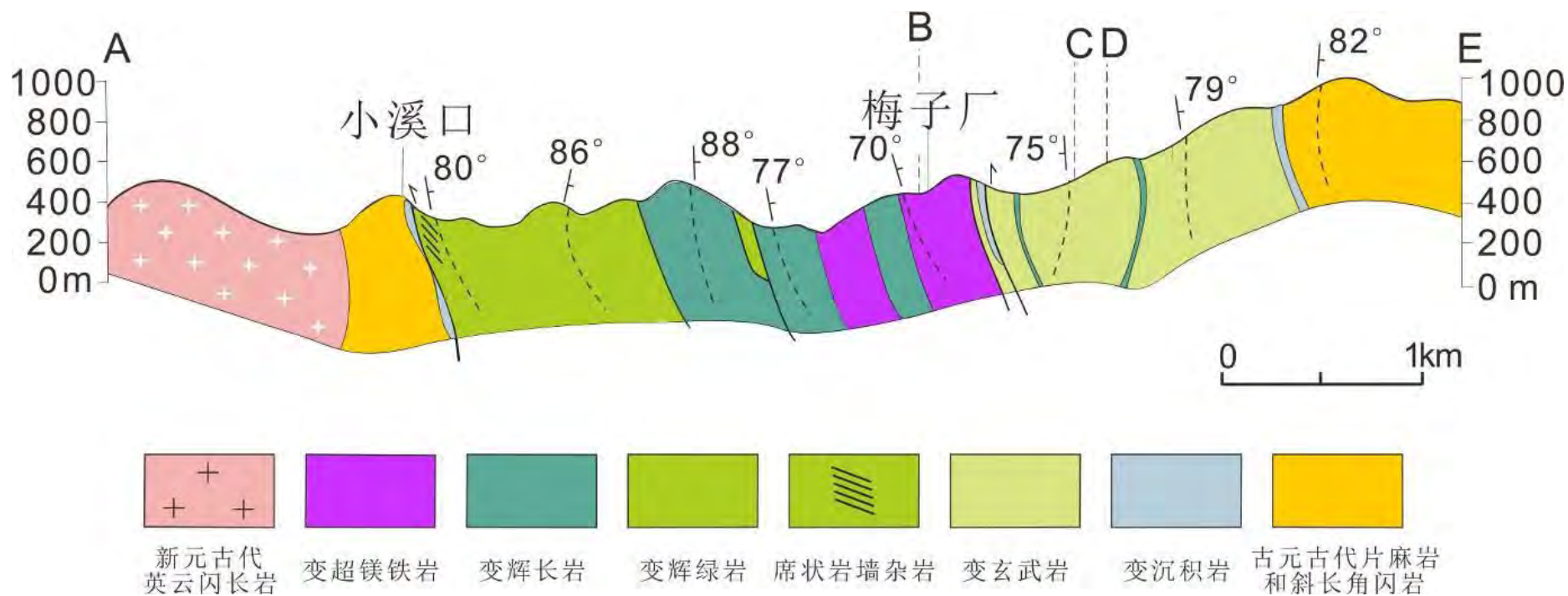
# 庙湾蛇绿杂岩地质特征



图例



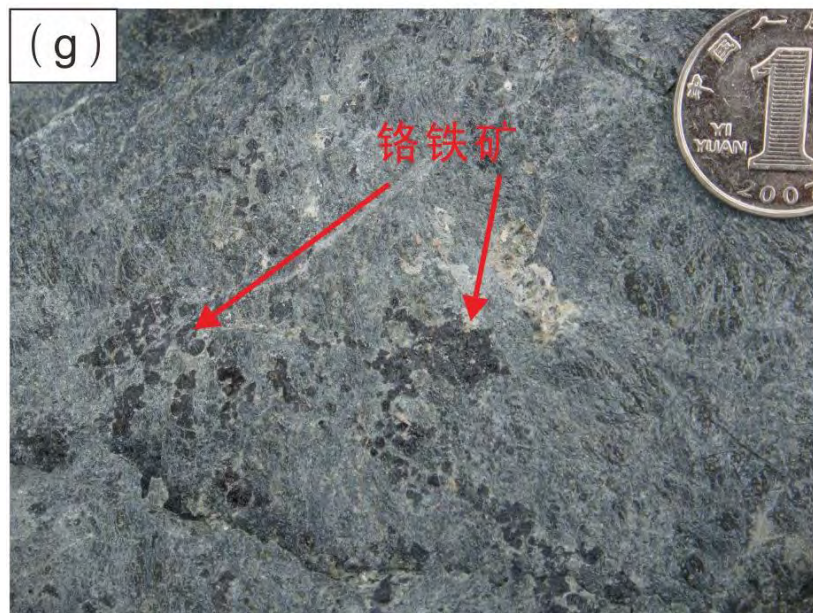
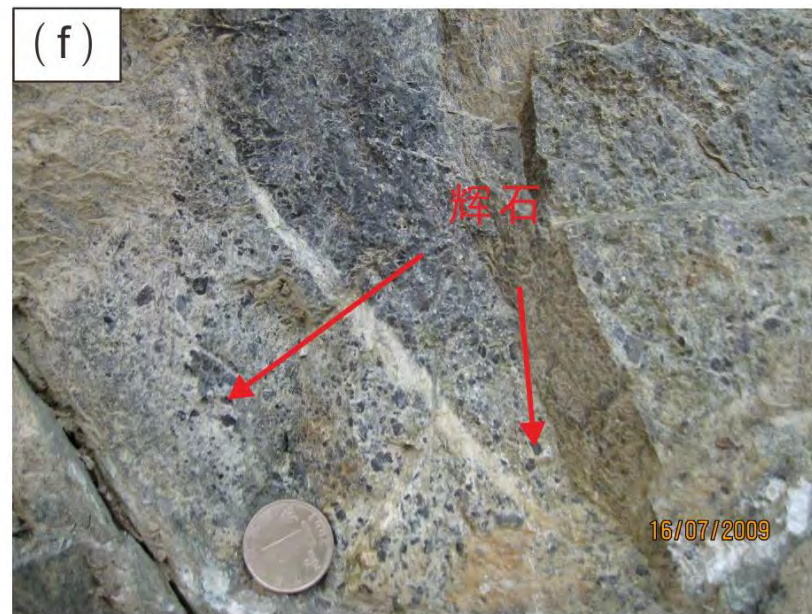
# 庙湾蛇绿杂岩地质特征



# 庙湾蛇纹绿杂岩早期变超镁铁岩地质特征



**a:** 蛇纹石化纯橄岩； **b:** 紧密共生的蛇纹石化纯橄岩、方辉橄榄岩； **c:** 蛇纹石化纯橄岩发育的面理和线理构造； **d:** 破碎带中的蛇纹岩；



**e:** 透镜状蛇纹石化方辉橄榄岩；**f:** 蛇纹石化辉橄榄岩中残留辉石颗粒；  
**g:** 蛇纹石化纯橄岩中的浸染状铬铁矿；**h:** 同心环状铬铁矿；



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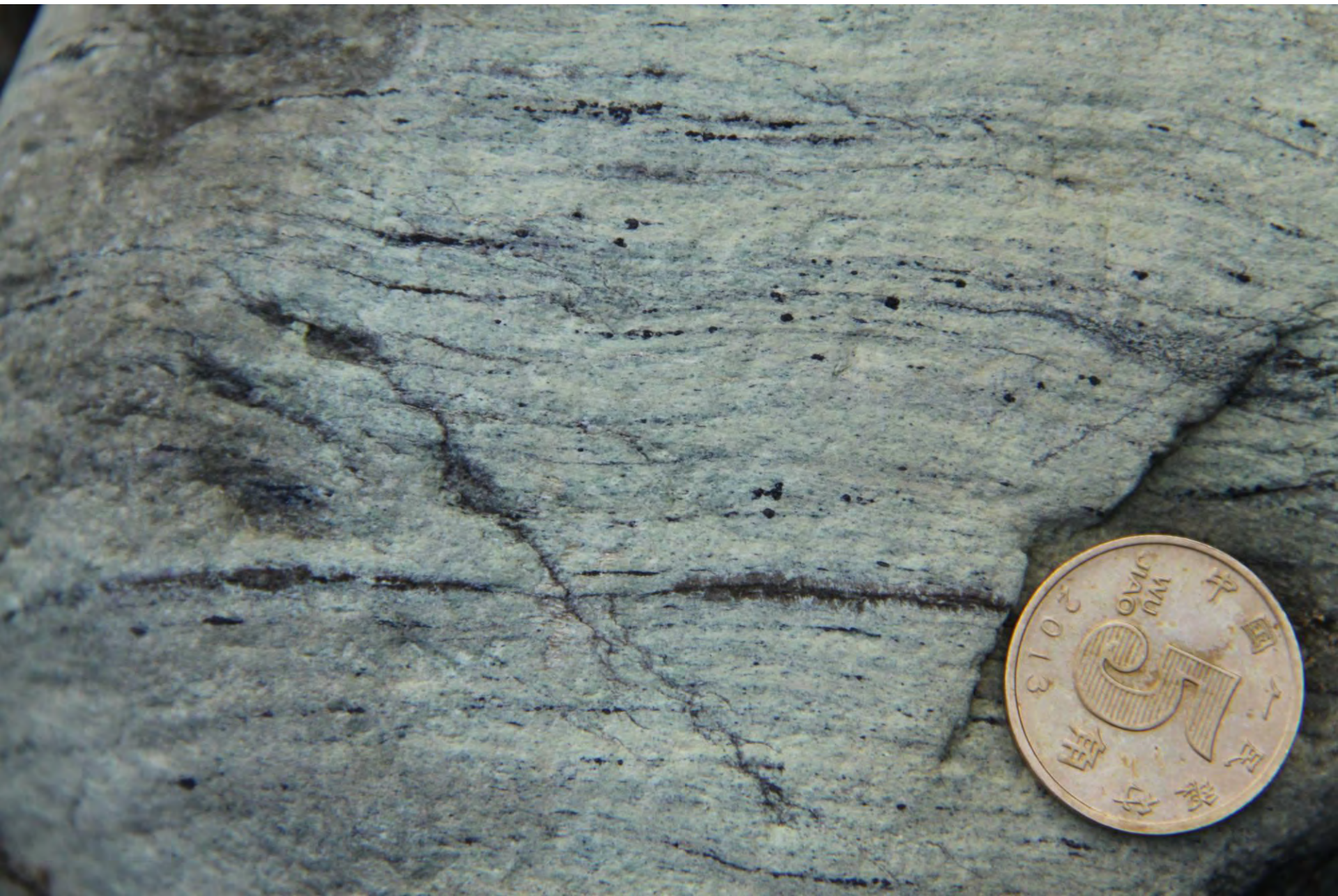






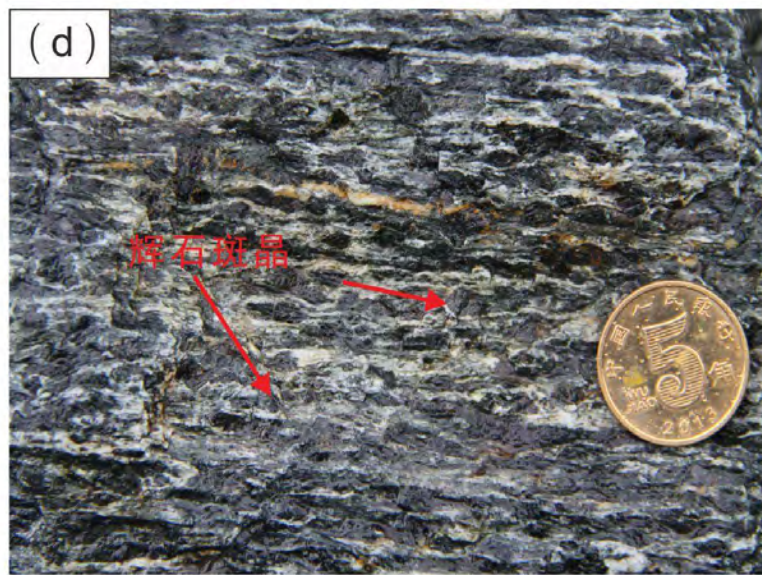








# 庙湾蛇绿杂岩早期变镁铁岩地质特征



a: 强烈面理化的变玄武岩; b: 变玄武质岩中褶皱构造;  
c: 韧性变形辉长岩和变玄武岩呈断层接触; d: 韧性变形辉长岩糜棱构造;



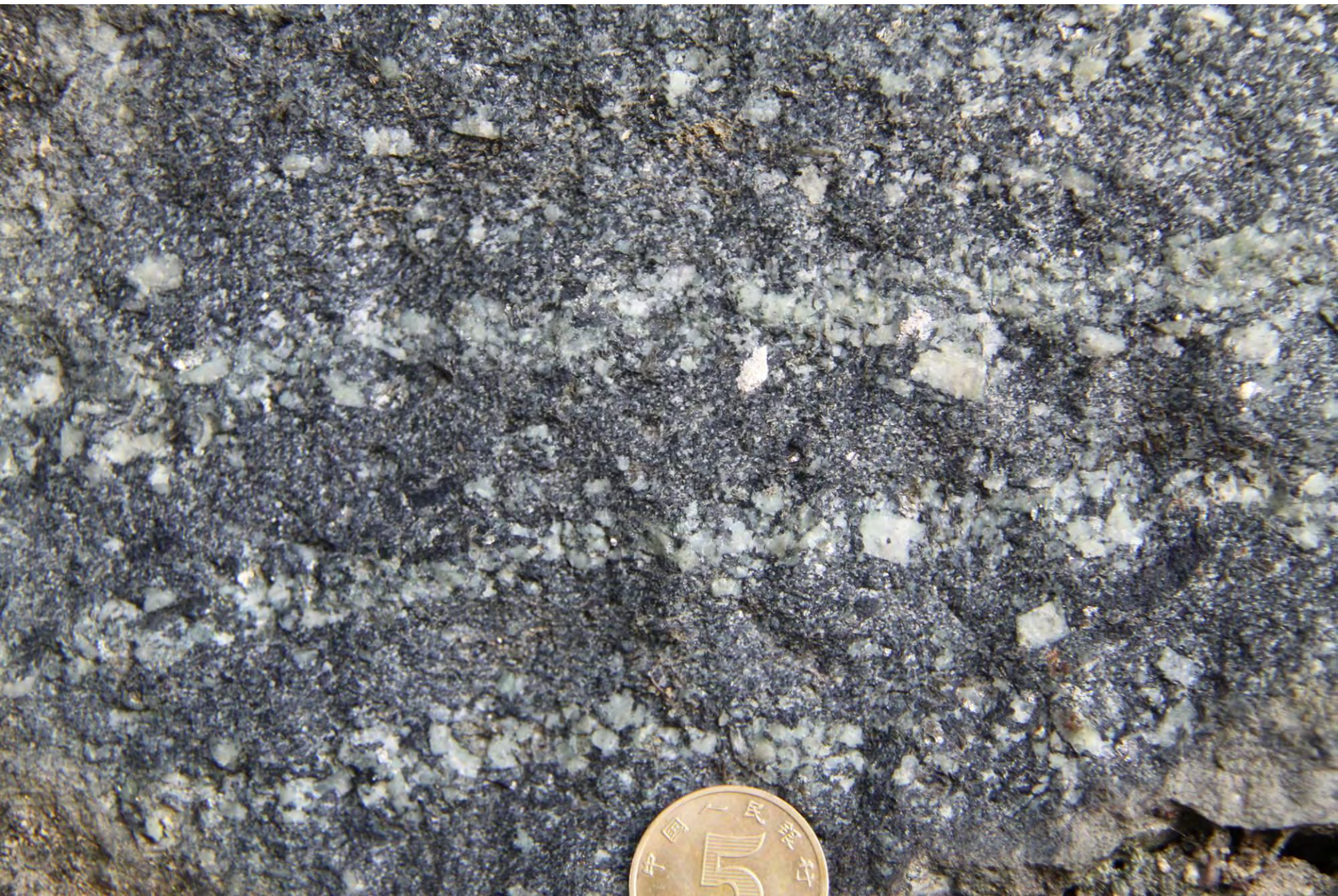
e: 晚期变伟晶辉长岩; f: 晚期块状变辉长岩与变辉绿岩呈相互穿插关系;  
g: 晚期块状变辉绿岩中的变辉长岩包体; h: 块状变辉绿岩





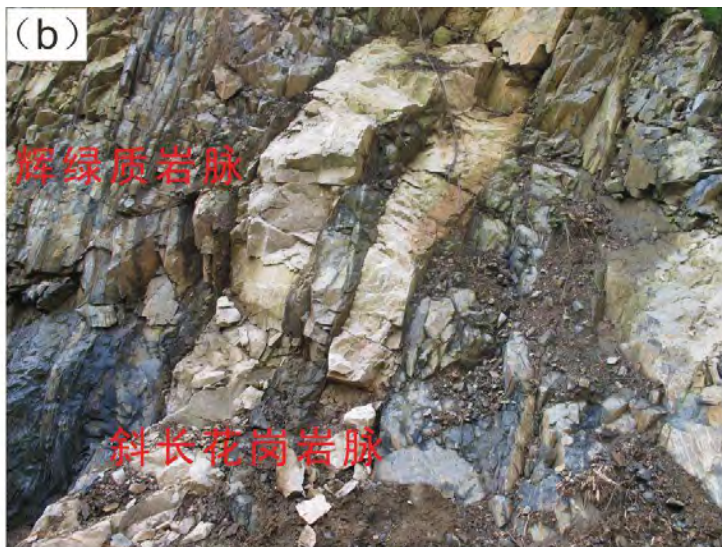




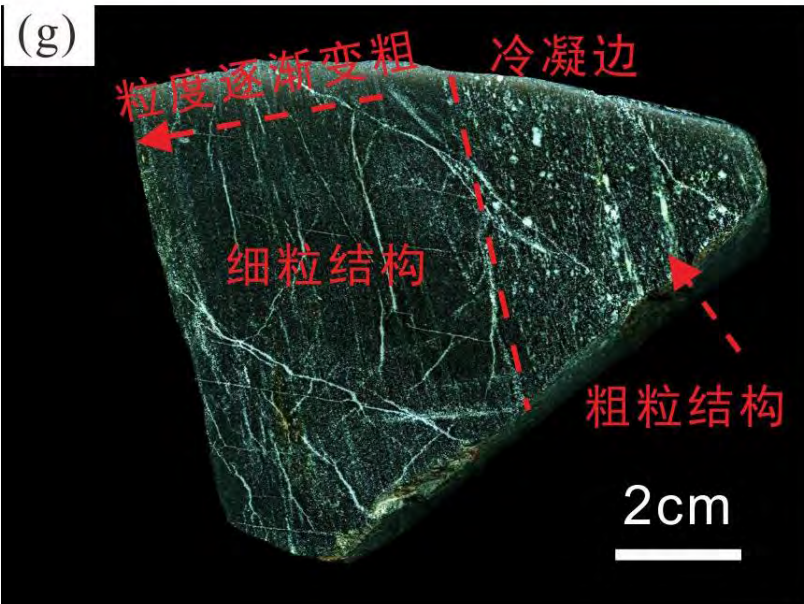
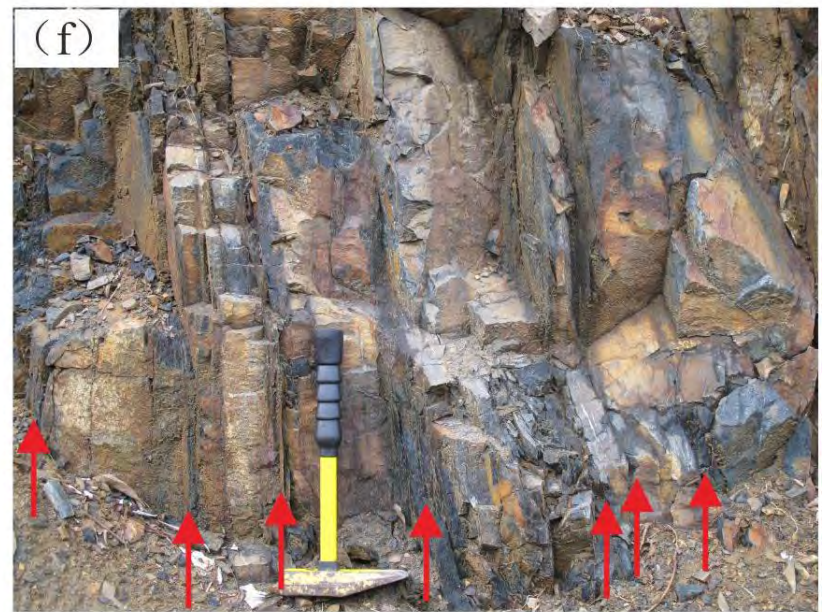




# 庙湾蛇绿杂岩早期辉绿岩席状岩墙地质特征



a: 辉绿岩墙; b: 斜长花岗岩脉穿插辉绿岩脉;  
c: 席状岩墙中的变橄辉岩团块; d: 席状岩墙中的绿帘岩;



e-f: 辉绿岩席状岩墙冷凝边结构;  
g: 席状岩墙冷凝边结构手标本照片; h: 变辉长岩和斜长花岗岩相互侵入关系

















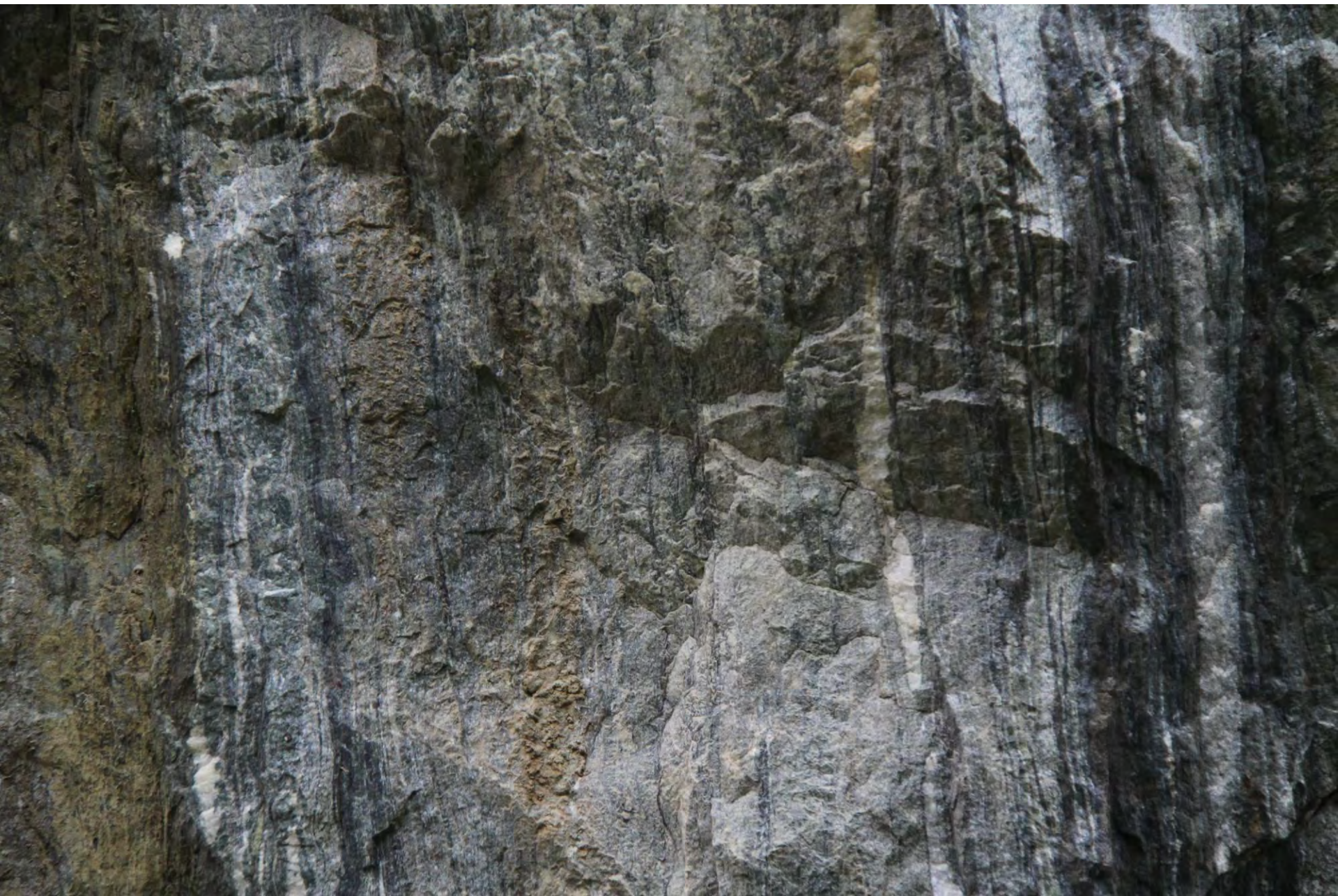
# 庙湾蛇绿杂岩变泥质-灰质-硅质沉积岩系地质特征



- a: 条带-条纹状石英岩-大理岩互层（原岩硅质岩-泥质灰岩）； b: 条带-条纹状石英岩；  
c: 条带-条纹状大理岩； d: 条带-条纹状大理岩和石英岩渐变接触关系手标本









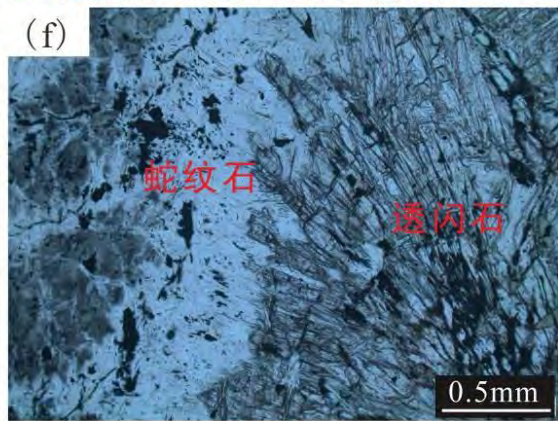
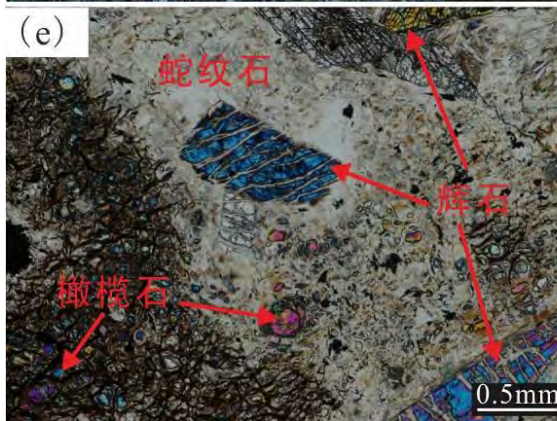
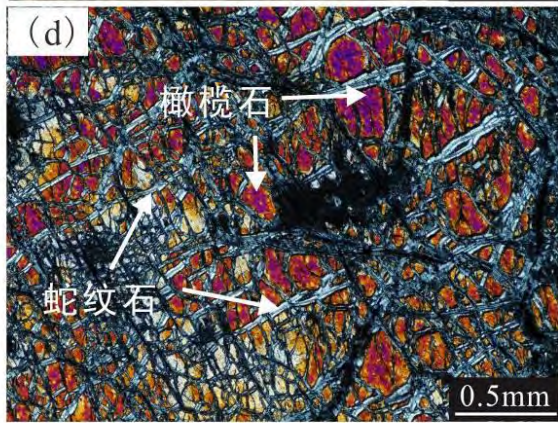
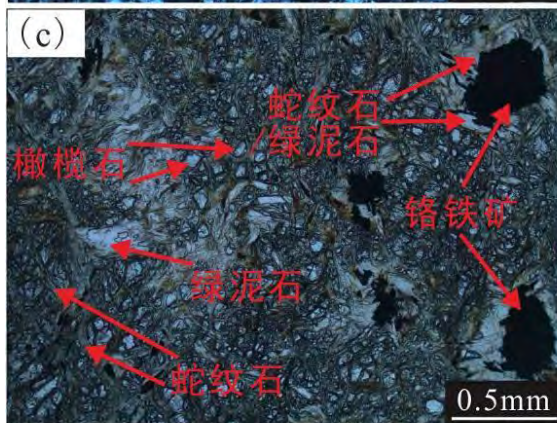
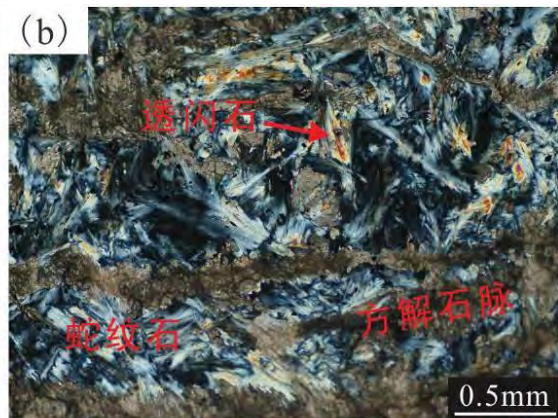
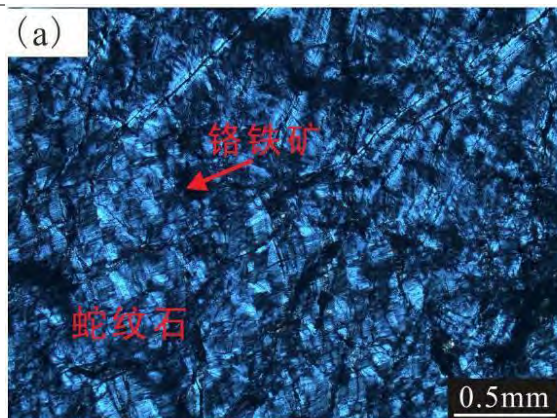






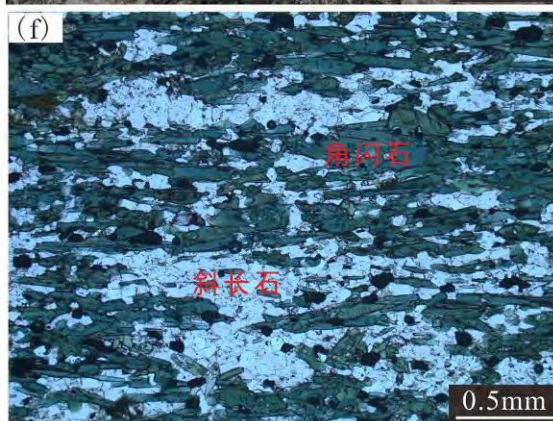
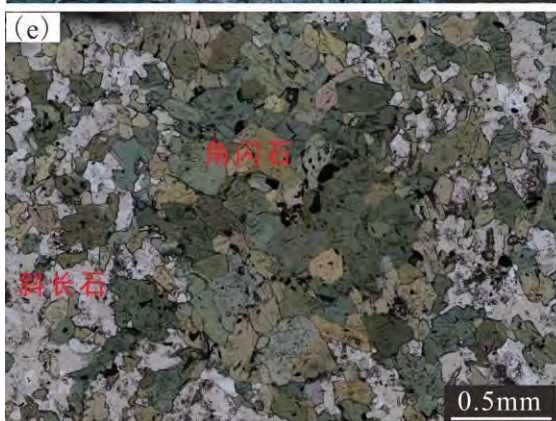
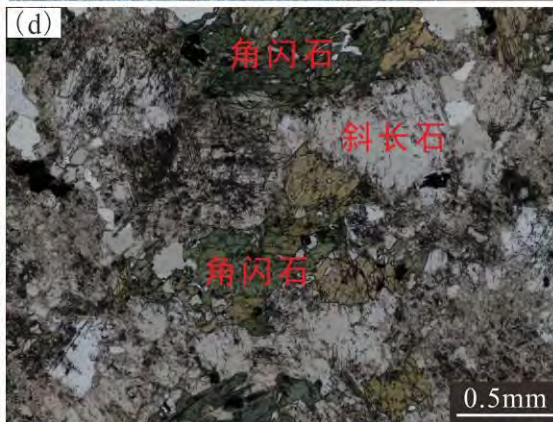
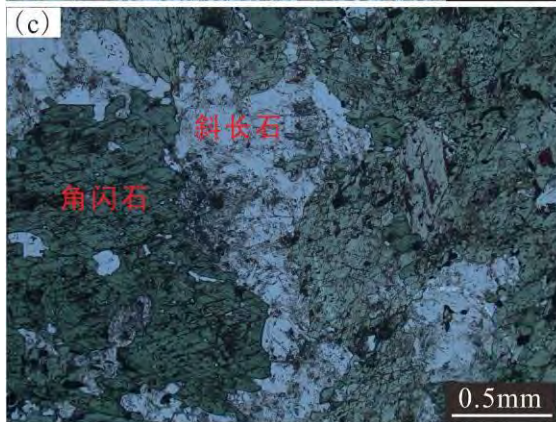
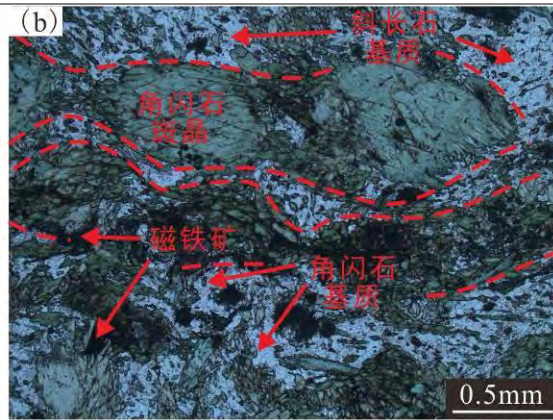
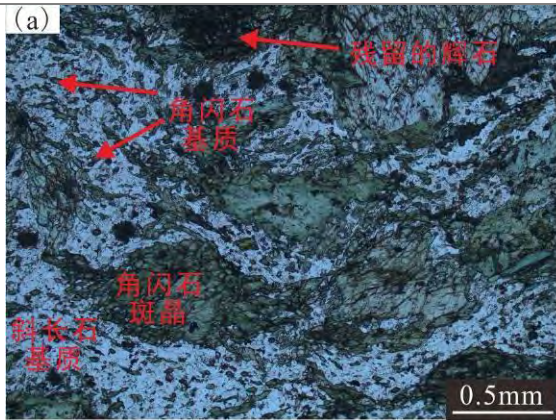


# 庙湾蛇绿杂岩早期蛇纹石化橄榄岩岩相学特征



- a: 含铬铁矿蛇纹岩;
- b: 含方解石脉蛇纹岩;
- c: 含铬铁矿蛇纹石化纯橄岩;
- d: 蛇纹石化纯橄岩;
- e: 蛇纹石化方辉橄榄岩;
- f: 透闪石蛇纹岩 (原岩为方辉橄榄岩)

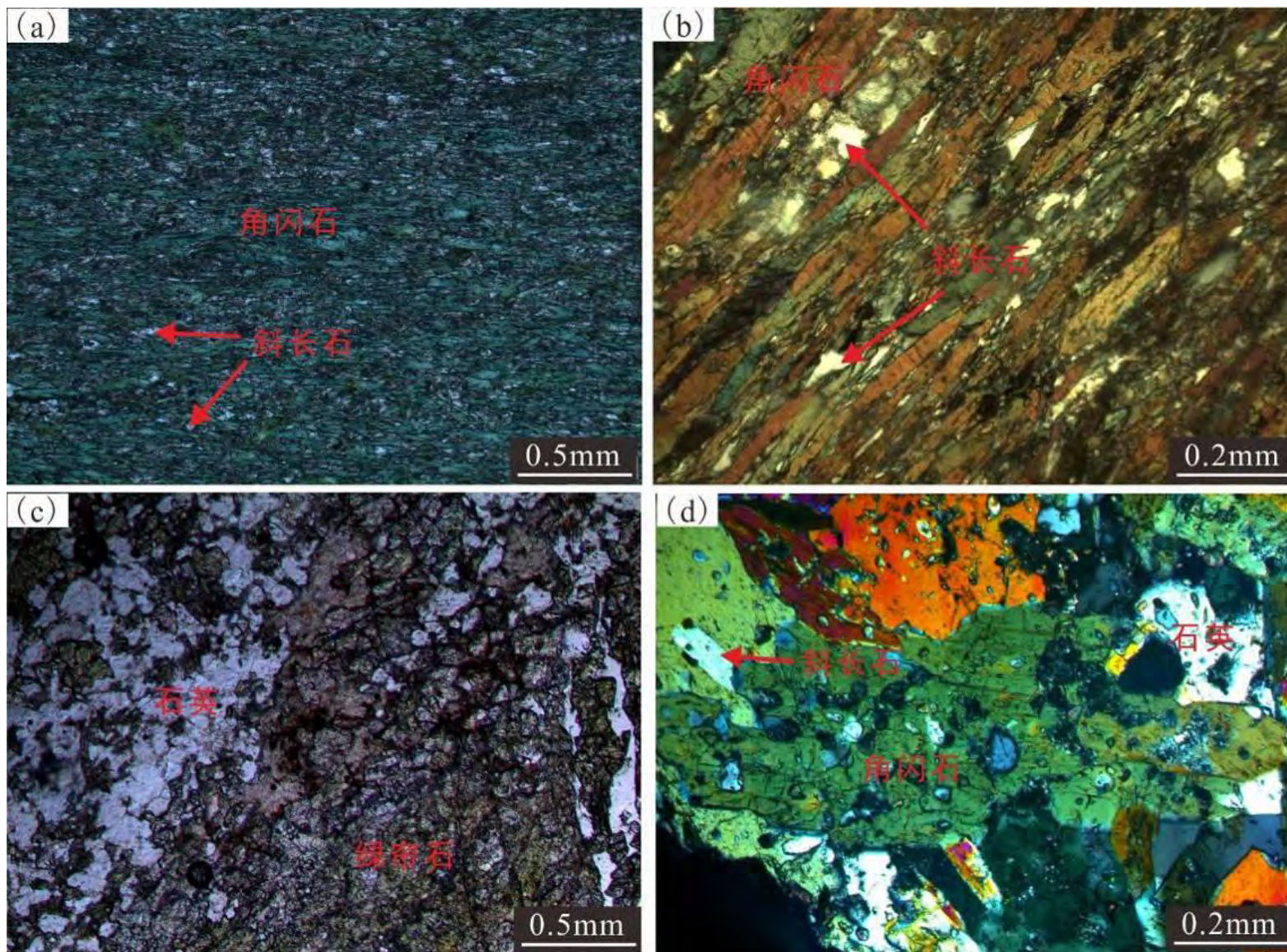
# 庙湾蛇绿杂早期强变形变质辉长-辉绿岩岩相学特征



- a: 韧性变形变质辉长;
- b: 韧性变形变质辉长岩糜棱结构;
- c: 伟晶变辉长岩;
- d: 块状变辉长岩;
- e: 块状变辉绿岩;
- f: 席状岩墙中辉绿岩脉

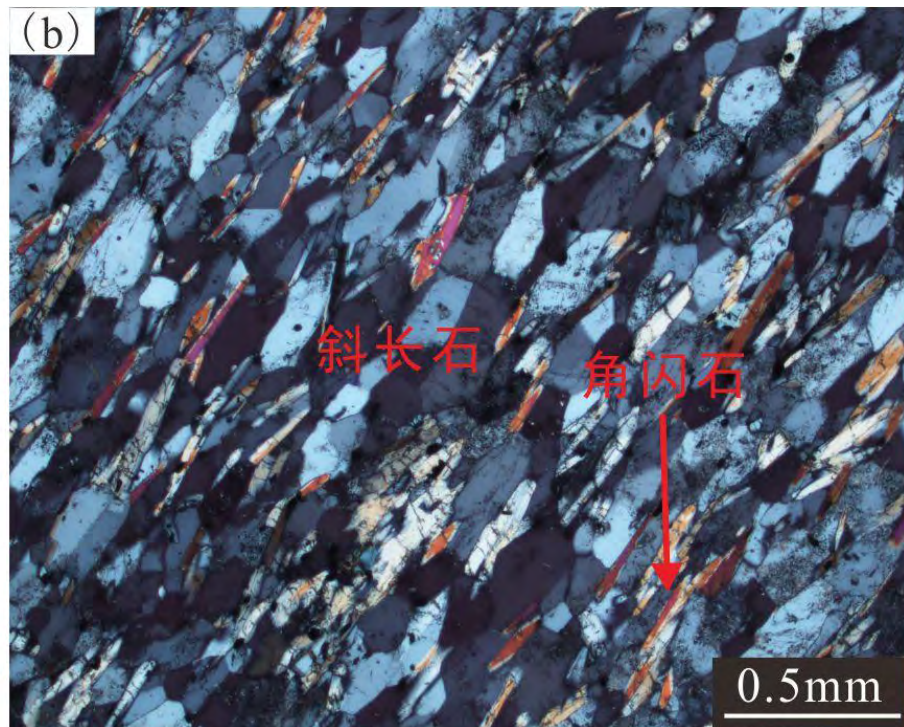
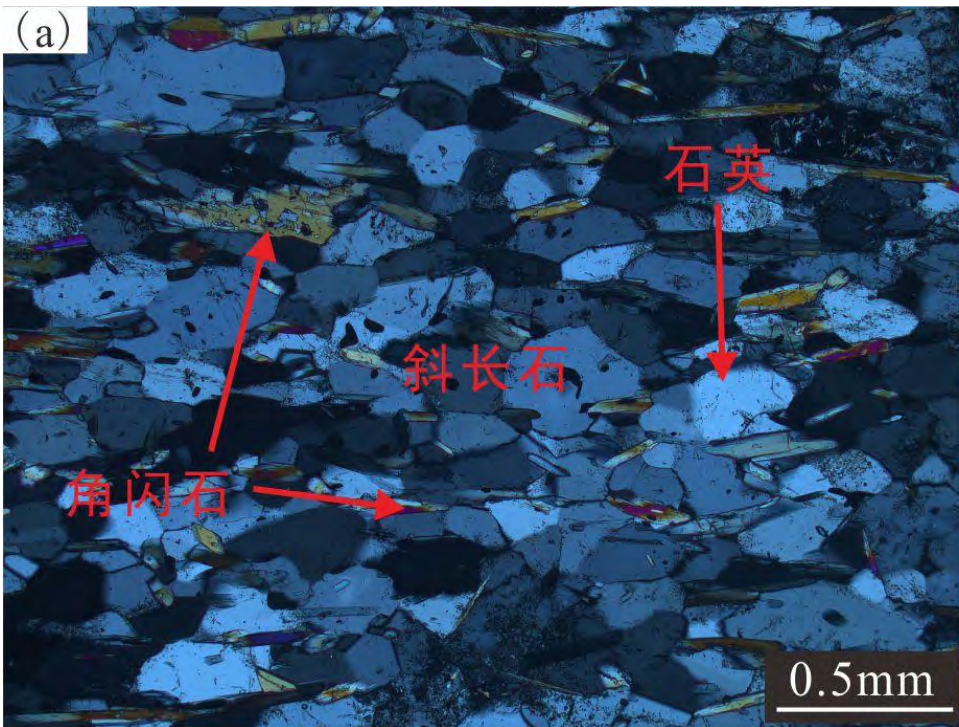


# 庙湾蛇绿杂岩早期变玄武岩岩相学特征



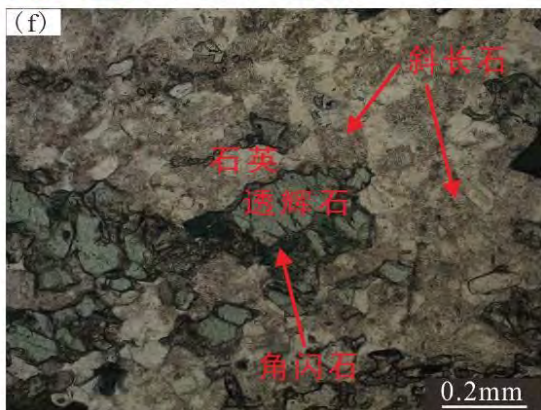
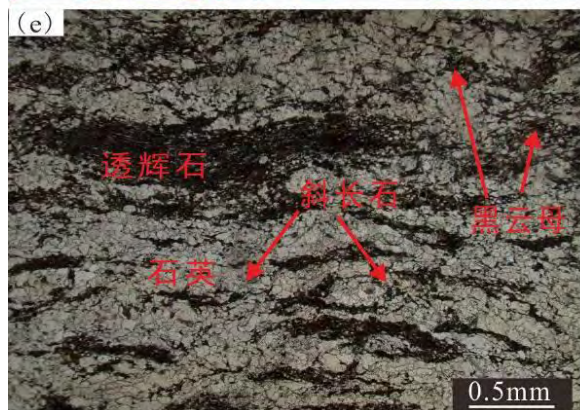
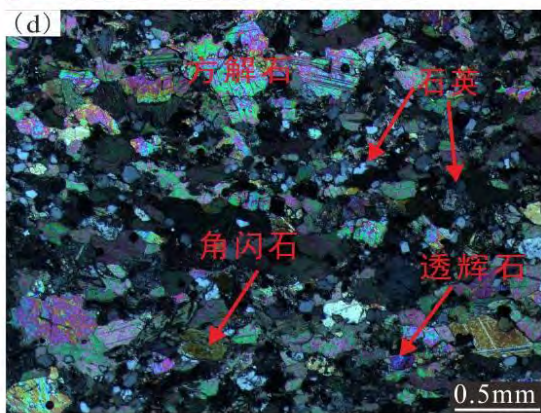
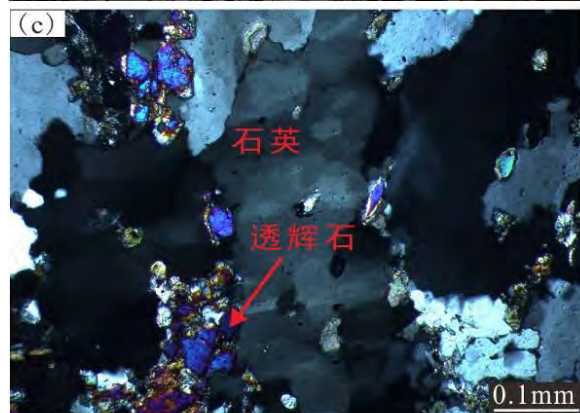
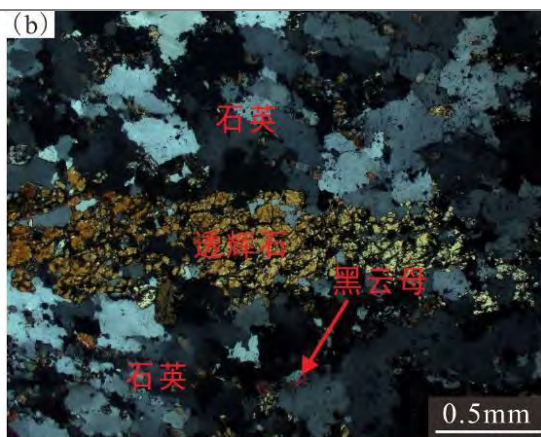
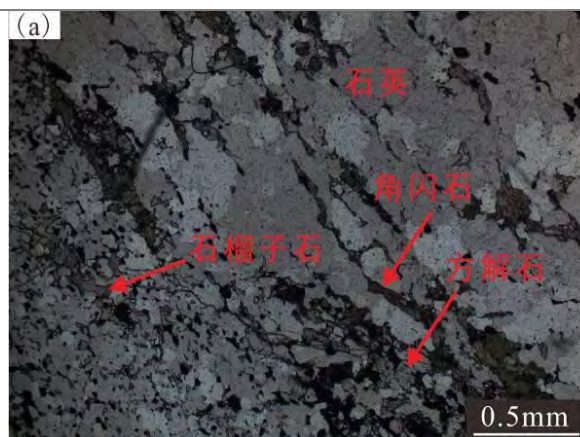
a-b: 细粒斜长角闪岩 (变玄武岩) ; c-d: 绿帘岩

# 庙湾蛇绿杂岩晚期变斜长花岗岩岩相学特征



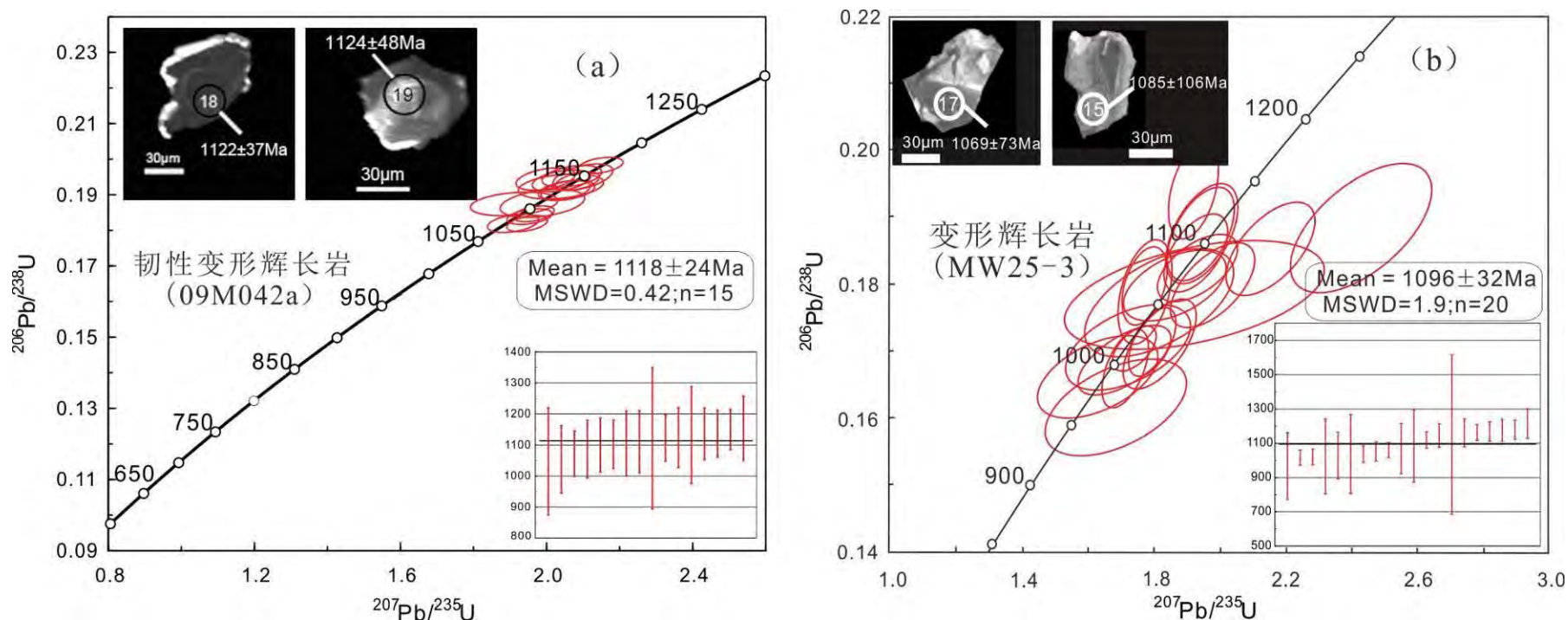
a-b: 变斜长花岗岩

# 庙湾蛇绿杂岩变沉积岩岩相学特征



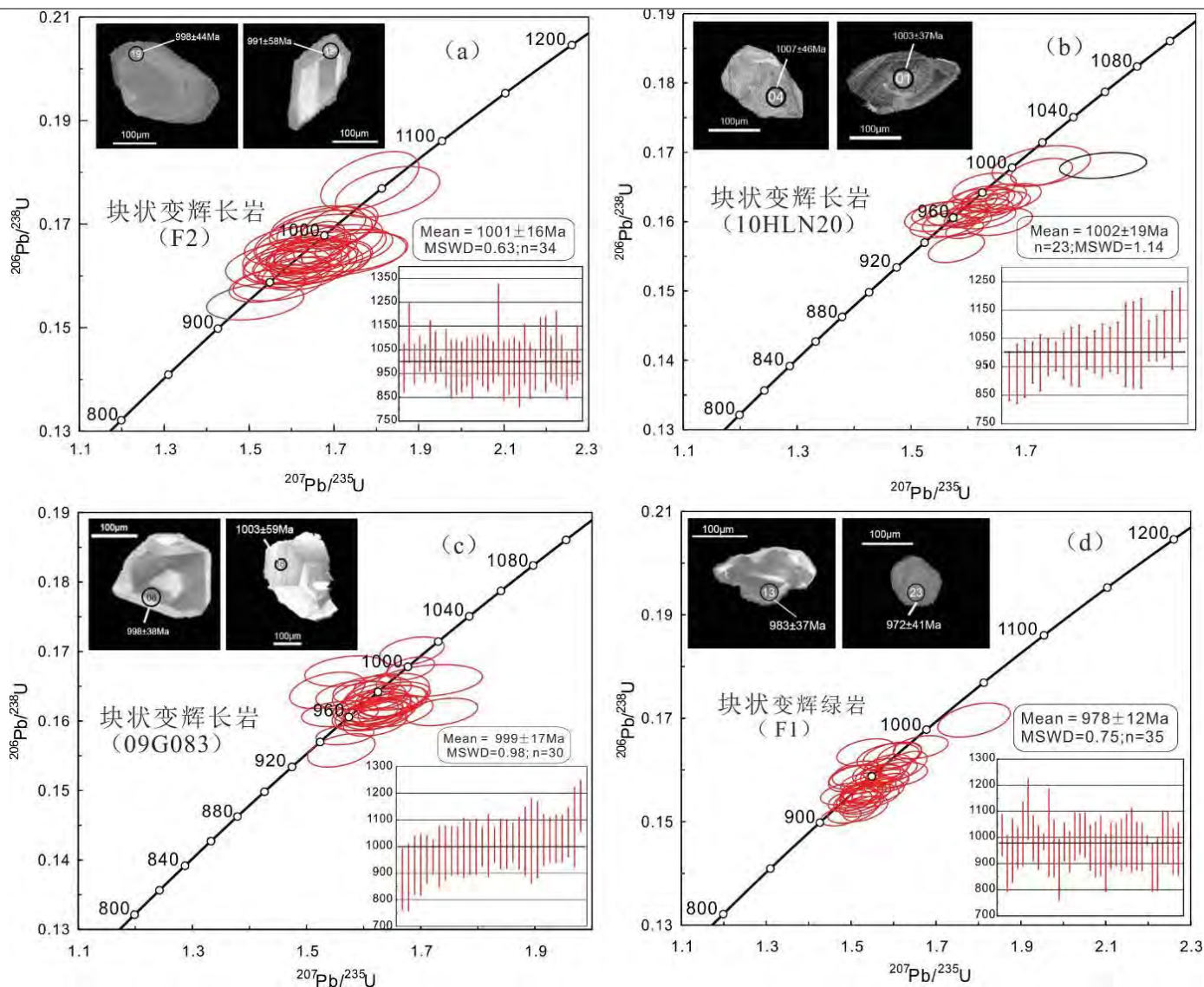
- a: 条带-条纹状石英岩;
- b: 条带-条纹状石英岩中透辉石、黑云母条纹和石英条带中的锯齿状构造;
- c: 条带-条纹状石英岩中的石英波状消光;
- d: 条带-条纹状大理;
- e: 条带状变质杂砂岩;
- f: 条带状变质砂岩中透辉石退变质为角闪石

# 庙湾蛇绿杂岩早期强变形变质辉长岩年代学特征



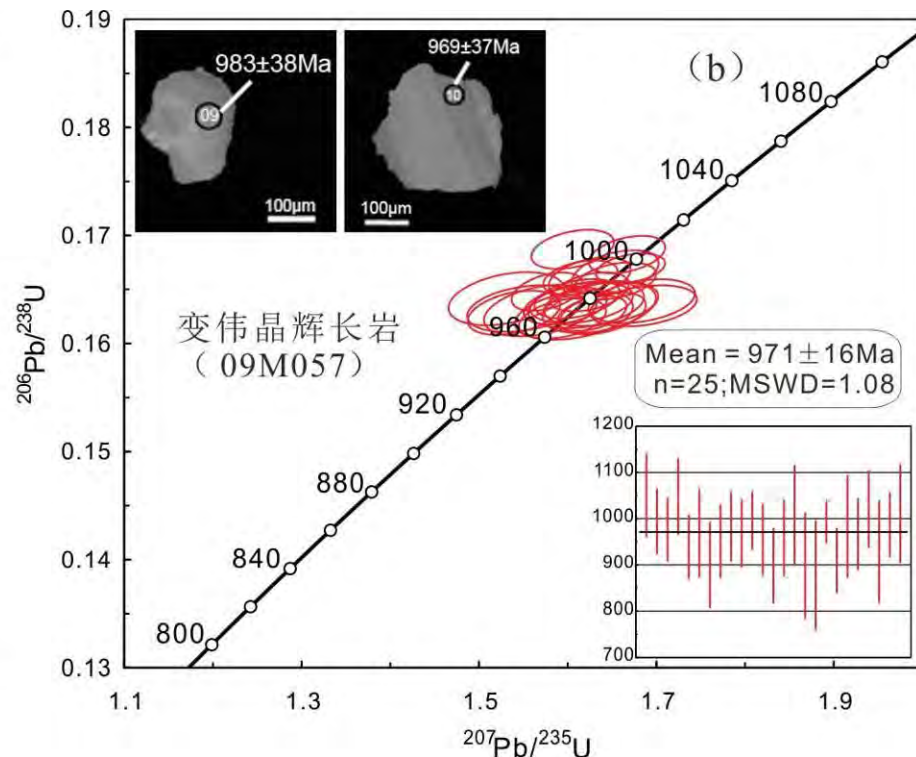
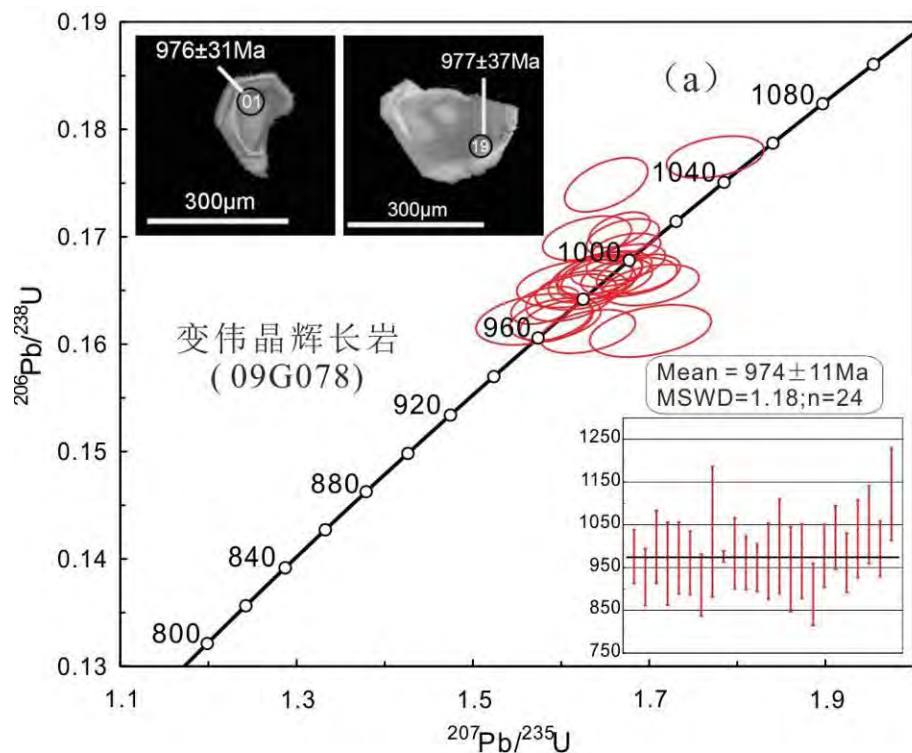
a-b: 庙湾蛇绿杂岩早期韧性变形辉长岩典型锆石的CL图像和U-Pb谐和图

# 庙湾蛇绿杂岩晚期变辉长岩-辉绿岩年代学特征



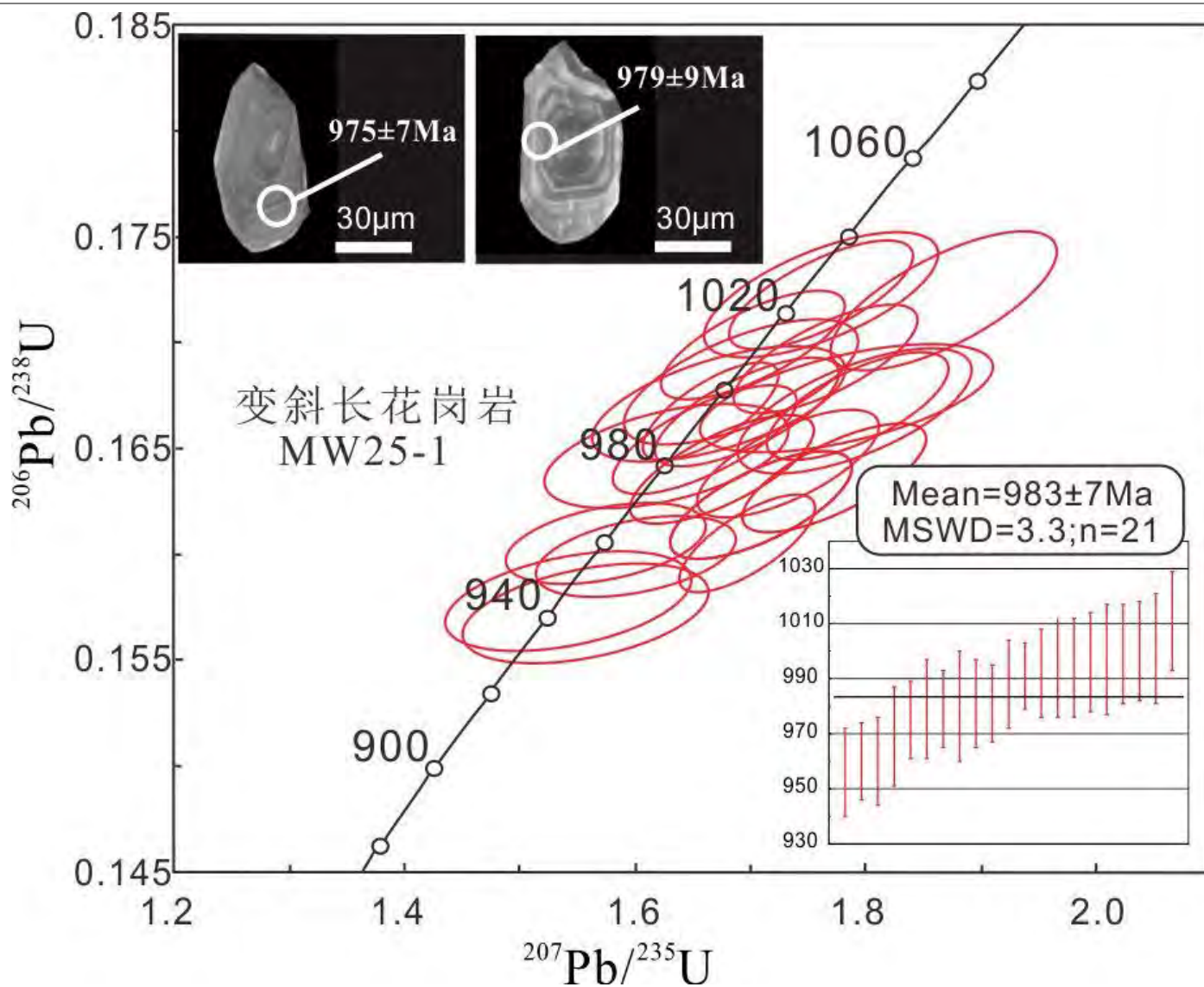
庙湾蛇绿杂岩晚期弱变形块状变辉长岩 (a, b, c) 和变辉绿岩 (d) 中典型锆石的CL图像和U-Pb谐和图

# 庙湾蛇绿杂岩晚期变辉长岩年代学特征



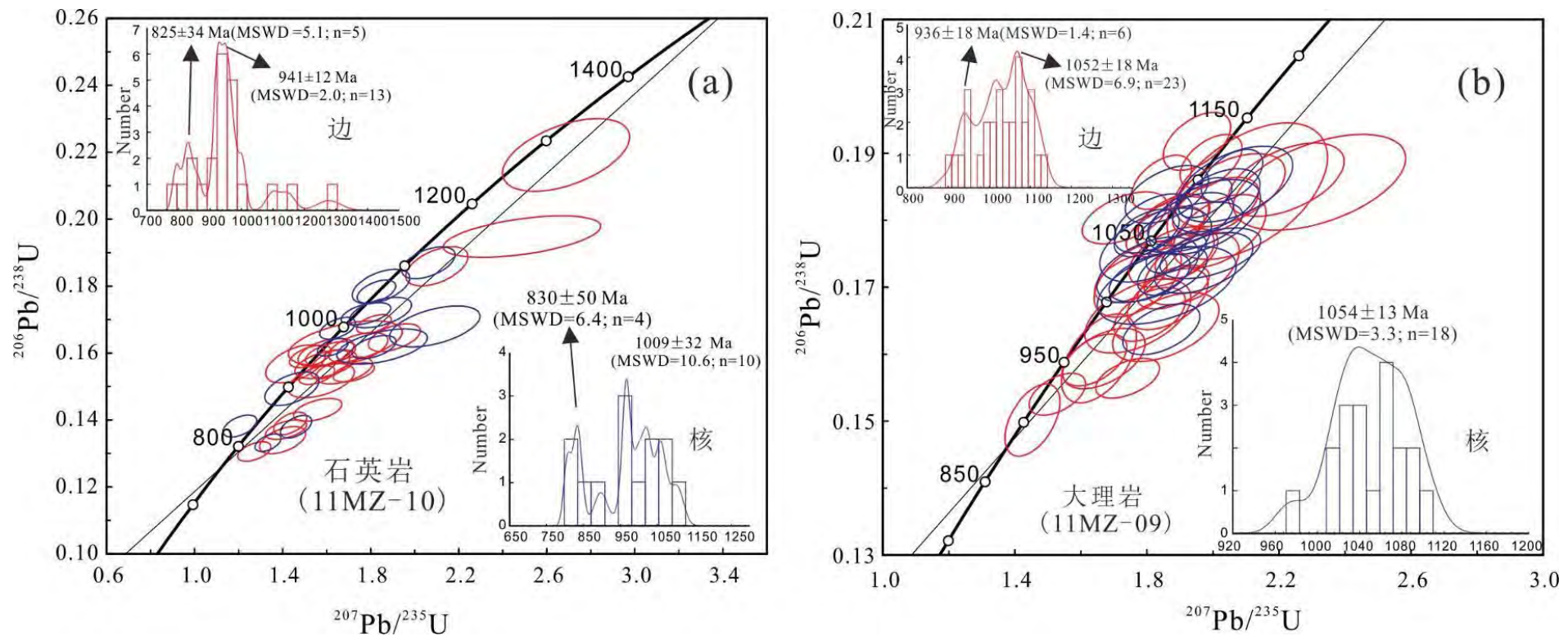
庙湾蛇绿杂岩晚期变伟晶辉长岩 (a, b) 中典型锆石的CL图像和U-Pb谐和图

# 庙湾蛇绿杂岩晚期斜长花岗岩年代学特征



庙湾蛇绿杂岩晚期弱变形斜长花岗岩脉锆石的CL图像和U-Pb谐和图

# 庙湾蛇绿杂岩变沉积岩年代学特征

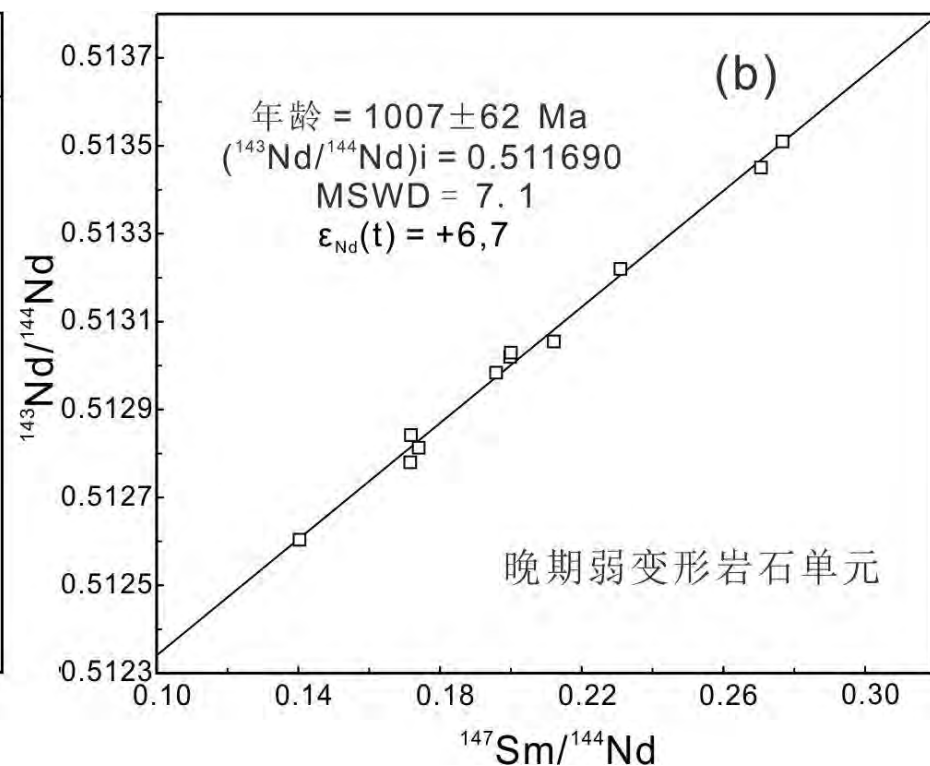
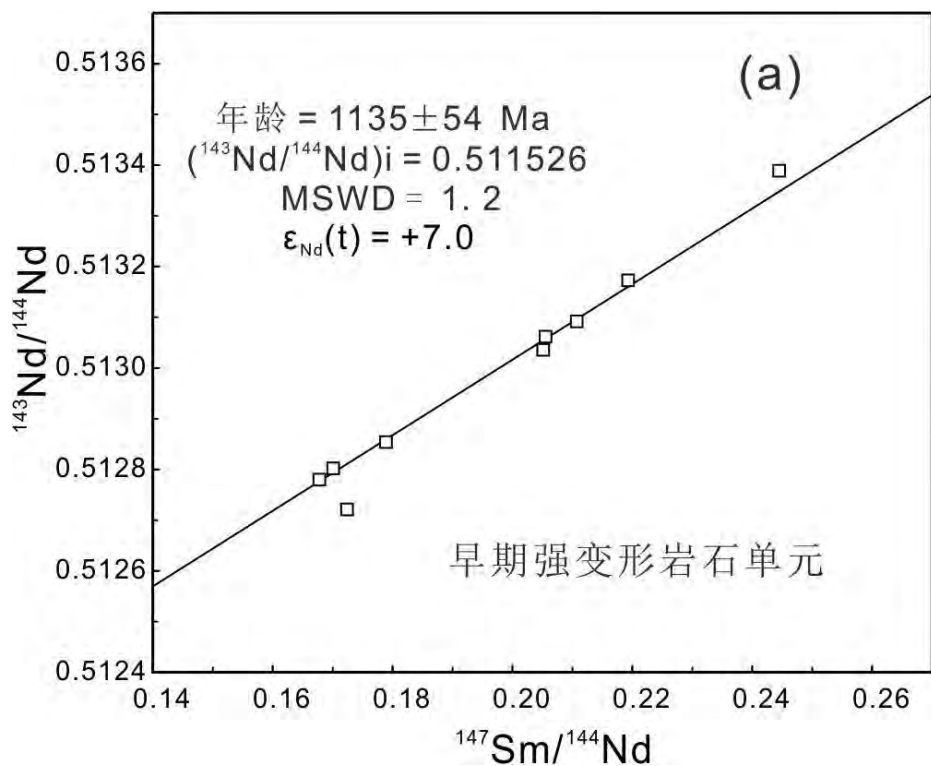


庙湾蛇绿杂岩变沉积岩中碎屑锆石U-Pb谐和图

a: 条带状石英岩; b: 条带状大理岩



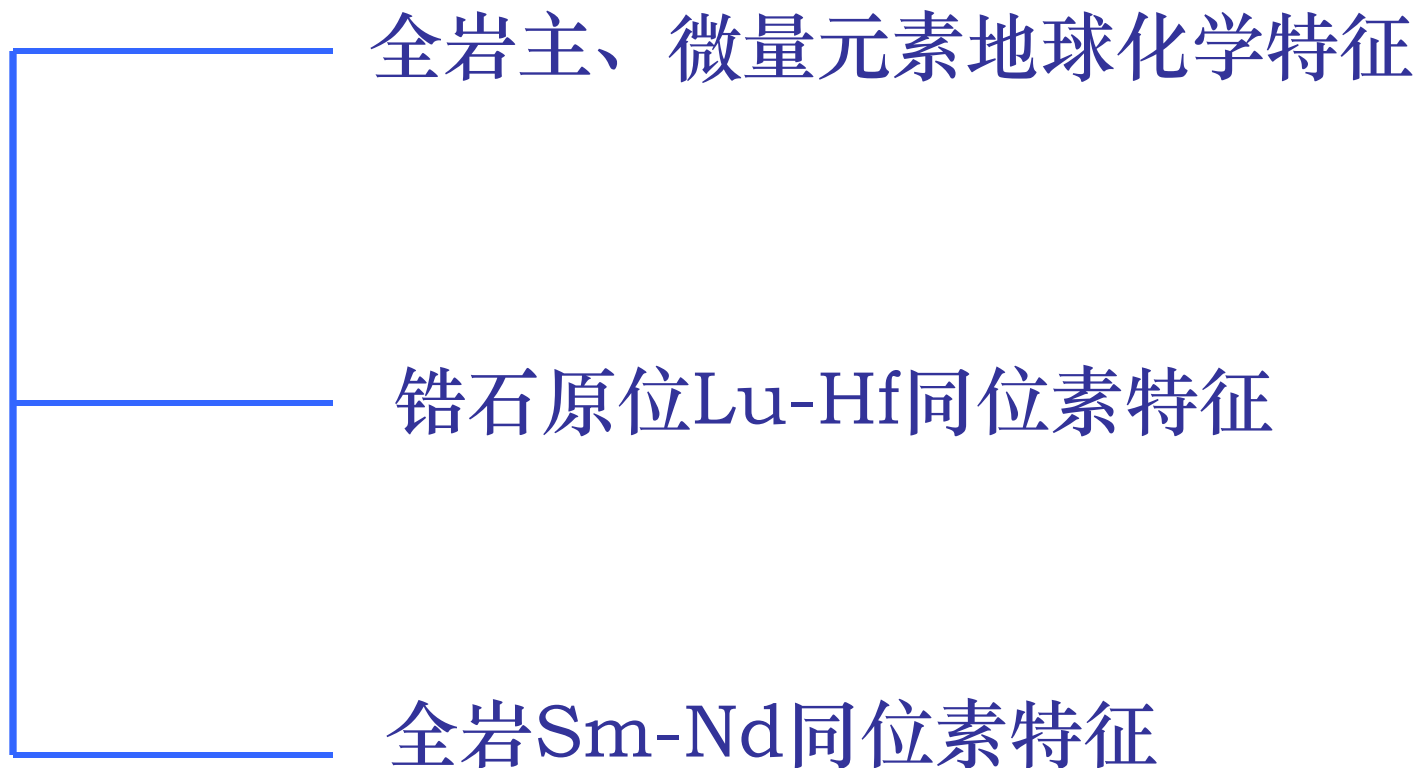
# 庙湾蛇绿杂岩早期和晚期变基性-超基性岩 年代学特征



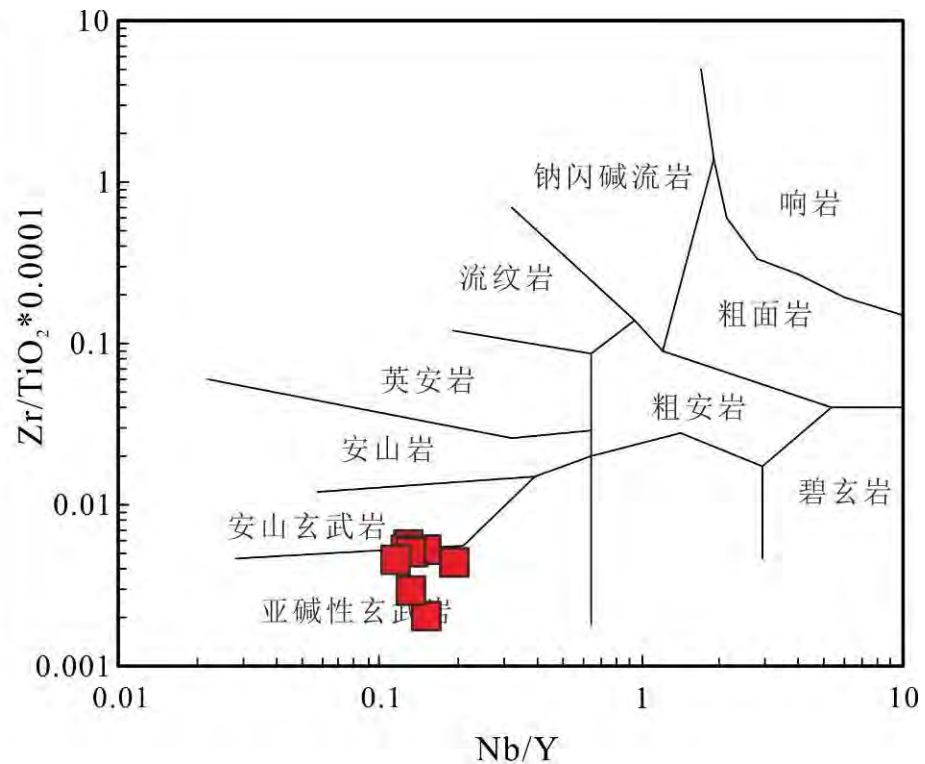
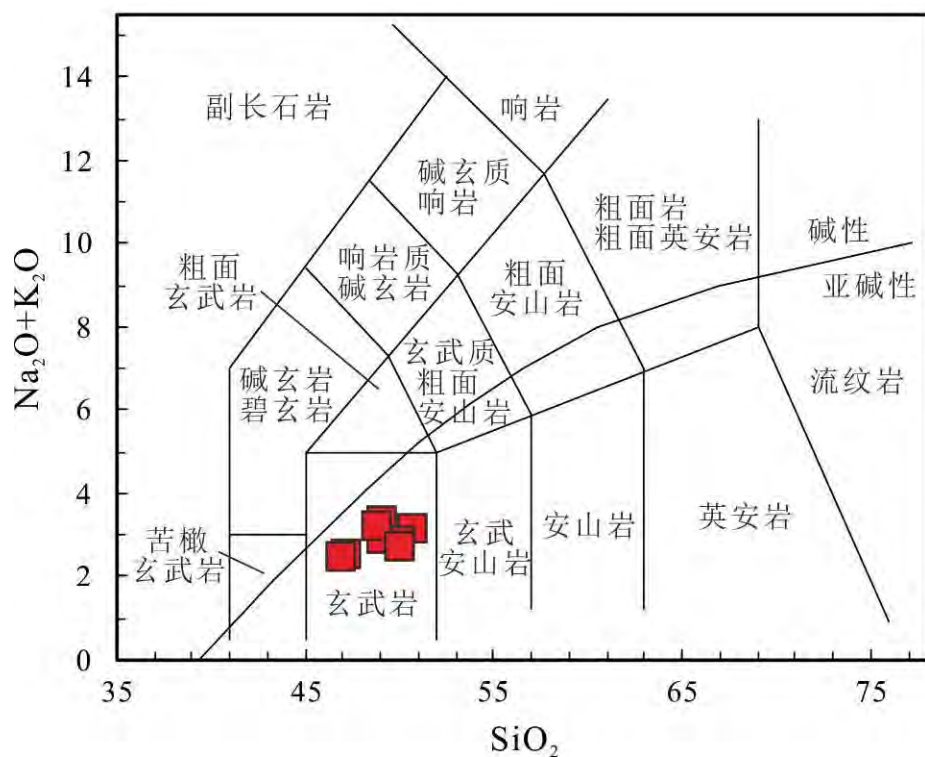
## 庙湾蛇绿杂岩全岩Sm-Nd等时线年龄图

- a: 早期强变形岩石单元 (蛇纹石化纯橄岩和方辉橄橄榄岩、变玄武岩、韧性变形辉长岩)  
b: 晚期弱变形岩石单元 (块状变辉绿岩、块状和伟晶变辉长岩)

# 庙湾蛇绿杂岩地球化学及源区特征



# 庙湾蛇绿杂岩主、微量地球化学特征

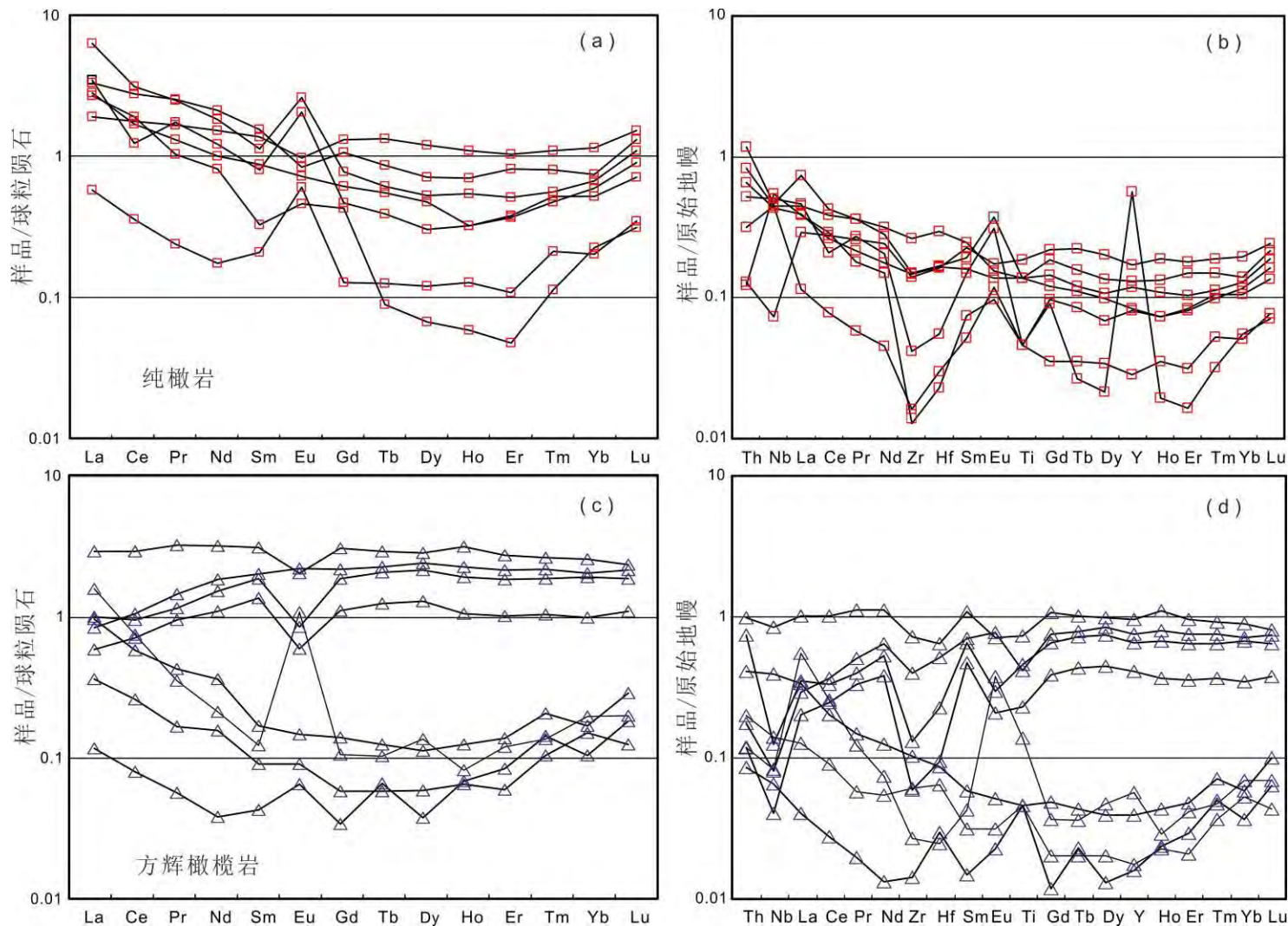


## 庙湾蛇绿杂岩早期变玄武岩岩石化学分类图解

a: TAS ( $\text{SiO}_2\text{-Na}_2\text{O+K}_2\text{O}$ ) (据Winchester and Floyd, 1977) ;

b: Nb/Y-Zr/TiO<sub>2</sub> (据Le Bas et al., 1986)

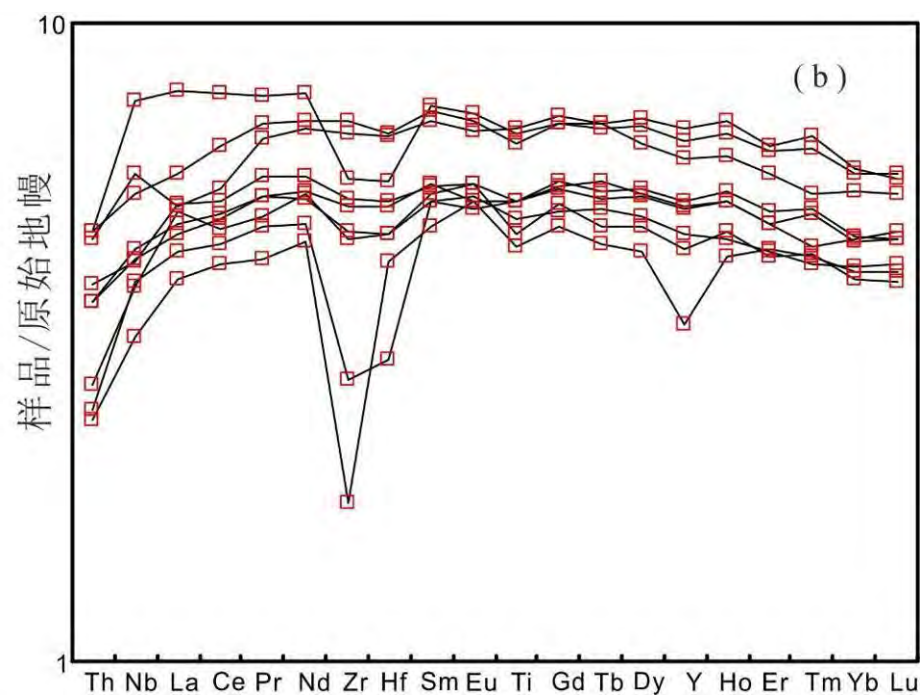
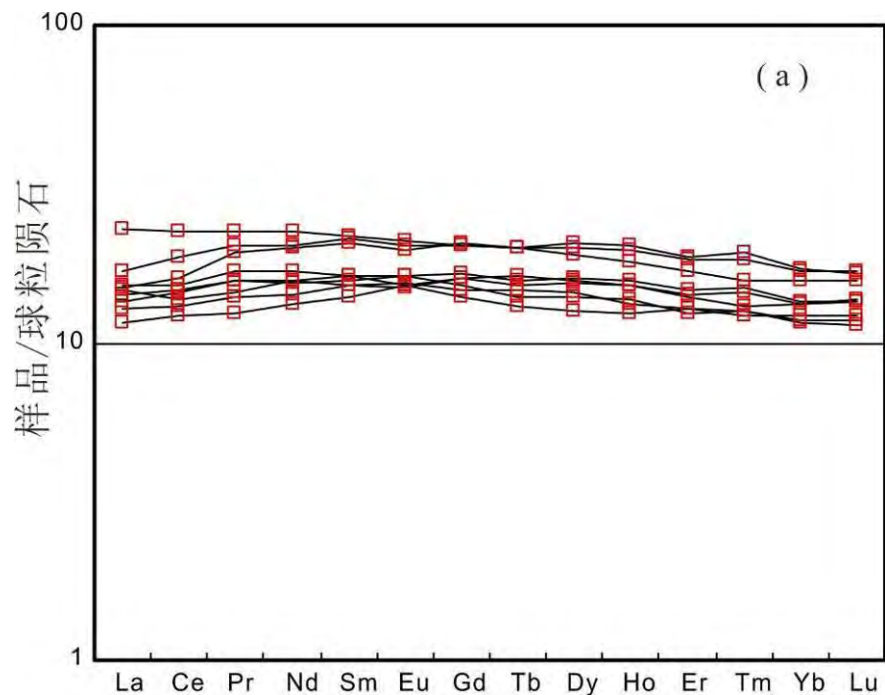
# 庙湾蛇绿杂岩主、微量地球化学特征



庙湾蛇绿杂岩早期变超镁铁岩稀土配分图和微量元素蛛网图

a-b: 纯橄岩 (红色方框) ; c-d: 方辉橄榄岩、辉橄岩 (蓝色三角)

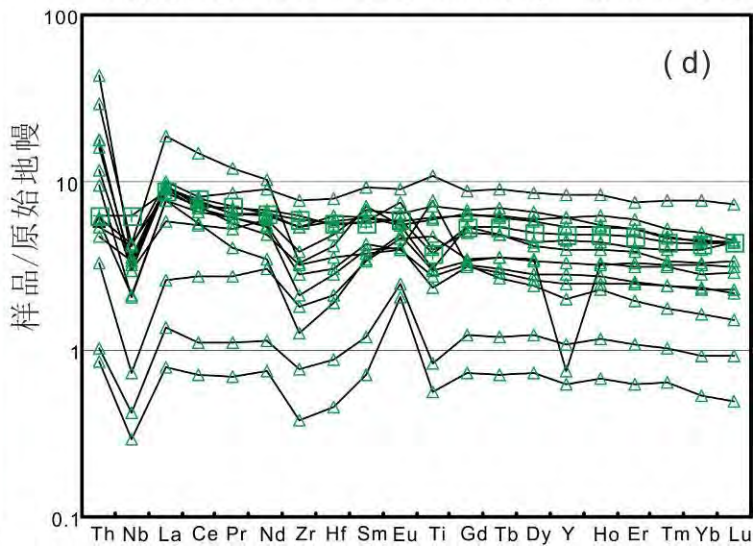
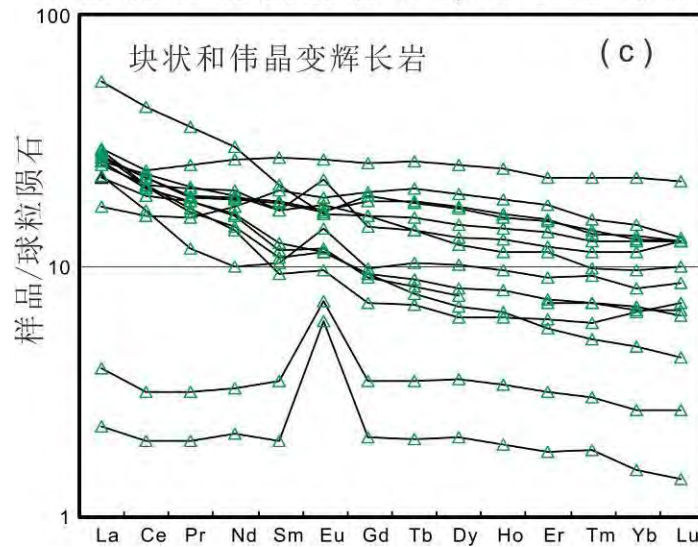
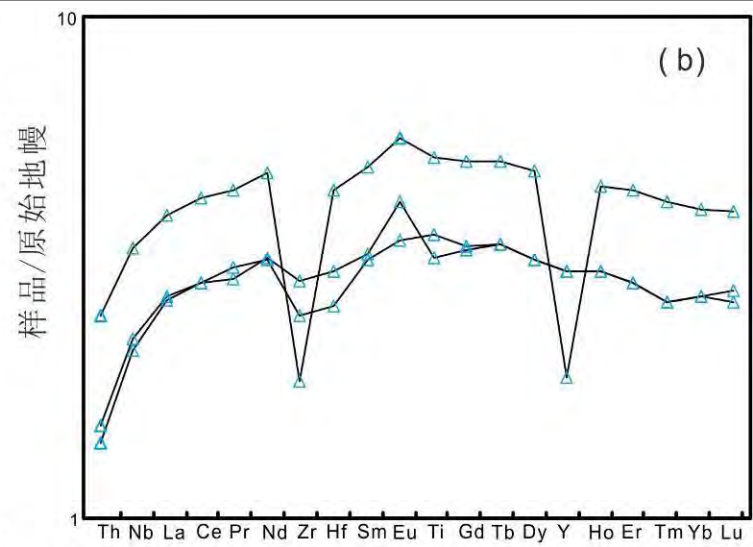
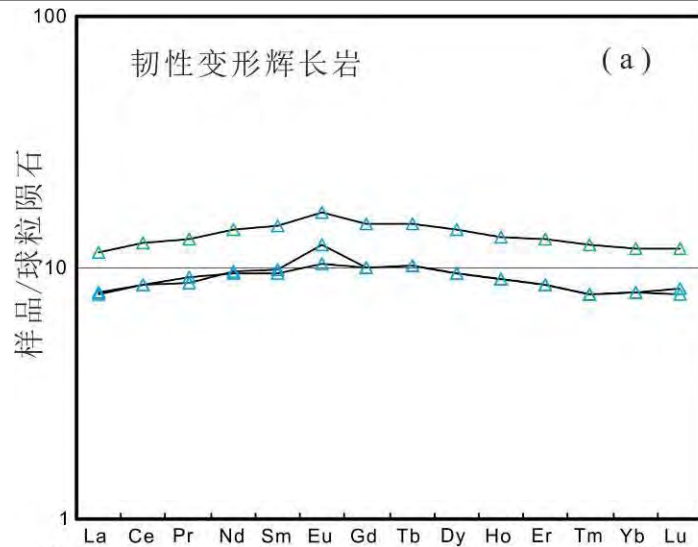
# 庙湾蛇绿杂岩主、微量地球化学特征



## 庙湾蛇绿杂岩早期变玄武岩

(a) 稀土元素配分图和 (b) 微量元素蛛网图

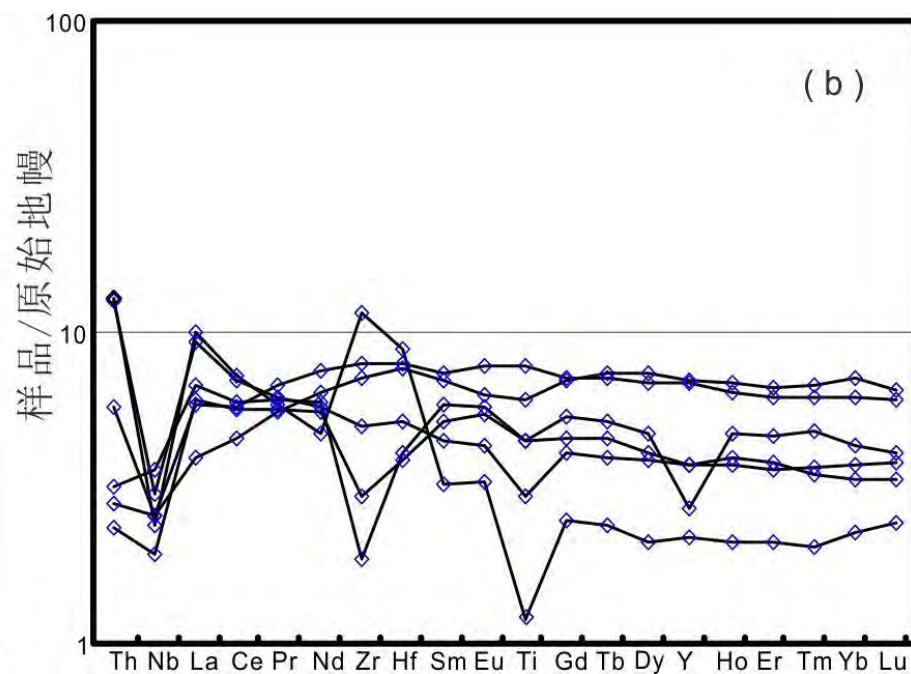
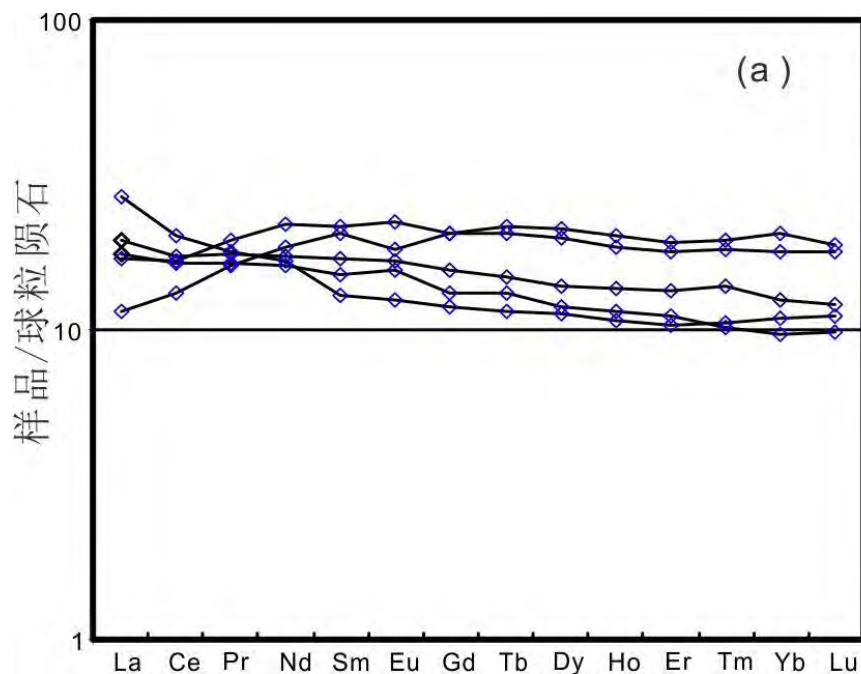
# 庙湾蛇绿杂岩主、微量地球化学特征



庙湾蛇绿杂岩变辉长岩稀土元素配分图和微量元素蛛网图

a-b: 早期韧性变形辉长岩 (浅蓝色三角) ; c-d: 晚期块状和伟晶变辉长岩 (绿色三角)

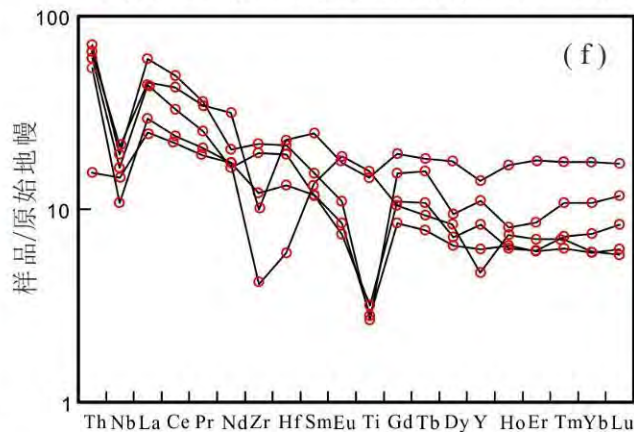
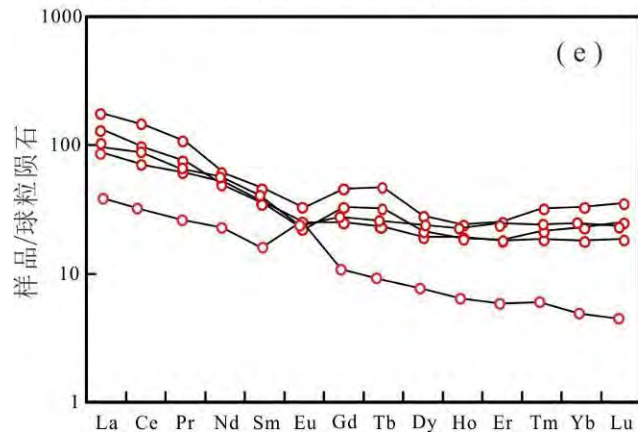
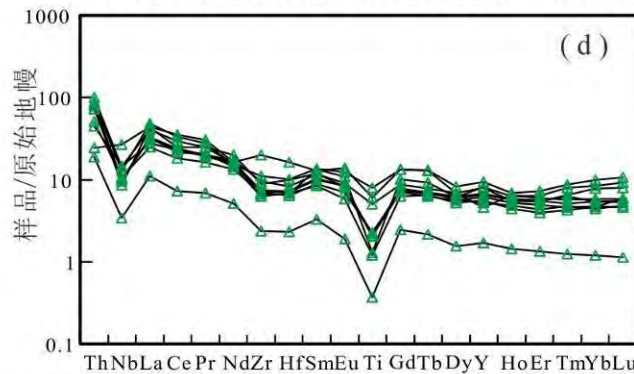
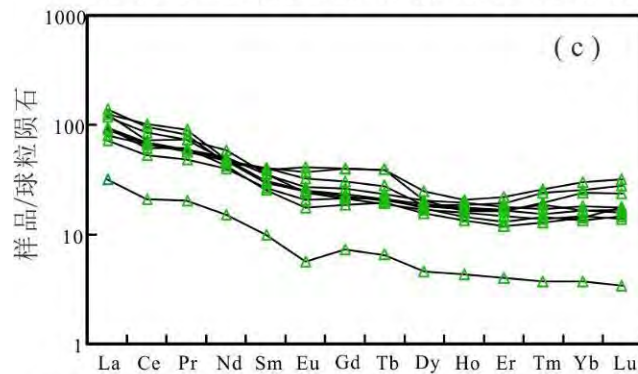
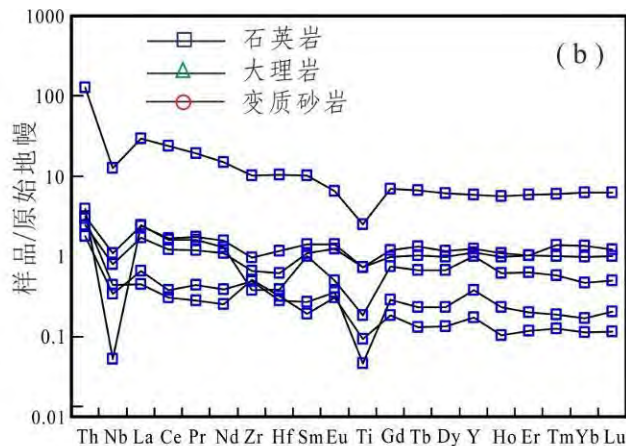
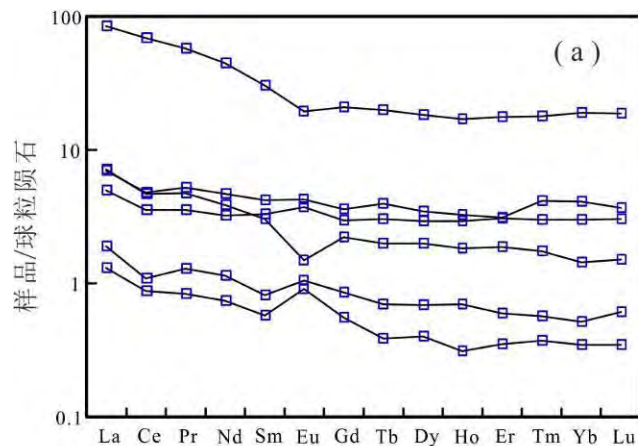
# 庙湾蛇绿杂岩主、微量地球化学特征



## 庙湾蛇绿杂岩晚期块状变辉绿岩

(a) 稀土元素配分图和 (b) 微量元素蛛网图

# 庙湾蛇绿杂岩主、微量地球化学特征

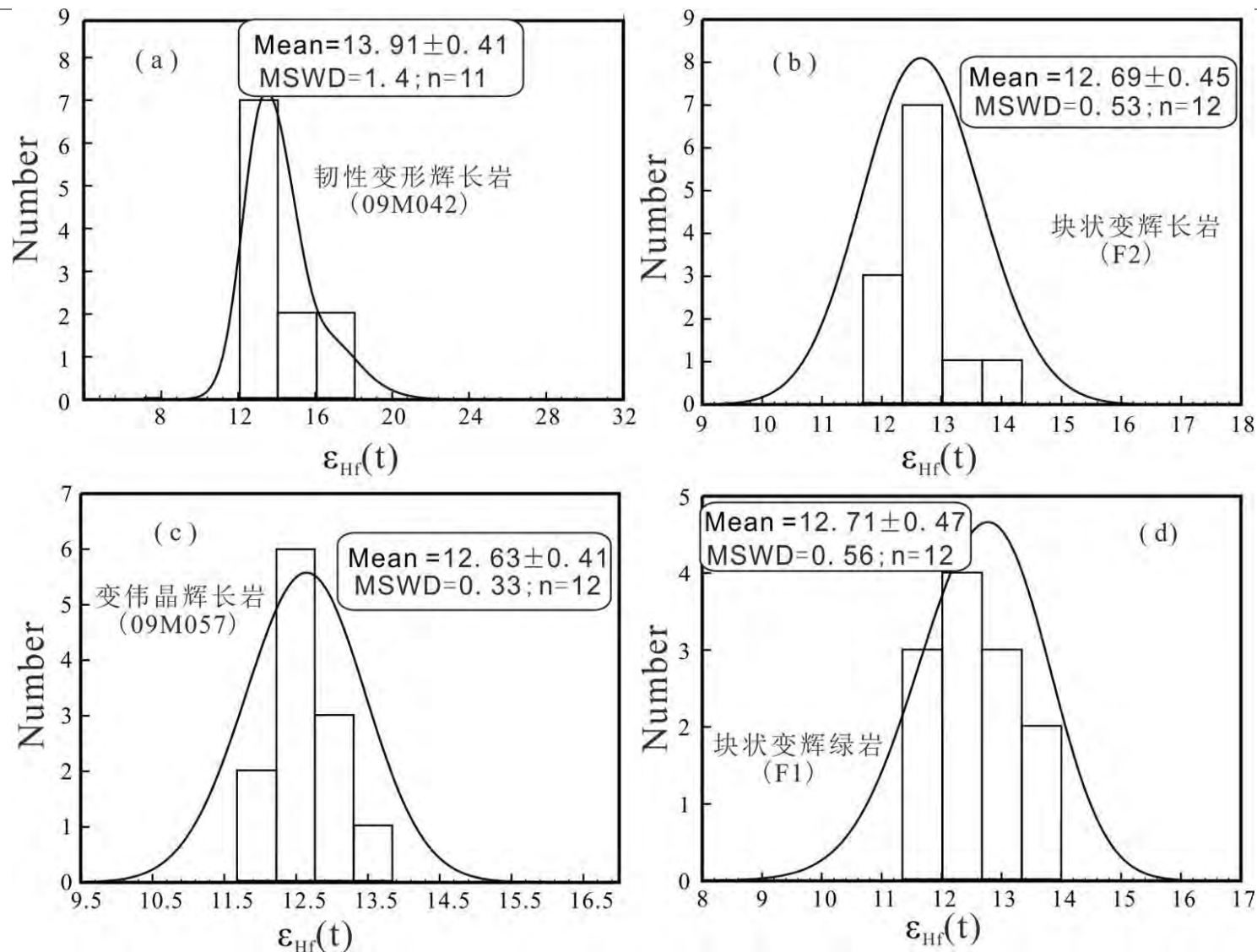


庙湾蛇绿杂岩中条带-  
条纹状变沉积岩稀土  
元素配分图和微量元  
素蛛网图

a-b: 石英岩(蓝色方);  
c-d: 大理岩(绿色三角);  
e-f: 变质砂岩(红色圆圈);

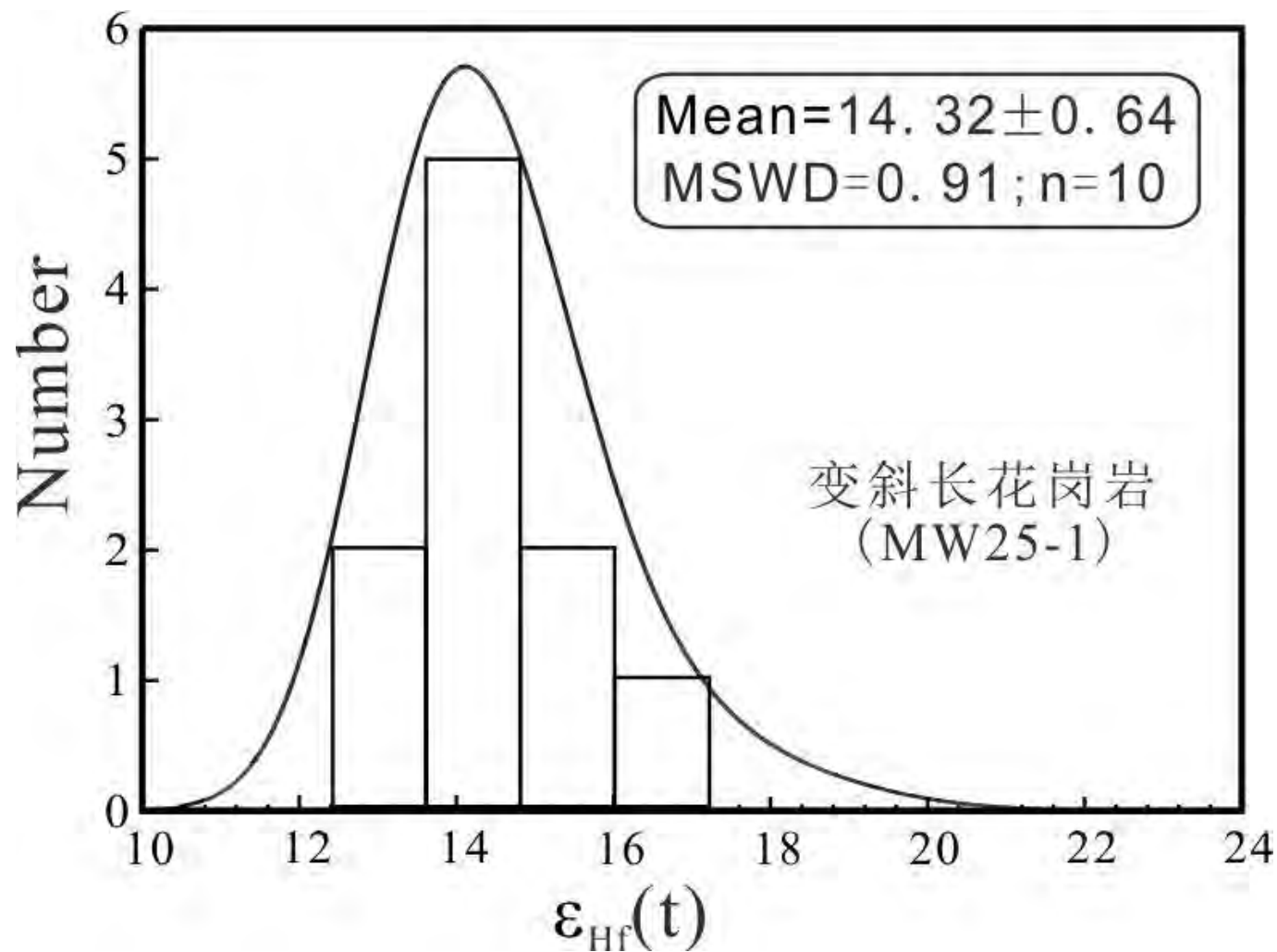


# 庙湾蛇绿杂岩锆石原位Lu-Hf同位素特征



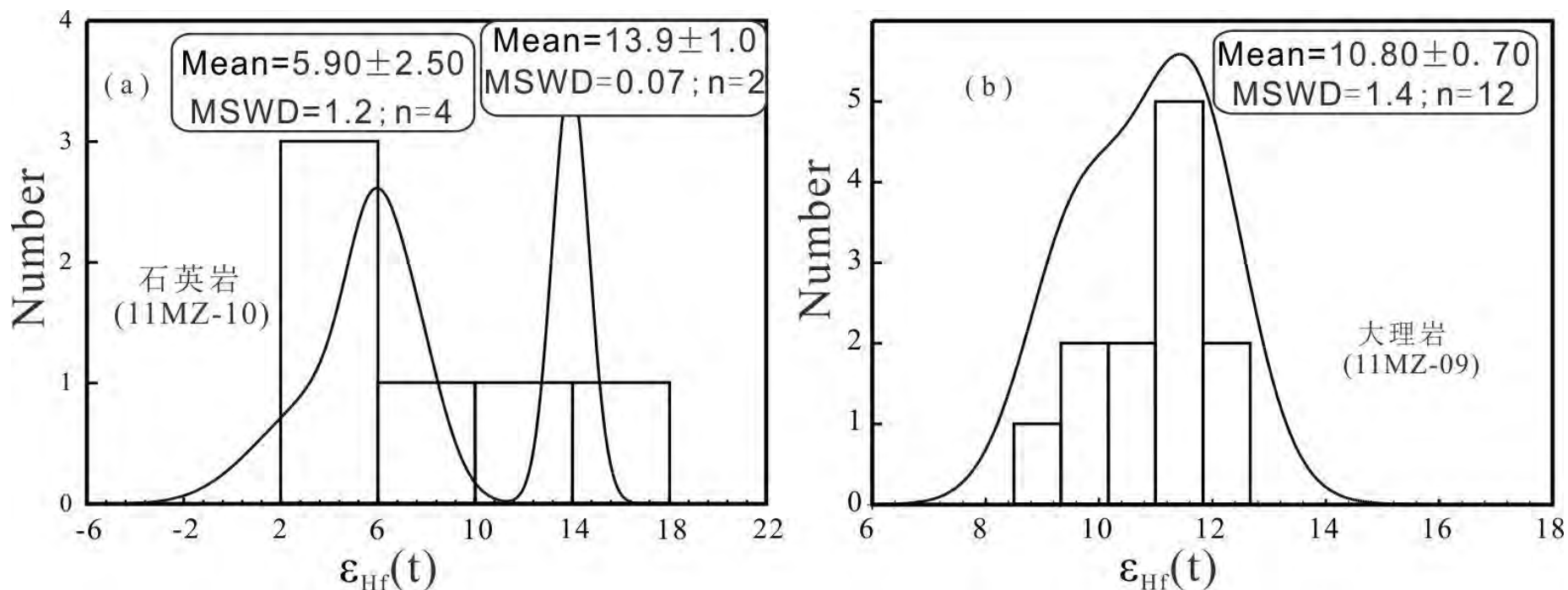
庙湾蛇绿杂岩早期强变形辉长岩 (a)、晚期弱变形块状 (b)、伟晶变辉长岩 (c) 和块状变辉绿岩 (d) 锆石原位Lu-Hf同位素统计分布图

# 庙湾蛇绿杂岩锆石原位Lu-Hf同位素特征



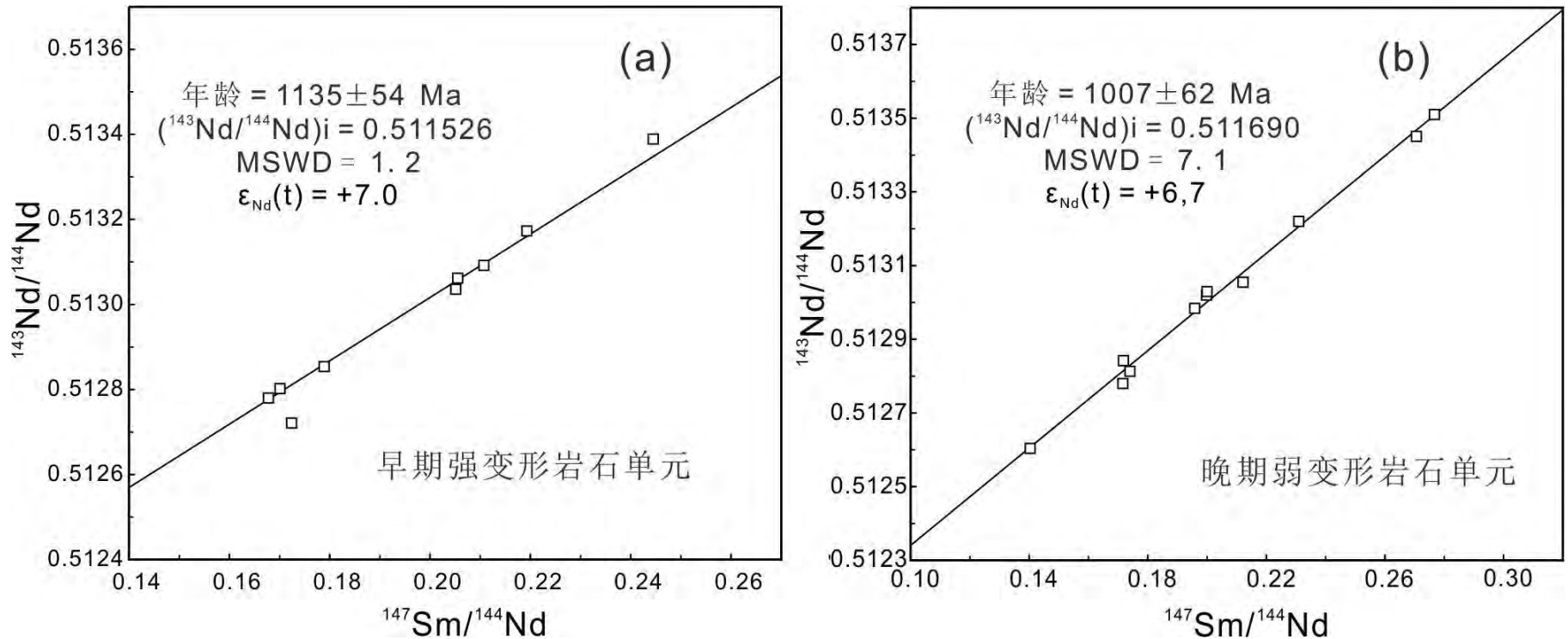
庙湾蛇绿杂岩晚期弱变形变斜长花岗岩锆石原位Lu-Hf同位素统计分布图

# 庙湾蛇绿杂岩锆石原位Lu-Hf同位素特征



庙湾蛇绿杂岩石英岩 (a) 和大理岩 (b) 锆石原位Lu-Hf同位素统计分布图

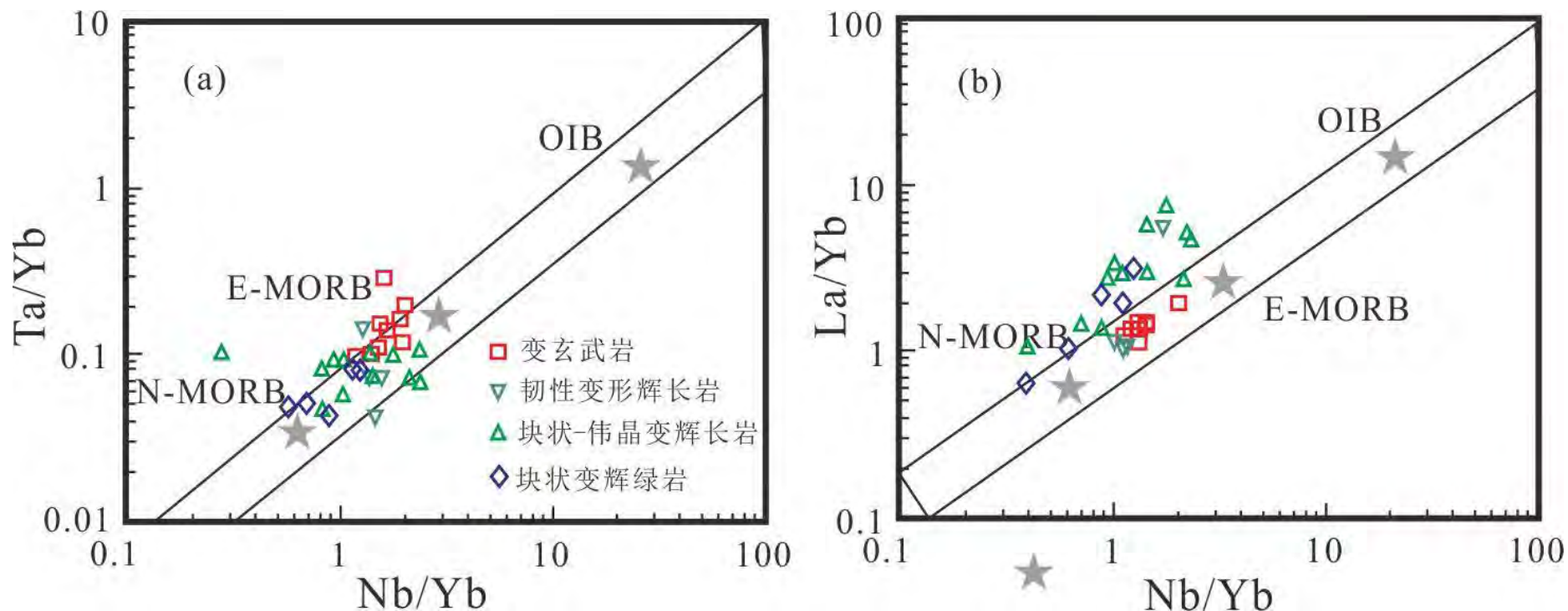
# 庙湾蛇绿杂岩全岩Sm-Nd同位素特征



## 庙湾蛇绿杂岩全岩Sm-Nd等时线年龄图

- a: 早期强变形岩石单元 (蛇纹石化纯橄岩、方辉橄榄岩、变玄武岩、韧性变形辉长岩)
- b: 晚期弱变形岩石单元 (块状变辉绿岩、块状和伟晶变辉长岩)

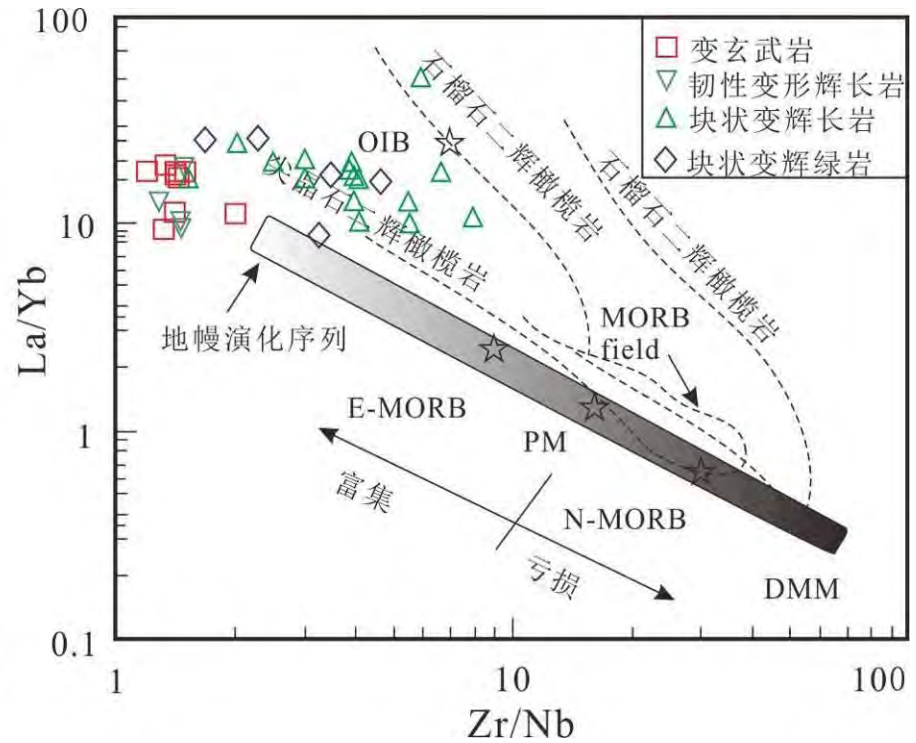
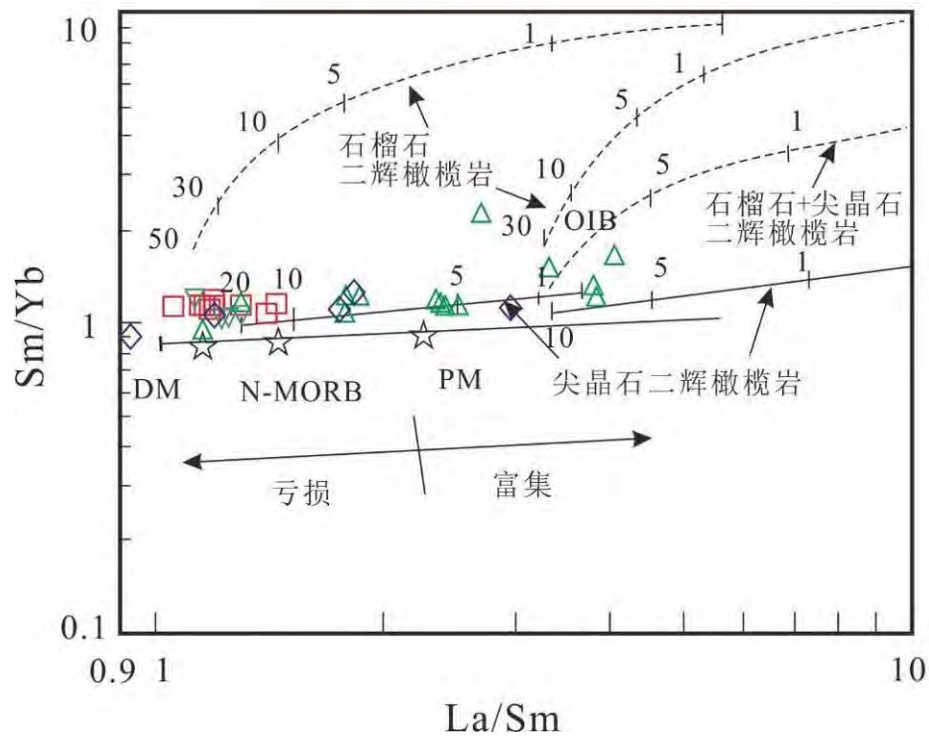
# 庙湾蛇绿杂岩源区特征



(1) 早期变玄武岩和韧性变形辉长岩绝大多数落在地幔序列中N-MORB和E-MORB之间，表明这些元素主要受岩浆源区控制；

(2) 晚期块状、伟晶变辉长岩和变辉绿岩在Ta/Yb-Nb/Yb图中也落入地幔序列中，但在La/Yb-Nb/Yb图中却偏离地幔序列，表明该类岩石除受岩浆源区控制外，后期过程（如流体交代/板片熔体等）对其有较大影响。

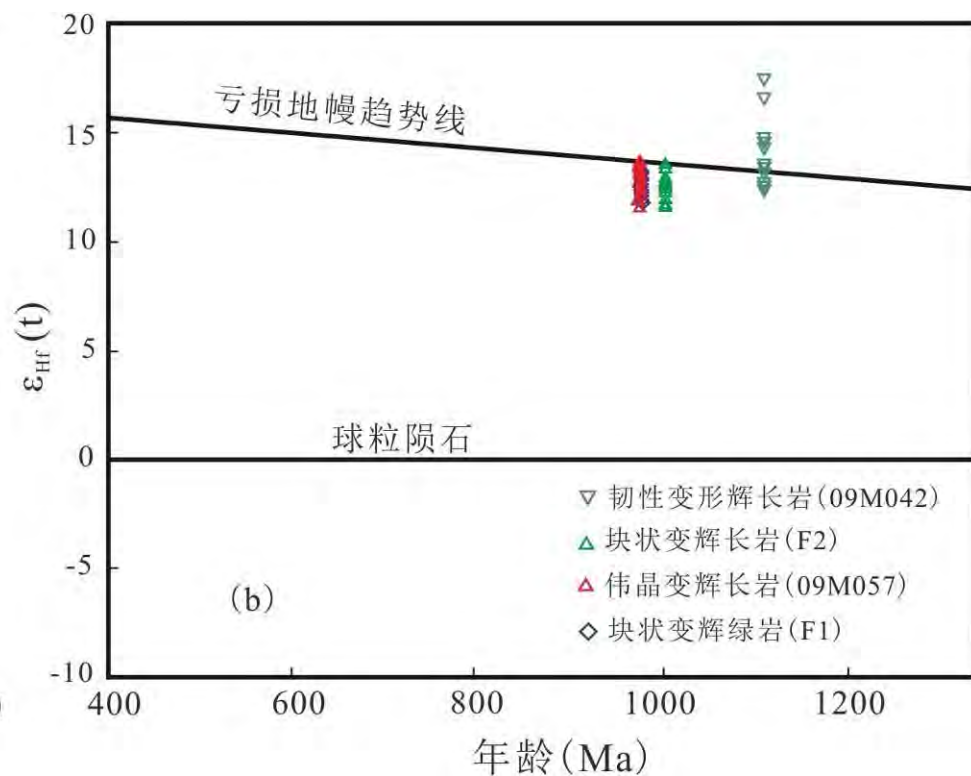
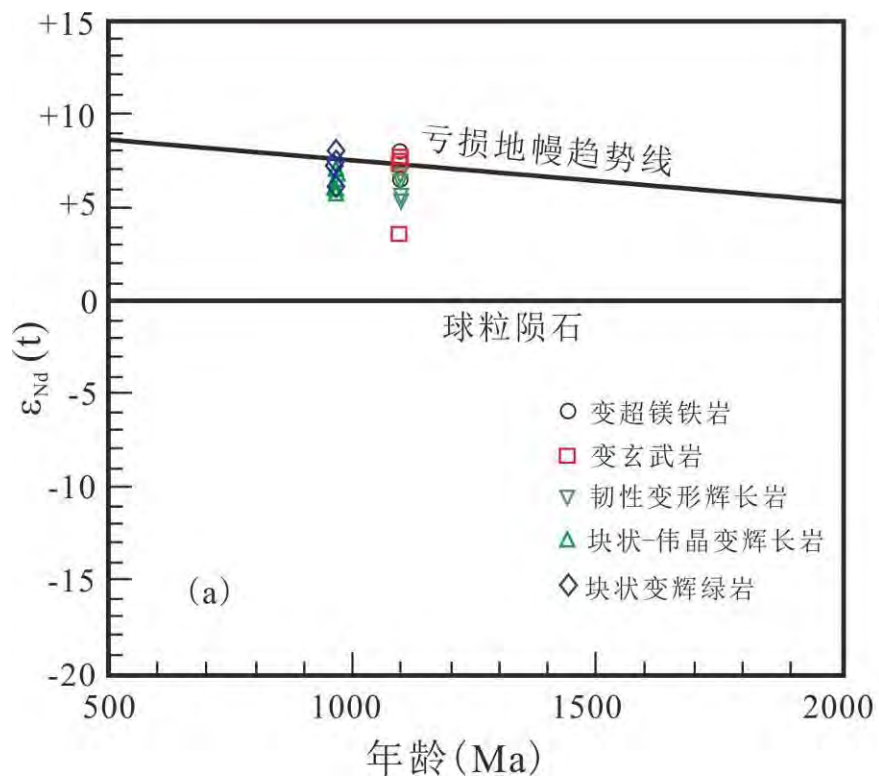
# 庙湾蛇绿杂岩源区特征



(1) 早期变玄武岩和韧性变形辉长岩落在10~20%尖晶石二辉橄榄岩部分熔融线附近，显示两者岩浆源区可能为**尖晶石二辉橄榄岩**地幔源区；

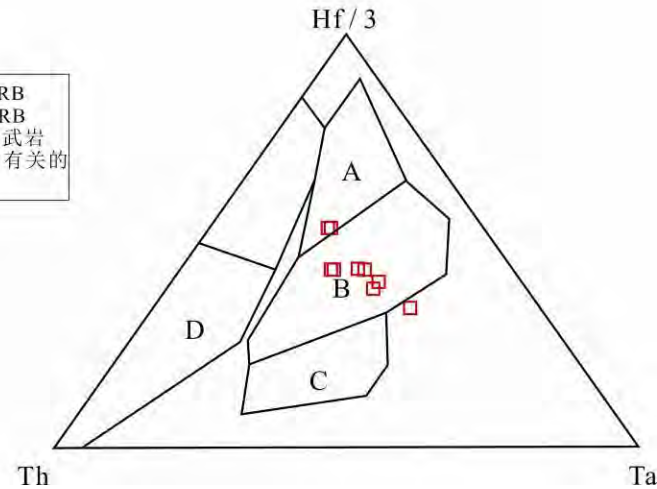
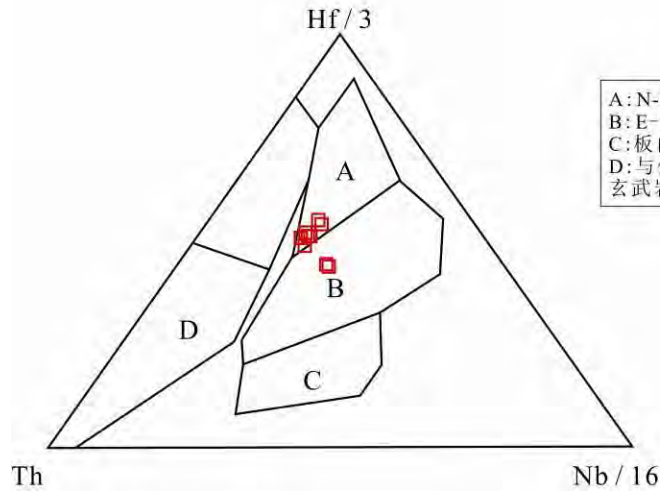
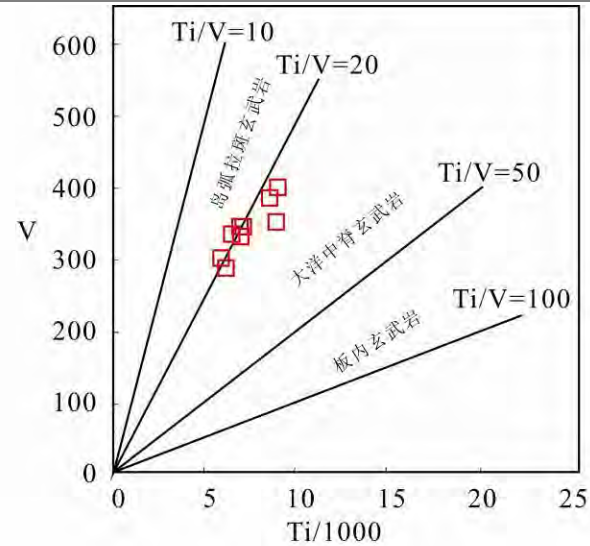
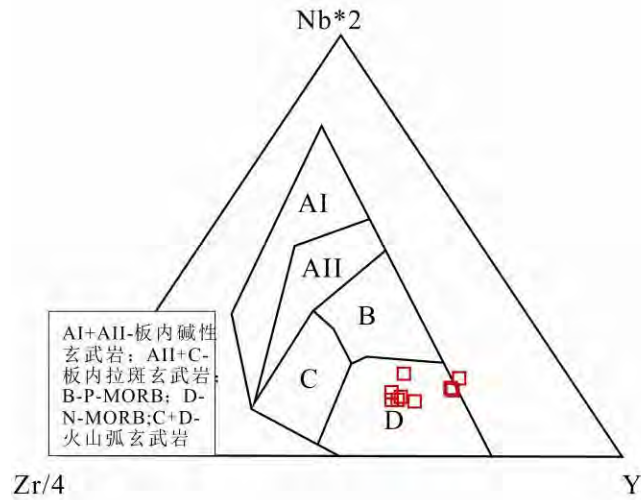
(2) 晚期块状、伟晶变辉长岩和变辉绿岩大多数落在尖晶石二辉橄榄岩演化曲线之上，少数落入石榴石-尖晶石二辉橄榄岩熔融线附近，尽管这些样品的熔融程度变化较大，但暗示弱变形-未变形辉长岩和变辉绿岩地幔源区可能为**石榴石+尖晶石二辉橄榄岩**。

# 庙湾蛇绿杂岩源区特征



庙湾蛇绿杂岩中锆石 $\epsilon_{Hf}(t)$ 值 (a) 和全岩 $\epsilon_{Nd}(t)$ 值 (b) 年龄图解

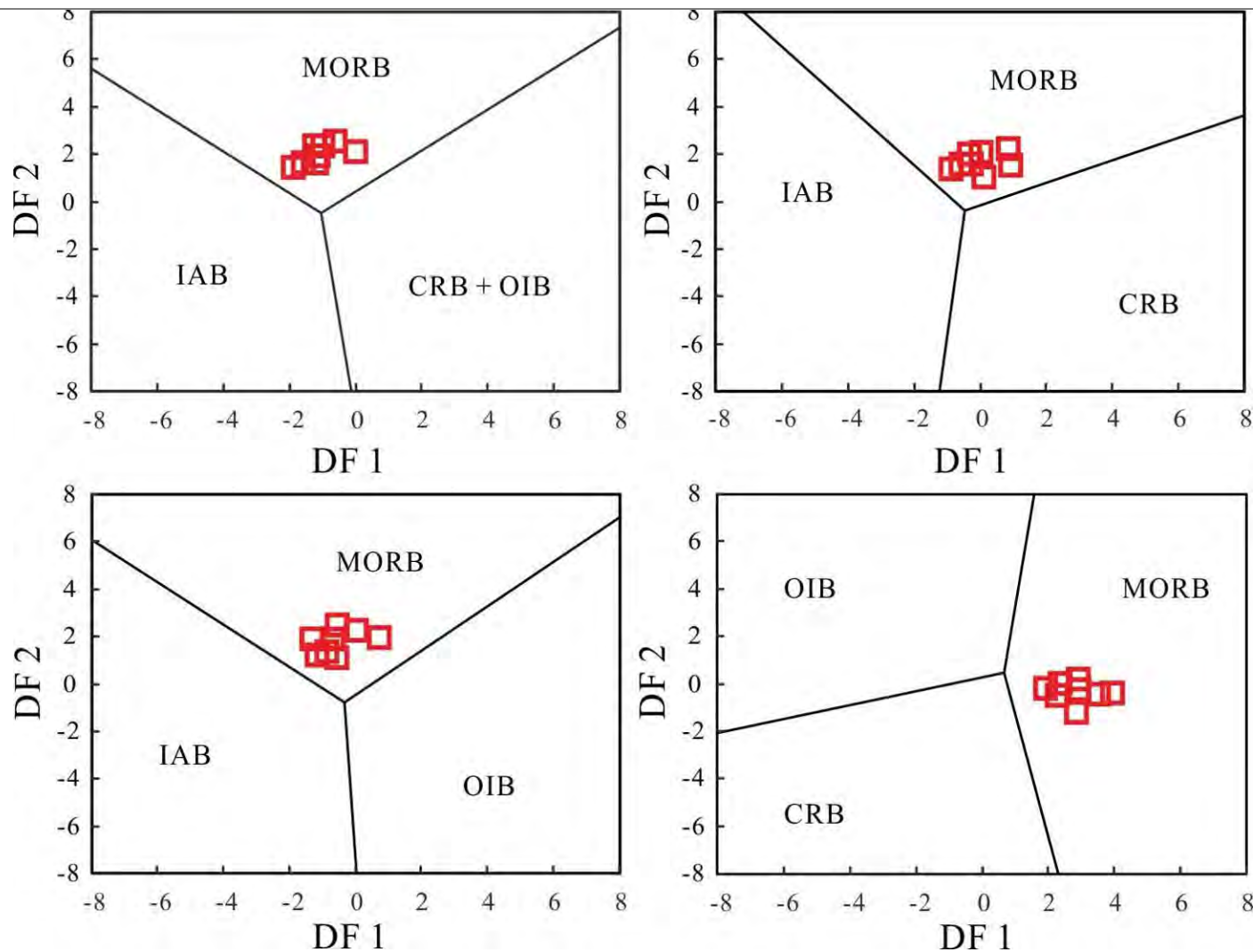
# 庙湾蛇绿杂岩形成大地构造环境



a:  $2 \cdot \text{Nb}-\text{Zr}/4-\text{Y}$ 构造环境判别图解 ; b:  $\text{Ti}-\text{V}$ 构造环境判别图解 ;  
c:  $\text{Hf}/3-\text{Th}-\text{Nb}/16$ 构造环境判别图解 ; d:  $\text{Hf}/3-\text{Th}-\text{Ta}$ 构造环境判别图解

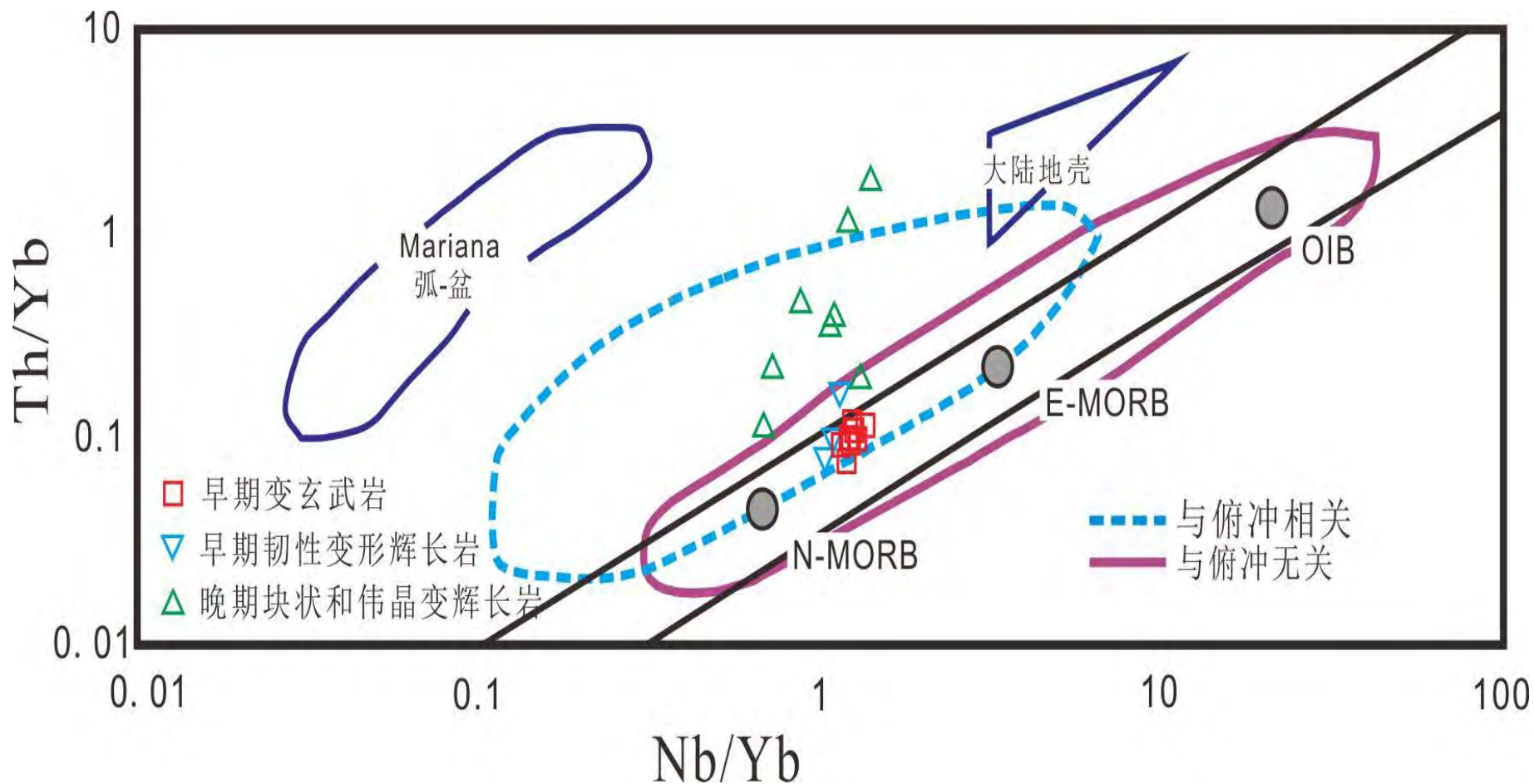


# 庙湾蛇绿杂岩形成大地构造环境



变玄武岩La/Th-Nb/Th-Sm/Th-Yb/Th构造环境判别图解 (Agrawal et al., 2008)  
MORB: 大洋中脊玄武岩; IAB: 岛弧玄武岩; OIB: 洋岛玄武岩; CRB: 大陆裂谷玄武岩

# 庙湾蛇绿杂岩形成大地构造环境



变基性岩Th/Yb-Nb/Yb图解 (Dilek and Furnes, 2011)

# 结论

1、黄陵背斜南部崆岭群呈北西西向展布的庙湾岩组实际上是一套中-新元古代蛇绿杂岩，由**早期 (1135-1096Ma)** 强变形蛇纹石化的纯橄岩、方辉橄榄岩、堆晶橄辉岩、辉石岩、辉长岩、辉绿席状岩墙、变玄武岩岩，以及条带-条纹状石英岩-黑云母片岩-不纯大理岩和**晚期 (1007-971Ma)** 弱变形块状变辉长岩、变辉绿岩组成；

2、早期蛇绿岩单元均遭受强烈变形变质作用，普遍发育倾向北北东高角度透入性面理和线理构造，晚期岩石单元变形较弱，但早期与晚期岩石单元普遍呈高角度逆冲断层接触关系，**表明庙湾蛇绿杂岩主要经历了由北向南挤压逆冲推覆构造变形变质作用；**

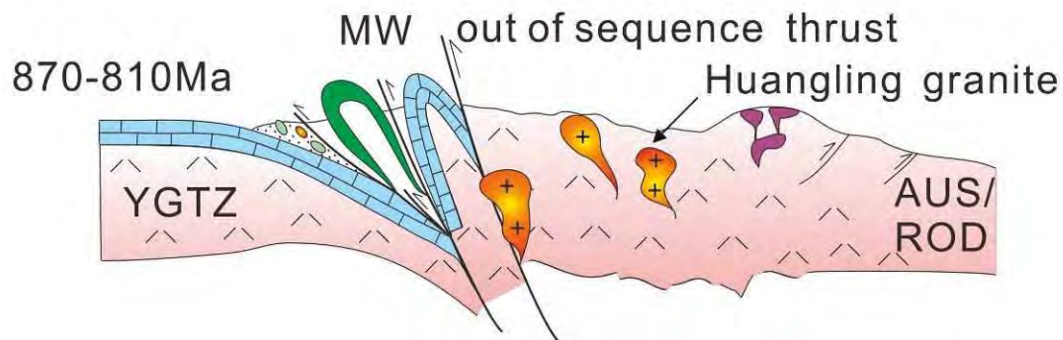
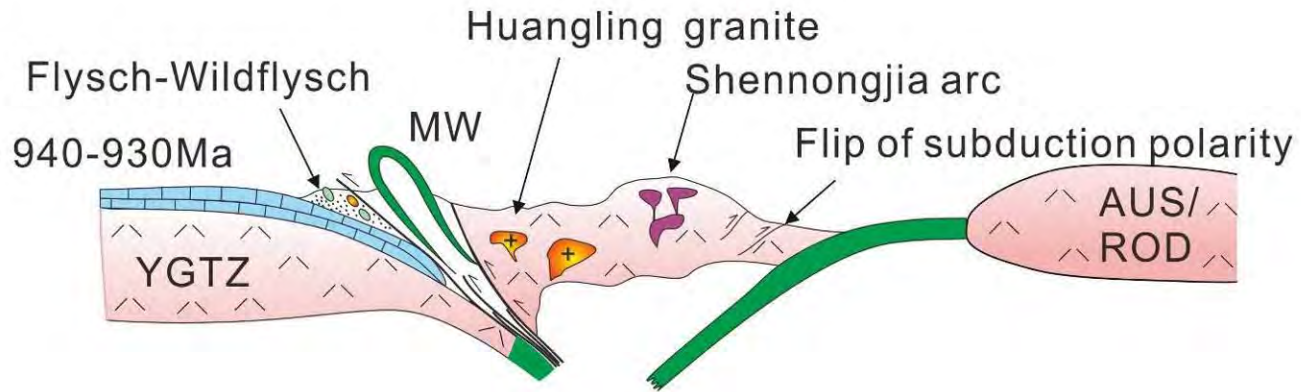
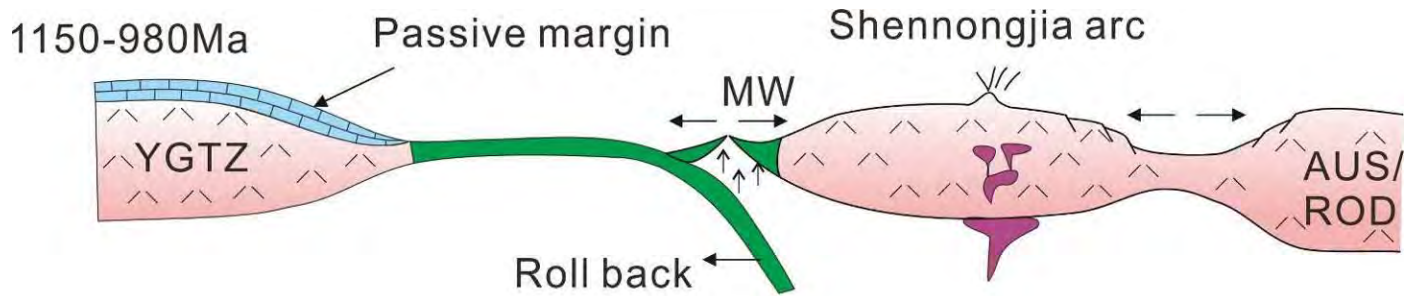
3、早期蛇纹石化纯橄岩、方辉橄橄岩，具低Ti、Al，稀土总量较低，轻稀土亏损和“U”型分布特征，微量元素含量绝大部分低于原始地幔，**表明其为形成于与俯冲有关构造环境的亏损残余大洋地幔橄橄岩**，而早期韧性变形辉长岩、变玄武岩，轻稀土均呈弱亏损或平坦N-MORB特征，亏损Th、Ti、Zr和Hf等元素，相对略富集Nb元素；晚期弱/未变形变辉长岩、变辉绿岩，轻稀土呈略富集E-MORB特征，亏损Nb元素，相对富集Th元素；

4、早期蛇纹石化纯橄岩、方辉橄橄岩、堆晶橄橄岩、变玄武岩、辉长岩 $\epsilon\text{Nd}(t) = +5.7 - +7.6$ ，其中韧性变形辉长岩锆石 $\epsilon\text{Hf}(t)$  介于 $+12.75 - +17.35$ ；晚期弱变形变辉长岩、变辉绿岩 $\epsilon\text{Nd}(t) = +6.0 - +7.2$ ，锆石 $\epsilon\text{Hf}(t)$  介于 $+11.91 - +13.54$ ，变斜长花岗岩锆石 $\epsilon\text{Hf}(t)$  介于 $+13.24 - +16.96$ ，**表明早期和晚期岩石单元均来自亏损地幔源区，且与世界上典型前寒武纪蛇绿岩Nd-Hf同位素特征一致。**

5、变沉积岩单元条带-条纹状石英岩和大理岩中岩浆碎屑锆石核部频谱年龄分别为1105-967Ma（峰值1009 Ma）和1095-1011Ma（峰值1054Ma），其中绝大多数锆石核部 $\epsilon_{\text{Hf}}(t) = +9.2 - +14.1$ ，这与庙湾变辉绿岩-辉长岩锆石的Hf同位素特征一致，推测岩浆碎屑锆石来源于庙湾变辉绿岩-辉长岩。锆石边部变质年龄为941-936Ma，则代表了庙湾蛇绿杂岩构造变质侵位的时代。这一构造变质年龄也是华南首次发现的与世界范围内罗迪尼亚超大陆聚合碰撞造山事件时代（格林威尔期）基本一致的变质年代记录；

6、庙湾蛇绿杂岩的构造演化过程可简单概括为：**中元古代晚期（1130-1100Ma）** 扬子克拉通古元古代基底地块裂解形成黄陵盆洋中庙湾蛇绿杂岩早期蛇绿岩岩石单元，并向北俯冲形成神农架岛弧；**新元古代早期（1000-970Ma）** 黄陵盆洋晚期的向北俯冲交代早期弧前扩张地幔楔或俯冲板片后撤形成庙湾晚期岩石单元（块状和伟晶变辉长岩、变辉绿岩）；**新元古代早期（941-936Ma）** 发生碰撞造山构造变质变形侵位，增厚地壳伸展垮塌裂解形成**新元古代晚期（860-790Ma）**黄陵花岗杂岩。

庙湾蛇绿杂岩发现和识别表明，扬子克拉通前南华纪变质结晶基底是由不同性质和时代陆块或岛弧地体，经中-新元古代俯冲-碰撞造山拼贴（晋宁期）最终形成的。



庙湾蛇绿杂岩构造演化模式图 (Peng et al., 2012)











A close-up photograph of two white flowers with yellow stamens, likely from a species of Iris or similar. The flowers are in full bloom, with six petals each. The background is a soft-focus green, suggesting foliage. The text '谢谢!' is overlaid in the center in a bold, red, stylized font.

谢谢!