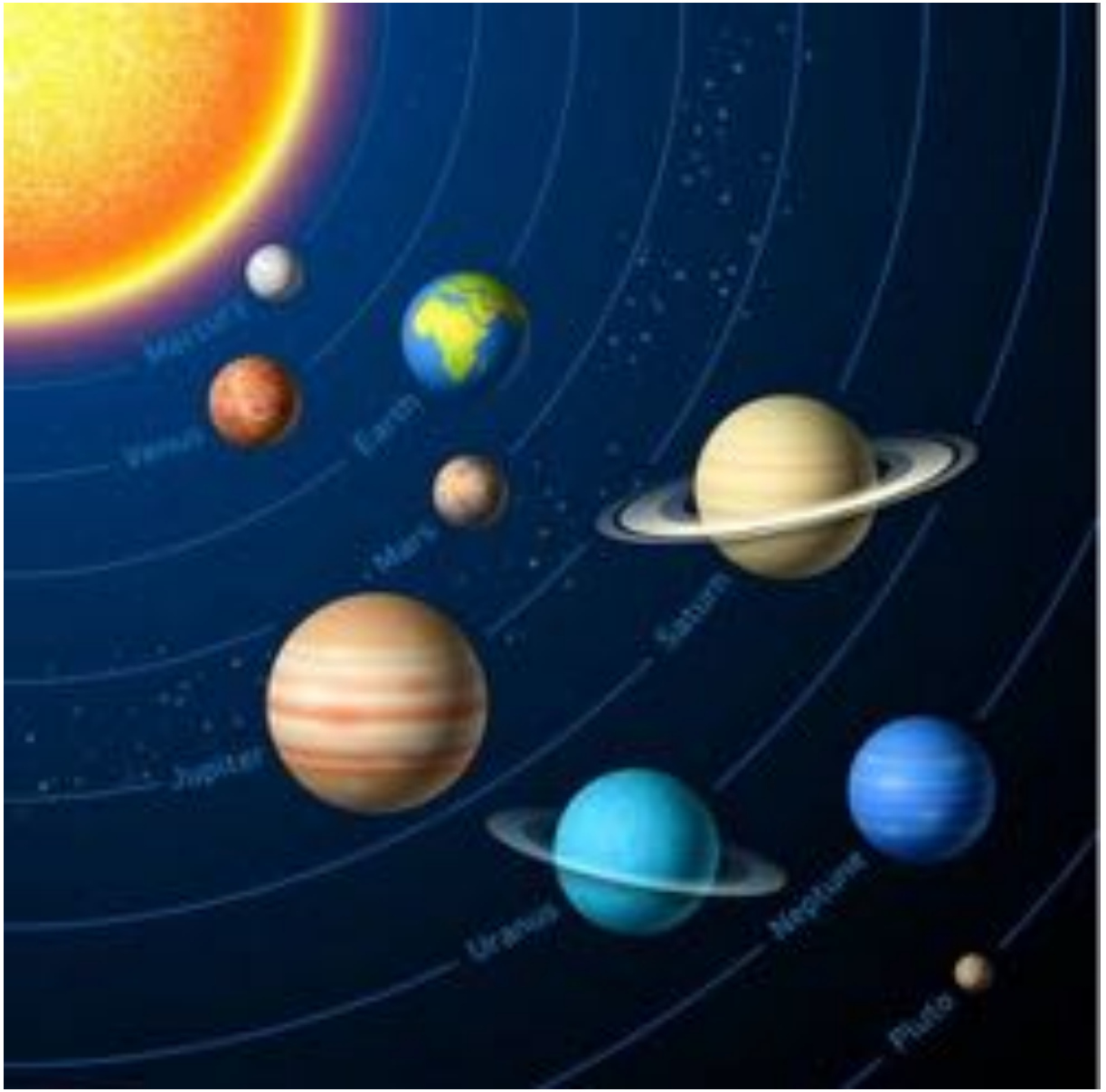
造山过程中大陆地壳的生长和演化

吴元保
中国地质大学（武汉）

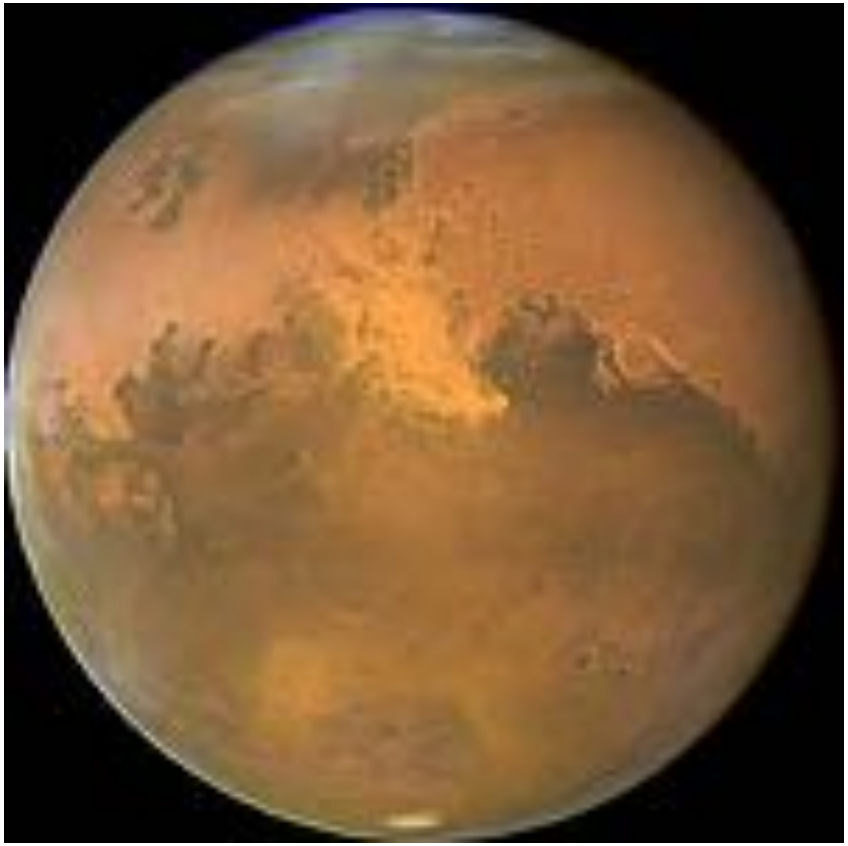

Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto

太阳系八大行星

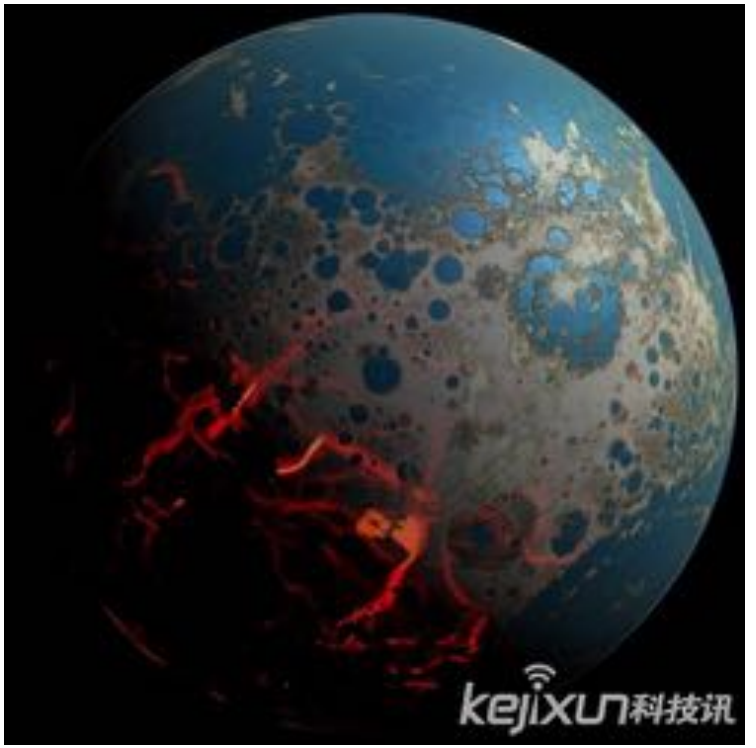
地球全貌

鸟语花香

果实累累



火星全景



早期地球

现代地球

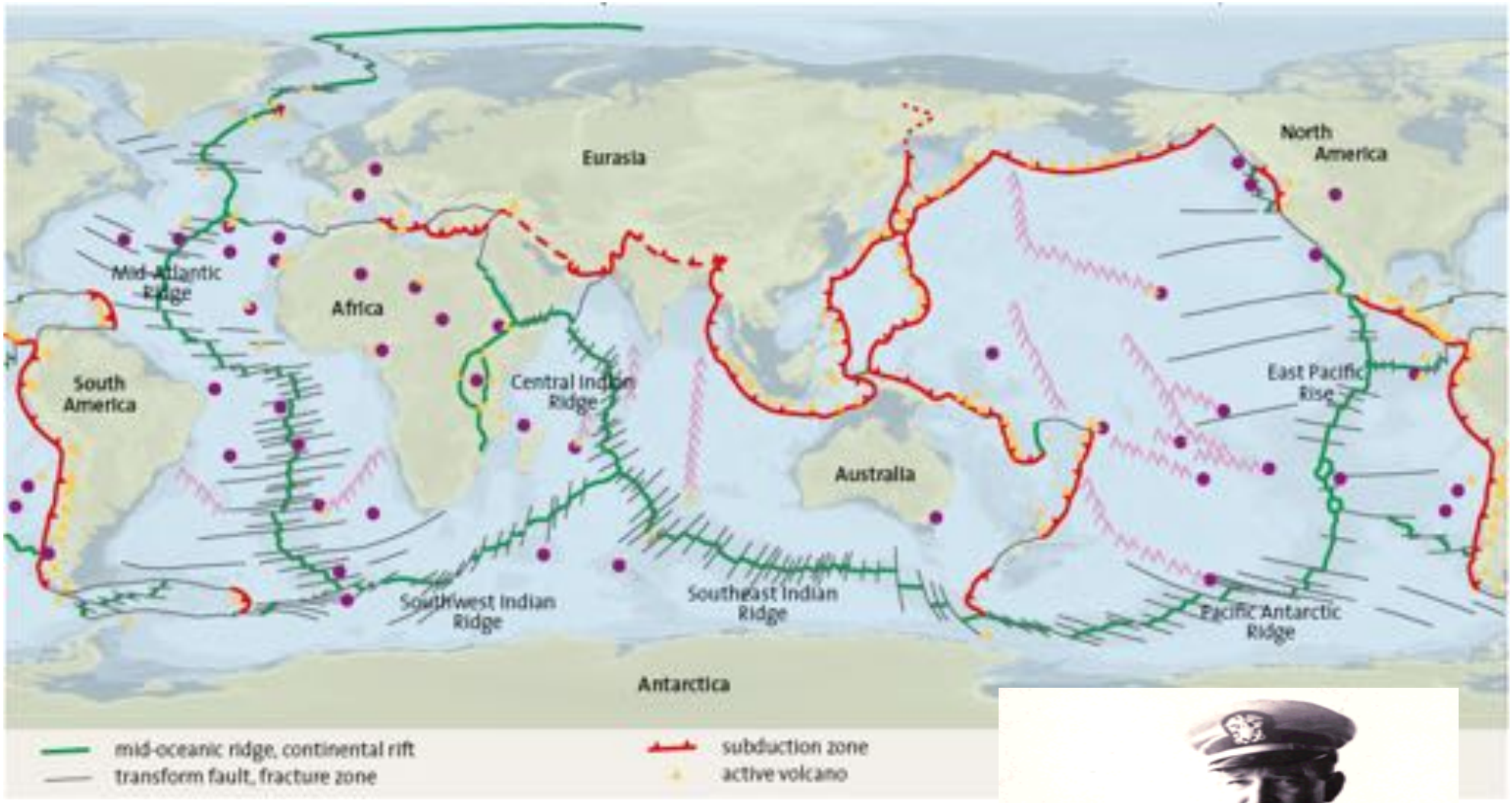
The earth external structure

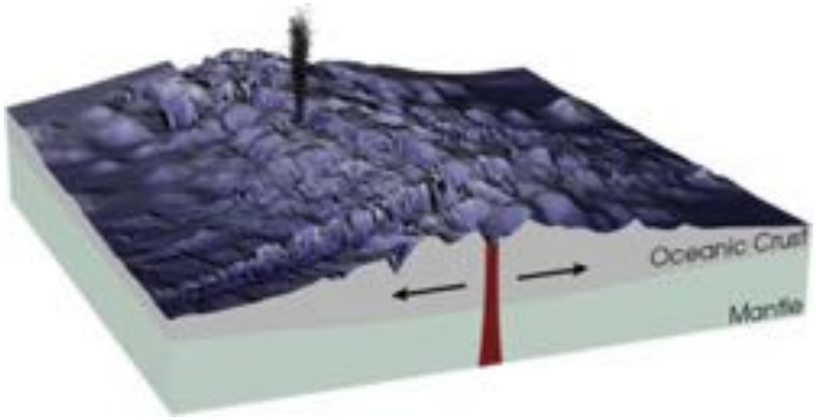
在第一次世界大战时曾参军并两度负伤。他留意到非洲大陆西岸和南美洲东岸的海岸线很相似，因此推测大陆原本是相连的，1915年出版《大陆与大洋的起源》一书。

1910 年 Continent Drift (Alfred Wegener)

Earth's mantle contained convection cells that dissipated radioactive hea t and moved the crust at the surface

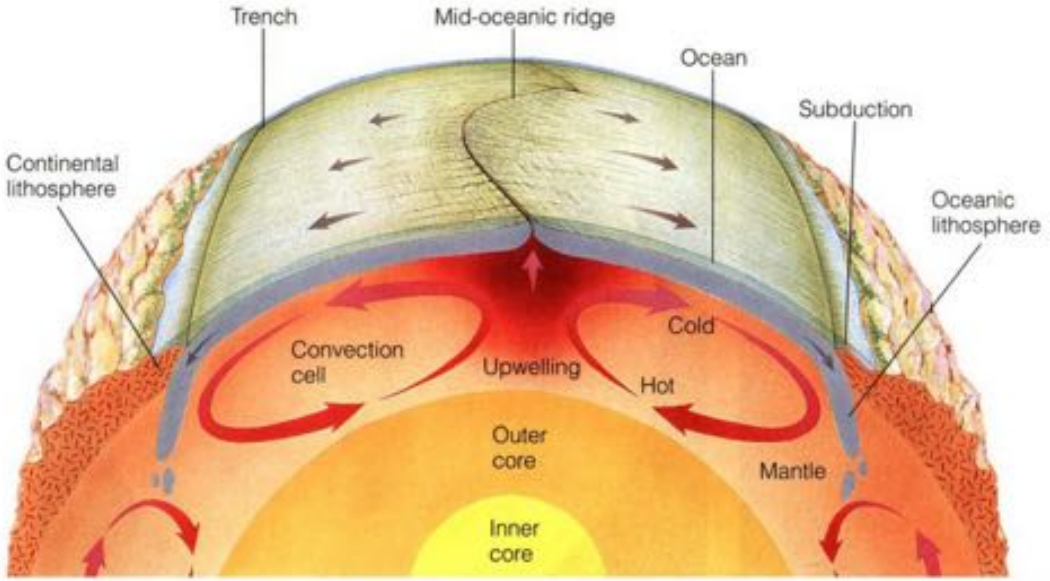
Arthur Holmes
1920s



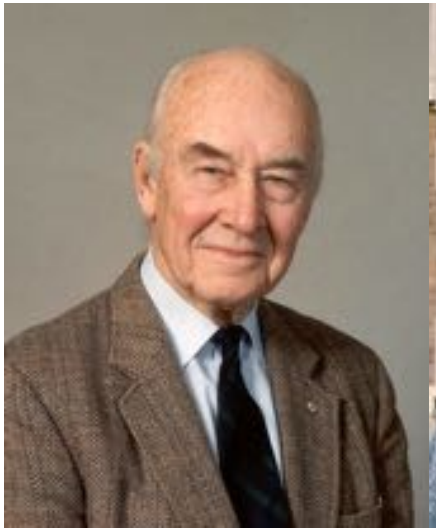


Harry Hammond Hess
1950s-1960s

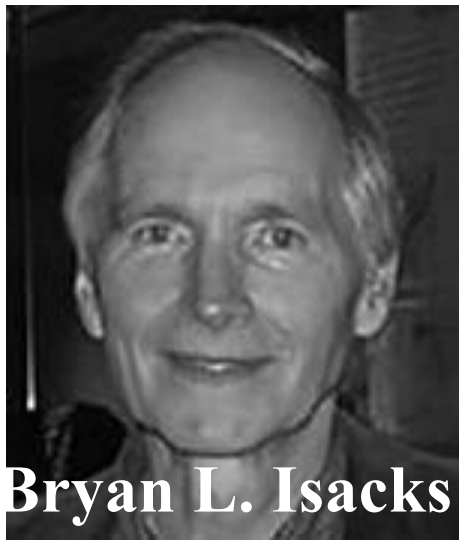
Hypothetical Mechanism of Plate Tectonics



The Earth's plates are thought to move as a result of underlying mantle convection cells in which warm material from deep within the Earth rises toward the surface, cools, and then, upon losing heat, descends back in the interior.



John Tuzo Wilson **William Jason Morgan**



Bryan L. Isacks

Donald Forsyth

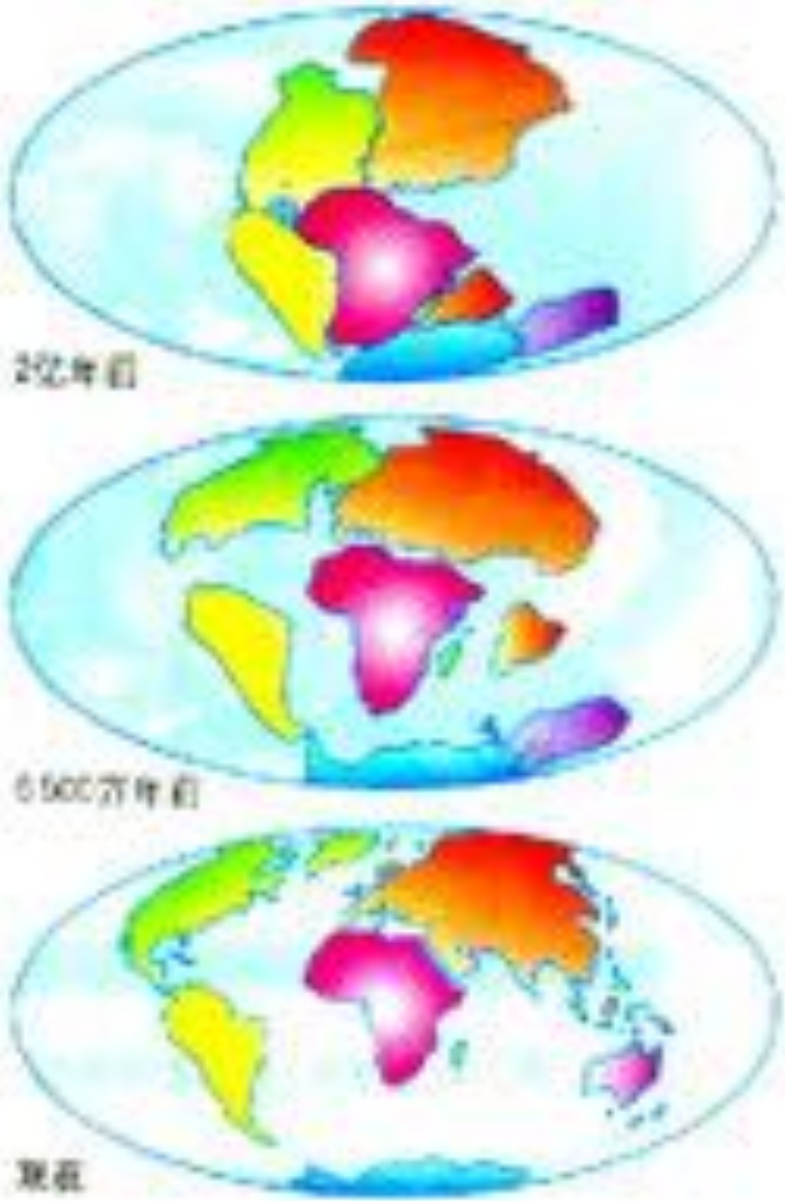
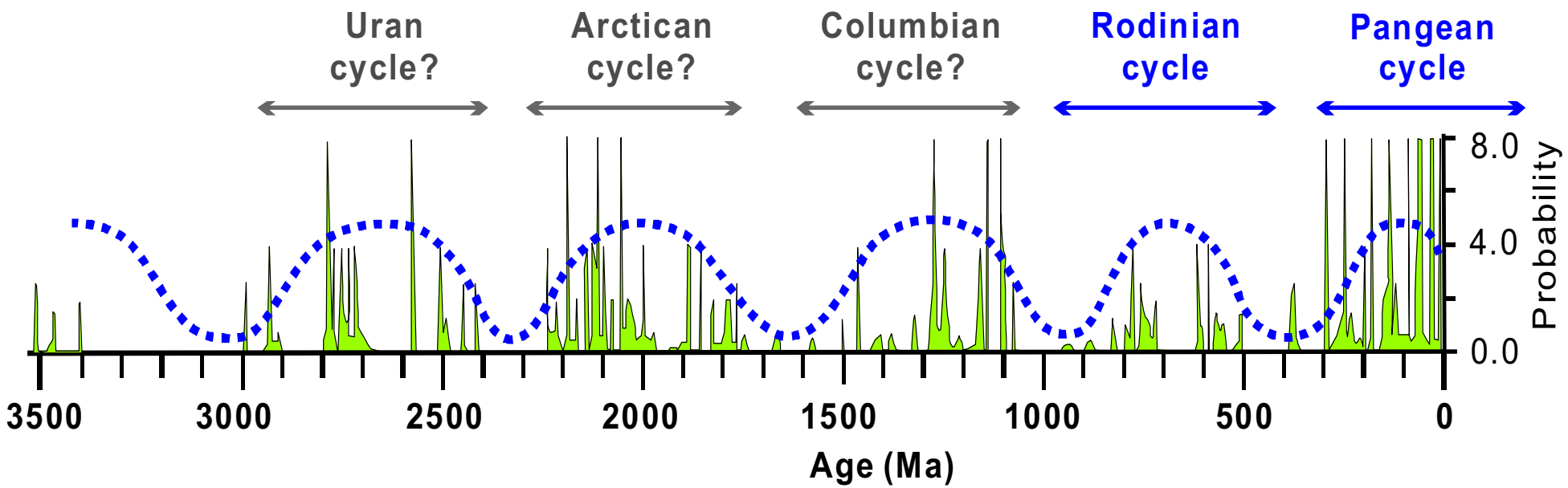


图2.15　大陆的漂移

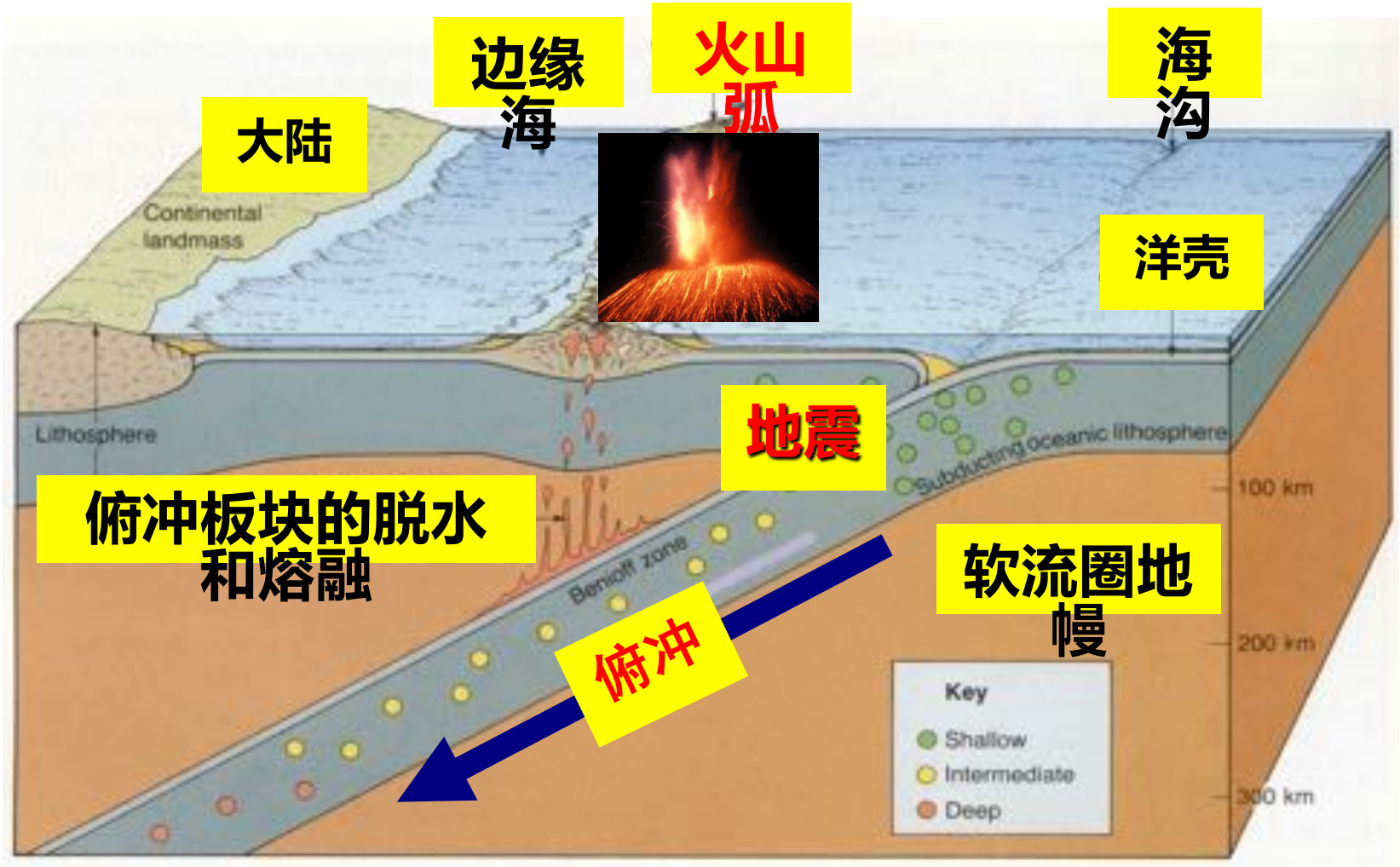
看看大西洋是怎样形成的？太平洋有什么变化？

地球演化的周期性?

Prokoph et al., 2004;
Li and Zhong, 2009



板块构造理论：固体地球科学的主导理论

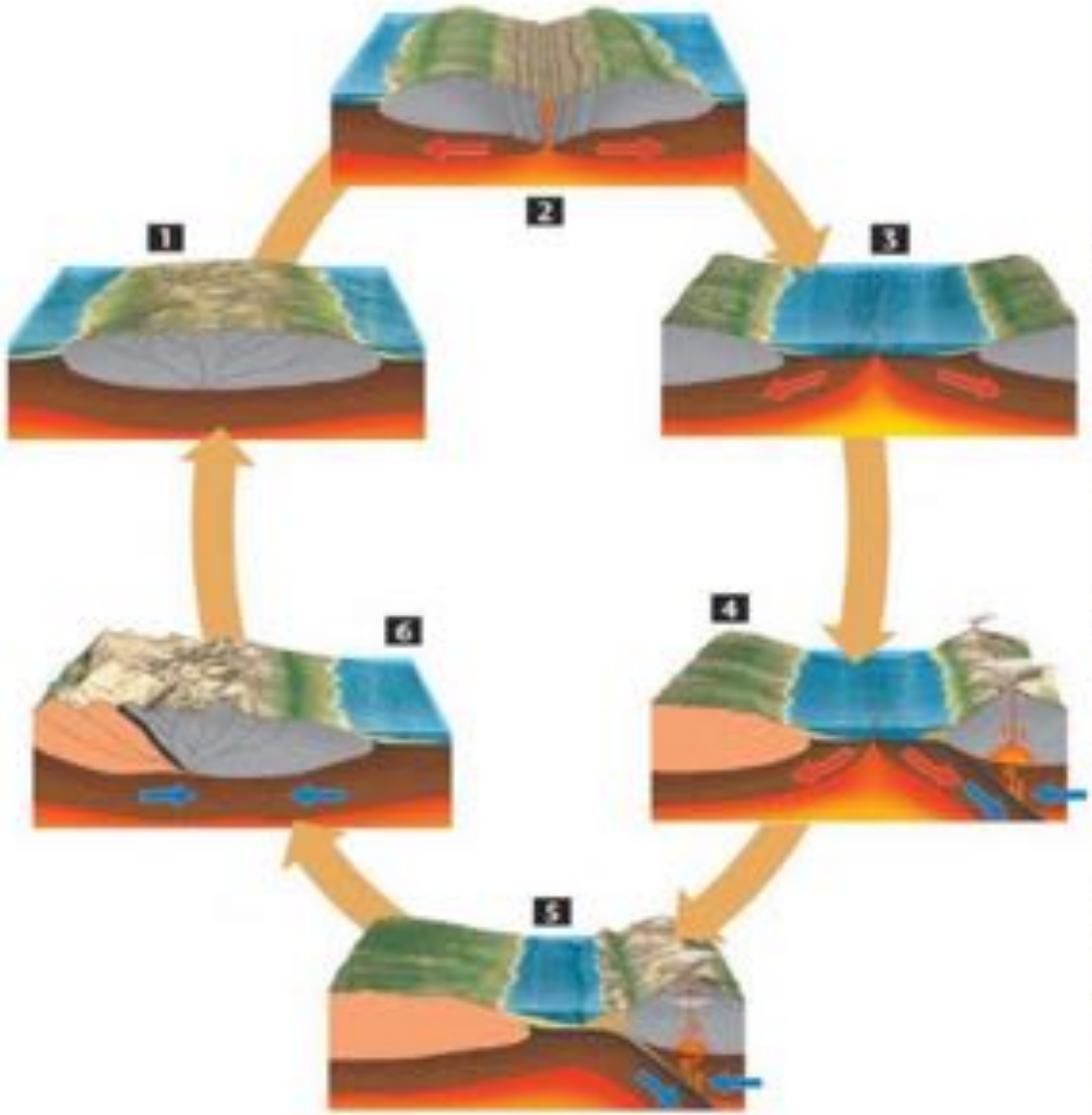


板块运动控制了地球上资源、灾害的形成和分布

（Zheng et al., 2012）

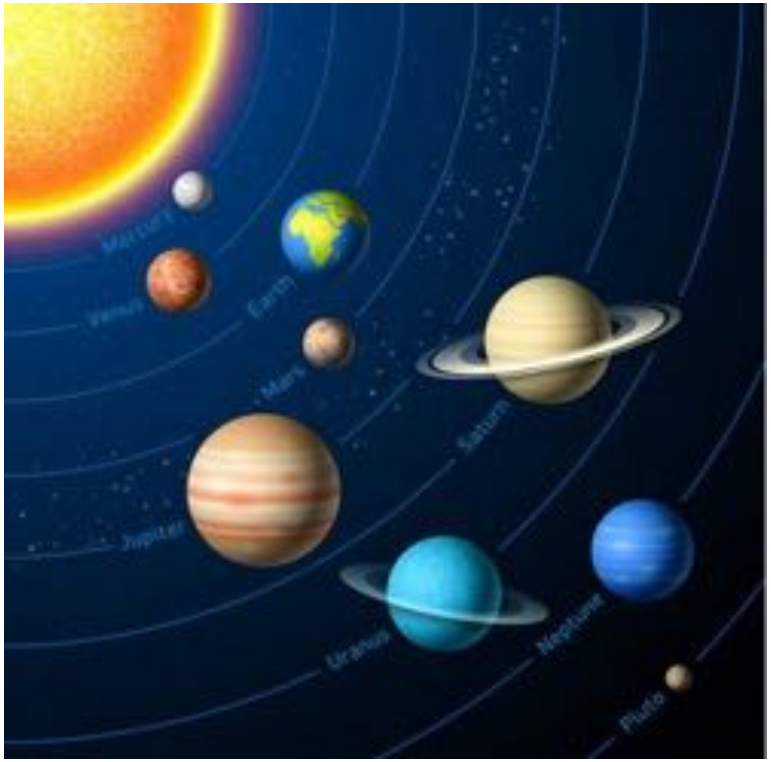
The Wilson Cycle

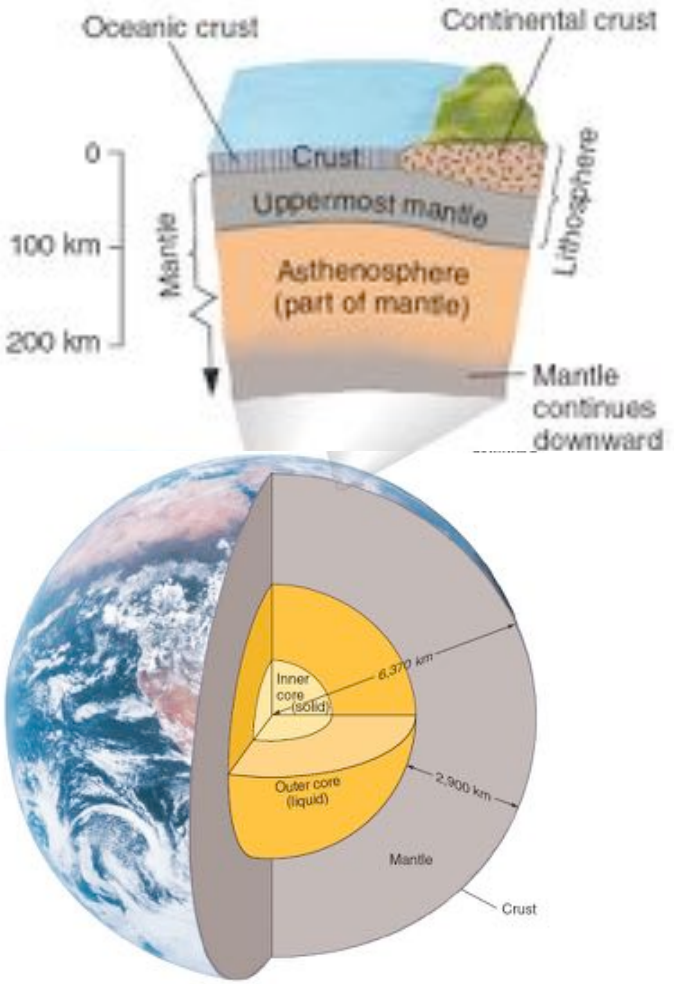
Wilson Cycle — The cyclical opening and closing of oceanic basins.



Here is a simplified model:

1. Stable craton;
2. Hot spot and Continental Rifting (e.g., East African Rift);
3. Early seafloor spreading (e.g., Red Sea) to Full seafloor spreading (e.g., Atlantic Ocean);
4. Volcanic Island Arc, Mountain Building (e.g., Pacific Ocean);
5. Volcanic Island Arc - Continent Collision;
6. Continent - Continent Collision and Mountain Building (e.g., Tibetan Plateau and Himalayas Mountains).





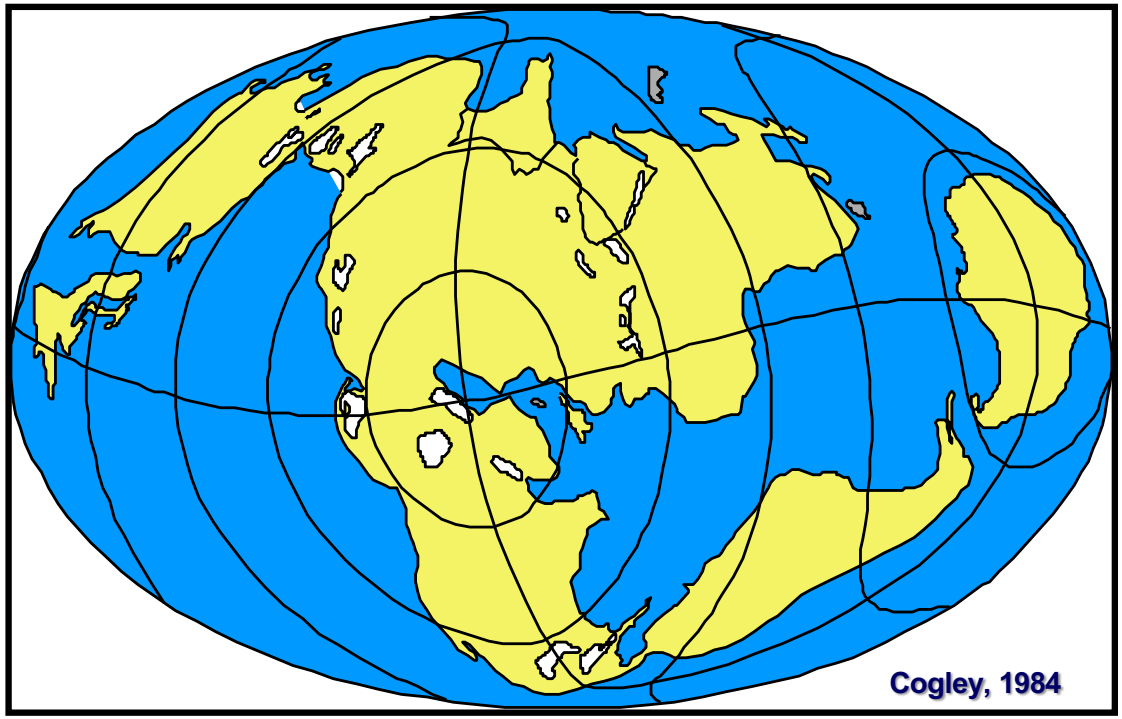
地球的层圈结构 ⟹ 高度分异演化

地球的大陆地壳 ⟹ 区别其它行星最重要特征

适合人类生存的环境条件

提供人类生存的矿产资源

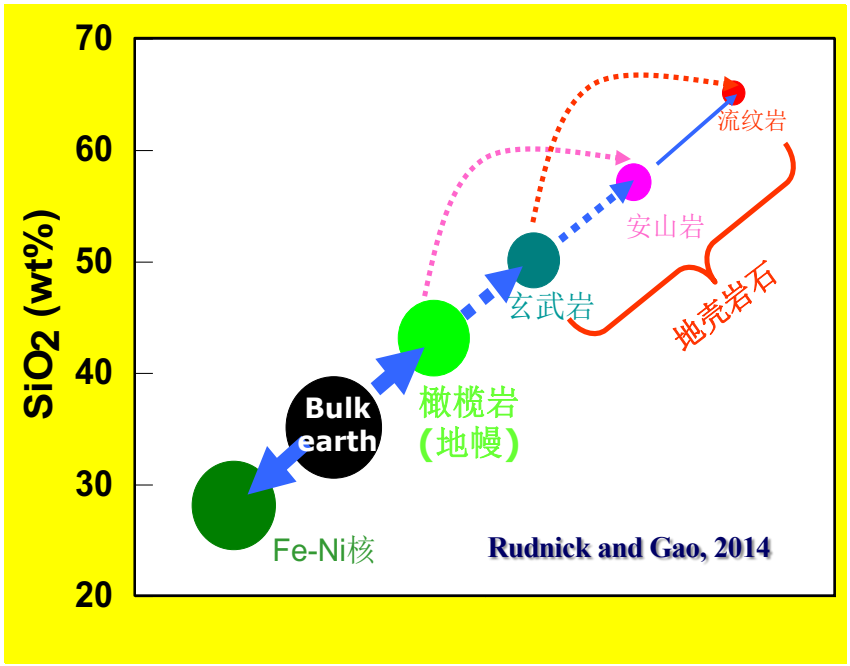
大陆地壳的分布情况

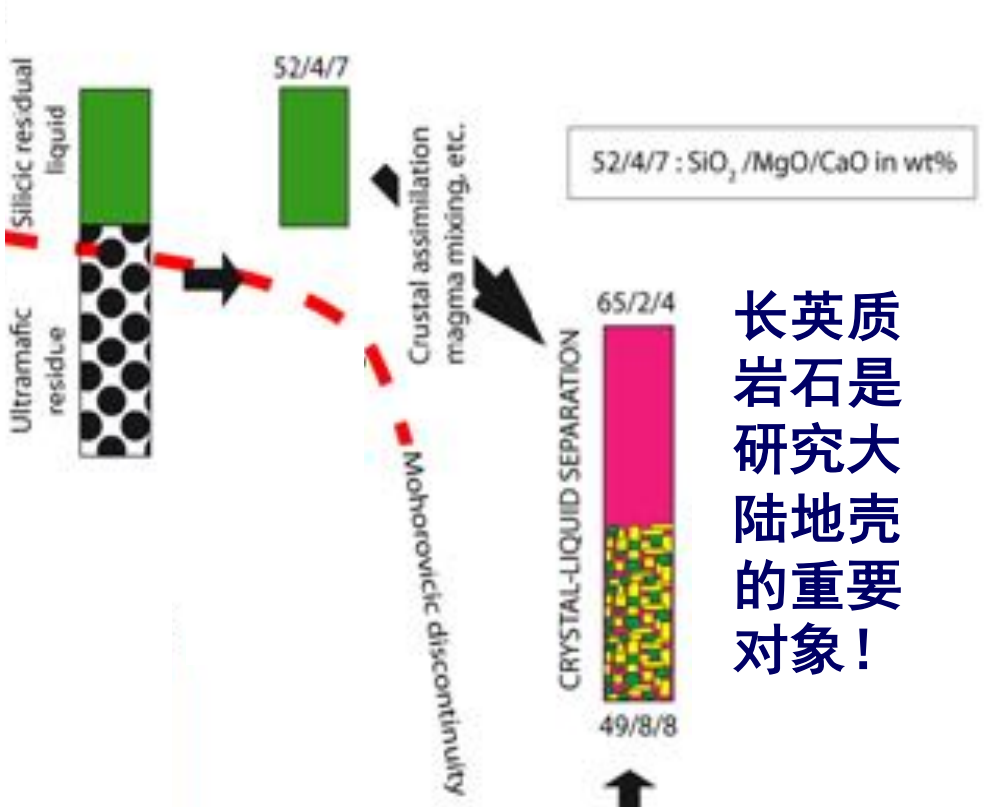


大陆地壳的生长和演化

- 是地球科学领域根本性的科学问题
- 受到国内外研究者的持续关注

大陆地壳的主要成分特征（安山质）



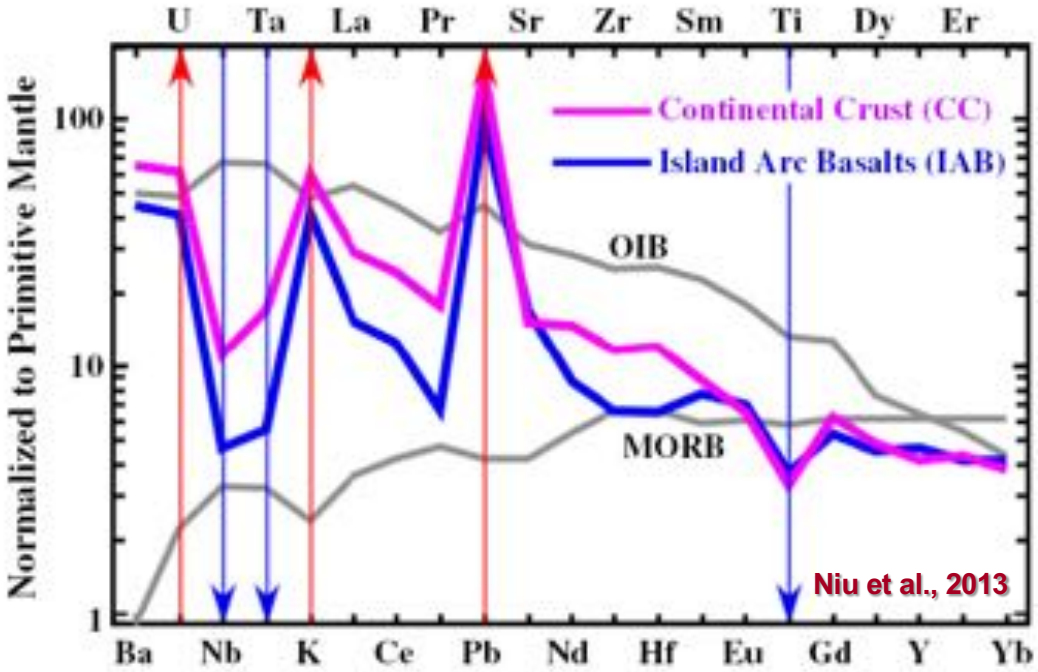


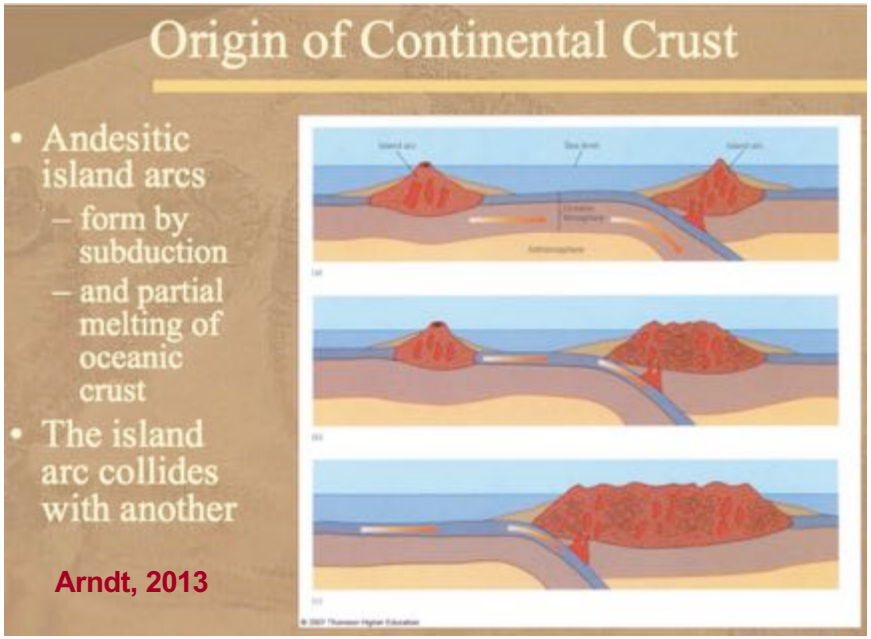
长英质岩石是研究大陆地壳的重要对象！

两阶段演化：地幔部分熔融形成基性岩浆

基性岩浆经历后期演化分异

大陆地壳的微量元素成分特征（岛弧型）

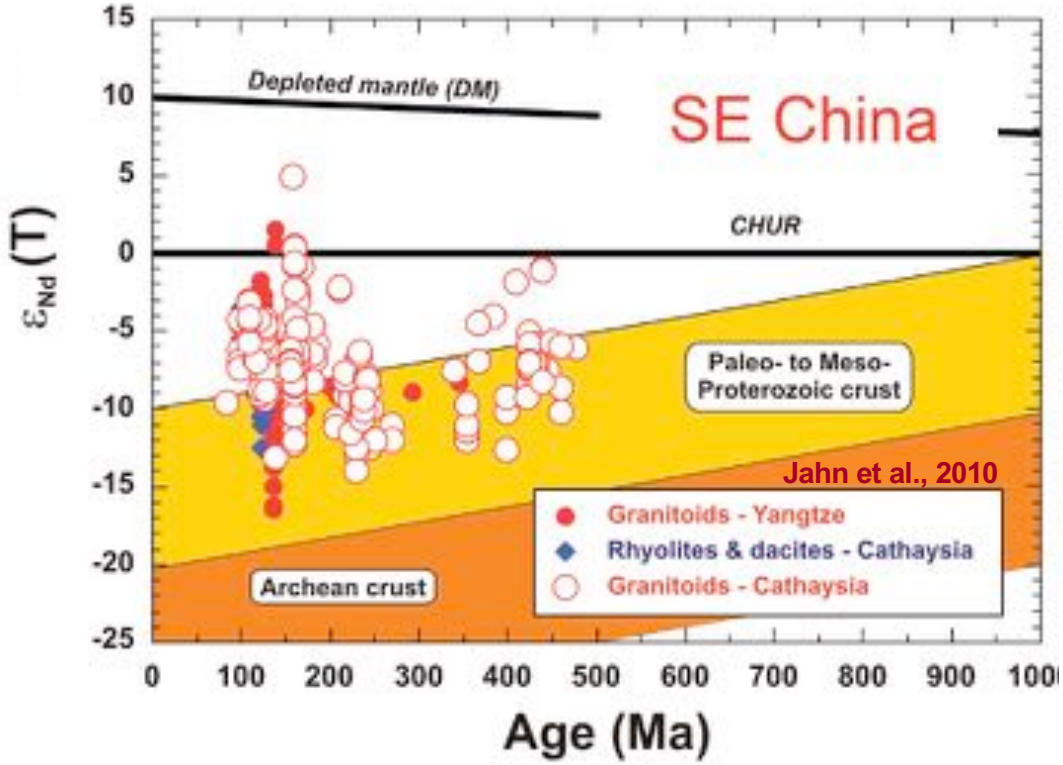




岛弧型特点：富集大离子亲石元素、亏损高场强元素

→ 大陆地壳形成与俯冲碰撞过程相关！

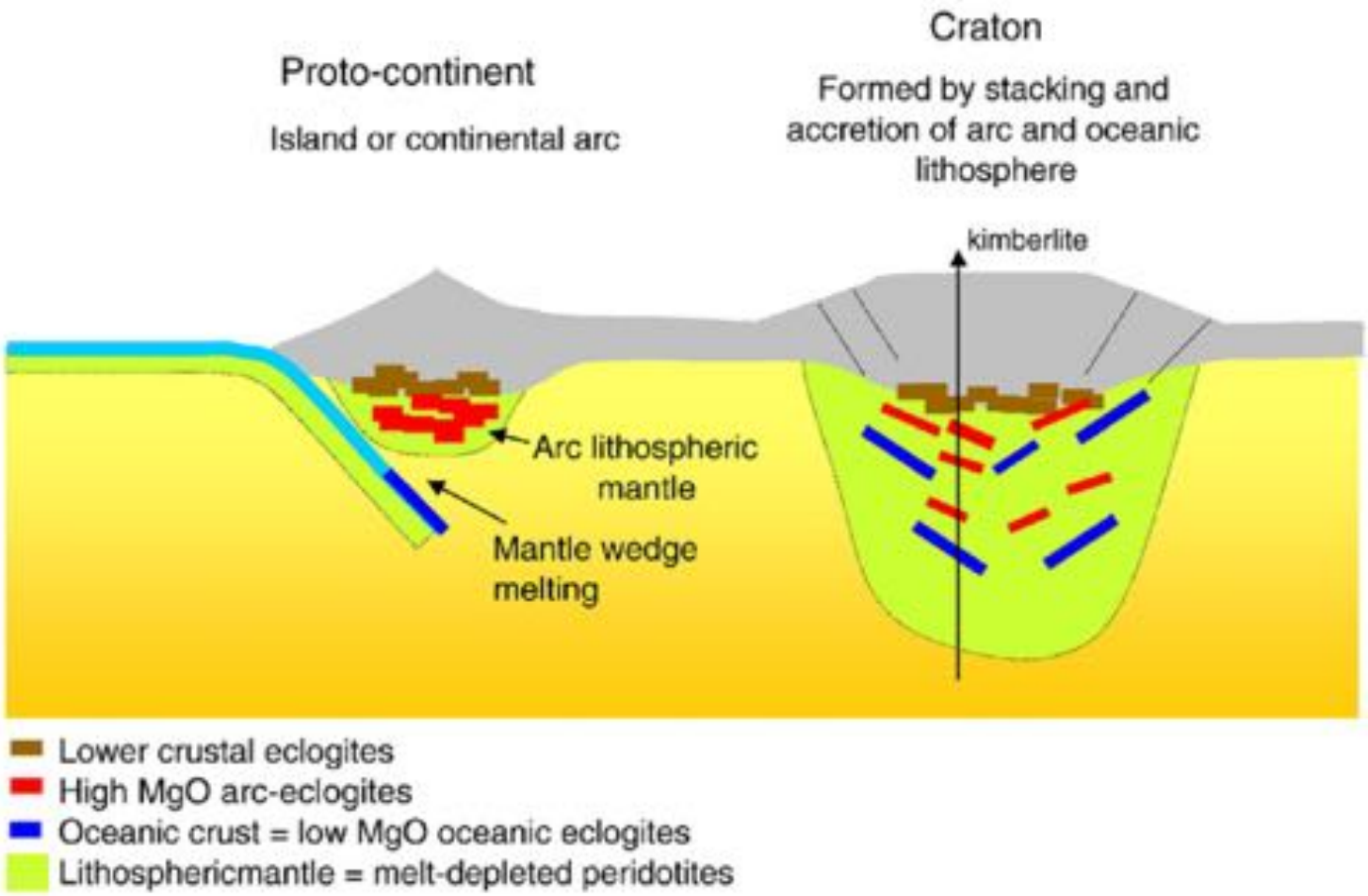
大陆地壳的同位素特征（亏损和富集）



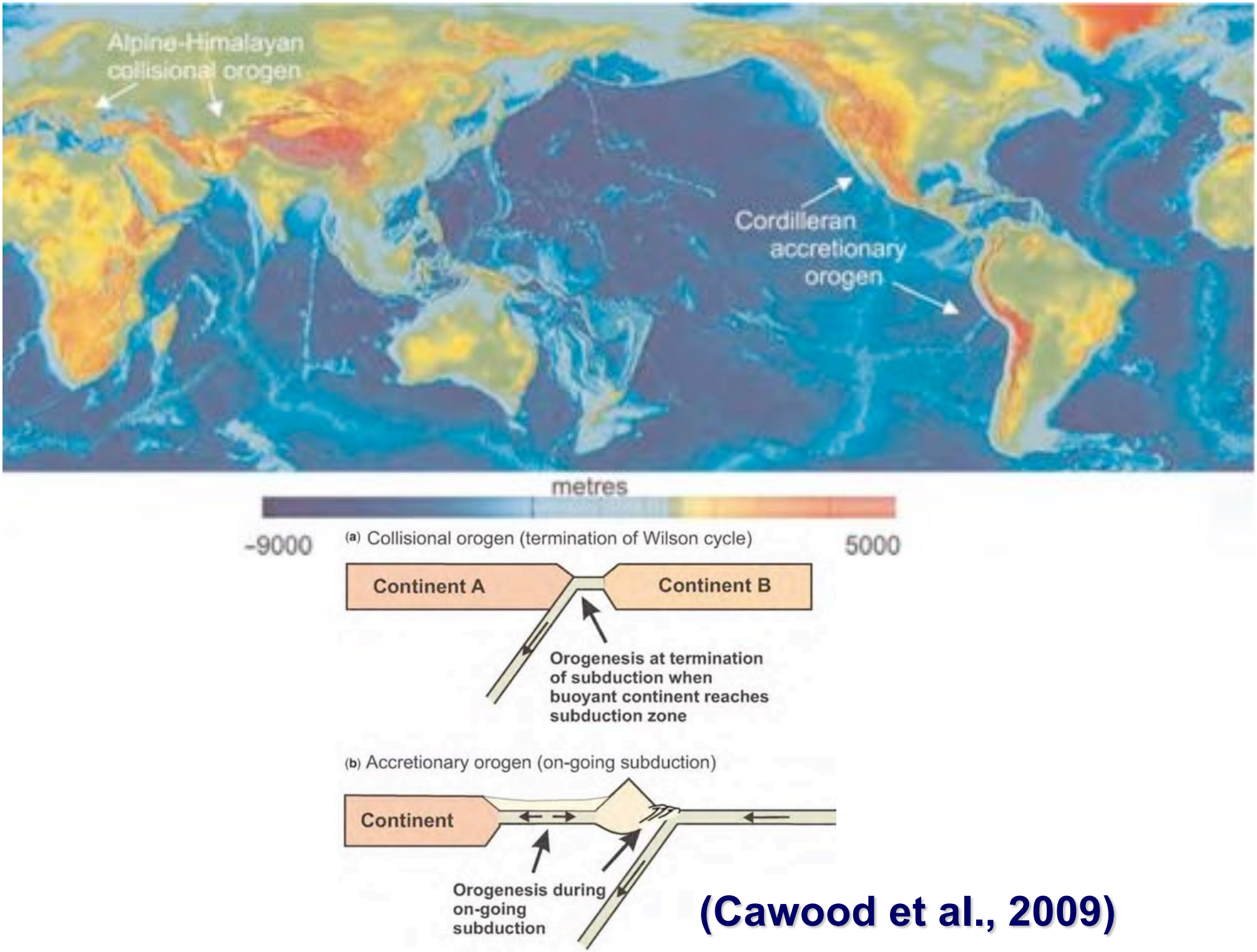
花岗质岩浆岩记录了大陆地壳的生长和演化过程

同位素亏损 → 来自地幔 → 地壳生长

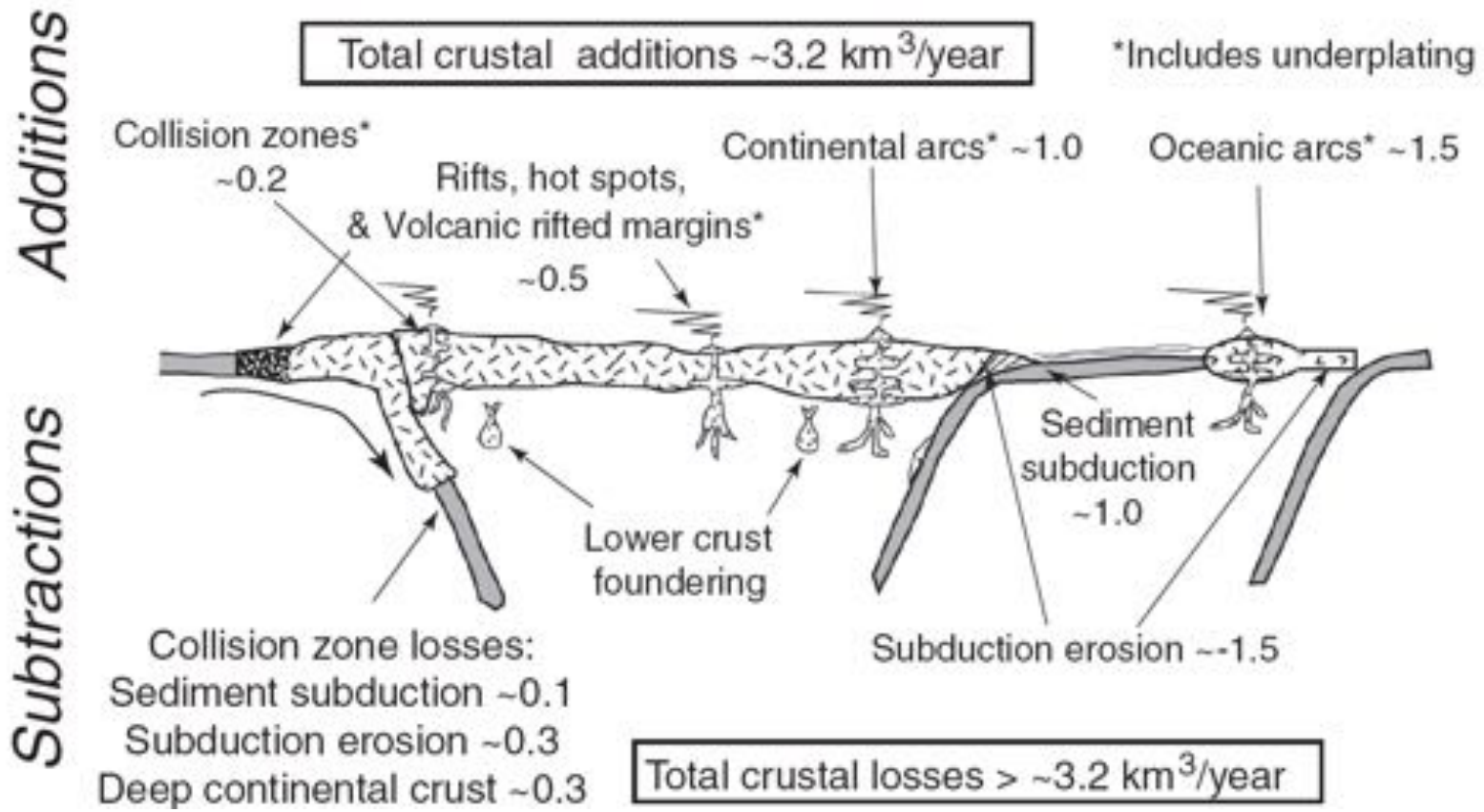
同位素富集 → 来自地壳 → 地壳演化

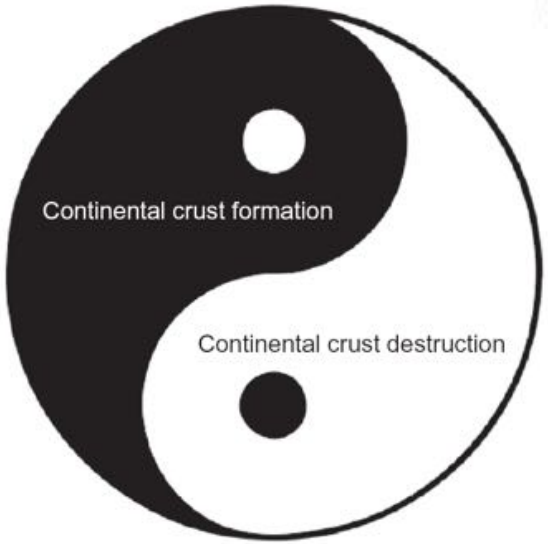


Cartoon illustrating two contrasting styles for generation of contiental crust (Modified after Horodyskyj et al., 2007)

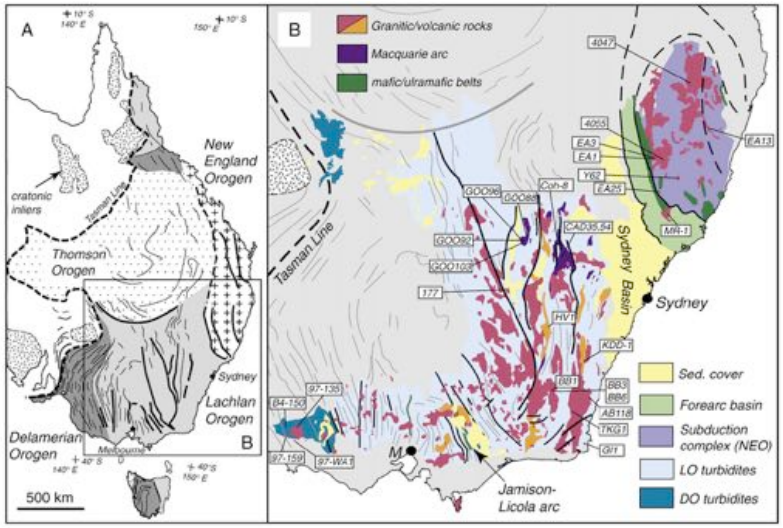


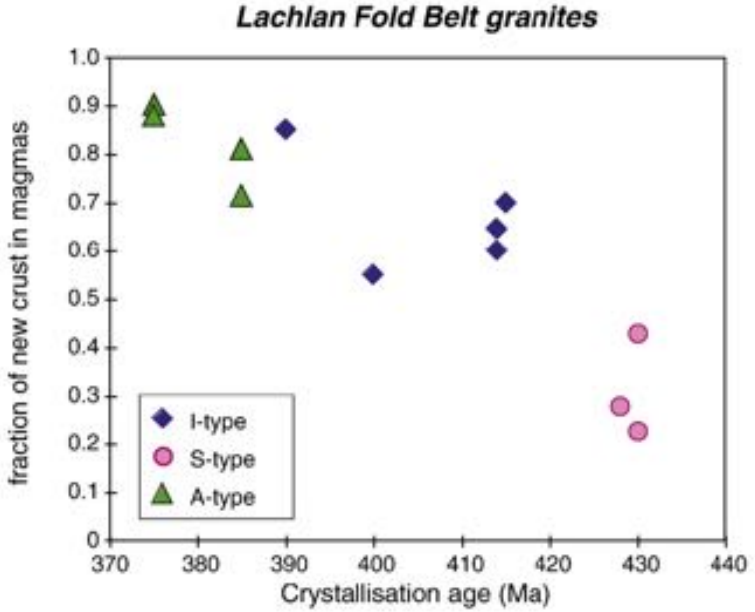
(Cawood et al., 2009)

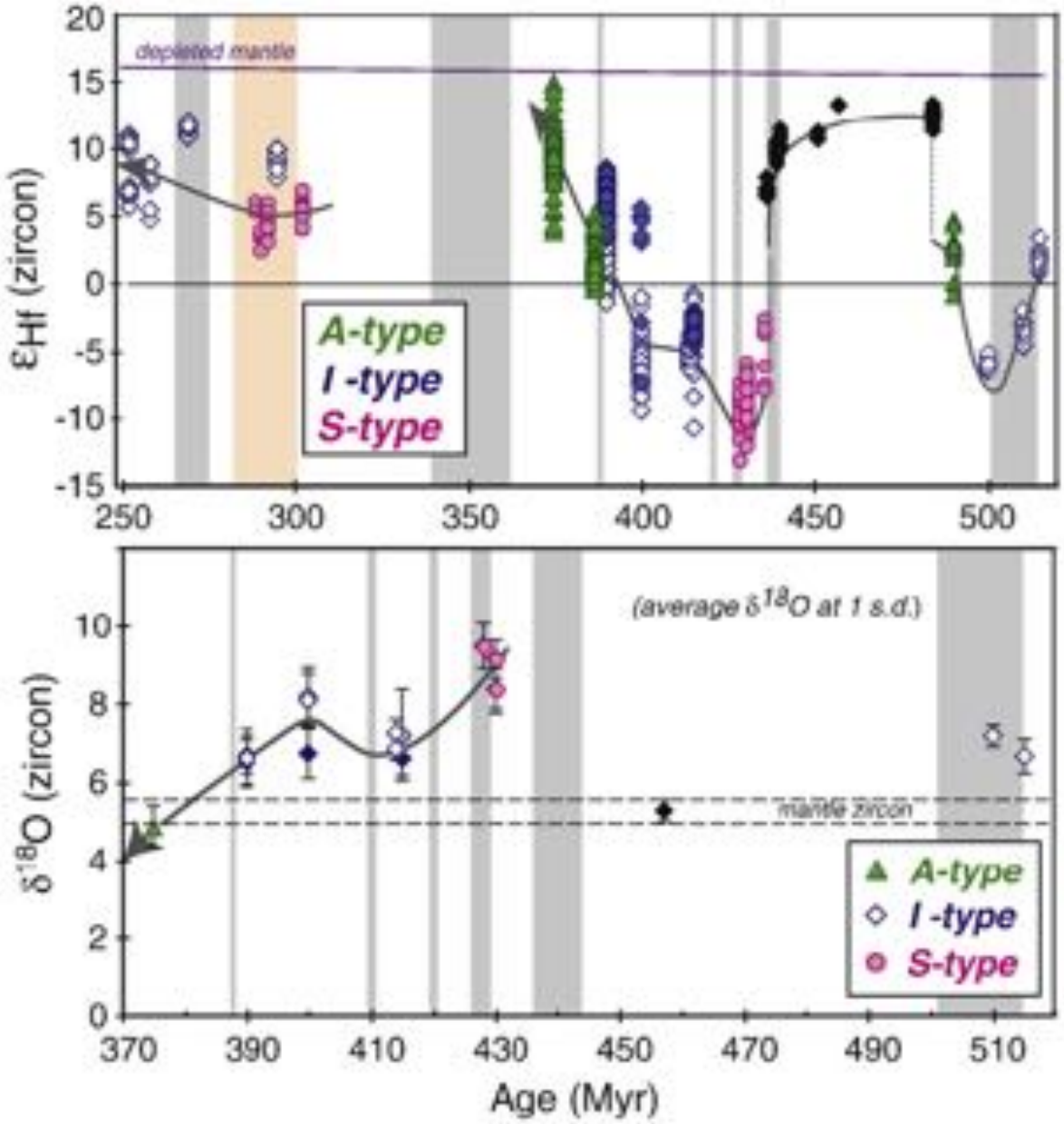




Synopsis of how continental crust forms today, note rates of crustal destruction are more poorly constrained than crustal generation (Stern et al., 2002)



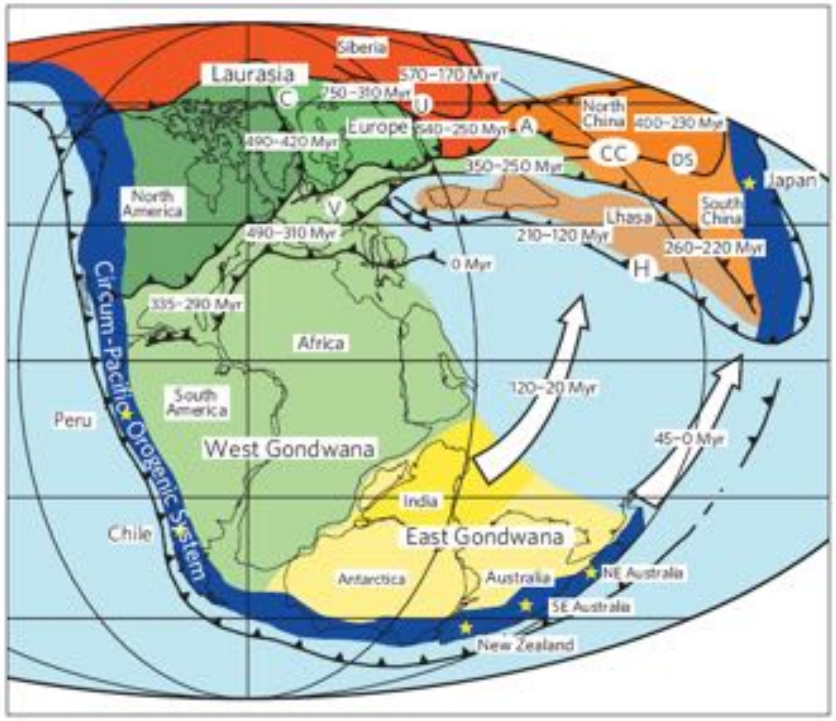


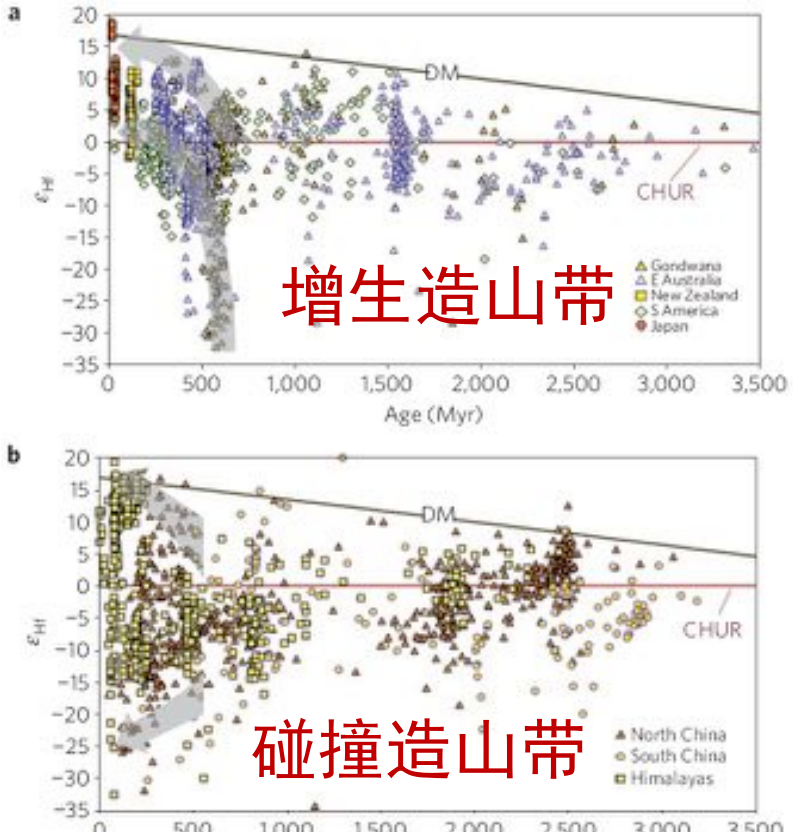


Isotopic evidence for rapid continental growth in an extensional accretionary orogen: The Tasmanides, eastern Australia

A.I.S. Kemp [a,*], C.J. Hawkesworth [b], W.J. Collins [a], C.M. Gray [a], P.L. Blevin [c], EIMF [d]

增生造山带是大陆地壳的主要生长场所？



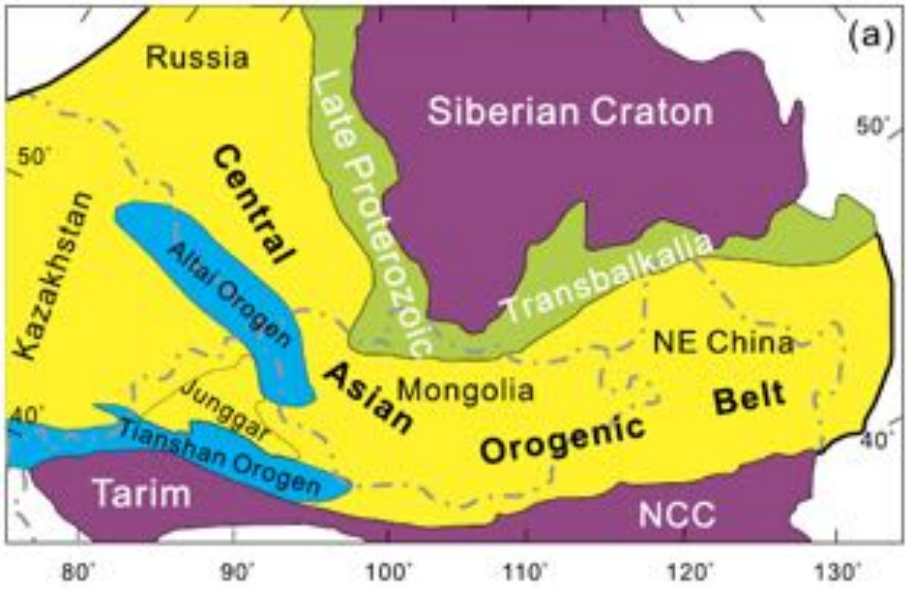


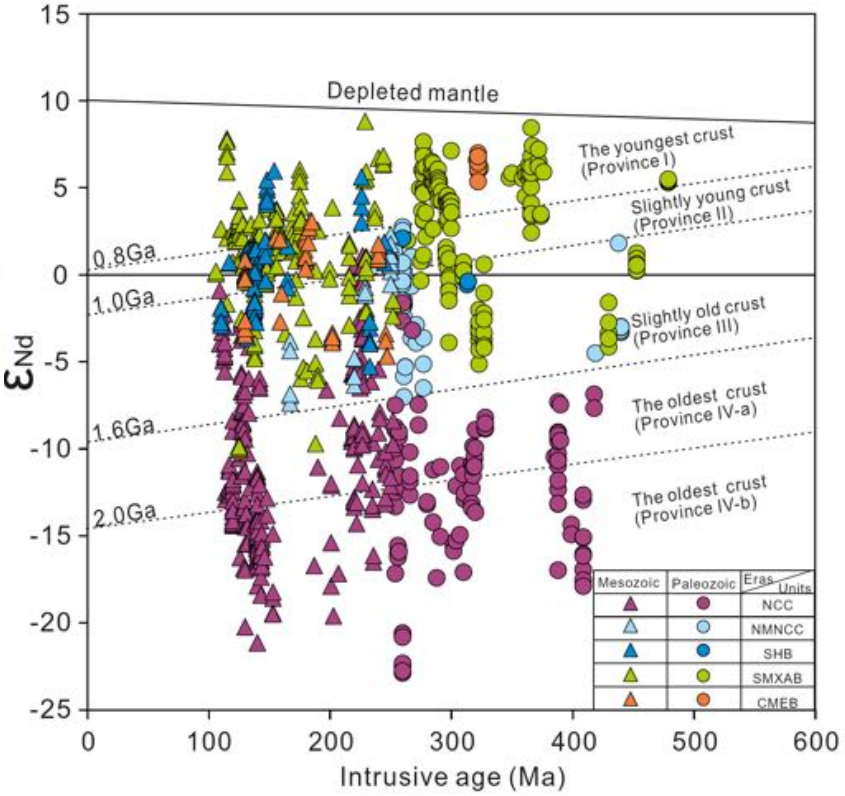
Isotopic evidence for rapid continental growth in an extensional accretionary orogen: The Tasmanides, eastern Australia

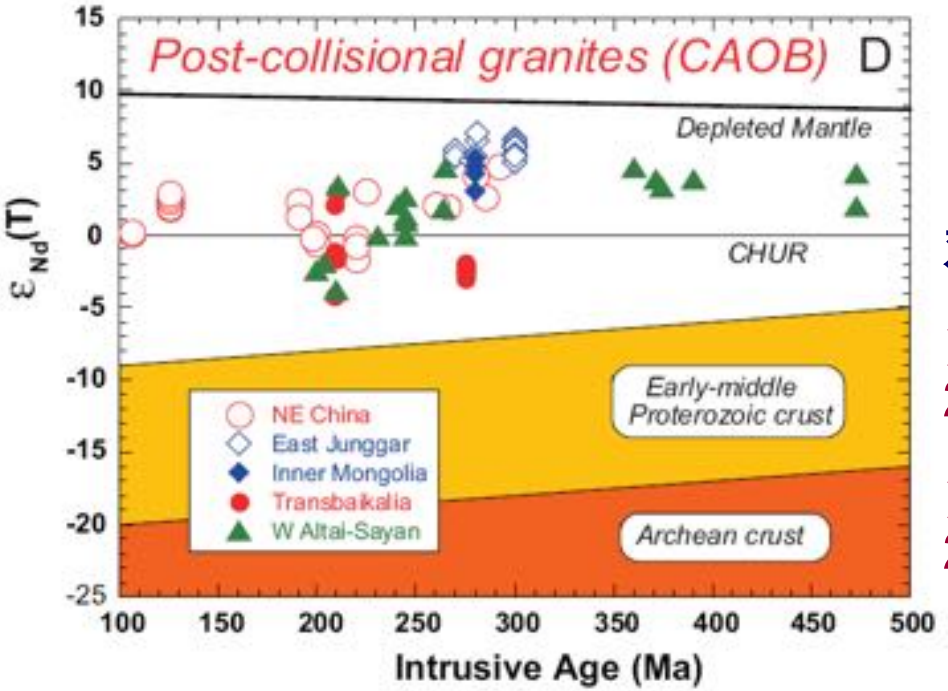
A.I.S. Kemp [a,*], C.J. Hawkesworth [b], W.J. Collins [a], C.M. Gray [a], P.L. Blevin [c], EIMF [d]

通过对全球不同类型造山带的研究发现: 显生宙以来增生造山带整体表现为地壳生长的特征(Collins et al., 2011; Kemp et al., 2009)

增生造山带是大陆地壳的主要生长场所？



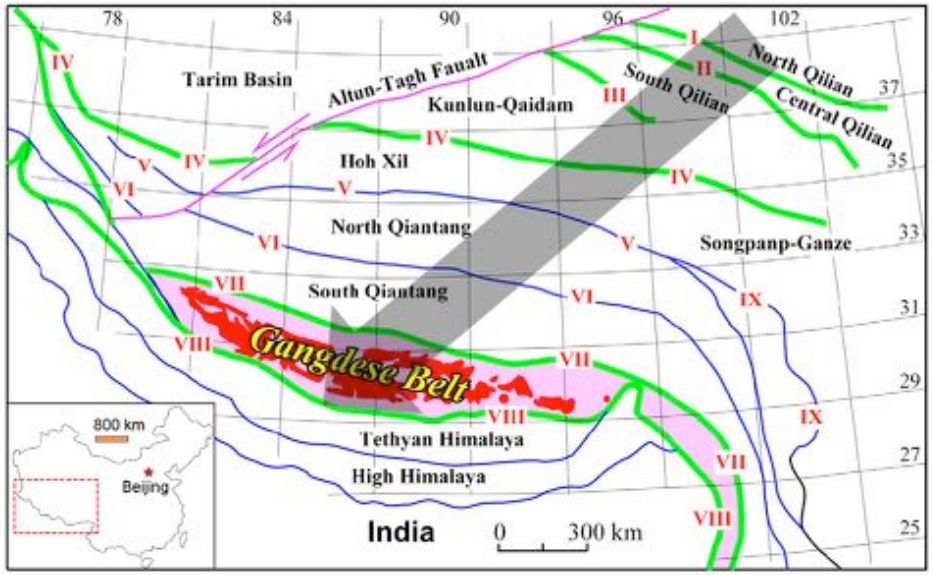


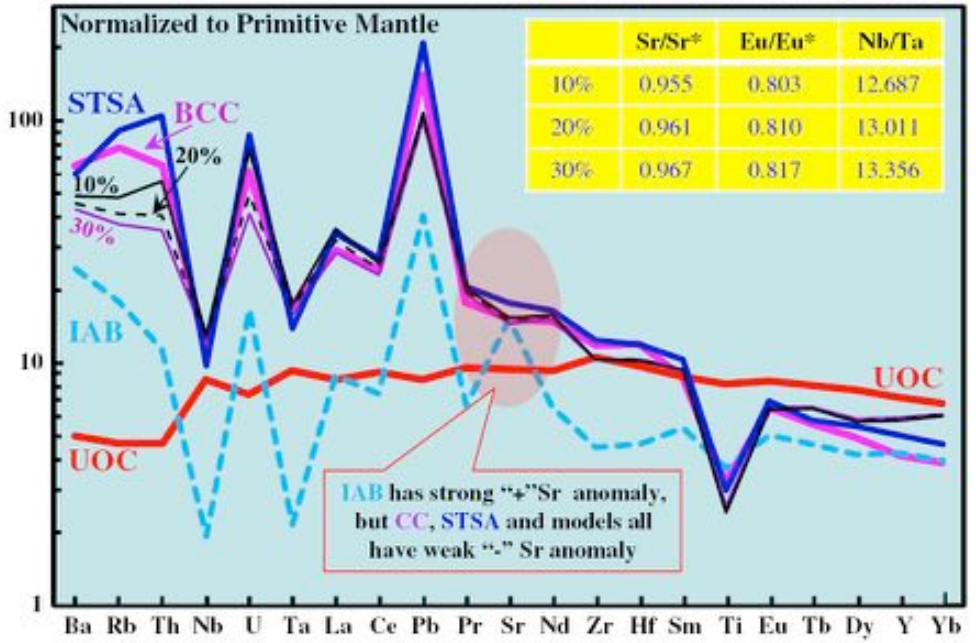


对全球最大的增生造山带中亚造山带的研究

- 70%以上大陆地壳的生长 (Jahn et al., 2010; Wu et al., 2004)
- 约20%大陆地壳的生长 (Kroner et al., 2017)

碰撞造山带是大陆地壳的主要生长场所？





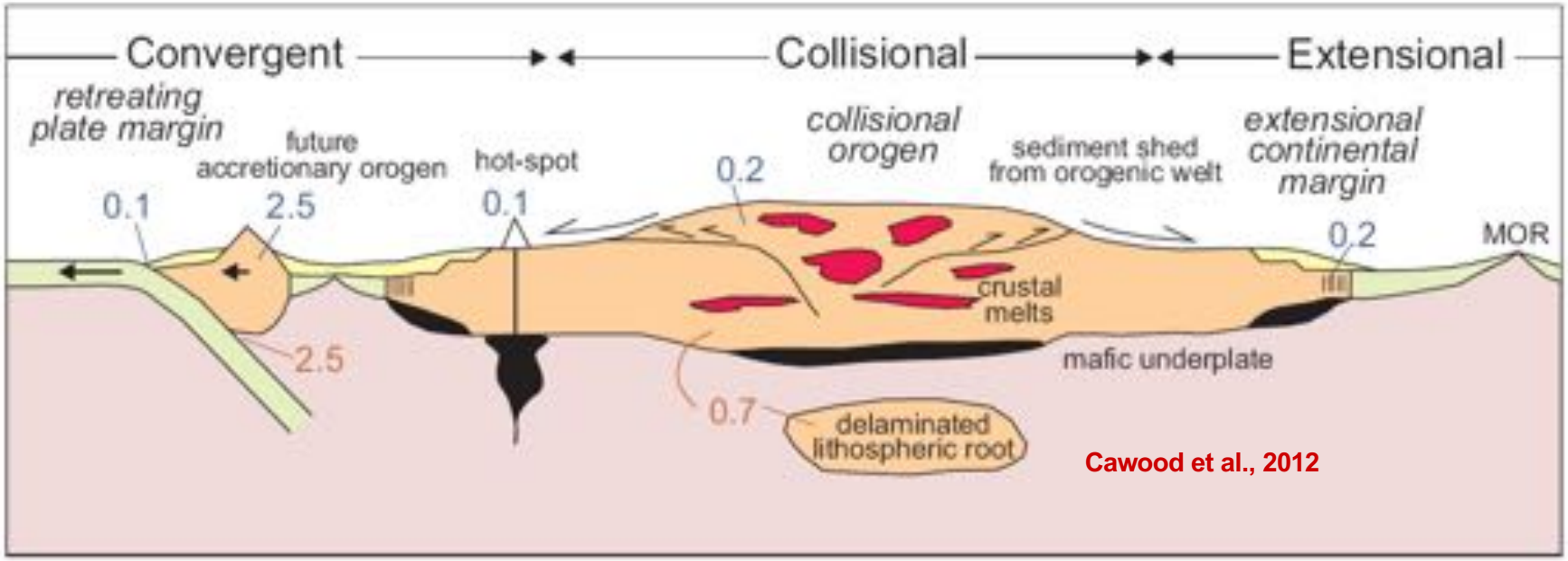
Continental collision zones are primary sites for net continental crust growth — A testable hypothesis

Yaoling Niu [a,b,c,*], Zhidan Zhao [c], Di-Cheng Zhu [c], Xuanxue Mo [c]

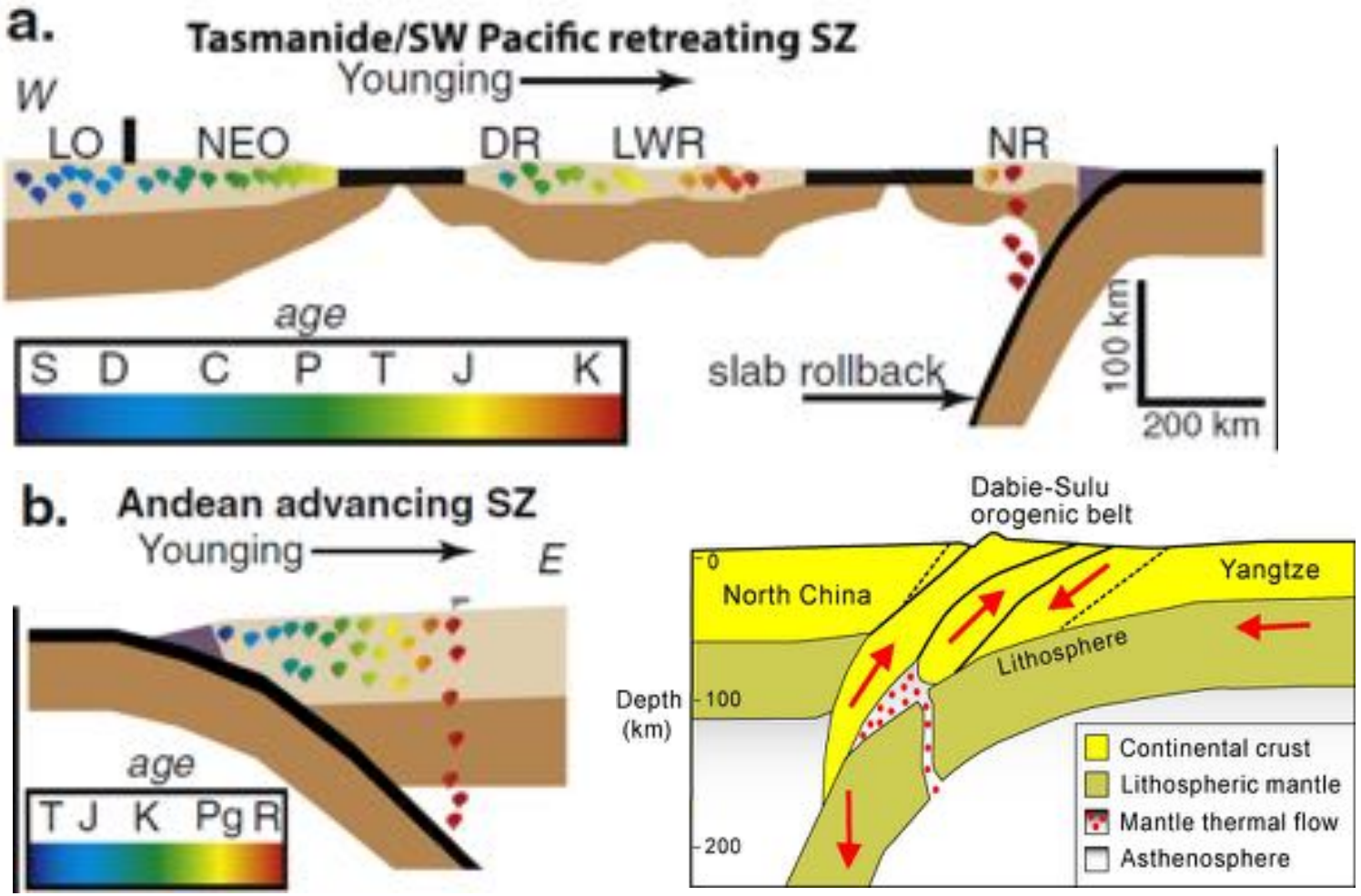
青藏高原由一系列碰撞造山带构成
岩浆岩具有安山质大陆地壳的成分

碰撞造山带是大陆地壳生长的主要场所 (Niu et al., 2013; Song et al., 2015)

大陆地壳的生长

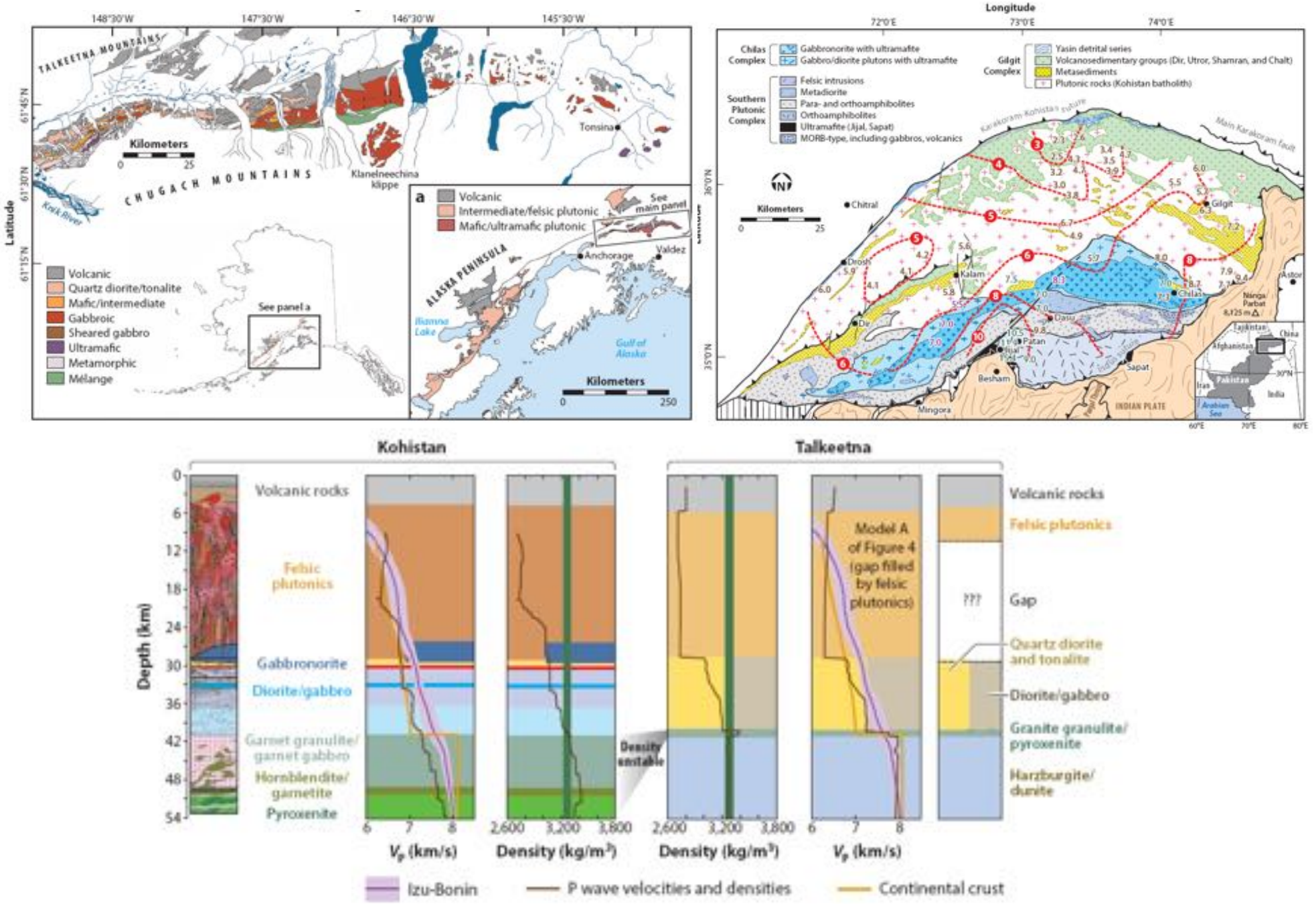


洋弧增生、陆弧增生或幔源岩浆底侵？

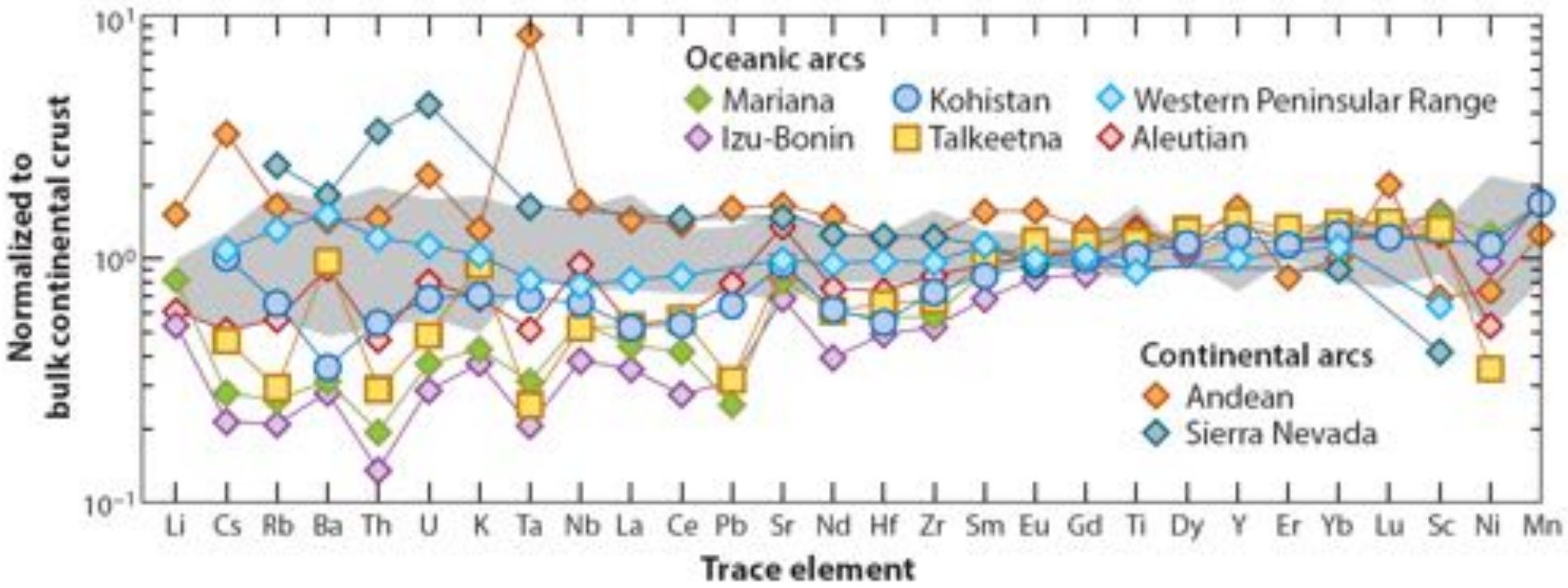


洋弧增生、陆弧增生或碰撞造山有不同的岩浆类型(Spencer et al., 2017)

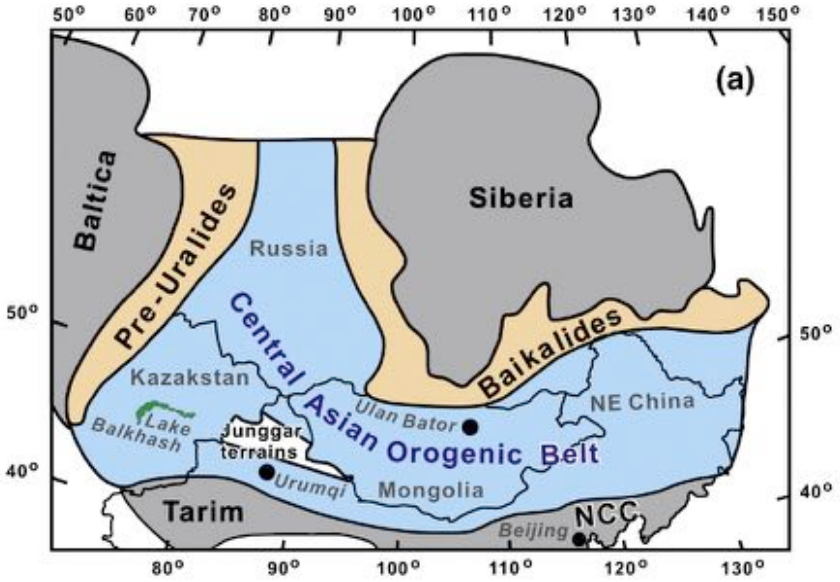
对应大陆地壳的不同生长方式

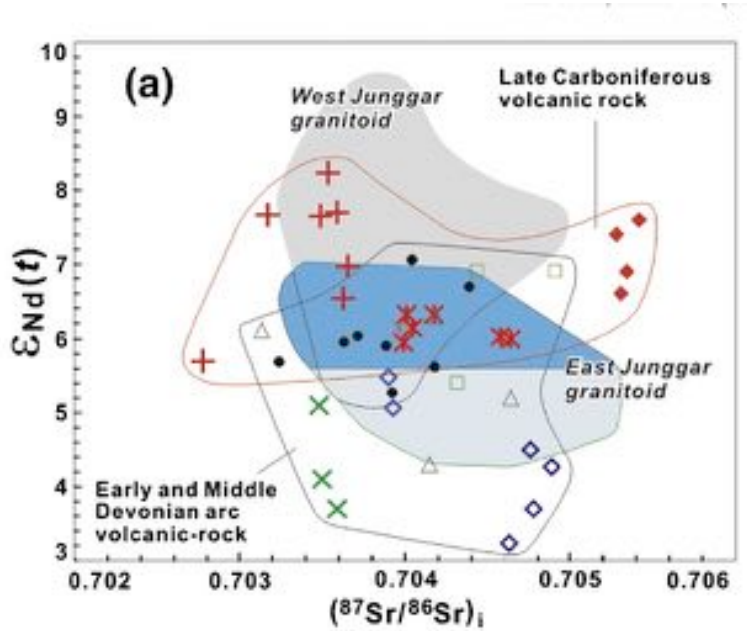


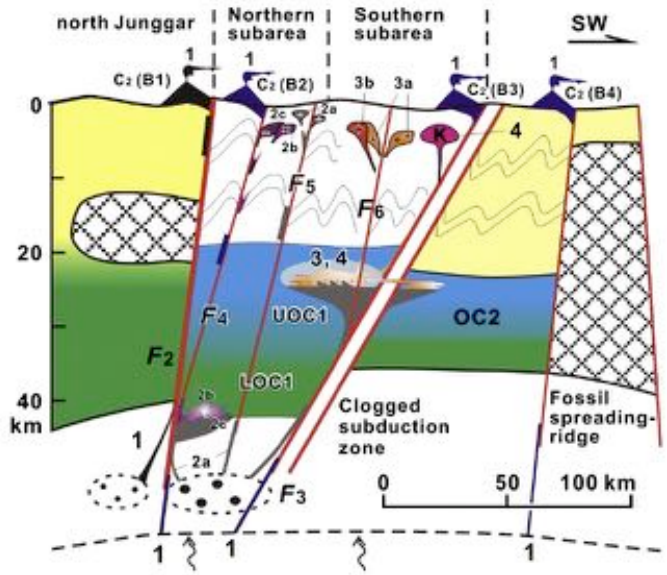
Schematic illustrations of the lithological, seismic and density properties of the Kohistan and Talkeetna arc sections (Jagoutz and Kelemen, 2015)

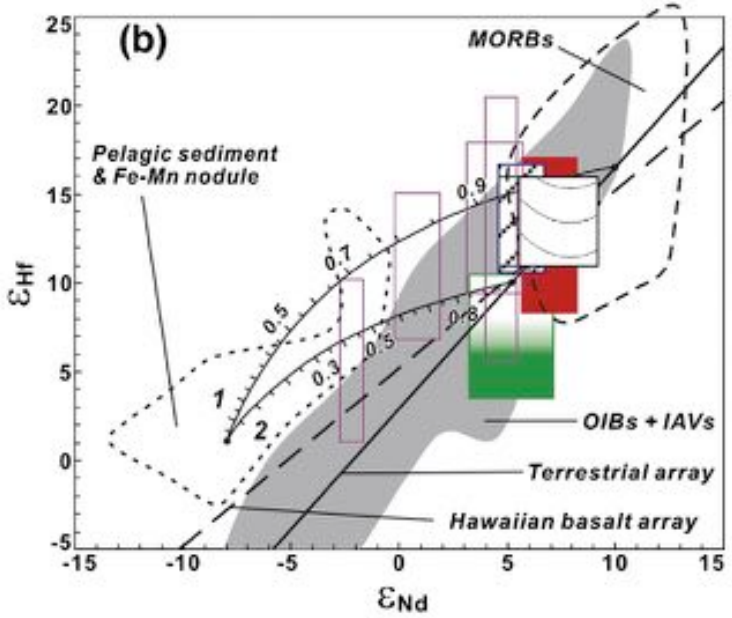


Continental crust–normalized trace element diagram of averaged volcanic and plutonic rocks from active arcs (Jagoutz and Kelemen, 2015)



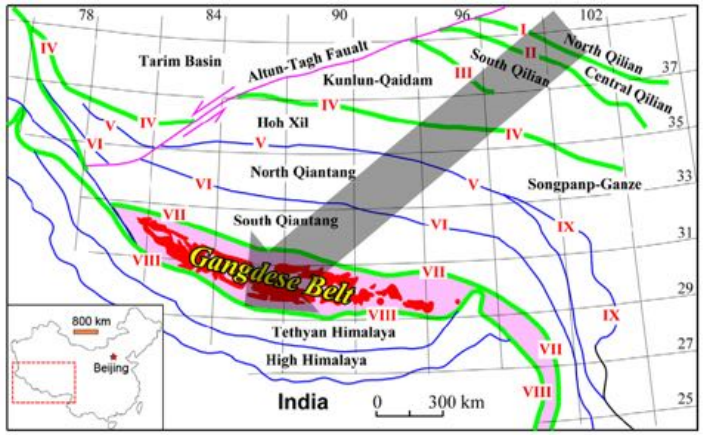


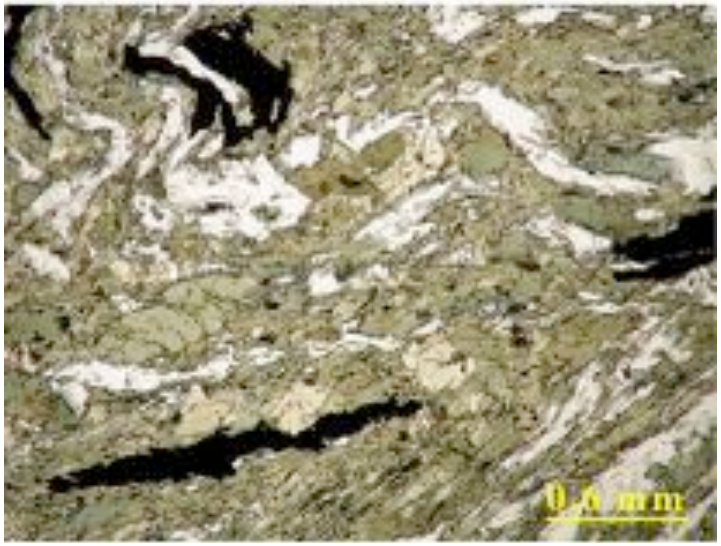


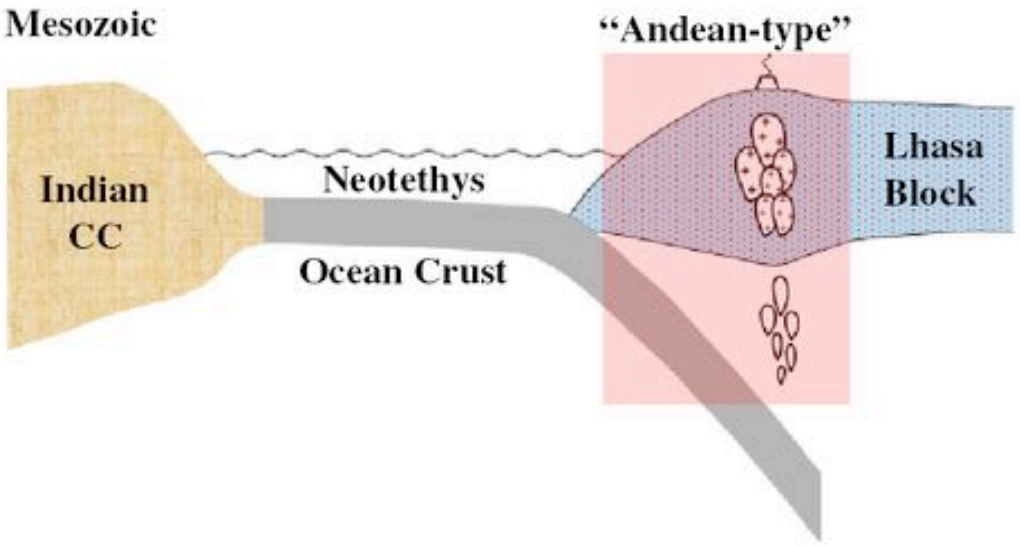


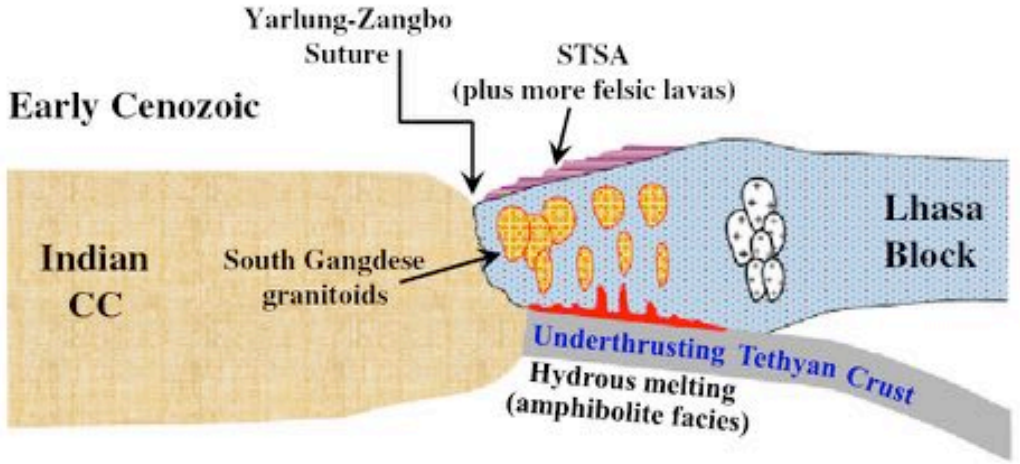
Generation of A- and I-type granitoids of the East Junggar from the lower and the upper oceanic crust with mixing of mafic magma (Liu et al., 2013)

碰撞造山是大陆地壳生长

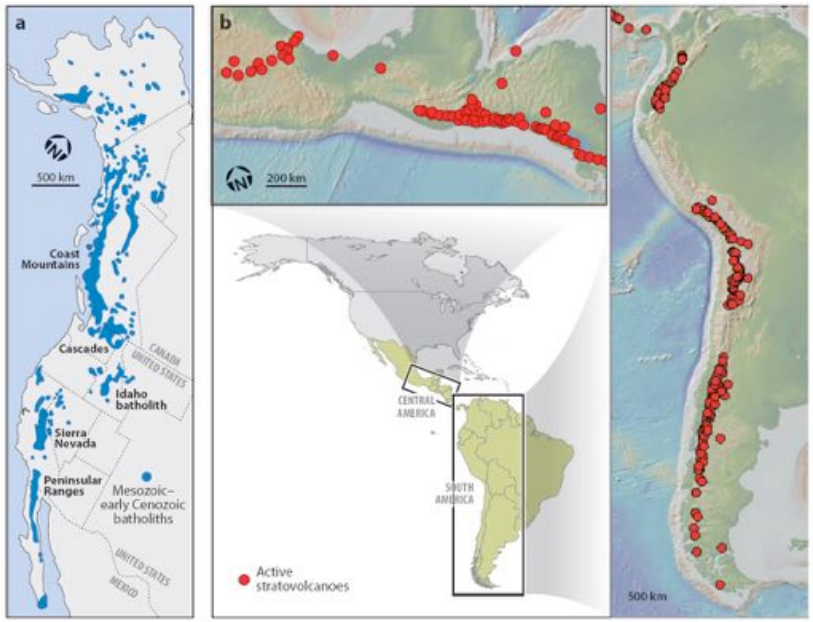


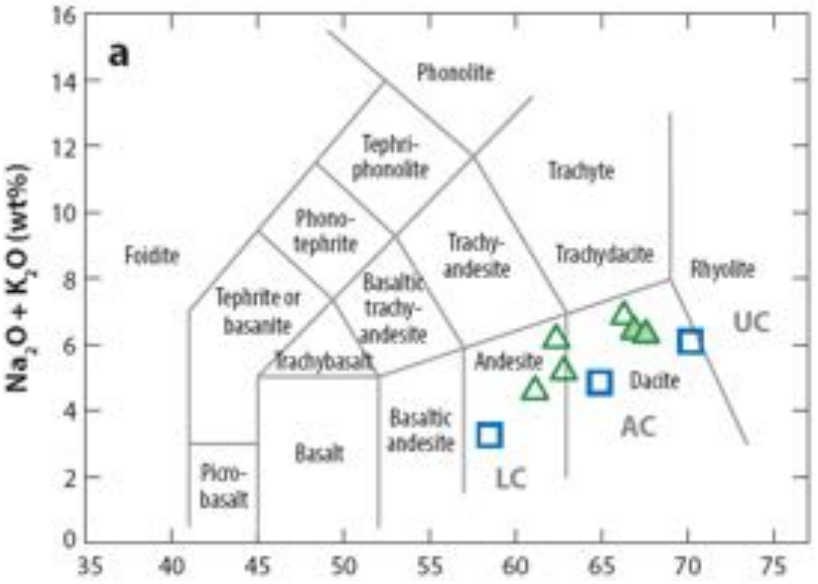


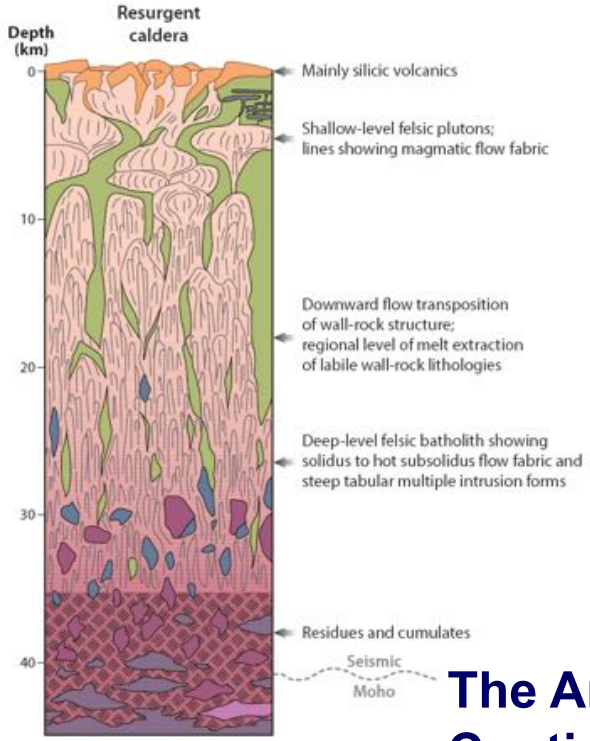


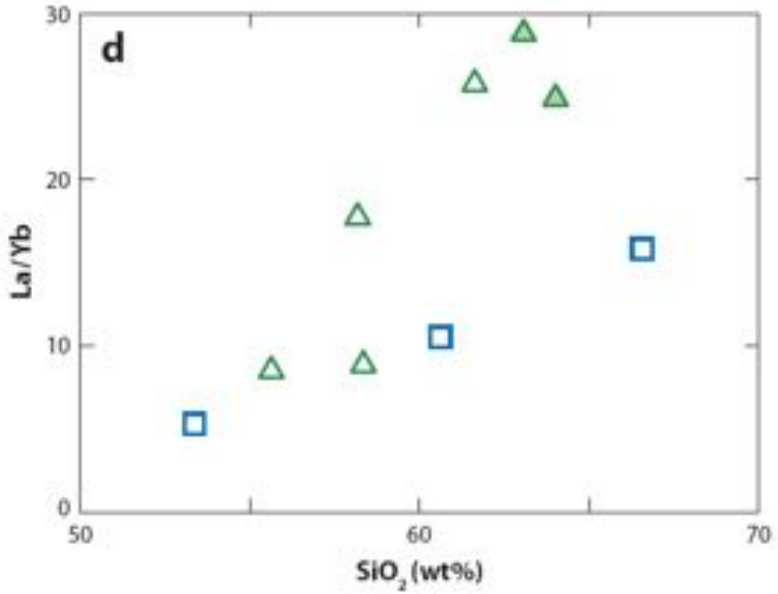


碰撞造山是大陆地壳的主要生长方式：前期俯冲洋壳 (Niu et al., 2013)



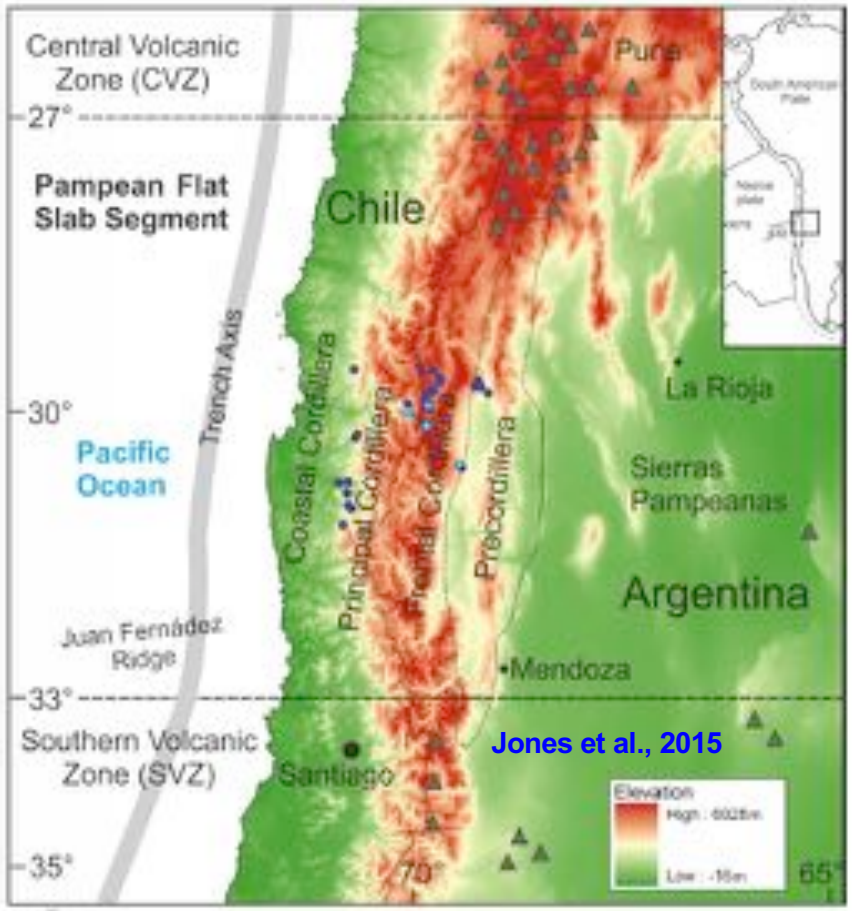


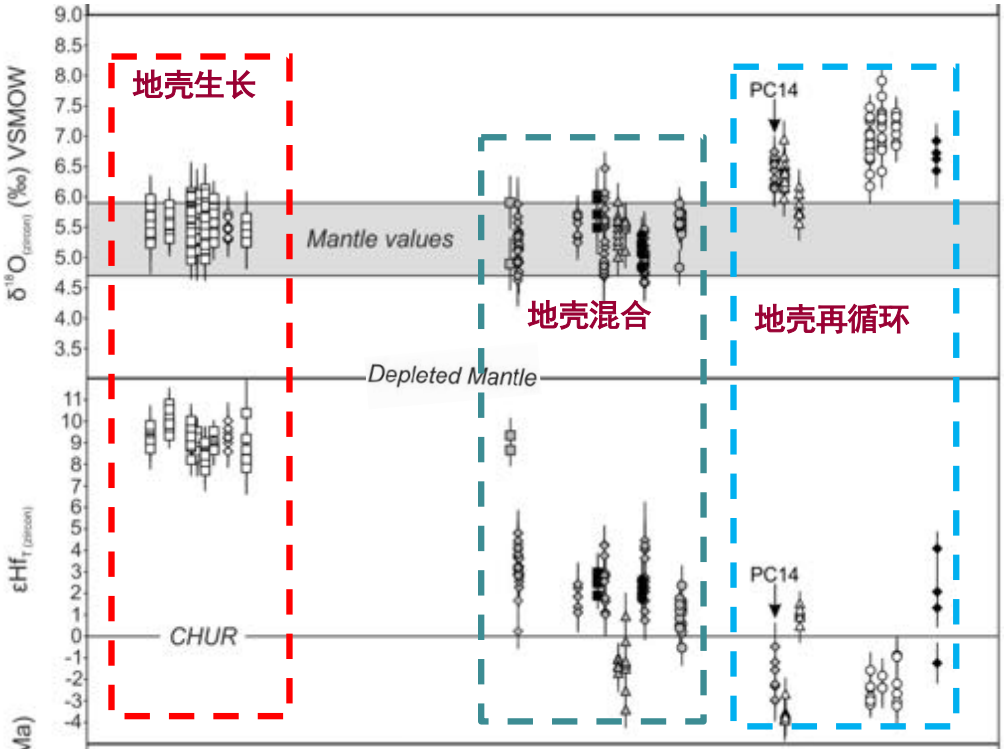




The Architecture, Chemistry, and Evolution of Continental Magmatic Arcs (Ducea et al., 2015)

增生陆弧是大陆地壳的主要生长方式

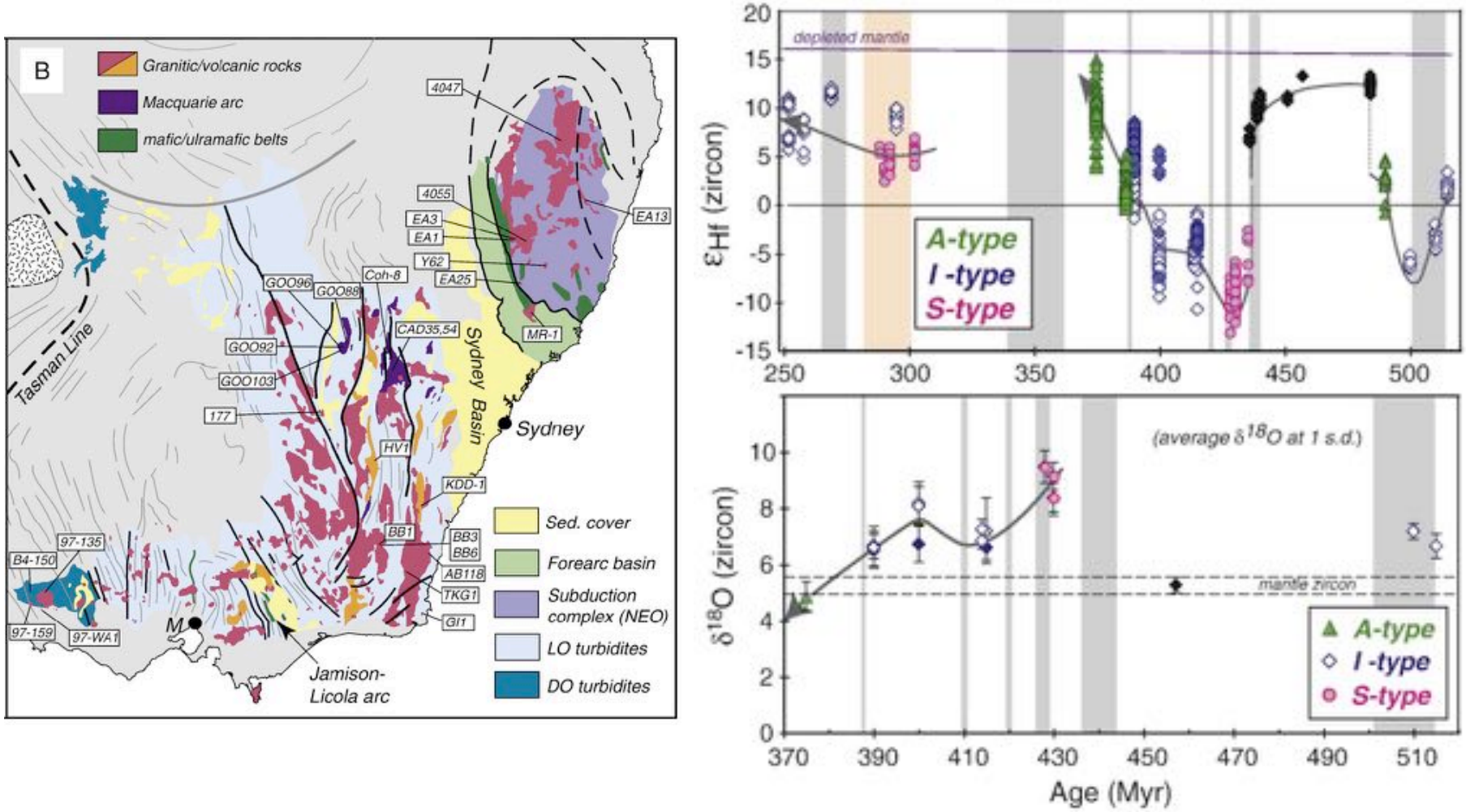




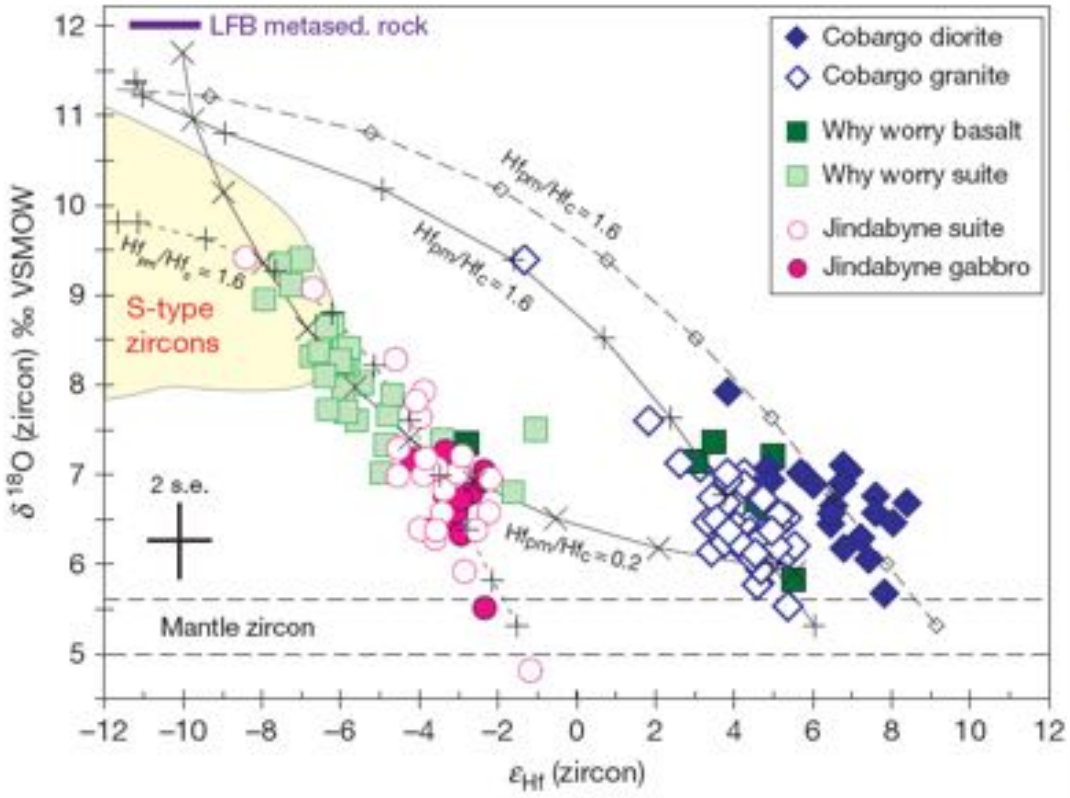
通过对典型的增生陆弧-安第斯弧系统研究发现：

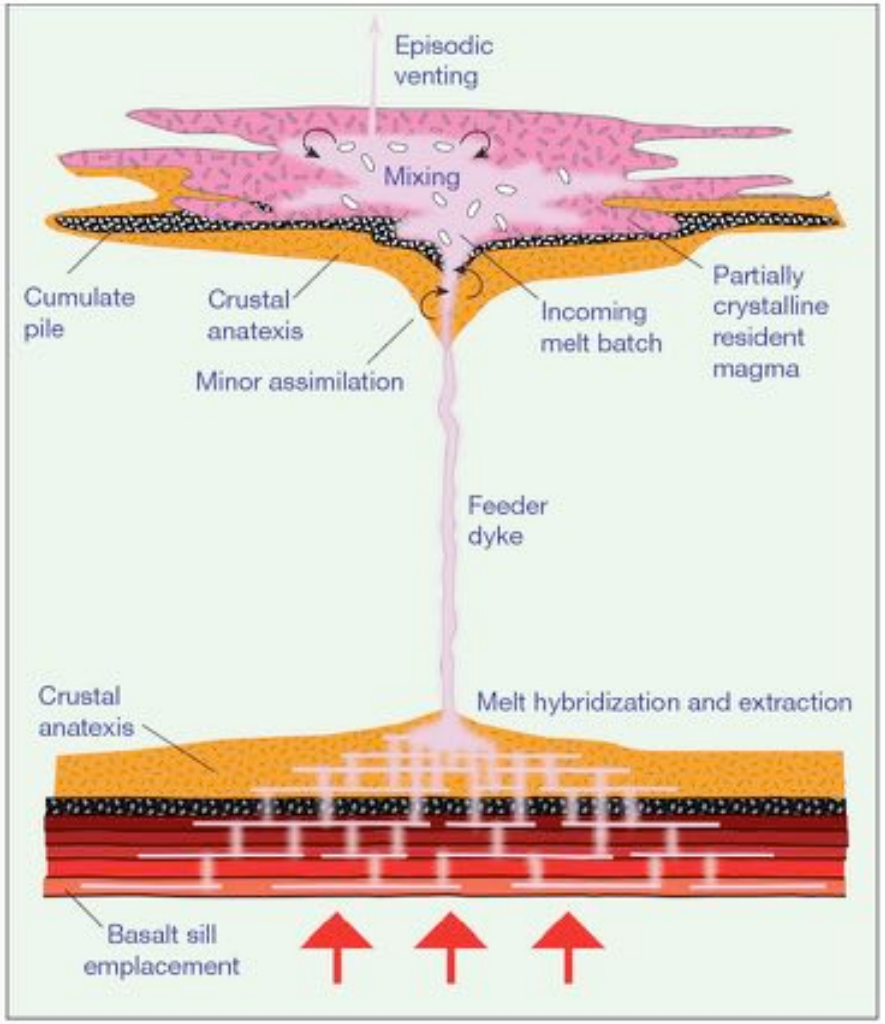
地壳生长、地壳再循环和地壳混合 (Jones et al., 2015)

基性岩浆底侵分异与大陆地壳生长

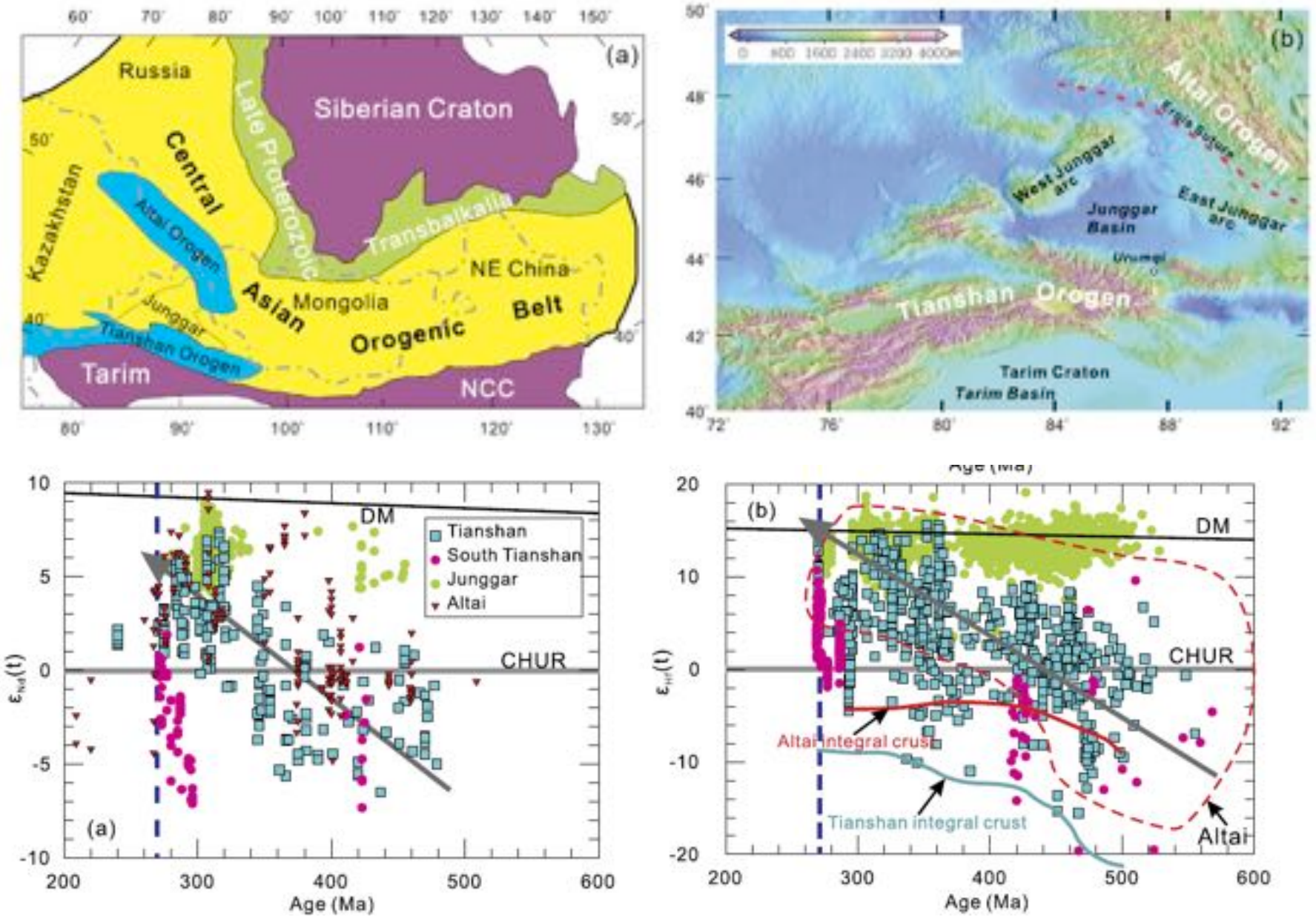


对澳大利亚西南部Tasmanides造山带的研究发现：大陆地壳明显特征 (Kemp et al., 2009)

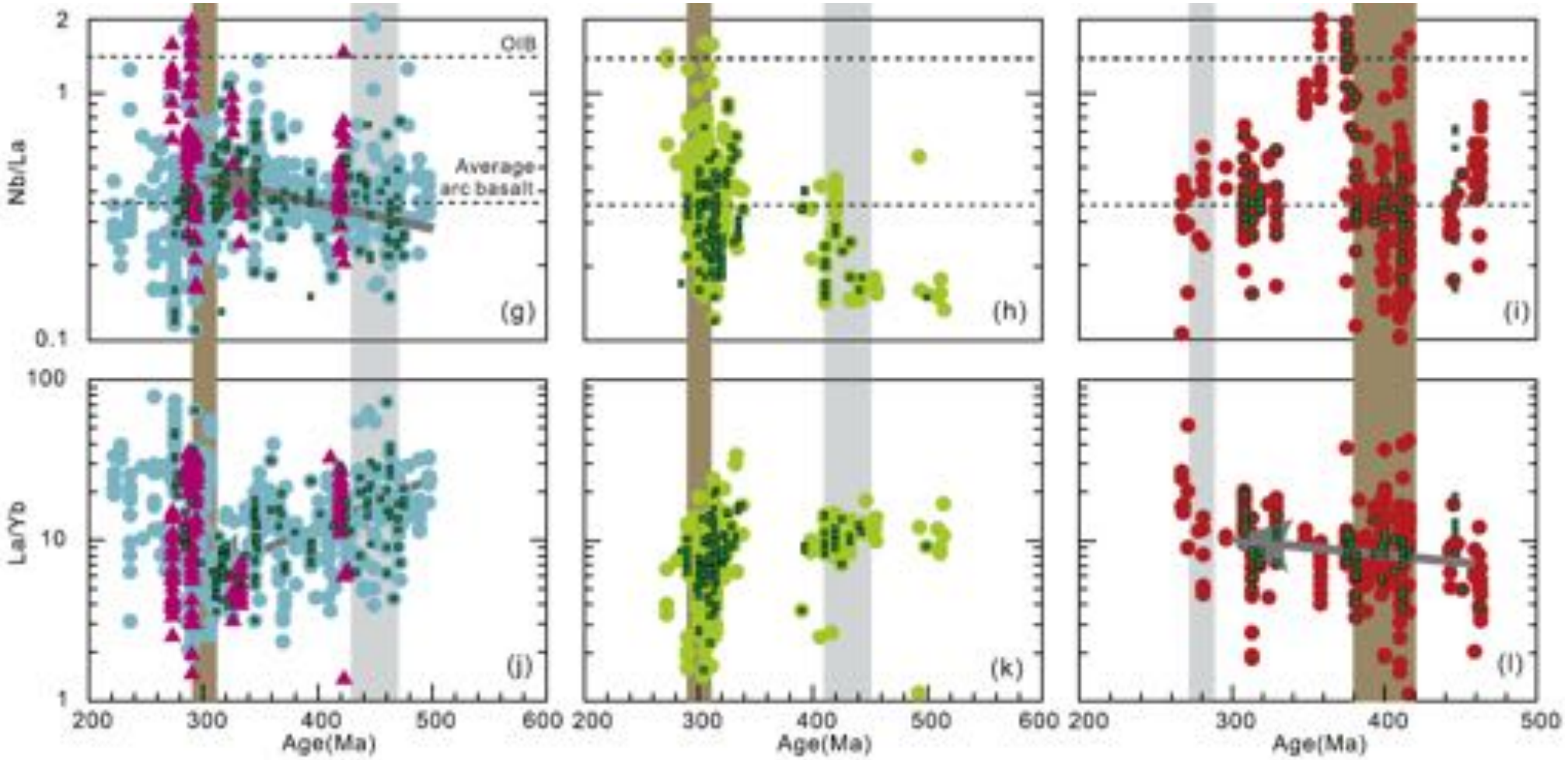




Crustal growth from mafic magmatism underplating by zircon isotope compositions in granite (Kemp et al., 2007)

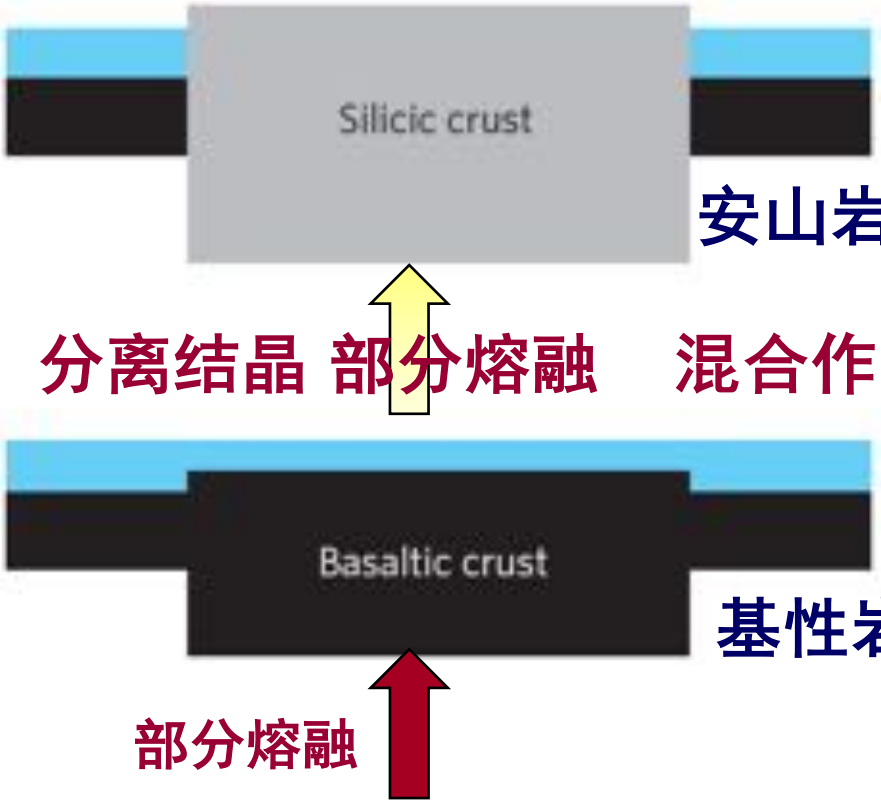


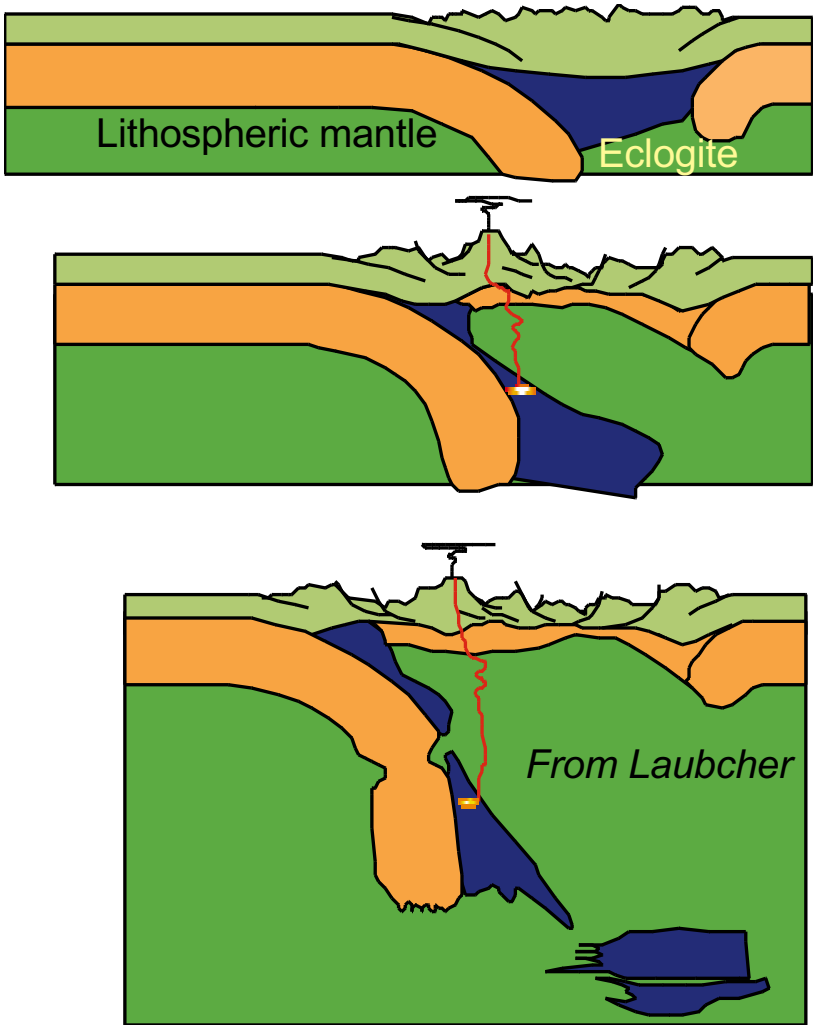
Whole rock Nd and Zircon Hf isotopic values of granitic rocks from the Altai, Junggar and Chinese Tianshan segments (Tang et al., 2017)



An increased contribution of intraplate magmatism, linked to an increased role of extensional tectonics (Tang et al., 2017)

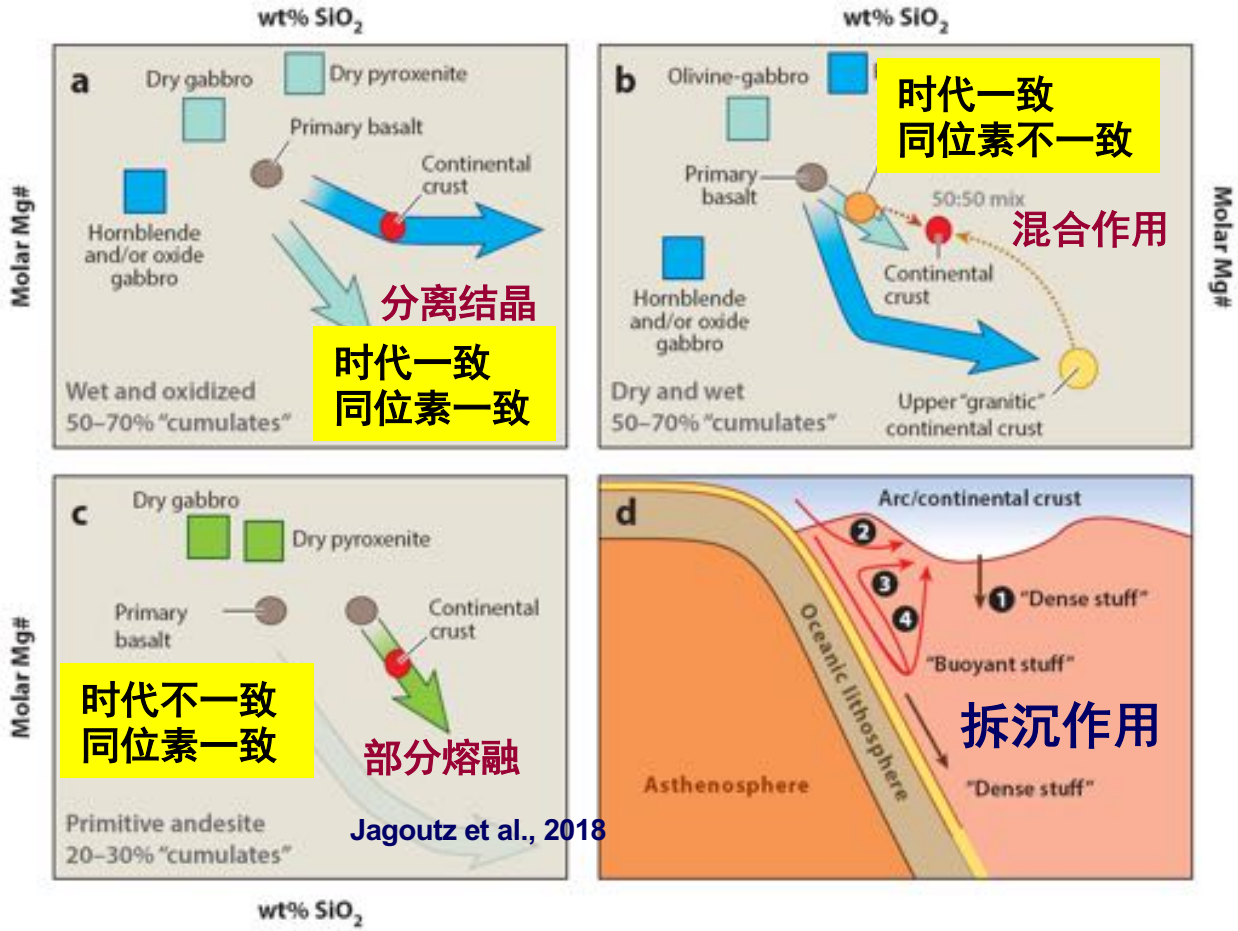
大陆地壳的演化和再造





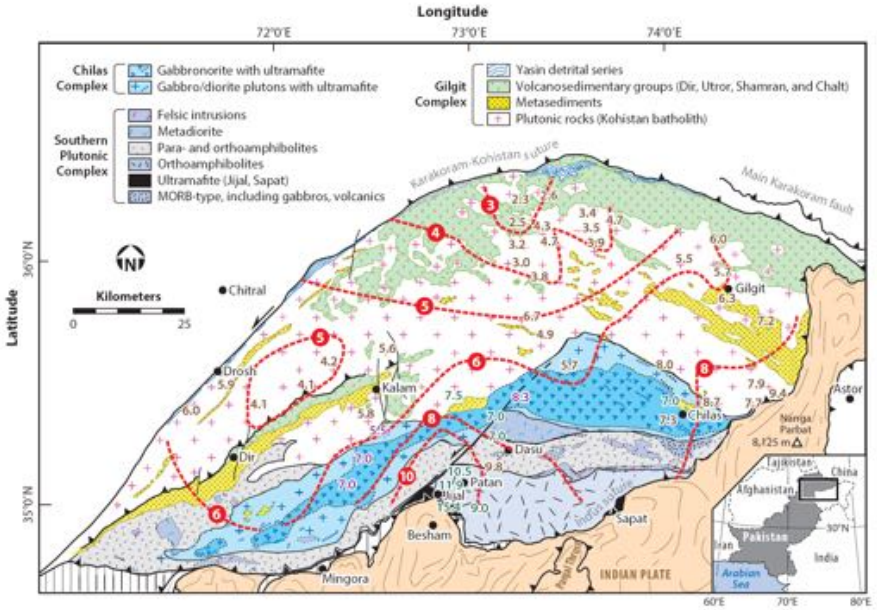
Lower Crustal foundering

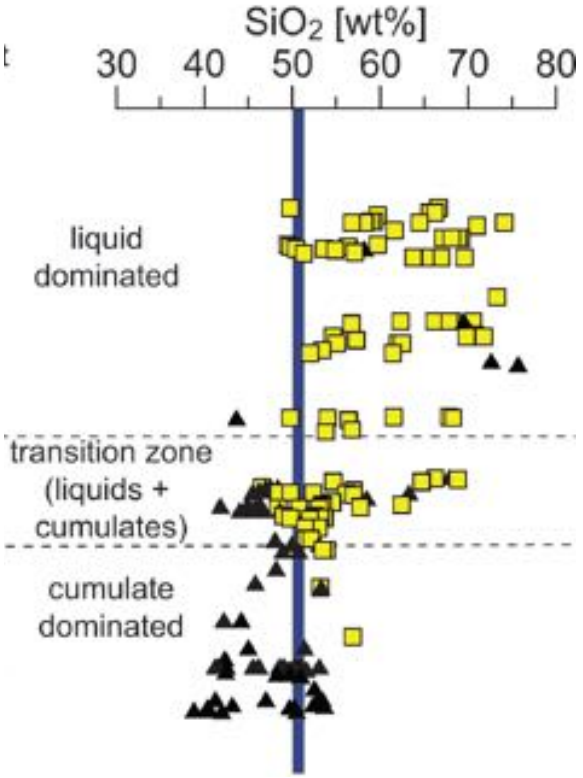
3、大陆地壳演化的过程



Jagoutz et al., 2018

结晶分异是大陆地壳的主要演化和再造过程？





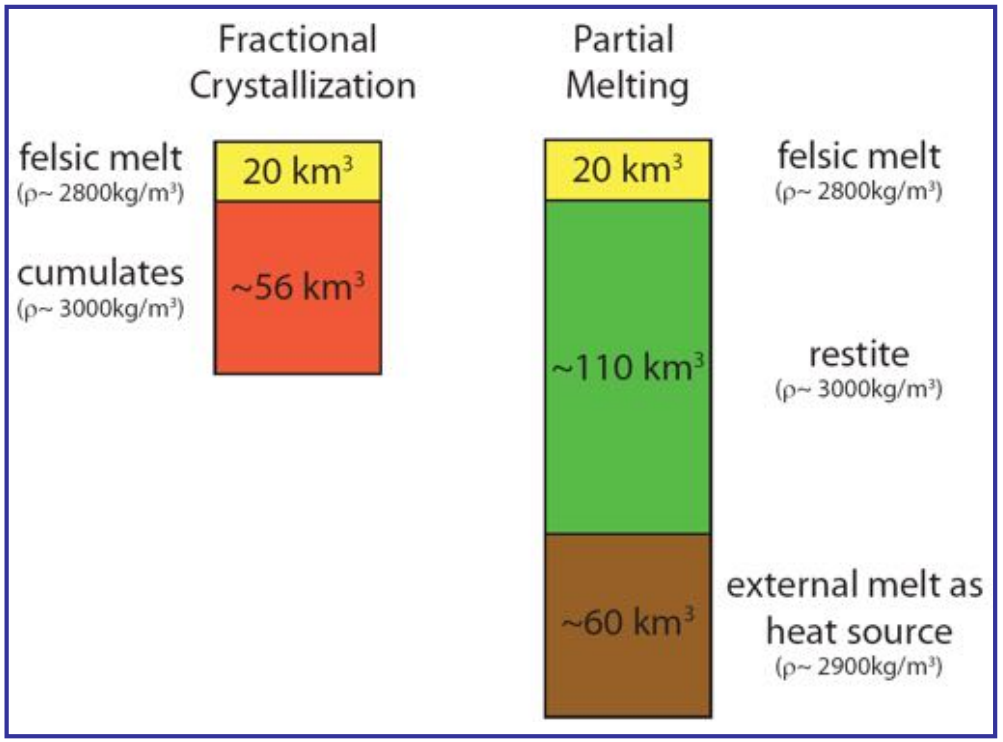
对喜马拉雅造山带Kohistan弧的研究发现：

大陆地壳演化成长英质成分的主要过程为

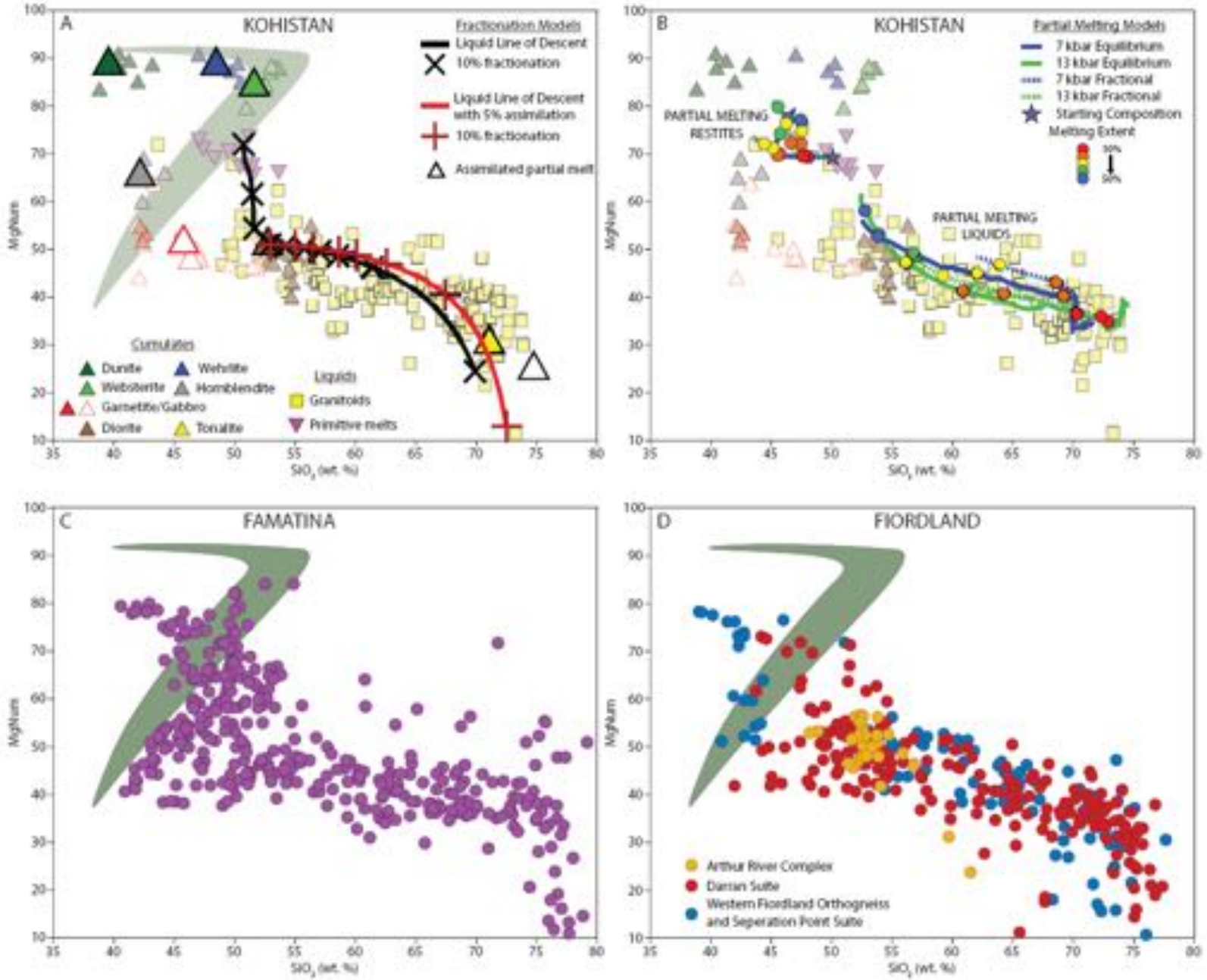
结晶分异 (Jagoutz et al., 2018)

[American Journal of Science, Vol. 318, January, 2018, P. 29–63, DOI 10.2475/01.2018.03]

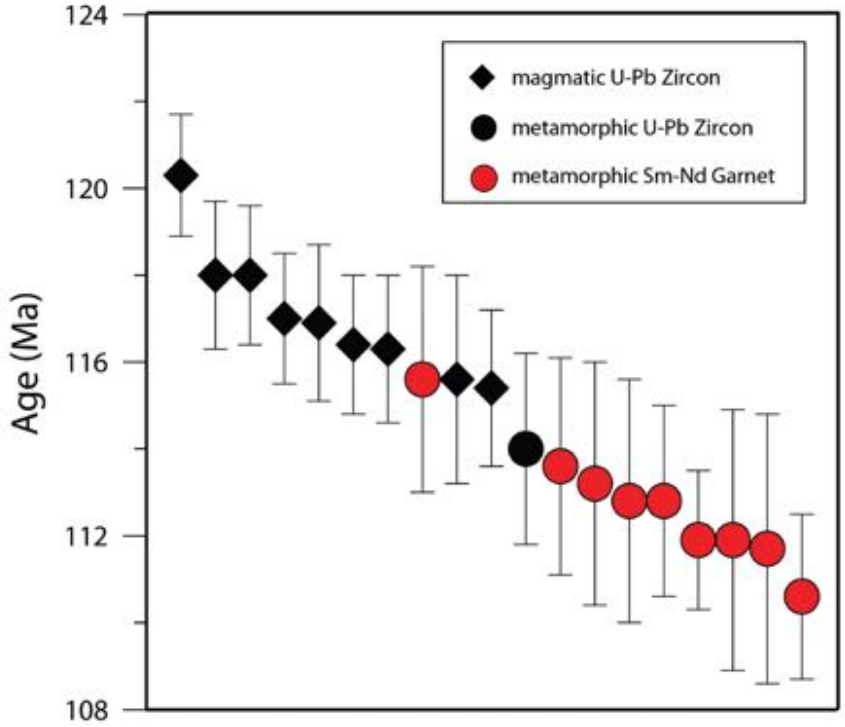
ON THE IMPORTANCE OF CRYSTALLIZATION-DIFFERENTIATION FOR THE GENERATION OF SiO_2-RICH MELTS AND THE COMPOSITIONAL BUILD-UP OF ARC (AND CONTINENTAL) CRUST

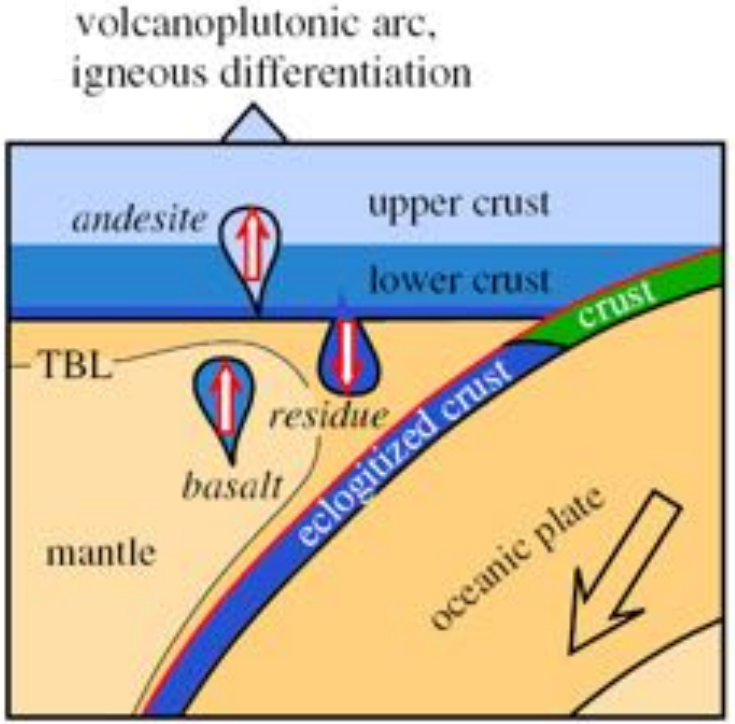


Mafic migmatites (Garrido and others, 2006) or high pressure cumulates (Ringuette and others, 1999; Jagoutz and others, 2009)

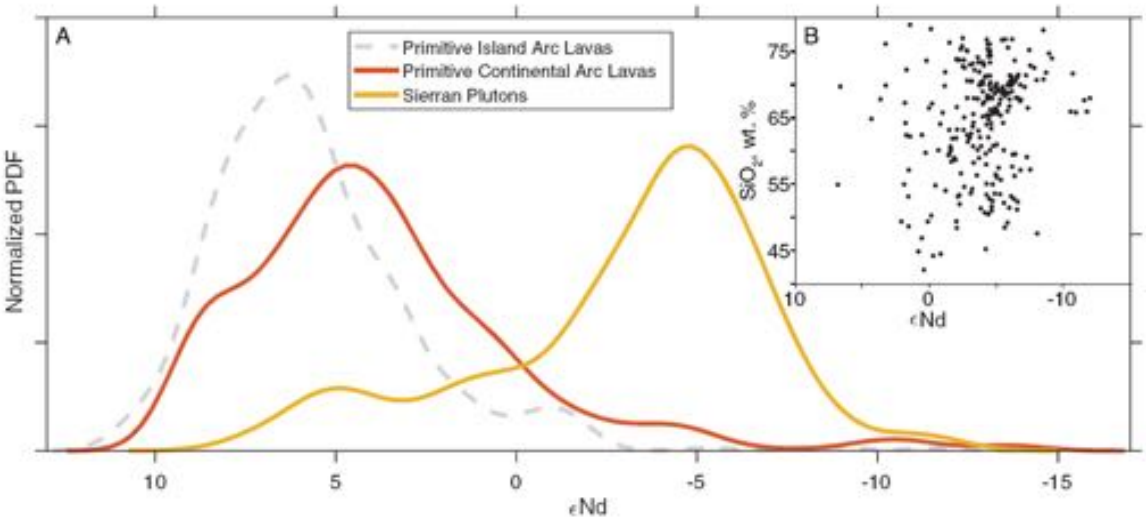


Compiled whole rock compositions from arc crustal sections: fractional crystallization or partial melting? (Jagoutz et al., 2018)



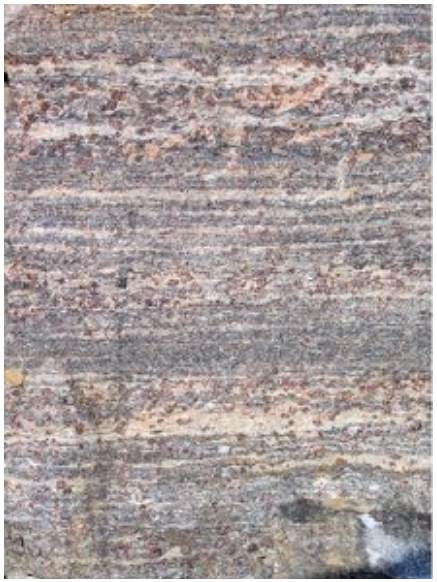


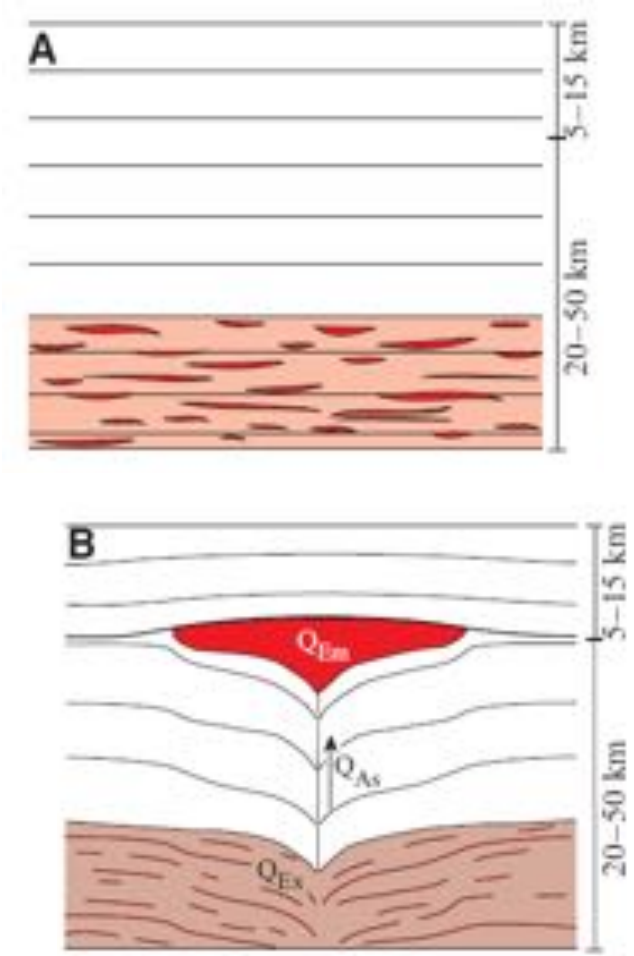
Arndt and Goldstein, 1989

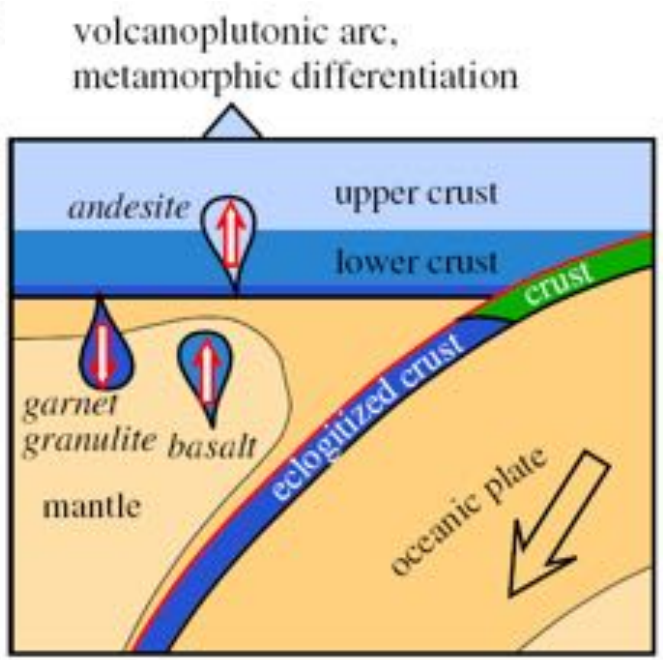


Age and Isotopic heterogeneity observed in primitive arc lavas and in an example arc batholith (Jagoutz et al., 2018)

部分熔融是大陆地壳的主要演化和再造过程？



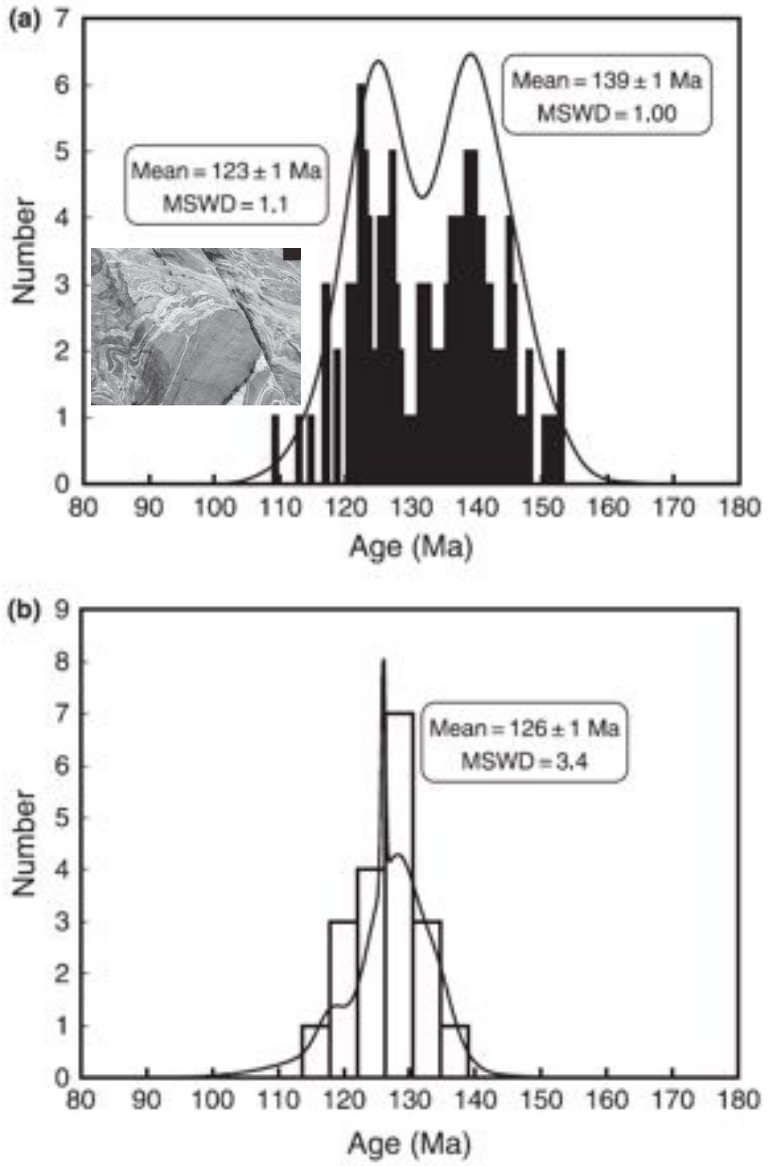




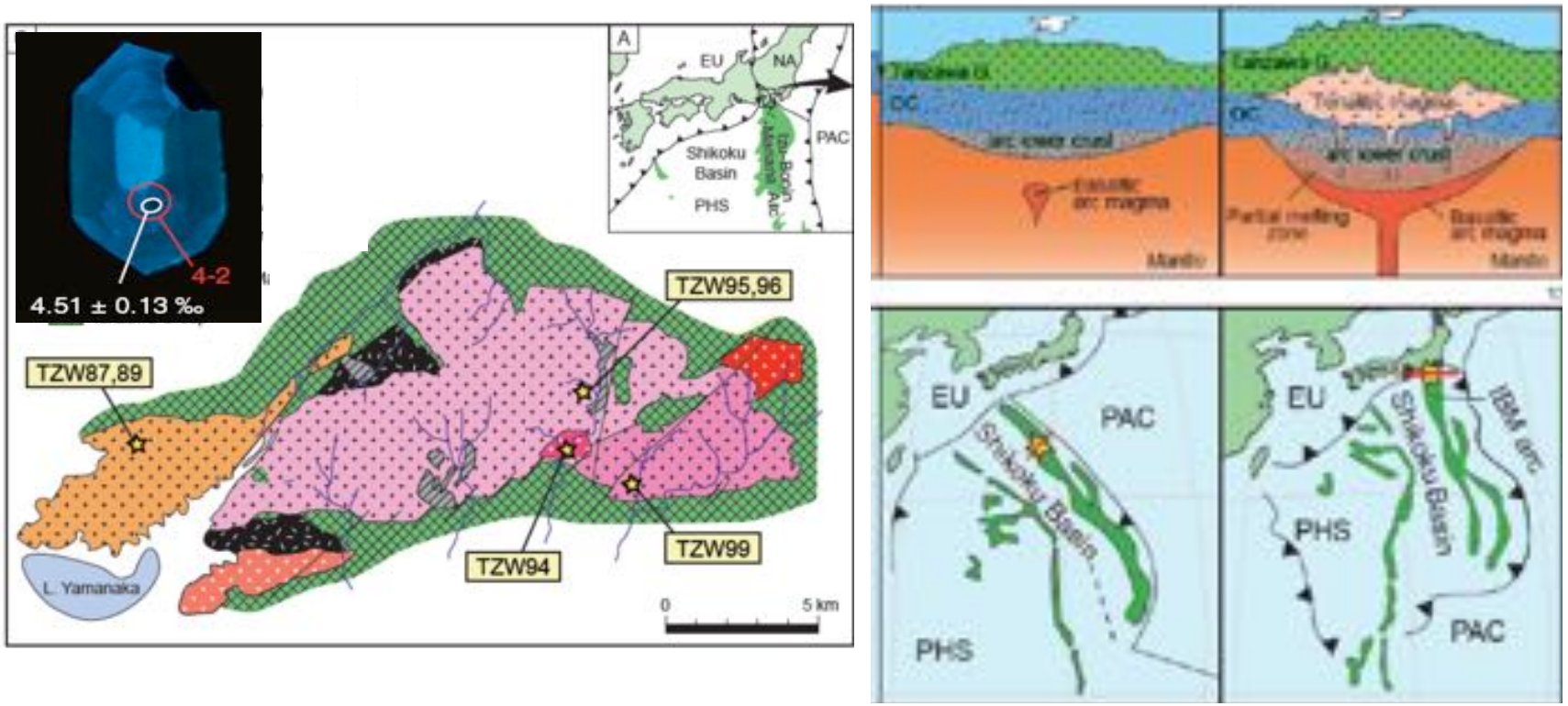
Herzberg et al., 1983

Field and schematic diagram to illustrate melt extraction, ascent, and emplacement along an active continental margin (Brown, 2013)

Cenozoic granulite-facies gneiss from the Hidaka metamorphic belt, northern Japan (Hawkesworth et al., 2011)



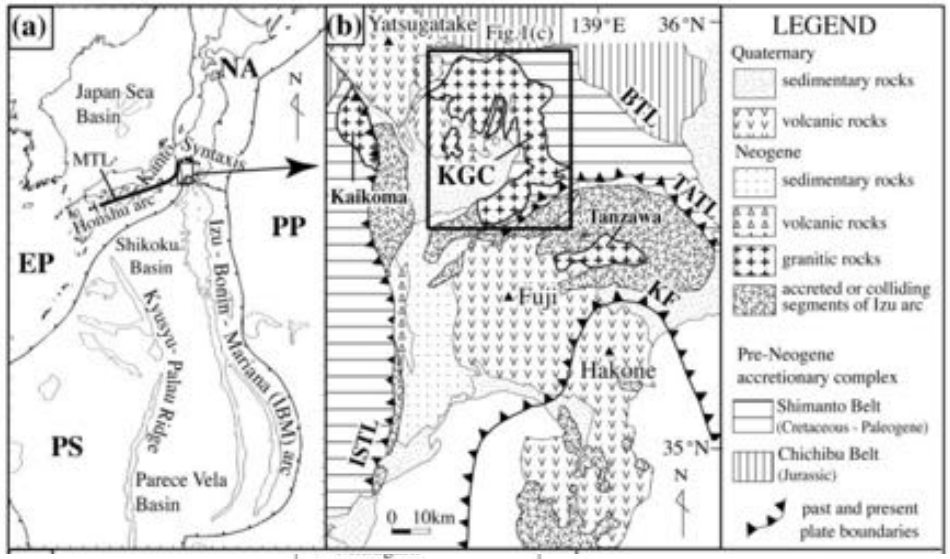
Histograms of metamorphic (a) and igneous (b) zircon U–Pb ages in the North Dabie zone (Wu et al., 2007)

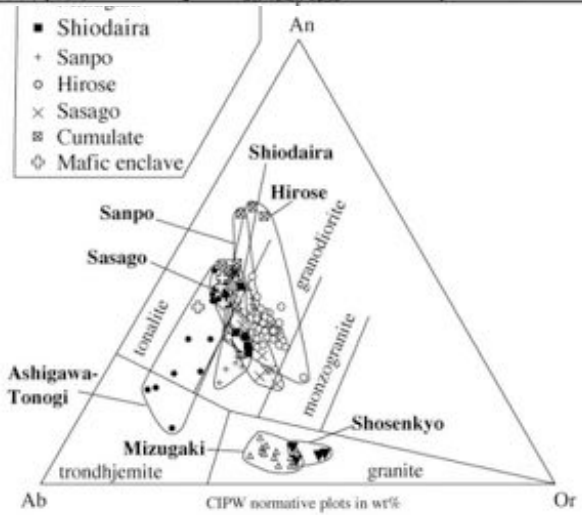


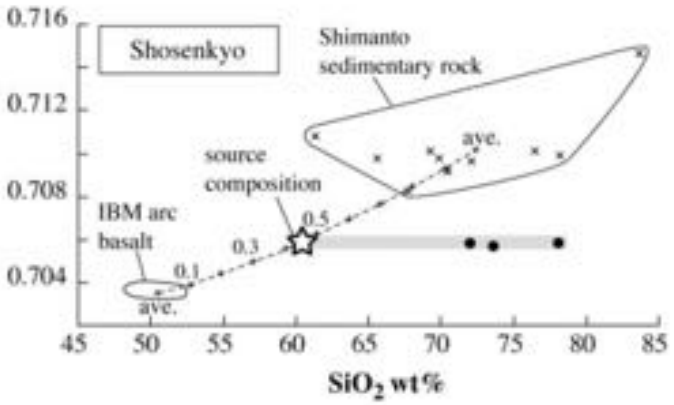
日本Izu岛弧地区的Tanzawa长英质地壳形成主要是部分熔融作用

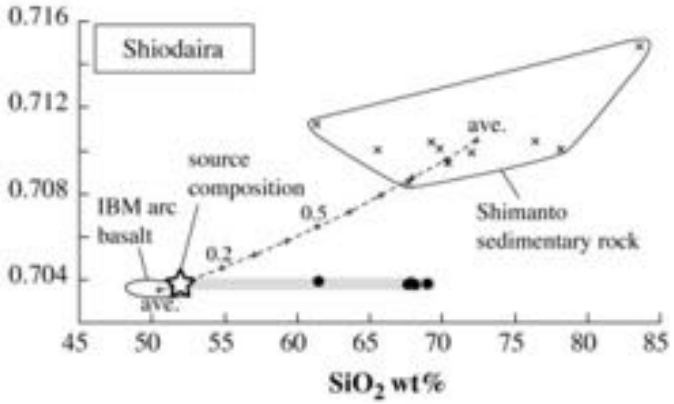
(Suzuki et al., 2015)

源区混合是大陆地壳演化和再造的主要过程

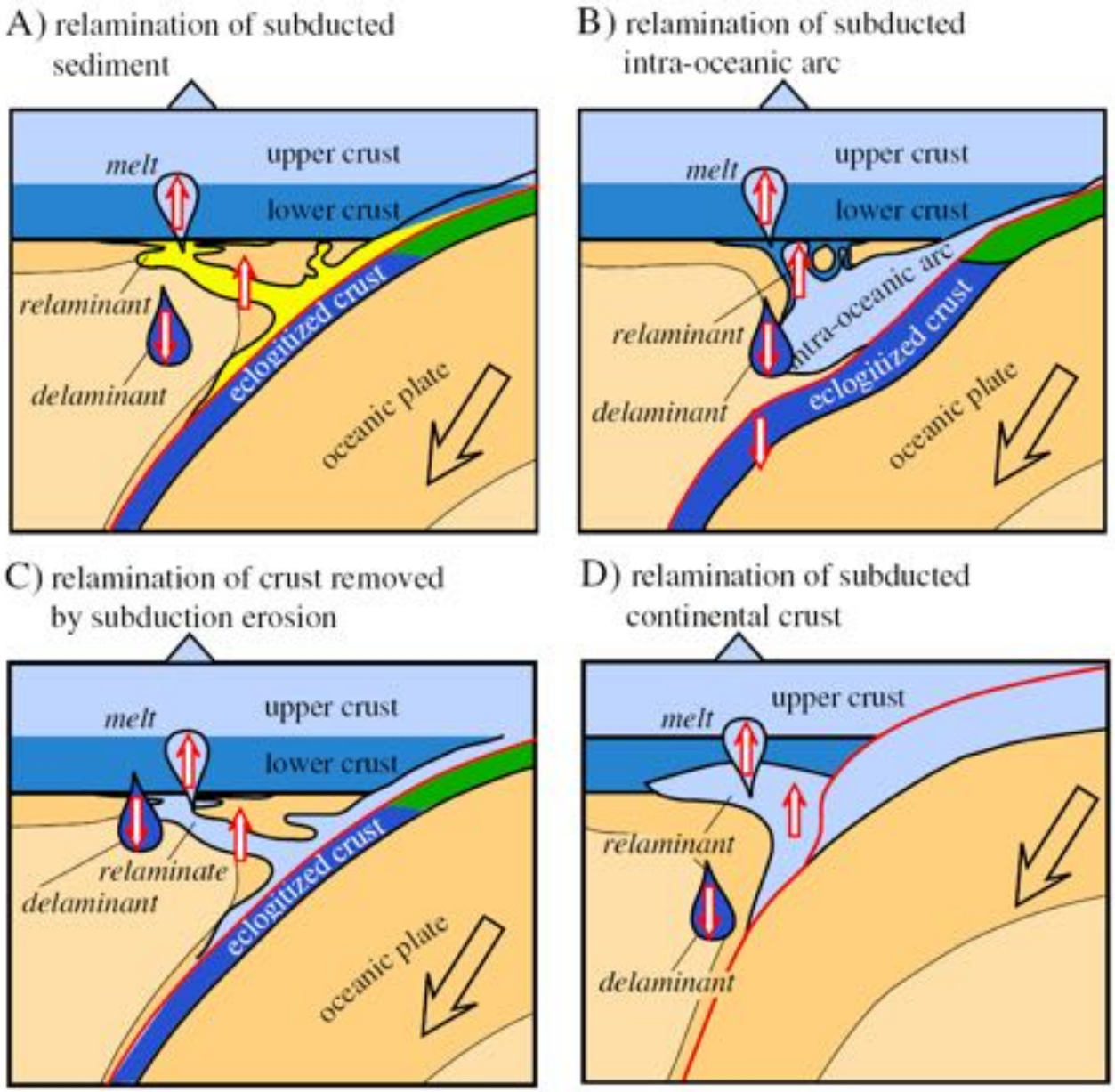








Formation of Distinct Granitic Magma Batches by Partial Melting of Hybrid Lower Crust in the Izu Arc Collision Zone, Central Japan (Saito et al., 2007)



Differentiation of the continental crust by relamination (Hacker et al., 2011)

谢谢！

Thanks for your attention!