俯冲带高压超高压变质作用与地球化学循环

High pressure-Ultrahigh pressure metamorphism and geochemical cycles in subduction zones

orphism and geochemical cycles in subduction zones

张立飞

北京大学地球与空间科学学院

Outline

一．项目基本情况

二．2023主要工作进展

三．2024 年工作计划

世界上超高压变质带分布metamorphism)

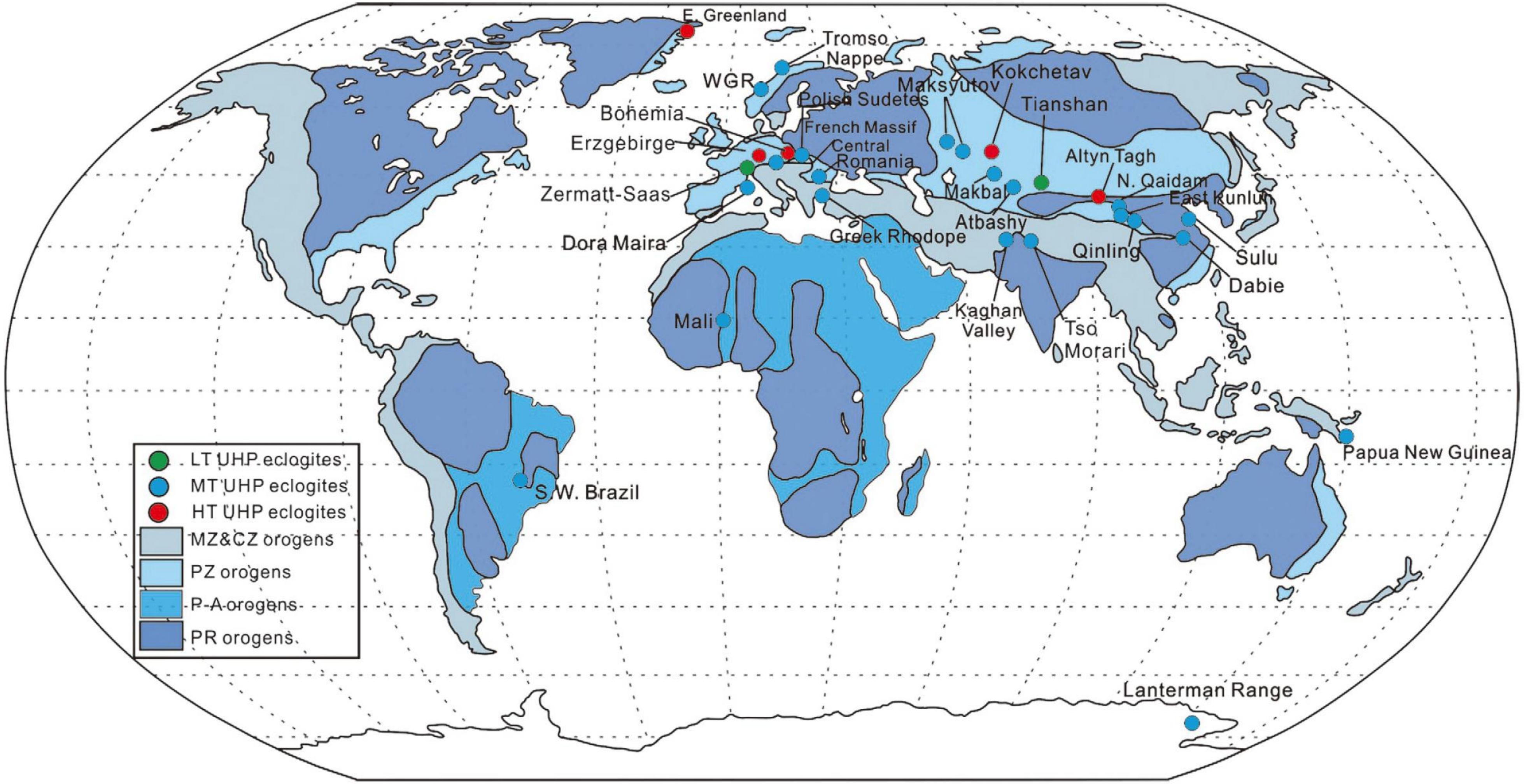
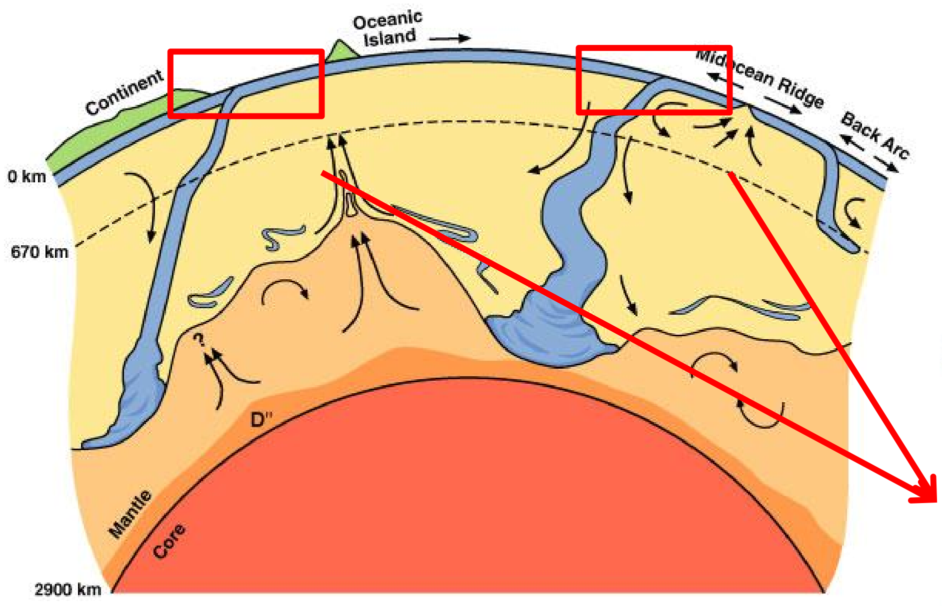


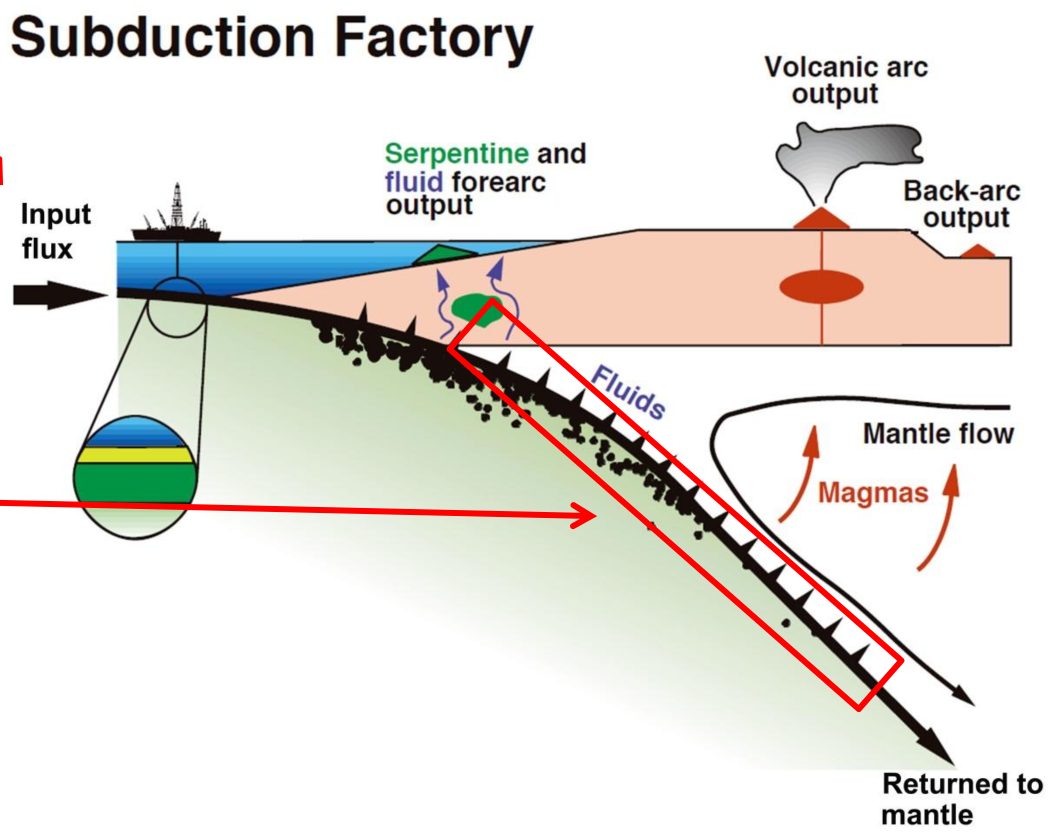
Fig. 2 The distribution of UHP eclogites in the world. Modified after Liou JG, Ernst WG, Zhang R, Tsujimori T and Jahn BM (2009) Ultrahigh-pressure minerals and metamorphic terranes—The view from China. *Journal of Asian Earth Sciences* 35: 199–231.

Zhang and Zhang, 2021
Encyclopedia of Geology

板块深俯冲超高压变质作用 metamorphism)

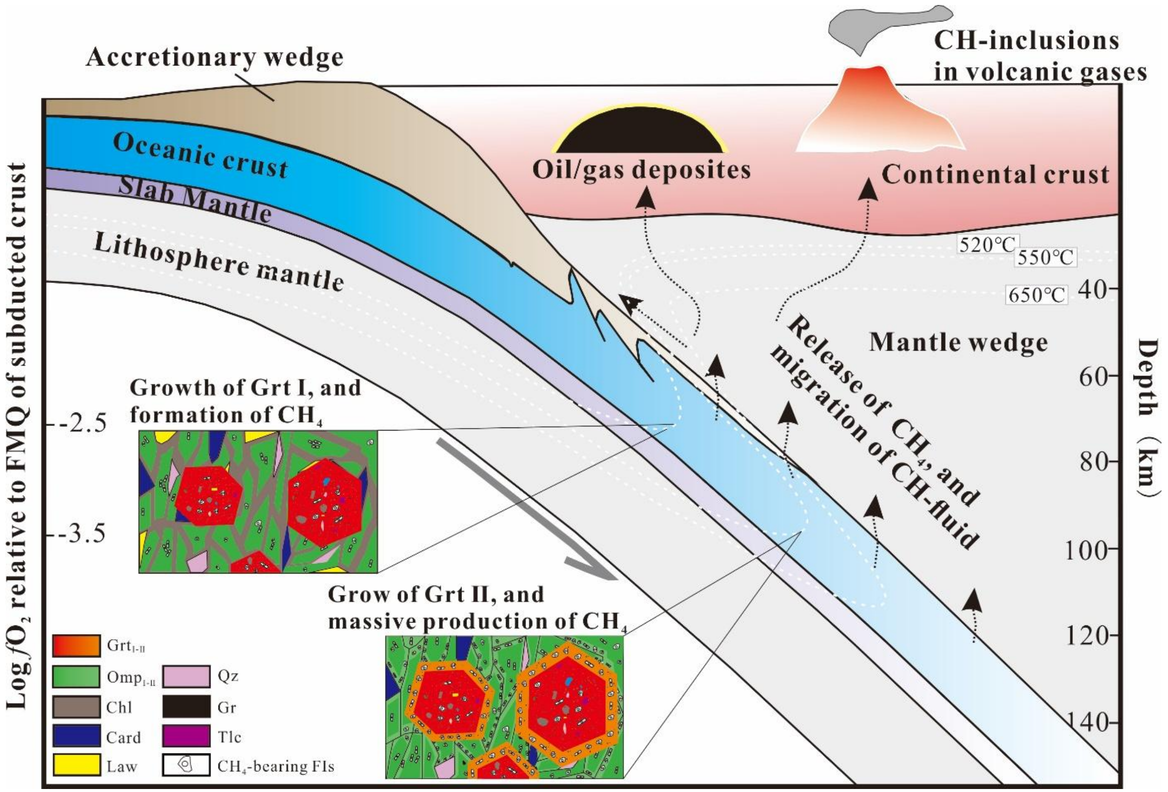


板块俯冲作用是地球上最重要的化学分异过程，对于在造山带中折返到地表的高压-超高压变质岩石开展岩石地球化学研究，对于探讨地球的物质循环、矿床资源形成以及大陆的形成与演化都具有重要意义。



深俯冲超高压变质作用是近40年来固体地球科学研究取得的突破性的研究成果。包括了矿物相变，*P-T*轨迹再建，微量元素变化及变质年代学等。

Deep Carbon Cycle in subduction zone



俯冲加碳（Carbon Inputs）

VS

岩浆脱碳（Carbon Outputs）

Subduction zone is a bridge
to join deep and surface carbon cycling

Aims

- Provide a platform for international experts to conduct a comparative study of HP-UHP metamorphic belts across the globe.
- Organize field trips including workshops and on-the-spot discussions of HP-UHP metamorphic belts of different ages, from the oldest Precambrian lithologies from Russia to the Cenozoic UHP eclogite from Western Alps, and the even younger eclogite-facies rocks from Himalaya.
- Improve our current understanding of HP-UHP metamorphism, related geotectonic processes and deep cycling of carbon and water ect. in subduction zones.
- Provide the basis for the development of a coherent model of evolution for convergent plate margins.

Project leaders:

Prof. Lifei Zhang (张立飞), （Peking University, China)

Dr. Hans-Peter Schertl (Ruhr-University Bochum, Germany)

Prof. Bishal N. Upreti (Nepal Academy of Science and Technology, Nepal)

Dr. Alexander I. Slabunov (Russian Academy of Sciences, Russia)

Dr. Alberto Vitale Brovarone （Università degli Studi di Torino, Italy）

Prof. Haissen Faouziya (Université Hassan II de Casablanca, Maroc)

Prof. Yilin Xiao(肖益林) (Chinese University of Science and Technology, China)

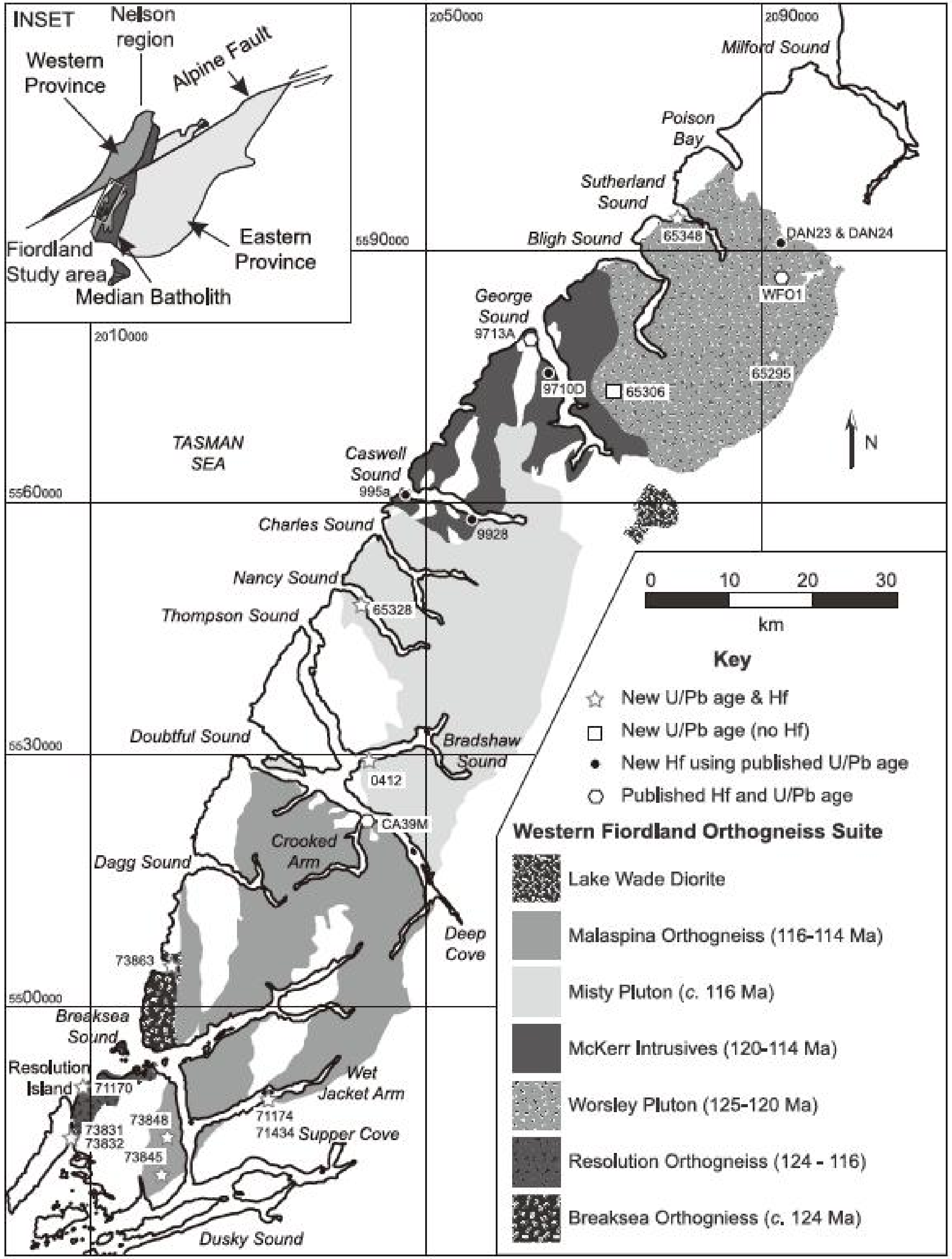
Prof. Chunjing Wei (魏春景) (Peking University, China)

Project Secretary:
Dr. Guibin Zhang (张贵宾)， (Peking University, China)

Outline

- 项目基本情况
- 2023主要工作进展
- 2024 年工作计划

2023:



Fiordland, New Zealand (*29 Oct.-03 Nov.*)

Prof. Geoffery Clark (University of Sydney)
Prof. Nathan Daczko (Macquarie University)
Dr. Timothy Chapman (University of New England)
Prof. Chunjing Wei (Peking University, China)

The origin of high-pressure metamorphic rocks in arc, slab subduction or arc crustal thickening

室内研讨：17个学术报告

Conference program (Monday, 30 OCT)

Time	Name	Institution	Title
Chair: Hans-Peter Schertl, Chunjing Wei			
9:00-9:10	Lifei Zhang	Peking University	Introduction for IGCP-709
9:10-9:30	Zeming Zhang	Institute of Geology, Chinese Academy of Geological Sciences	The lower crust of the Gangdese magmatic arc, southern Tibet
9:30-9:50	Guibin Zhang	Peking University	UHT metamorphism, partial melting and heat source in the central Himalaya
9:50-10:10	Jie Dong	Peking University	Two phases of UHTM in one orogenic cycle: a case study from the East Kunlun Orogen, NW China
10:10-10:30	Chao Wang	The University of Hongkong	Calc-alkaline plutons in a Proto-Tethyan intra-oceanic arc (Qilian Orogen, NW China): implications for the construction of arc crust
10:30-10:40	**Break**		
Chair: Lifei Zhang, Geoffery Clarke			
10:40-11:00	Zeng Lyu	Peking University	Fluid infiltration in the UHP meta-ophiolite of southwestern Tianshan, NW China
11:00-11:20	Renxu Chen	University of Science and Technology of China	Serpentinization and deserpentinization of the mantle wedge at a convergent plate margin
11:20-11:40	Yixiang Chen	University of Science and Technology of China	The role of serpentinite in crust-mantle interaction and arc magma formation
11:40-12:00	Huijuan Li	Center for High Pressure Science & Technology Advanced Research	Melting of subducted slab dictates trace element recycling in global arcs
Lunch			
Chair: Yilin Xiao, Nathan Daczko			
14:00-14:20	Chunjing Wei	Peking University	Paleoproterozoic oceanic subduction in the North China Craton
14:20-14:40	Lu Wang	China University of Geosciences (Wuhan)	Modern-style plate tectonics operates in the late Archean: Evidences from petrology and mineralogy
14:40-15:00	Timothy Kusky	China University of Geosciences (Wuhan)	New developments in understanding the Late Archean arc/continent collision of the Central Orogenic Belt, North China Craton
15:00-15:20	Faouziya Haissen	Université Hassan II de Casablanca	The Geology of Morocco: Special emphasis on my current research
15:20-15:40	**Break**		
Chair: Faouziya Haissen, Guibin Zhang			
15:40-16:00	Hans-Peter Schertl	Ruhr-Universität Bochum	Cathodoluminescence microscopy of metamorphic minerals: typical, uncommon and enigmatic microstructures
16:00-16:20	Nathan Daczko	Macquarie University	The geological setting of Fiordland
16:20-16:40	Timothy Chapman	University of New England	The early igneous and metamorphic history of the Breaksea Gneiss and Malaspina Pluton
16:40-17:00	Geoffery Clarke	University of Sydney	The later history of the Breaksea Gneiss and the juxtaposition of 1.8 and 1.4 GPa elements of Fiordland

室内研讨

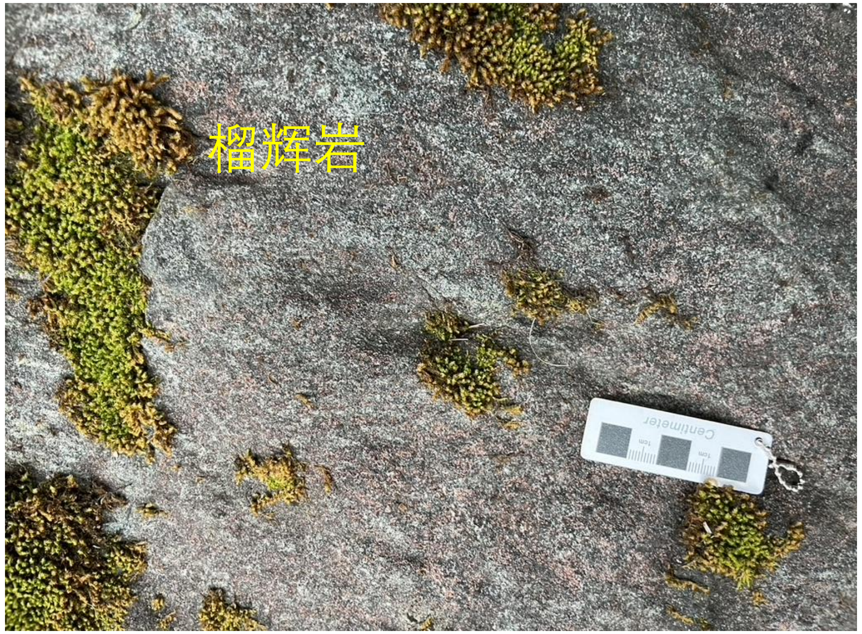

IGCP-709 project:
HP-UHP metamorphism and geochemical cycles in subduction zones
Lifei Zhang
School of Earth and Space Sciences, Peking University

野外考察：船+直升机

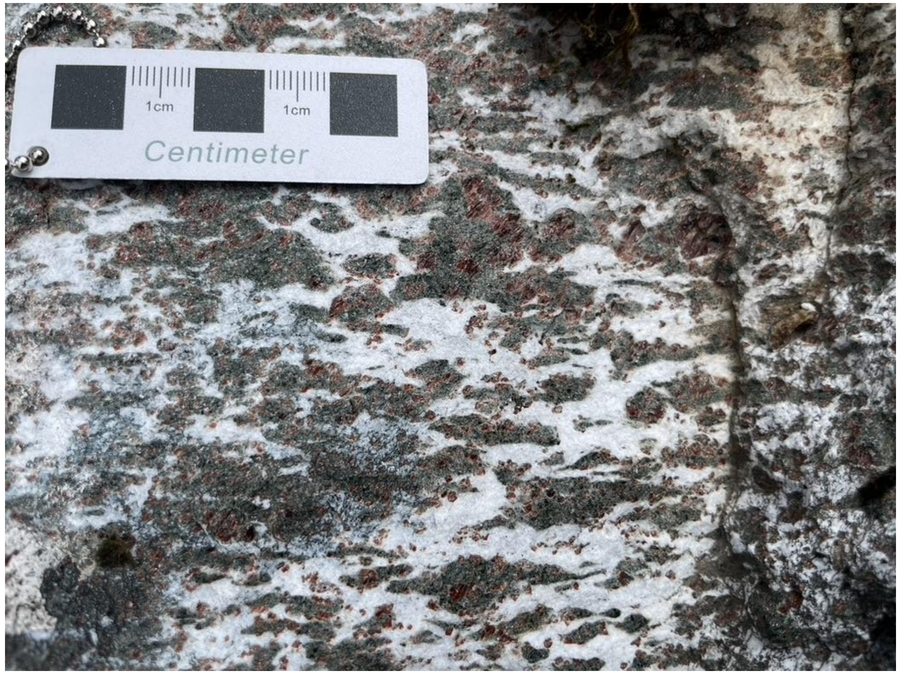
FIELD EXCURSION SCHEDULE

Date	Activity	Accommodation
Tue 31 Oct	Departure of first group on helicopter to Breaksea Tops and examine the Breaksea Orthogneiss Shuttle group down to boats in Breaksea Sound by helicopter	Stay at the boat overnight: Tutoku I & II
Wen 1 Nov	Examine coastal outcrops of the Breaksea Orthogneiss and Resolution Orthogeneiss, on and around Entry Island Examine the Malaspina Pluton and Palaeozoic metasediment, south shore of Wet Jacket Arm opposite Oke Island	Stay at the boat overnight: Tutoku I & II
Thu 2 Nov	Early departure for transit to Doubtful Sound and view of Kellard Point and the well-exposed Doubtful Sound Shear Zone, Malaspina Pluton. Bus at Deep Cove Wharf to go back over Wilmot Pass.	Distinction Luxmore Hotel, Te Anau
Fri 3 Nov	Travel to Queenstown, end of the field excursion	


TUTOKO II


榴辉岩
Centimeter


ZK-IRM


1cm
1cm
Centimeter

CGU专题

中国地球科学联合学术年会各专题学术交流内容

序号前标"*"号的报告为特邀报告（口头报告），序号前标"◎"为学生报告

第75专题 变质作用过程的观察与模拟

(召集人:陈 意 张贵宾 魏春景 吴春明 张

会议时间:10月17日 会议地点:第36会议室(

主持人:魏春景 张贵宾 王佳敏

时间	序	
08:30-08:55	*1	喜马拉雅高压/中压型变质
08:55-09:10	2	Two phases of ultrahigh orogenic cycle
09:10-09:25	◎3	印度-欧亚板块的碰撞时间：质作用的启示
09:25-09:40	4	Low-temperature Eclogi Himalayan Syntaxis: Po Implications
09:40-09:55	5	Clockwise metamorphic revealed by thermobaro
09:55-10:10	◎6	北秦岭造山带秦岭岩群两期 造山带早期构造格局和演化
10:10-10:20		休 息
10:20-10:45	*7	贫硅石榴辉石岩部分熔融和
10:45-11:00	◎8	大陆碰撞带熔体与碳酸盐反
11:00-11:15	9	现代板块构造体制再启动：
11:15-11:30	10	Discovery of Late Neopr granulites in the Central implications
11:30-11:45	◎11	华北克拉通阿拉善地块高压
11:45-12:00	◎12	辽宁清原新太古代石榴二辉

主持人:吴春明 陈意 刘鹏雷

时间	序	
13:30-13:55	*13	汇聚板块边界的热-动力学
13:55-14:10	14	相平衡模拟揭示平衡和非平
14:10-14:25	15	加厚下地壳成分和形成机制
14:25-14:40	16	石榴子石扩散年代学有限元
14:40-14:55	◎17	嫦娥五号月壤中非月海物质
14:55-15:10	◎18	华北克拉通东南缘荆山花岗

第87专题 中央造山系构造过程及其资源能源效应

(召集人:孙圣思 于胜尧 王勇生 张贵宾 李佐臣)

会议时间:10月17日 会议地点:第37会议室(展览中心二层珠海厅9号厅)

主持人:李佐臣 于胜尧 张贵宾 付长垒

时间	序	报告题目	报告人
08:30-08:55	*1	中国大陆	
08:55-09:10	2	东秦岭地	
09:10-09:25	3	大陆岩石	
09:25-09:40	◎4	北秦岭泥	
09:40-09:55	◎5	北秦岭造	
09:55-10:10	◎6	北秦岭西	
10:10-10:20		休 息	
10:20-10:45	*7	张八岭构	
10:45-11:00	8	西秦岭武 展的启示	
11:00-11:15	◎9	西秦岭北	
11:15-11:30	10	扬子西北	
11:30-11:45	◎11	南秦岭北 造演化的	
11:45-12:00	12	Petrogen Miandas	

主持人:王勇生 孙圣思 李佐臣

时间	序	
13:30-13:55	*13	柴北缘碰
13:55-14:10	14	北山南部
14:10-14:25	15	北祁连东
14:25-14:40	◎16	东昆仑造
14:40-14:55	17	东昆仑祁
14:55-15:10	◎18	青藏高原

第81专题 地球深部碳、氧、氢循环

(召集人:刘盛遨 刘勇胜 李曙光 张立飞 许 成 陈 唯 陶仁彪)

会议时间:10月16日 会议地点:第30会议室(展览中心二层珠海厅2号厅)

主持人:刘盛遨 刘勇胜 李曙光 张立飞 许成 陈唯 陶仁彪

时间	序	报告题目	报告人
08:30-08:55	*1	太古宙陆壳无氧风化作用与大氧化事件的关联	李曙光
08:55-09:10	2	俯冲板片脱碳过程的实验研究	张艳飞
09:10-09:25	3	中国东部大地幔楔碳含量的估计：来自板内玄武岩锌同位素及化学组成的约束	杨 春
09:25-09:40	4	中国东北地幔捕虏体揭示两种含碳熔体-橄榄岩反应机制	王春光
09:40-09:55	5	Vanadium isotopes record transformation of carbonated melt to alkali basalt	Zhenwu Chen(陈振武)
09:55-10:10	6	新特提斯洋俯冲与大气二氧化碳浓度变化的动力学联系	沈 昊
10:10-10:20		休 息	
10:20-10:45	*7	地球与行星内部的氢化物	陶仁彪
10:45-11:00	8	大别山辉石岩流体包裹体内的矿物碳酸盐化和非生物甲烷合成	张 龙
11:00-11:15	9	Li同位素示踪和区分俯冲带熔体交代作用	谭东波
11:15-11:30	◎10	岛弧岩浆高镁同位素揭示俯冲大洋地幔脱水	邓 忻
11:30-11:45	11	富硫酸盐金伯利岩驱动金属和稀土元素迁移	张军波
11:45-12:00	12	冈底斯大陆弧镁铁质侵入岩的N同位素研究	吴 鹏
13:30-13:55	*13	中国东部新生代玄武岩Cr同位素研究	沈 骥
13:55-14:10	14	再循环钙质碳酸盐岩引发的玄武岩Ca-Zn-Sr同位素协同变化	何德涛
14:10-14:25	◎15	再循环碳酸盐引发的地幔氧化：来自板内玄武岩的Mg-Zn-Fe-Cu同位素研究	吴天昊
14:25-14:40	◎16	再循环含碳酸盐沉积物交代富钾玄武岩岩石圈地幔：Mg-Zn-Fe同位素证据	王照雪
14:40-14:55	17	晋北钾镁煌斑岩成因机制研究：揭示再循环碳酸盐对地幔的改造	虞凯章
14:55-15:10	18	造山带中碳酸盐熔体的起源：逆冲推覆碳酸盐沉积物的深熔作用	汪程远
15:10-15:20		休 息	
15:20-15:35	19	中国东部新生代玄武岩的轻Ca同位素异常：来自再循环碳酸盐和熔融过程分馏的混合信号	王 阳
15:35-16:00	20	张贴报告介绍	

48篇论文：包括Communications Earth & Environment 1篇；NSR2篇，PNAS1篇，GRL1篇，EPSL 2篇，GCA5篇，JGR-SE1篇等

Geochimica et Cosmochimica Acta 351 (2023) 14–31
Contents lists available at ScienceDirect
Geochimica et Cosmochimica Acta
journal homepage: www.elsevier.com/locate/gca

Fingerprinting crustal anatexis with apatite trace element, halogen, and Sr isotope da…

Shuaiqi Liu, …

PERSPECTIVE

National Science Review
10: nwad203, 2023
https://doi.org/10.1093/nsr/nwad203
Advance access publication 24 July 2023

EARTH SCI…

Deep … diamo…

Xiaoxia W… Deshi Jin…

RESEARCH ARTICLE

National Science Review
10: nwac207, 2023
https://doi.org/10.1093/nsr/nwac207
Advance access publication 30 September 2022

PNAS RESEARCH ARTICLE | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES | OPEN ACCESS

Supercritical fluid in deep subduction zones as revealed by multiphase fluid inclusions in an ultrahigh-pressure metamorphic vein

Deshi Jin, Yilin Xiao, Dong-Bo Tan, Yang-Yang Wang, Xiaoxia Wang, Wancai Li, Wen Su, and Xiaoguang Li

JGR Solid Earth
RESEARCH ARTICLE
10.1029/2023JB027395

Omphacite Melting and the Destruction of Early High-Pressure Rock Records

Shuaiqi Liu[1], Guibin Zhang[1], Lifei Zhang[1], and A. Alexander G. Webb[2]

[1]The Key Laboratory of Orogenic Belts and Crustal Evolution, MOE, School of Earth and Space Sciences, Peking University, Beijing, China, [2]Department of Earth Sciences and Laboratory for Space Research, University of Hong Kong, Hong Kong, China

Key Points:
- The granulitized eclogite has experienced omphacite dominated melting with phengite contributions at eclogite-facies stage
- Melts from omphacite breakdown have low Nb/Ta and high Zr/Sm, similar to tonalite-trondhjemite-granodiorites
- Omphacite dominated melting could erase early high-pressure records of modern-style tectonics

Abstract The presence of eclogite marks high-pressure metamorphism and deep, cold burial of crust, and is therefore a widely accepted indicator for the onset of modern-style plate tectonics. However, eclogite is rarely preserved in many heavily granulite-overprinted orogens, which are particularly common across ancient metamorphic terranes (i.e., Archean and Paleoproterozoic terranes). Here, we show that eclogite melting processes may be principally responsible for the poor preservation of high-pressure records. We demonstrate eclogite melting via detailed petrological, geochronological, and geochemical analyses on eclogites and separated centimetric leucosomes from the central Himalaya. The central Himalayan eclogites were overprinted by strong granulite-facies metamorphism, such that omphacite is only sparsely preserved. Thermodynamic modeling results indicate the eclogite experienced two types of anatectic reactions: phengite dehydration melting at high-pressure in the presence of omphacite, and subsequent omphacite dominated melting during exhumation. Diagnostic features for these melting reactions include (a) the occurrence of Kfs-Pl-Qz multiphase solid inclusions and Cpx-Pl-Qz polymineralic inclusions; (b) the high Na_2O/K_2O melts and Na-rich plagioclase in leucosomes; (c) the consistent trace elements patterns between omphacite and leucosomes; and (d) obvious Na_2O zonation in clinopyroxene. Omphacite dominated melting is characterized by the jadeite breakdown, releasing Na and Al into the melts. This melting mechanism subsequently forms a less sodic clinopyroxene and high Na_2O/K_2O melts. These Himalayan findings appear relevant to early Earth explorations because of the high thermal gradients and intense granulite-facies overprints, implying that partial melting of eclogite dominated by omphacite breakdown could have erased early high-pressure records of modern-style plate tectonics.

Plain Language Summary Eclogites are high-pressure metamorphic rocks mainly composed of garnet and omphacite. The occurrence of high-pressure and low-temperature eclogite is representative of modern-style plate tectonics. Eclogite partial melting is an important process for material transfer in subduction zones and has been regarded as an important mode of continental growth. In this paper, we found that the central Himalayan eclogites underwent two types of melting reactions: phengite breakdown in the presence of omphacite in the high-pressure eclogite-facies domain and subsequent omphacite dominated melting on the exhumation. These melting reactions make the breakdown of jadeite in omphacite and form a less sodic clinopyroxene. Considering the similar high thermal gradients and intense granulite-facies overprint, we propose that eclogite melting by omphacite breakdown could be a viable mechanism for the rare preservation of high-pressure records on early earth (Archean and Paleoproterozoic).

Supporting Information:
Supporting Information may be found in the online version of this article.

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Author Contributions:
Conceptualization: Guibin Zhang
Formal analysis: Shuaiqi Liu
Investigation: Shuaiqi Liu
Methodology: Guibin Zhang
Supervision: Guibin Zhang
Writing – original draft: Shuaiqi Liu, Guibin Zhang
Writing – review & editing: Lifei Zhang, A. Alexander G. Webb

1. Introduction

Eclogites are high-pressure metabasic rocks and record the Earth's deep-crustal and upper-mantle conditions and processes (Tsujimori & Mattinson, 2021; Wang et al., 2014). The occurrence of oceanic eclogite or eclogite-facies rocks is widely accepted as a key indicator for the operation of modern-style plate tectonics on early Earth, which is driven by the deep subduction of oceanic lithosphere (Brown et al., 2020; Holder et al., 2019; Stern et al., 2016). Partial melting of eclogite occurs in oceanic (e.g., Qilian) (Chen, Xia, & Song, 2012) and continental subduction zones (e.g., Dabie-Sulu, Qaidam, Bohemian) (Miyazaki et al., 2016; Wang et al., 2014; Zhang et al., 2015). Eclogite melting is of great significance for modulating continental crust growth (Rapp et al., 2003; Song et al., 2014), mantle compositional heterogeneity (Lambart et al., 2019), lithospheric rheology, and element transfer through subduction zones (Labrousse et al., 2011; Wang et al., 2014). Furthermore, the tonalite-trondhjemite-granodiorite (TTG) magmatic rocks that dominate the Archean continental crust may have

EARTH SCIENCES

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Petrological evidence for deep subduction of organic carbon to subarc depths

Han Hu[1], Lifei Zhang[1✉], Chunyuan Lan[1] & Zhicheng Liu[1]

The significance of subducted organic carbon for the deep carbon cycle has been demonstrated by the presence of ultra-deep diamonds and arc emissions. However, there is no convincing evidence that organic carbon can be subducted to subarc depths. This study provides the evidence for deep subduction of sedimentary organic carbon to mantle depths through petrological observation, Raman and isotopic analyses of ultrahigh-pressure (UHP) coesite- and graphite-bearing pelitic schists. The analyzed graphite shows light $\delta^{13}C$ values (−24.7 to −22.5‰), indicating a sedimentary organic carbon source. Petrological characteristics of graphite co-existing with coesite in garnet and P-T calculations suggest that organic graphite was subducted to the subarc depths exceeding 90 km. This research represents the petrological evidence for the deep subduction of organic carbon to mantle depths and may provide insight into the origin of diamonds with light $\delta^{13}C$ values and contribute as key evidence for the Lomagundi event.

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High-pressure experimental and thermodynamic constraints on the solubility of carbonates in subduction zone fluids

Chunyuan Lan[a,b], Renbiao Tao[b,*], Fang Huang[c], Runze Jiang[b], Lifei Zhang[a,*]

[a] MOE Key Laboratory of Orogenic Belts and Crustal Evolution, School of Earth and Space Sciences, Peking University, Beijing 100871, China
[b] Center for High Pressure Science and Technology Advanced Research (HPSTAR), Beijing 100094, China
[c] CSIRO Mineral Resources, Kensington, WA 6151, Australia

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Keywords:
subduction zone
decarbonation fluxes
solubility of carbonates
high-pressure experiments
DEW model

ABSTRACT

Carbon on the Earth's surface can be carried into the mantle by subducting slabs in the form of carbonates and organics. However, not all the subducting carbon could be recycled into the Earth's deep mantle because parts of them will be released from the subducting slabs by decarbonation processes (e.g., metamorphism and dissolution). In comparison with metamorphic decarbonation, the dissolution of carbonates in subduction zone fluids is more essential, but not well constrained. In this study, we systematically constrained the solubility of different carbonates (e.g., calcite/aragonite, dolomite, and magnesite) under high-pressure and high-temperature conditions relevant to subduction zones by combining experimental and thermodynamic simulations. We simultaneously compared the dissolution processes of calcite/aragonite, dolomite, and magnesite in aqueous fluids under the same P–T conditions using the four-hole gasket technique in diamond anvil cell (DAC) experiments. *In situ* Raman spectra of fluids in the DAC clearly showed that dolomite had a similar solubility to aragonite, while the solubility of magnesite was much lower than that of aragonite and dolomite under the same P–T conditions. Notably, we also found that the dissolution of dolomite was an incongruent process via the reaction $CaMg(CO_3)_{2(solid)}$ in $H_2O = MgCO_{3(solid)} + Ca^{2+}_{(aqueous)} + CO_3^{2-}{}_{(aqueous)}$. Based on the experimental results, we reasonably suppressed some aqueous species in the DEW model and quantitatively calculated the speciation and solubility of calcite/aragonite, dolomite, and magnesite in aqueous fluids at pressures up to 5 GPa and temperatures up to 800 °C. Then, we modeled and compared the decarbonation fluxes between metamorphism and dissolution from typical marine sediment and altered oceanic crust in subduction zones. In the cold or intermediate subducting slabs, the cold subducting slabs fluxes by the dissolution of carbonates are about three times larger than that from metamorphism. Considering the total decarbonation fluxes of metamorphism and dissolution, the cold subducting slabs could release a similar magnitude of carbon as the hot ones.

1. Introduction

The increasing CO_2 concentration in the atmosphere has resulted in an unprecedented frequency of extreme climate events in recent decades (Duffy and Duffy, 2021). The short-term carbon cycle fluxes between the Earth's surface reservoirs (i.e., atmosphere, ocean, and biosphere) have been well studied and quantified (Le Noë et al., 2021); however, more than 98 mol.% of carbon on the Earth is estimated to be stored in the deep interior (i.e., mantle and core) (Javoy, 1997; DePaolo, 2015). Therefore, the deep carbon cycle between the Earth's surface and deep interior in geological time scale profoundly impacts the Earth's ecosystem and governs its long-term habitability (Lee et al., 2019). Subduction and volcanism are the two key geological processes for exchanging carbon between the Earth's surface and deep interior (Dasgupta and Hirschmann, 2010). Subducting slabs can deliver a significant amount of the Earth's surface carbon, in the form of carbonate and organic matter, into the Earth's interior along with plate subduction (Plank and Manning, 2019). However, not all input carbon in subducting slabs can be carried into the Earth's deep mantle (i.e., beyond the subarc mantle), and parts of the carbon may be released from subducting slabs through different decarbonation processes under high-pressure (high-P) and high-temperature (high-T) conditions in subduction zones. Hence, understanding the processes and efficiency of decarbonation from subducting slabs

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《地质学报》（英文版）专栏：俯冲带深部碳循环与非生物甲烷气

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俯冲带深部碳循环与非生物甲烷气

专栏主编：张立飞

Special Section

Preface: Deep Carbon Cycle and Abiotic Methane in the Subduction Zone

GSC

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Two kinds of carbon cycle on Earth have been recognized: surface short-term and deep long-term carbon cycles (Berner, 2003; Zhang et al., 2017). Over the years, the surface short-term carbon cycle has been attracted extensive attention because of their significance implications in the study of environmental changes of human beings. Recently, scientists found more than 98% carbon is stored in the solid Earth which takes great role on the surface carbon cycle (DePaolo, 2015; Kelemen and Manning, 2015; Plank and Manning, 2019; Mao and Mao, 2020). Therefore, the research of deep carbon cycle is very significant to the study of the formation and evolution, multi-layered interaction and habitability of the Earth. On the other hand, recent petrological study combined with high pressure-temperature experimental simulation shows that abiotic methane can be formed by the metamorphic reduction of carbonates during the subduction metamorphism (Tao et al., 2018; Wang et al., 2022; Zhang et al., 2023). Thus, deep carbon cycle research also has important resource effects. This special section reports the update progress of the project "Deep Subduction and Abiotic Methane" supported by National Key Research and Development Program of China (2019YFA0708500). The subduction zone acts as a link between the Earth's surface and processes inside the Earth. The metamorphic abiotic methane and C-H-O fluids released from the reduction of carbonate or decarbonation and dehydration during high-pressure and ultrahigh pressure metamorphism in subduction zone can be stored in the fore-arc basin (Fig. 1[A, D]). The further metamorphic methane and C-H-O fluids released from residual subducted carbonates should be deposited in back-arc basin or erupted associated with continental basalt or igneous carbonate rocks through mantle wedge as evidenced by Li et al. (2020) (Fig. 1[B, C, D]). The multiple metamorphic reactions or phase changes should happen during the further deep subduction of residual carbon-bearing rocks in the subducted slice (Fig. 1[B]).

Eight papers have been selected for this special section. The first paper by Wang et al. (2023, this issue) summarizes the petrological, thermodynamic and experimental investigations of possible pathways for the formation of particular species of abiotic hydrocarbon molecules systems. The formation process has been distinguished into three classes: (1) pre- to early planetary processes; (2) mantle and magmatic processes; and (3) the gas/water-rock reaction processes in low-pressure ultramafic rock and high-pressure subduction zone systems. The second paper by Gui et al. (2023, this issue) summarizes the updated phase stability of $CaCO_3$ mainly from high pressure-temperature experiments. They concluded that the fate of subducted $CaCO_3$ into the deep mantle is still an open question. Thus, they point out the several potential problems in the future such as whether or not $CaCO_3$ exists in the transition zone or even the lower mantle and how the formation of abiotic hydrocarbon during the reduction of subducting $CaCO_3$. The third paper by Liu and Zhang (2023, this issue) compares the carbon cycle in Paleoproterozoic and Neoproterozoic comprehensively. In the Paleoproterozoic, intense weathering in a highly CO_2 and CH_4 rich atmosphere resulted in more nutritional elements being carried into the ocean. Consequently, they concluded that from the Paleoproterozoic through the Neoproterozoic to the Phanerozoic, the carbon cycle had promoted the evolution of a habitable Earth. The fourth paper by Xu et al. (2023, this issue) shows that the molecular compositional

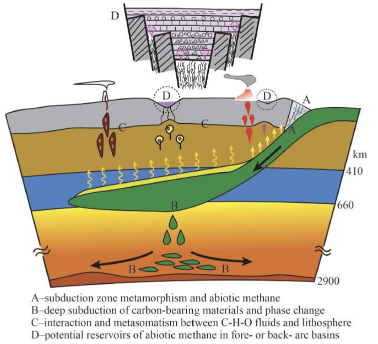

Fig. 1. Deep carbon cycle and abiotic methane in subduction zone.

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http://www.geojournals.cn/dzxbcn/ch/index.aspx; https://onlinelibrary.wiley.com/journal/17556724

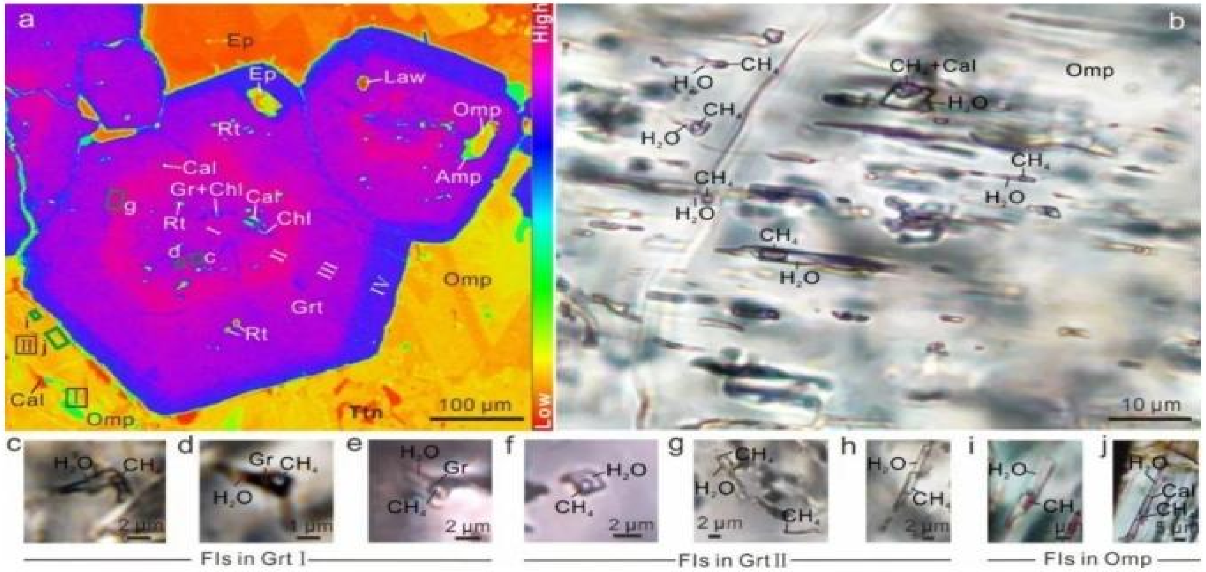
代表性成果1：榴辉岩相变质过程中产生巨量的无机甲烷气

甲烷气的最大非生物来源：板块冷俯冲变质作用 | NSR

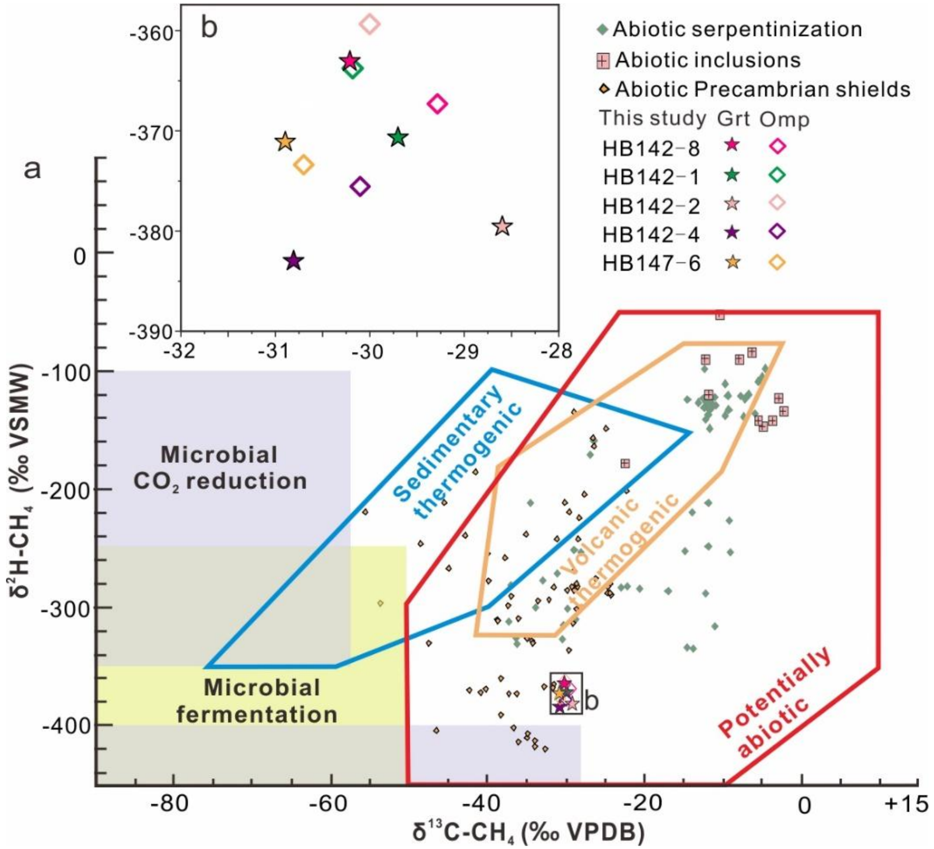
原创 《国家科学评论》 中国科学杂志社 2022-11-10 14:37

地球上的甲烷（CH_4）从何而来？其最主要的来源为生物来源，由有机物质经生物埋藏降解作用形成。此外，一些非生物过程也可以形成甲烷。

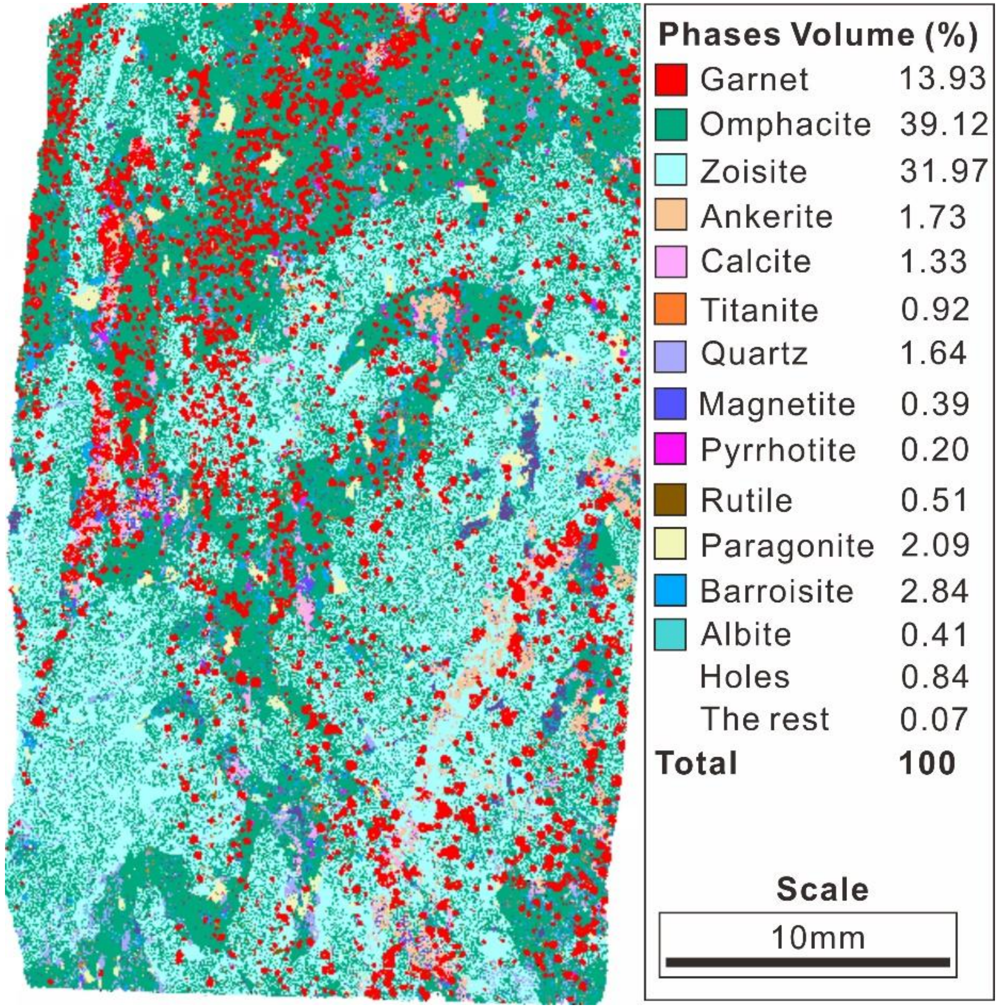
在最近发表于《国家科学评论》（*National Science Review*, NSR）的文章中，**北京大学张立飞教授团队在西天山榴辉岩中发现了大量富含甲烷-流体包裹体，并进而研究证明：板块冷俯冲变质过程可以形成大量甲烷气，这是目前所知的地球上规模最大的非生物甲烷气来源，可能形成潜在的天然气田，也可能作为温室气体释放对气候产生重要影响。**

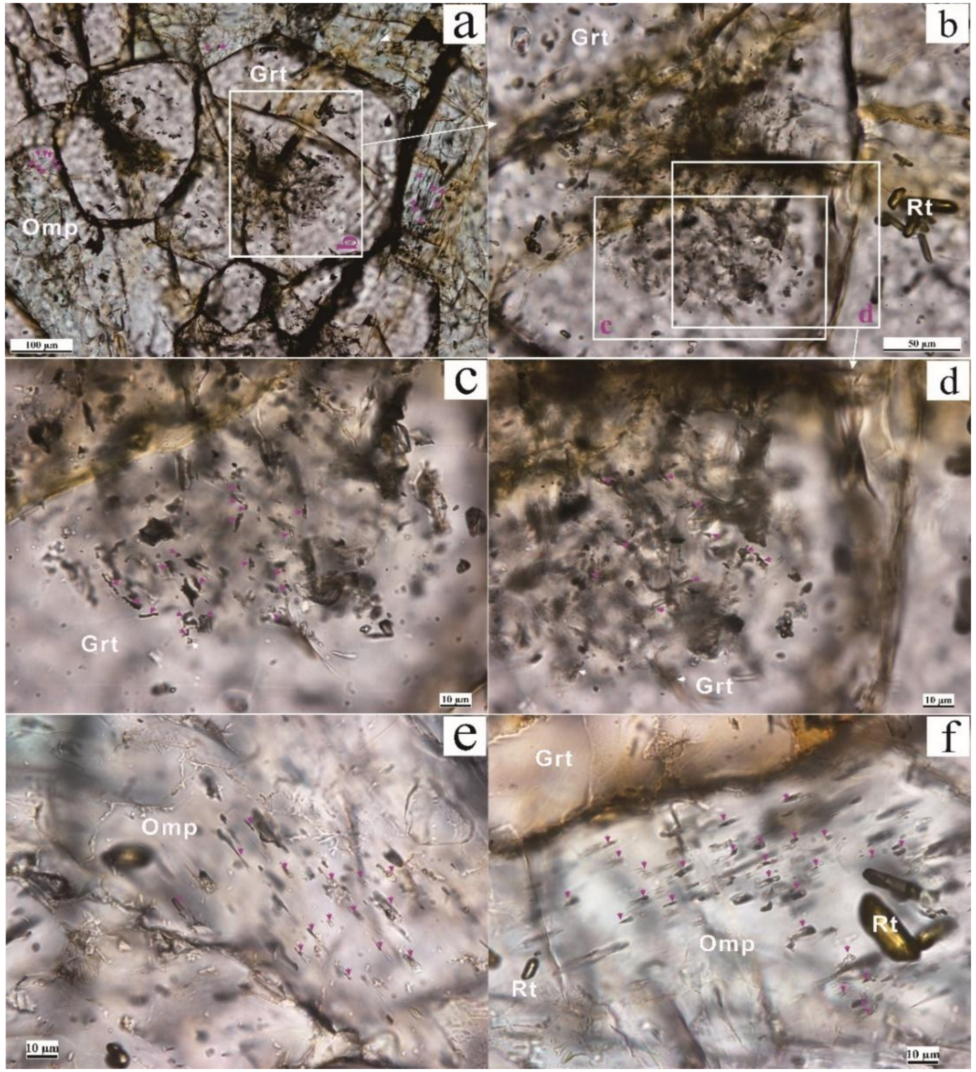


西天山榴辉岩中存在大量原生富含甲烷流体包裹体



榴辉岩中的含CH_4流体包裹体的定量研究

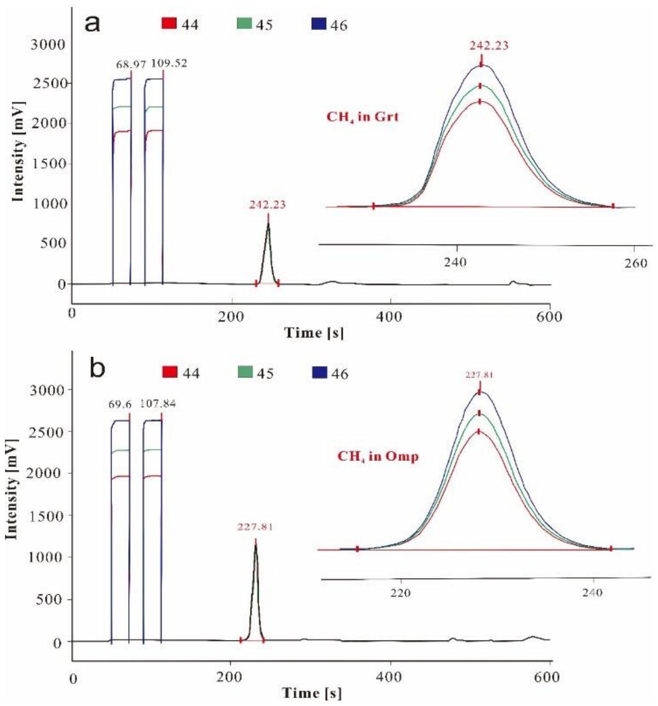




在榴辉岩的主要矿物中都发现有CH4流体包裹体

甲烷储量计算：至少有113Mt的甲烷存储在西南天山榴辉岩中

方法1：通过甲烷峰面积计算

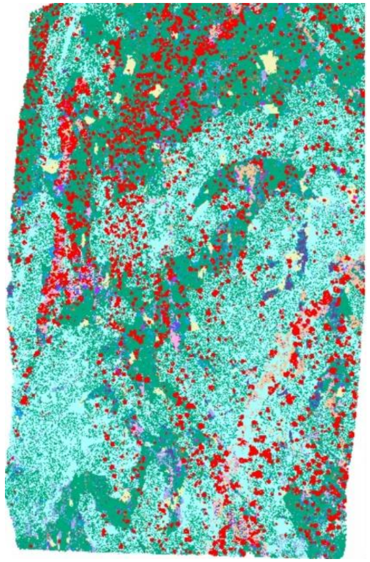


$$K = \frac{AreaStd - AreaBlank}{(\%Tstd * Wstd)/100}$$

$$X\% = \frac{(AreaSample - AreaBlank)/K}{Wsample} * 100$$

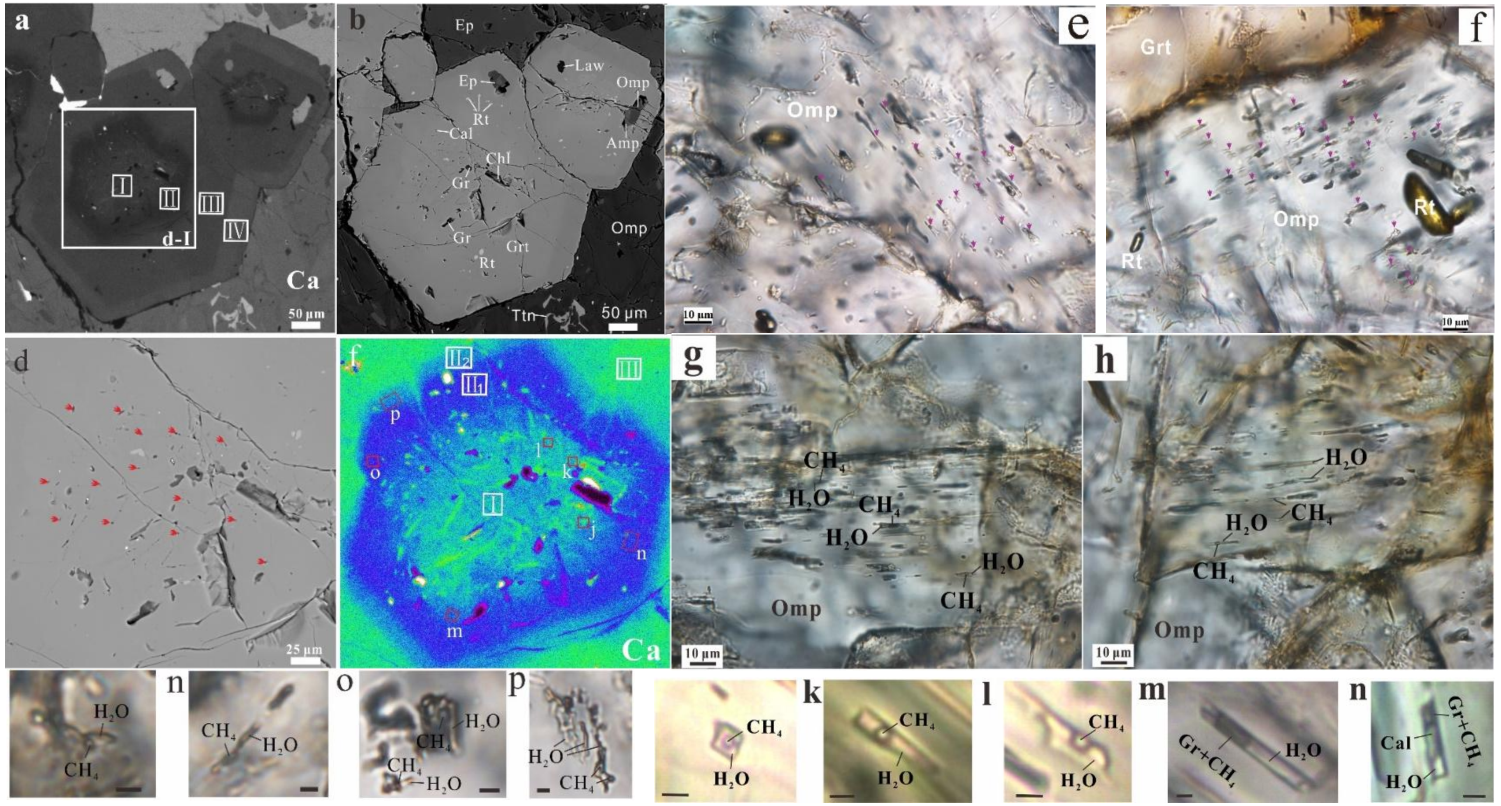
每克Grt含192-618 nmol CH_4
每克Omp含811-1273 nmol CH_4
西南天山榴辉岩存储142-285 Mt CH_4

两者共用



Grt占13.9%
Omp占39.1%

方法2：通过甲烷流体包裹体个数及拉曼剩余压力计算



80km*20 km*(110-70km)
榴辉岩占5%-10%

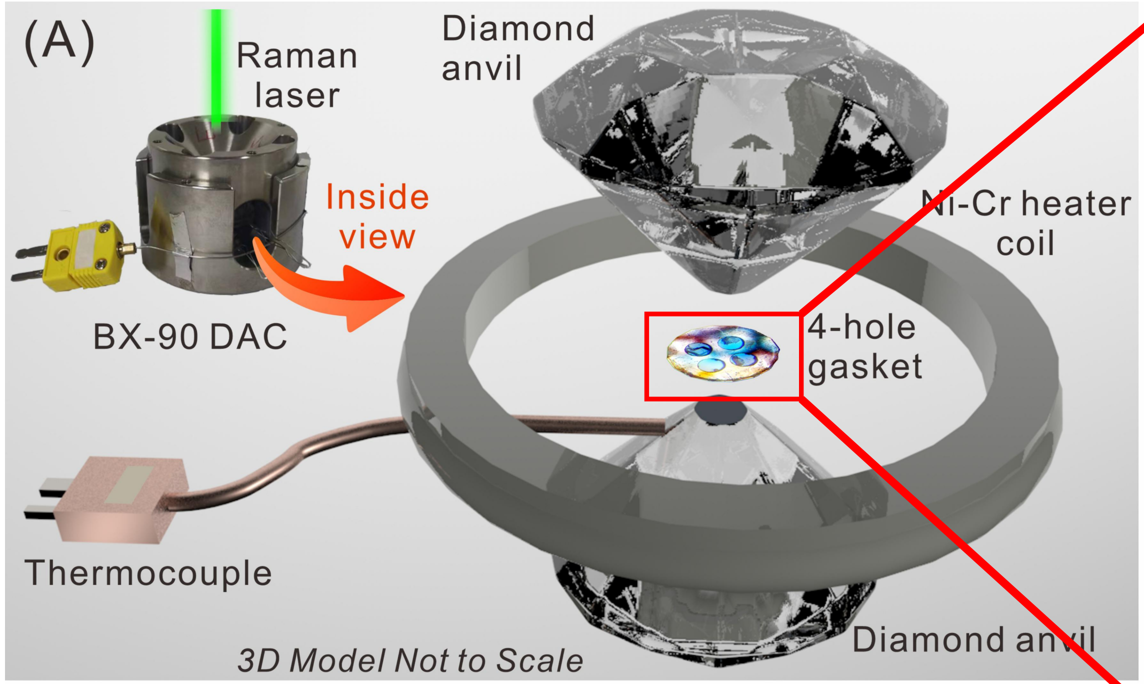
$$PV = nRT$$

每克Grt含485-924 nmol CH_4
每克Omp含974-1860 nmol CH_4
西南天山榴辉岩存储113-430 Mt CH_4

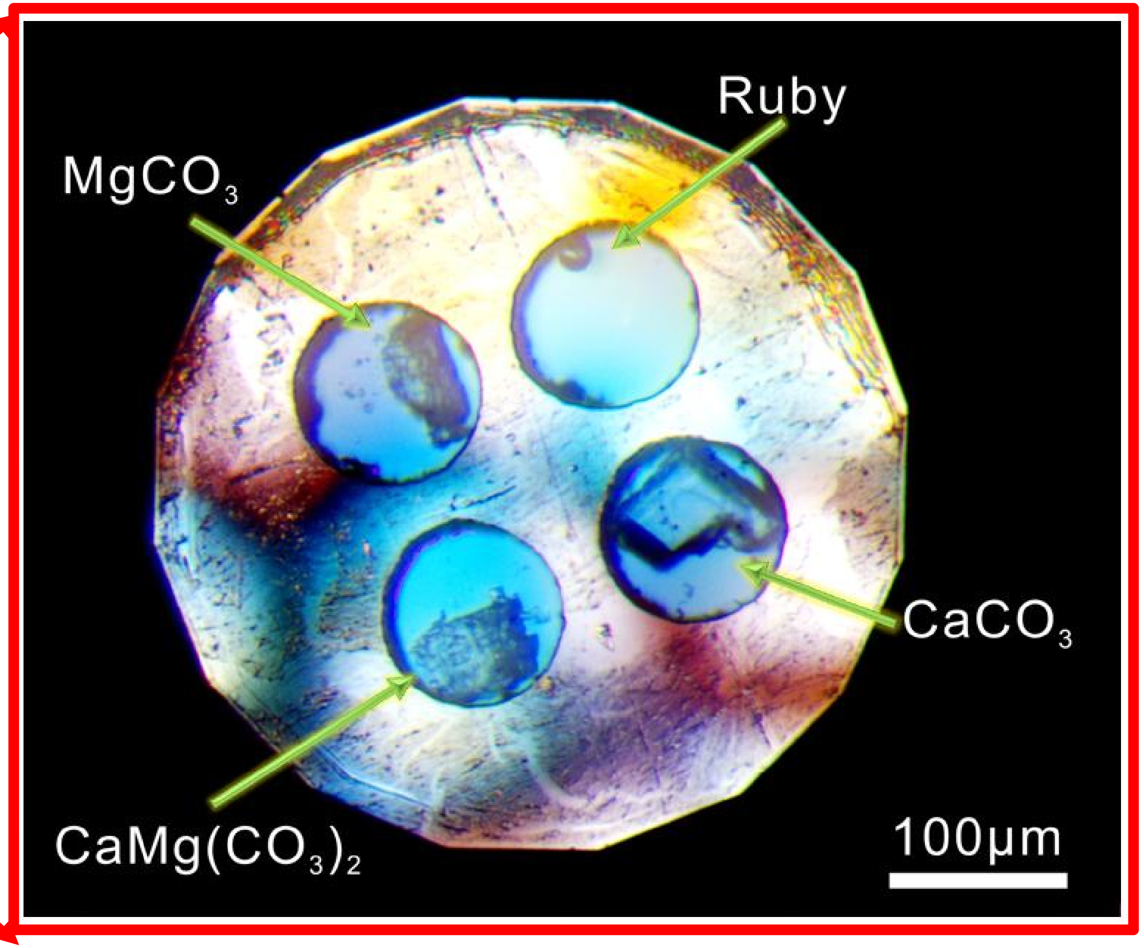
⟵ 两种方法结果一致 ⟶

Zhang et al, 2023, AGS

代表性成果2：俯冲带溶解脱碳-碳酸盐矿物溶解度研究

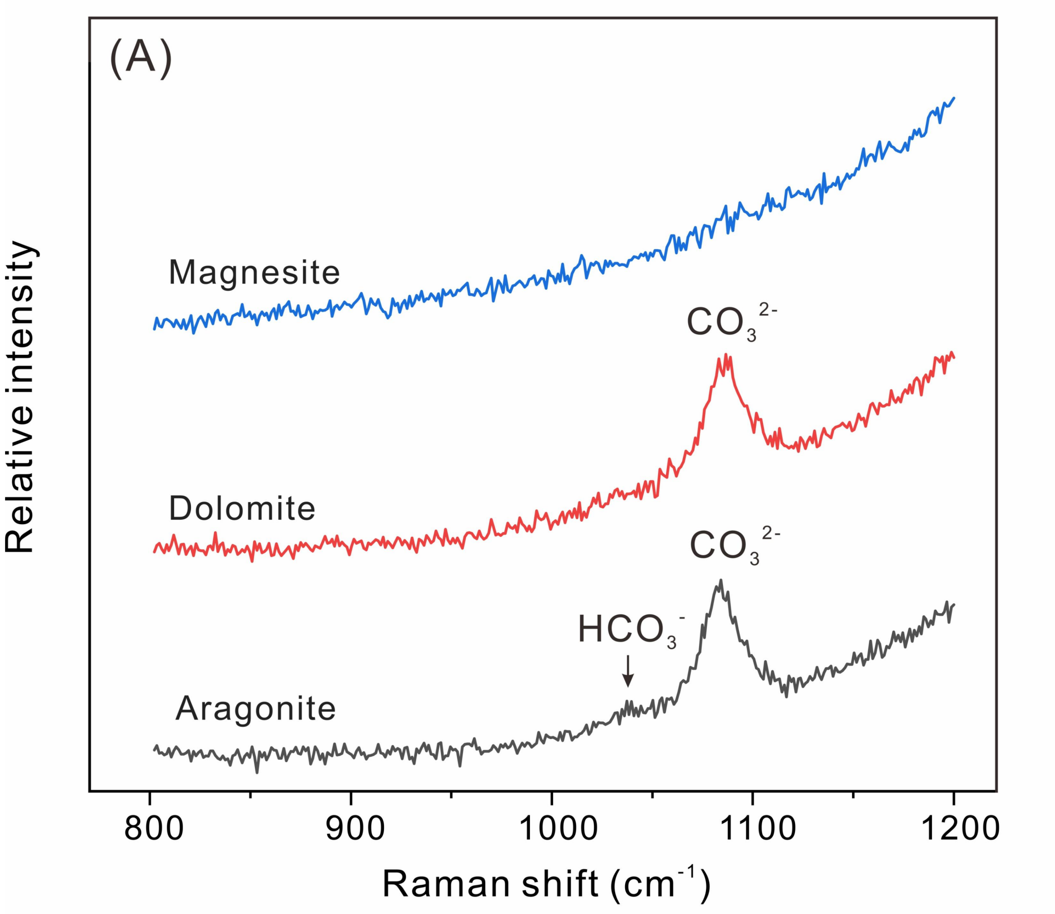


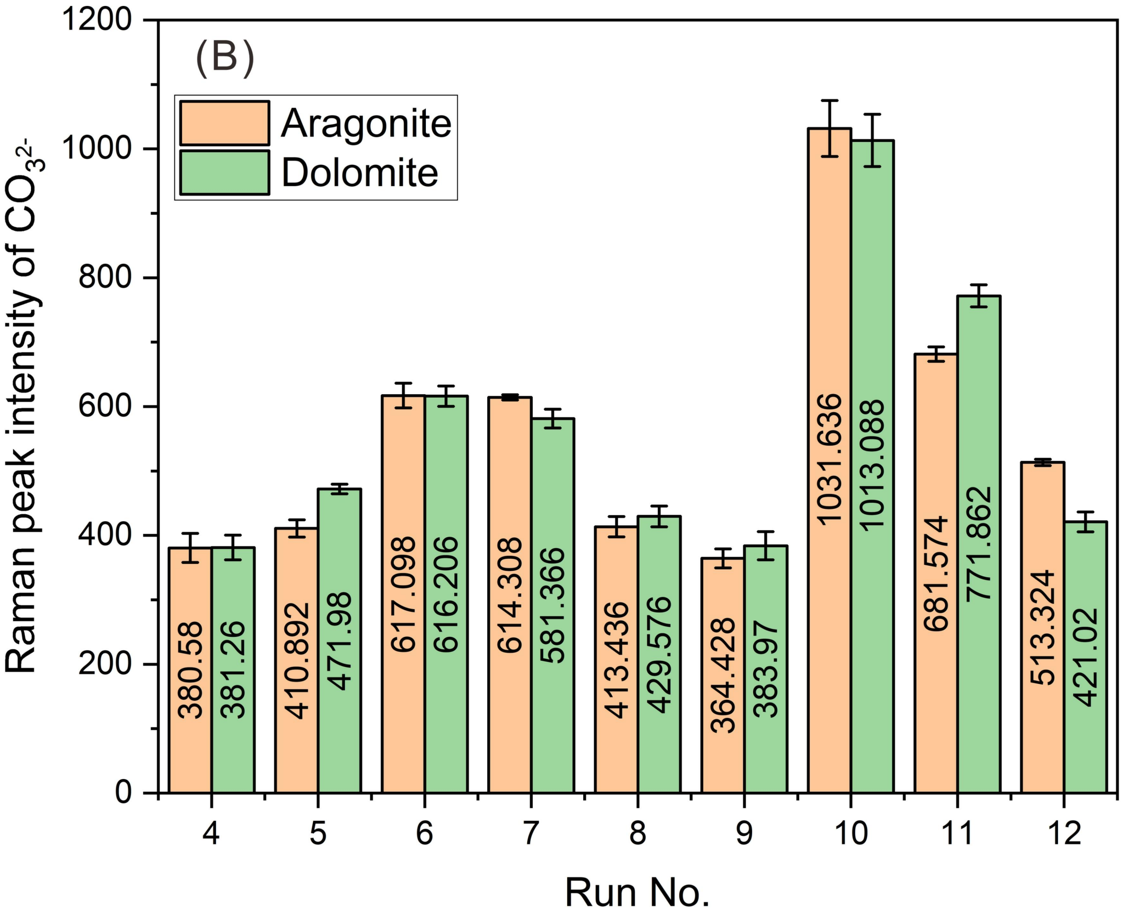
Lan and Zhang* et al., 2023, EPSL



Jiang et al., 2022, RSI

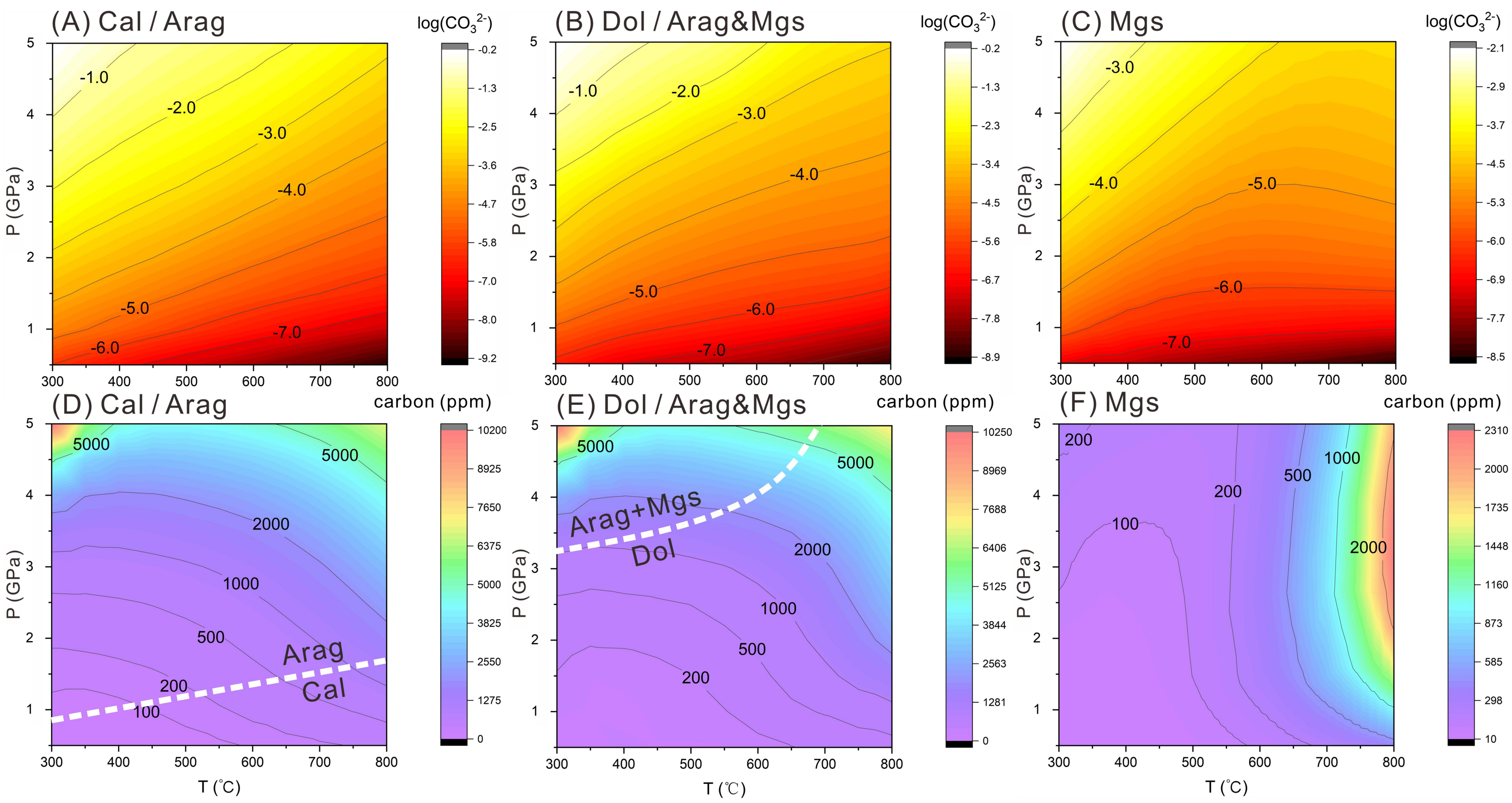
俯冲带溶解脱碳-高压实验确定碳酸盐溶解度





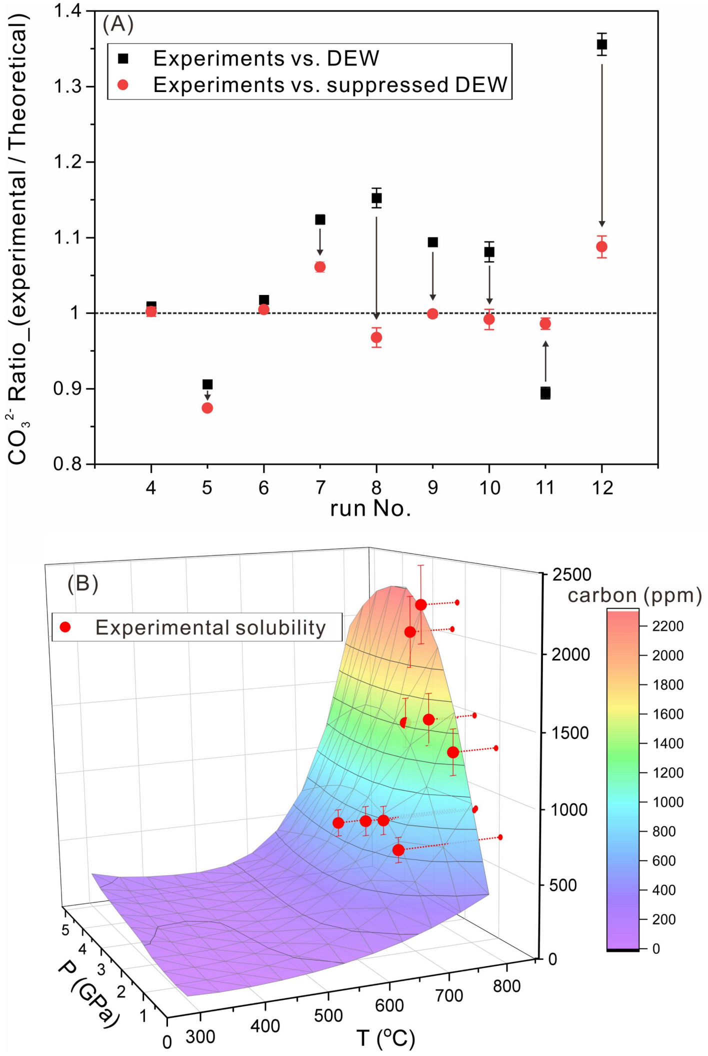
Lan and Zhang* et al., 2023, EPSL

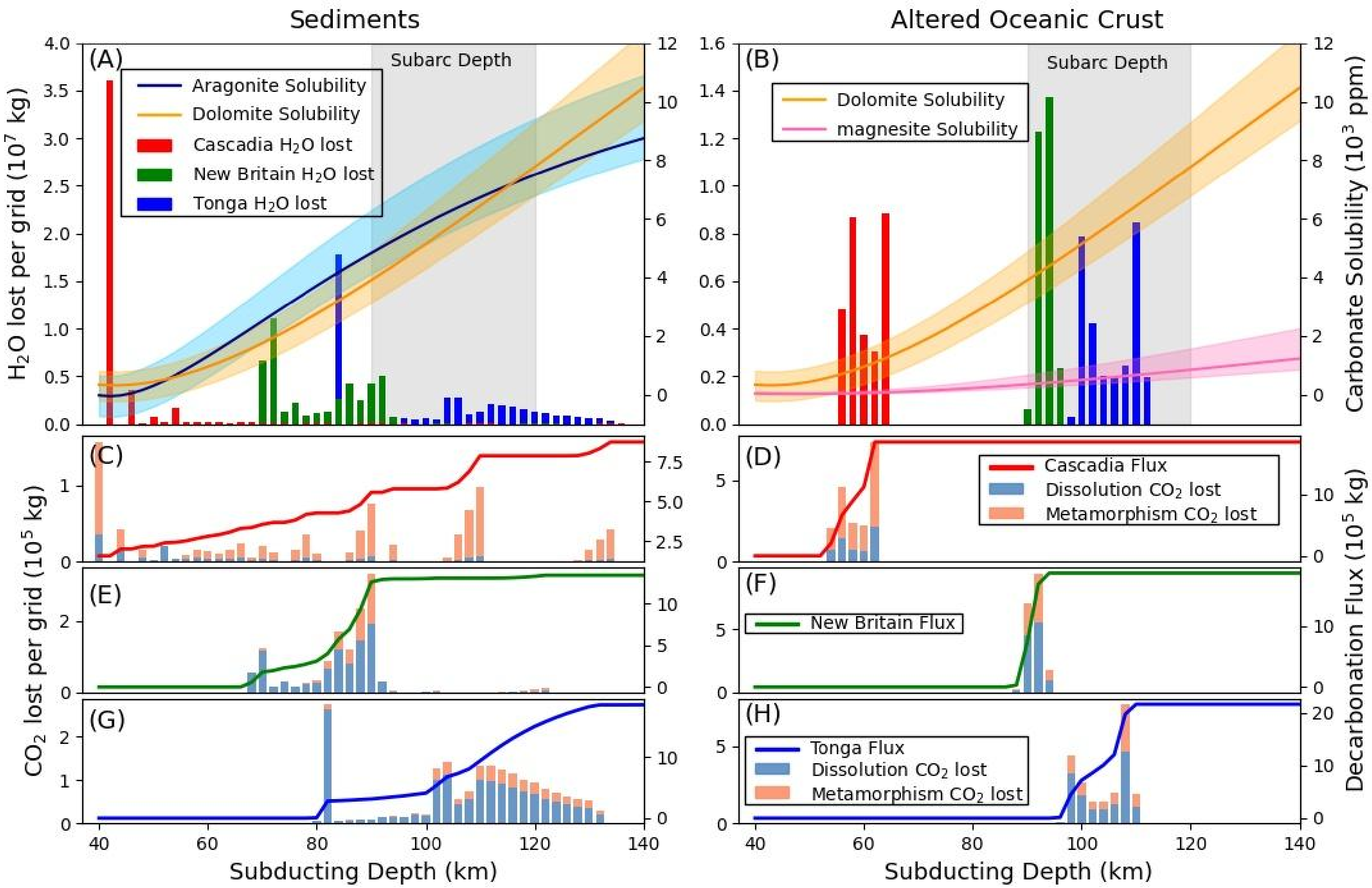
俯冲带溶解脱碳-热力学模拟计算碳酸盐溶解度



Lan and Zhang* et al., 2023, EPSL

俯冲带溶解脱碳-脱碳通量估算

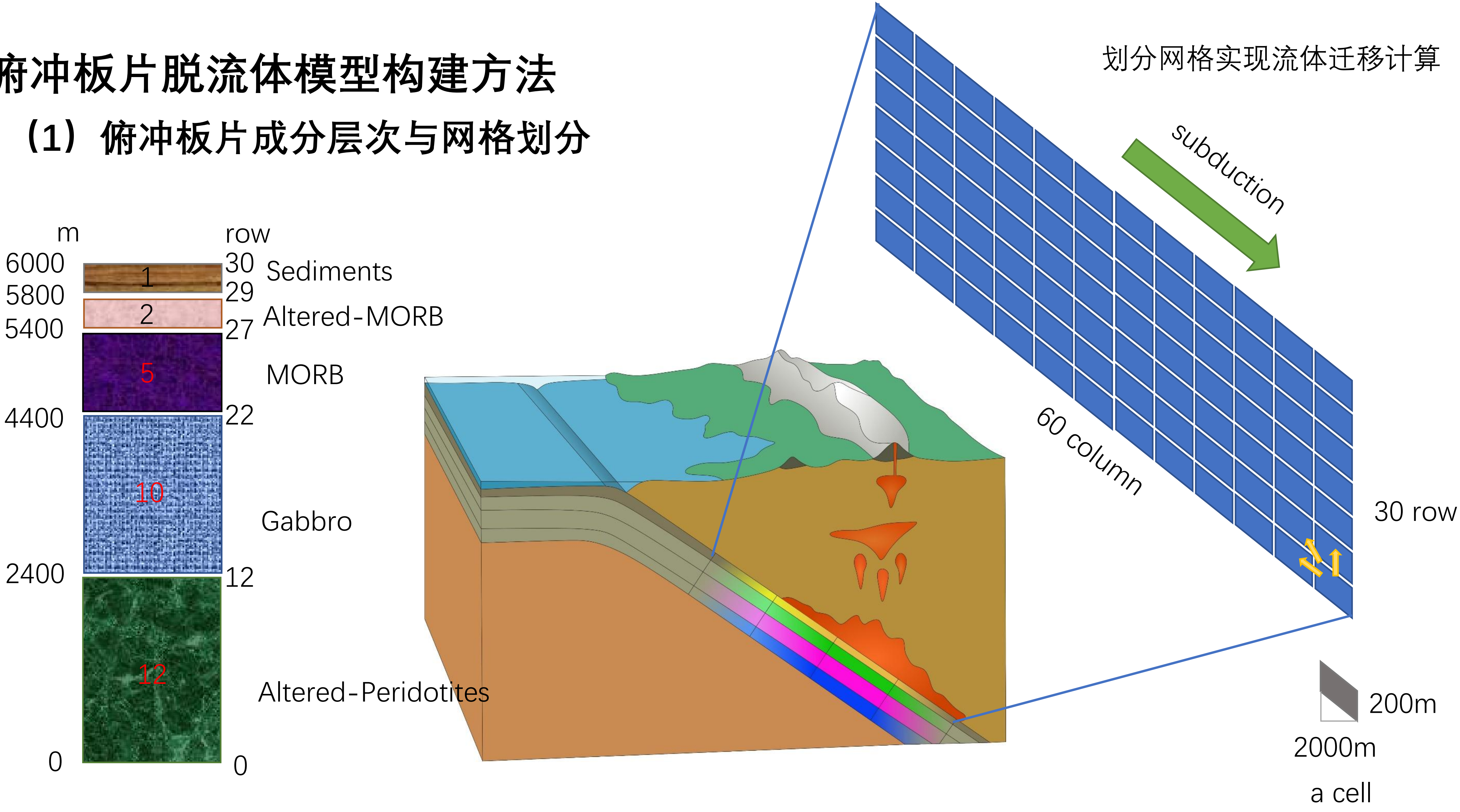




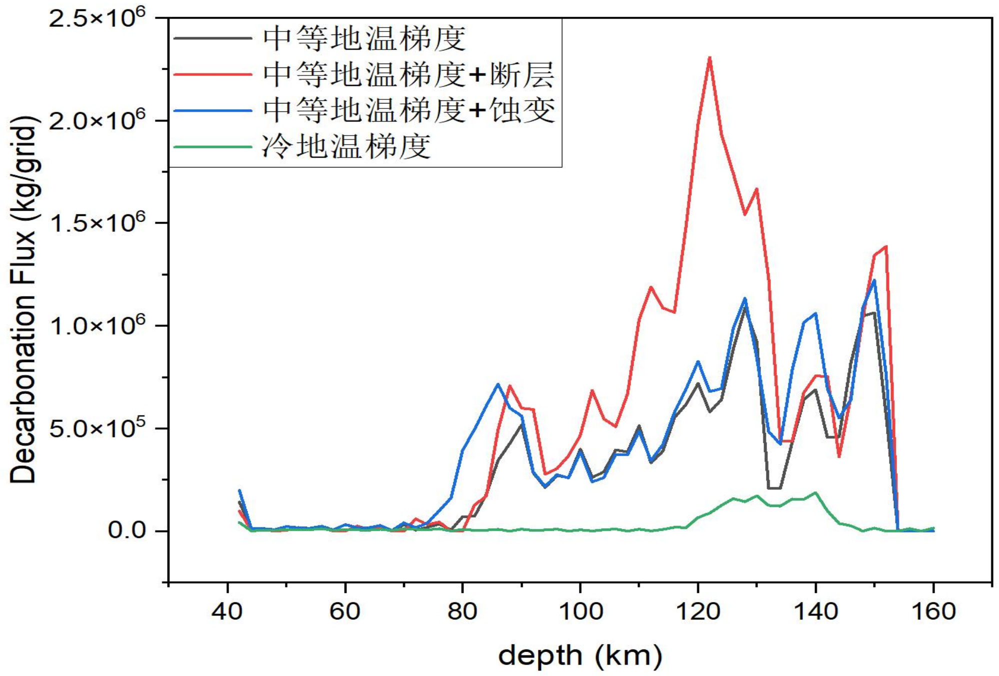
Lan and Zhang* et al., 2023, EPSL

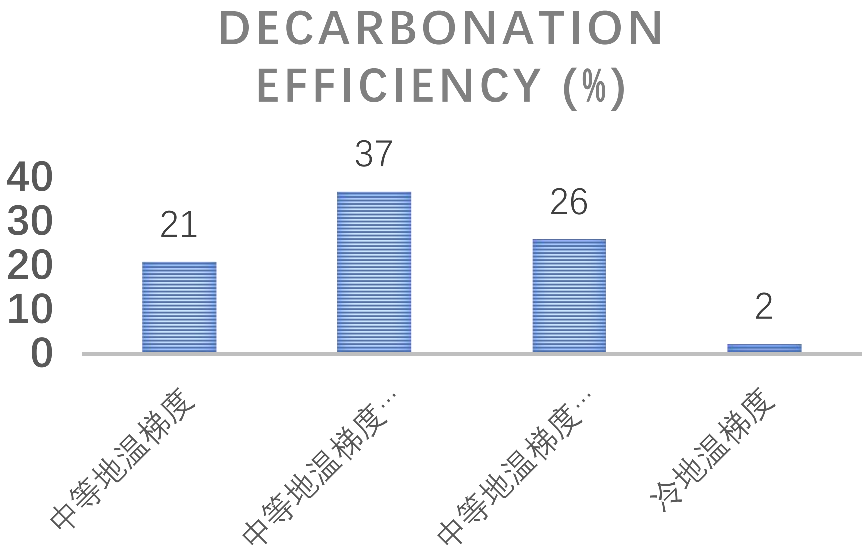
俯冲板片脱流体模型构建方法

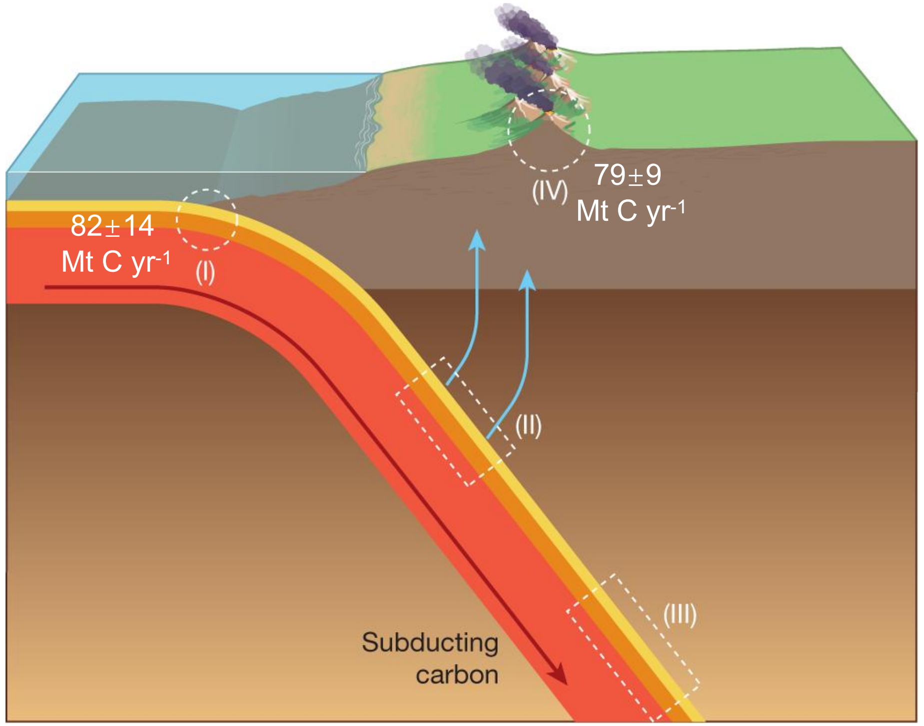
（1）俯冲板片成分层次与网格划分



俯冲板片脱碳不同条件下计算结果对比





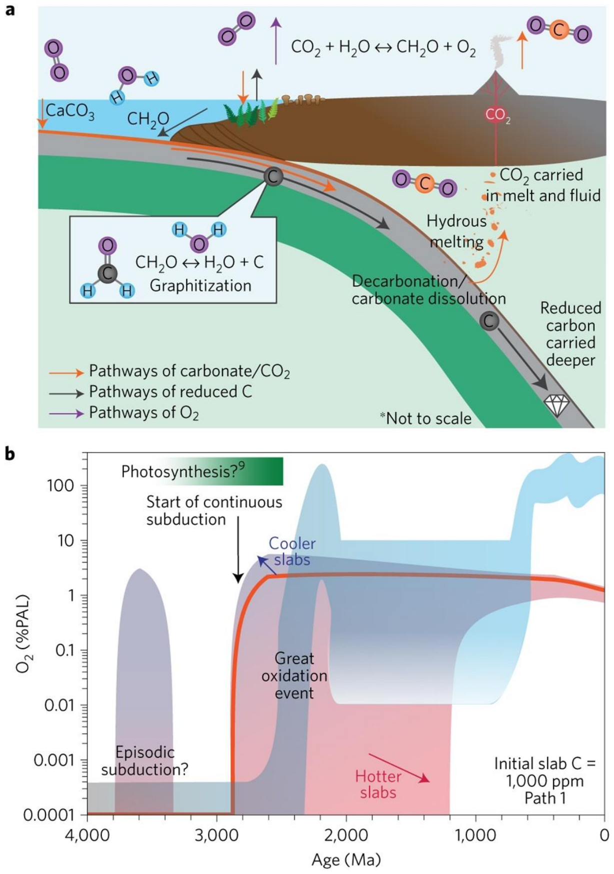


Plank & Manning, 2019, Nature

>60%的碳被板块俯冲至地幔深处

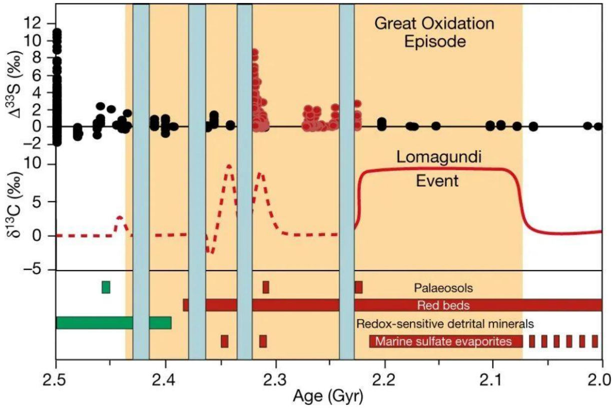
代表性成果3: 有机碳深俯冲到弧下深度的岩石学证据

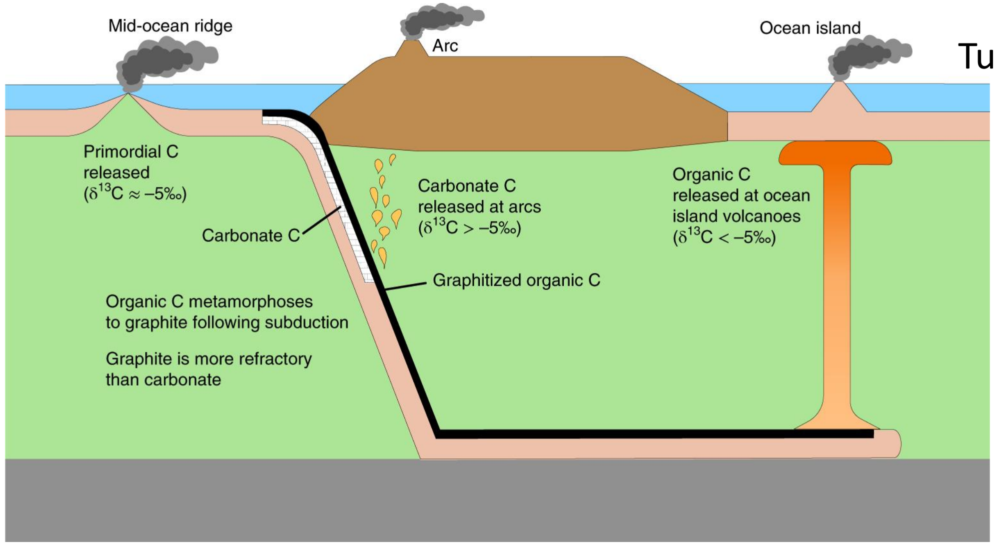
◘ 大氧化事件



Duncan & Dasgupta, 2017, NG

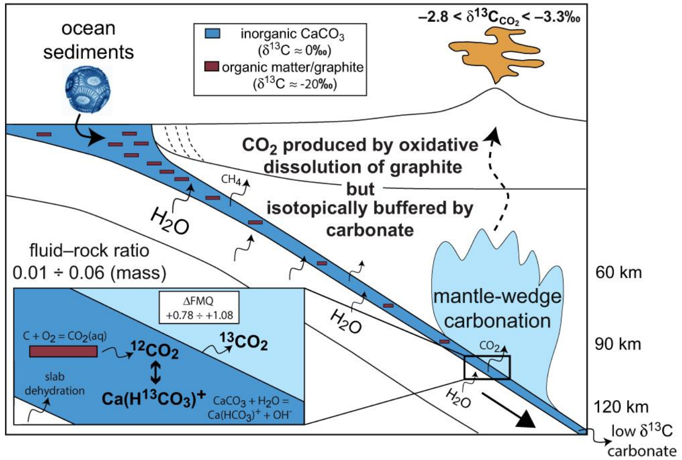
◘ Lomagundi 事件





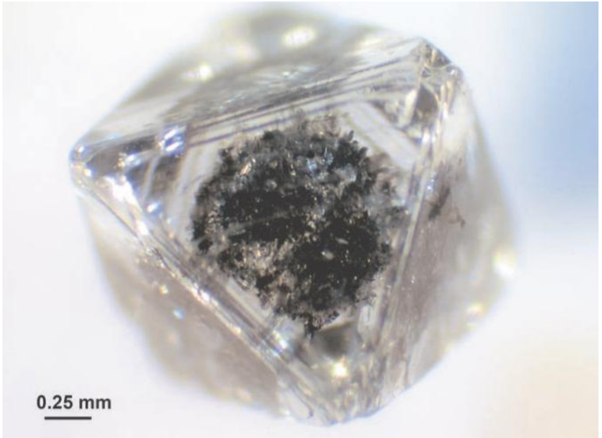
Eguchi et al., 2020, NG; Poulton et al., 2021, Nature

◘ 岛弧火山的碳排放



Tumiati et al., 2022, NC

◘ 地幔金刚石



Yang et al., 2021, NREE

一直缺乏岩石学证据？

■ 有机碳可以俯冲到地幔？

- 洋壳沉积物中的有机碳随着俯冲深度的增加，会变质形成石墨。
- 金刚石是石墨的一种高压多相物质，形成于岩石圈地幔，其形成条件为深度超过140公里或压力大于4.5 GPa (Sobolev et al., 2000)。
- 金刚石为研究地幔碳提供了主要的数据来源。

一些金刚石表现出较轻的碳同位素特征（即低于地幔范围）(Cartigny et al., 2014; Schulze et al., 2013)，特别是蛇绿岩型金刚石，其$\delta^{13}C$值在−29‰至−18‰之间，峰值为−25‰ (Yang et al., 2021; Lian and Yang, 2019)。人们提出了各种理论来解释这些金刚石的轻$\delta^{13}C$组成，包括原始碳储库、地幔内同位素分馏或俯冲生物碳（即有机碳）的加入 (Cartigny, 2005)。然而，地幔Sr、Nd和O同位素地球化学数据排除了地幔中原始碳同位素非均质性保存的可能性。此外，单个金刚石的$\delta^{13}C$值范围窄，不支持正常地幔碳源（$\delta^{13}C$值为-5±2‰）的同位素分馏。因此，蛇绿岩型金刚石记录的轻$\delta^{13}C$特征可能反映了俯冲有机碳的贡献。然而，由于缺乏可靠的岩石学证据，这一猜测尚存争议。

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ARTICLE

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Petrological evidence for deep subduction of organic carbon to subarc depths

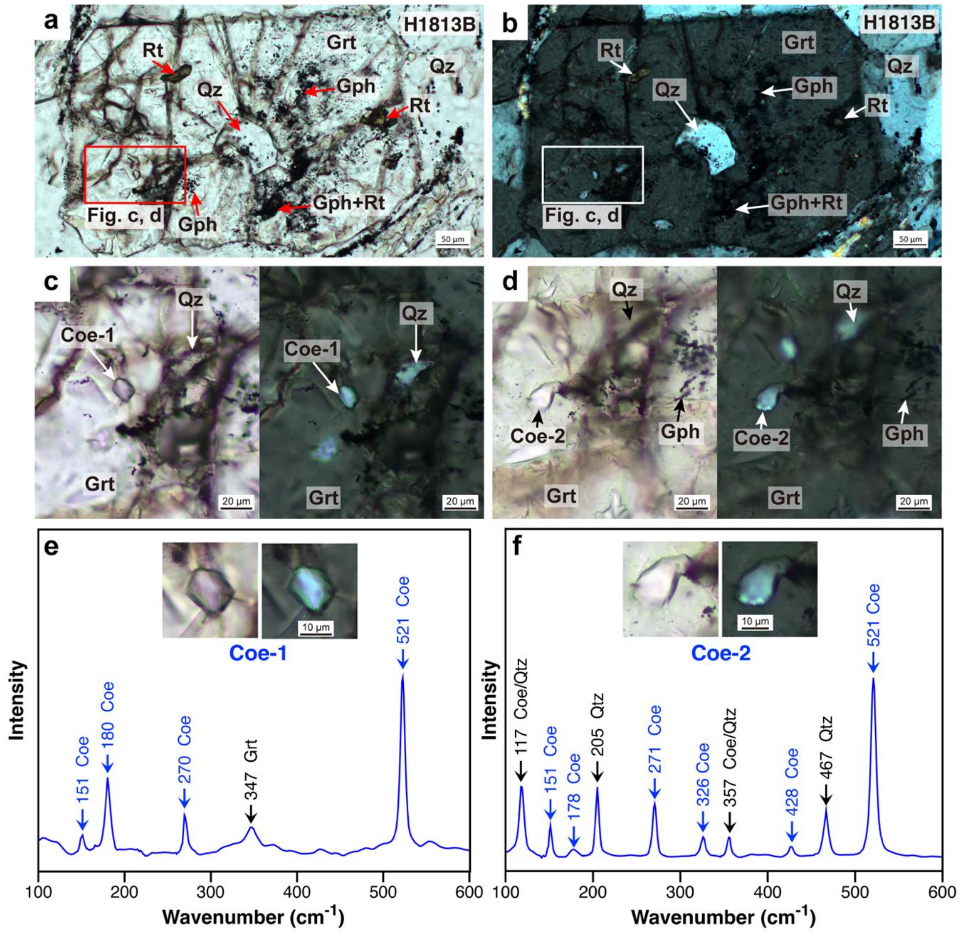
Han Hu[1], Lifei Zhang[1]✉, Chunyuan Lan[1] & Zhicheng Liu[1]

有机碳俯冲到弧下深度的岩石学证据

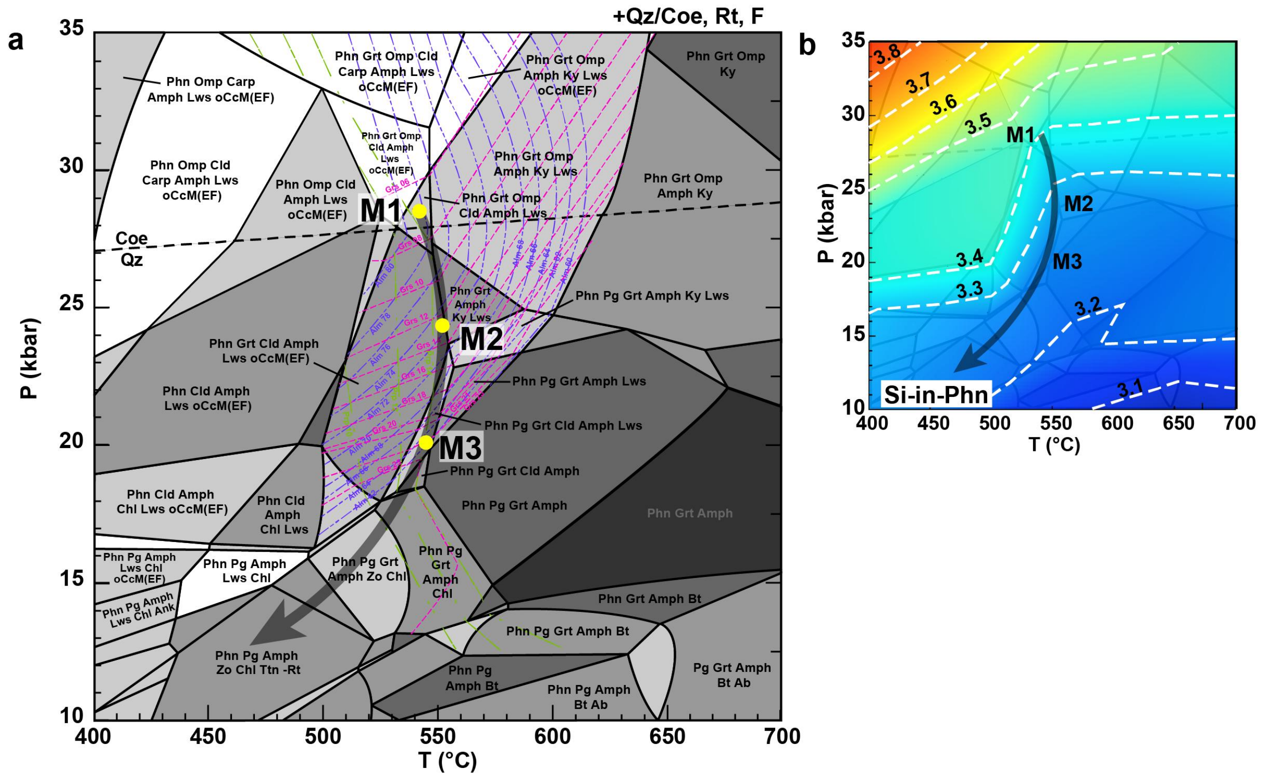
有机碳俯冲到弧下深度的岩石学证据

➢ 研究对象：中国新疆西南天山超高压变质带的**富含石墨泥质片岩**

□ 岩相学：柯石英 (Coe) 和石墨 (Gph) 在石榴石中共存

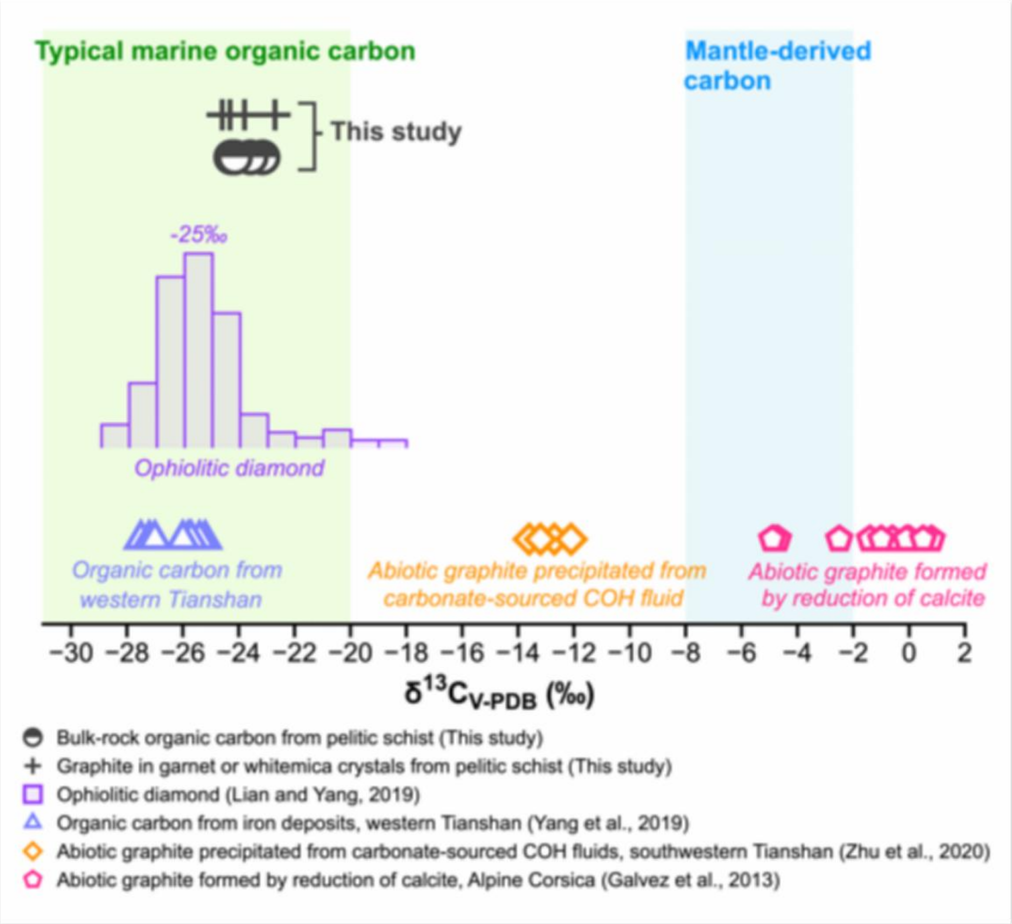


□ 相平衡模拟：石榴石和多硅白云母记录了超高压条件



Hu & Zhang et al., 2023, CEE

■ 有机碳俯冲到弧下深度的岩石学证据

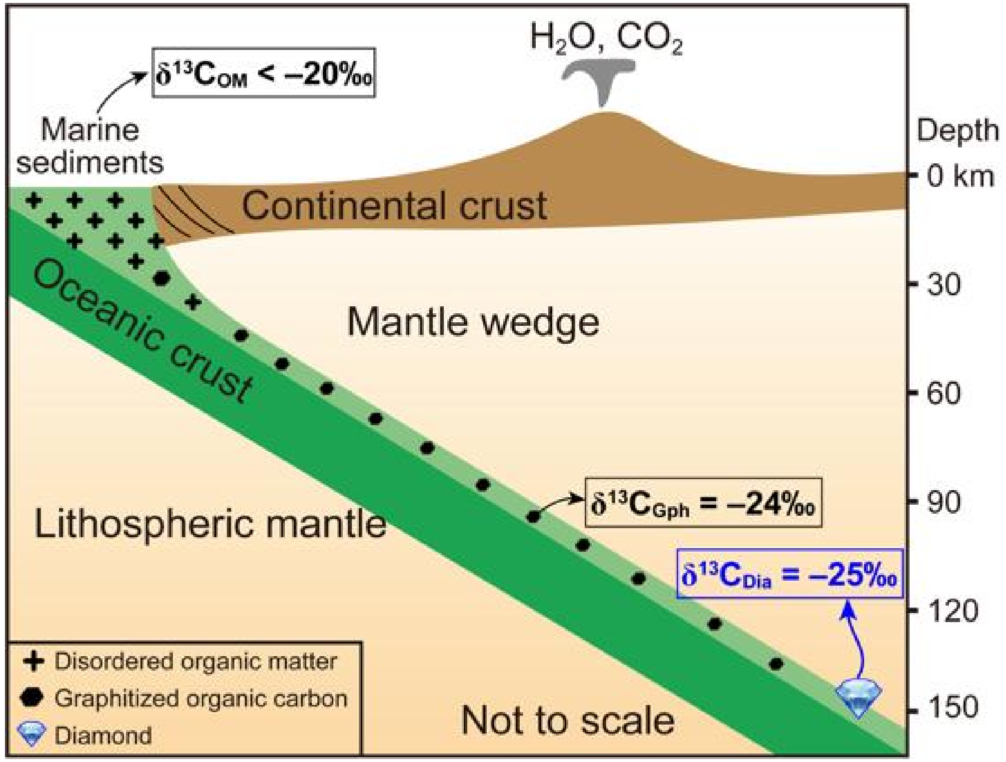


- 石墨显示出较轻的$\delta^{13}C$值（−24.7至−22.5‰），表明其来源于海相沉积物中的有机碳。
- 蛇绿岩型金刚石的$\delta^{13}C$值为−29至−17 ‰，峰值为−25‰ (Lian & Yang, 2019)。
- 推测：这种源自地表有机碳的结晶石墨的进一步俯冲，有可能形成蛇绿岩型金刚石。

Hu & Zhang et al., 2023, CEE

■ 有机碳俯冲到弧下深度的岩石学证据

揭示俯冲带有机碳命运的卡通示意图



0 km 地表：海相沉积物中的**有机质 (<–20‰)**

(petrological evidence + C isotopic values)

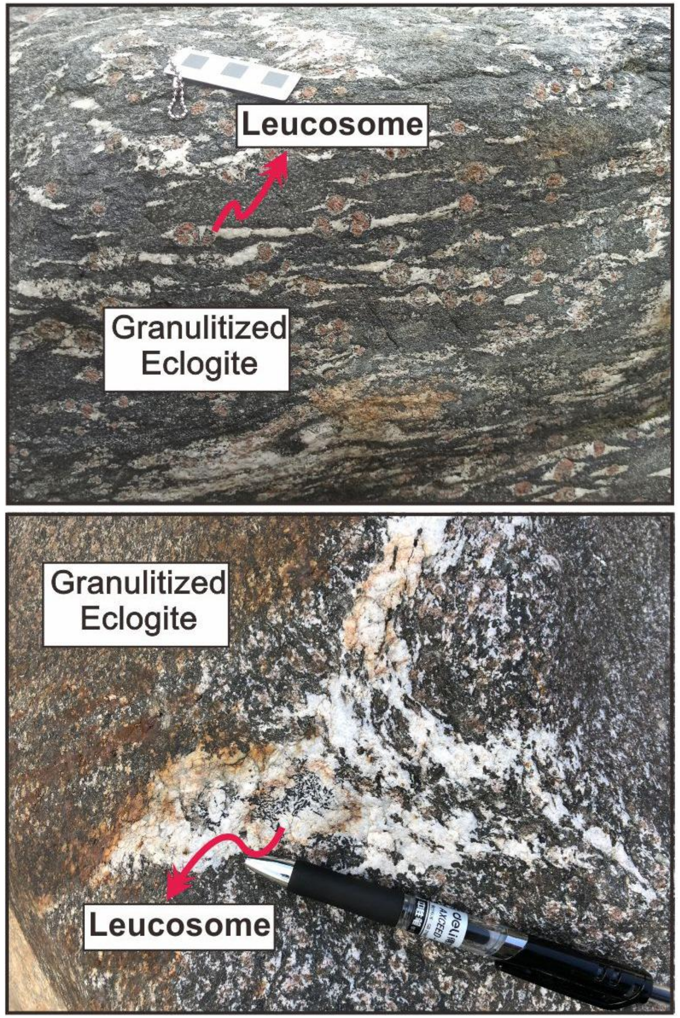
90 km 弧下深度：结晶**石墨 (–24‰)**

140 km 岩石圈地幔深度：（蛇绿岩型）**金刚石 (–25‰)**

Hu & Zhang* et al., 2023, CEE

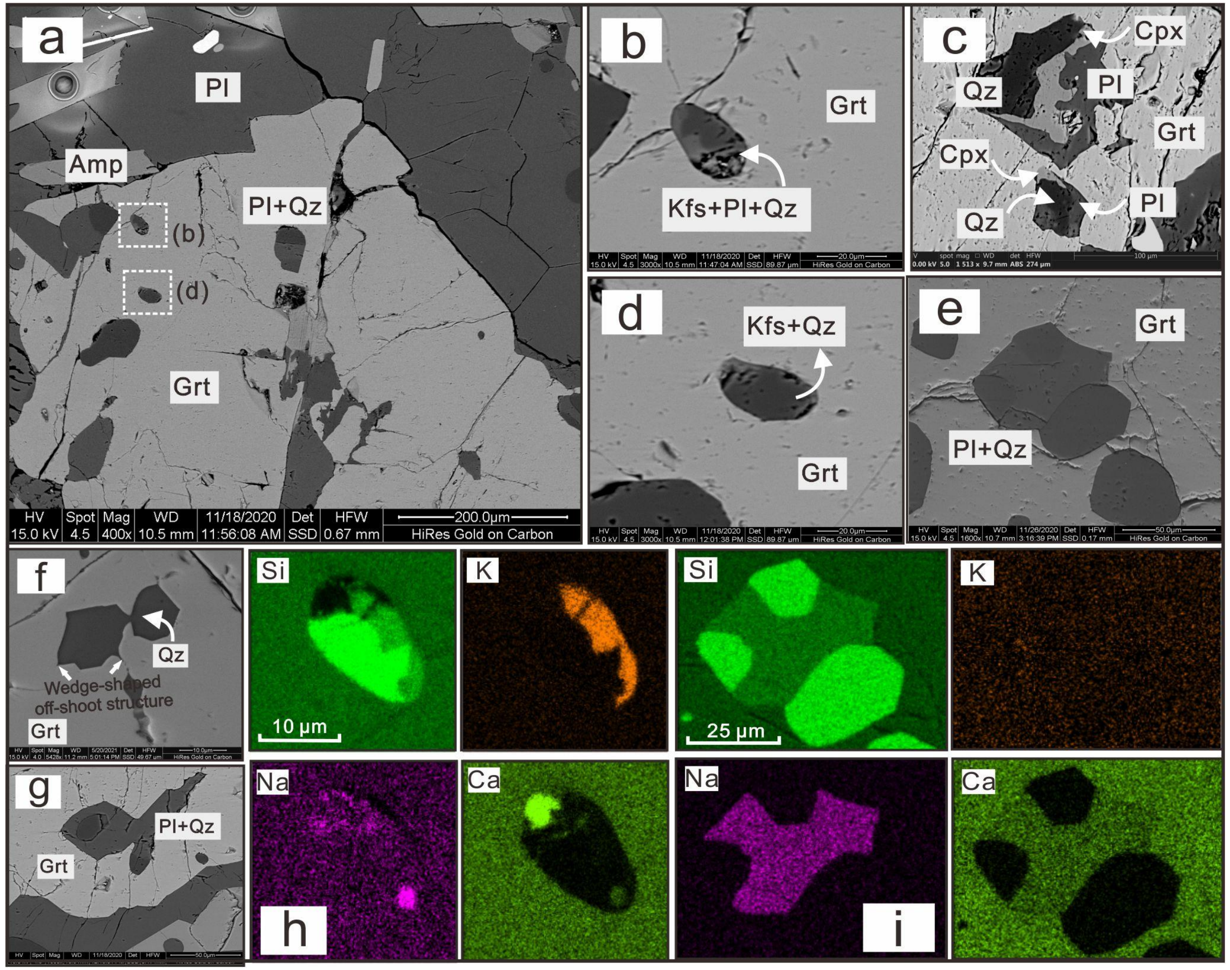
代表性成果4：:喜马拉雅榴辉岩部分熔融

- 部分熔融的野外产状



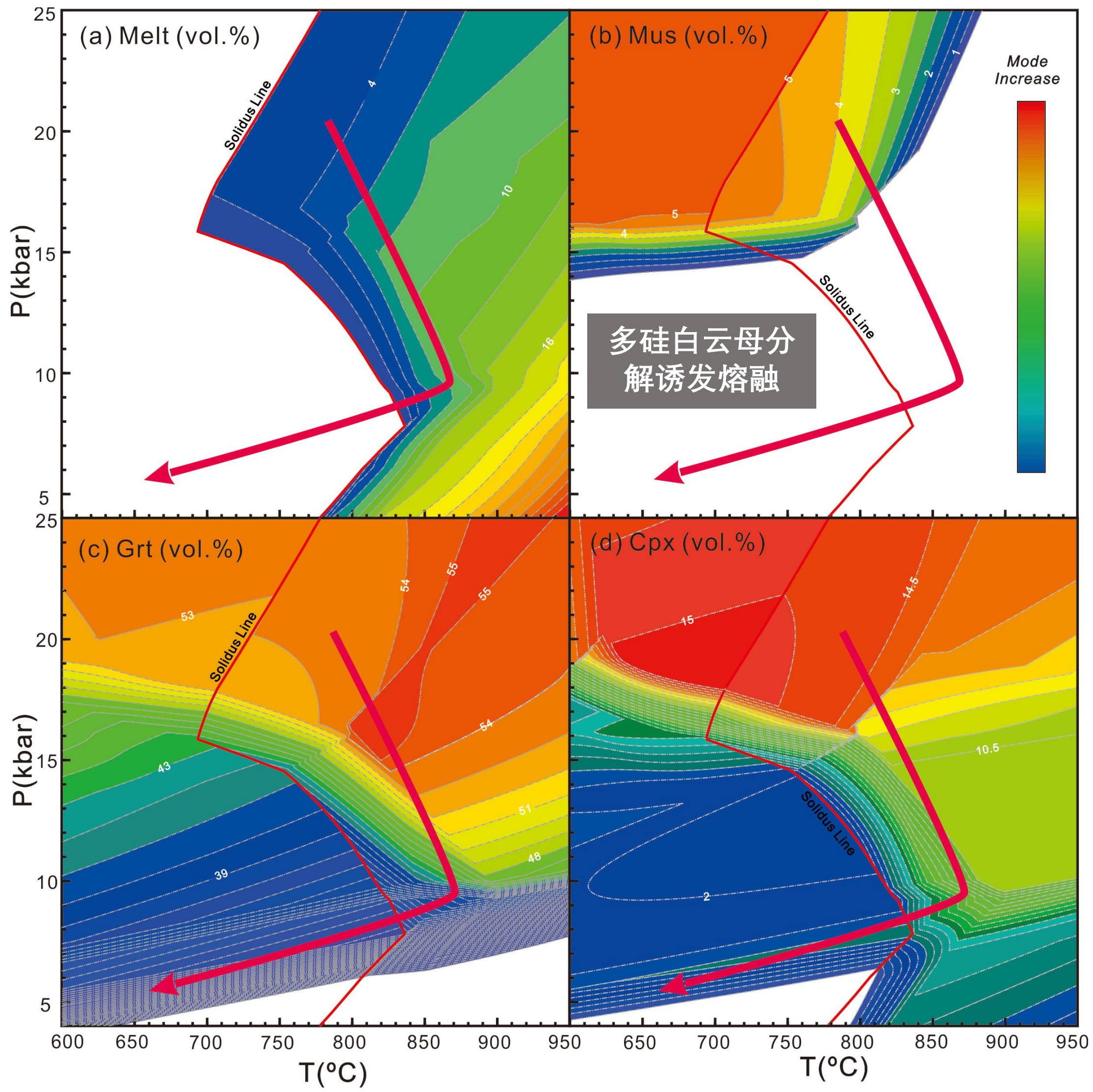
浅色体呈细脉状、囊状、斑块状穿插在榴辉岩中

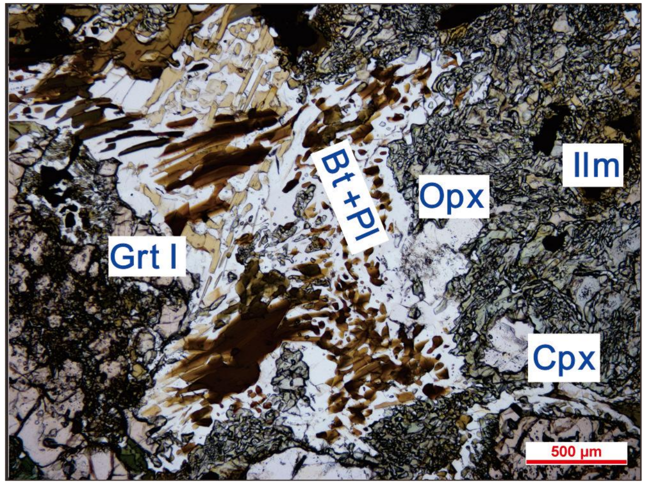
石榴石中发现有熔融矿物多相包裹体，
以Pl–Qz, Kfs–Qz, Kfs–Pl–Qz为主



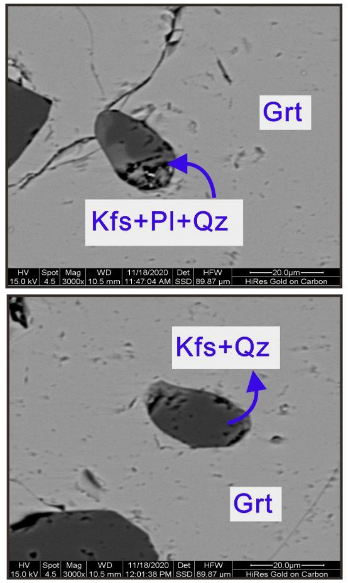
中喜马拉雅榴辉岩部分熔融

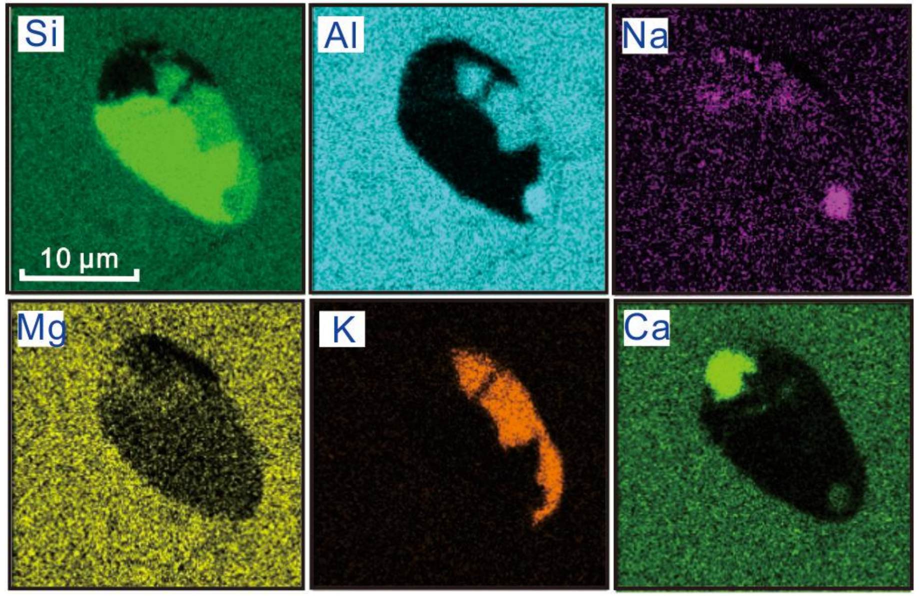
◆部分熔融的机制----峰期阶段以绿辉石参与下多硅白云母分解为主 (Ph+Omp+Qz→Melt+Grt)





- Bt-Pl后成合晶为多硅白云母分解的产物
- 富钾相熔融多相包裹体 (Kfs-Pl-Qz)表明多硅白云母发生分解
- 相平衡模拟指示多硅白云母的丰度在穿过固相线后开始减少，并伴随着绿辉石减少和石榴石丰度增加

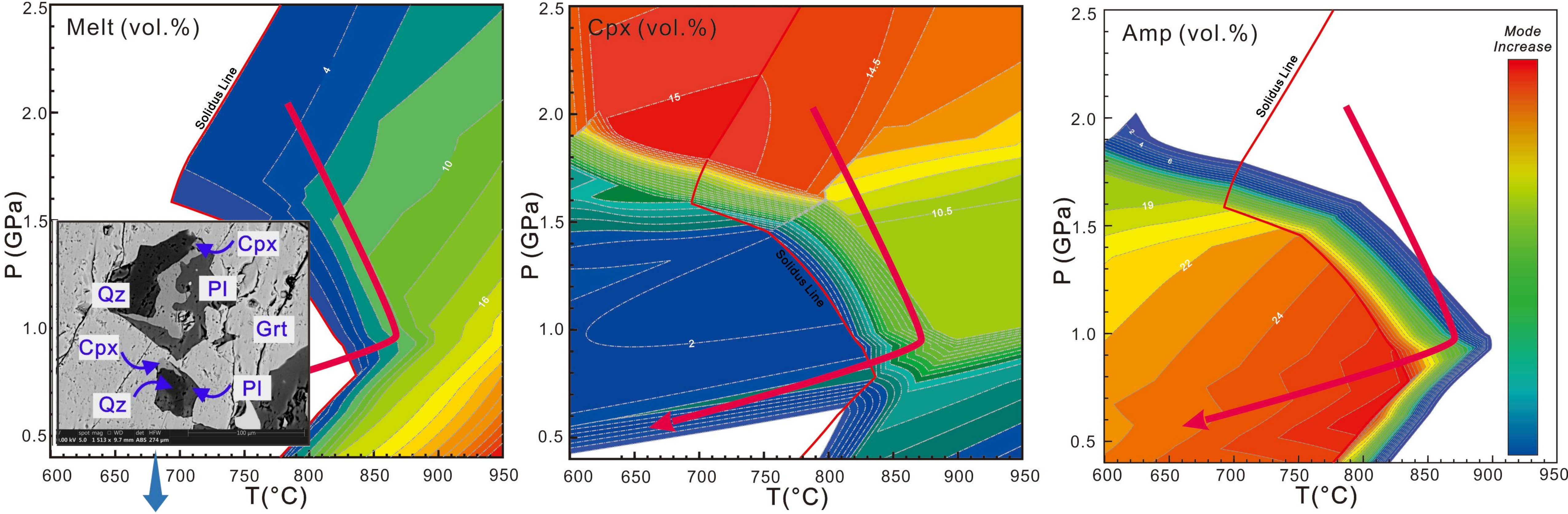




中喜马拉雅榴辉岩部分熔融

- **部分熔融的机制----降压阶段以绿辉石分解为主 (Omp+Qz+Rt→Melt+Grt+Cpx+Opx)**

含水矿物角闪石在高压阶段消失，与熔体丰度变化不相符。绿辉石分解可以解释熔体成分变化

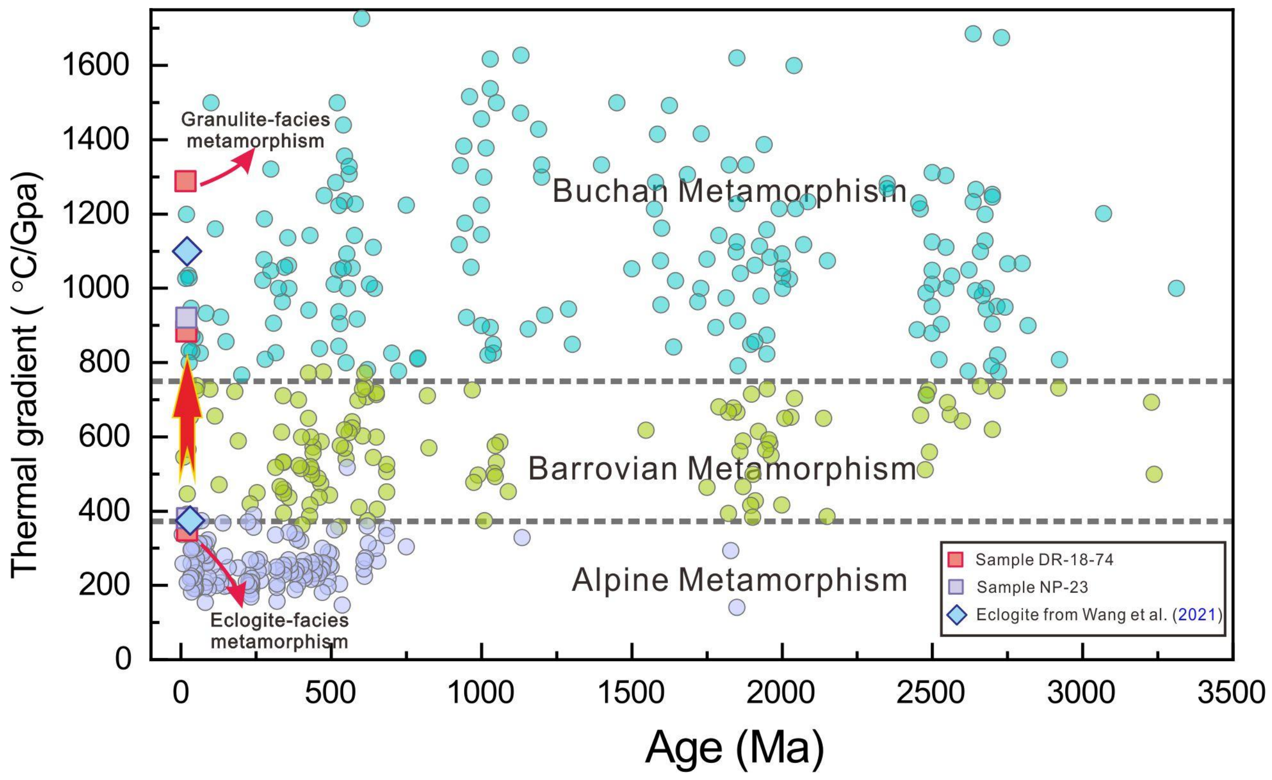


辉石呈残蚀状与长石、石英构成多相包裹体
辉石为早期残余矿物或绿辉石分解的转熔矿物

与普遍观点认为含水矿物分解诱发熔融的机制相比，
名义上无水矿物分解也可以是榴辉岩熔融的主要机制

绿辉石分解熔融的指示意义

- 绿辉石分解熔融导致中喜马拉雅榴辉岩的高压记录被抹平，其也**可能是地球早期高压榴辉岩相记录难以保存的潜在机制。**



JGR Solid Earth

RESEARCH ARTICLE

10.1029/2023JB027395

Key Points:

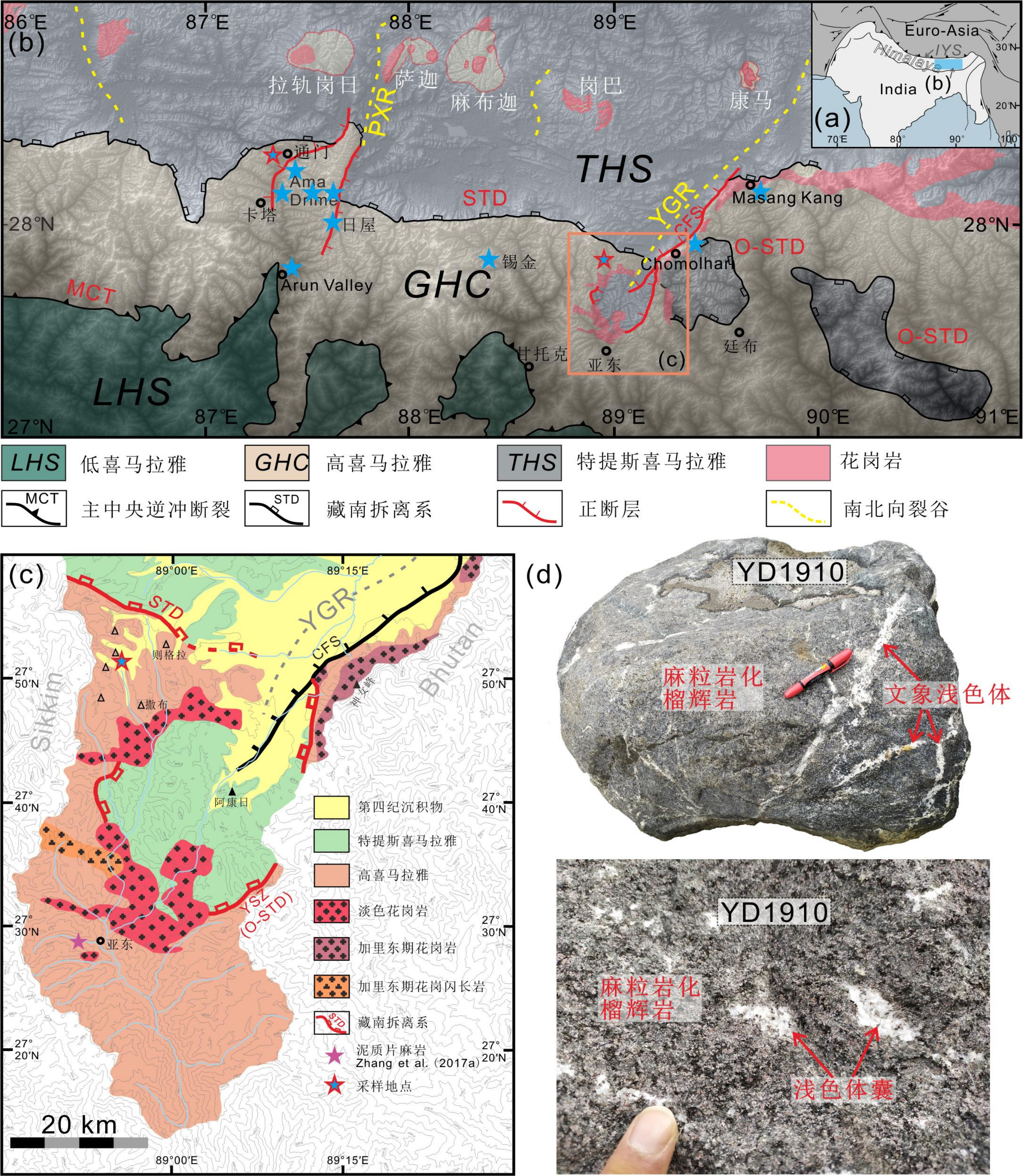
- The granulitized eclogite has experienced omphacite dominated melting with phengite contributions at eclogite-facies stage
- Melts from omphacite breakdown have low Nb/

Omphacite Melting and the Destruction of Early High-Pressure Rock Records

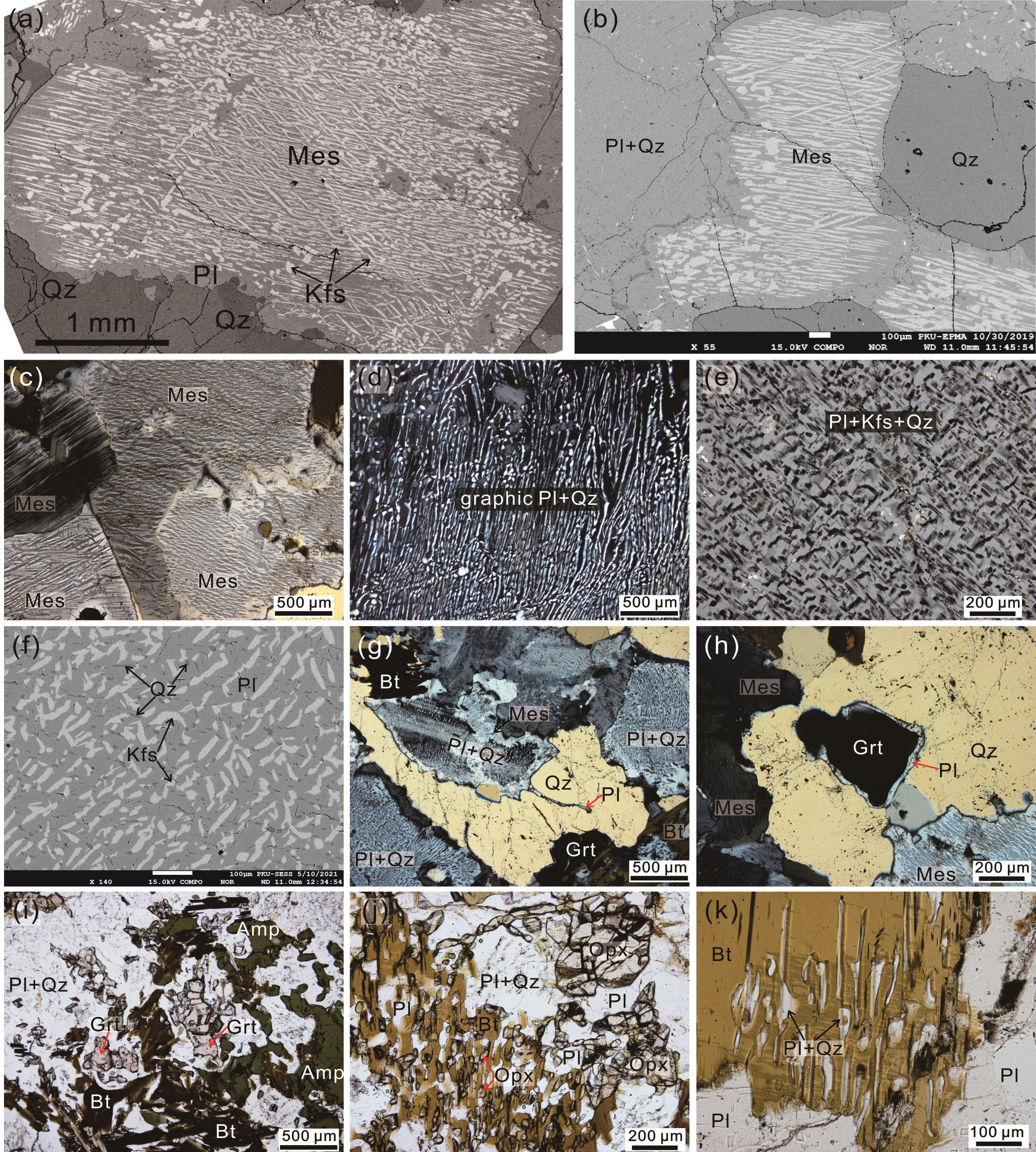
Shuaiqi Liu[1], Guibin Zhang[1], Lifei Zhang[1], and A. Alexander G. Webb[2]

[1]The Key Laboratory of Orogenic Belts and Crustal Evolution, MOE, School of Earth and Space Sciences, Peking University, Beijing, China, [2]Department of Earth Sciences and Laboratory for Space Research, University of Hong Kong, Hong Kong, China

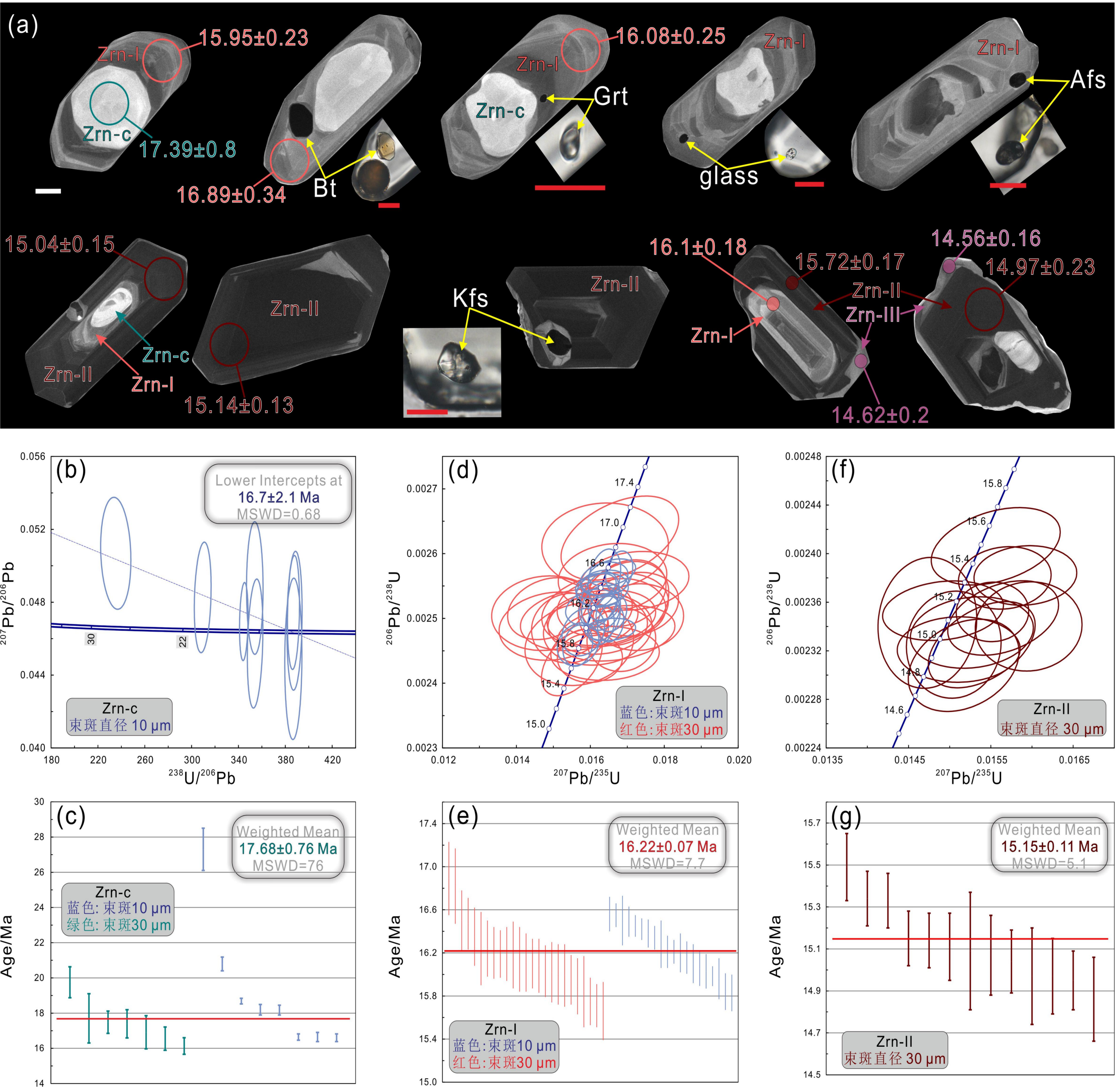
中喜马拉雅榴辉岩记录了高的地热梯度并叠加了高温-超高温变质，与古元古宙甚至太古宙变质记录类似，中喜马拉雅造山带可作为类比地球早期的一个范例

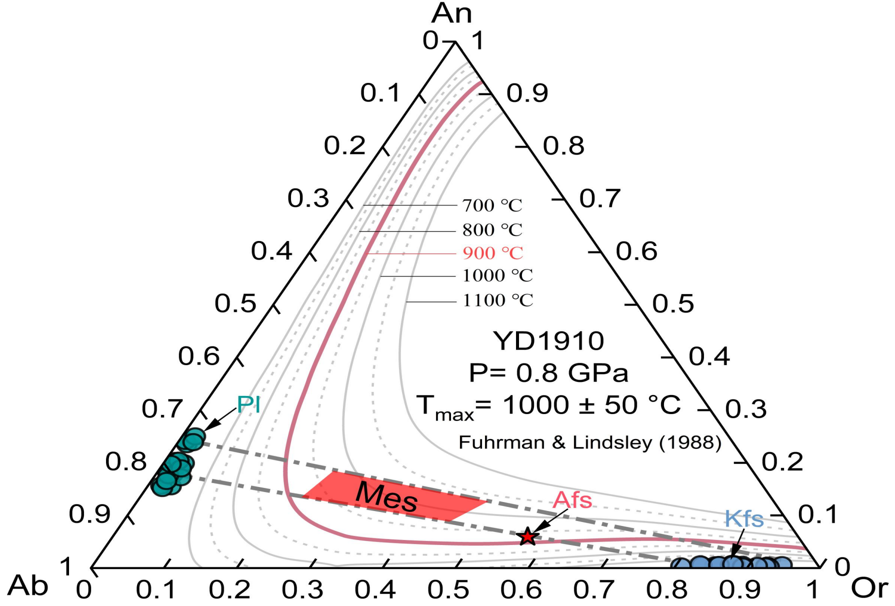


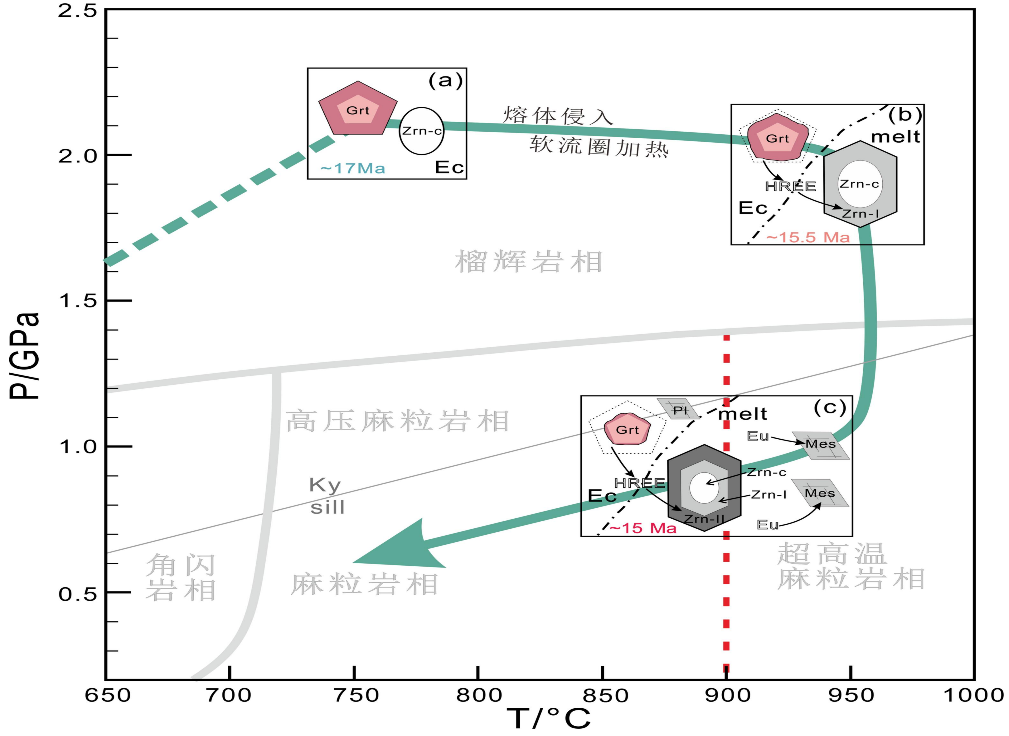
(b)
86°E
87°E
88°E
89°E
90°E
91°E
27°N
28°N
拉轧岗日
萨迦
麻布迦
岗巴
康马
PXR
YGR
THS
GHC
LHS
STD
O-STD
MCT
CFS
通门
Ama
Drime
卡塔
日屋
Arun Valley
锡金
Chomolhari
Masang Kang
甘托克
亚东
廷布
(c)
Euro-Asia
IYS
Himalaya
India
(a)
70°E
80°
90°
100°
30°N
20°N
LHS 低喜马拉雅
GHC 高喜马拉雅
THS 特提斯喜马拉雅
花岗岩
MCT 主中央逆冲断裂
STD 藏南拆离系
正断层
南北向裂谷
(c)
89°00'E
89°15'E
27°50'N
27°40'N
27°30'N
27°20'N
STD
YGR
CFS
Sikkim
Bhutan
则格拉
撒布
阿康日
亚东
YSZ (O-STD)
第四纪沉积物
特提斯喜马拉雅
高喜马拉雅
淡色花岗岩
加里东期花岗岩
加里东期花岗闪长岩
藏南拆离系
泥质片麻岩 Zhang et al.（2017a）
采样地点
20 km
(d)
YD1910
麻粒岩化榴辉岩
文象浅色体
YD1910
麻粒岩化榴辉岩
浅色体囊



(a)
Mes
Qz
Pl
Kfs
Qz
1 mm
(b)
Pl+Qz
Mes
Qz
(c)
Mes
Mes
Mes
Mes
500 μm
(d)
graphic Pl+Qz
500 μm
(e)
Pl+Kfs+Qz
200 μm
(f)
Qz
Pl
Kfs
(g)
Bt
Mes
Pl+Qz
Pl+Qz
Qz
Pl
Pl+Qz
Grt
Bt
500 μm
(h)
Mes
Mes
Grt
Pl
Qz
Mes
200 μm
(i)
Amp
Pl+Qz
Grt
Grt
Amp
Bt
Bt
500 μm
(j)
Opx
Pl+Qz
Pl
Bt
Pl
Pl
Opx
Opx
200 μm
(k)
Bt
Pl+Qz
Pl
Pl
100 μm





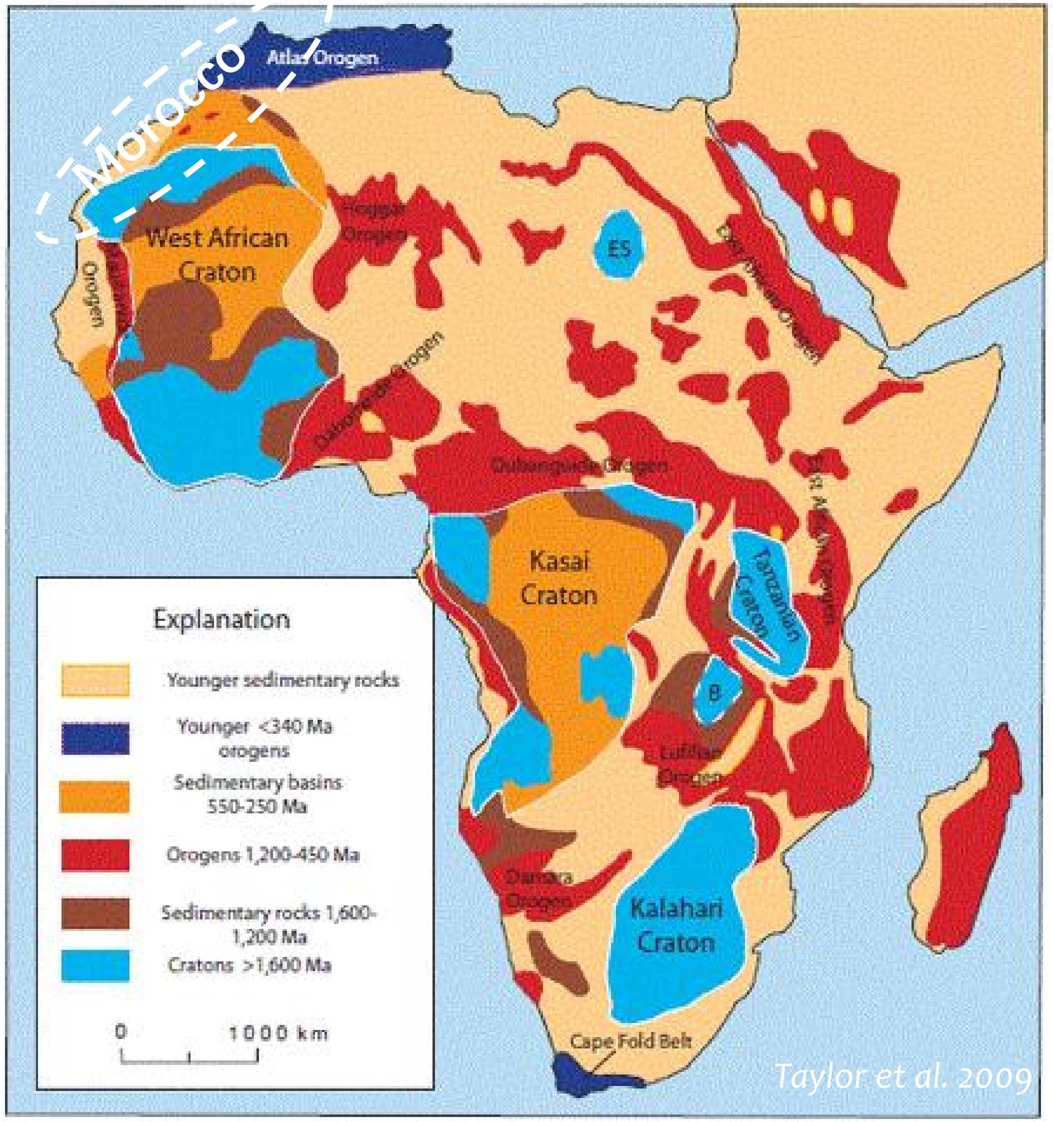


吴晨光 张立飞*等，2023，岩石学报

Outline

- 项目基本情况
- 2023主要工作进展
- 2024 年工作计划

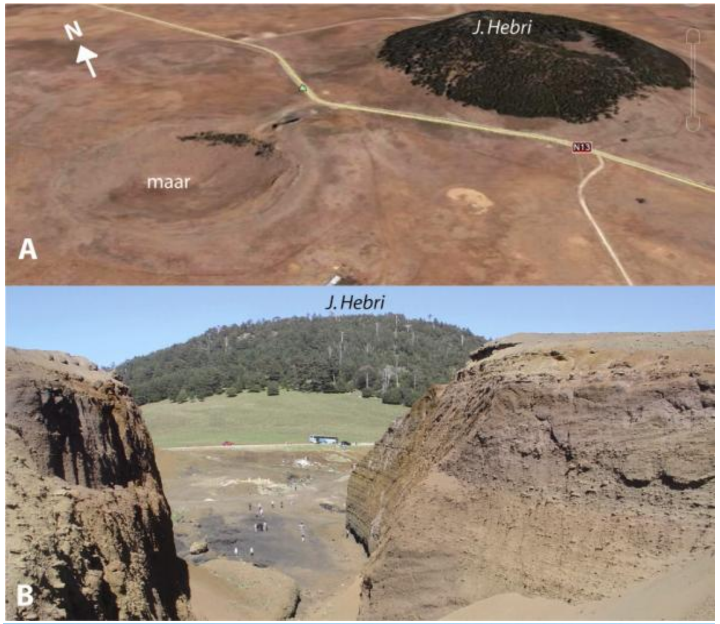
2024年计划：摩洛哥麻粒岩及榴辉岩

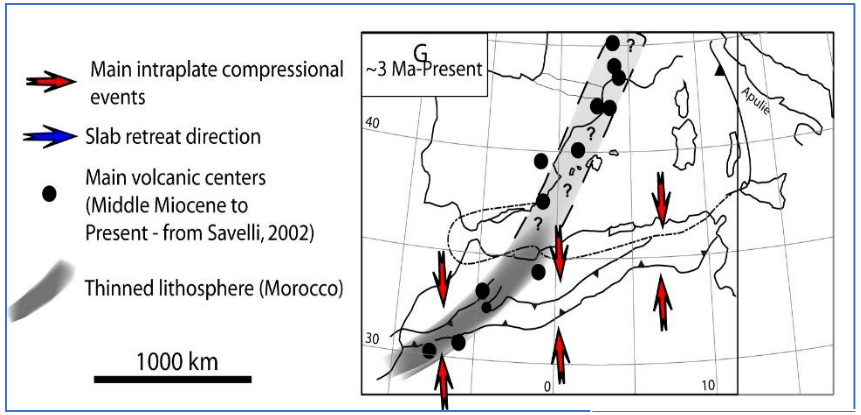


Prof. Haissen Faouziya

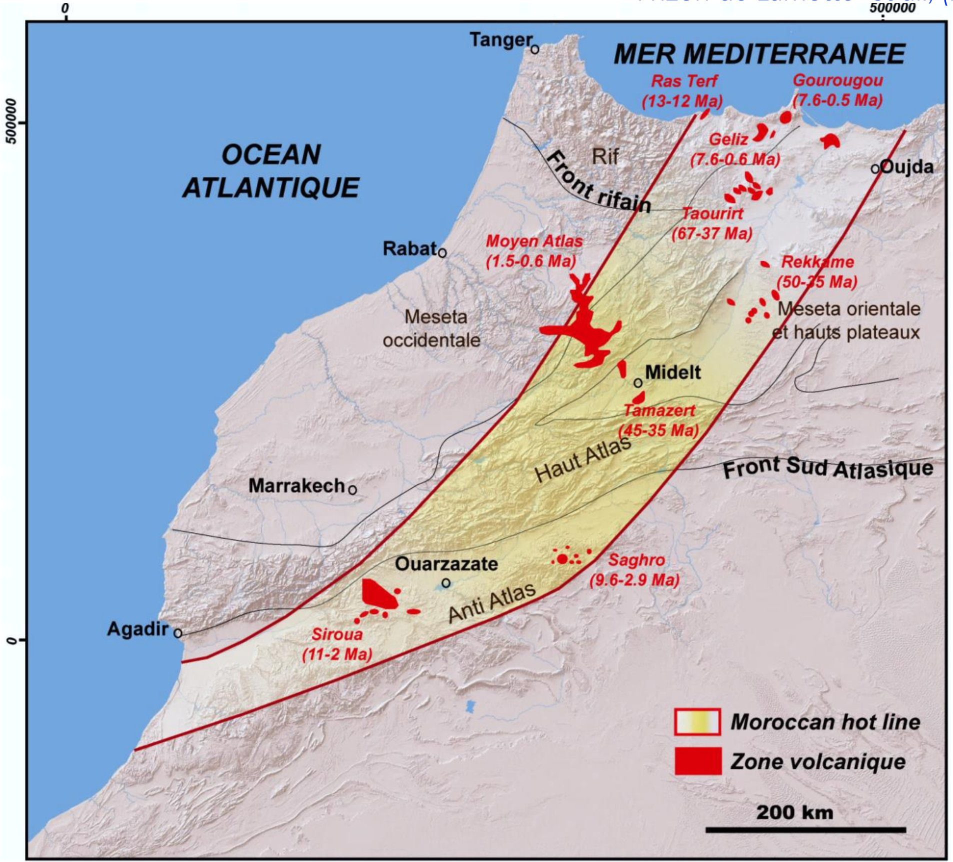
FSBM
FACULTE DES SCIENCES BEN M'SIK
UNIVERSITE HASSAN II DE CASABLANCA

MHL and recent alcaline volcanism

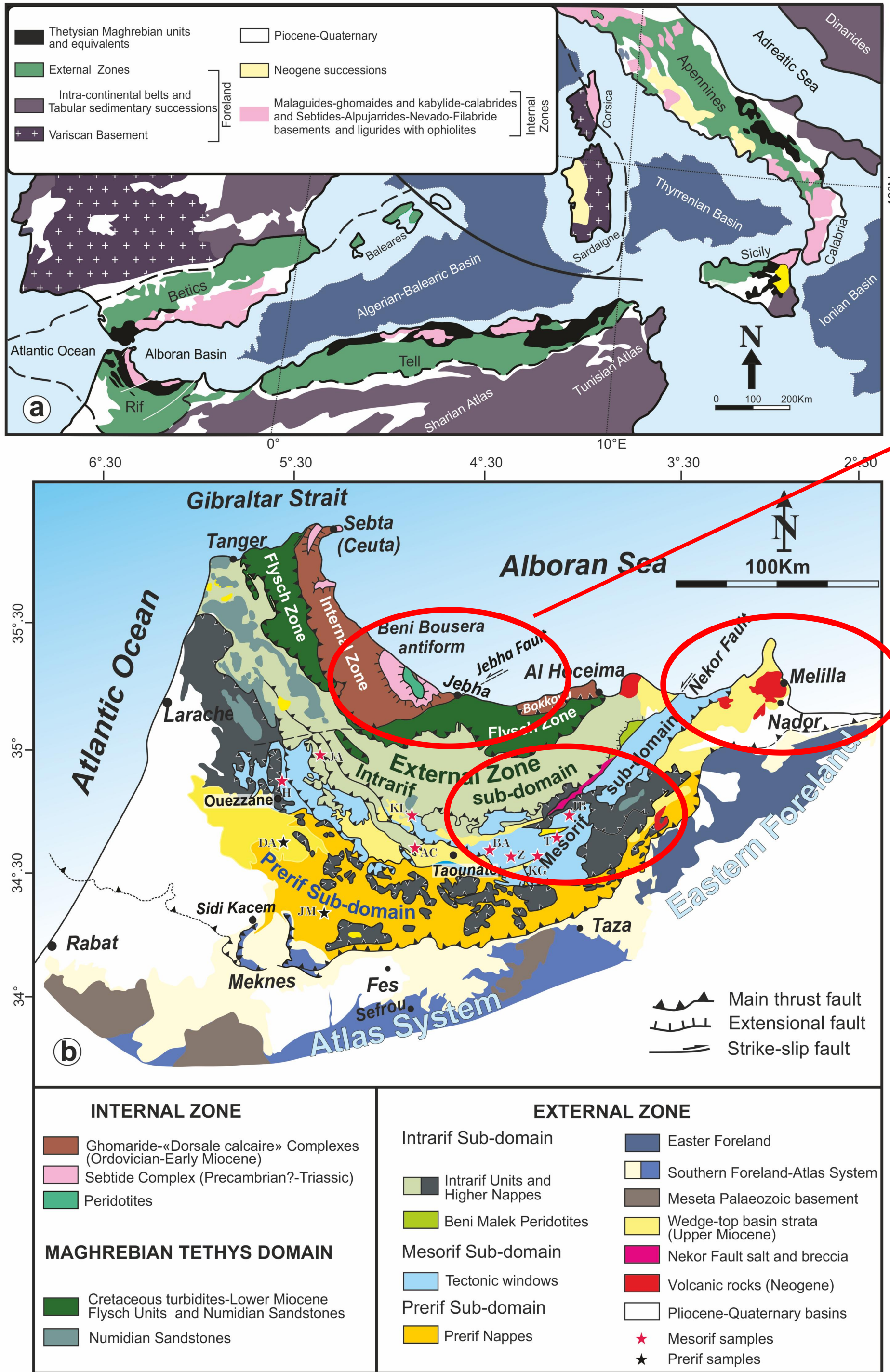




Frizon de Lamotte et al., (2009)

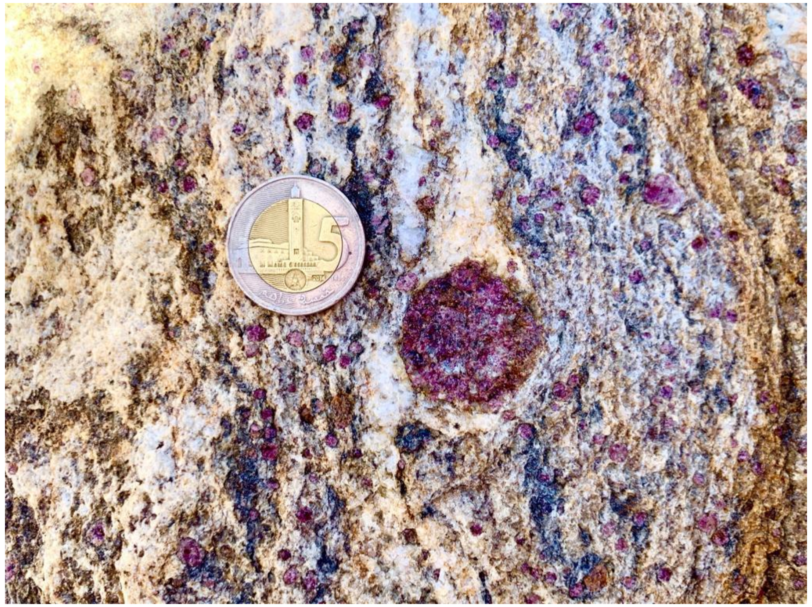


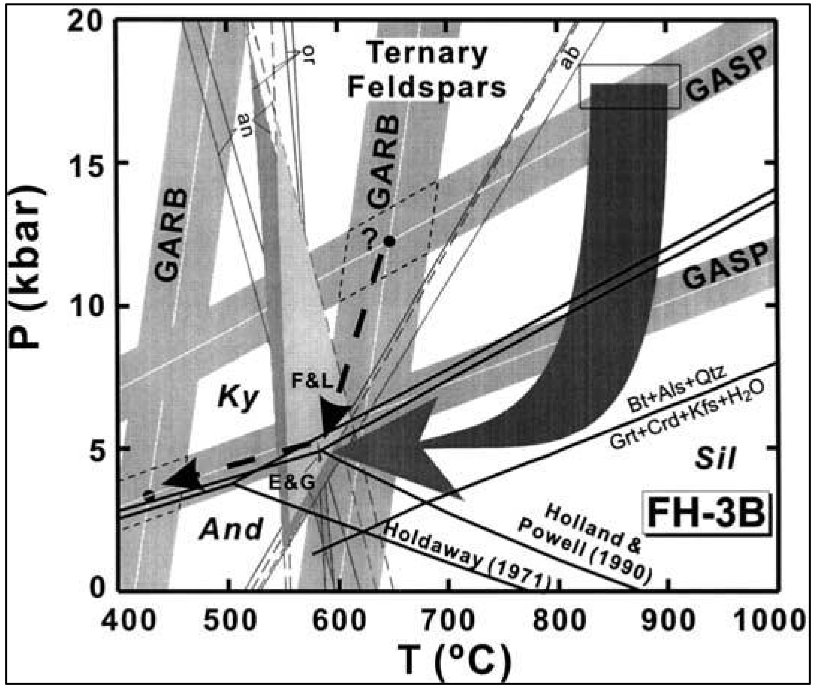
Internal zones (granulites)

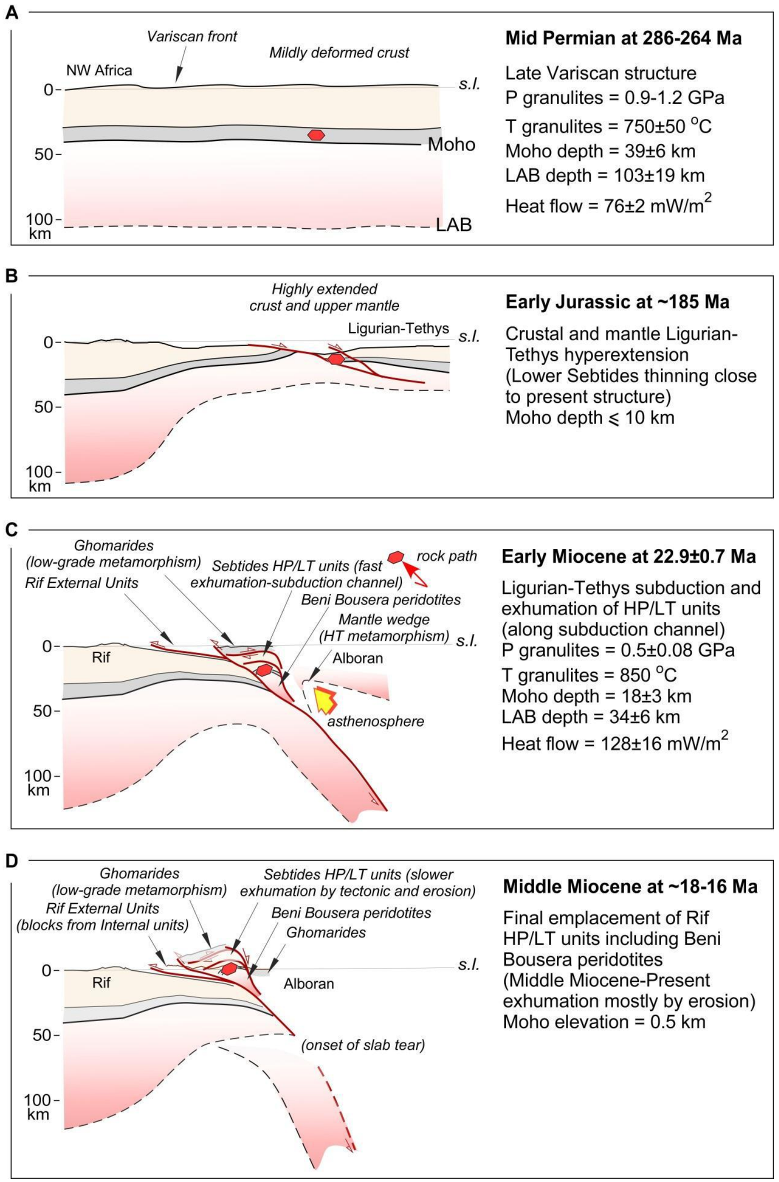


- *Internal zones (granulites)*
- *External zones (mafic rocks)*
- *Oriental Rif (Quaternary volcanism)*

麻粒岩

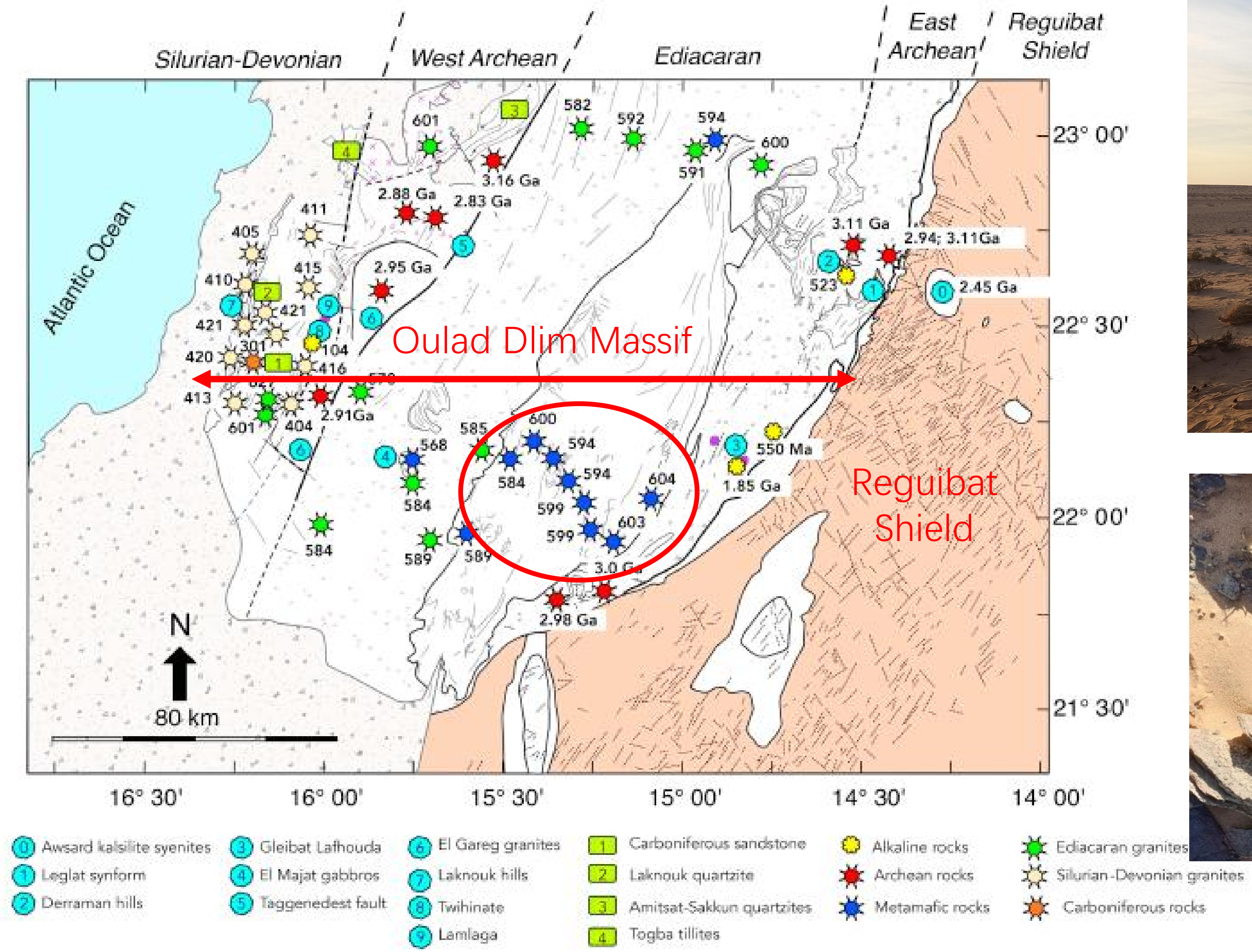






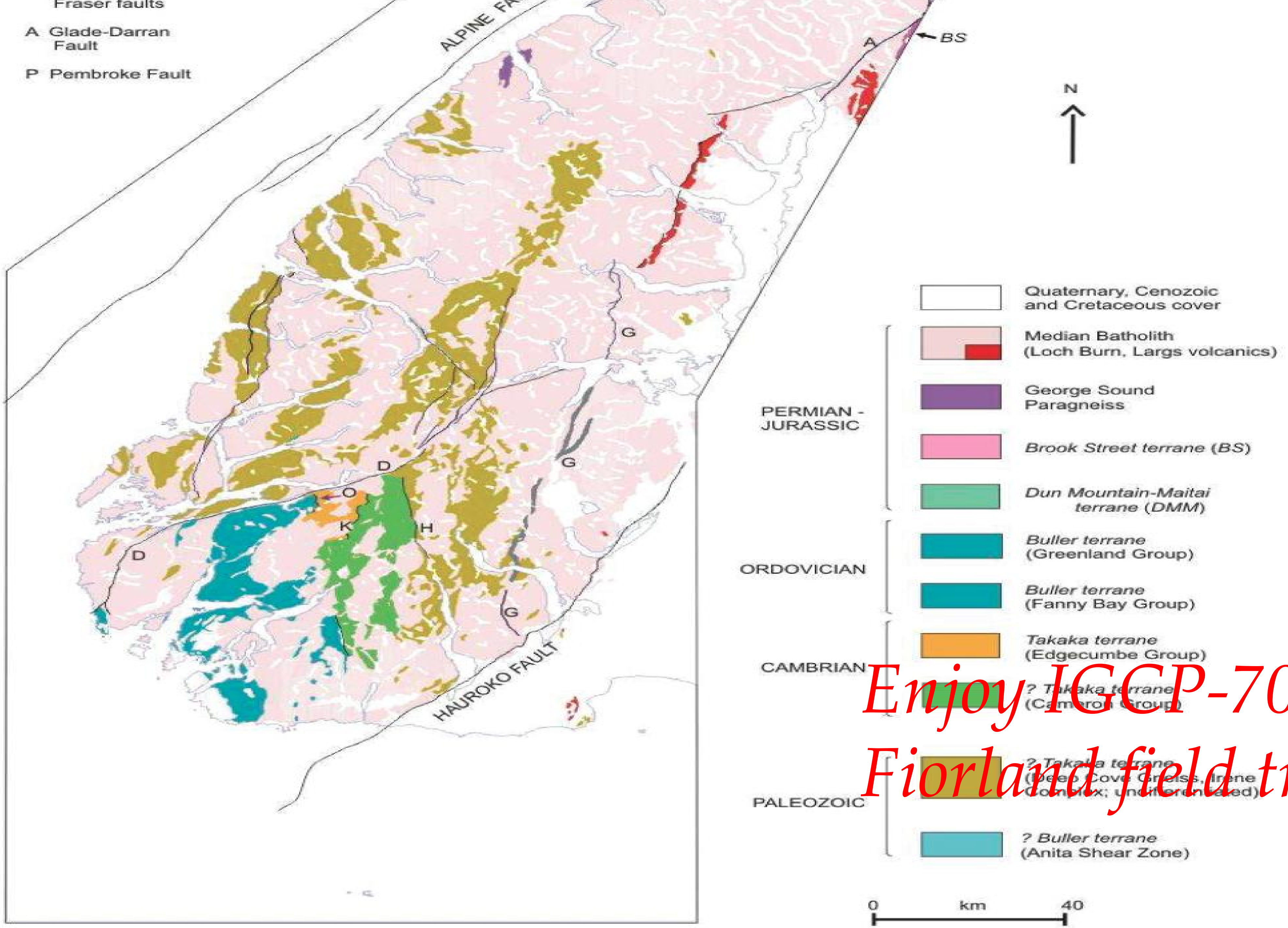
Melchiorre et al. 2015

新发现的榴辉岩



Silurian-Devonian
West Archean
Ediacaran
East Archean
Reguibat Shield
Atlantic Ocean
Oulad Dlim Massif
Reguibat Shield
23° 00'
22° 30'
22° 00'
21° 30'
16° 30'
16° 00'
15° 30'
15° 00'
14° 30'
14° 00'
N
80 km
601
582
592
594
600
591
3.16 Ga
2.88 Ga
2.83 Ga
411
405
415
410
2.95 Ga
421
421
301
104
420
416
413
2.91Ga
601
404
585
600
594
568
584
594
604
584
599
603
599
589
589
584
3.0 Ga
2.98 Ga
3.11 Ga
2.94; 3.11Ga
523
2.45 Ga
550 Ma
1.85 Ga
0 Awsard kalsilite syenites
1 Leglat synform
2 Derraman hills
3 Gleibat Lafhouda
4 El Majat gabbros
5 Taggenedest fault
6 El Gareg granites
7 Laknouk hills
8 Twihinate
9 Lamlaga
1 Carboniferous sandstone
2 Laknouk quartzite
3 Amitsat-Sakkun quartzites
4 Togba tillites
Alkaline rocks
Archean rocks
Metamafic rocks
Ediacaran granites
Silurian-Devonian granites
Carboniferous rocks


谢谢！
未名湖



Enjoy IGCP-709, enjoy Fiorland field trip!

EARTH SCIENCE FOR SOCIETY

Project 709 - High pressure-Ultrahigh pressure metamorphism and geochemical cycles in subduction zones"

Brief outline of the project

HP-UHP metamorphism and geochemical cycles in subduction zones" is widely discussed topic in the Solid Earth Sciences. The subduction zone is a major environment for material recycling between crust and mantle and are causing mantle heterogeneities. Especially fluids released from the subducting plate play a dominant role and are a significant trigger for melting processes.

However,

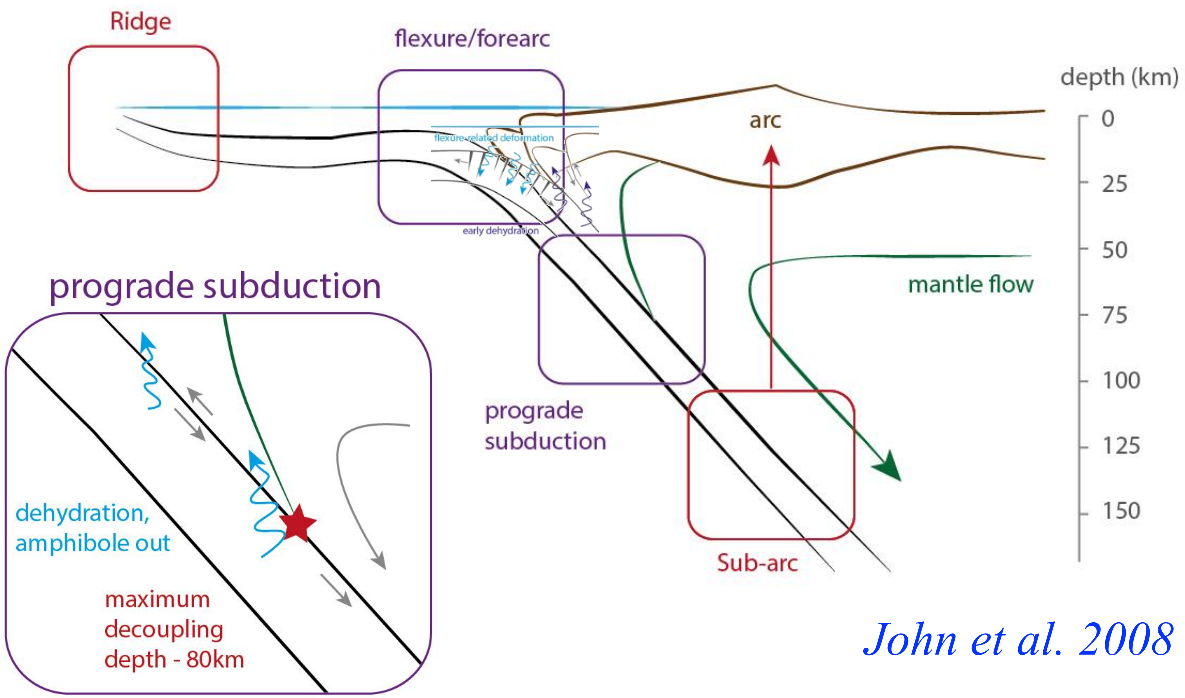
1. How to quantitively constrain the HP-UHP metamorphism?
2. How the evaluate the material cycle between the surface and the deep mantle?
3. Which geodynamic processes occur in subduction zone settings?

We plan to conduct comparative studies on different HP-UHP metamorphic belts such as for instance on the Early Proterozoic HP granulite belt in Trans-North China Craton, the Precambrian eclogite-facie belt in Karelia, Russia, the Mesozoic eclogite and blueschist belt in New Zealand, the HP-UHP metamorphic belt in the Western Alps and the young eclogitefacies belt in central Himalaya. This project will promote (semi-) quantitive description of HP-UHP metamorphism and material cycles in subduction zones, and to expand our understanding of the geodynamic processes in subduction zone settings. A key focus will be on material and fluid transport, evolution of melts, processes of mantle metasomatism, geochemical and isotope cycles as well as on petrological and geochronological features. Localities of HP- and UHP rocks from developed but especially also developing countries /regions are scheduled to become involved. Thus one of our aims is also to enhance a high-level cooperation between scientists from diverse social and political environments.

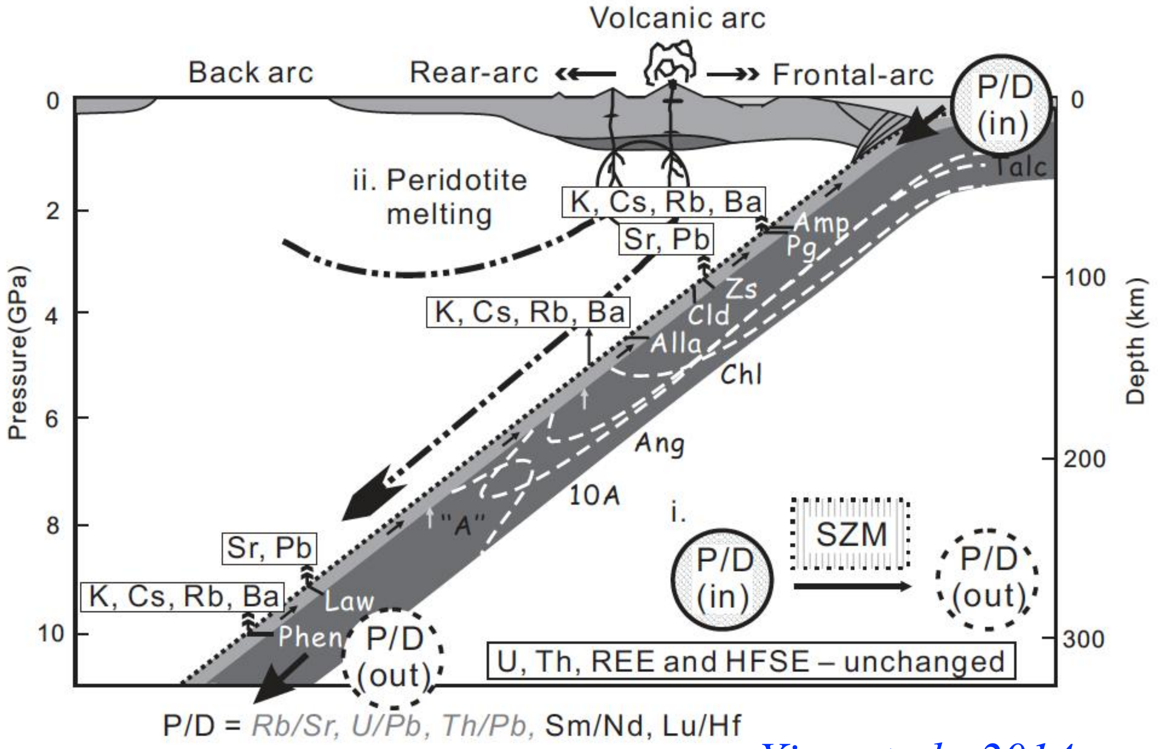
RELATED INFORMATION

- **Lifei Zhang (China)**
- **Address**: School of Earth and Space Sciences, Peking University, Beijing, 100871 China
- **E-mail**: Lfzhang@pku.edu.cn
- **Duration:** 2020-2024
- **IGCP Theme**: Geodynamics

Geochemical cycles in subduction zone



John et al. 2008



Xiao et al., 2014

Fluids from devolatilization reactions, metasomatize the mantle wedge, trigger the island volcanism.

Some fluids will be subducted below 200 km, and contribute to various intra-plate volcanic activities

The subducted slab, after its devolatilization, is transported into deeper lower mantle regions or even towards the core-mantle boundary mantle heterogeneities