

Precambrian eclogite and its implication for plate tectonics

Докембрийский эклогит и его геодинамическое значение

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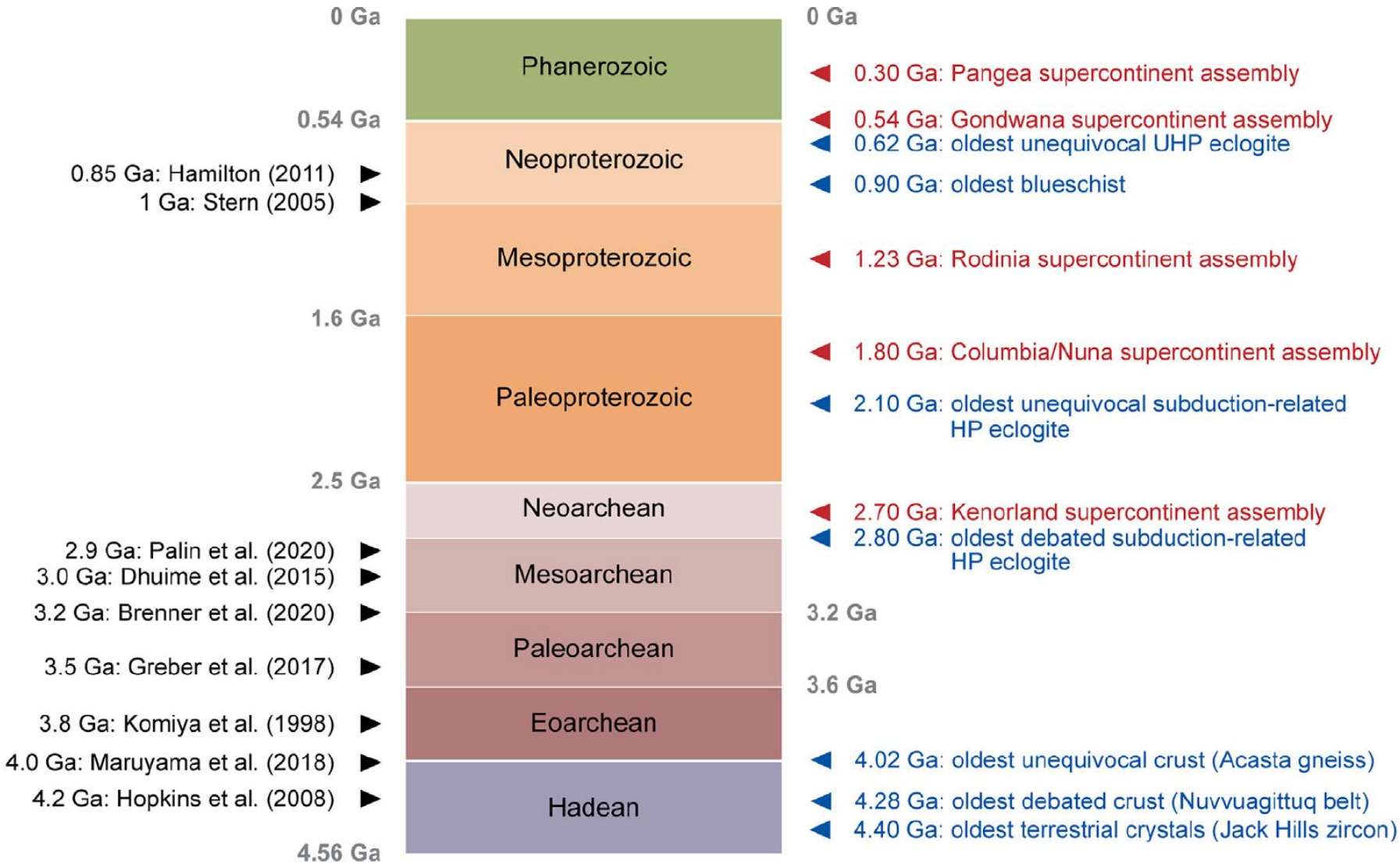
1

Geological Background

Геологическое Положение



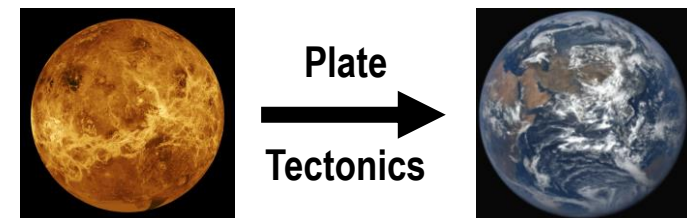
When Plate Tectonics started



Palin et al., 2020

Evidences:

- ✓ Tectonic (structural)
- ✓ Geochemical (isotopic)
- ✓ Geophysical
- ✓ Numerical modeling
- ✓
- ✓ Petrological (metamorphic)



What is Plate Tectonics

- Divergent Plate
- Convergent Plate
- Transform Fault

Subduction / Collision



(ultra-)high-pressure metamorphism

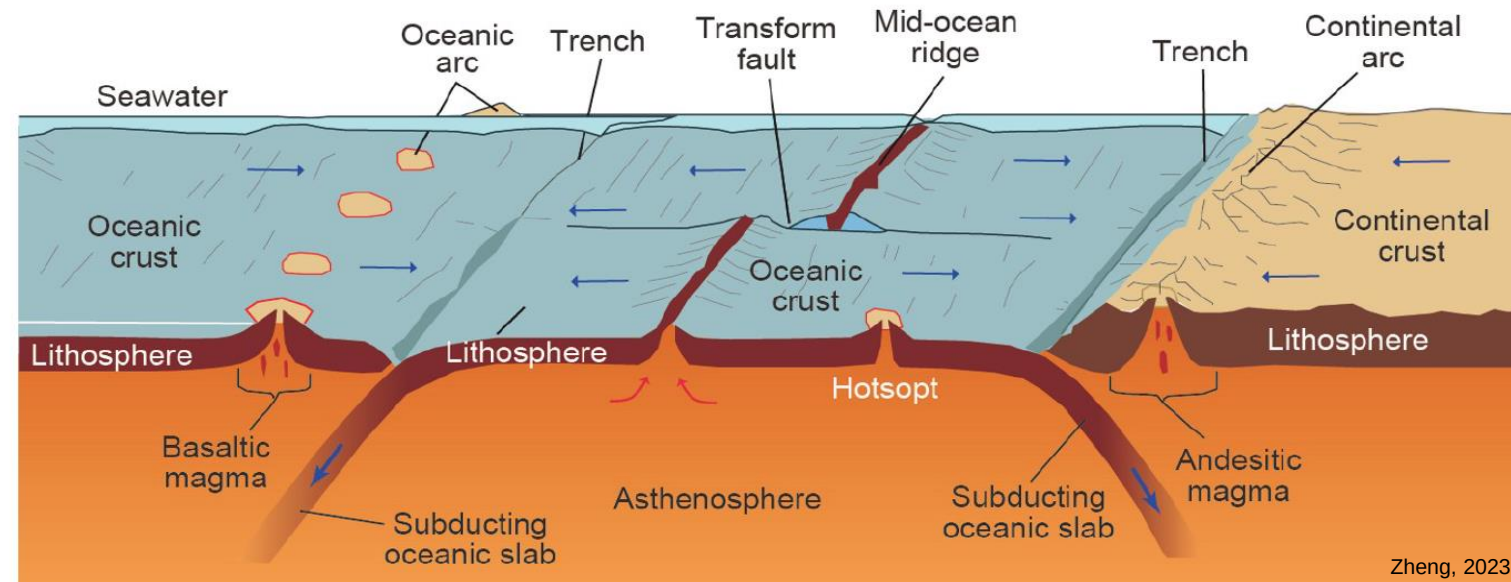
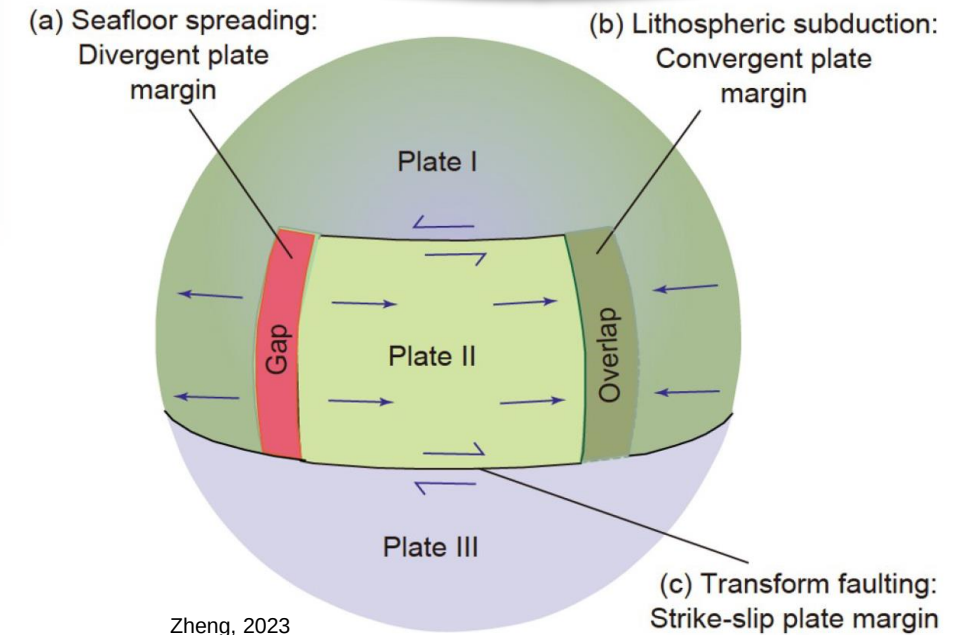


Eclogite & Blueschist (facies)

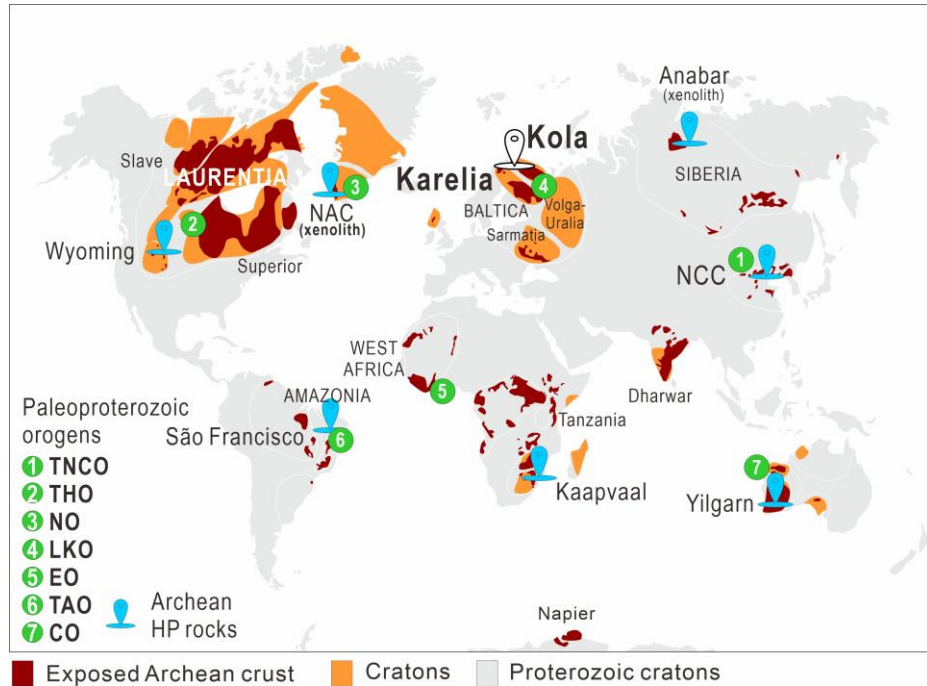
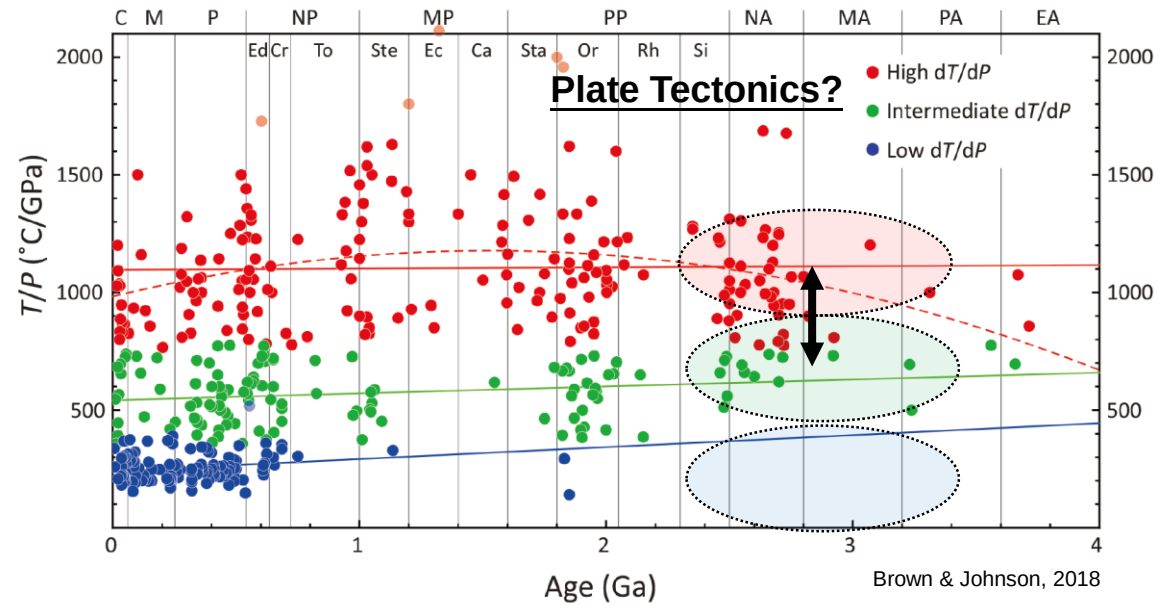


robust evidence of plate subduction-collision

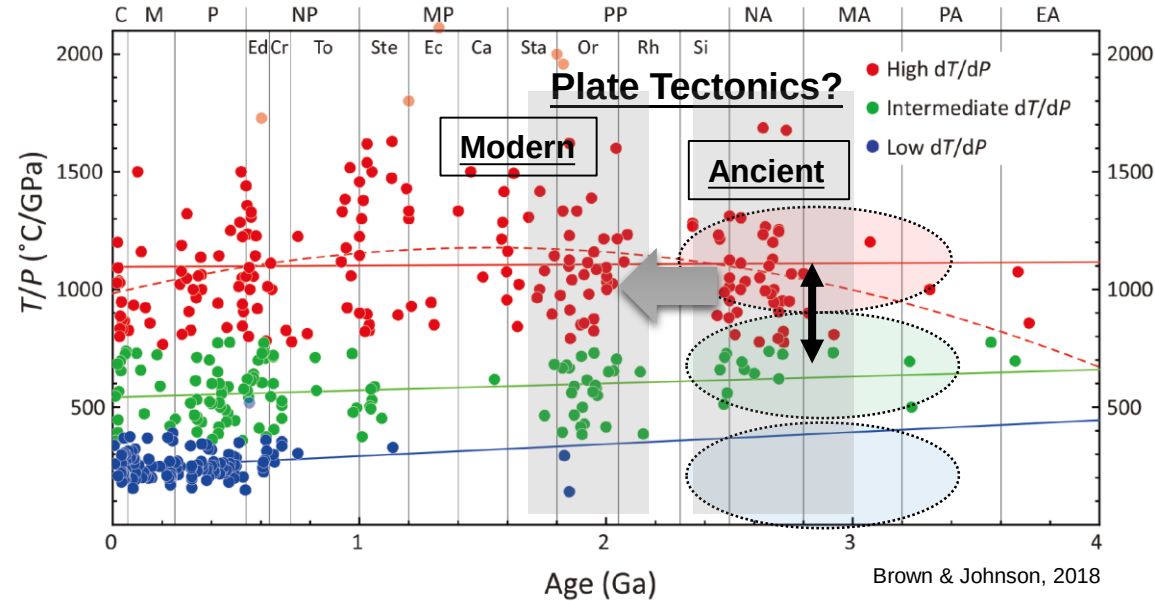
P-T → depth



Metamorphic T/P of worldwide localities



Metamorphic T/P of worldwide localities

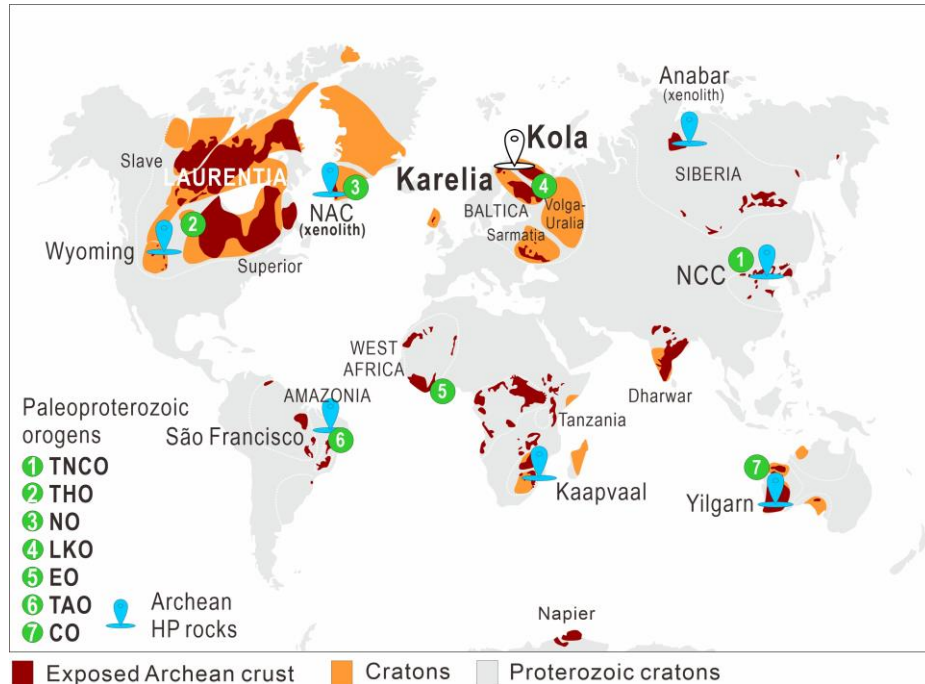


**Rare HP rocks > 2.5 Ga
(no cold lithology)**

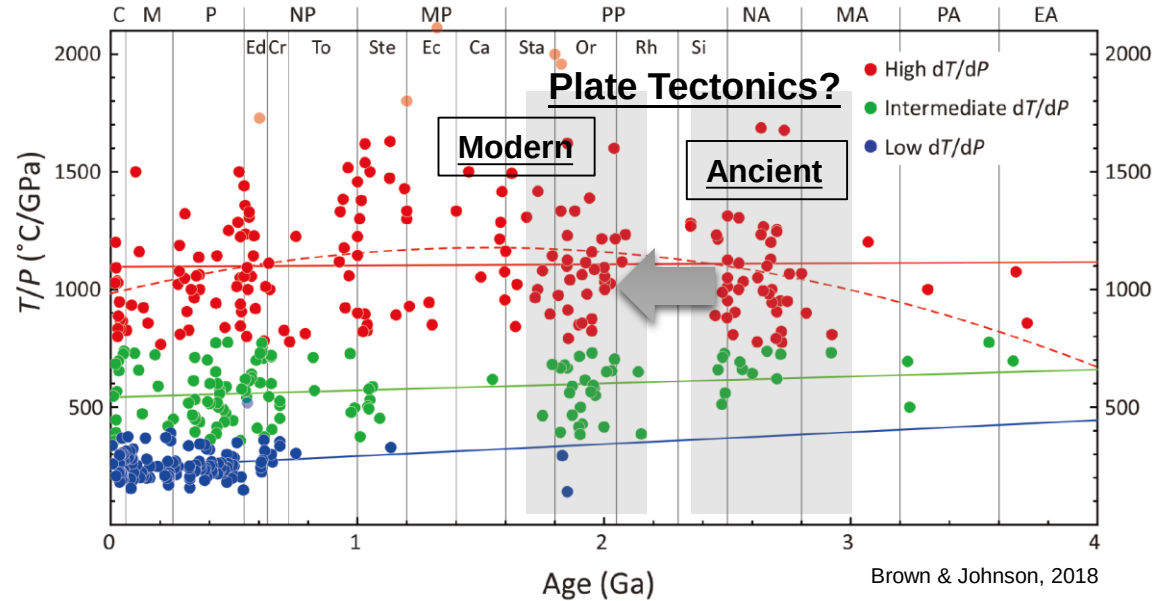
**Rare eclogite > 2.0 Ga
(cold lithology)**

- 2.7 Ga, 3.2 Ga Amphibolite (Barberton, Yilgarn)
- 2.7 Ga HP granulite (Wyoming, Sao Francisco)
- 2.5 Ga pyroxenite (NCC)
- **2.82 Ga Eclogite ? (Belomorian)**

- 2.0 Ga blueschist ? (W.Africa)
- 2.0 Ga eclogite (W.Africa)
- **1.9 Ga eclogite (Belomorian)**
- 1.9 Ga xenolith eclogite (NCC)
- 1.8 Ga UHP metabasite (W.Greenland)
- 1.8 Ga apaelcoigte (N.America)



Metamorphic T/P of worldwide localities



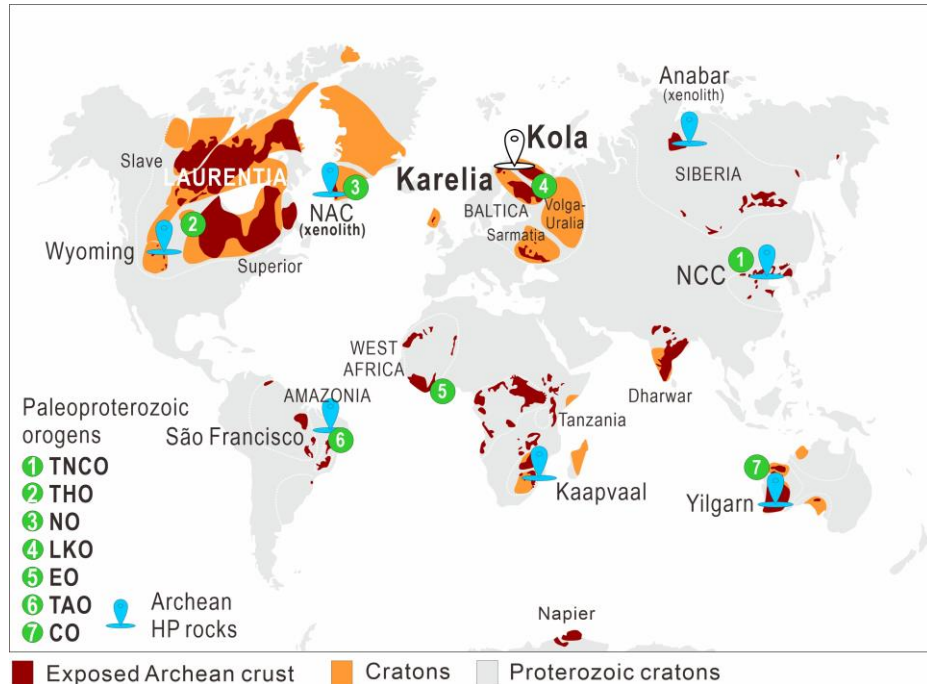
Rare HP rocks > 2.5 Ga
(no cold lithology)

Rare eclogite > 2.0 Ga
(cold lithology)

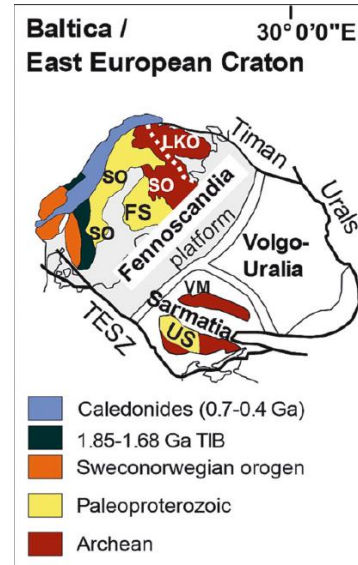
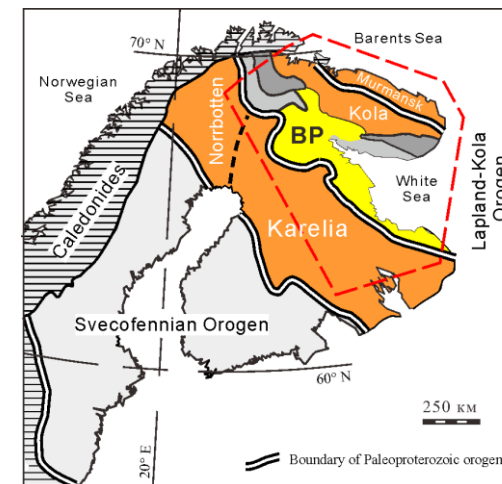
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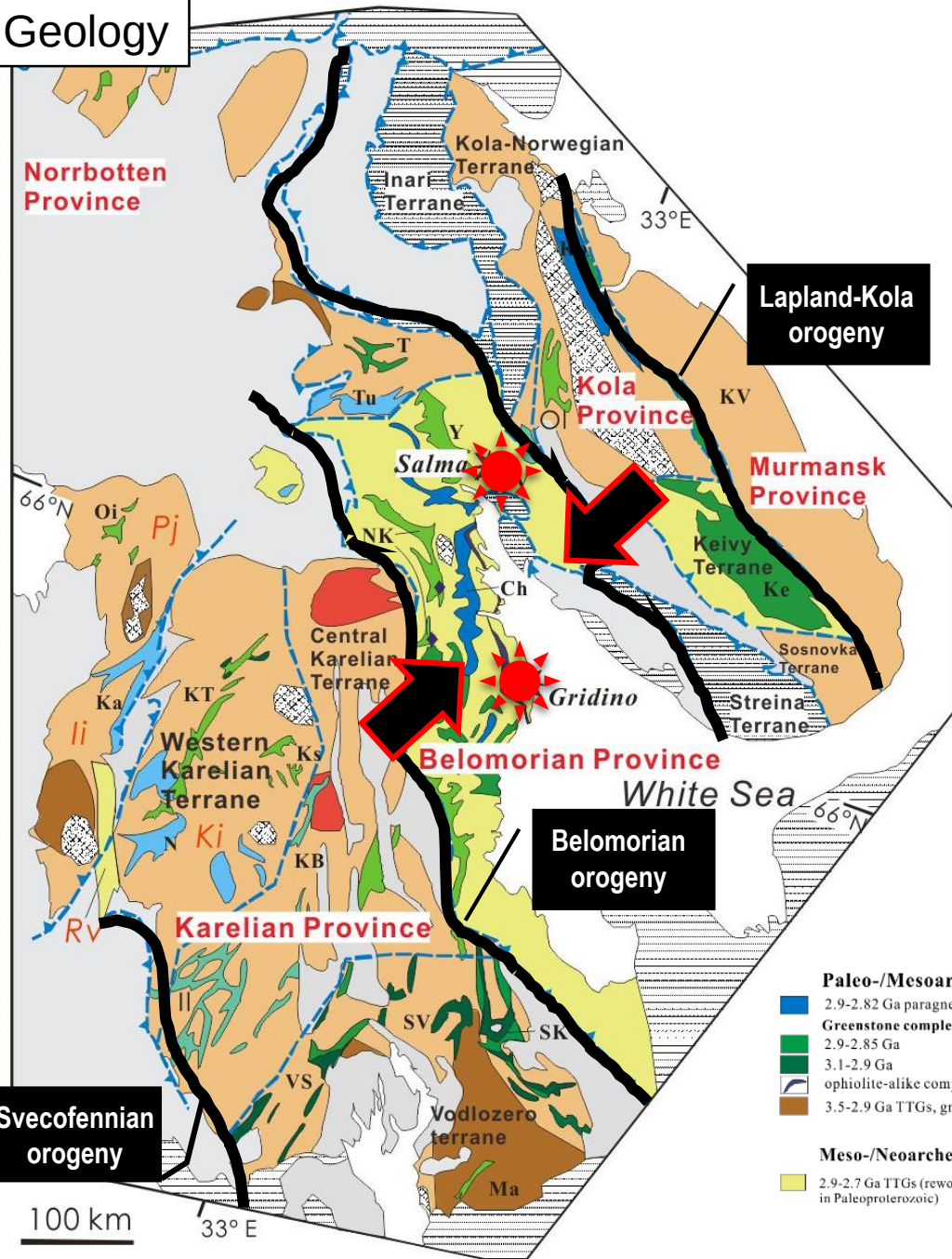
Belomorian Province (BP) b/w Kola and Karelian cratons



Archean
vs.
Paleoproterozoic
Eclogite/Subduction



Geology



TTG complexes: Paragneisses + Granitoids (sanukitoids etc.)

3.5-2.9 Ga // 2.9-2.7 Ga, 2.8-2.7 Ga // 2.7 Ga // 1.8 Ga

Greenstone belt: Amphibolite + Ophiolite-alike (?) + Eclogite

3.1-2.9 Ga, 2.9-2.85 Ga, 2.8-2.75 Ga, 2.75-2.68 Ga

in Archean: High-grade Metamorphism + Migmatization

($> 9\text{-}12$ kbar, $> 650\text{-}950$ °C)

❖ **Eclogite *sensu stricto***omphacite + garnet $\pm$ amphibole, epidote, kyanite

❖ Eclogitized dyke

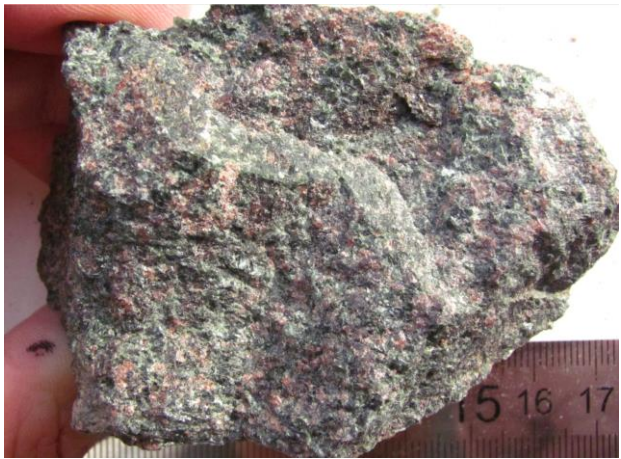
metagabbro-gabbronorite, Ol-gabbronorite, pyroxenite (Opx), zoisitite, enderbite, etc.

Neoproterozoic

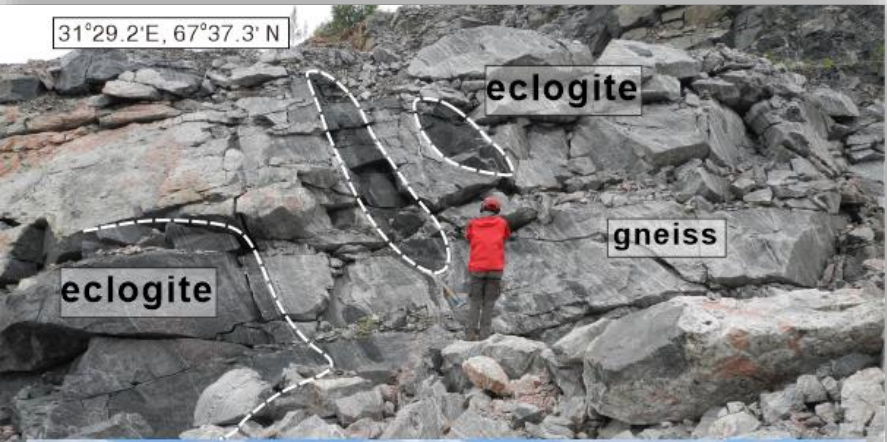
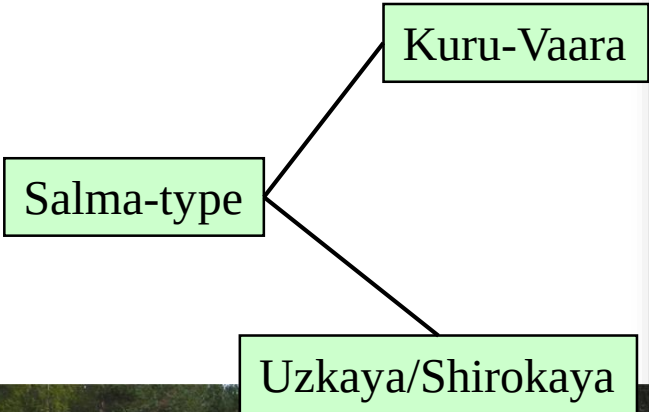
-  2.7 Ga sanukitoid
-  Eclogite outcrops
-  Granulite-facies complex
-  2.7-2.78 Ga paragneisses
-  **Greenstone complexes**
-  2.75-2.68 Ga
-  2.8-2.75 Ga
-  2.8-2.7 Ga TTGs and amphibolites
-  SSZ-ophiolite

 Tectonic mixture of Neoproterozoic and Paleoproterozoic
 Paleoproterozoic
 Caledonides platform cover

Chupa-Gridino



coarse-grain eclogite



fine-grain eclogite



Retrogressed eclogite (amphibolite)

2

Scientific Problems

Научные Проблемы



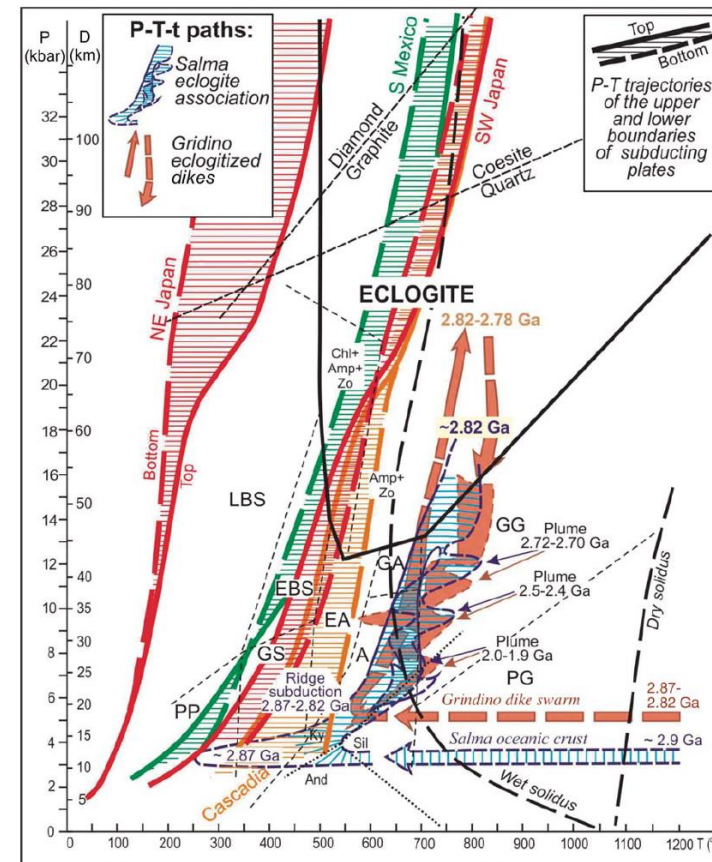
Prograde → Peak → Retrogression (peak Temperature)

poorly
constrained

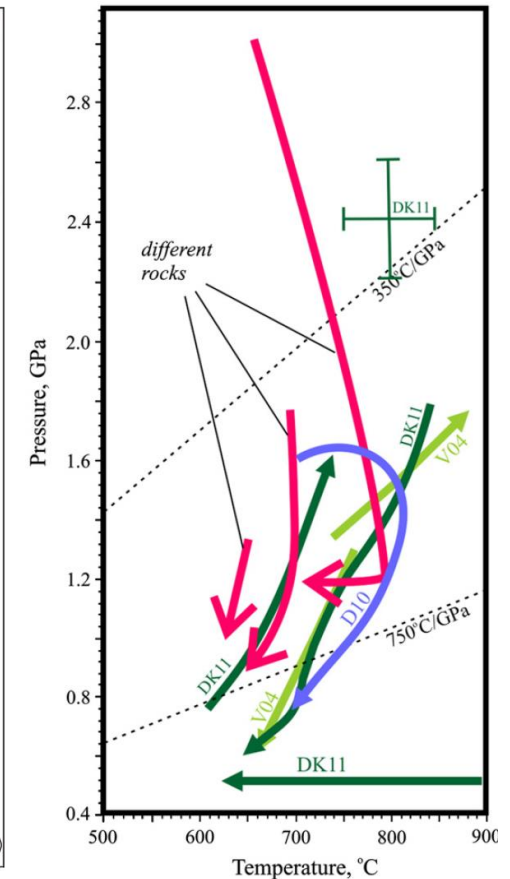
UHP?

UHT?

Mints et al., GSA SP, 2015



Perchuk & Morgunova, Gondwana Res., 2014



1

UHT?

 z 620-650 °C

Perchuk & Morgunova, Gondwana Res., 2014

(3.0 GPa, 660 °C ?)

2.2-2.3 GPa, 650-670 °C

 $\sim 1.5 \text{ GPa}, \sim 750^\circ\text{C}$ z 1.0 GPa, 850-900 °C

Table 1
Variety of correlations of major magmatic and metamorphic events in the Gridino terrain.

Scenario	Major events			Method and data source
	2.8–2.7 Ga	~2.4 Ga	1.9–1.8 Ga	
I	HP metamorphism 1	Mafic dike swarm, HP metamorphism 2.	Amphibolite facies metamorphism	Zircon, U–Pb method, NORDSIM, SHRIMP (Volodichev et al., 2004; Slabunov et al., 2011; Volodichev et al., 2012)
II	(U?)HP metamorphism followed by granulite facies metamorphism	Leucocratic Bt-Cpx-Opx-Pl-Q veins in metagabbroids	Amphibolite facies metamorphism	Zircon, U–Pb method, SHRIMP (Dokukina et al., 2009, 2012a; Dokukina and Konilov, 2011)
III	Mafic dike swarm	No events	Eclogite facies metamorphism followed by amphibolite facies metamorphism	Zircon, U–Pb, SHRIMP – both events (Skublov et al., 2011); Lu–Hf mineral isochrones, eclogitic event (Herwartz et al., 2012).

Perchuk & Morgunova, Gondwana Res., 2014

Geological Facts

Archean Belomorian Orogen, 2.8 – 2.7 Ga

- Island-arc system
- Granitoid/paragneiss
- Sanukitoid intrusion
- Volcanic intrusions (Calc-alkaline-, adakite-)
- Greenstone belts
- Leucogranite, K-granite, volcanic molasse

Eclogite ?

Paleoproterozoic LIPs 2.5-2.4, 2.3, 2.2, 2.1 Ga

- Gabbro-norite
- Pyroxenite (?)

Paleoproterozoic Svecofennia & Lapland-Kola Orogen 2.0 – 1.8 Ga

- Subduction-collision

Eclogite

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Paleoproterozoic Svecofennia & Lapland-Kola Orogen 2.0 – 1.8 Ga

- Subduction-collision
- Eclogite

Eclogite Info

- 2.9 Ga ($T_{DM} = 3.1$ Ga)

Protolith (basite)

2.82 Ga, 2.72 Ga

– Eclogite-Granulite facies (Zrn U-Pb)
- 2.5-2.4 Ga

– Granulite-facies (LIPs)

1.9-1.8 Ga

– Eclogite-Granulite facies (Zrn U-Pb, Lu-Hf)
- 1.7 Ga

– Amphibolite facies (Ttn U-Pb)

Fact

- Tectonic mélange of TTG + greenstone belts + eclogite/amphibolite, ultra-/mafic dykes, granulite-charnockite/enderbite
- **2.74-2.73 Ga** TTG gneiss (Salma) *Glebovitsky, 2005; Slabunov et al., 2006; Slabunov, 2008; Li et al., 2017b*
- **2.9-3.1 Ga** protolith of eclogite (Salma) *Mints et al., 2010; Konilov et al., 2011; Li et al., 2017b*
- **1.9 Ga** mafic eclogite & eclogite facies (Salma) *Li et al., 2017a, b; Yu et al., 2019a, b; Melnik et al., 2021*
- Peak eclogite facies PT: **22-23 Kbar, 650-670 °C** (Salma) *Li et al., 2023, 2025*
- **2.72 Ga** eclogite (Gridino) *Volodichev et al., 2004, 2021; Li et al., 2015*

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Artefact

- ✓ **2.8 Ga** Ophiolite-like complex (mafite-ultramafite belts) *Slabunov et al., 2019*
- ✓ **2.7 Ga** (HP) granulite facies (Salma) *Kaulina et al., 2010; Konilov et al., 2011; Li et al., 2017b*
- ✓ **2.82-2.72 Ga** eclogite facies (Salma) *Mints et al., 2010; Konilov et al., 2011; Shchipansky et al., 2012b; Balagansky et al., 2015*
- ✓ **1.9 Ga** amphibolite facies against eclogite (Salma) *Konilov et al., 2011; Dokukina et al., 2016; Imayama et al., 2017*
- ✓ **UHT** overprint (~ 900 °C) on eclogite (Salma) *Dokukina et al., 2016; Liu et al., 2017; Li et al., 2018, 2021*



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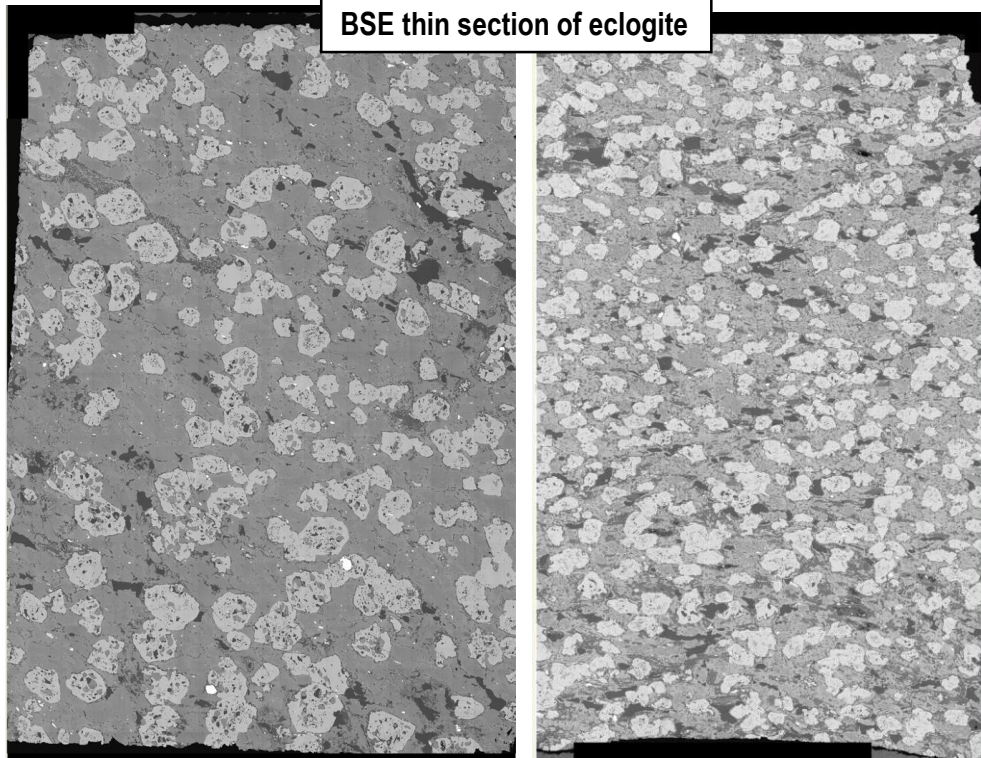
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Metamorphic Petrology

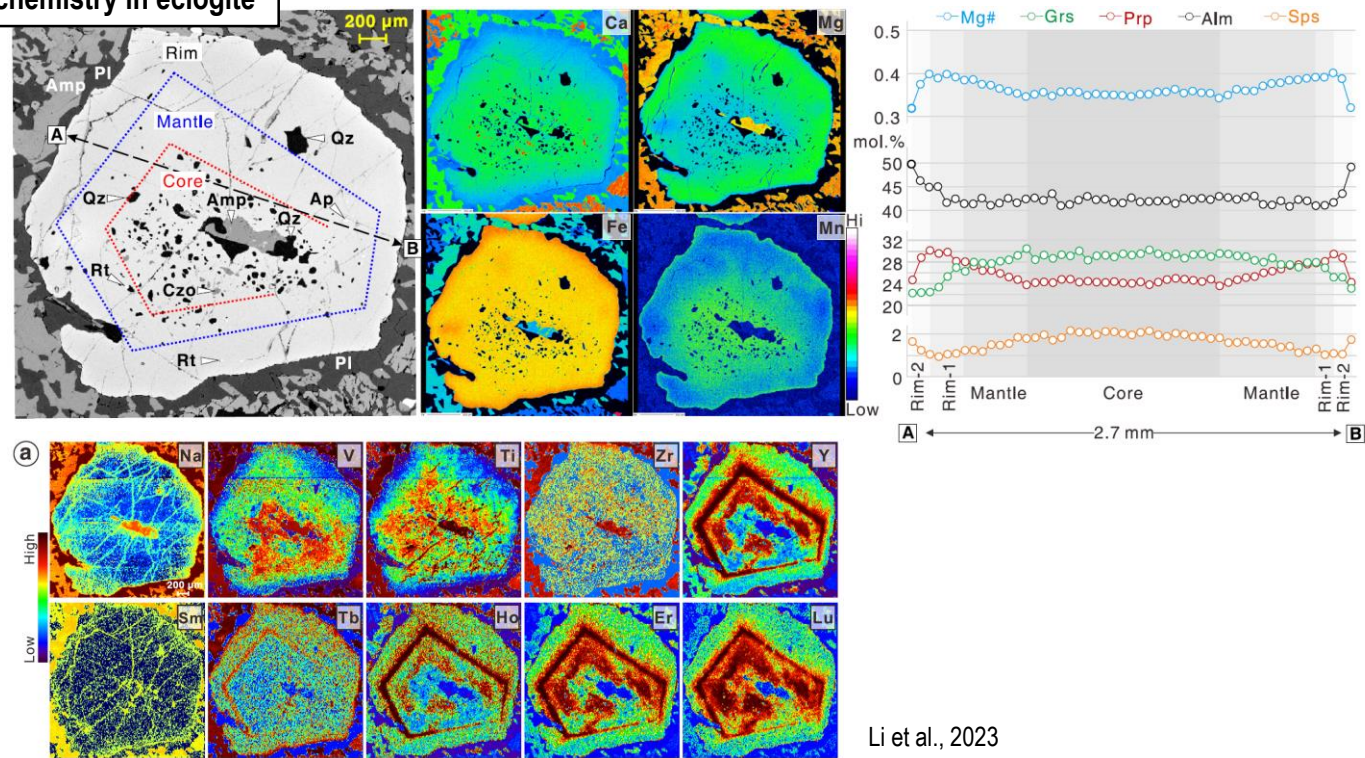
Метаморфическая Петрология



BSE thin section of eclogite

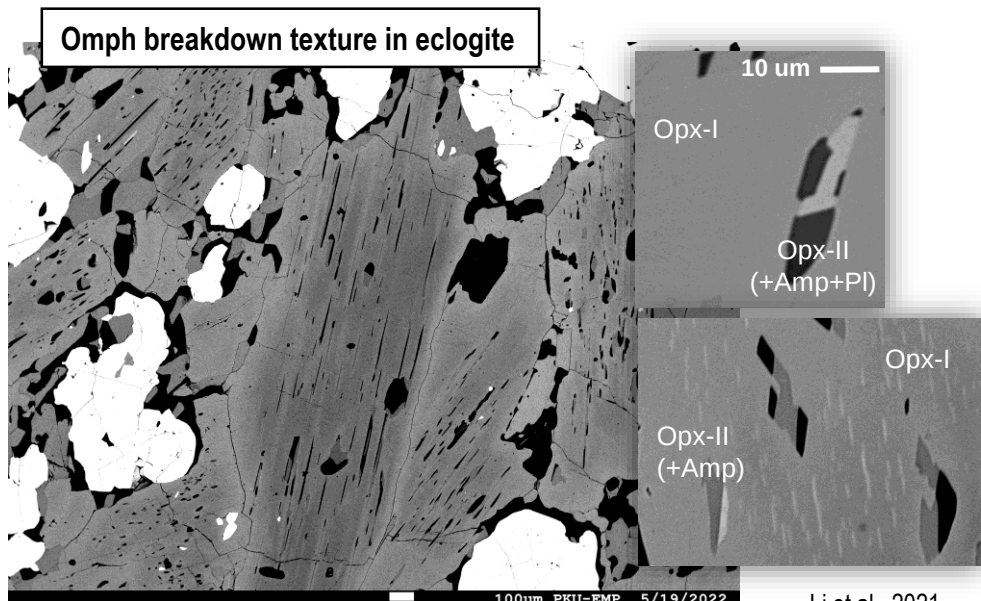


Garnet chemistry in eclogite



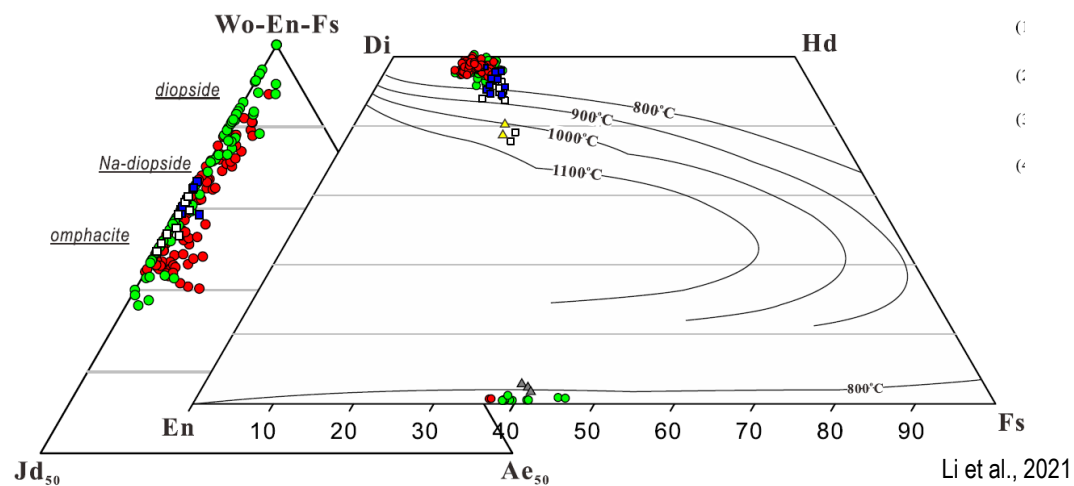
Li et al., 2023

Omph breakdown texture in eclogite



Li et al., 2021

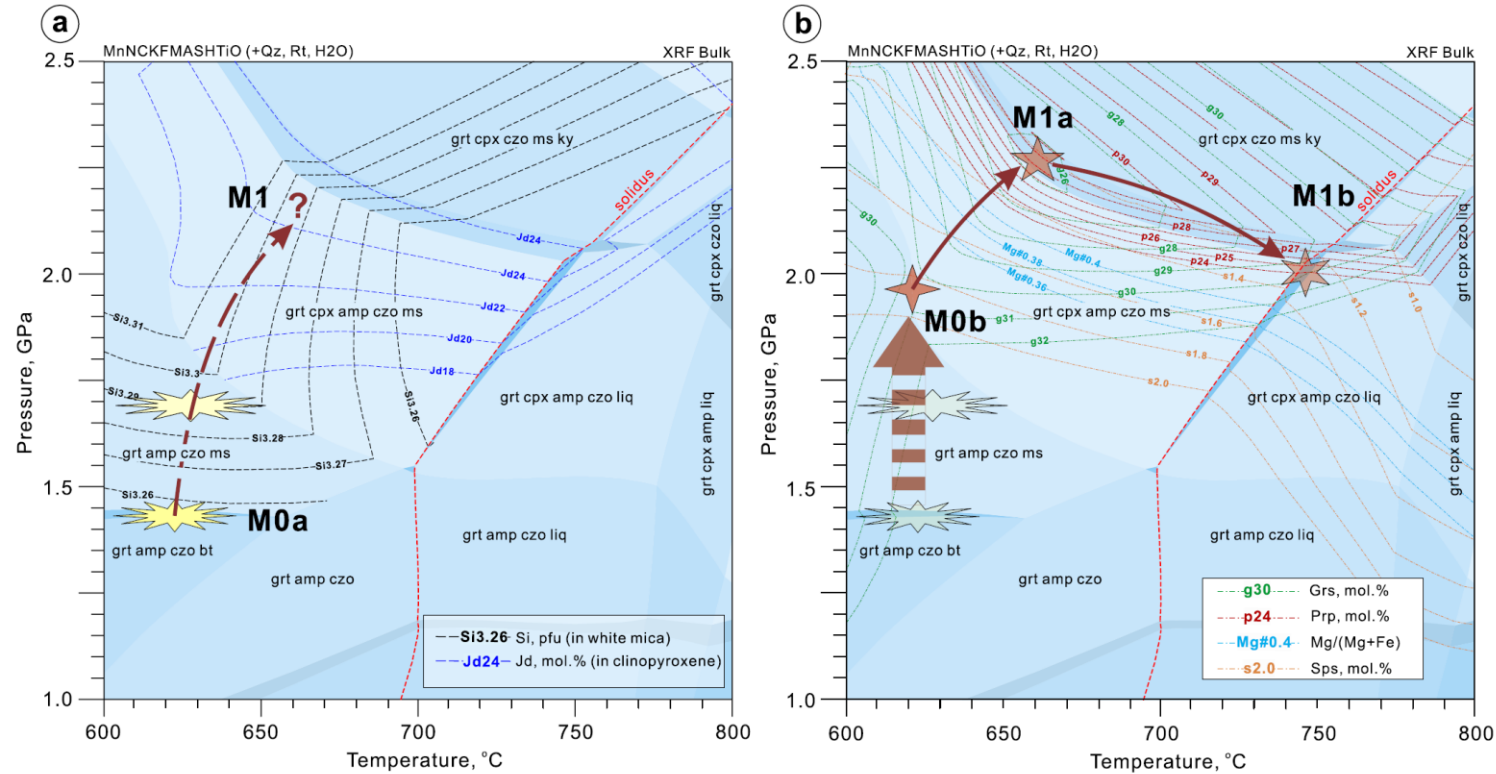
Pyroxene chemistry in eclogite



Li et al., 2021

Phase equilibrium modeling

Bulk chemistry by XRF analyses

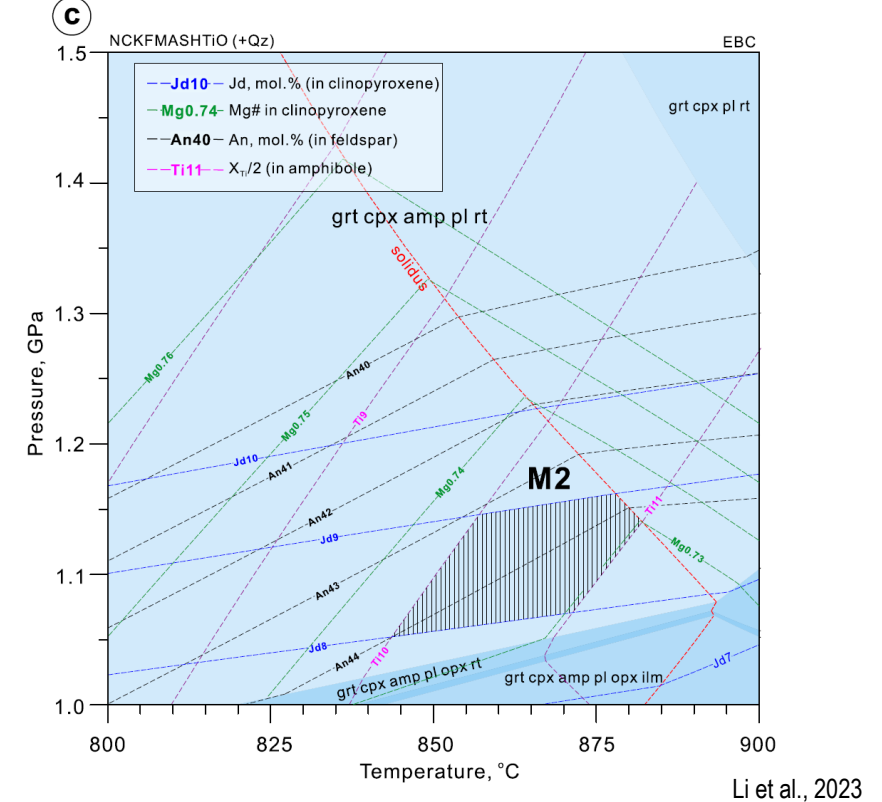


Limitation:

- (1) closed system
- (2) Isochemical reaction
- (3) Systematic and random errors are inevitable

VS.

Effective Bulk Chemistry of domainal equilibria on thin section



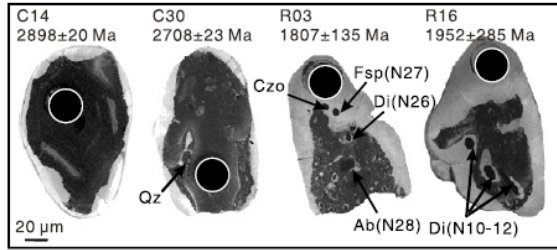
Li et al., 2023

Geothermobarometer:

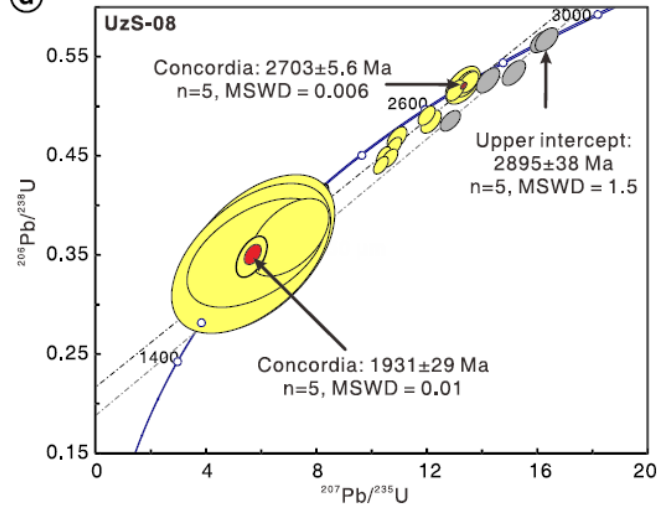
- (1) Equilibrated paragenesis
- (2) Domainal equilibrium
- (3) Analytical error (by EPMA)

Zircon U-Pb dating

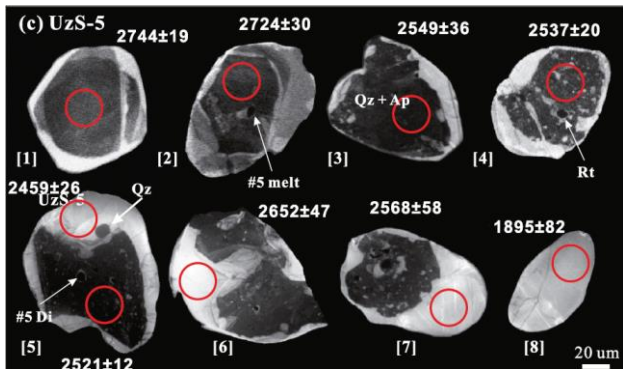
(a) UzS-08 Li et al., 2023



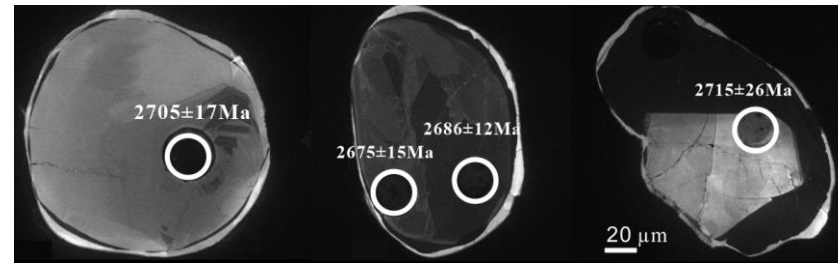
(d) UzS-08



Li et al., 2017a



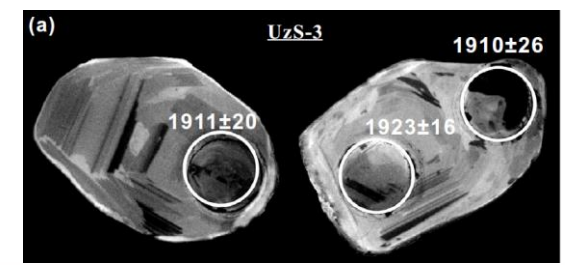
Li et al., 2015



Gridino eclogite

- Metamorphic zircon: 2.71-2.68 Ga

Li et al., 2017b



Salma eclogite

- Metamorphic zircon: 1.92-1.91 Ga

Accurate interpretation of U-Pb age is somehow problematic

- (1) Crystal texture (CL-BSE image)
- (2) Mineral inclusions in-situ (omphacite, garnet etc.)
- (3) REE pattern, Th/U ratio
- (4) REE differentiation coefficient with garnet, omphacite, amphibole
- (5) Lu-Hf-O isotope

.....

Salma retrogressed eclogite

- dark-CL Core: 2.8-2.7 Ga + 2.5 Ga
- bright-CL Rim: 1.9-1.8 Ga



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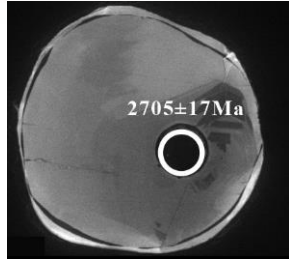
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Preliminary Conclusions

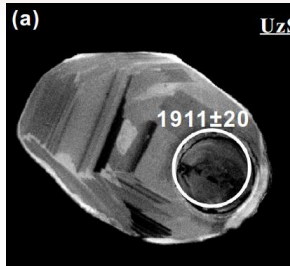
Предварительные заключения



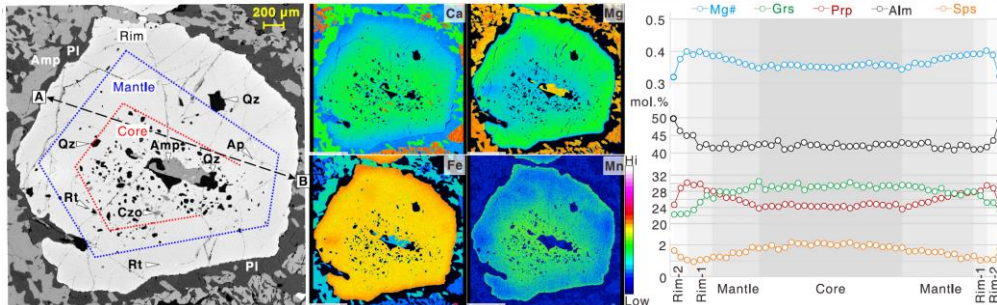
(1) 2.7 Ga mafic eclogite in Griding Li et al., 2015, PR



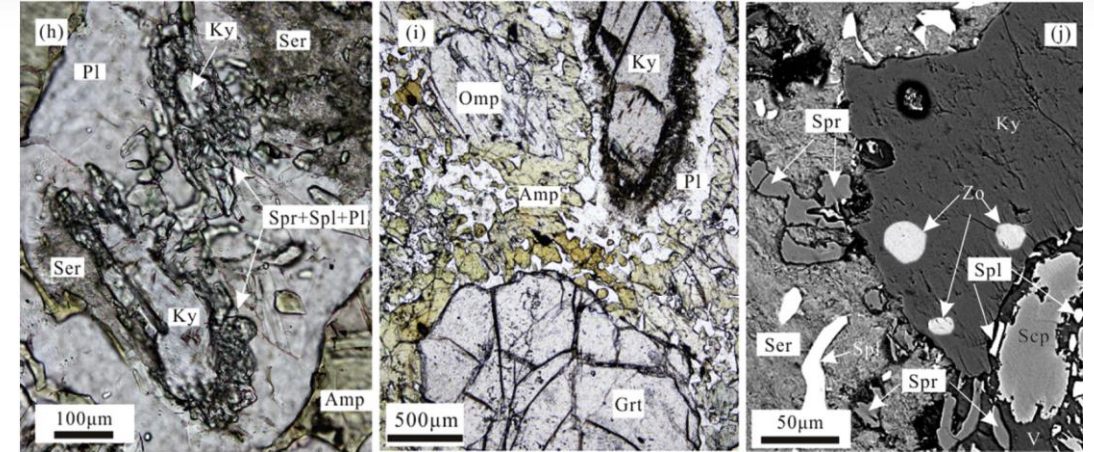
(2) 1.9 Ga mafic eclogite in Salma



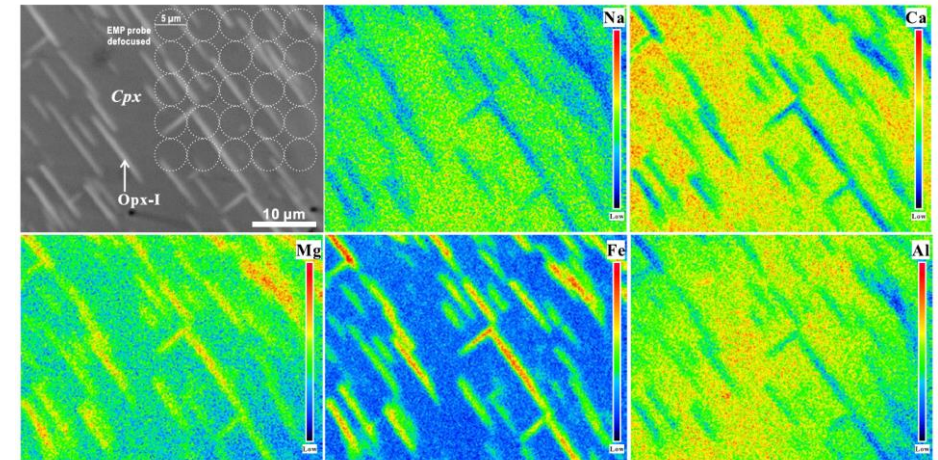
(3) 1.9 Ga cold subduction mafic eclogite in Salma



(4) UHT overprint on 1.9 Ga(?) mafic eclogite in Salma



Sapphirine + Spinel within Cpx-Pl symplectite



Opx lamellae exsolution within Cpx

Li et al., 2017, Sci Bull.

Li et al., 2023, EPSL

Li et al., 2025, EPSL

Li et al., 2018, 2021, JMG

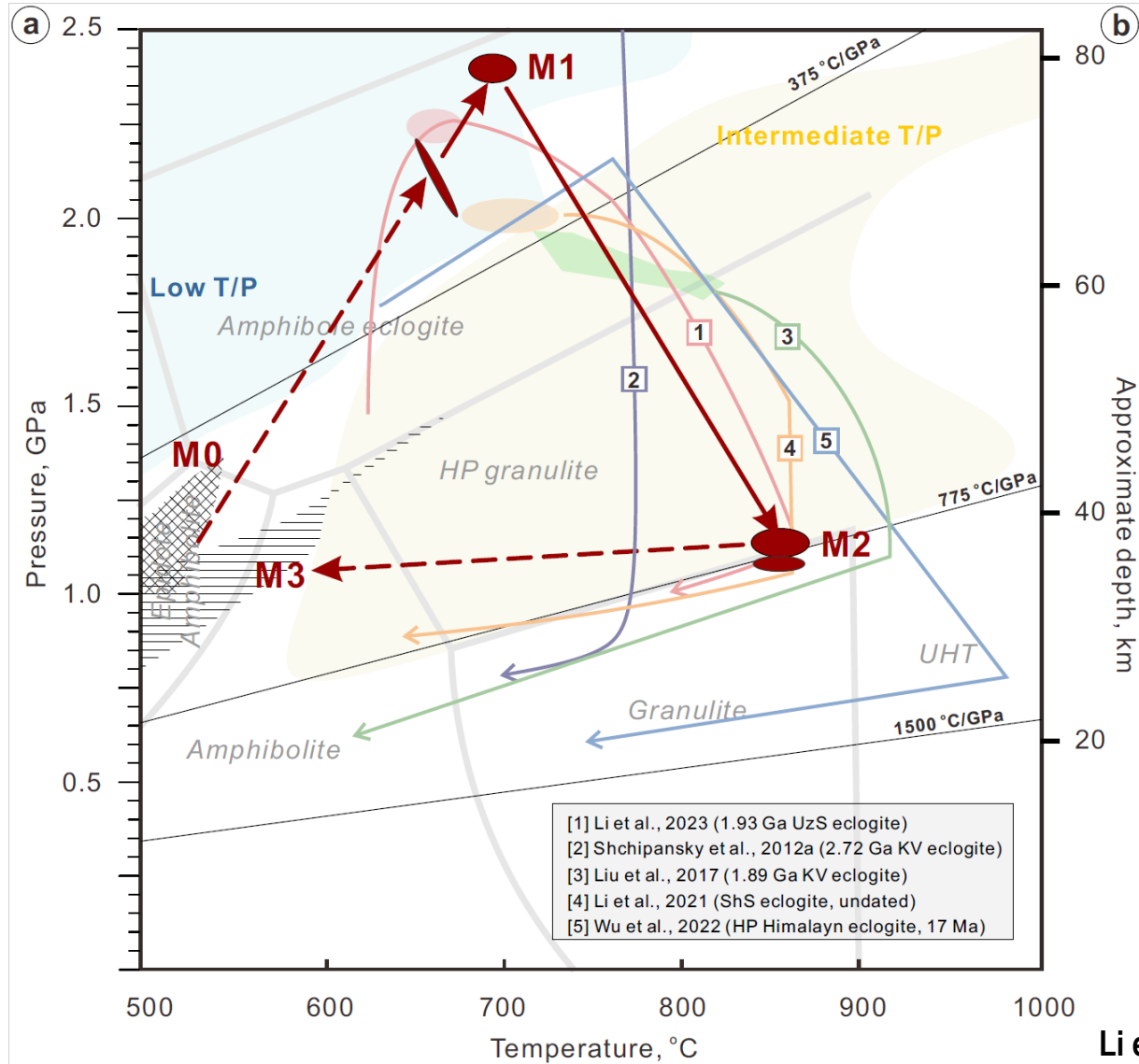
[5] Himalayan eclogite (17 Ma)



Metamorphic PT paths of

[1-4] Belomorian eclogites (1.9 Ga, 2.7 Ga?)

[5] Himalayan eclogite (17 Ma)

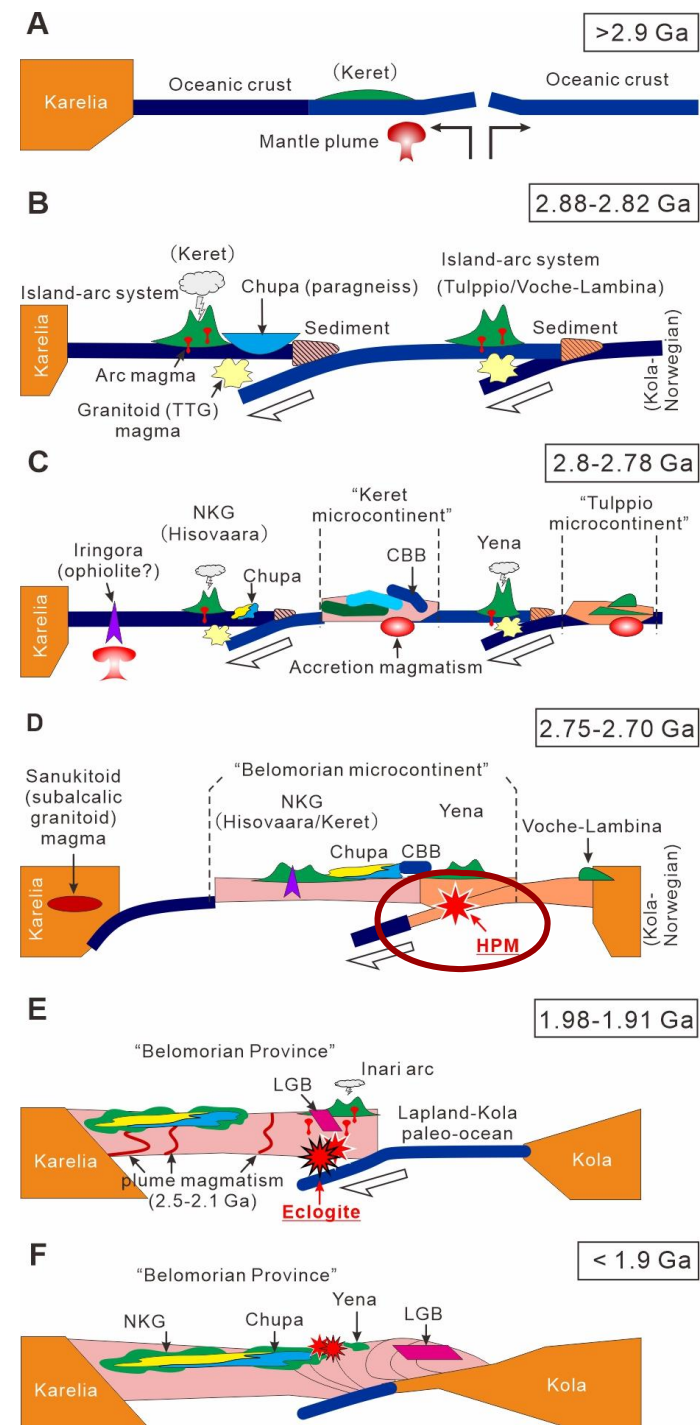


Li et al., 2025, EPSL

Tectonic mode

If Archean subduction was true.....

Yo-Yo tectonics???



in prep.

5

Future Perspectives

Перспективы



Columbia Supercontinent

PALEOPROTEROZOIC EVENT

Belomorian Salma eclogite

$300 \pm 10^\circ\text{C/GPa}$

- Low T/P cold subduction
- Global scale
- Mega-orogen 2.1-1.8 Ga (Himalaya counterpart?)

$250 \pm 15^\circ\text{C/GPa}$

NCC xenolith eclogite
(Xu et al., 2018)

140°C/GPa

Nagssugtoqidian UHP
(Glassley et al., 2014)

Trans-Hudson eclogite
(Weller & St-Onge, 2017)

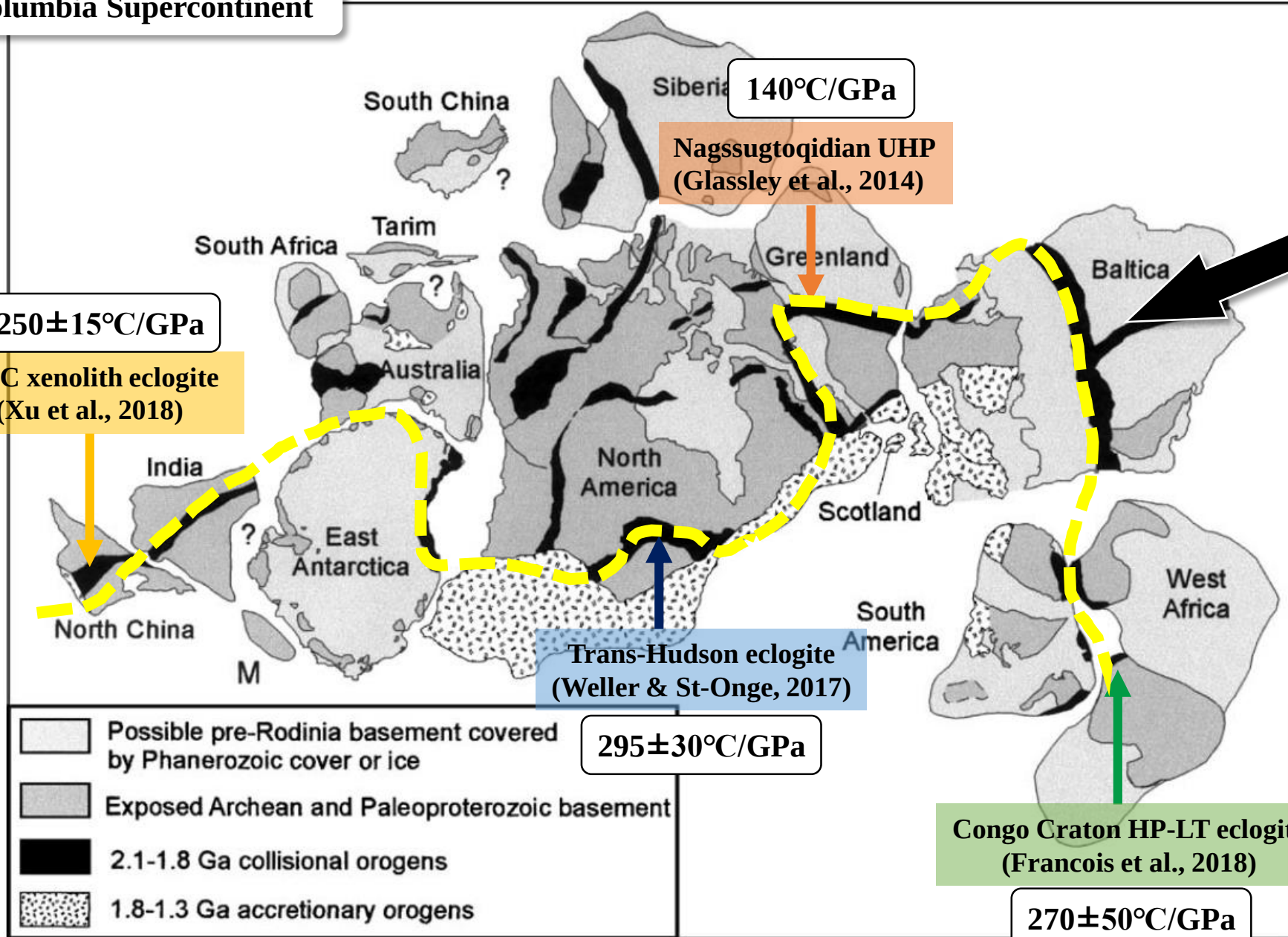
$295 \pm 30^\circ\text{C/GPa}$

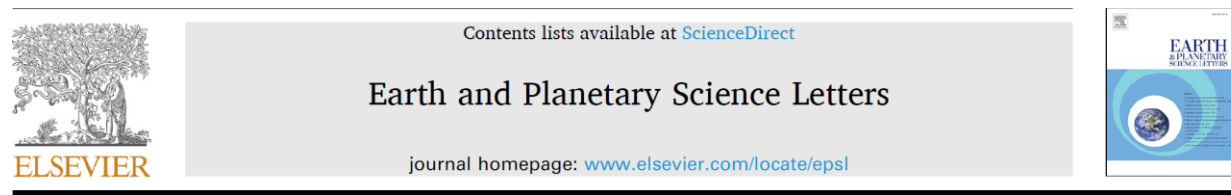
Congo Craton HP-LT eclogite
(Francois et al., 2018)

$270 \pm 50^\circ\text{C/GPa}$

- Possible pre-Rodinia basement covered by Phanerozoic cover or ice
- Exposed Archean and Paleoproterozoic basement
- 2.1-1.8 Ga collisional orogens
- 1.8-1.3 Ga accretionary orogens

Zhao et al., 2004





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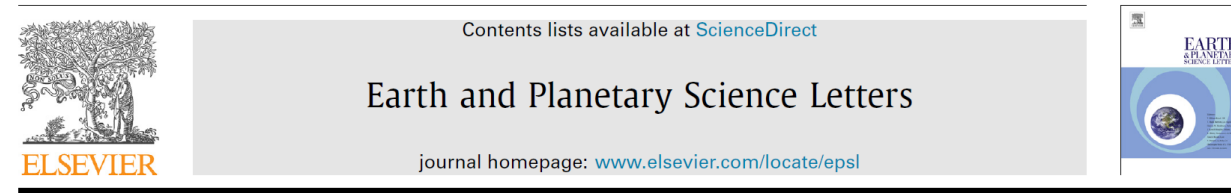
journal homepage: www.elsevier.com/locate/epsl



Orosirian cold eclogite from Baltica marks the onset of modern plate tectonics

Xiaoli Li^{a,*}, Lifei Zhang^{a,*}, Chunjing Wei, Guibing Zhang

^a The Key Laboratory of Orogenic Belts and Crustal Evolution, MOE, School of Earth and Space Sciences, Peking University, Beijing, China, 100871



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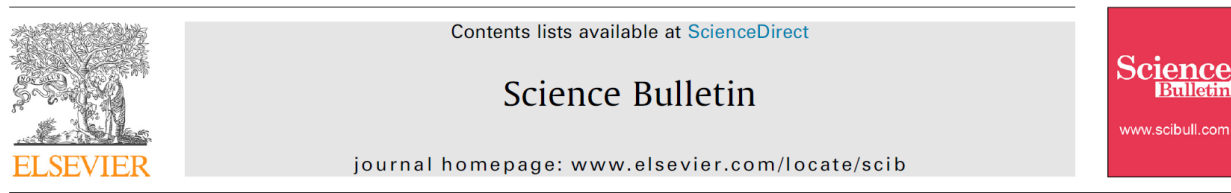


Cold subduction recorded by the 1.9 Ga Salma eclogite in Belomorian Province (Russia)

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Short Communication

1.9 Ga eclogite from the Archean-Paleoproterozoic Belomorian Province, Russia

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Precambrian Research

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Neoarchean-Paleoproterozoic granulite-facies metamorphism in Uzkaya Salma eclogite-bearing mélange, Belomorian Province (Russia)



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ORIGINAL ARTICLE

WILEY [Journal of METAMORPHIC GEOLOGY](#)

Age and P – T conditions of the Gridino-type eclogite in the Belomorian Province, Russia

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Lithos

journal homepage: www.elsevier.com/locate/lithos



Garnet Lu—Hf geochronology and P-T path of the Gridino-type eclogite in the Belomorian Province, Russia



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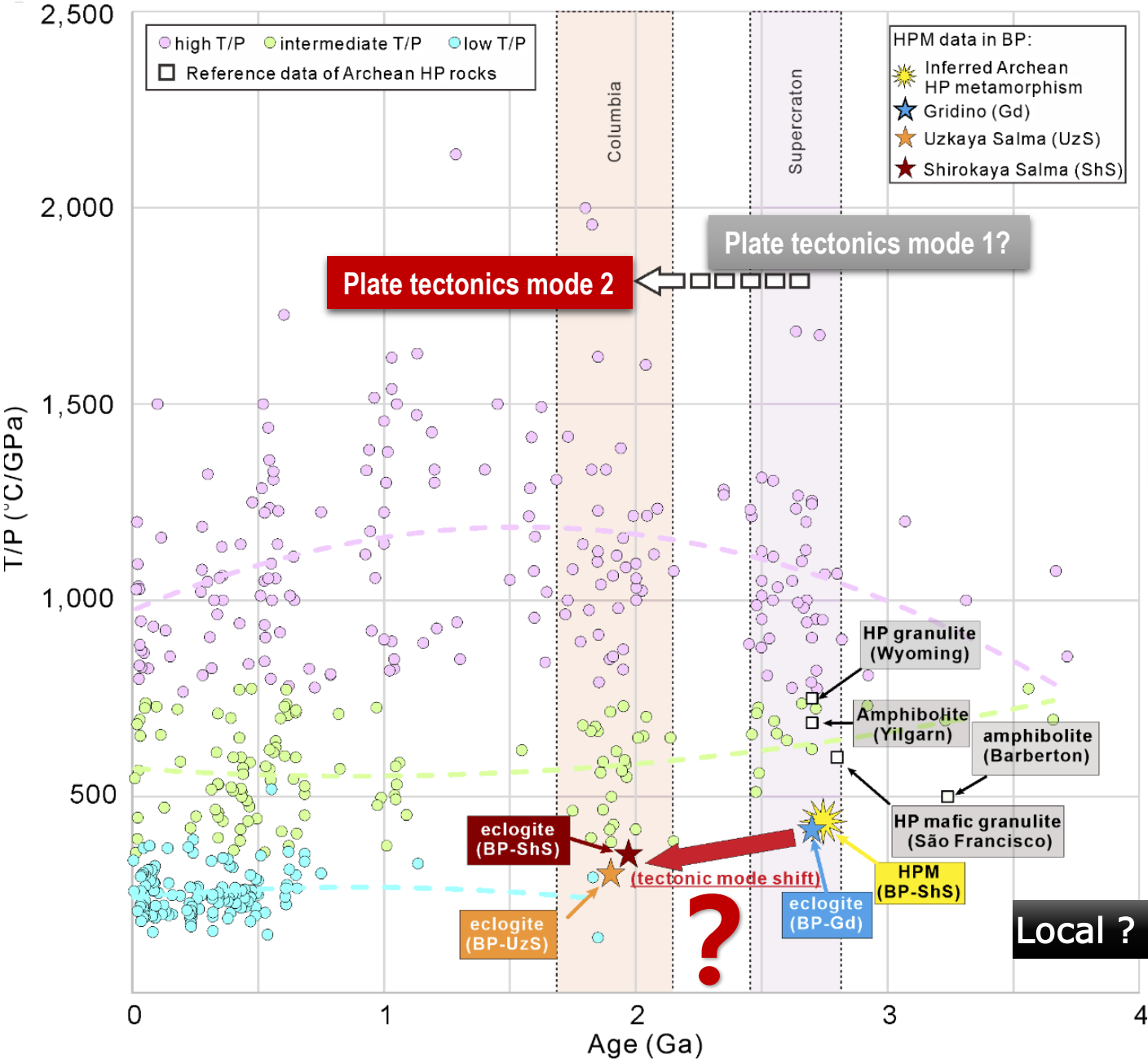
The metamorphic evolution of Salma-type eclogite in Russia: Constraints from zircon/titanite dating and phase equilibria modeling



Huanglu Yu^a, Lifei Zhang^{a,*}, Lijuan Zhang^a, Chunjing Wei^a, Xiaoli Li^a, Jinghui Guo^b, Thomas Bader^a, Yunfei Qi^a

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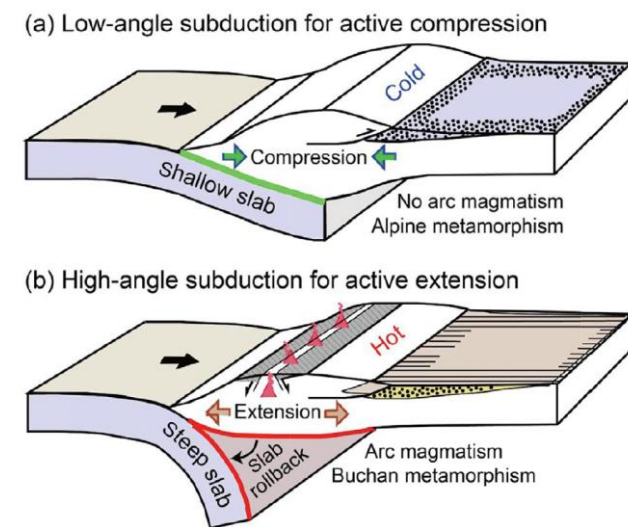
ARCHEAN EVENT

2.7 Ga Belomorian Gridino/Salma eclogite?



Plate tectonics Ancient vs. Modern style
Large-scale (global) horizontal vertical motion
(subduction-collision)

- ✓ Modern-style
- ✓ Ancient-style



Zheng & Zhao, 2020



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Metamorphic *PT* path and zircon U–Pb dating of Archean eclogite association in Gridino complex, Belomorian province, Russia



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ORIGINAL ARTICLE

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METAMORPHIC GEOLOGY

Quartz and orthopyroxene exsolution lamellae in clinopyroxene and the metamorphic *P–T* path of Belomorian eclogites

Xiaoli Li¹ | Lifei Zhang¹ | Chunjing Wei¹ | Alexander I. Slabunov^{2,3} | Thomas Bader¹

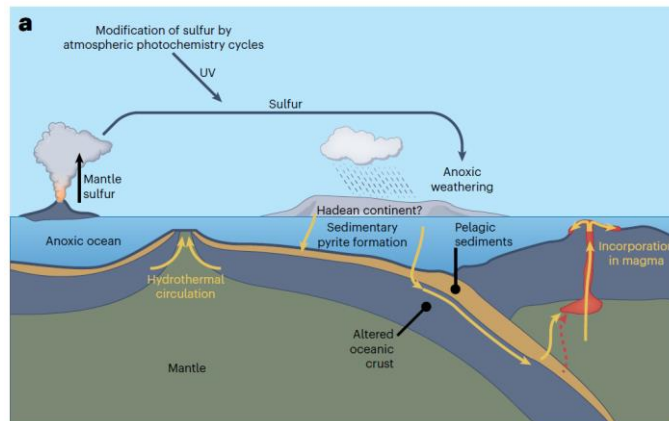
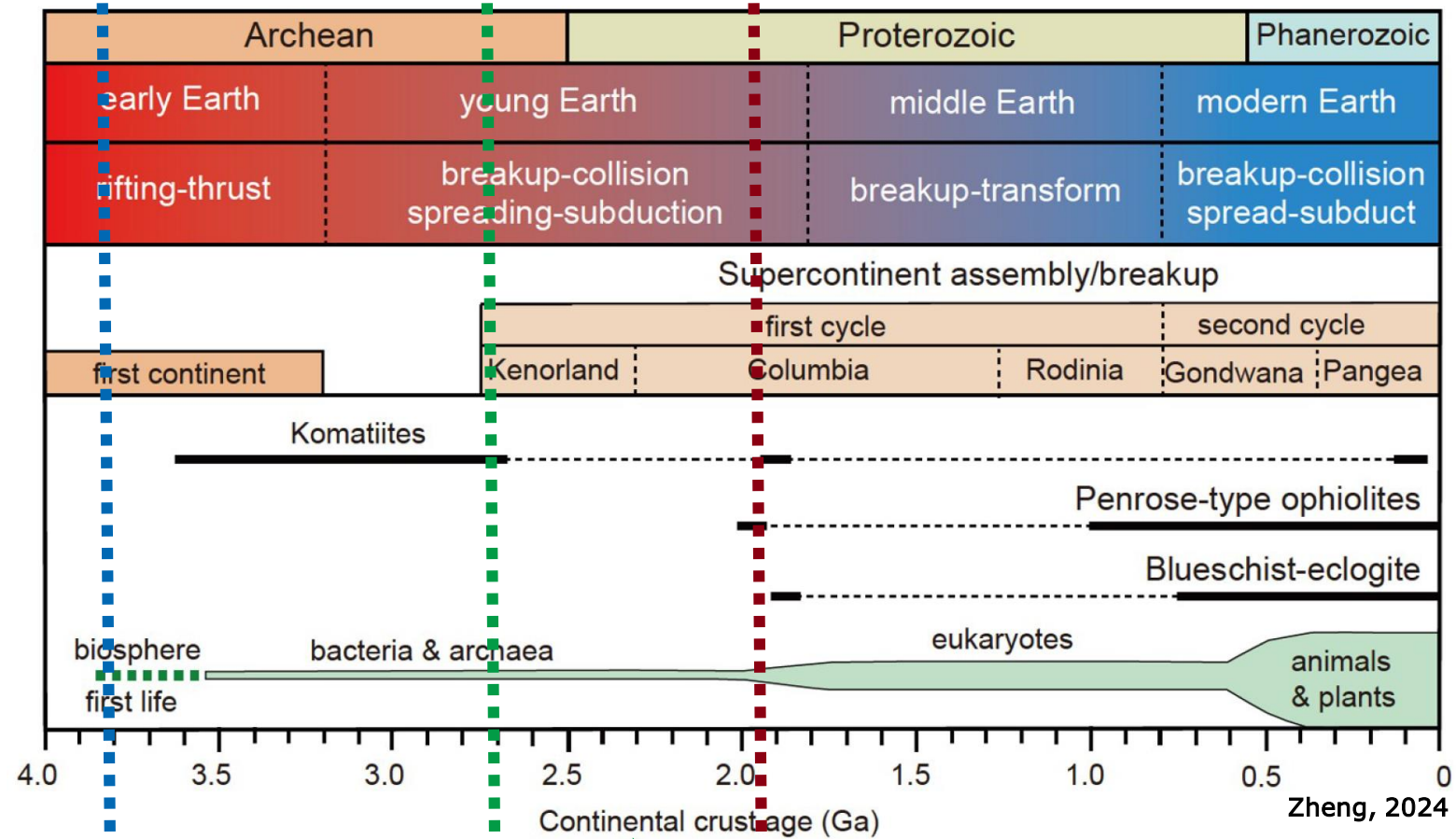
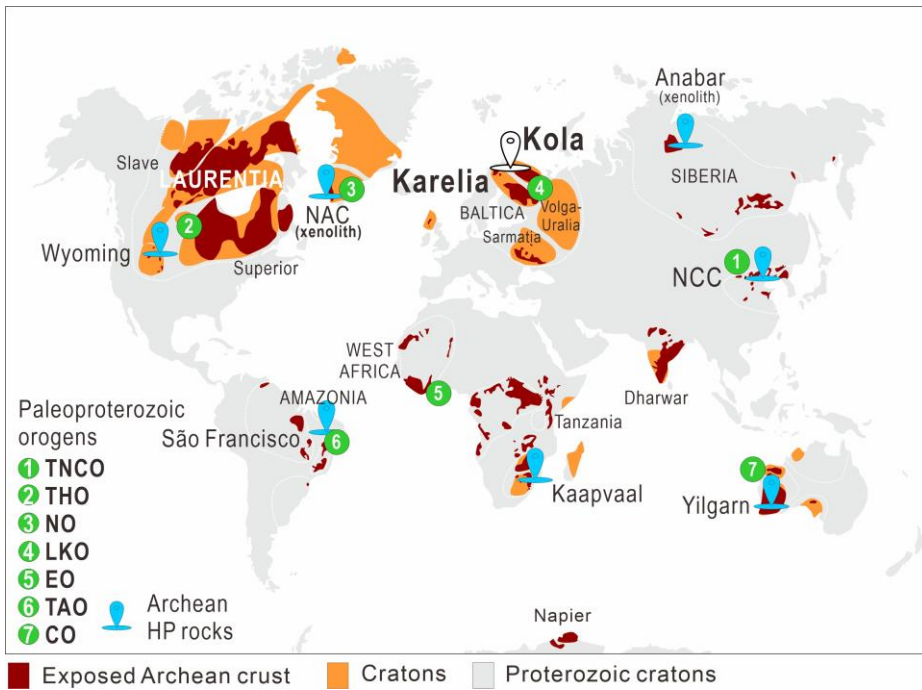
ORIGINAL ARTICLE

Journal of
METAMORPHIC GEOLOGY WILEY

The metamorphic *PT* history of Precambrian Belomorian eclogites (Shirokaya Salma), Russia

Xiaoli Li  | Lifei Zhang  | Thomas Bader 

Maybe there will be more results incoming.....



nature geoscience

Article **Early Archean onset of volatile cycling at subduction zones**

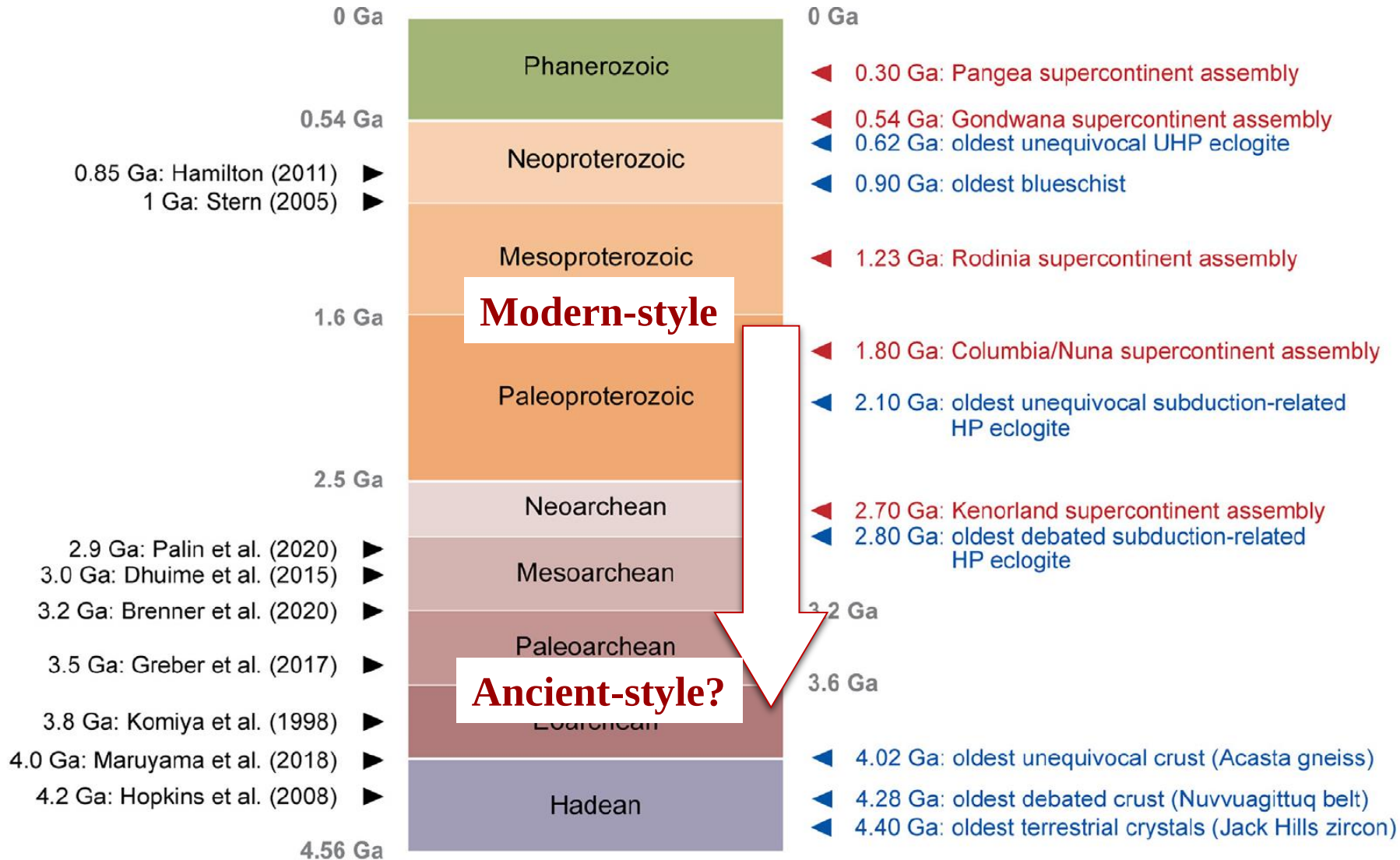
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Caro^{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144,145,146,147,148,149,150,151,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,167,168,169,170,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,195,196,197,198,199,200,201,202,203,204,205,206,207,208,209,210,211,212,213,214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,229,230,231,232,233,234,235,236,237,238,239,240,241,242,243,244,245,246,247,248,249,250,251,252,253,254,255,256,257,258,259,260,261,262,263,264,265,266,267,268,269,270,271,272,273,274,275,276,277,278,279,280,281,282,283,284,285,286,287,288,289,290,291,292,293,294,295,296,297,298,299,300,301,302,303,304,305,306,307,308,309,310,311,312,313,314,315,316,317,318,319,320,321,322,323,324,325,326,327,328,329,330,331,332,333,334,335,336,337,338,339,340,341,342,343,344,345,346,347,348,349,350,351,352,353,354,355,356,357,358,359,360,361,362,363,364,365,366,367,368,369,370,371,372,373,374,375,376,377,378,379,380,381,382,383,384,385,386,387,388,389,390,391,392,393,394,395,396,397,398,399,400,401,402,403,404,405,406,407,408,409,410,411,412,413,414,415,416,417,418,419,420,421,422,423,424,425,426,427,428,429,430,431,432,433,434,435,436,437,438,439,440,441,442,443,444,445,446,447,448,449,450,451,452,453,454,455,456,457,458,459,460,461,462,463,464,465,466,467,468,469,470,471,472,473,474,475,476,477,478,479,480,481,482,483,484,485,486,487,488,489,490,491,492,493,494,495,496,497,498,499,500,501,502,503,504,505,506,507,508,509,510,511,512,513,514,515,516,517,518,519,520,521,522,523,524,525,526,527,528,529,530,531,532,533,534,535,536,537,538,539,540,541,542,543,544,545,546,547,548,549,550,551,552,553,554,555,556,557,558,559,560,561,562,563,564,565,566,567,568,569,570,571,572,573,574,575,576,577,578,579,580,581,582,583,584,585,586,587,588,589,590,591,592,593,594,595,596,597,598,599,600,601,602,603,604,605,606,607,608,609,610,611,612,613,614,615,616,617,618,619,620,621,622,623,624,625,626,627,628,629,630,631,632,633,634,635,636,637,638,639,640,641,642,643,644,645,646,647,648,649,650,651,652,653,654,655,656,657,658,659,660,661,662,663,664,665,666,667,668,669,670,671,672,673,674,675,676,677,678,679,680,681,682,683,684,685,686,687,688,689,690,691,692,693,694,695,696,697,698,699,700,701,702,703,704,705,706,707,708,709,710,711,712,713,714,715,716,717,718,719,720,721,722,723,724,725,726,727,728,729,730,731,732,733,734,735,736,737,738,739,740,741,742,743,744,745,746,747,748,749,750,751,752,753,754,755,756,757,758,759,760,761,762,763,764,765,766,767,768,769,770,771,772,773,774,775,776,777,778,779,780,781,782,783,784,785,786,787,788,789,790,791,792,793,794,795,796,797,798,799,800,801,802,803,804,805,806,807,808,809,810,811,812,813,814,815,816,817,818,819,820,821,822,823,824,825,826,827,828,829,830,831,832,833,834,835,836,837,838,839,840,841,842,843,844,845,846,847,848,849,850,851,852,853,854,855,856,857,858,859,860,861,862,863,864,865,866,867,868,869,870,871,872,873,874,875,876,877,878,879,880,881,882,883,884,885,886,887,888,889,890,891,892,893,894,895,896,897,898,899,900,901,902,903,904,905,906,907,908,909,910,911,912,913,914,915,916,917,918,919,920,921,922,923,924,925,926,927,928,929,930,931,932,933,934,935,936,937,938,939,940,941,942,943,944,945,946,947,948,949,950,951,952,953,954,955,956,957,958,959,960,961,962,963,964,965,966,967,968,969,970,971,972,973,974,975,976,977,978,979,980,981,982,983,984,985,986,987,988,989,990,991,992,993,994,995,996,997,998,999,1000,1001,1002,1003,1004,1005,1006,1007,1008,1009,1010,1011,1012,1013,1014,1015,1016,1017,1018,1019,1020,1021,1022,1023,1024,1025,1026,1027,1028,1029,1030,1031,1032,1033,1034,1035,1036,1037,1038,1039,1040,1041,1042,1043,1044,1045,1046,1047,1048,1049,1050,1051,1052,1053,1054,1055,1056,1057,1058,1059,1060,1061,1062,1063,1064,1065,1066,1067,1068,1069,1070,1071,1072,1073,1074,1075,1076,1077,1078,1079,1080,1081,1082,1083,1084,1085,1086,1087,1088,1089,1090,1091,1092,1093,1094,1095,1096,1097,1098,1099,1100,1101,1102,1103,1104,1105,1106,1107,1108,1109,1110,1111,1112,1113,1114,1115,1116,1117,1118,1119,1120,1121,1122,1123,1124,1125,1126,1127,1128,1129,1130,1131,1132,1133,1134,1135,1136,1137,1138,1139,1140,1141,1142,1143,1144,1145,1146,1147,1148,1149,1150,1151,1152,1153,1154,1155,1156,1157,1158,1159,1160,1161,1162,1163,1164,1165,1166,1167,1168,1169,1170,1171,1172,1173,1174,1175,1176,1177,1178,1179,1180,1181,1182,1183,1184,1185,1186,1187,1188,1189,1190,1191,1192,1193,1194,1195,1196,1197,1198,1199,1200,1201,1202,1203,1204,1205,1206,1207,1208,1209,1210,1211,1212,1213,1214,1215,1216,1217,1218,1219,1220,1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When Plate Tectonics started



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Associations of Trace Elements in the Sulfides of Black Smokers from the Broken Spur, Menez Gwen, and Snake Pit Hydrothermal Fields

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SHORT COMMUNICATIONS

Trace Elements and Their Distribution in Sulfides from Black Smokers of the Broken Spur Hydrothermal Vent Field (Mid-Atlantic Ridge)

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Application of microprobe-based flank method analysis of Fe³⁺ in garnet of North Qilian eclogite and its geological implication

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Electron microprobe analysis of Hf and Ti in ultrahigh temperature zircon: Optimized approaches and perspectives

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