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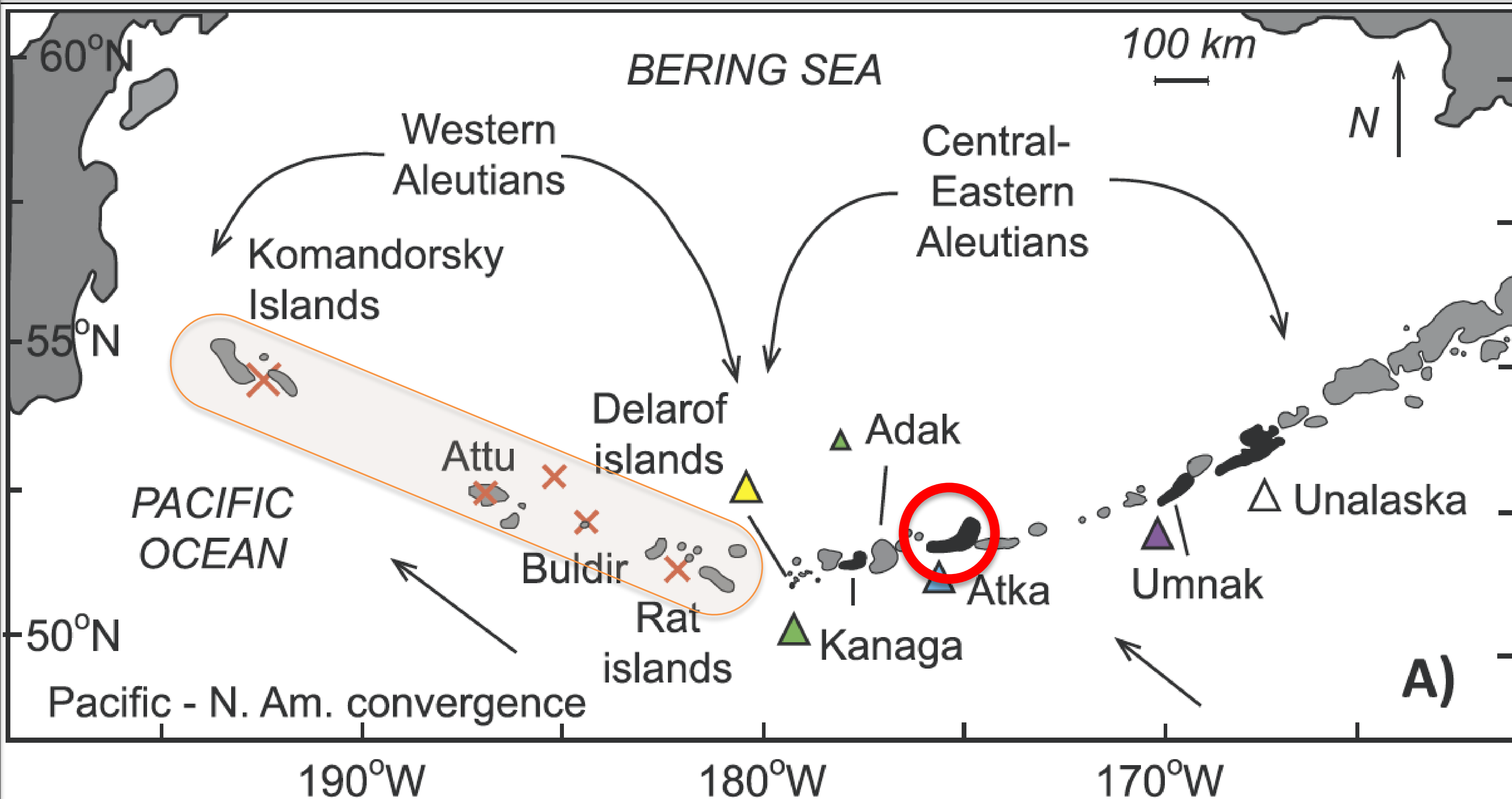
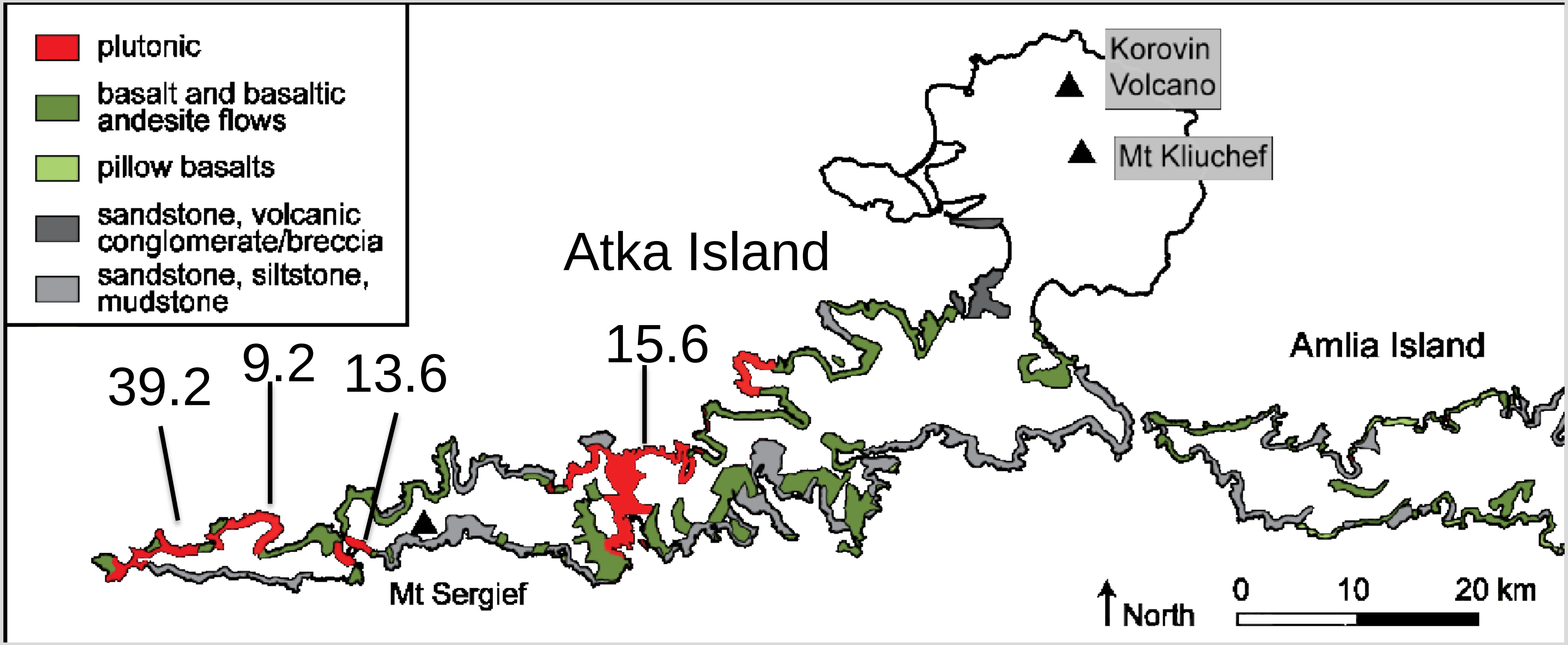
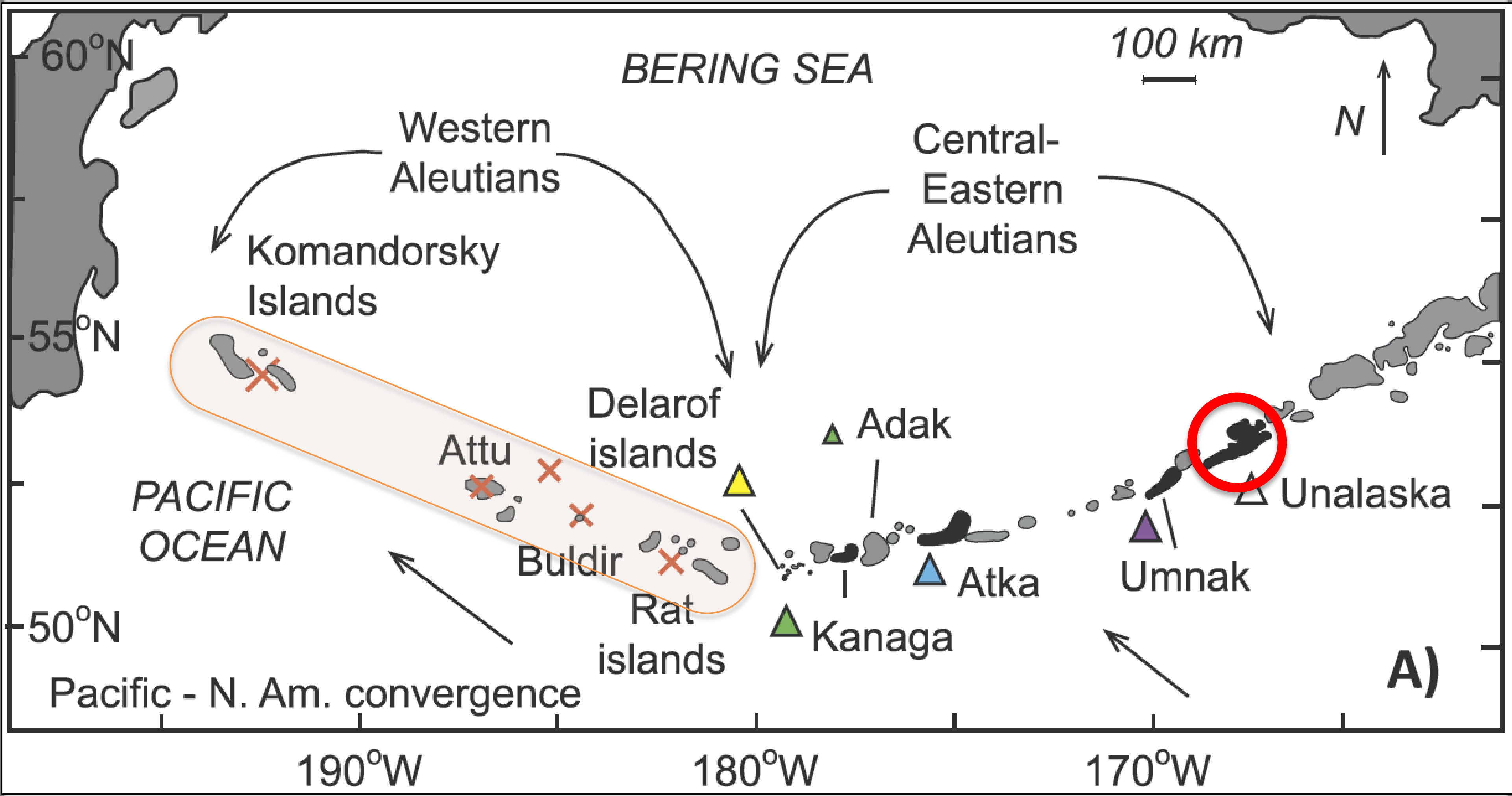
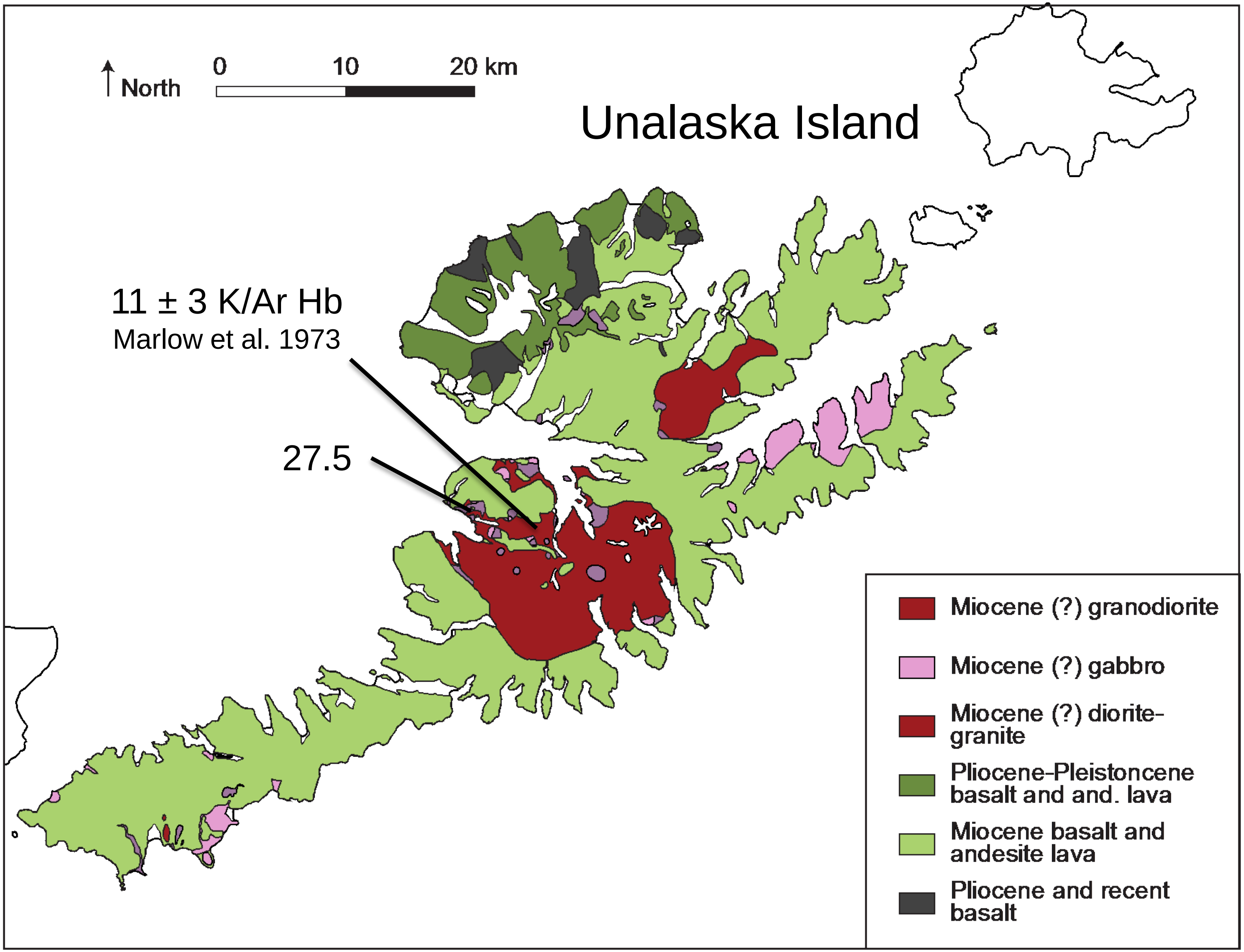
Distinctly different parental magmas for calc-alkaline plutons and tholeiitic lavas in the central and eastern Aleutian arc

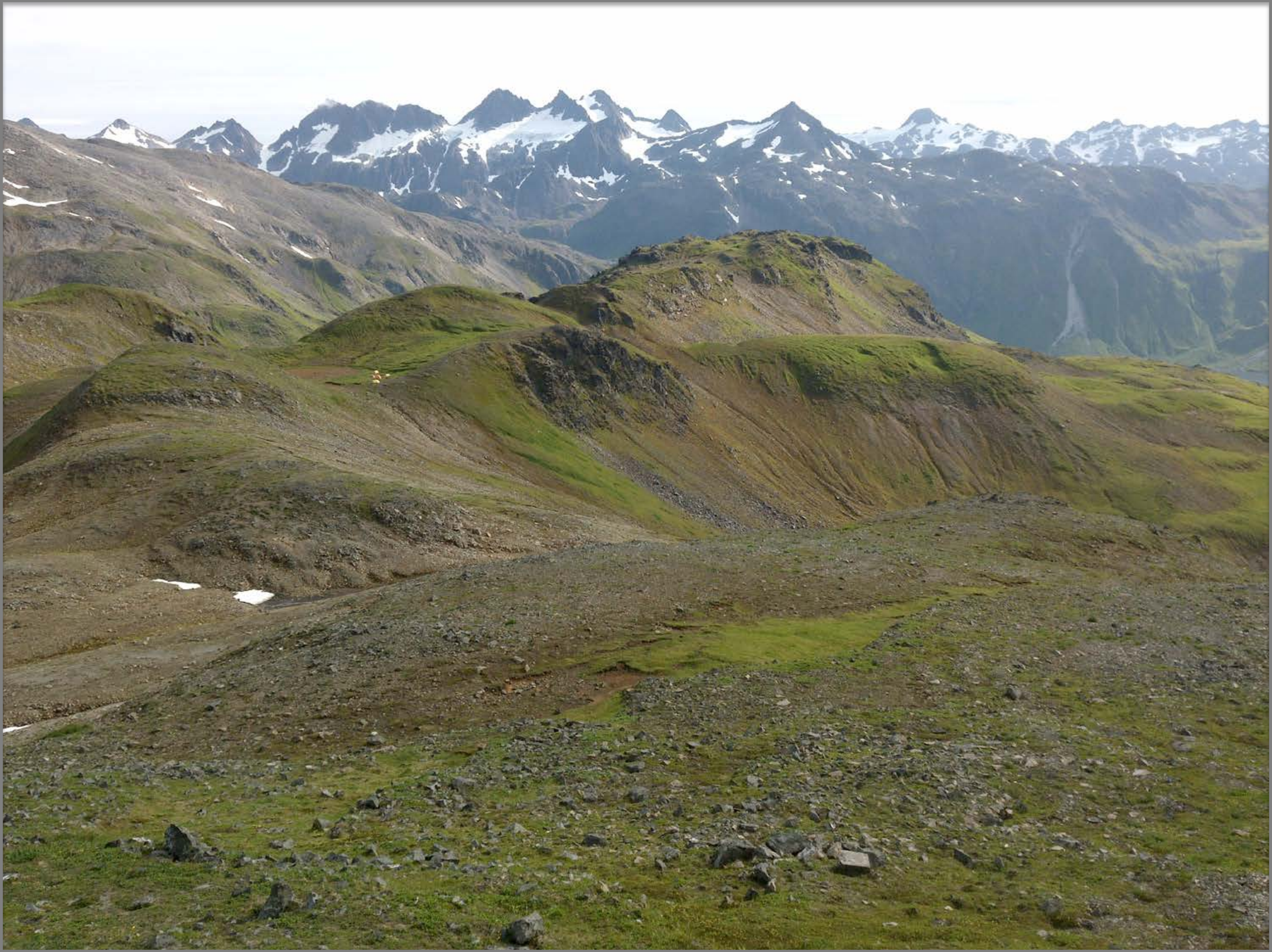
Yue Cai [a,*], Matthew Rioux [b], Peter B. Kelemen [a,c], Steven L. Goldstein [a,c], Louise Bolge [a], Andrew R.C. Kylander-Clark [d]

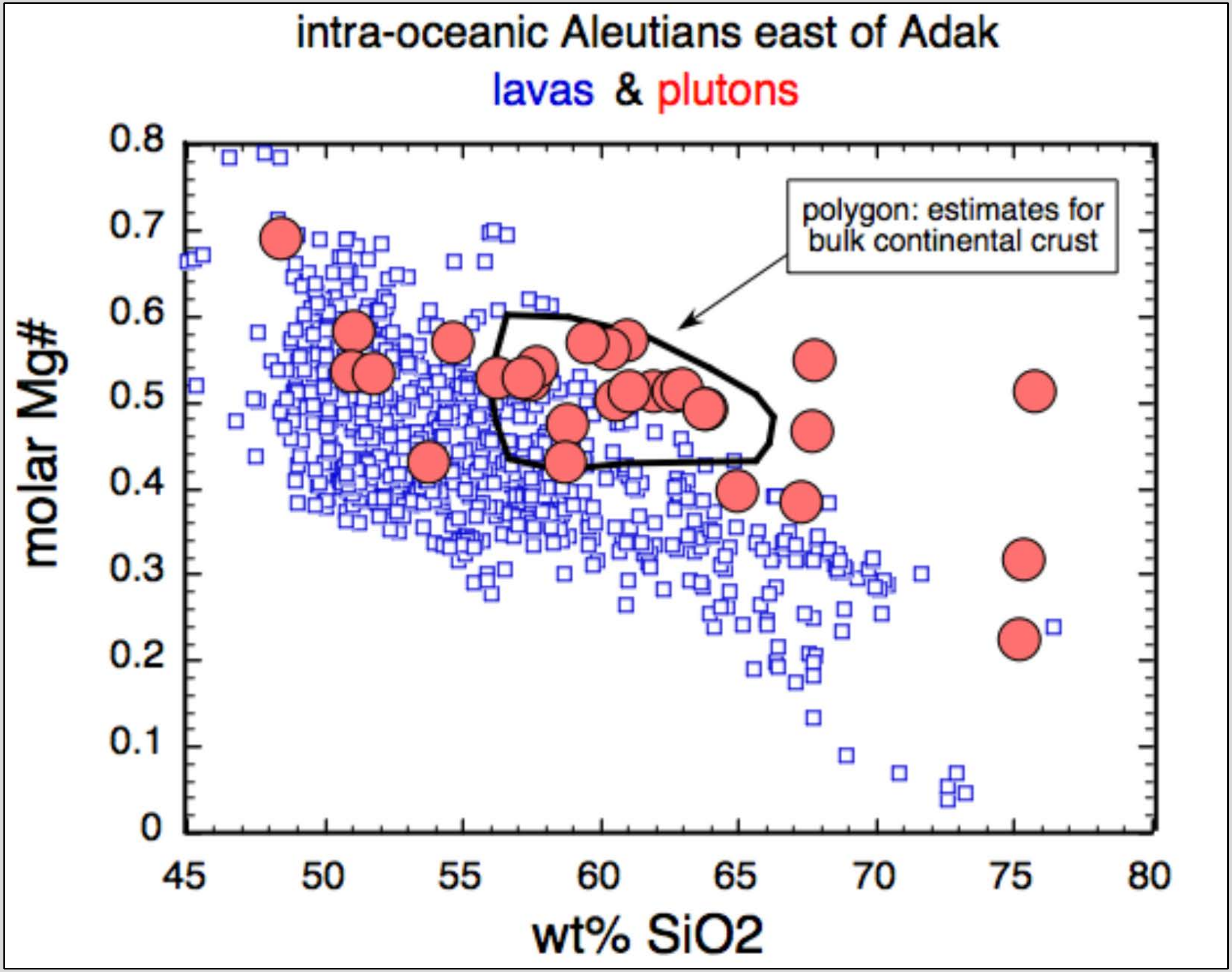

BERING SEA
100 km
N
60°N
55°N
50°N
Western
Aleutians
Central-
Eastern
Aleutians
Komandorsky
Islands
Delarof
islands
Adak
Attu
PACIFIC
OCEAN
Buldir
Rat
islands
Kanaga
Atka
Umnak
Unalaska
A)
Pacific - N. Am. convergence
190°W
180°W
170°W


plutonic
basalt and basaltic andesite flows
pillow basalts
sandstone, volcanic conglomerate/breccia
sandstone, siltstone, mudstone
Korovin Volcano
Mt Kliuchef
Atka Island
Amlia Island
39.2
9.2
13.6
15.6
Mt Sergief
North
0
10
20 km

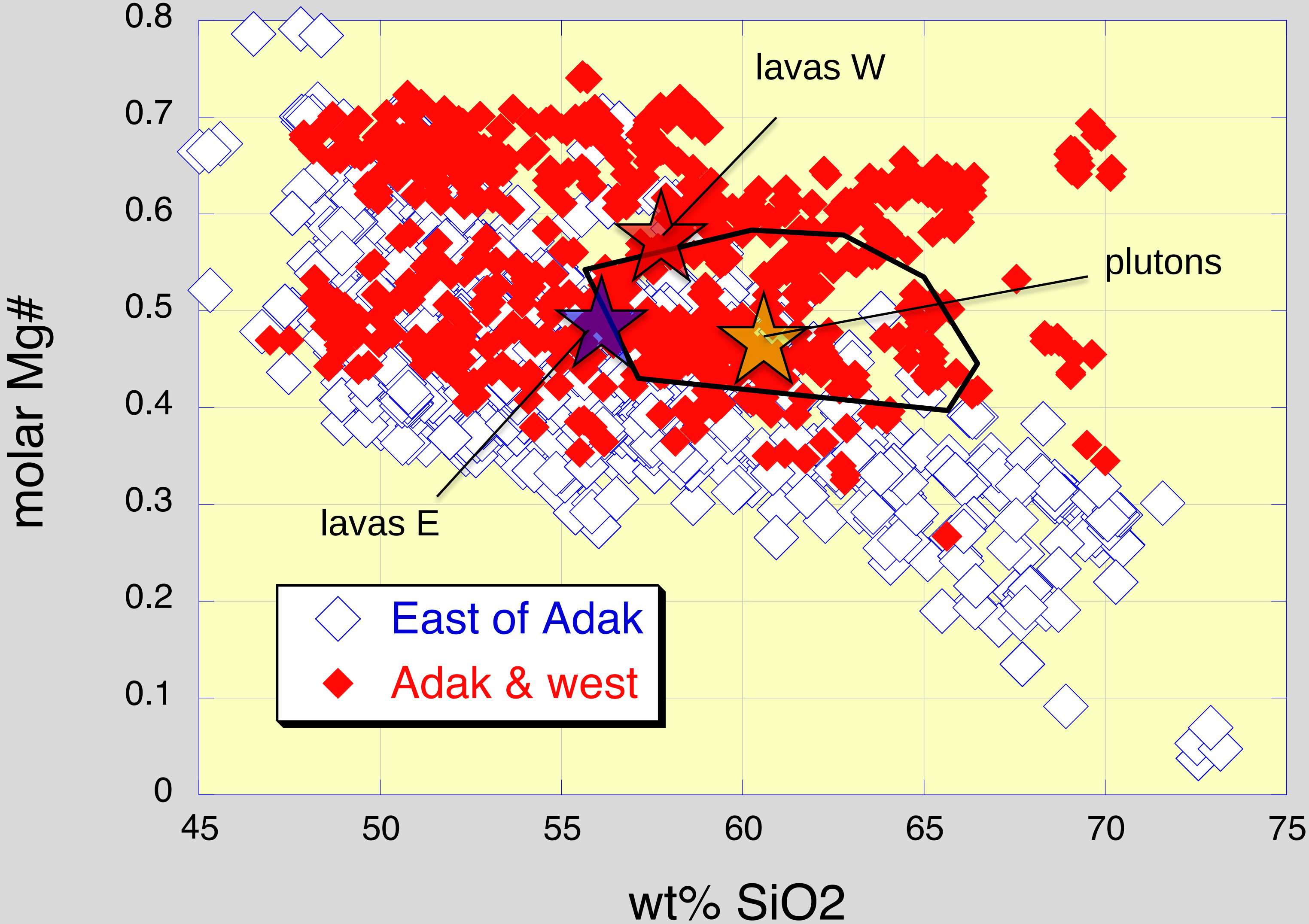

BERING SEA
100 km
N
60°N
55°N
50°N
Western
Aleutians
Central-
Eastern
Aleutians
Komandorsky
Islands
Delarof
islands
Adak
Attu
PACIFIC
OCEAN
Buldir
Rat
islands
Kanaga
Atka
Umnak
Unalaska
A)
Pacific - N. Am. convergence
190°W
180°W
170°W


North
0
10
20 km
Unalaska Island
11 ± 3 K/Ar Hb
Marlow et al. 1973
27.5
Miocene (?) granodiorite
Miocene (?) gabbro
Miocene (?) diorite-granite
Pliocene-Pleistoncene basalt and and. lava
Miocene basalt and andesite lava
Pliocene and recent basalt




intra-oceanic Aleutians east of Adak
lavas & plutons
polygon: estimates for bulk continental crust
molar Mg#
wt% SiO2
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
45
50
55
60
65
70
75
80

Aleutian lavas



Kelemen & Behn 2014, submitted; Data compilations:
Kelemen et al. 2003 AGU Ch11, Singer et al. 2007,
Yogodzinski et al. WAVE dredging expedition 2005,
Yogodzinski, Hoernle, Portnyagin pers. comm. 2013

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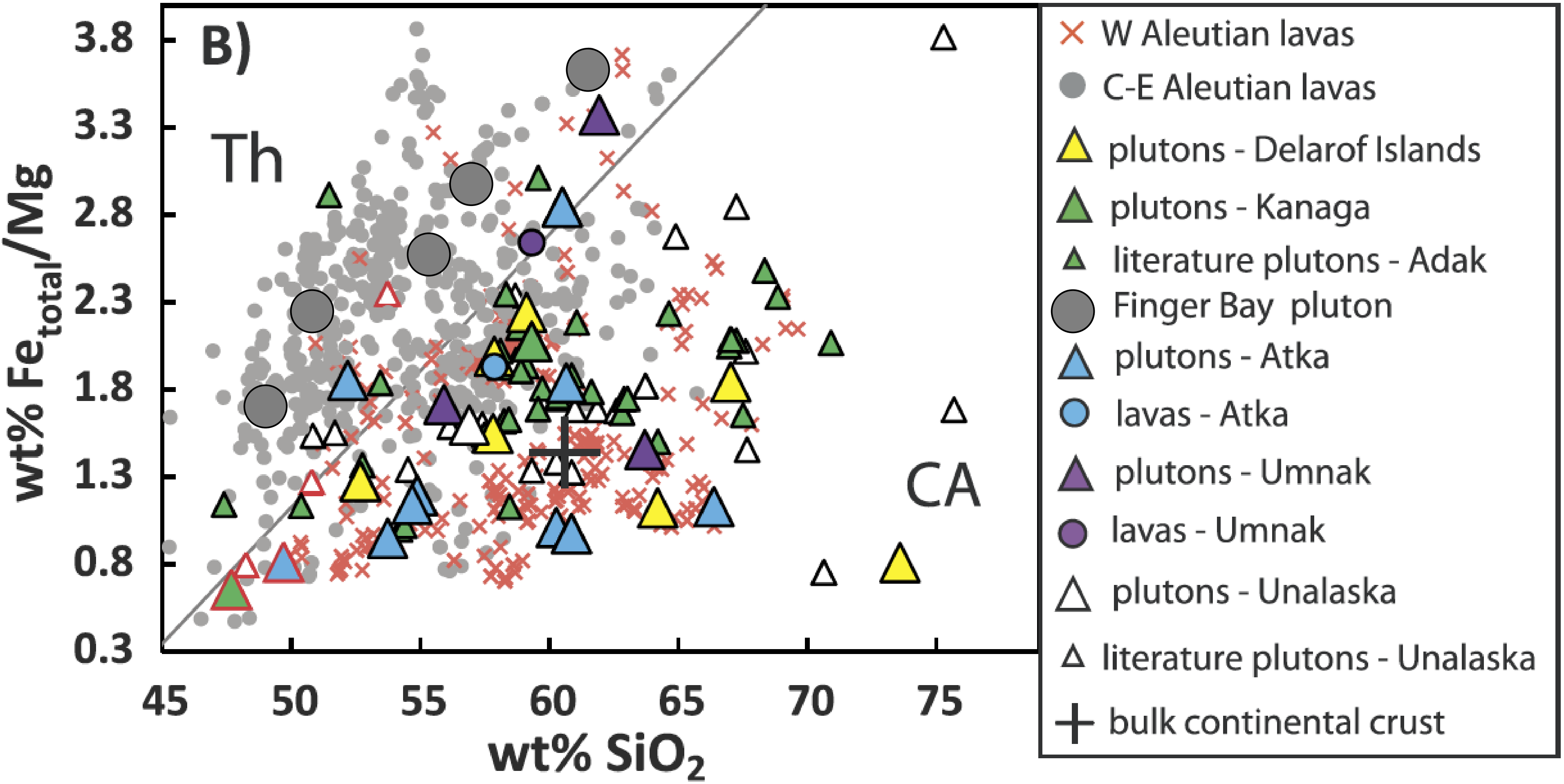
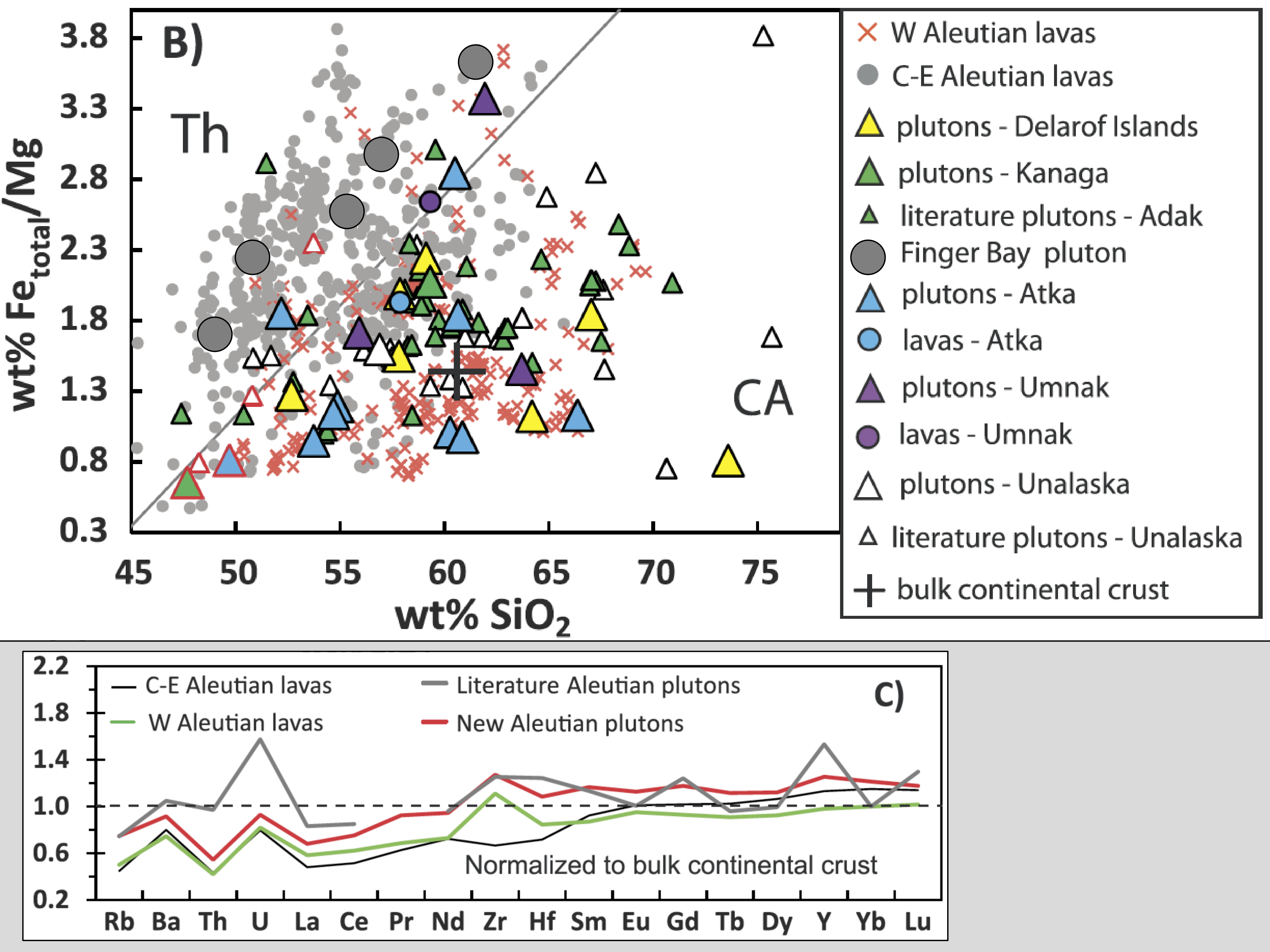
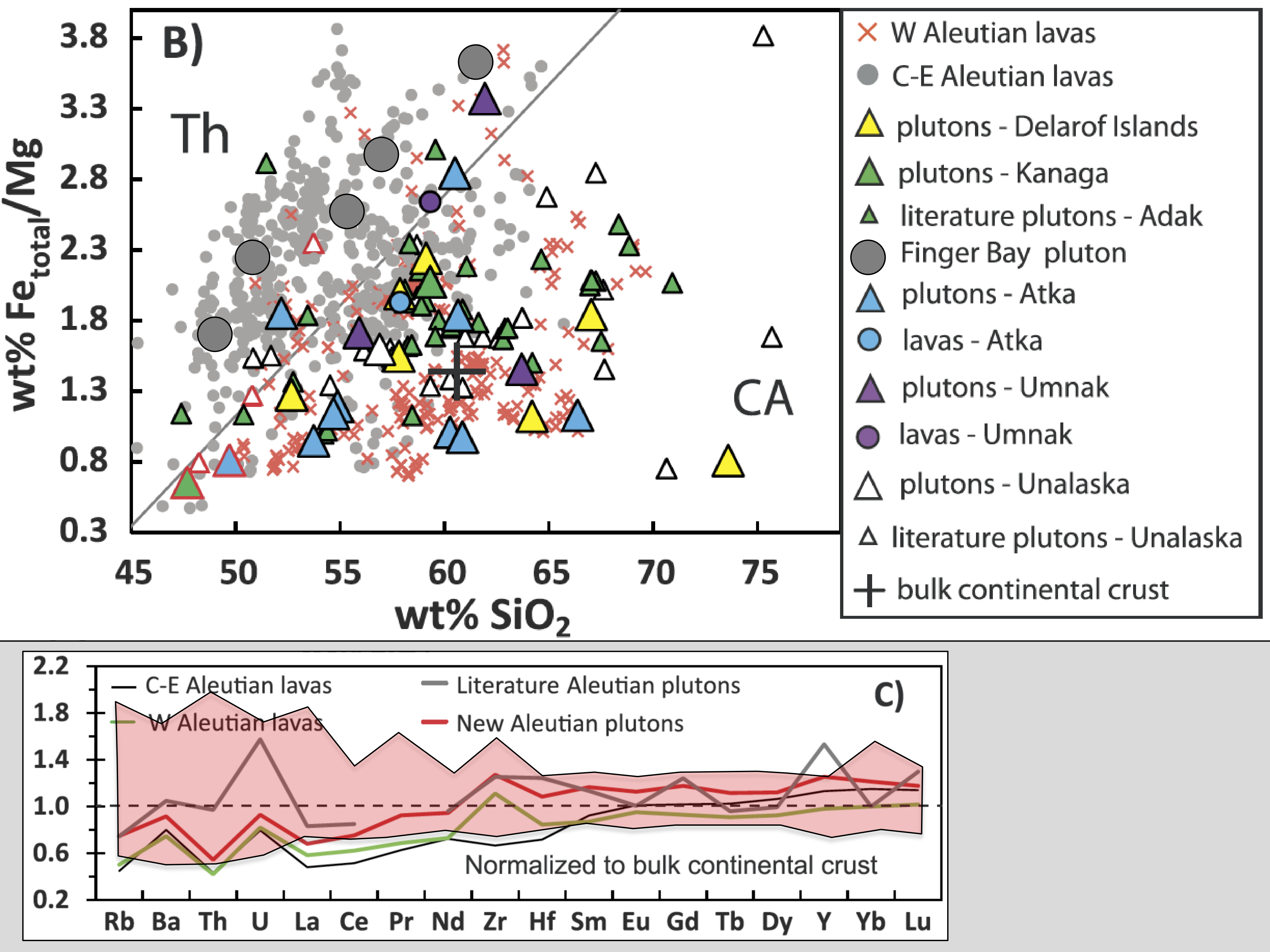
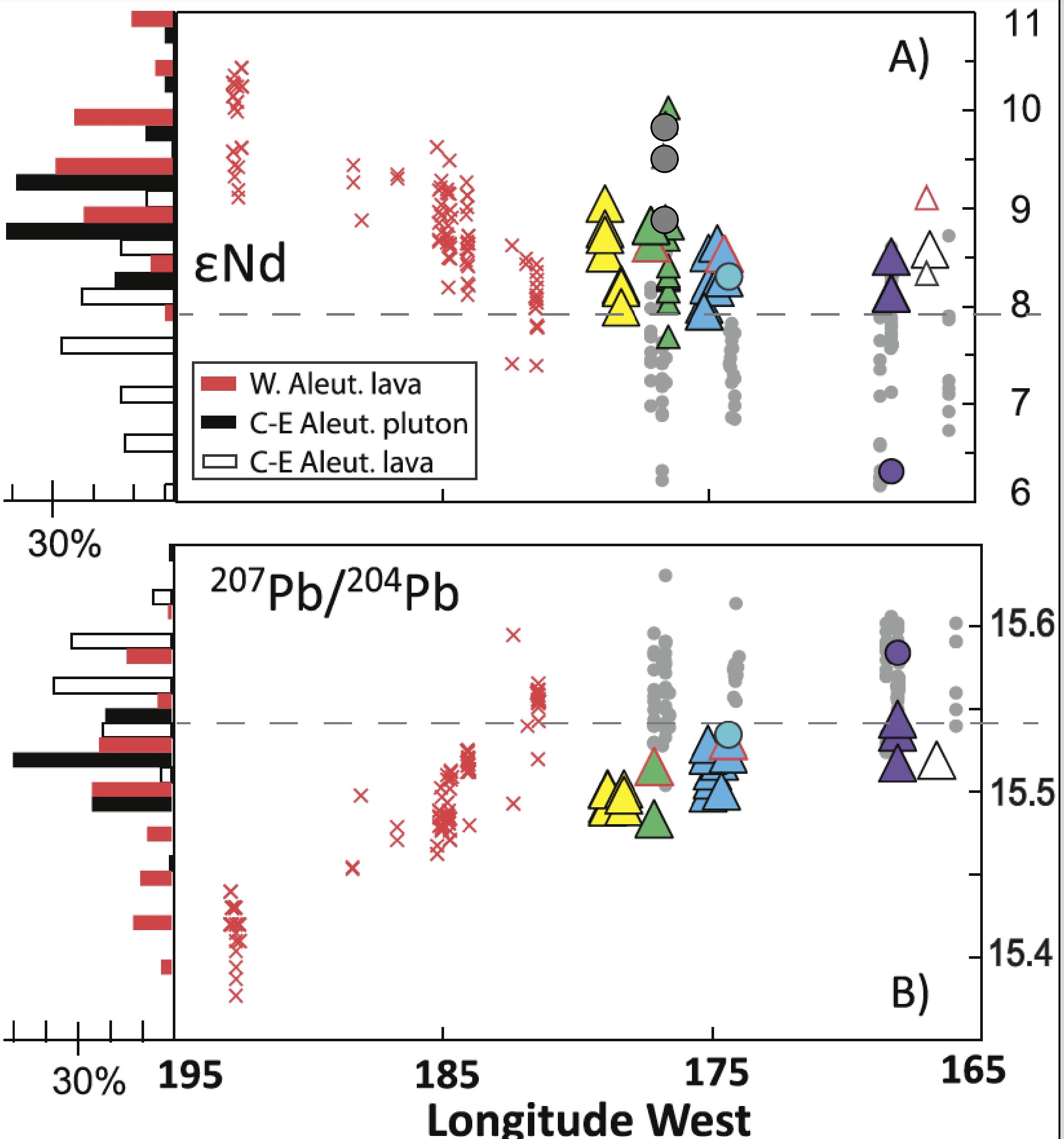


B)
Th
CA
wt% Fe$_{total}$/Mg
wt% SiO_2
3.8
3.3
2.8
2.3
1.8
1.3
0.8
0.3
45
50
55
60
65
70
75
W Aleutian lavas
C-E Aleutian lavas
plutons - Delarof Islands
plutons - Kanaga
literature plutons - Adak
Finger Bay pluton
plutons - Atka
lavas - Atka
plutons - Umnak
lavas - Umnak
plutons - Unalaska
literature plutons - Unalaska
bulk continental crust

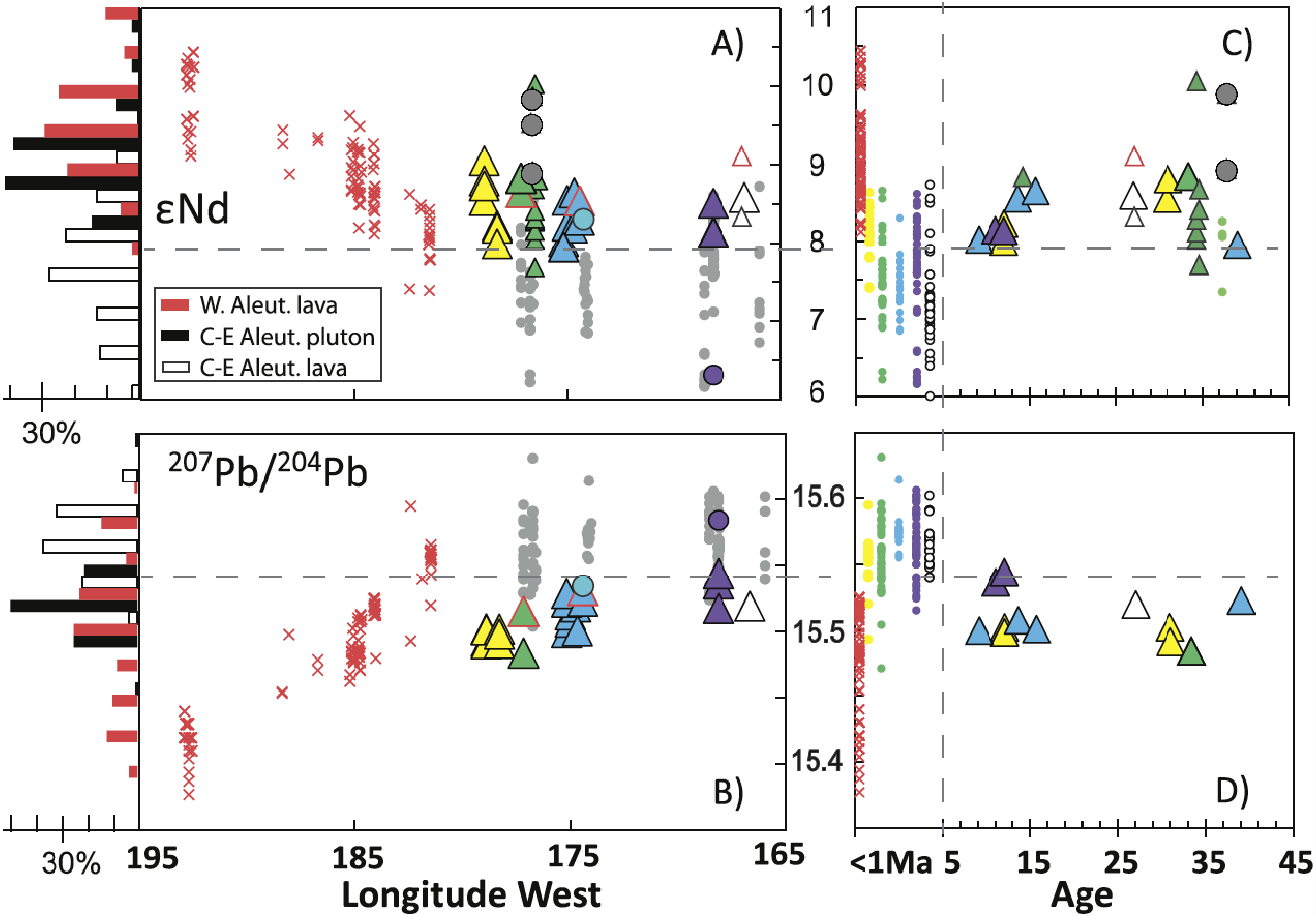


B)
Th
CA
3.8
3.3
2.8
2.3
1.8
1.3
0.8
0.3
wt% Fe$_{total}$/Mg
45
50
55
60
65
70
75
wt% SiO_2
W Aleutian lavas
C-E Aleutian lavas
plutons - Delarof Islands
plutons - Kanaga
literature plutons - Adak
Finger Bay pluton
plutons - Atka
lavas - Atka
plutons - Umnak
lavas - Umnak
plutons - Unalaska
literature plutons - Unalaska
bulk continental crust
C)
C-E Aleutian lavas
W Aleutian lavas
Literature Aleutian plutons
New Aleutian plutons
Normalized to bulk continental crust
2.2
1.8
1.4
1.0
0.6
0.2
Rb
Ba
Th
U
La
Ce
Pr
Nd
Zr
Hf
Sm
Eu
Gd
Tb
Dy
Y
Yb
Lu

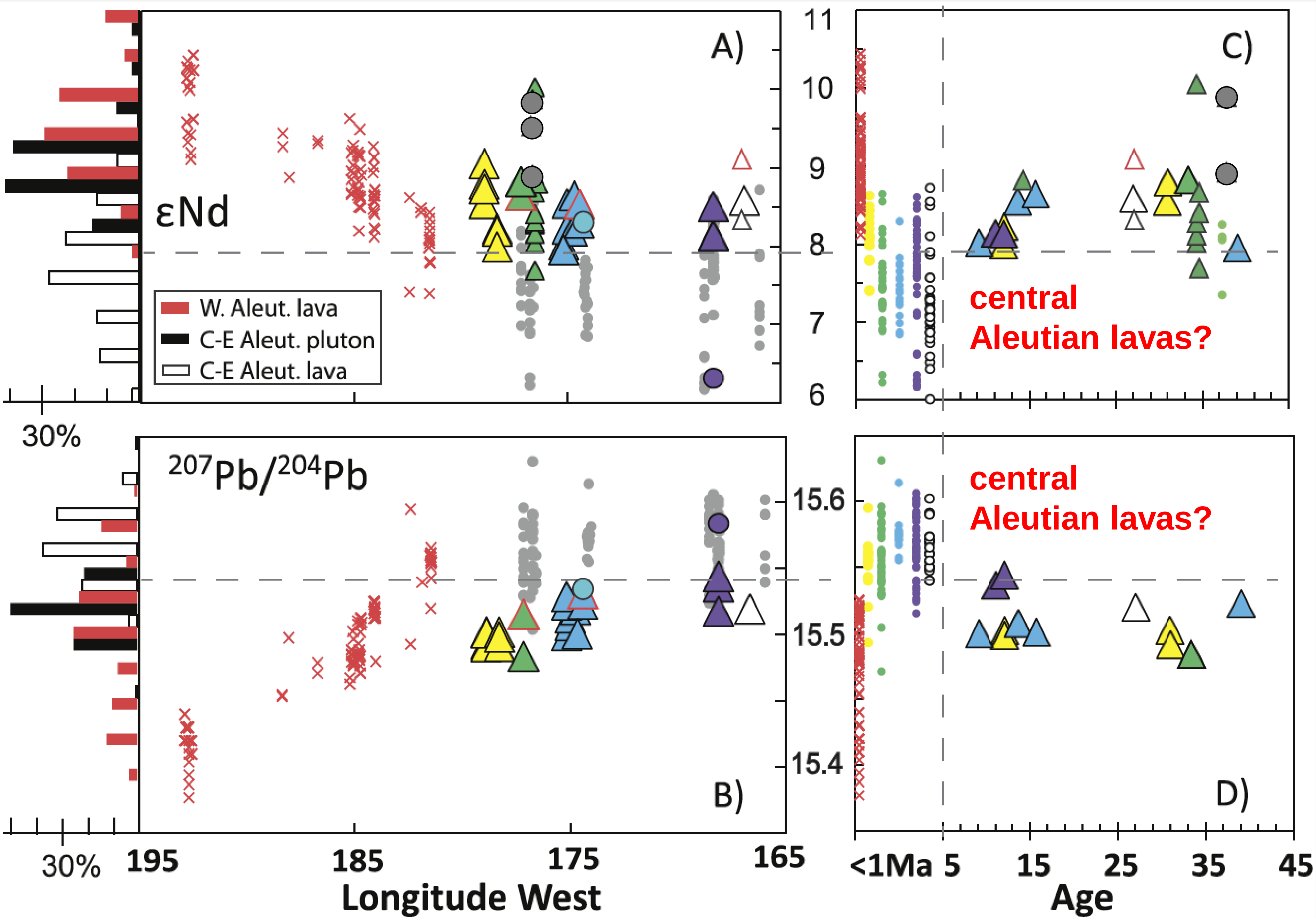

B)
Th
CA
wt% Fe$_{total}$/Mg
wt% SiO$_2$
3.8
3.3
2.8
2.3
1.8
1.3
0.8
0.3
45
50
55
60
65
70
75
W Aleutian lavas
C-E Aleutian lavas
plutons - Delarof Islands
plutons - Kanaga
literature plutons - Adak
Finger Bay pluton
plutons - Atka
lavas - Atka
plutons - Umnak
lavas - Umnak
plutons - Unalaska
literature plutons - Unalaska
bulk continental crust
C)
C-E Aleutian lavas
W Aleutian lavas
Literature Aleutian plutons
New Aleutian plutons
Normalized to bulk continental crust
2.2
1.8
1.4
1.0
0.6
0.2
Rb
Ba
Th
U
La
Ce
Pr
Nd
Zr
Hf
Sm
Eu
Gd
Tb
Dy
Y
Yb
Lu



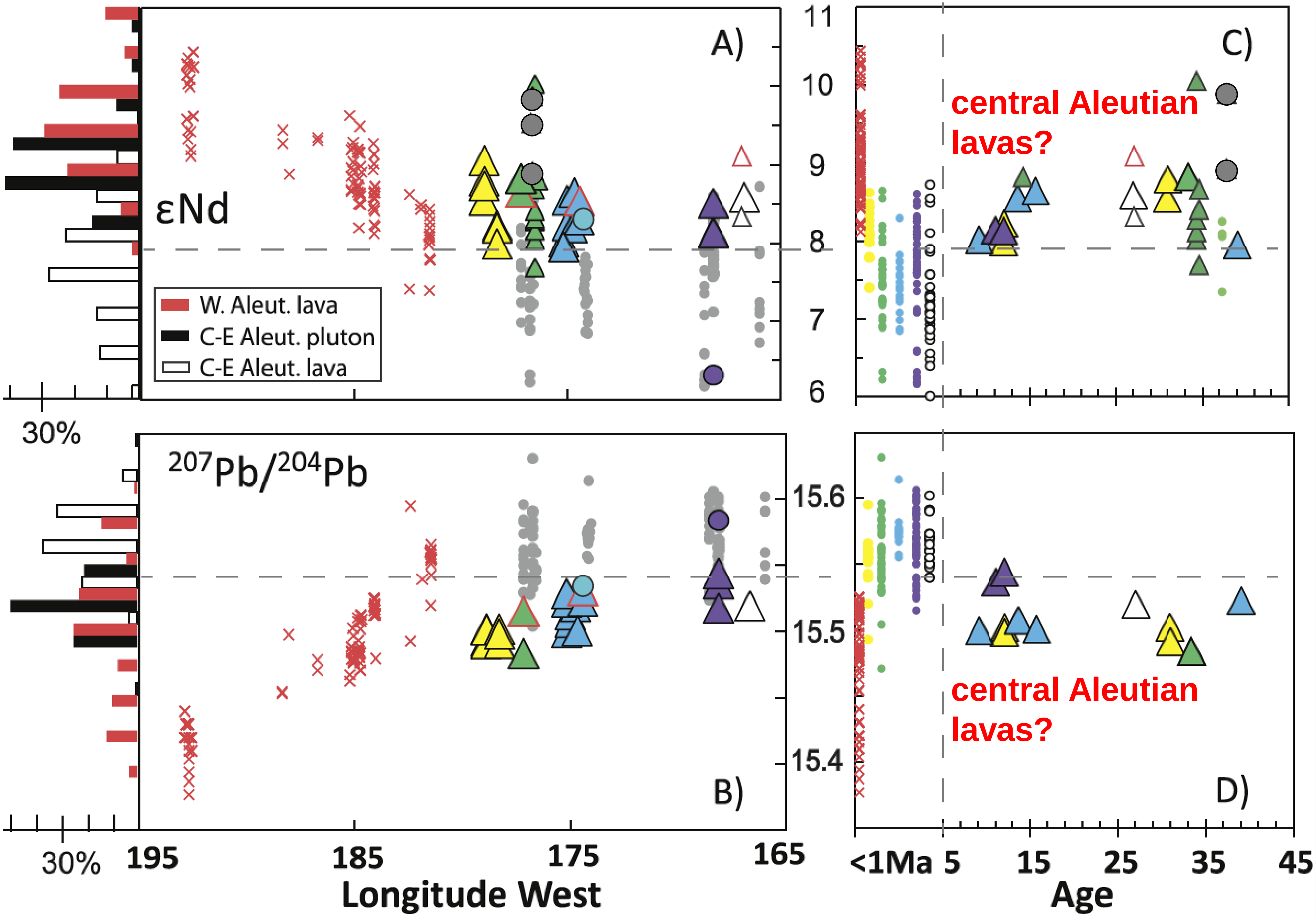
A)
εNd
11
10
9
8
7
6
W. Aleut. lava
C-E Aleut. pluton
C-E Aleut. lava
30%
$^{207}Pb/^{204}Pb$
15.6
15.5
15.4
B)
30%
195
185
175
165
Longitude West



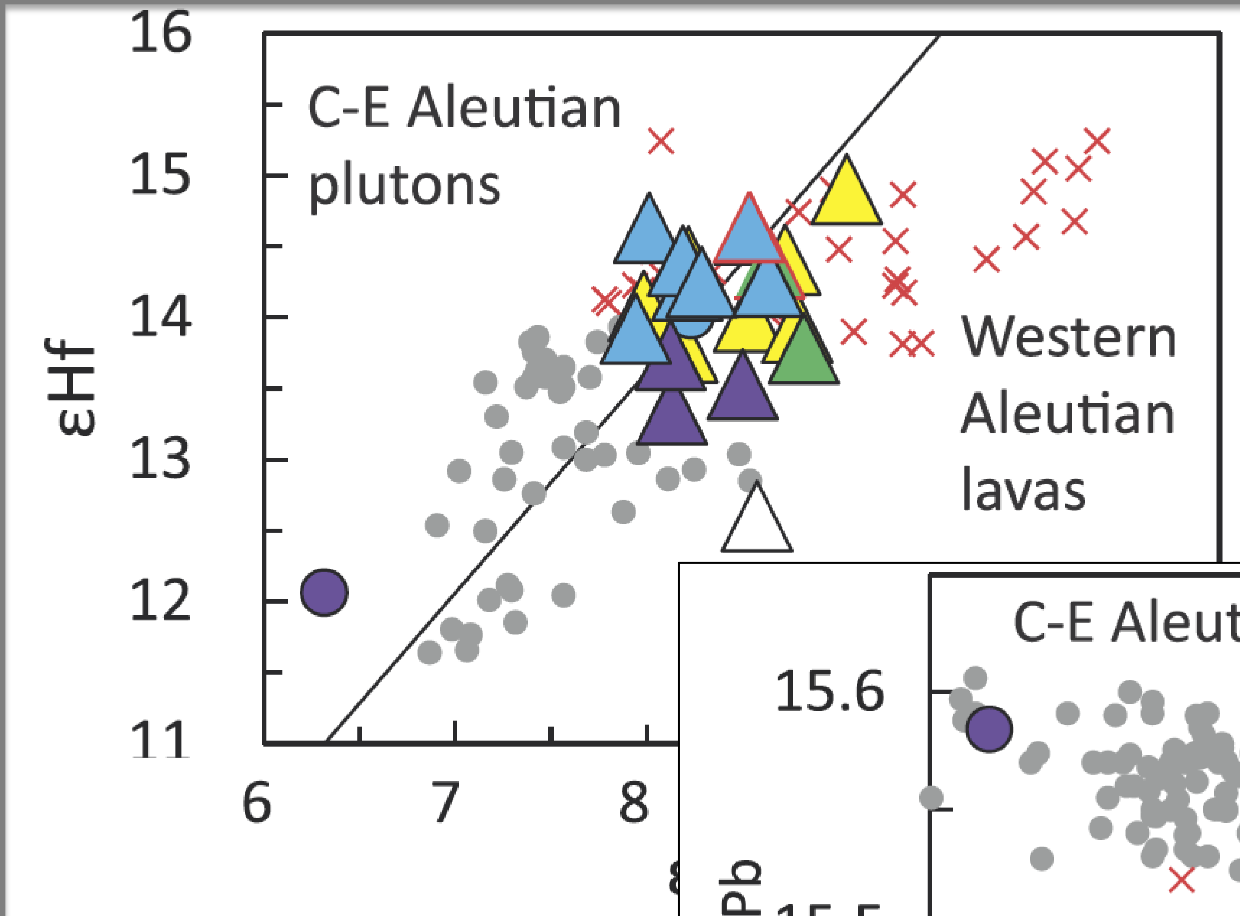
A)
B)
C)
D)
εNd
207Pb/204Pb
W. Aleut. lava
C-E Aleut. pluton
C-E Aleut. lava
30%
30%
11
10
9
8
7
6
15.6
15.5
15.4
195
185
175
165
Longitude West
<1Ma
5
15
25
35
45
Age



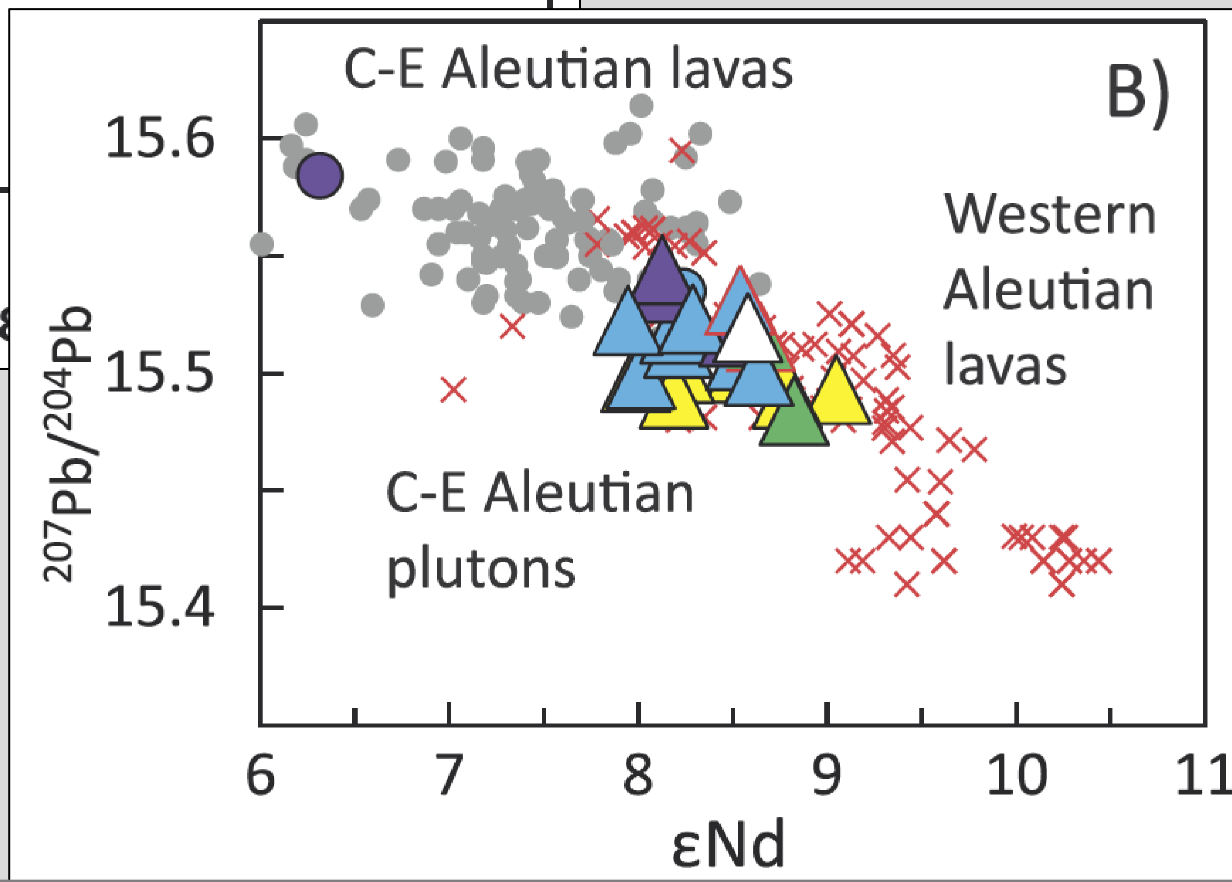
A)
εNd
W. Aleut. lava
C-E Aleut. pluton
C-E Aleut. lava
30%
11
10
9
8
7
6
C)
central
Aleutian lavas?
$^{207}Pb/^{204}Pb$
15.6
15.5
15.4
B)
central
Aleutian lavas?
D)
30%
195
185
175
165
Longitude West
<1Ma
5
15
25
35
45
Age



A)
εNd
W. Aleut. lava
C-E Aleut. pluton
C-E Aleut. lava
30%
11
10
9
8
7
6
C)
central Aleutian
lavas?
$^{207}Pb/^{204}Pb$
B)
15.6
15.5
15.4
D)
central Aleutian
lavas?
30%
195
185
175
165
Longitude West
<1Ma
5
15
25
35
45
Age



in any case, …



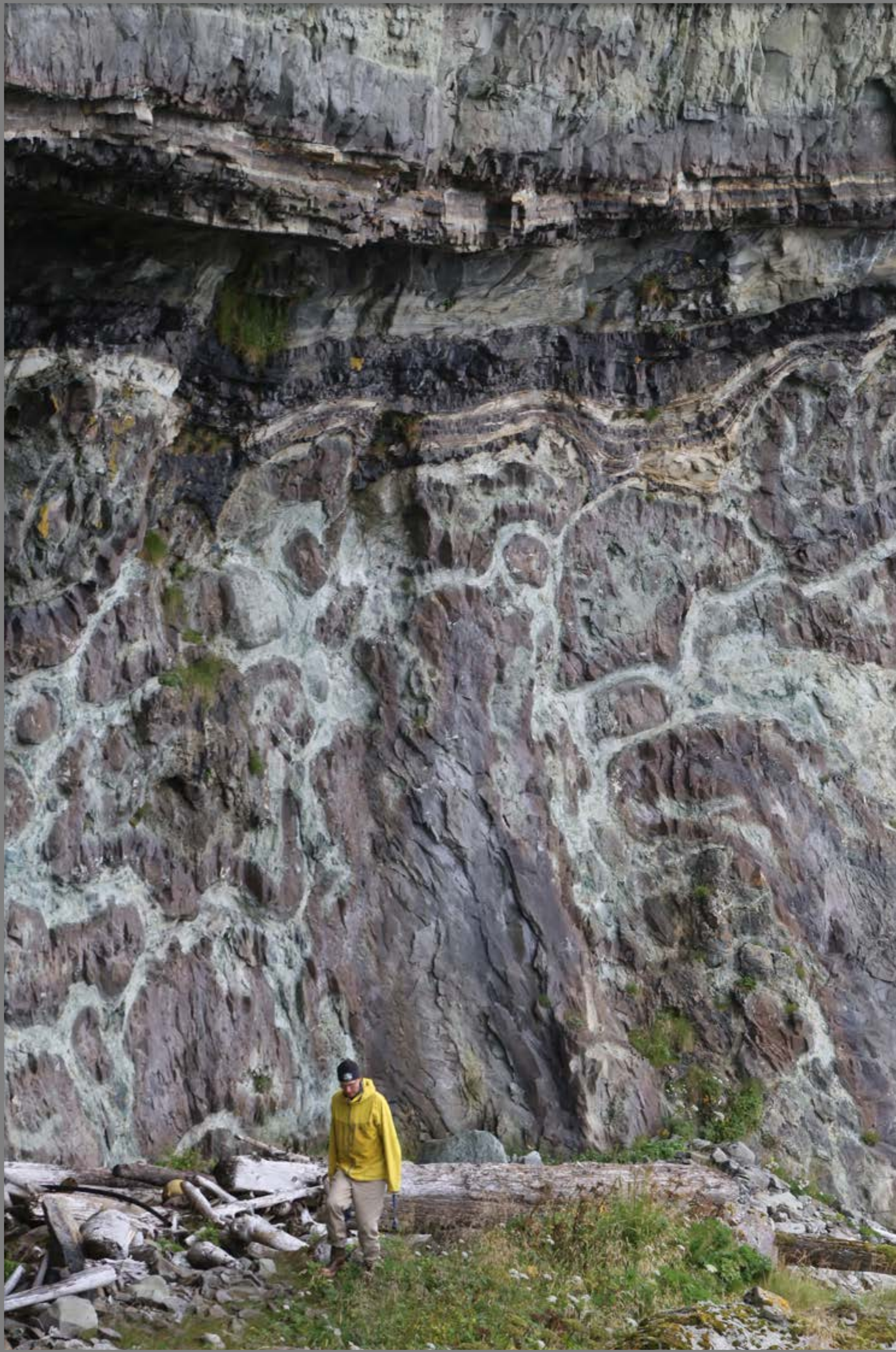
central Aleutian lavas & plutons are isotopically distinct

central Aleutian plutons have distinctly different sources from central Aleutian lavas

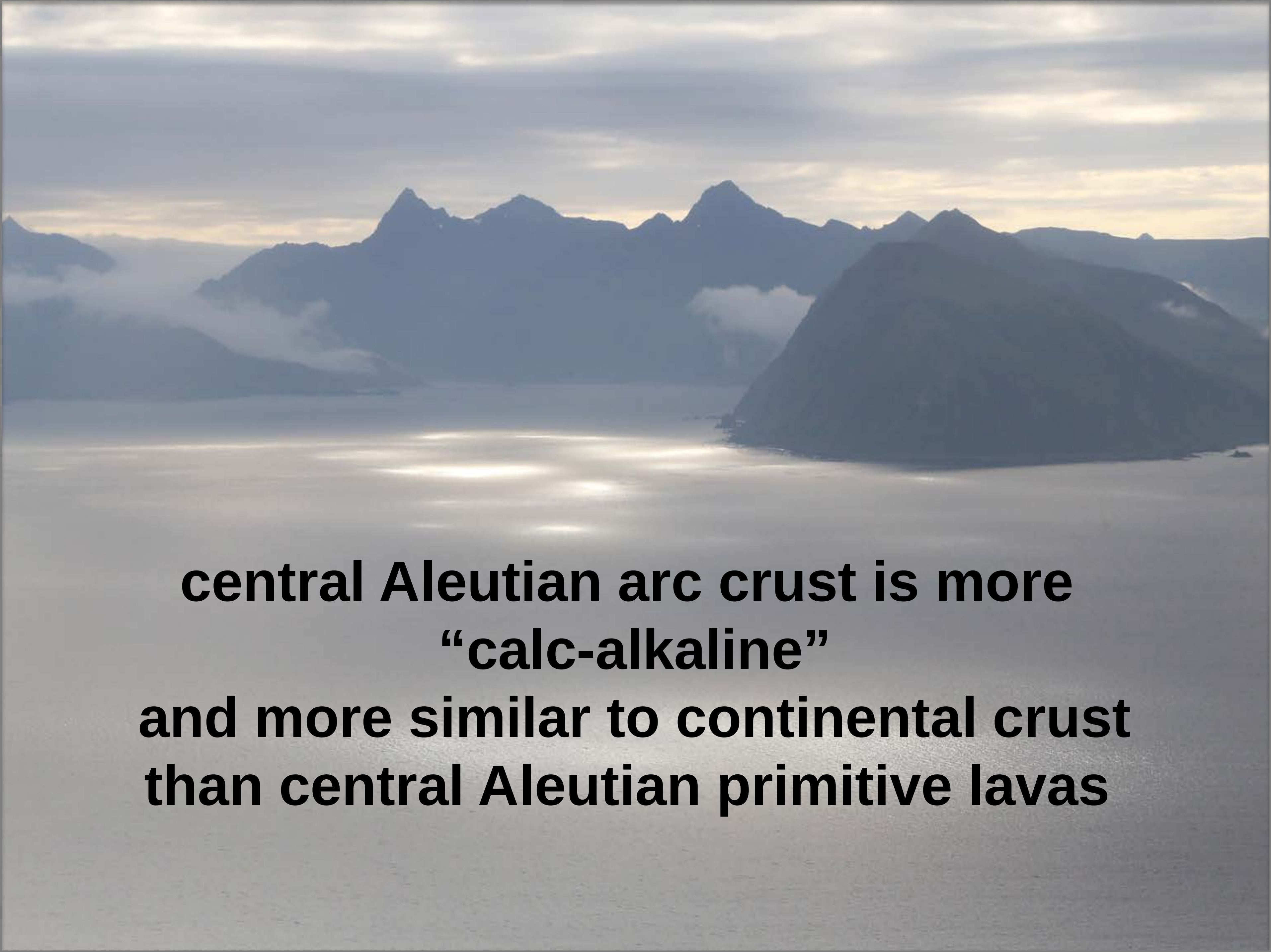
primitive Holocene Aleutian lavas are not representative of bulk arc crust

either the source of central Aleutian magmas changed rapidly after 9 Ma,
or there have been two distinct types of magma source throughout Aleutian history

if there have been two different sources throughout Aleutian history:
wetter, more SiO_2-rich magmas may stall when they degas in the mid-crust



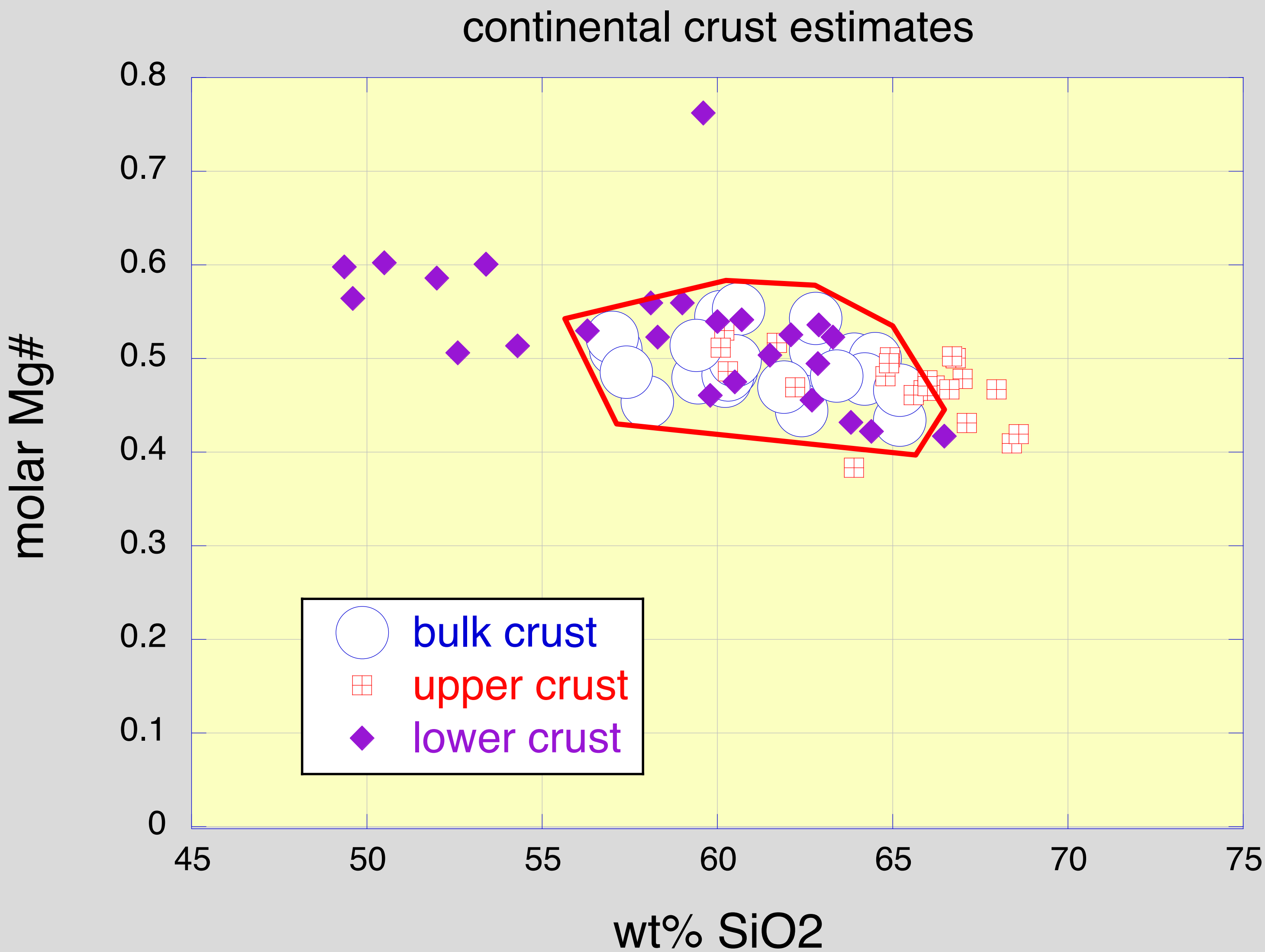

central Aleutian plutons have distinctly different sources from central Aleutian lavas


central Aleutian arc crust is more
“calc-alkaline”
and more similar to continental crust
than central Aleutian primitive lavas

relamination not delamination: continental lower crust forms from arc upper crust

Peter Kelemen & Mark Behn
review article accepted for Nature Geoscience

(also check out Hacker, Kelemen & Behn, Ann. Rev. Earth Planet. Sci. 2015)



Kelemen & Behn 2015, Nature Geoscience
compilations: Kelemen 1995; Rudnick & Gao 2003; Hacker et al. 2015

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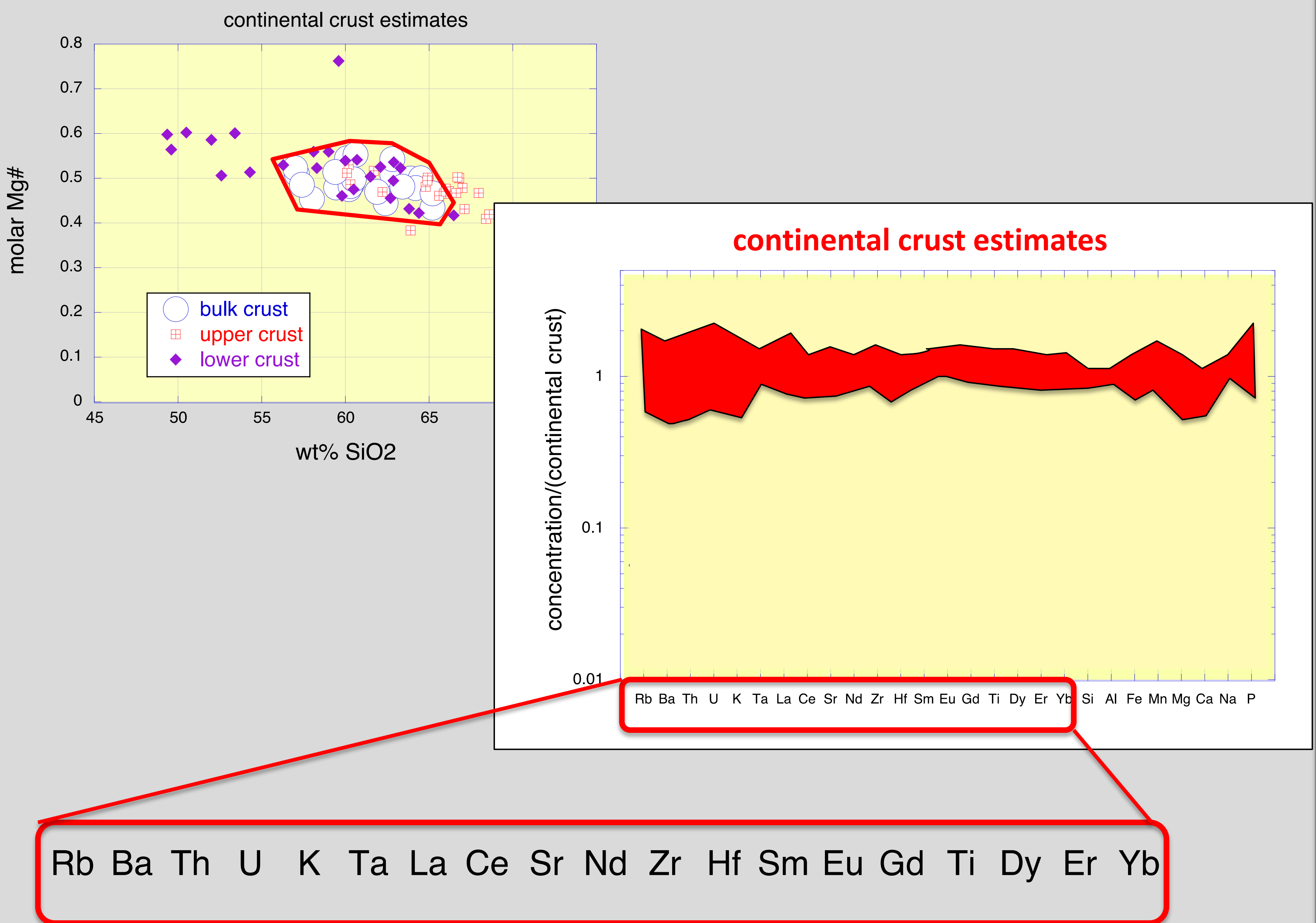
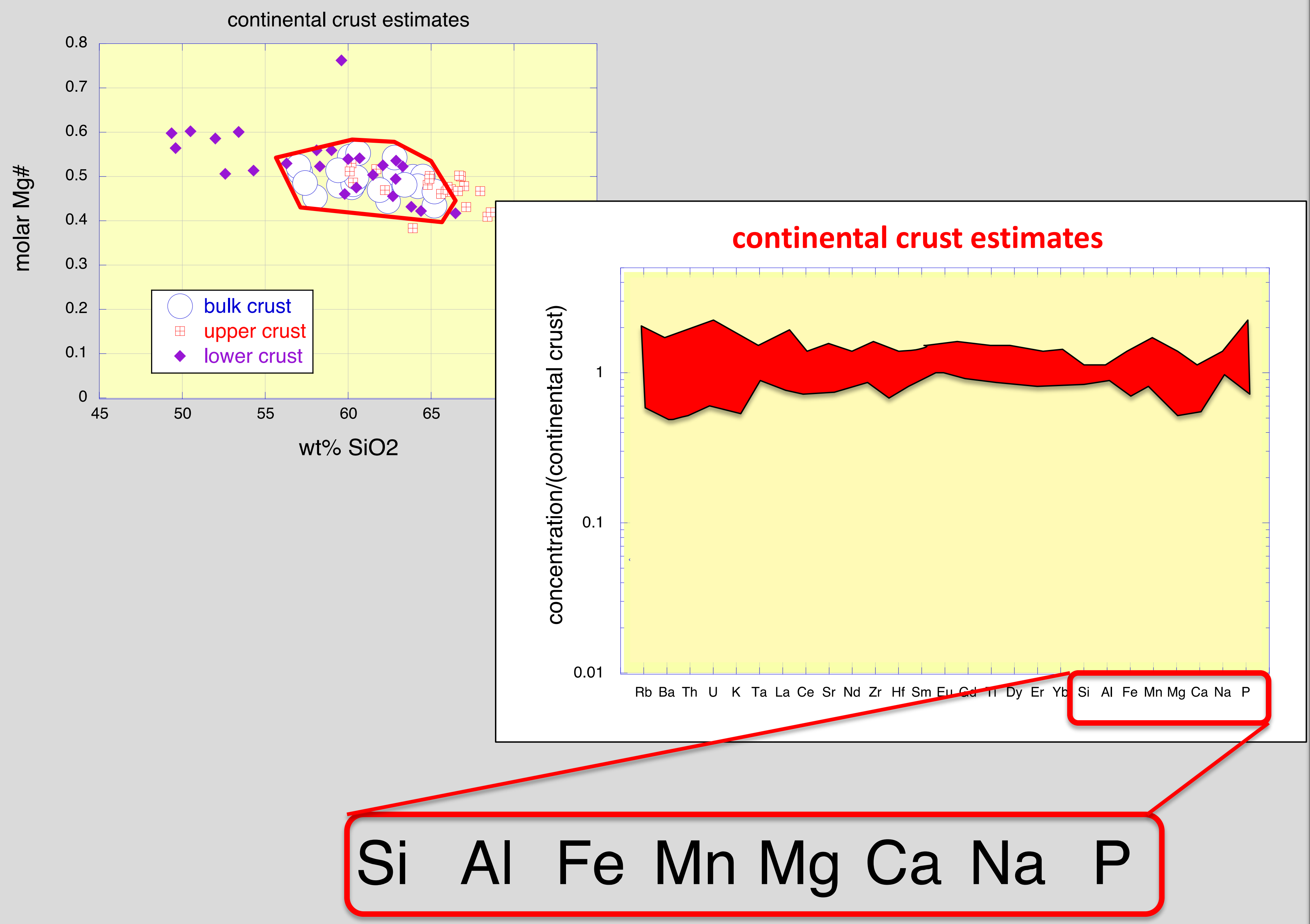
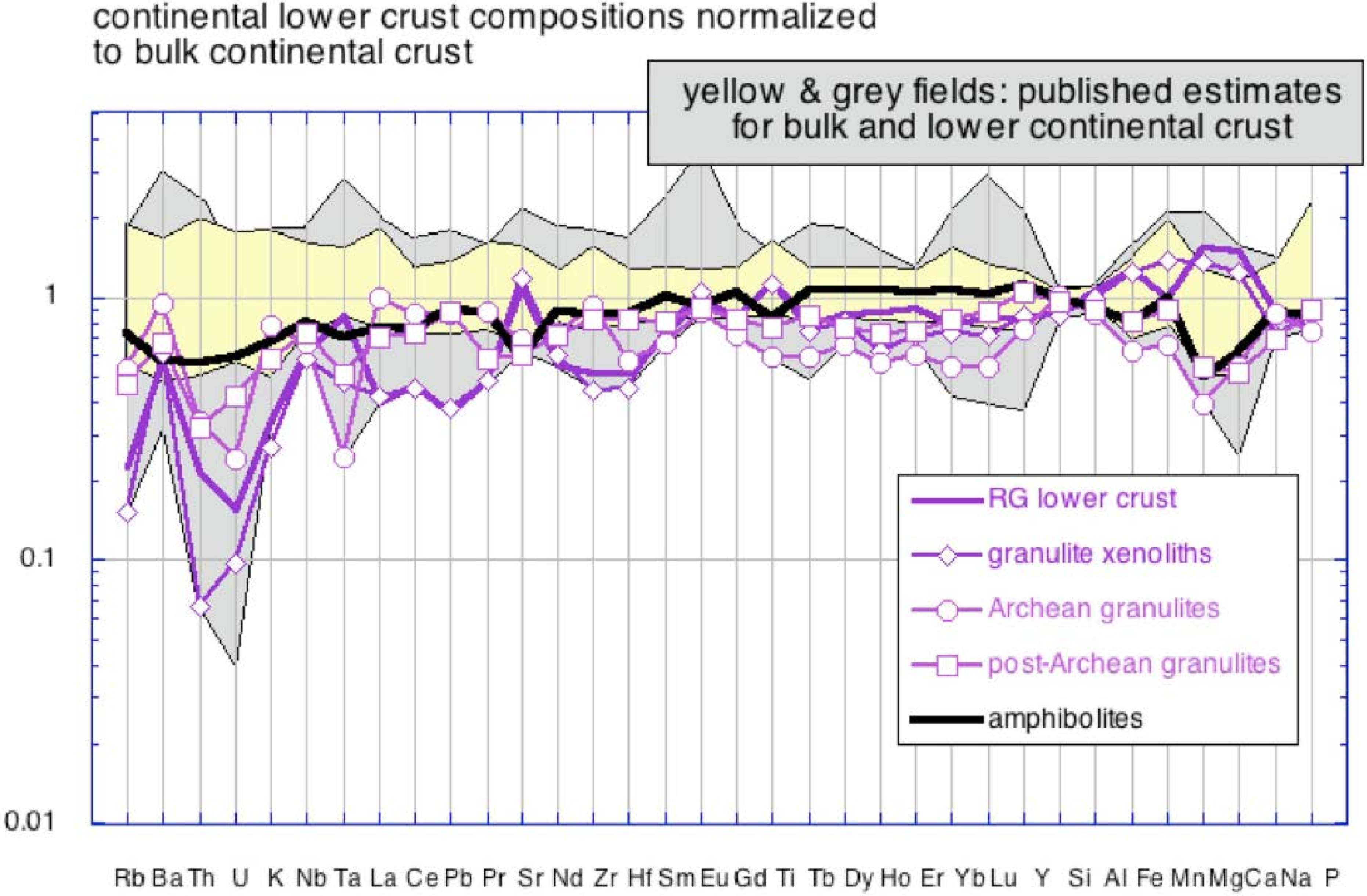


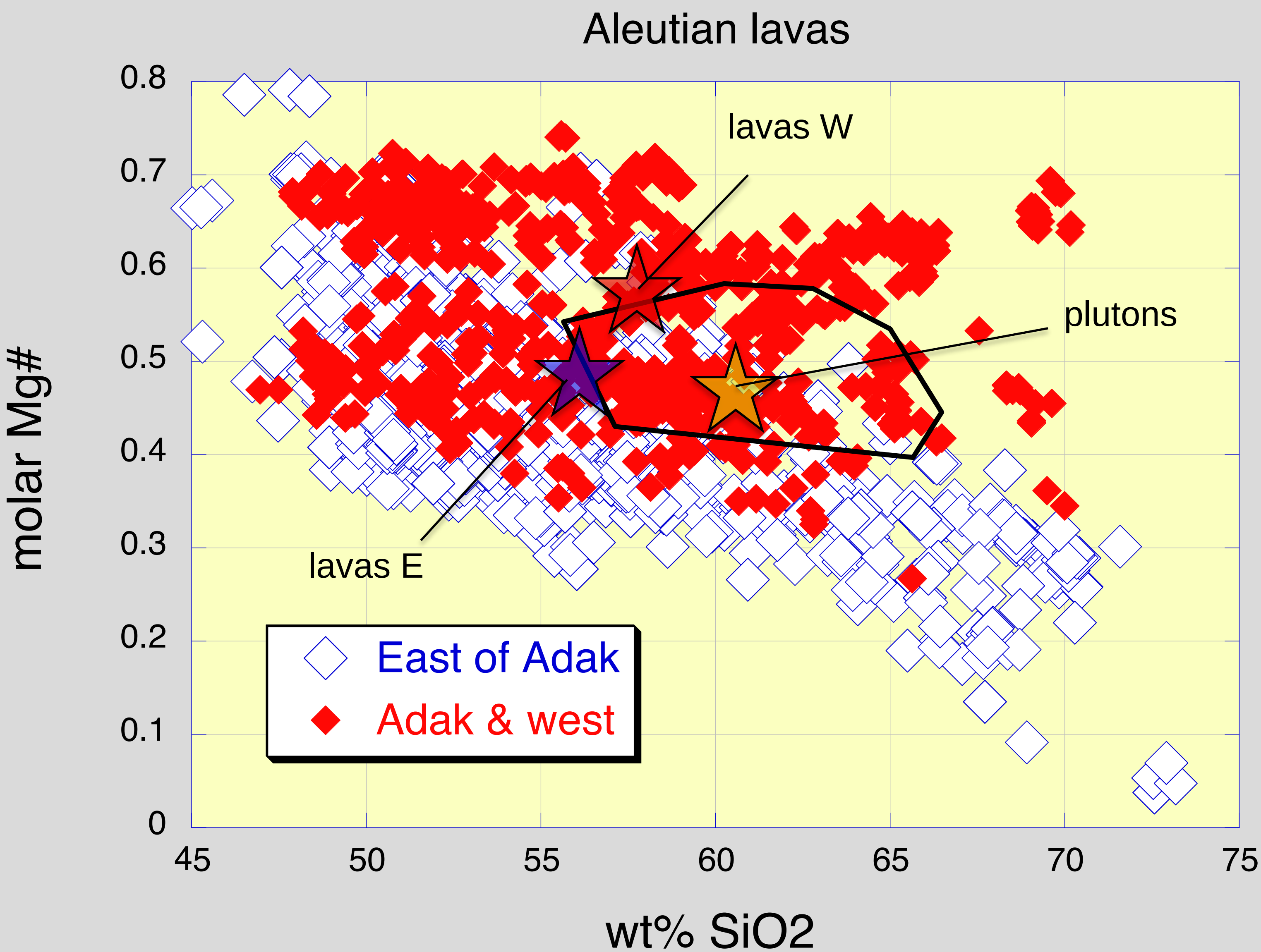
continental crust estimates
molar Mg#
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
45
50
55
60
65
wt% SiO2
bulk crust
upper crust
lower crust
continental crust estimates
concentration/(continental crust)
1
0.1
0.01
Rb Ba Th U K Ta La Ce Sr Nd Zr Hf Sm Eu Gd Ti Dy Er Yb Si Al Fe Mn Mg Ca Na P
Rb Ba Th U K Ta La Ce Sr Nd Zr Hf Sm Eu Gd Ti Dy Er Yb


continental crust estimates
molar Mg#
wt% SiO2
bulk crust
upper crust
lower crust
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
45
50
55
60
65
continental crust estimates
concentration/(continental crust)
1
0.1
0.01
Rb Ba Th U K Ta La Ce Sr Nd Zr Hf Sm Eu Gd Ti Dy Er Yb Si Al Fe Mn Mg Ca Na P
Si Al Fe Mn Mg Ca Na P

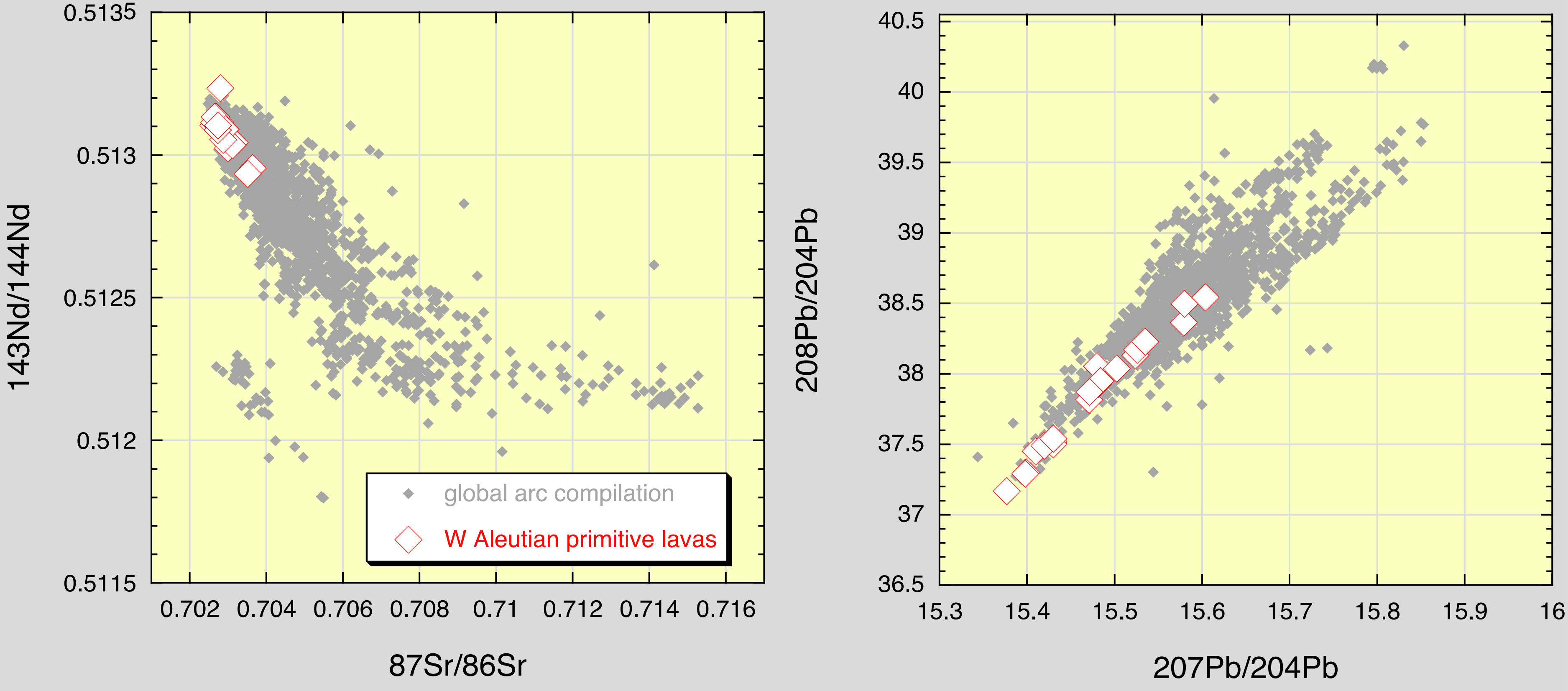


Kelemen & Behn 2015, Nature Geoscience

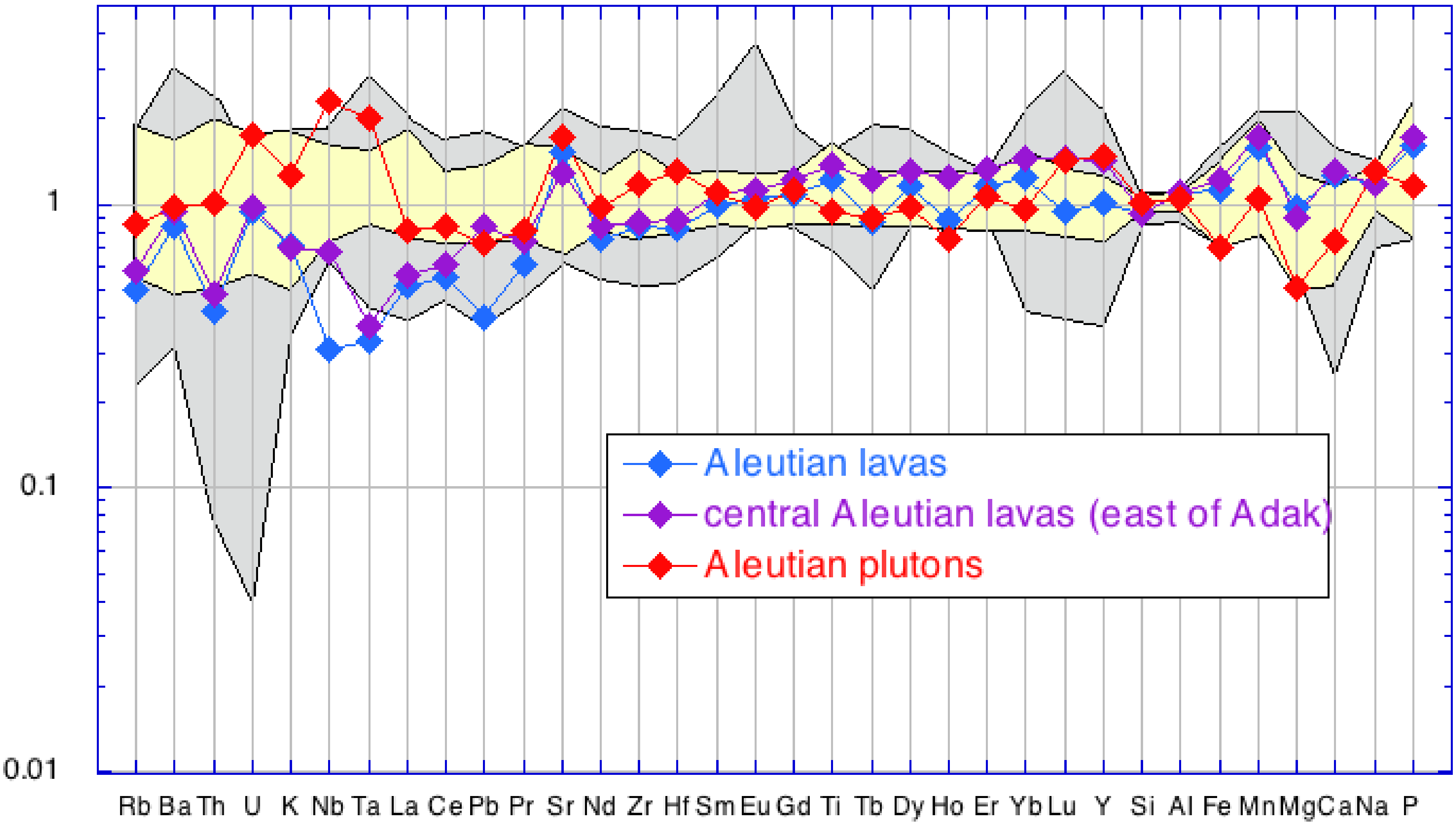
compilations: Rudnick & co-workers 1990-2014; Huang et al. 2013; Hacker et al. 2015



Kelemen & Behn 2015, Nature Geoscience
compilations: Kelemen et al. 2003 AGU Ch11, Singer et al. 2007, Yogodzinski et al. 2015



Kelemen & Behn 2015, Nature Geoscience
Data compilation: Kelemen et al. ToG 2003, 2014



Kelemen & Behn 2015, Nature Geoscience;
compilations: Kelemen et al. 2003 AGU Ch11, Singer et al. 2007,
Yogodzinski et al. 2015

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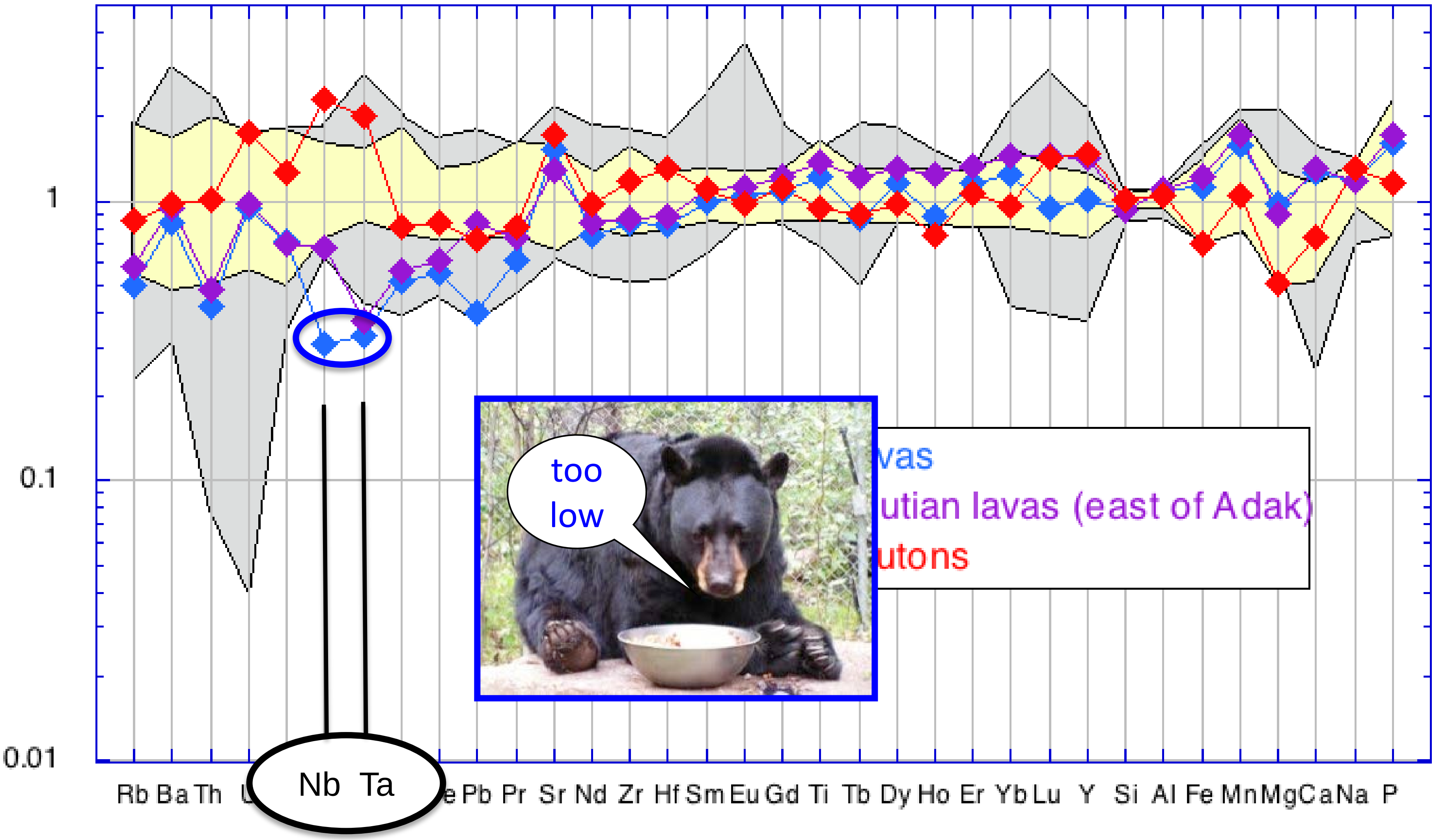
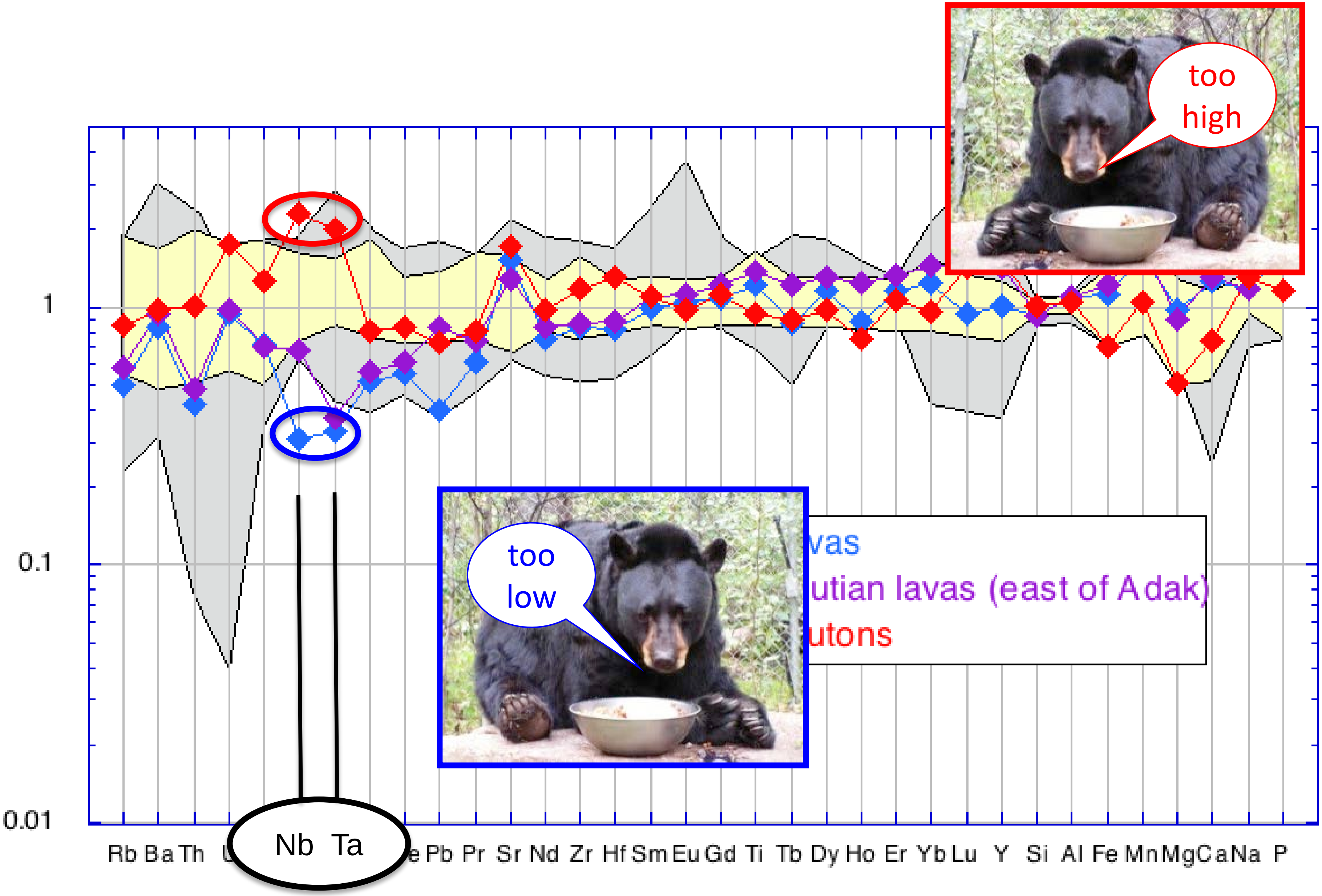
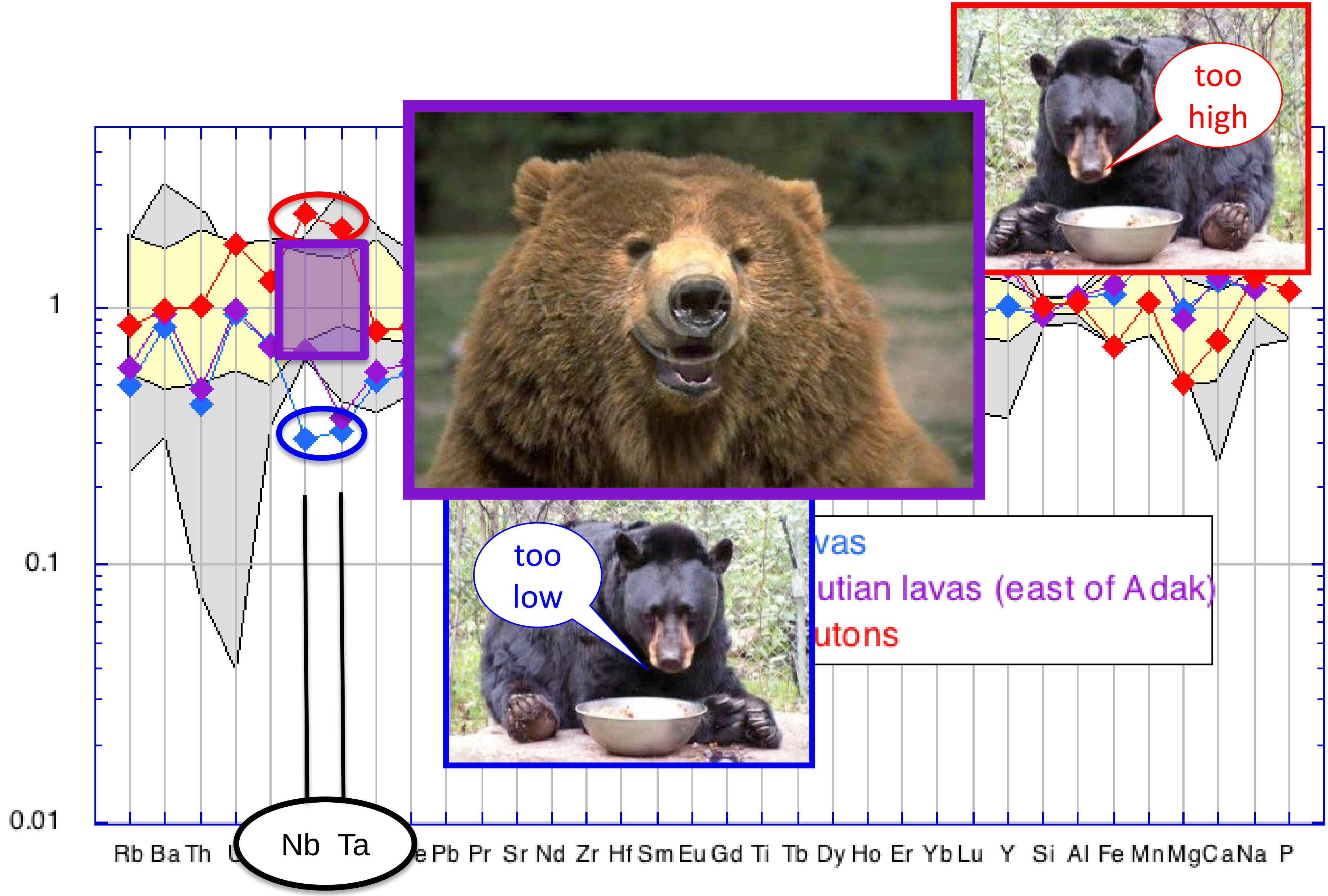
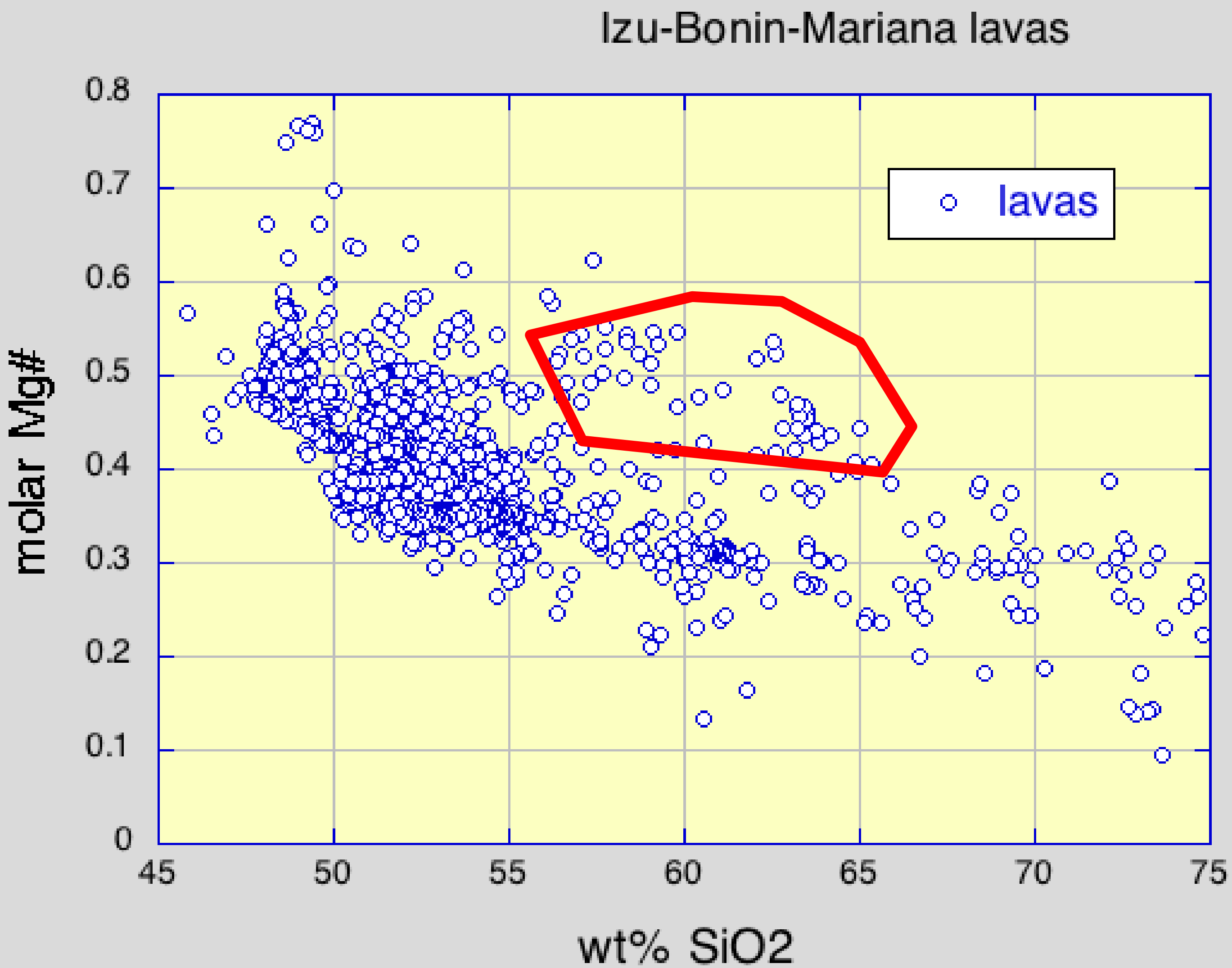
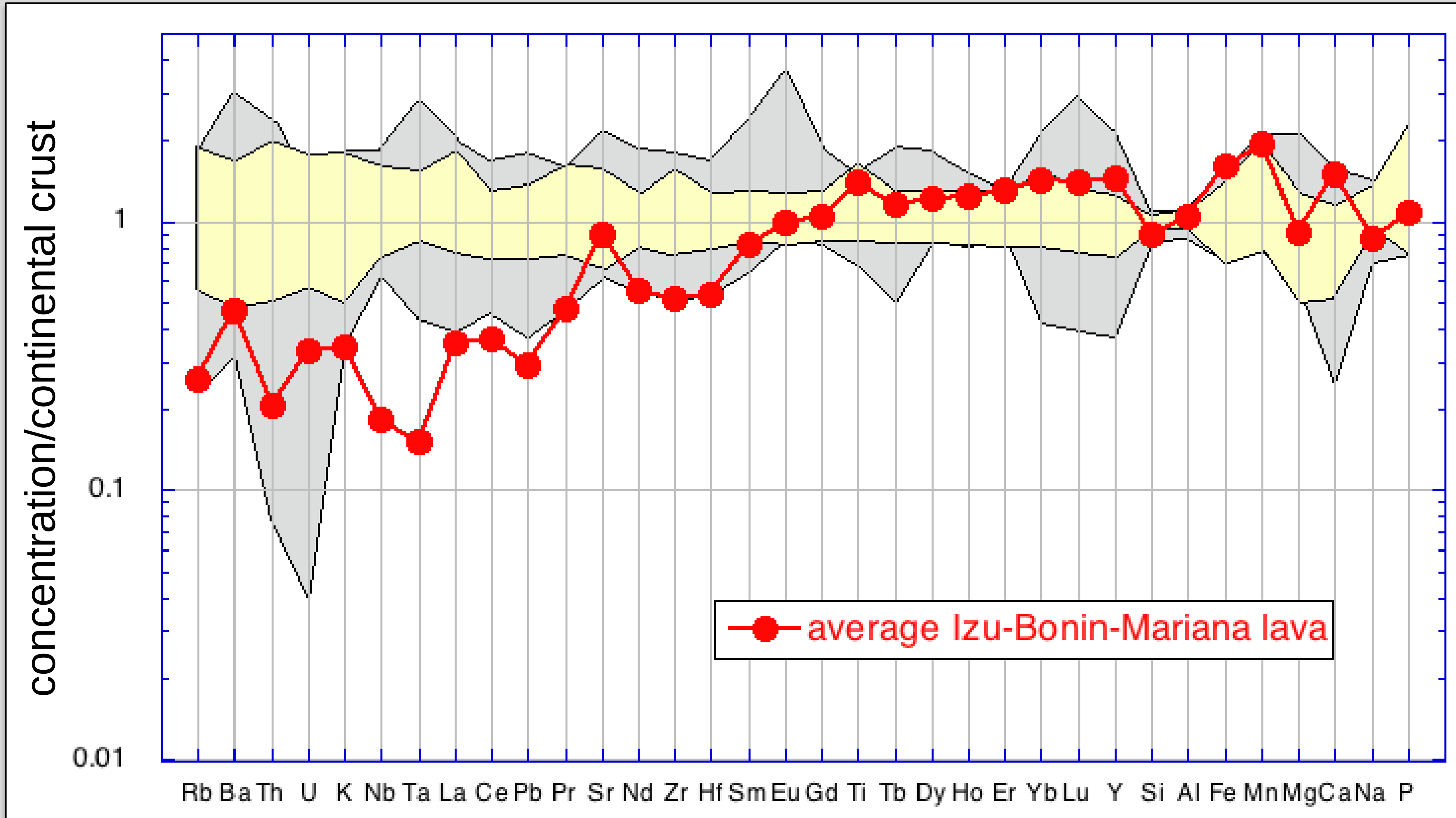

1
0.1
0.01
Rb Ba Th U Nb Ta e Pb Pr Sr Nd Zr Hf Sm Eu Gd Ti Tb Dy Ho Er Yb Lu Y Si Al Fe Mn Mg Ca Na P
vas
utian lavas (east of Adak)
utons
too low
Nb Ta


too high
too low
1
0.1
0.01
Nb Ta
Rb Ba Th U
e Pb Pr Sr Nd Zr Hf Sm Eu Gd Ti Tb Dy Ho Er Yb Lu Y Si Al Fe Mn Mg Ca Na P
vas
utian lavas (east of Adak)
utons

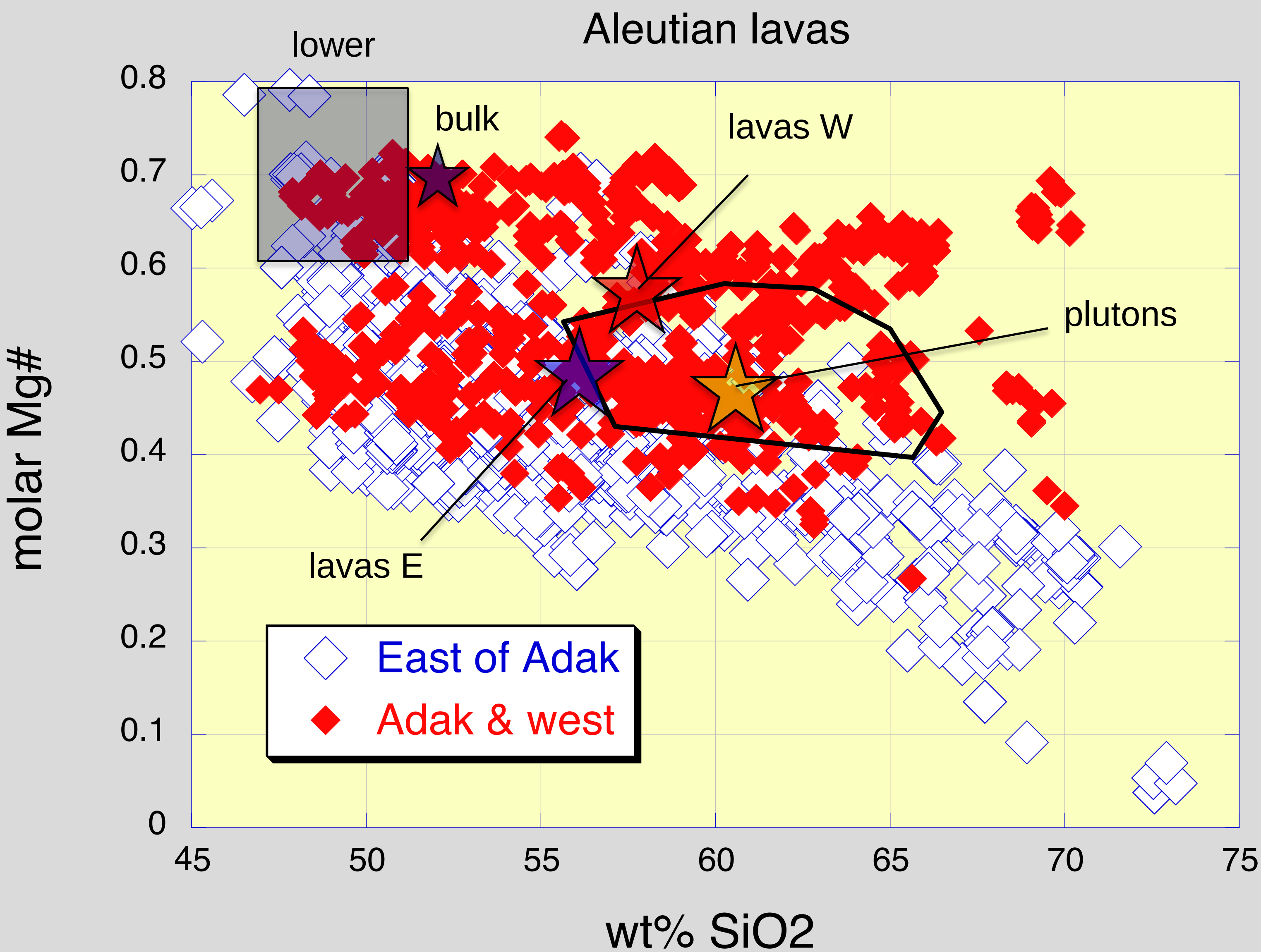

too
high
1
0.1
0.01
too
low
vas
utian lavas (east of Adak)
utons
Rb Ba Th U
Nb Ta
e Pb Pr Sr Nd Zr Hf Sm Eu Gd Ti Tb Dy Ho Er Yb Lu Y Si Al Fe Mn Mg Ca Na P



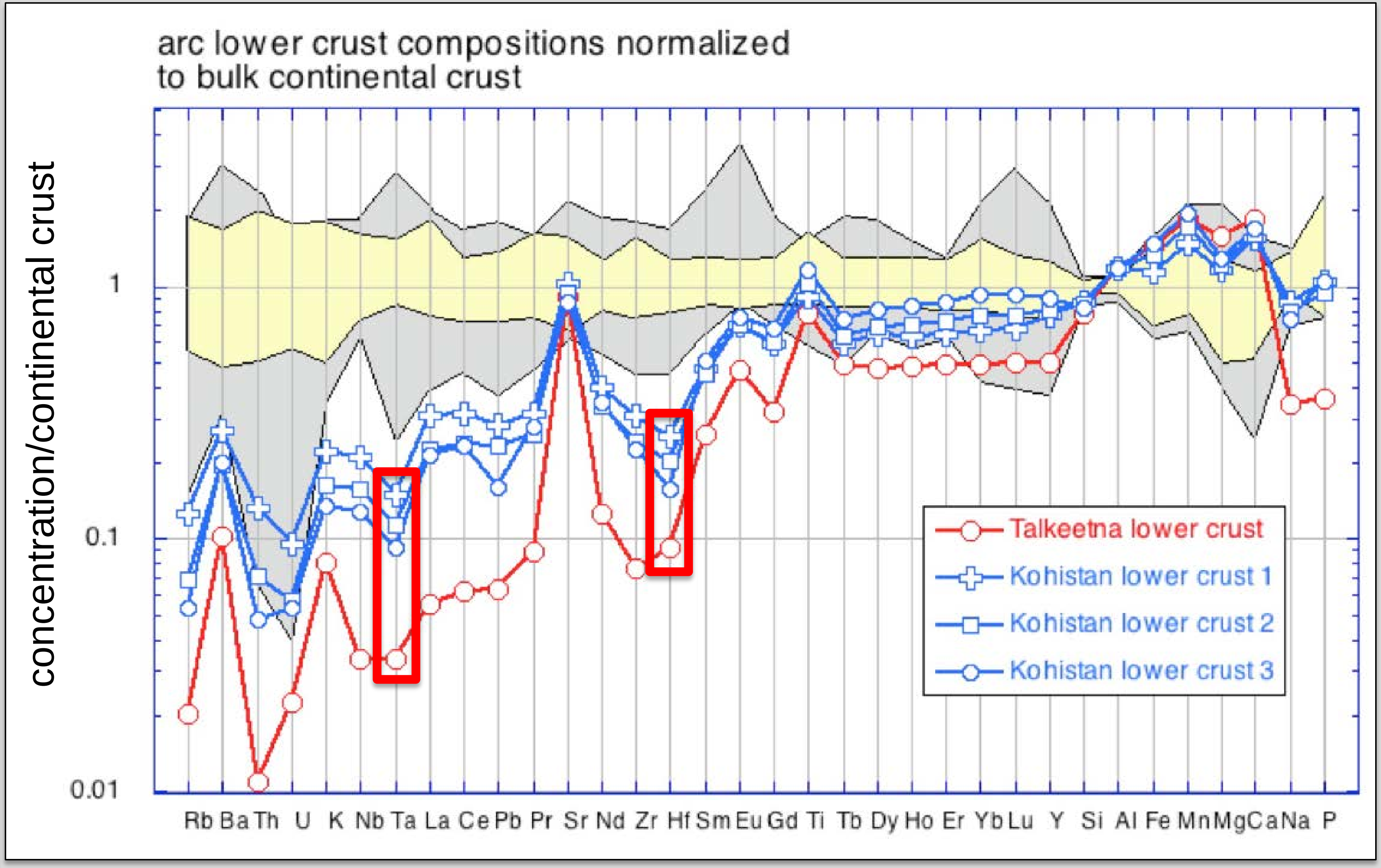
Kelemen & Behn 2015, Nature Geoscience
compilation: Jordan et al. CentAm & IBM Geochem Database v. 1.02



Kelemen & Behn 2015, Nature Geoscience
compilation Jordan et al., CentAm & IBM Geochem Database, 2012



Kelemen & Behn 2015, Nature Geoscience
compilations: Kelemen et al. 2003 AGU Ch11, Singer et al. 2007, Yogodzinski et al. 2015



Kelemen & Behn 2015, Nature Geoscience
compilations: Kelemen et al. ToG 2003, 2014;
Jagoutz & Schmidt Chem Geol 2012; Jagoutz EPSL 2014

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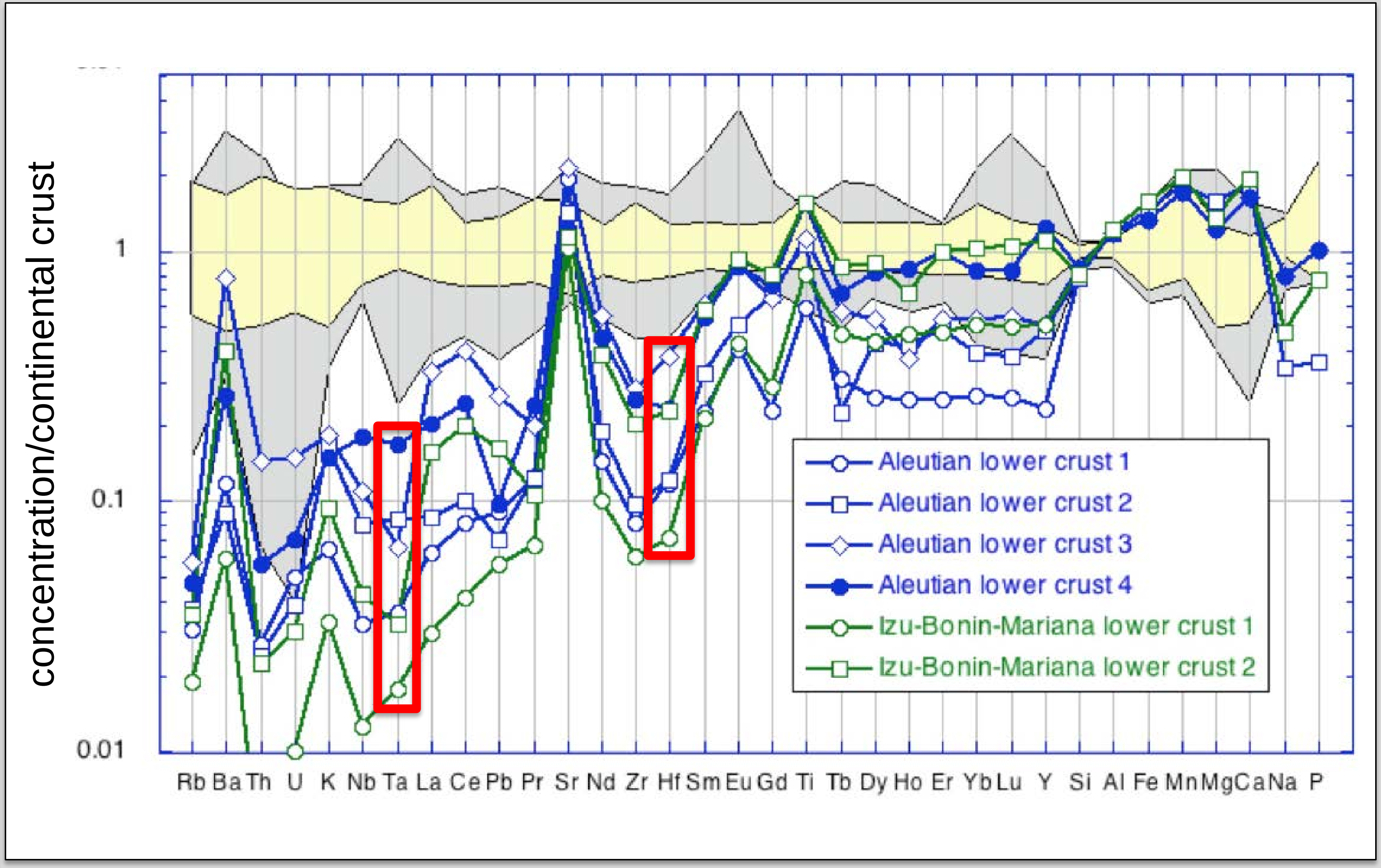
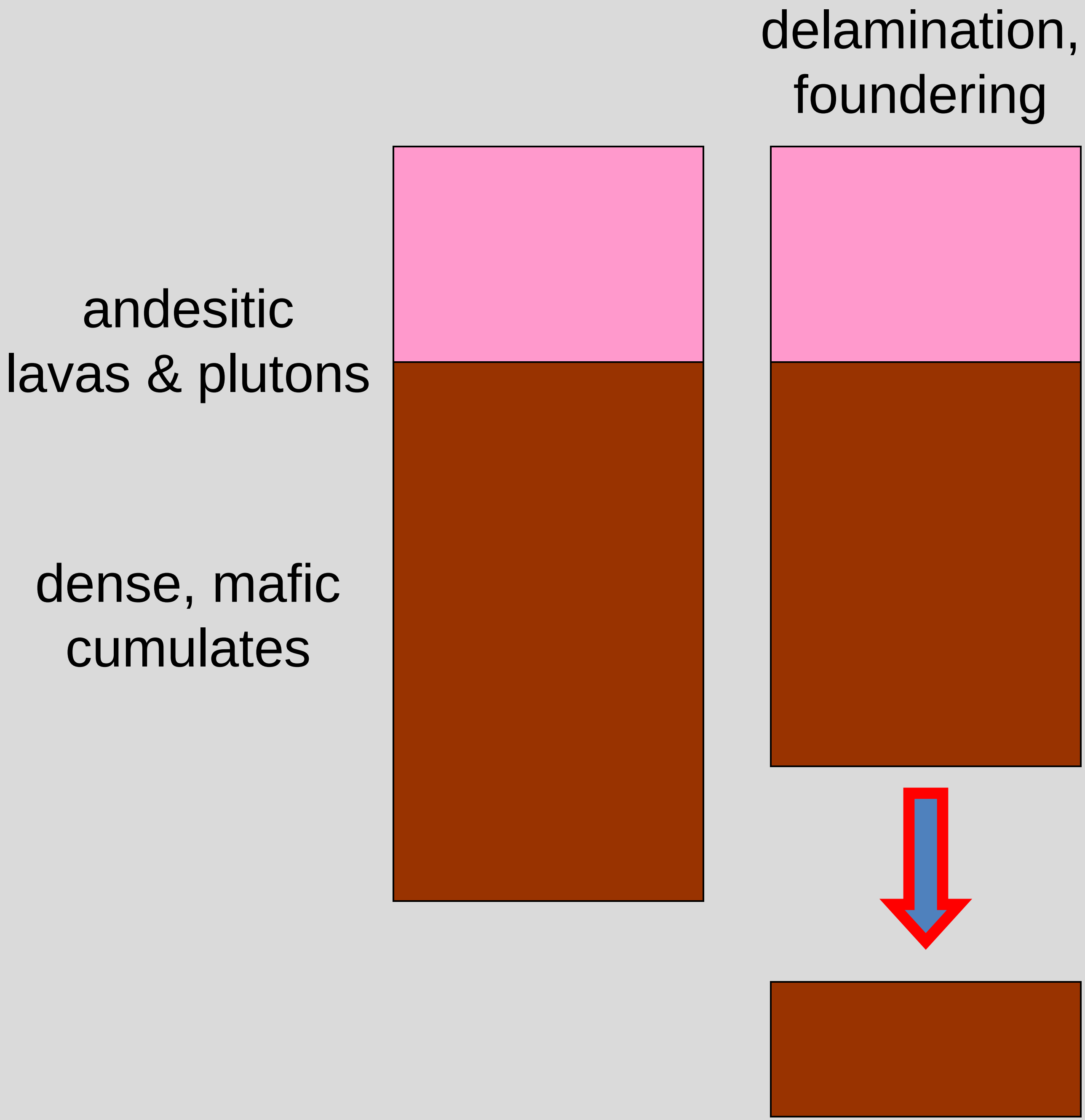
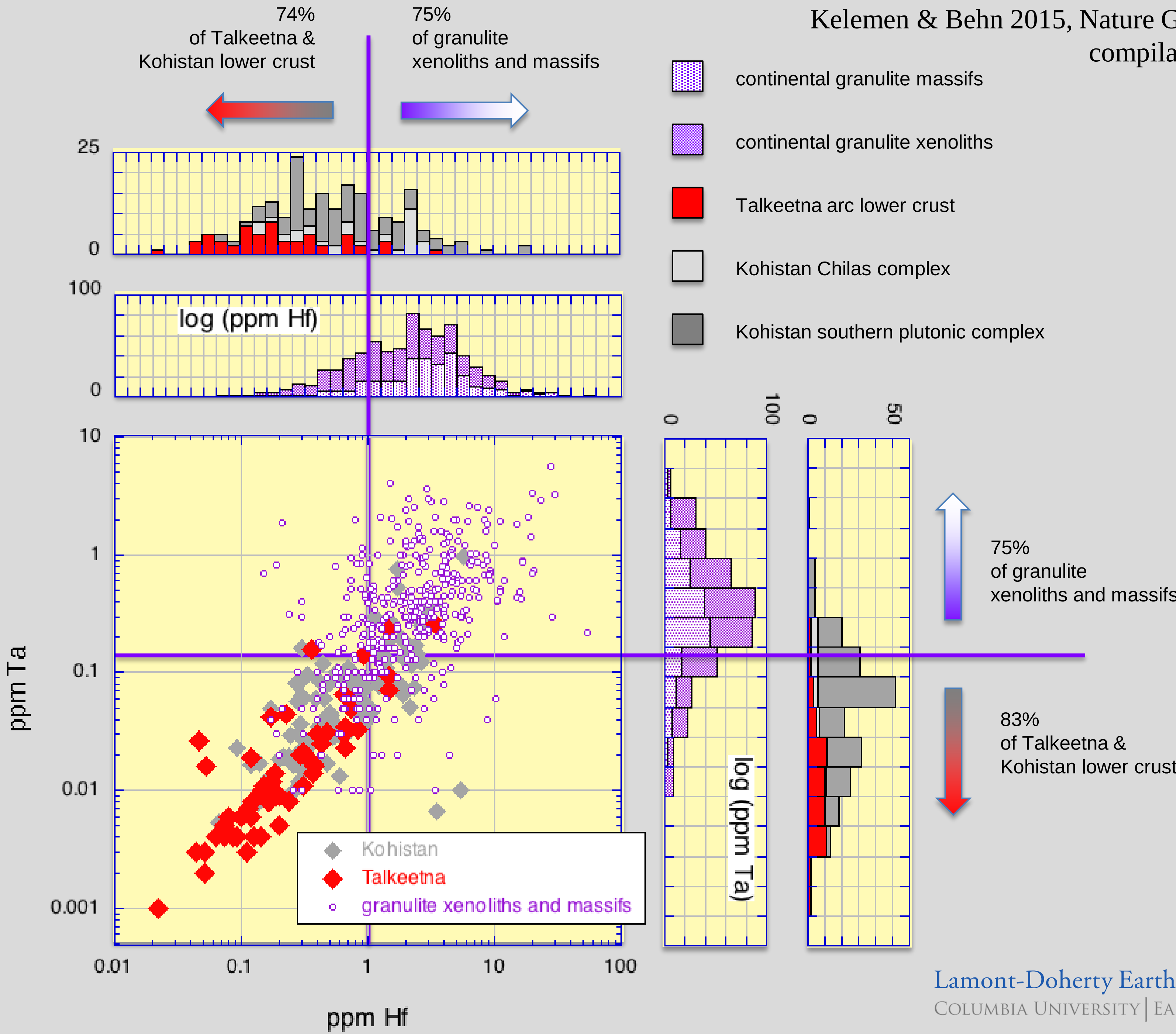


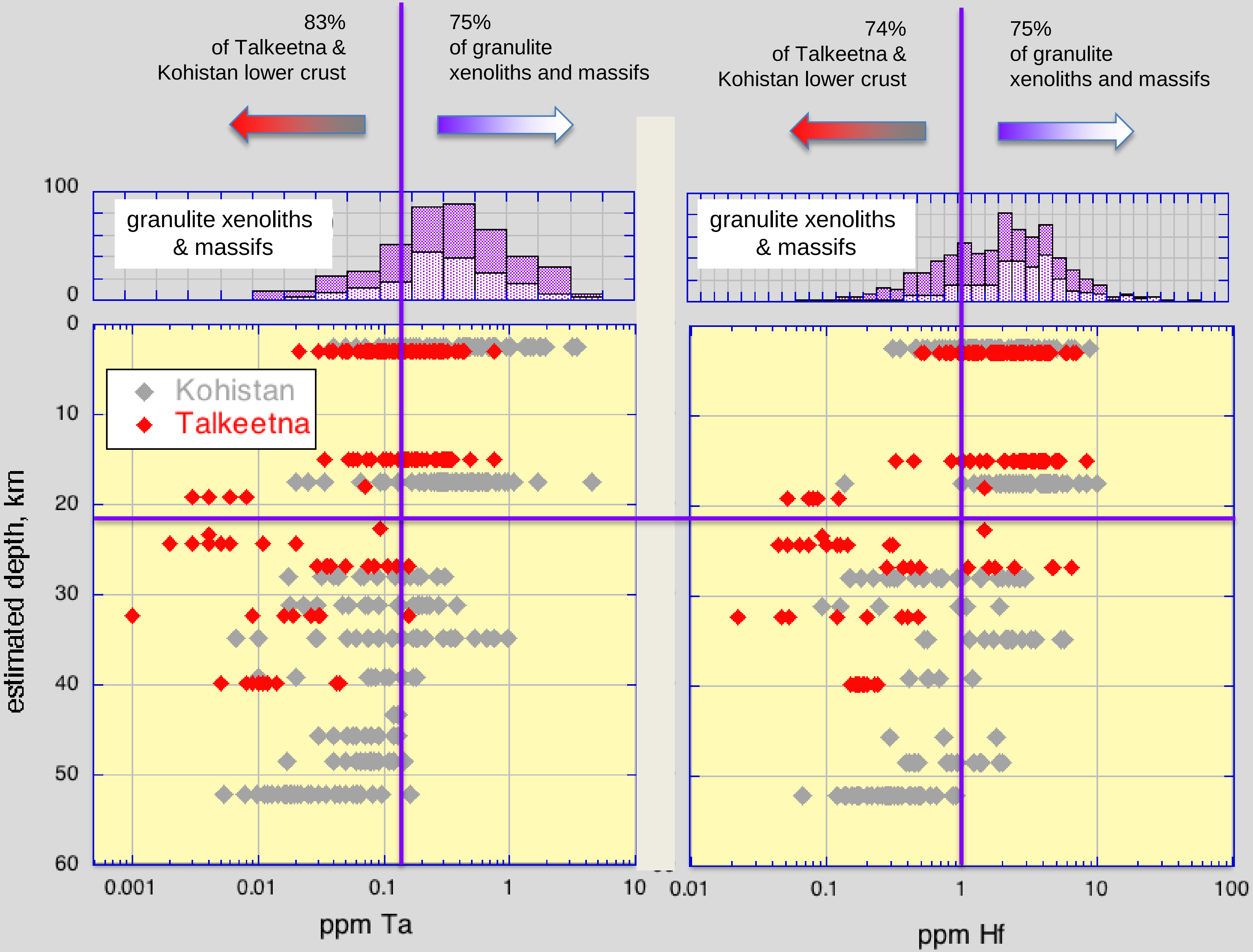
Kelemen & Behn 2015, Nature Geoscience
calculated using arc data x lava/(lower crust)
& pluton(lower crust) fr Talkeetna & Kohistan



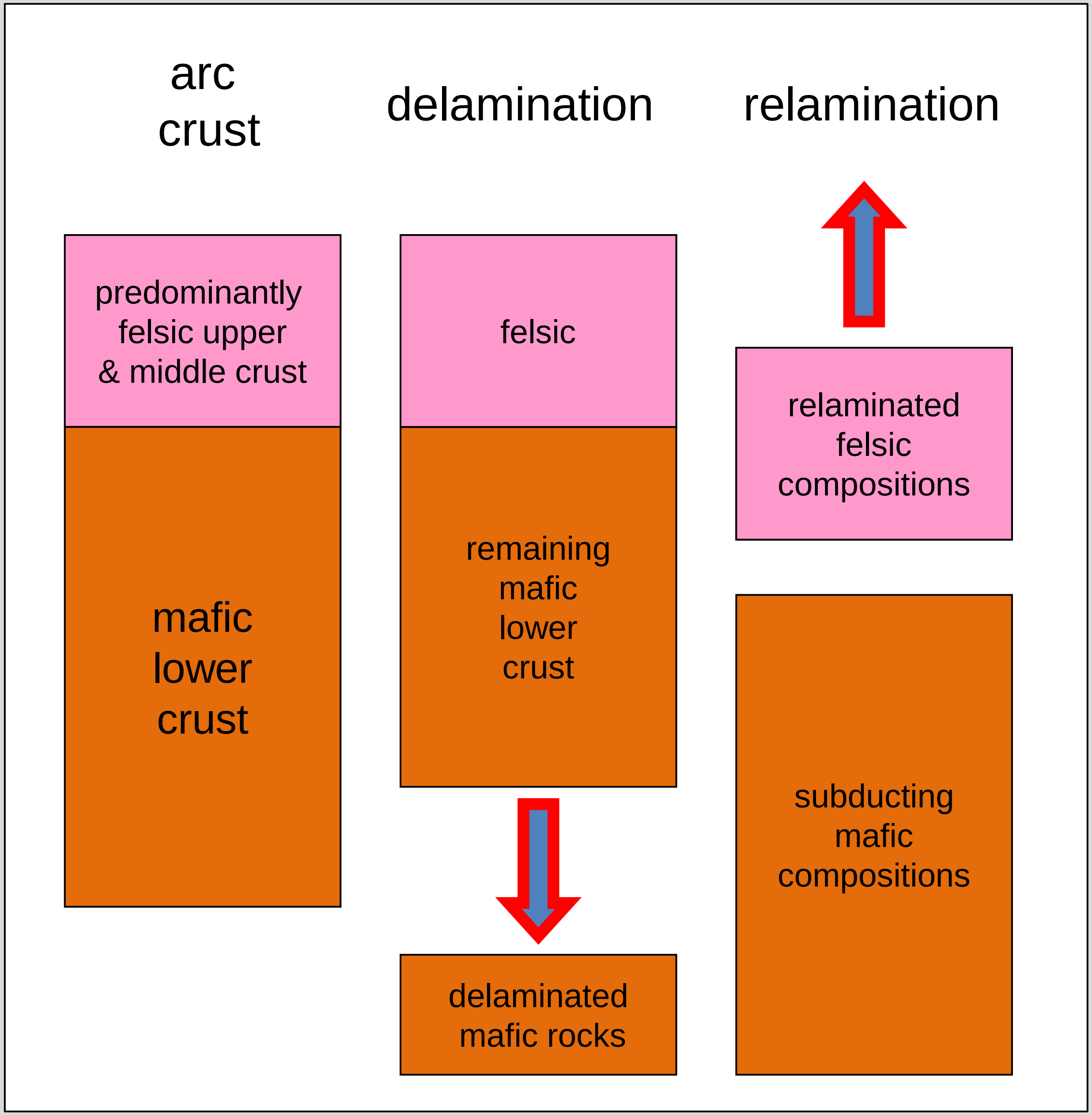
Ringwood & Green, 1966; Herzberg et al 1983; Kay et al. 1985; Kay & Kay 1990, 1991; Ducea & Saleeby 1996; Jull & Kelemen 2001

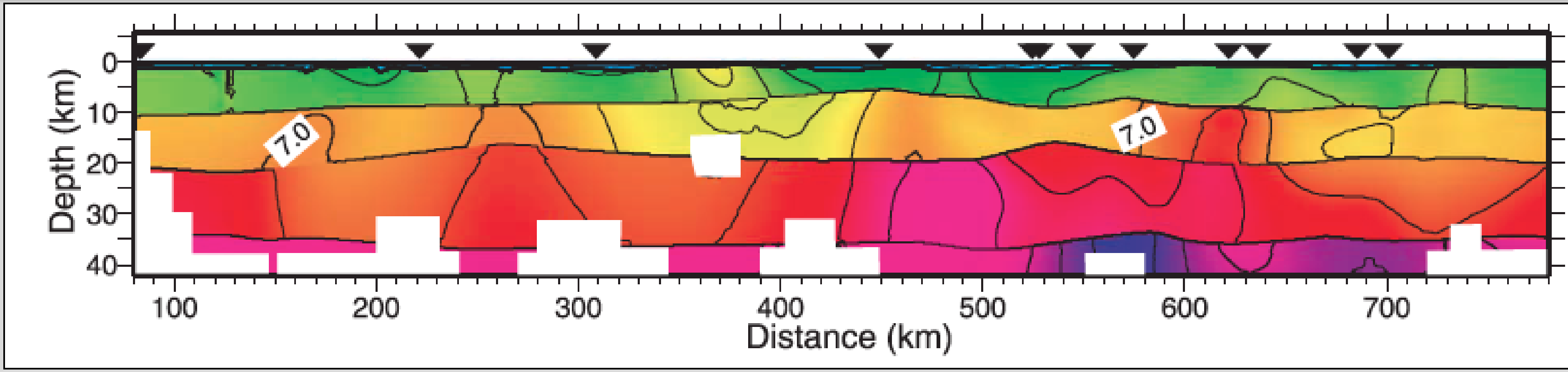
Kelemen & Behn 2015, Nature Geoscience; compilations as in previous slides



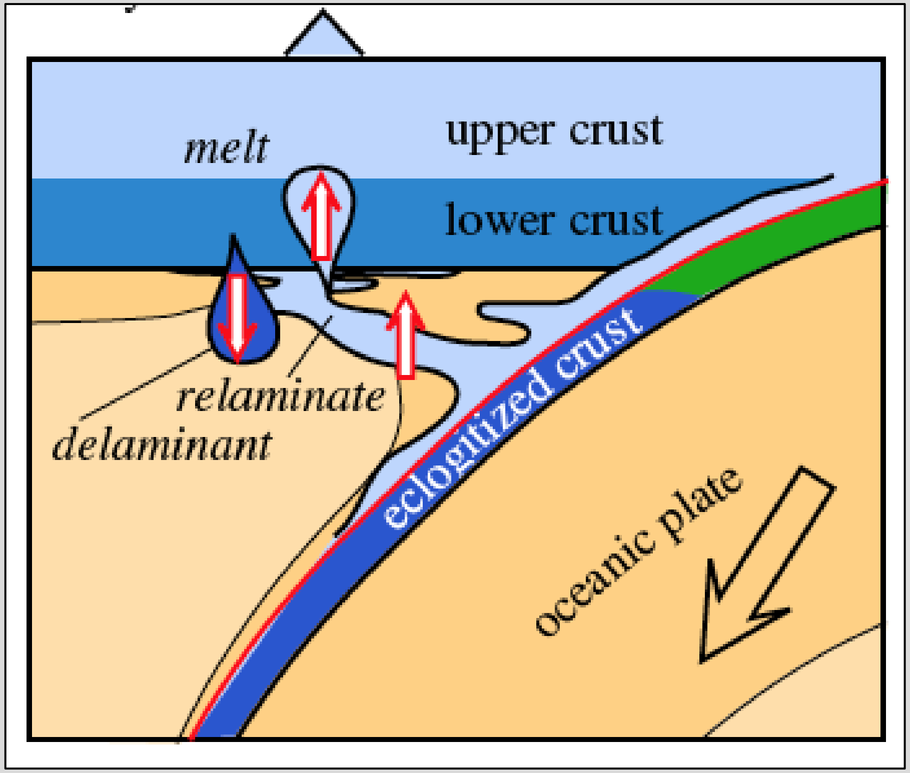


Kelemen & Behn 2015, Nature Geoscience
compilations as in previous slides

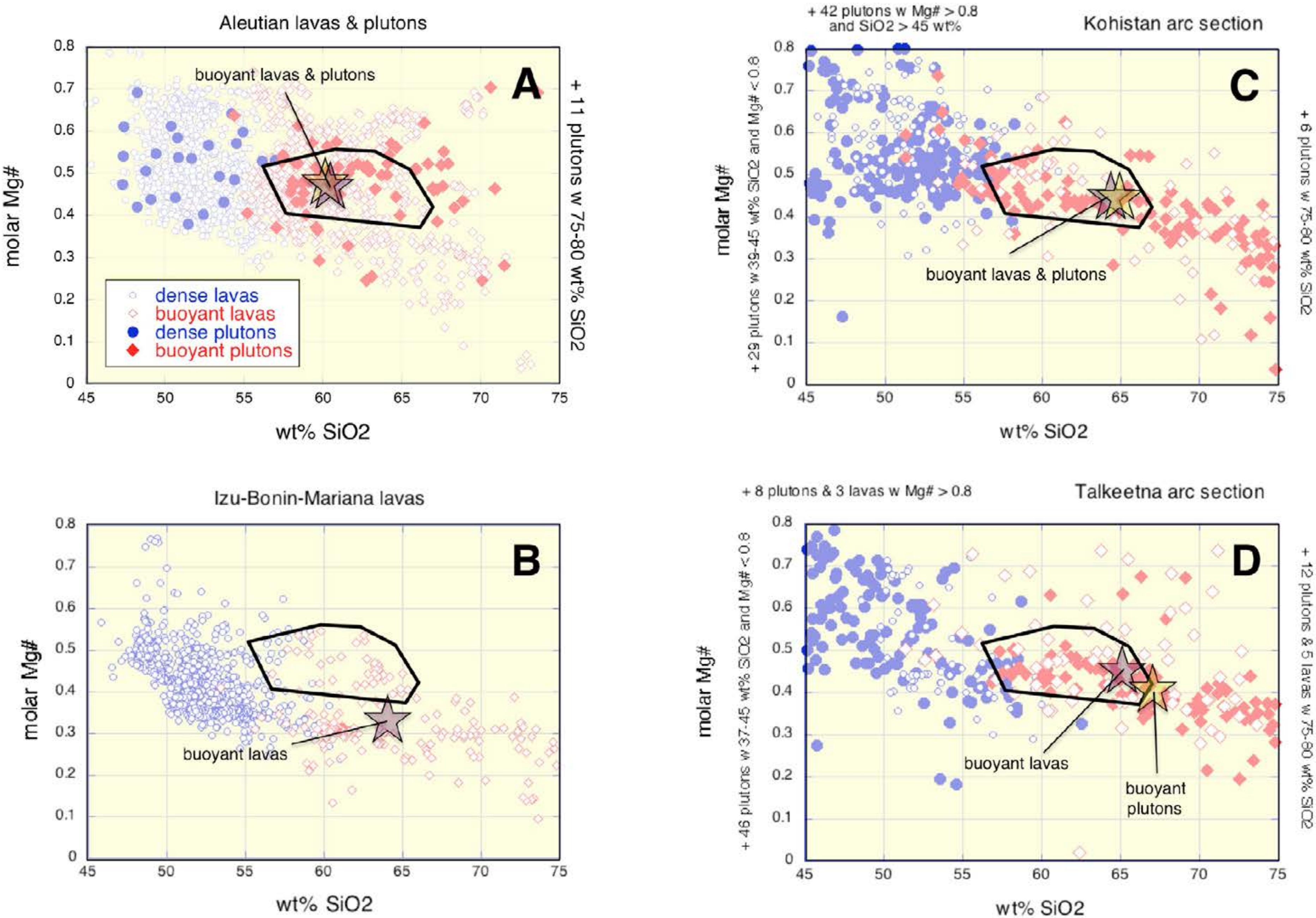

arc
crust
delamination
relamination
predominantly
felsic upper
& middle crust
mafic
lower
crust
felsic
remaining
mafic
lower
crust
delaminated
mafic rocks
relaminated
felsic
compositions
subducting
mafic
compositions



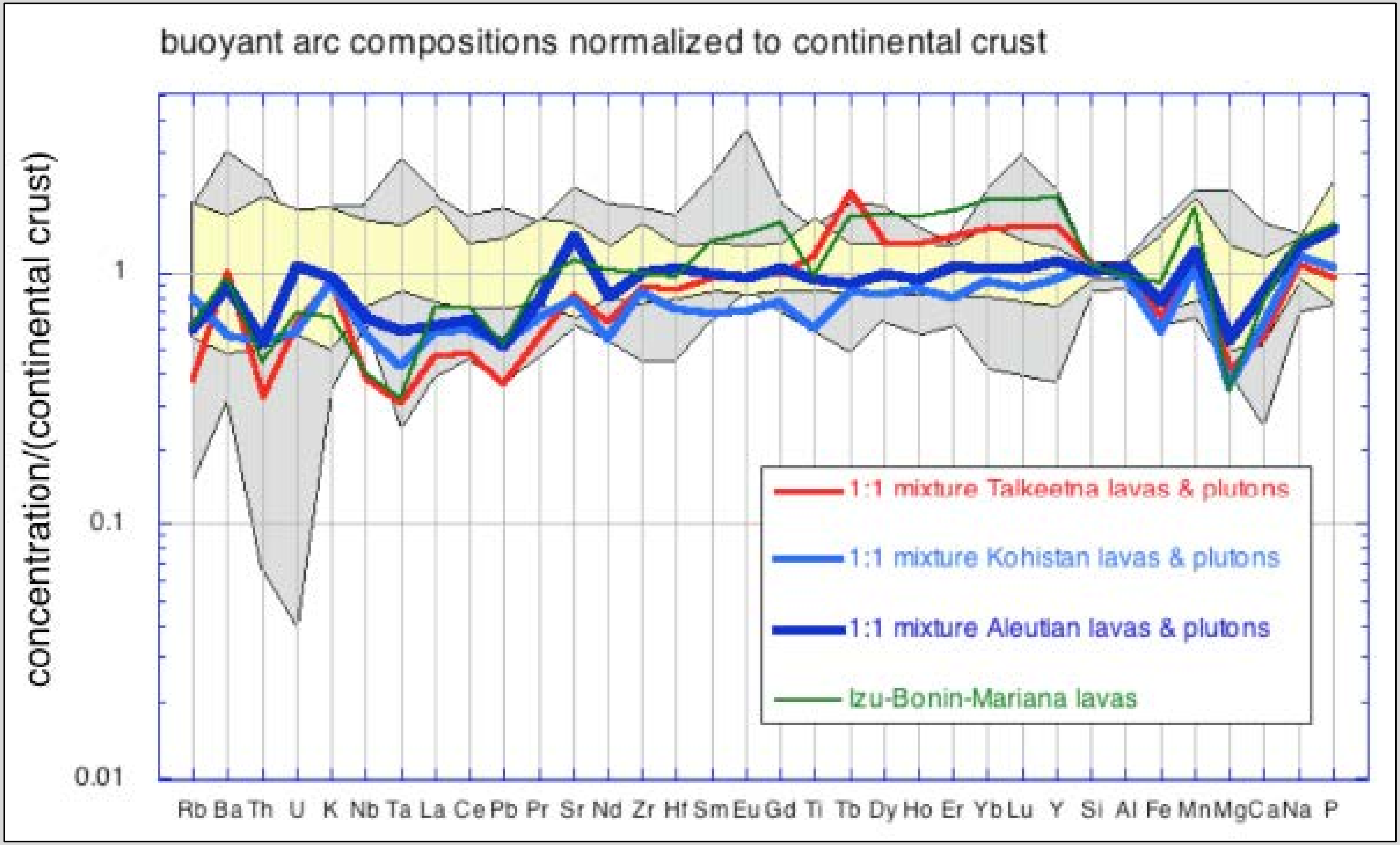
Aleutian lower crust is definitely mafic with Vp > 7.3 in large regions …
but what if the Aleutians were gradually subducted via subduction erosion?



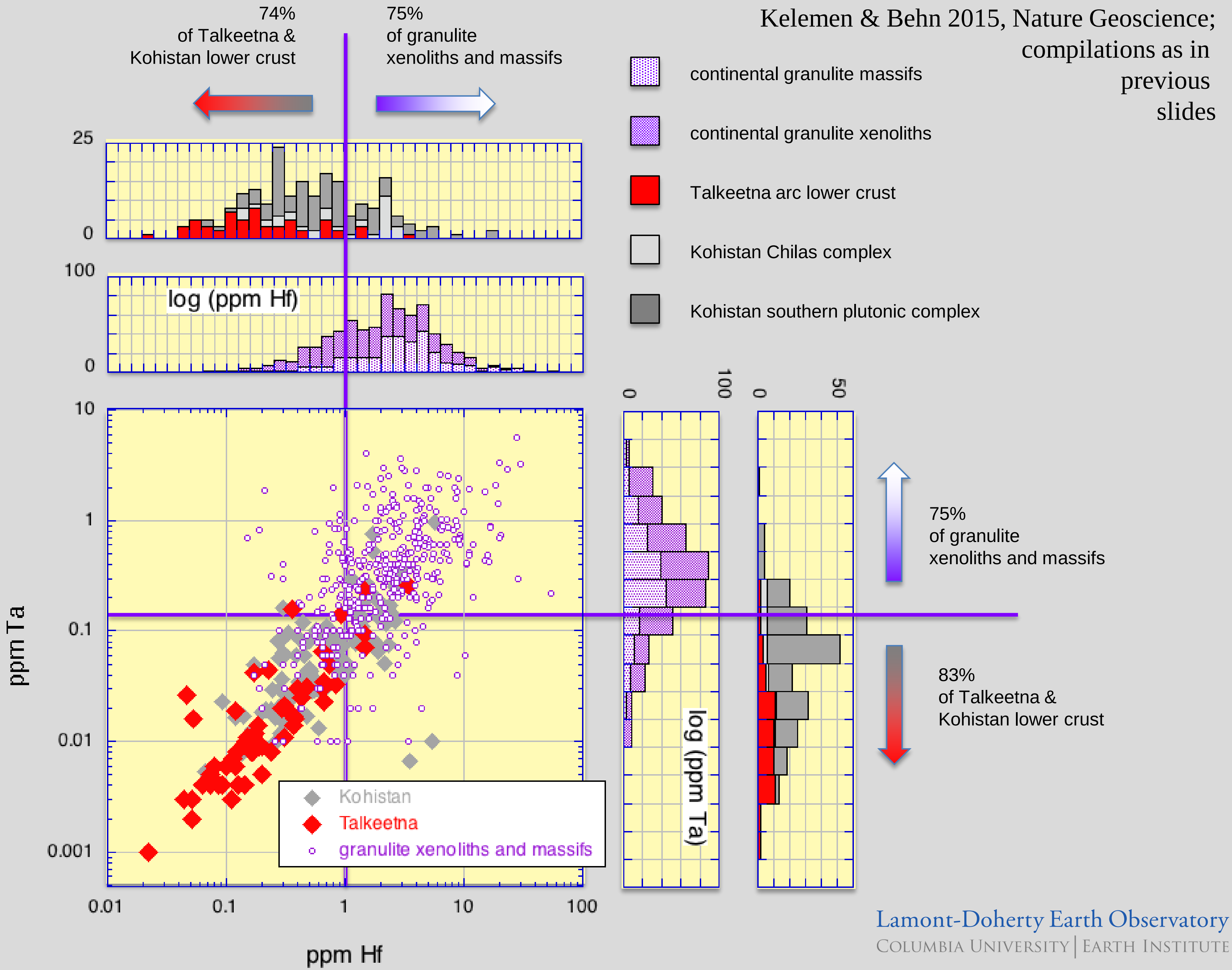
Shillington et al. G[3] 2004, Hacker et al. 2011



Kelemen & Behn 2015, Nature Geoscience
using data compilations as in previous slides



Kelemen & Behn 2015, Nature Geoscience
using data compilations as in previous slides


Kelemen & Behn 2015, Nature Geoscience; compilations as in previous slides
74% of Talkeetna & Kohistan lower crust
75% of granulite xenoliths and massifs
continental granulite massifs
continental granulite xenoliths
Talkeetna arc lower crust
Kohistan Chilas complex
Kohistan southern plutonic complex
log (ppm Hf)
log (ppm Ta)
ppm Ta
ppm Hf
Kohistan
Talkeetna
granulite xenoliths and massifs
75% of granulite xenoliths and massifs
83% of Talkeetna & Kohistan lower crust
Lamont-Doherty Earth Observatory
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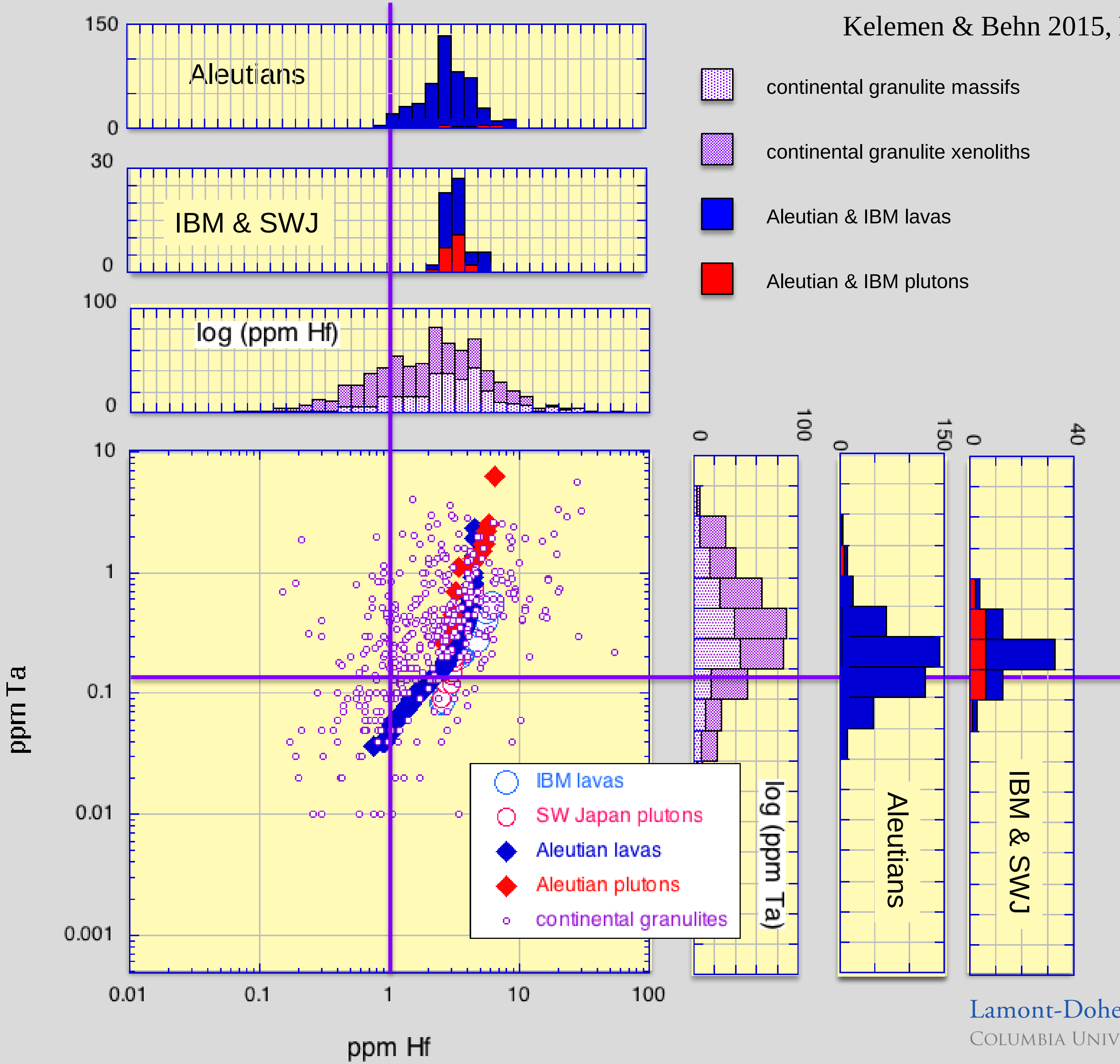
Kelemen & Behn 2015, Nature Geoscience; compilations as in previous slides



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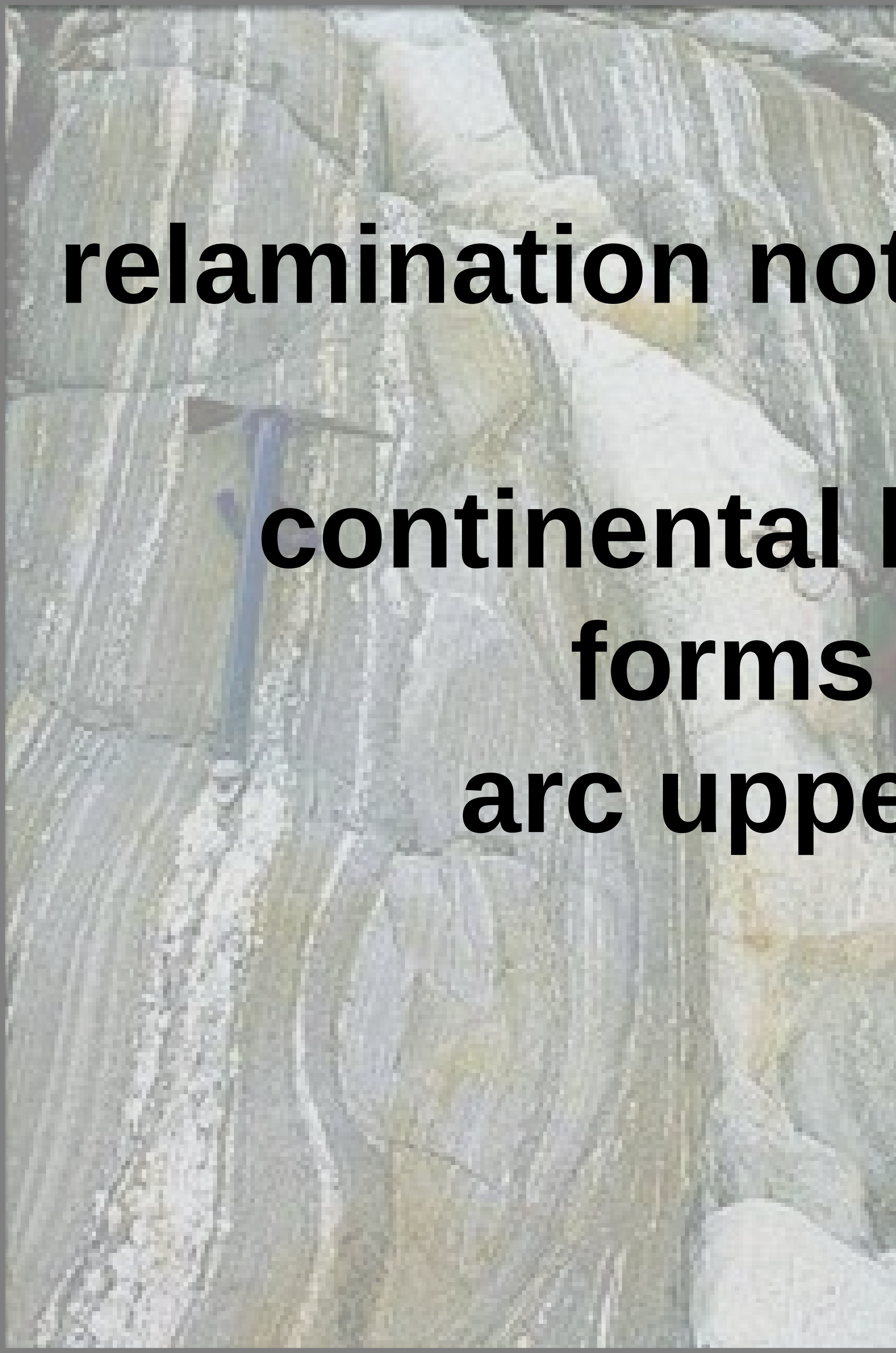
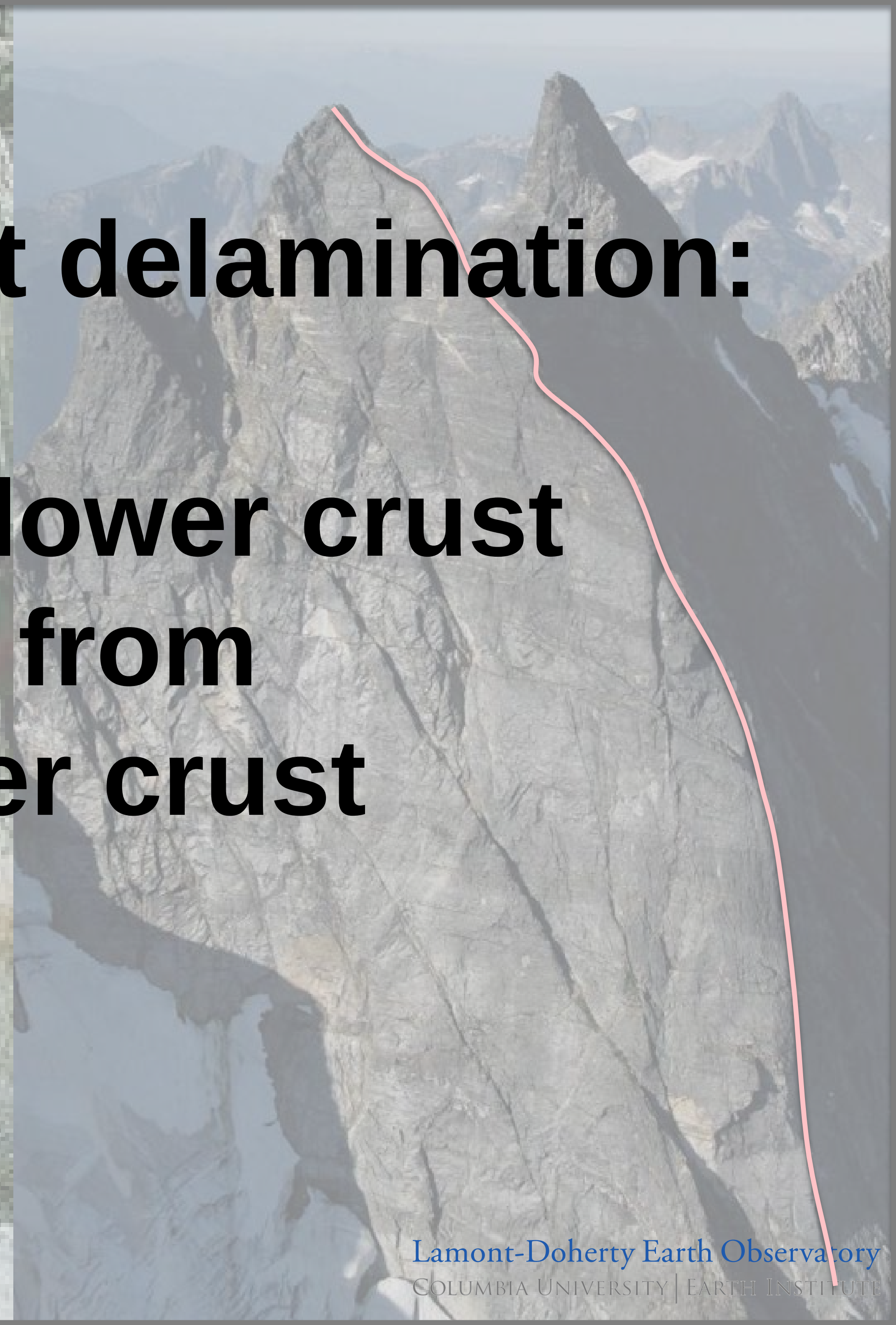




relamination not delamination:

continental lower crust forms from arc upper crust

thank you for your attention and thanks GeoPRISMS!!!

warning: the speaker is about to embark on an entirely different talk

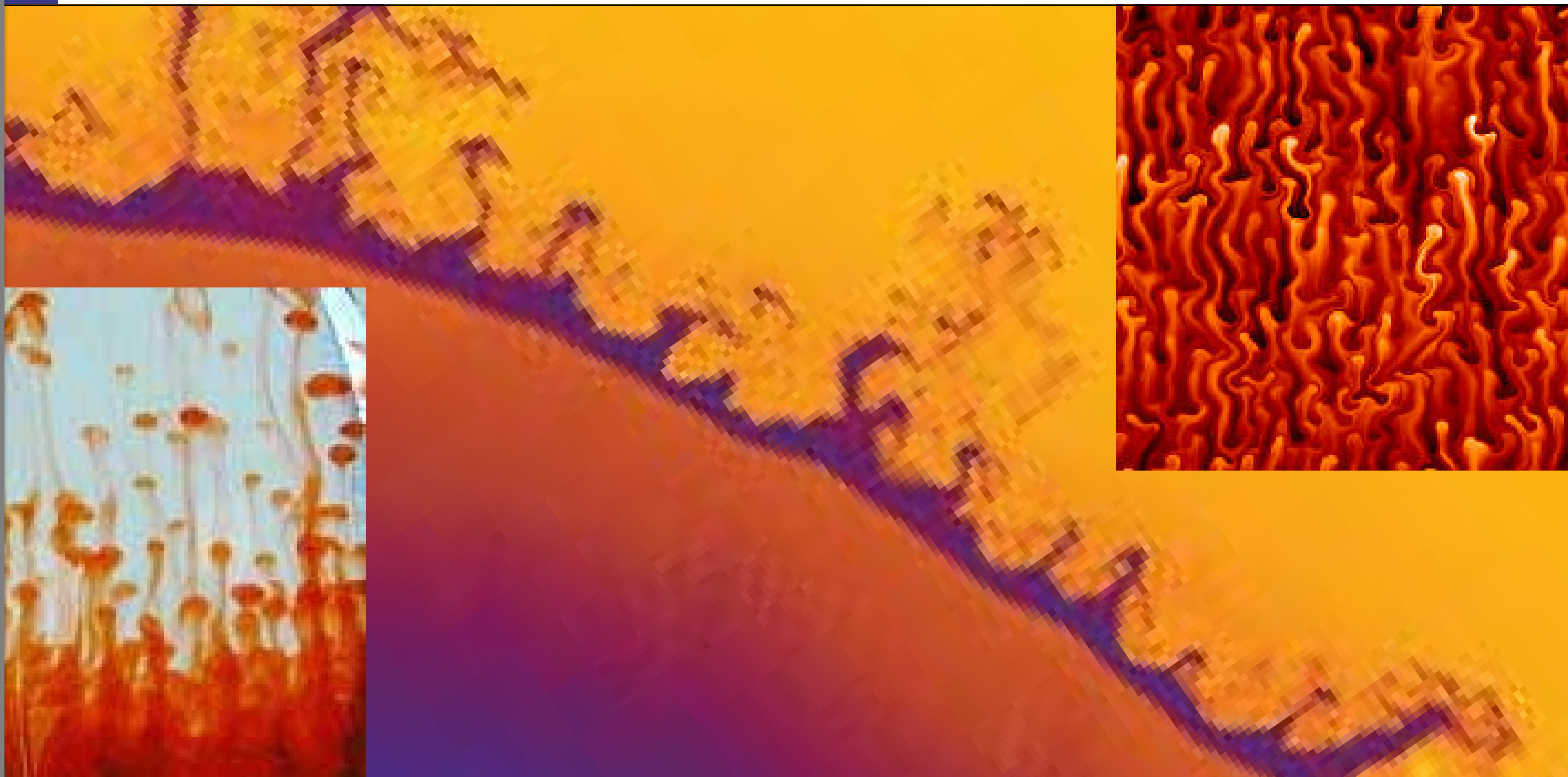
Reevaluating carbon fluxes in subduction zones, what goes down, mostly comes up

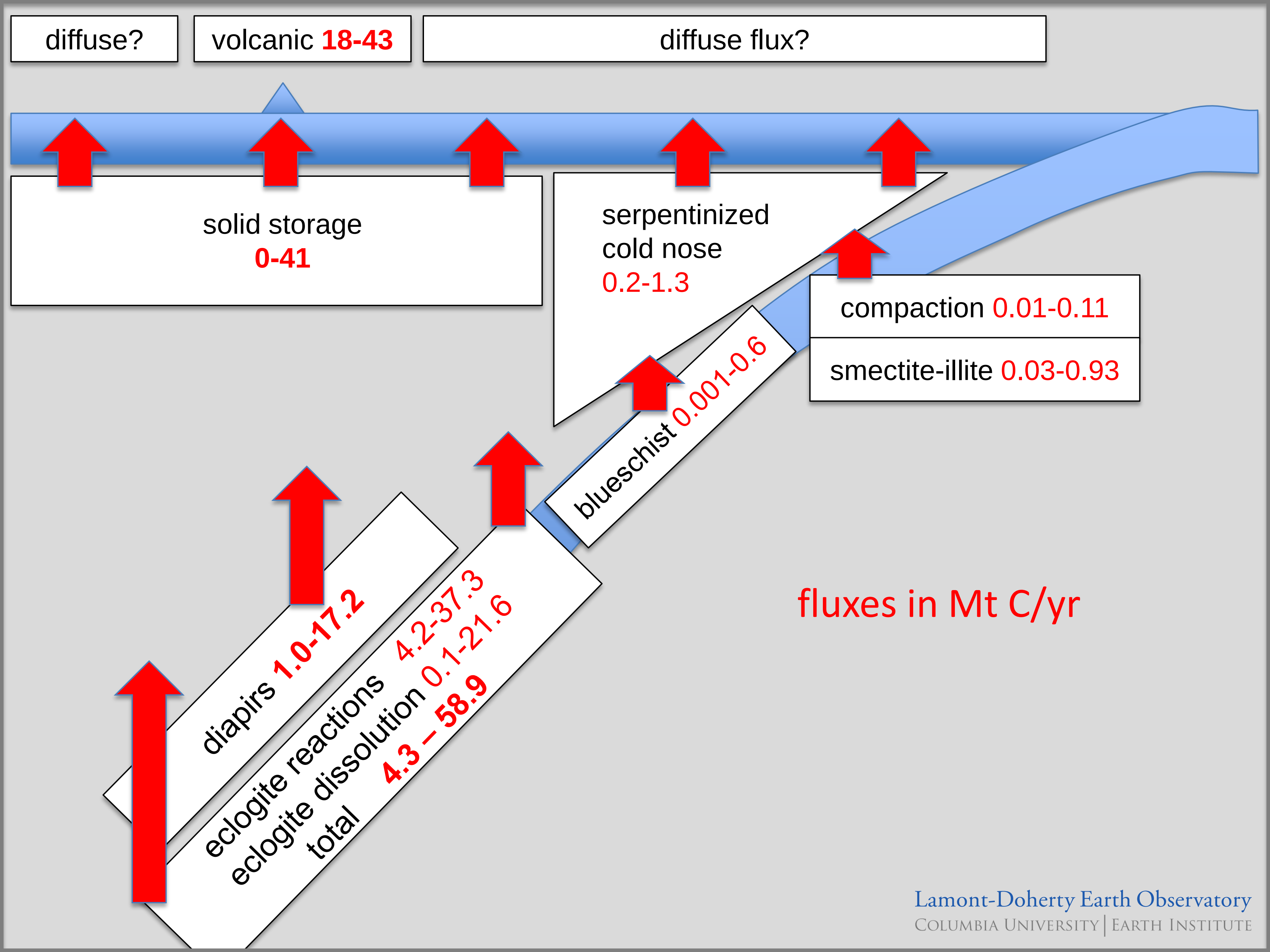
Peter B. Kelemen[a,1] and Craig E. Manning[b,1]

[a]Department of Earth & Environmental Sciences, Columbia University, Lamont–Doherty Earth Observatory, Palisades, NY 10964; and [b]Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, CA 90095

This contribution is part of the special series of Inaugural Articles by members of the National Academy of Sciences elected in 2014.

Contributed by Peter B. Kelemen, April 23, 2015 (sent for review August 7, 2014; reviewed by Jay J. Ague, James Connolly, Rajdeep Dasgupta, and Dimitri Sverjensky)




diffuse?
volcanic 18-43
diffuse flux?
solid storage
0-41
serpentinized
cold nose
0.2-1.3
compaction 0.01-0.11
smectite-illite 0.03-0.93
blueschist 0.001-0.6
diapirs 1.0-17.2
eclogite reactions 4.2-37.3
eclogite dissolution 0.1-21.6
total 4.3 – 58.9
fluxes in Mt C/yr
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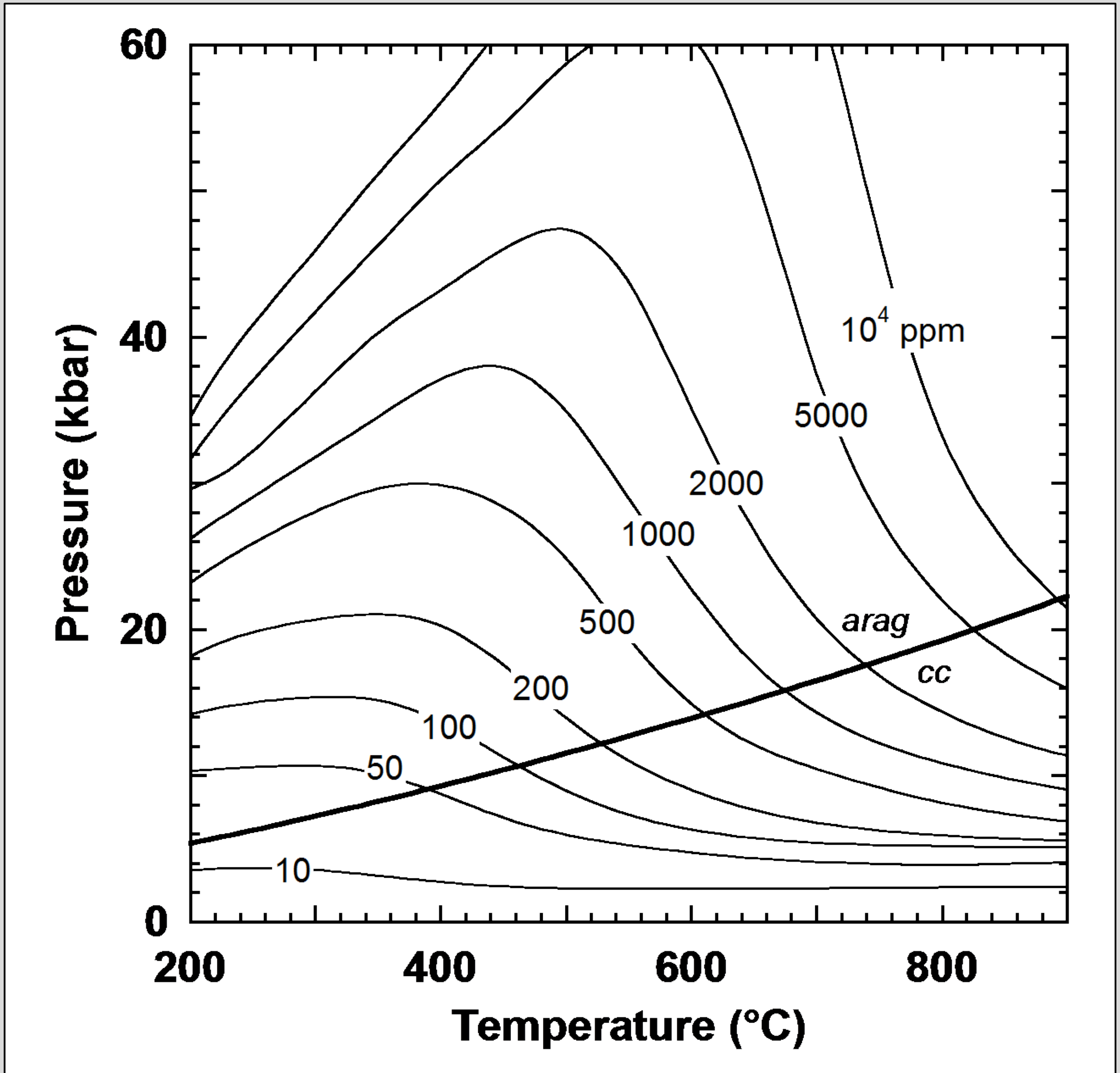
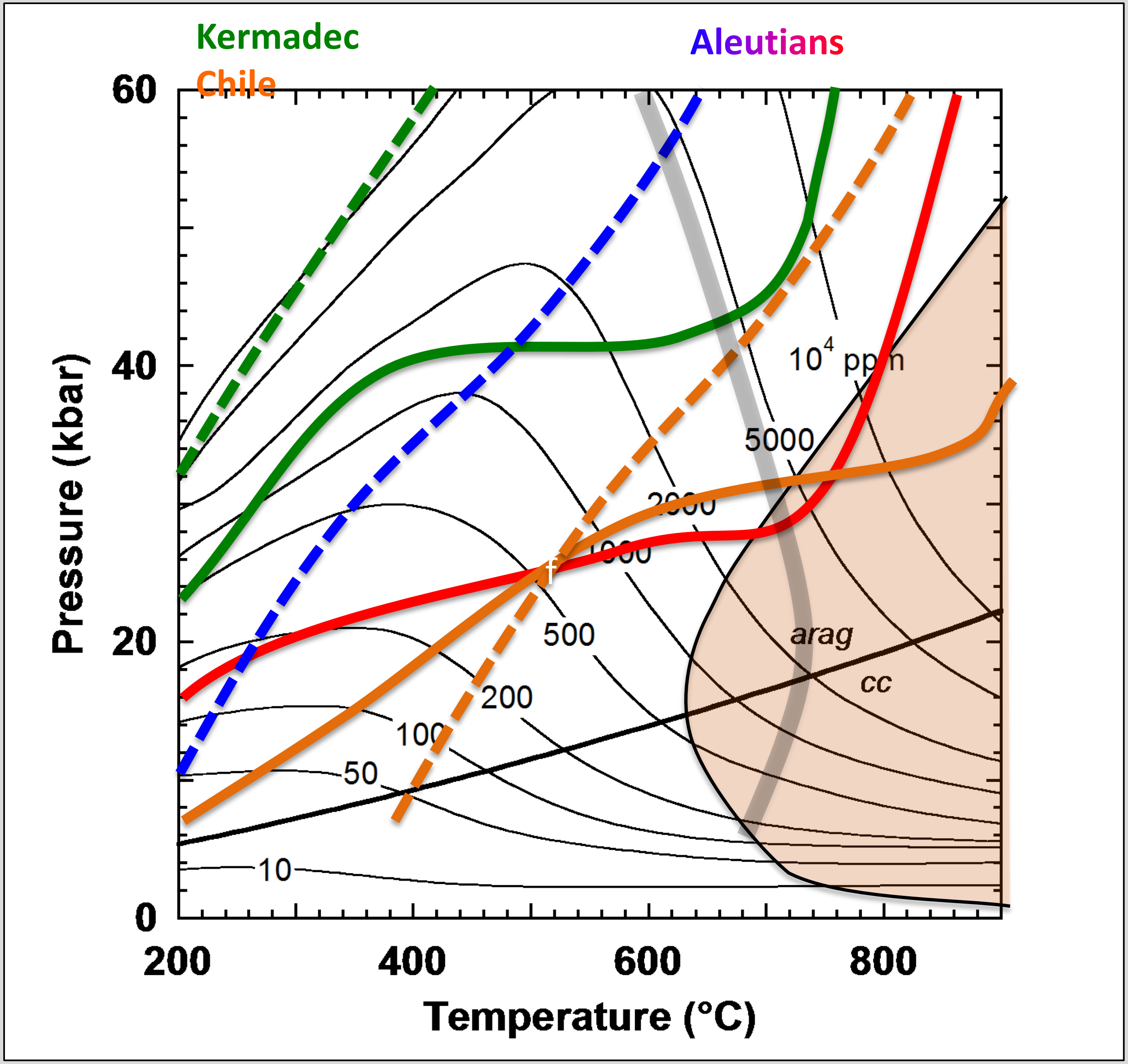
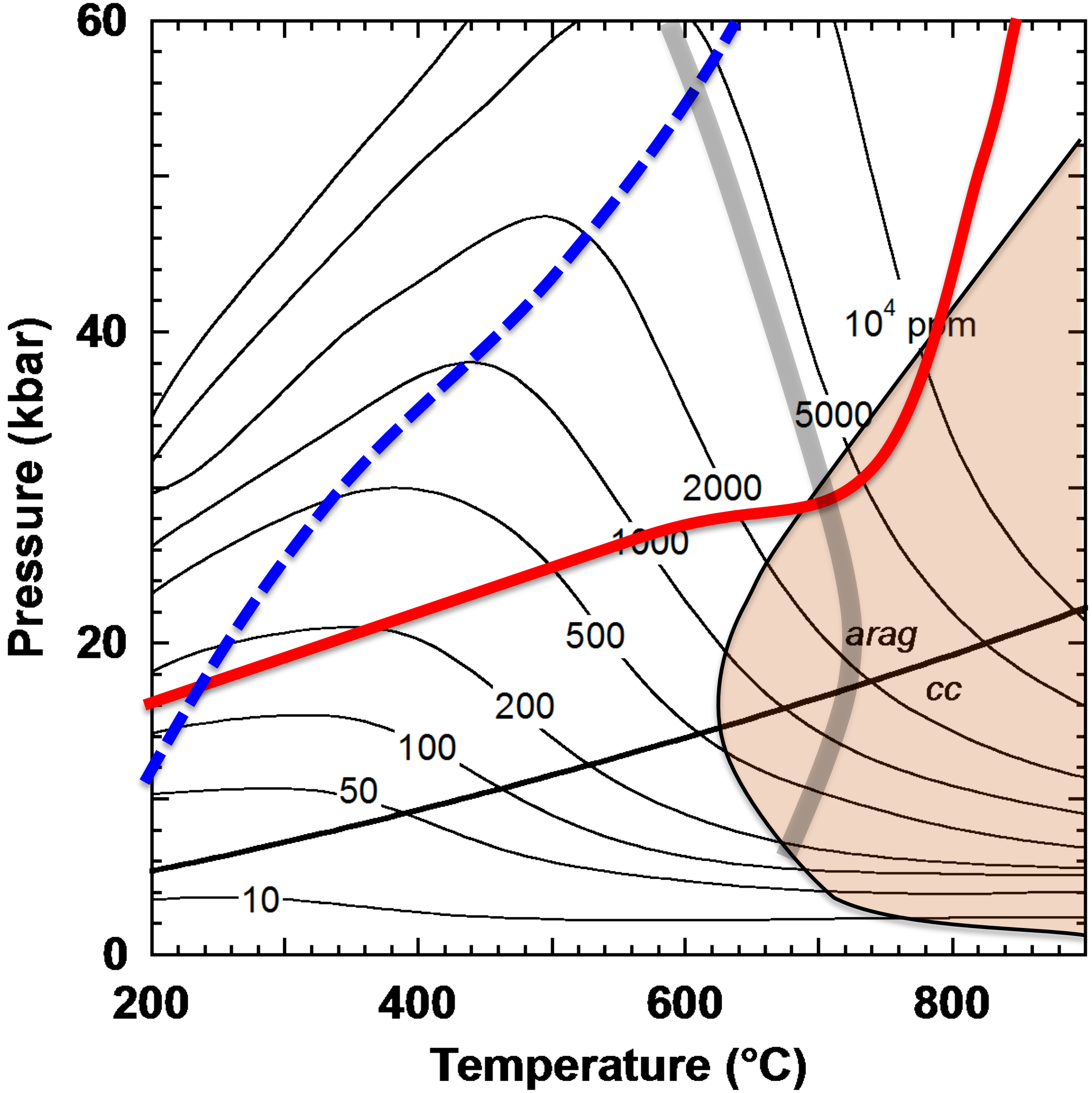


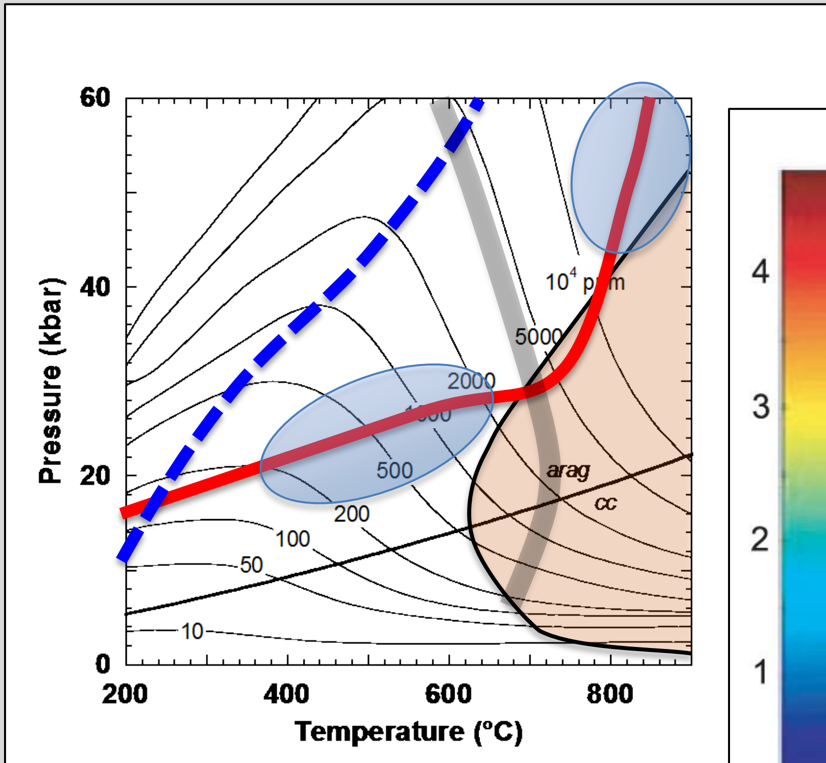
Pressure (kbar)
60
40
20
0
200
400
600
800
Temperature (°C)
10^4 ppm
5000
2000
1000
500
200
100
50
10
arag
cc

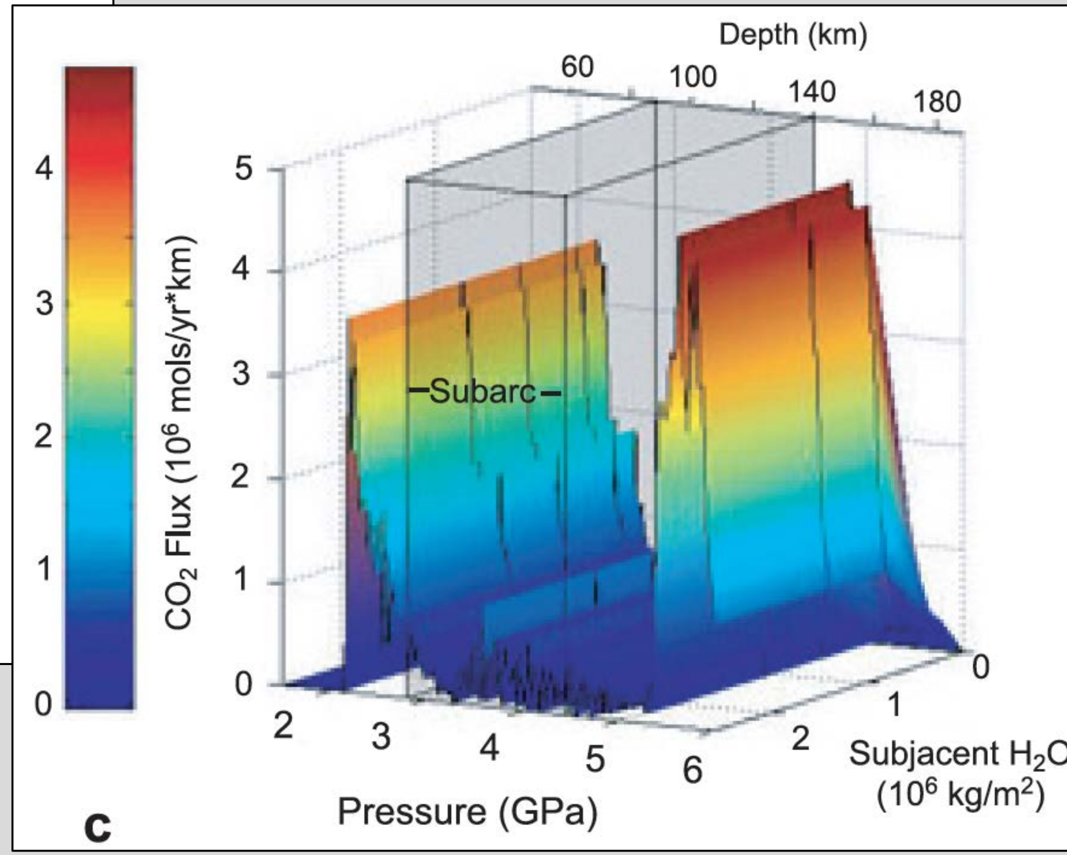


X25 subduction geotherms from Syracuse et al. PEPI 2010;
solidus from Schmidt et al. EPSL 2004; serp out from Ulmer & Trommsdorff Science 1995

Aleutians only

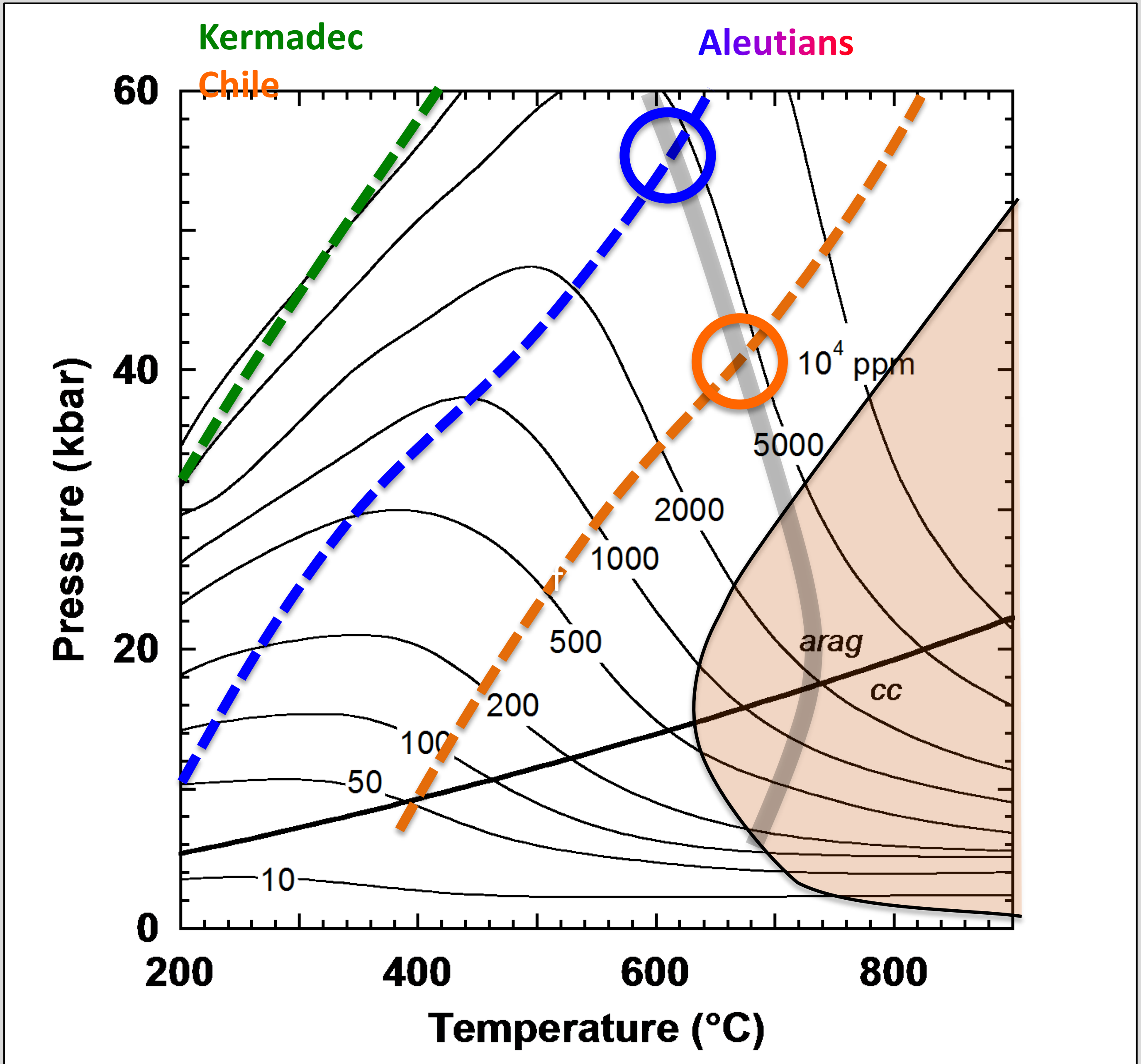






metamorphic decarbonation reactions (Gorman et al. 2006)

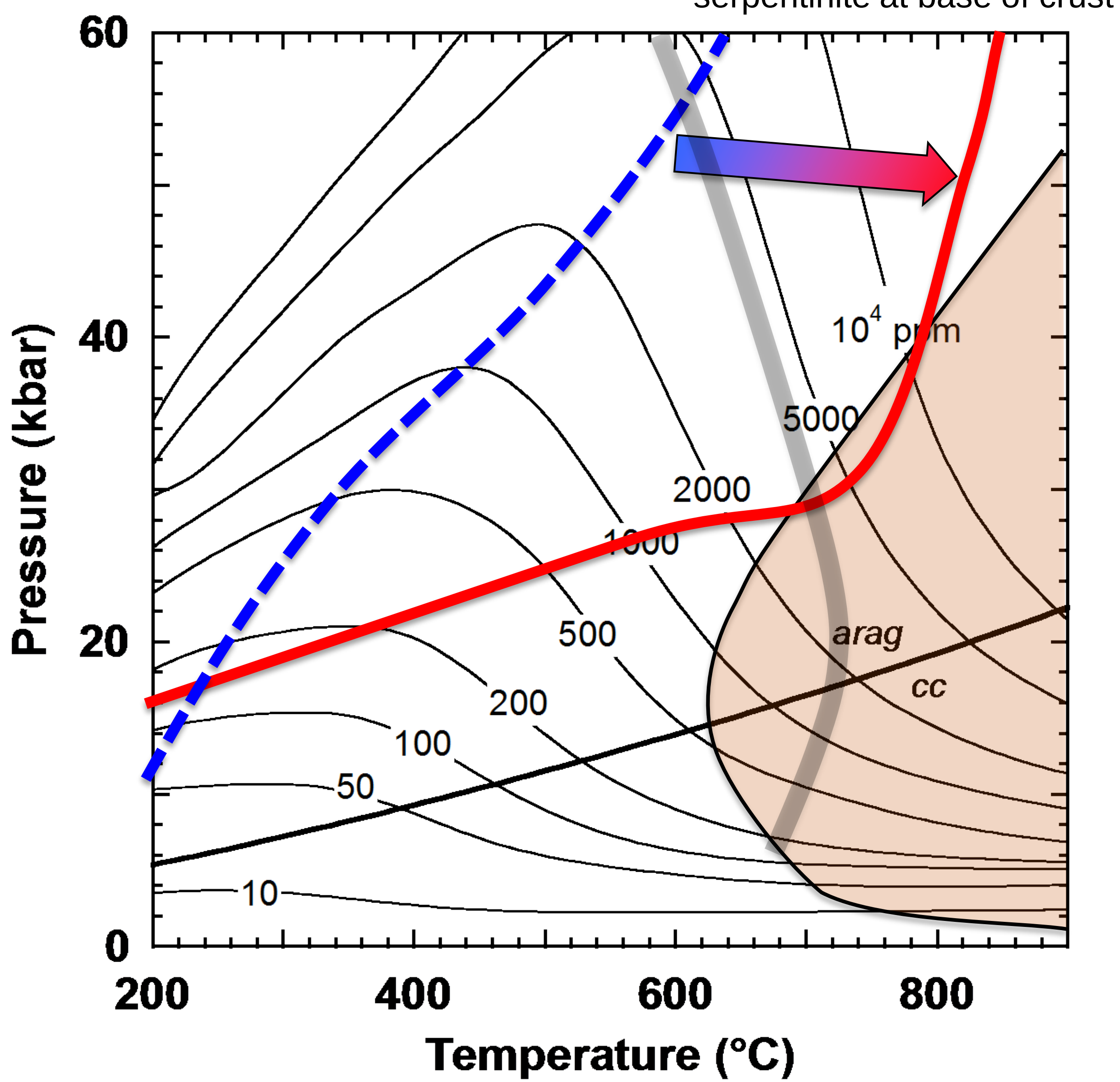
4-37 Mt C/yr

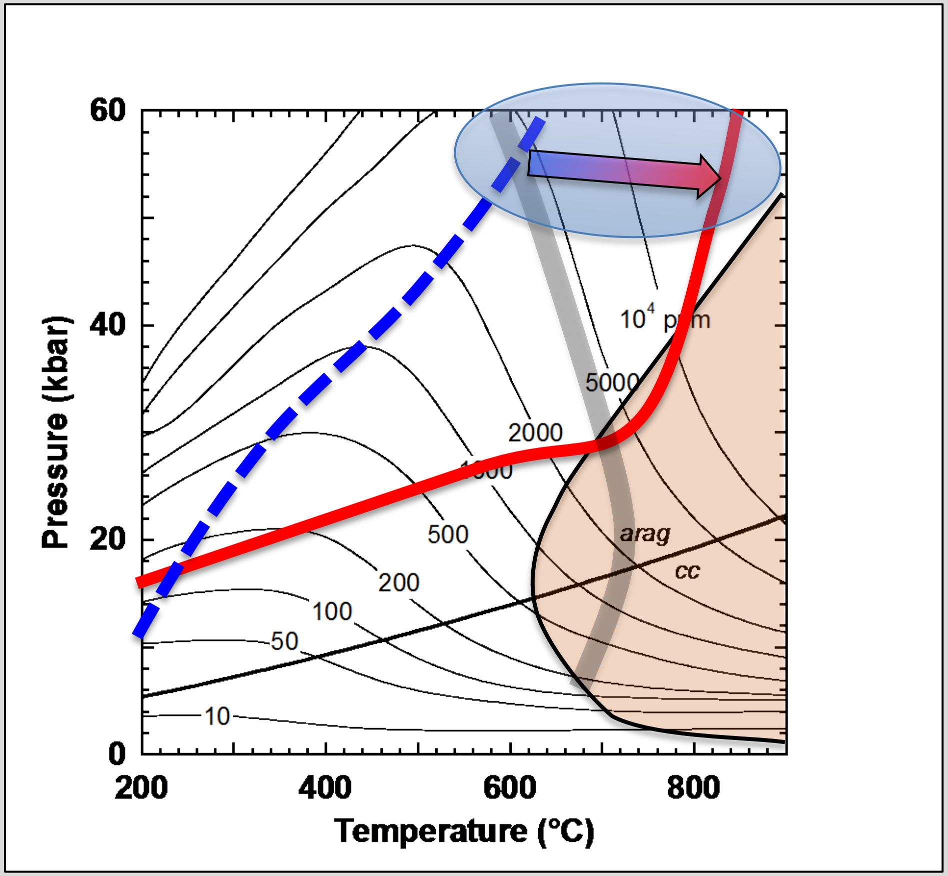


subduction geotherms from Syracuse et al. PEPI 2010;
solidus from Schmidt et al. EPSL 2004; serp out from Ulmer & Trommsdorff Science 1995

Aleutians only

fluids from
carbonate-bearing
serpentinite at base of crust





dehydration ≤ 10 wt% aqueous fluid, **3 wt%** total C in fluid

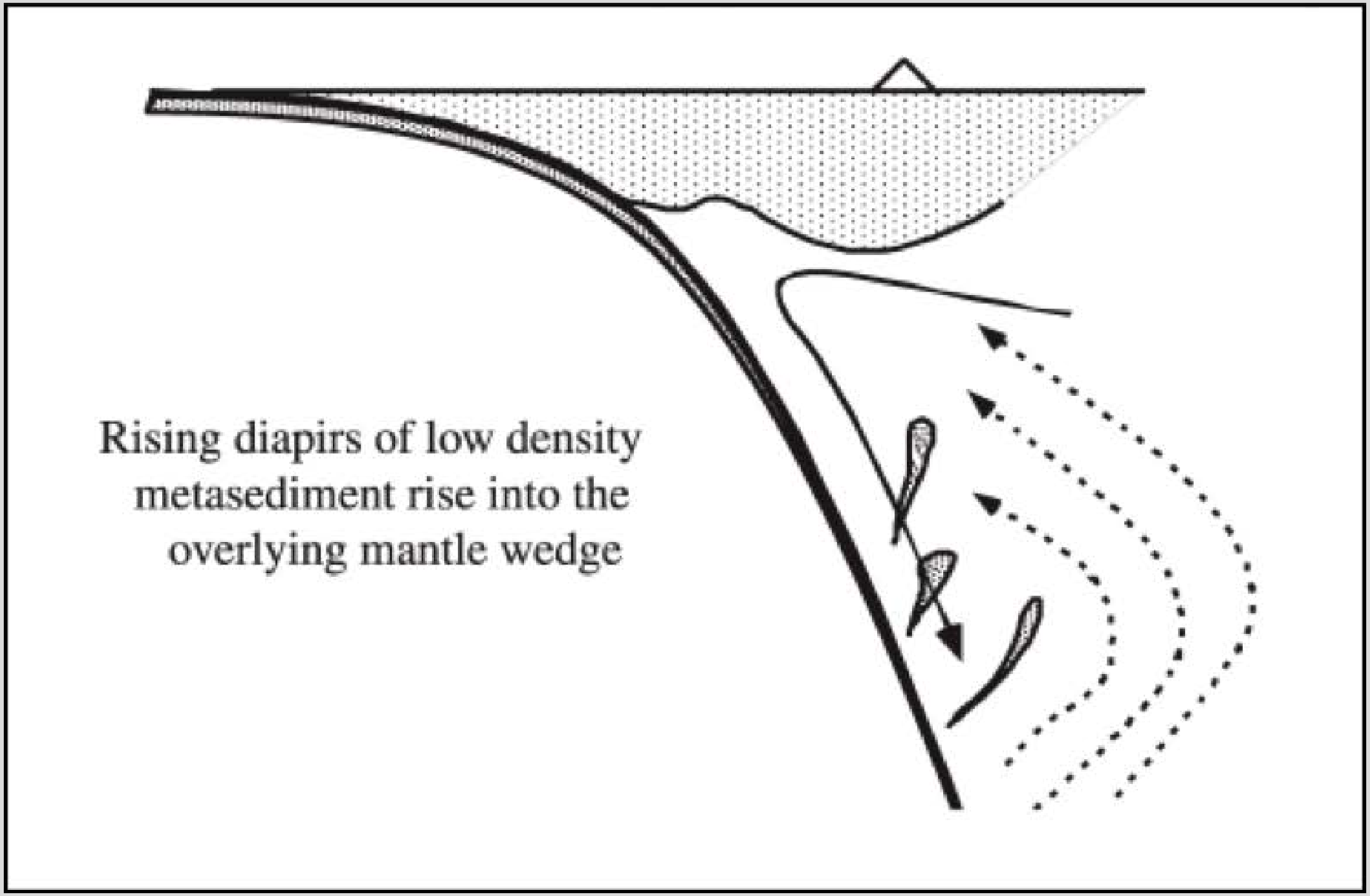
500 m sediment + 500 m carbonated basalt

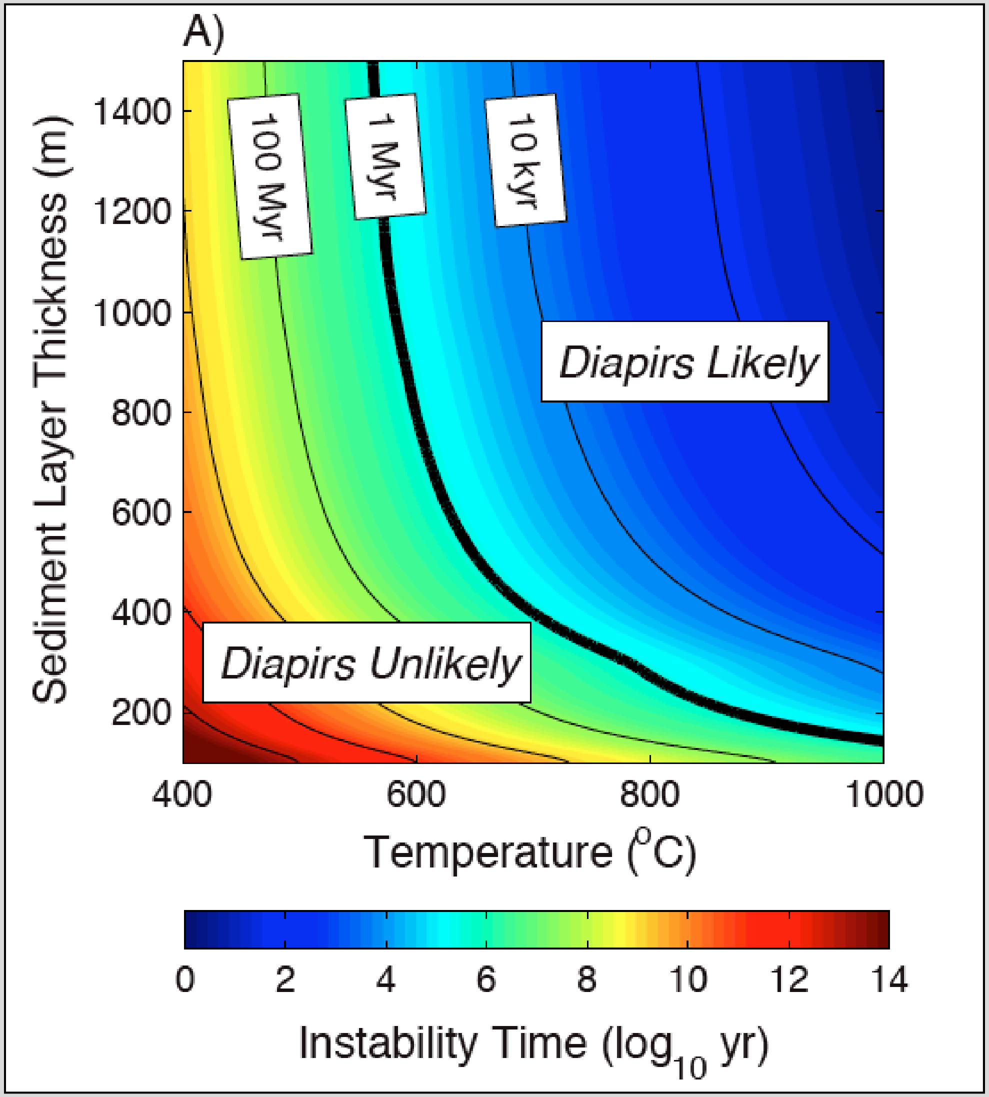
0.05 m/yr subduction velocity, 50,000 km subduction zones

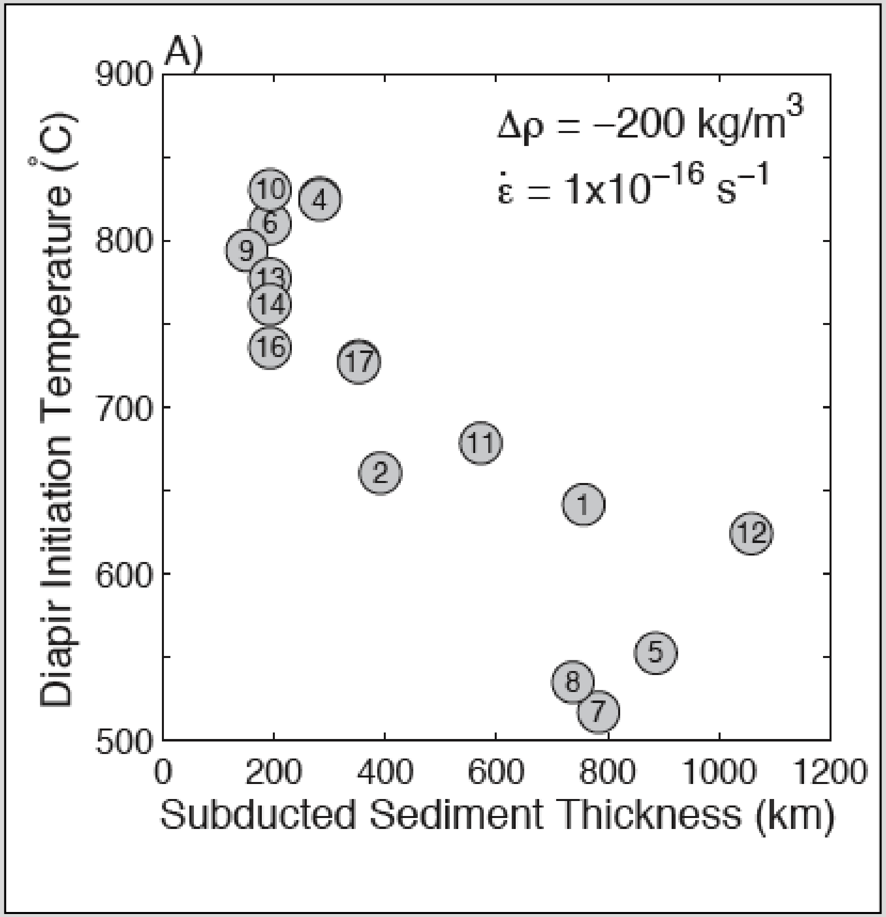
≤ 21 Mt C/yr

Slab decarbonation via metasedimentary diapirs

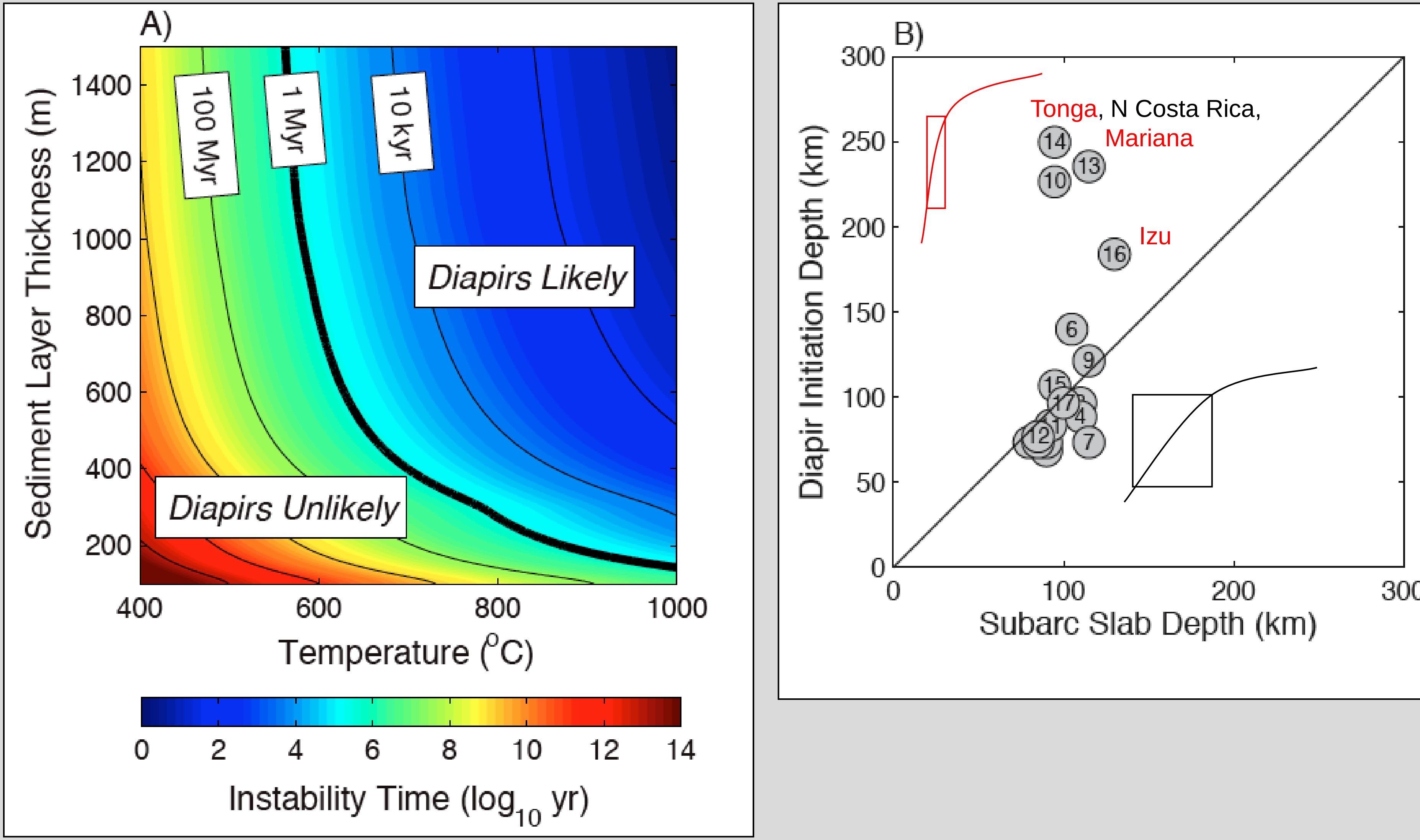
(Kelemen et al Treatise on Geochemistry, 2003, 2014, Behn et al Nature Geoscience 2011)







Behn et al., Nature Geoscience 2011



Behn et al., Nature Geoscience 2011

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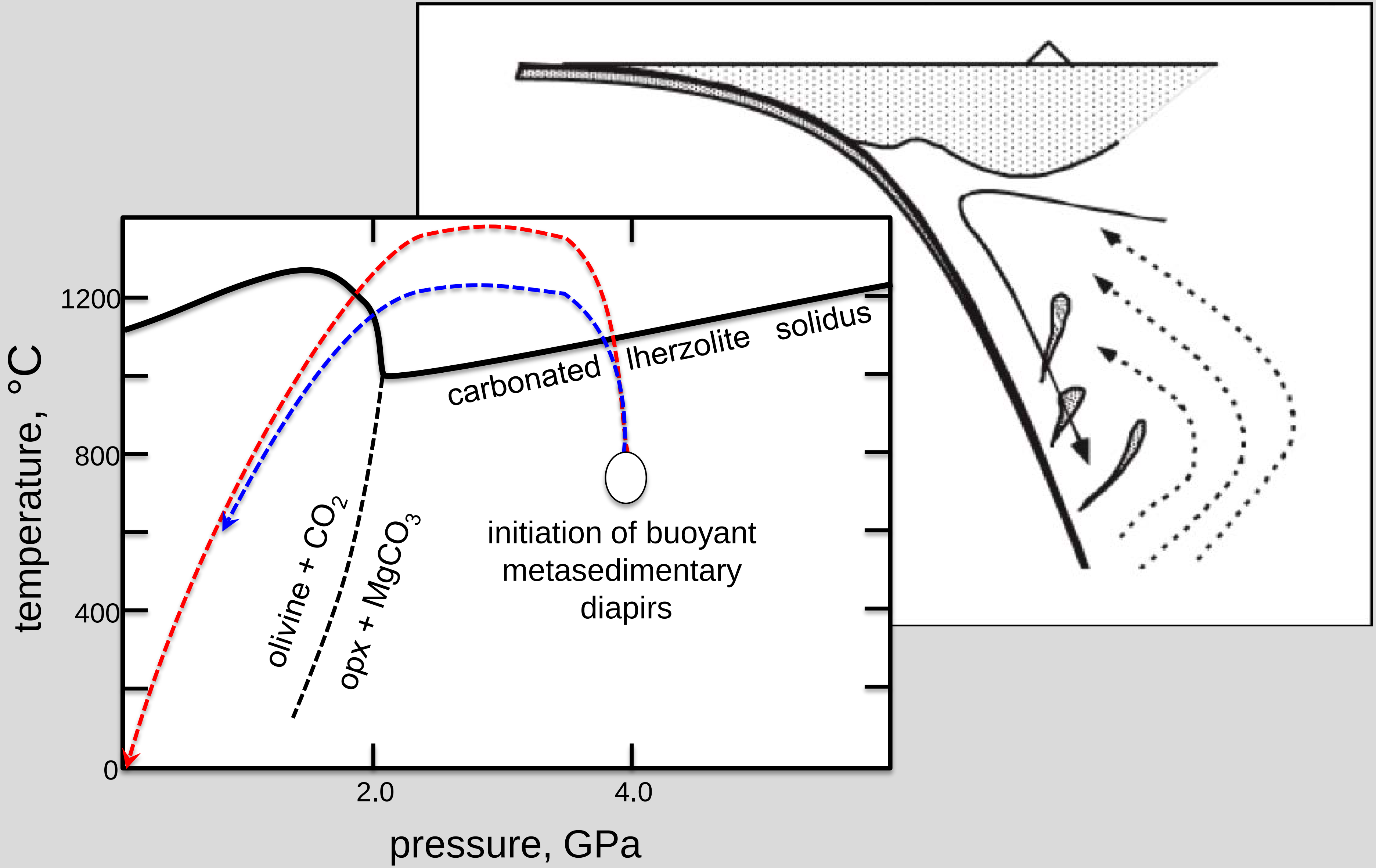
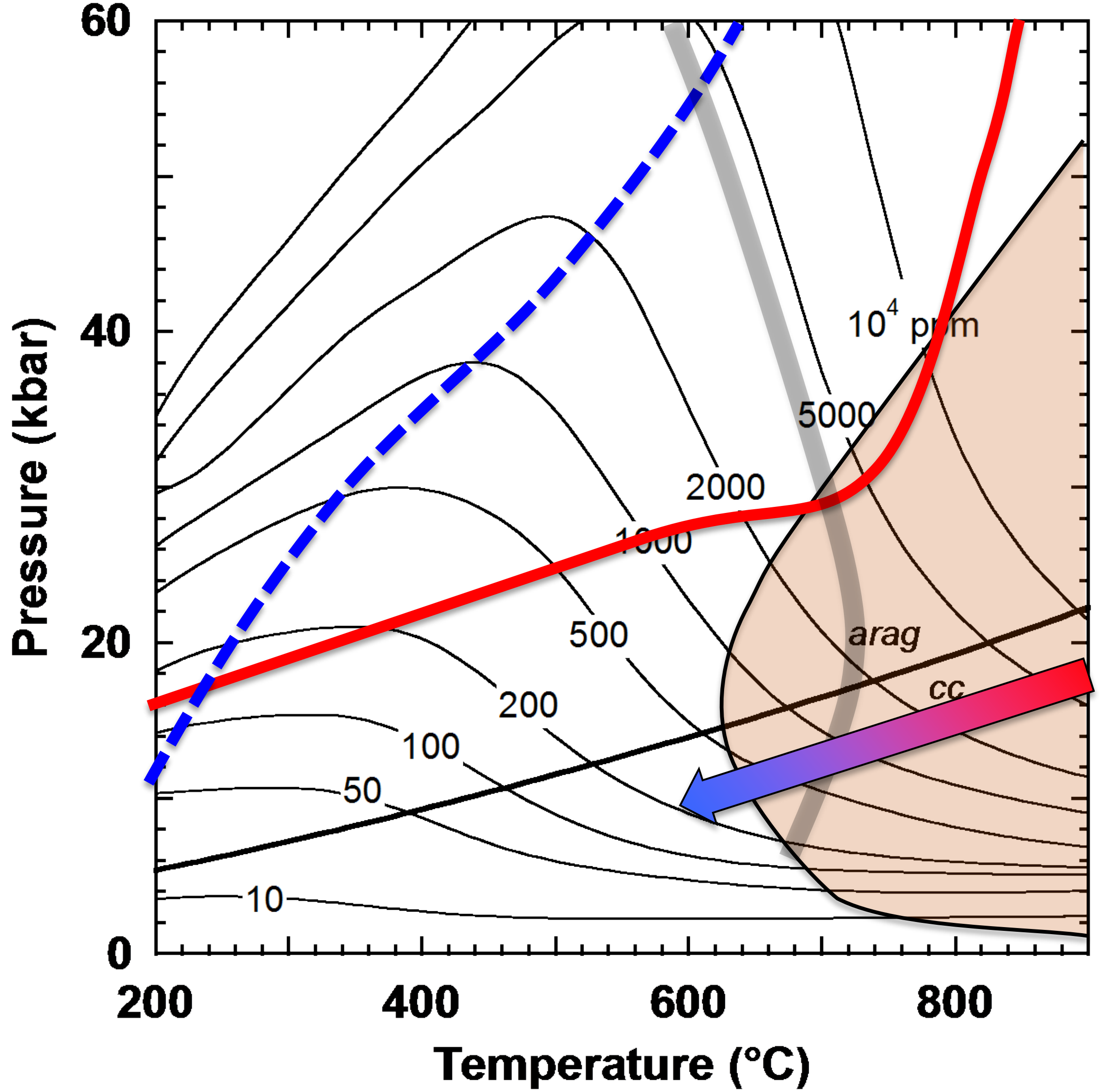
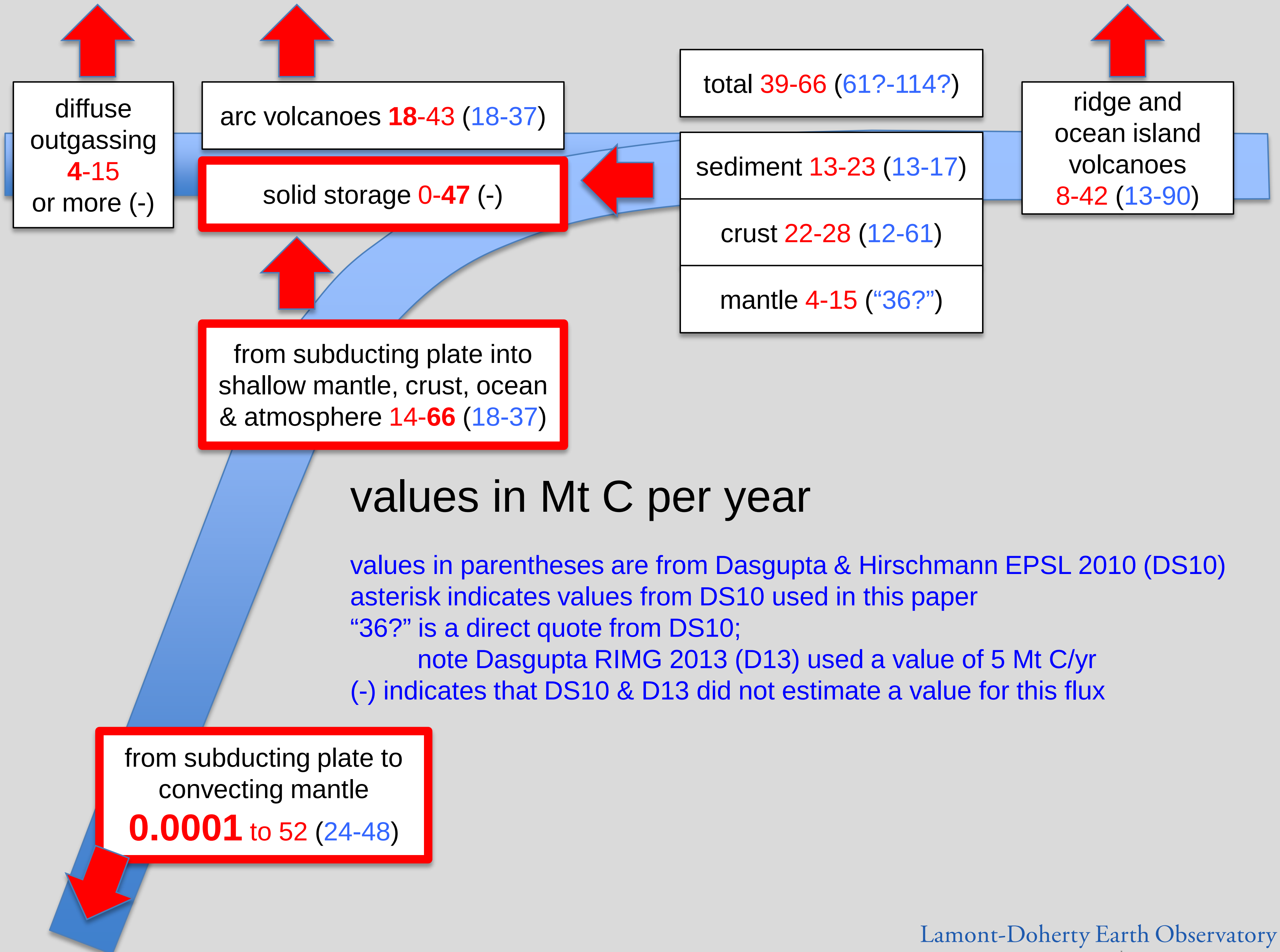


Eggler 1978; Ellis &Wyllie 1980; Falloon &Green 1989; 1990;
Wyllie & Huang 1976; Dasgupta & Hirschmann 2006

Aleutians only



aqueous melts & fluids from C-bearing melts of subducting material, diapirs, &/or mantle)



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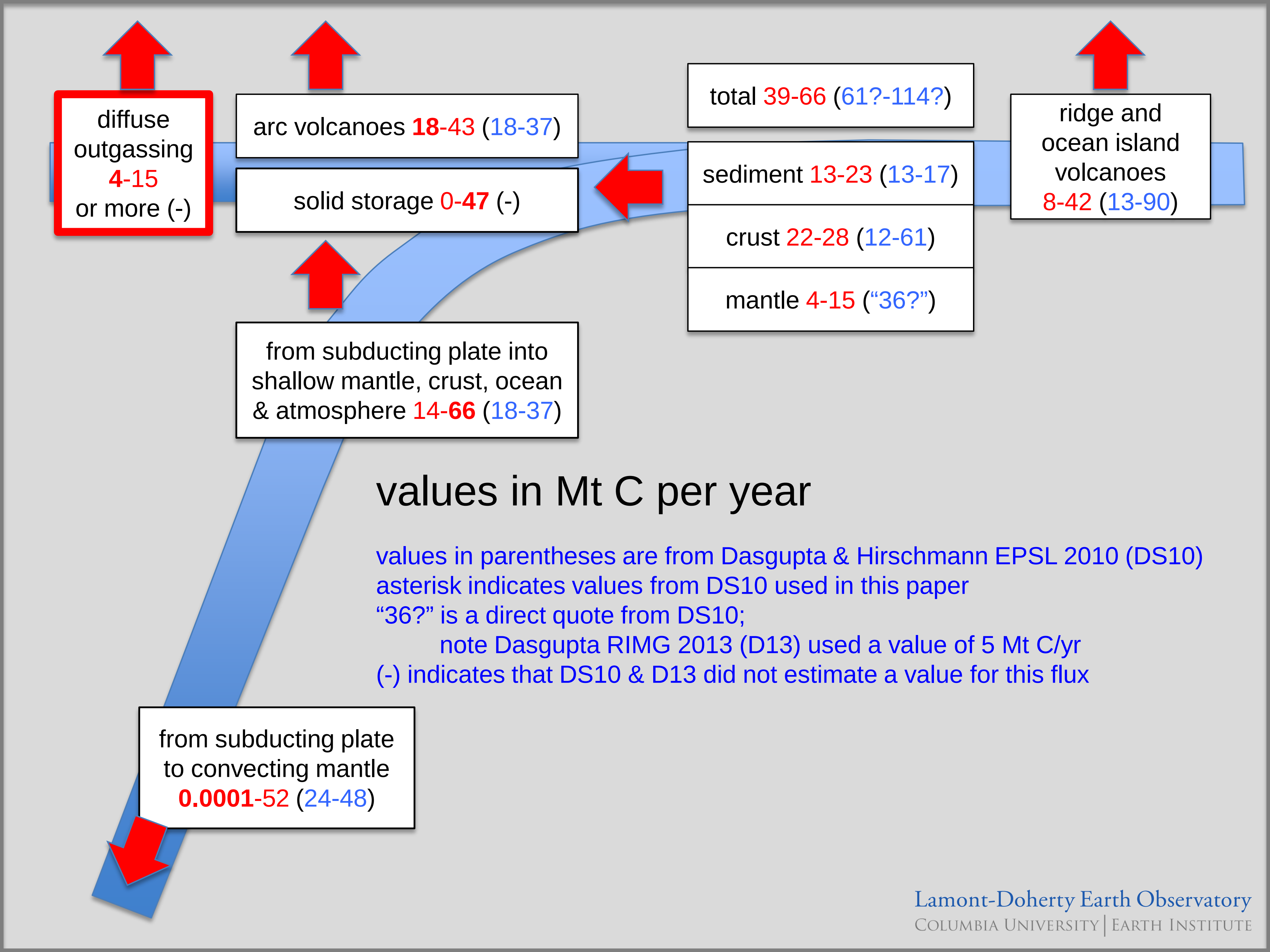
diffuse outgassing 4-15 or more (-)
arc volcanoes 18-43 (18-37)
solid storage 0-47 (-)
total 39-66 (61?-114?)
sediment 13-23 (13-17)
crust 22-28 (12-61)
mantle 4-15 (“36?”)
ridge and ocean island volcanoes 8-42 (13-90)
from subducting plate into shallow mantle, crust, ocean & atmosphere 14-66 (18-37)
values in Mt C per year
values in parentheses are from Dasgupta & Hirschmann EPSL 2010 (DS10)
asterisk indicates values from DS10 used in this paper
“36?” is a direct quote from DS10;
note Dasgupta RIMG 2013 (D13) used a value of 5 Mt C/yr
(-) indicates that DS10 & D13 did not estimate a value for this flux
from subducting plate to convecting mantle 0.0001-52 (24-48)
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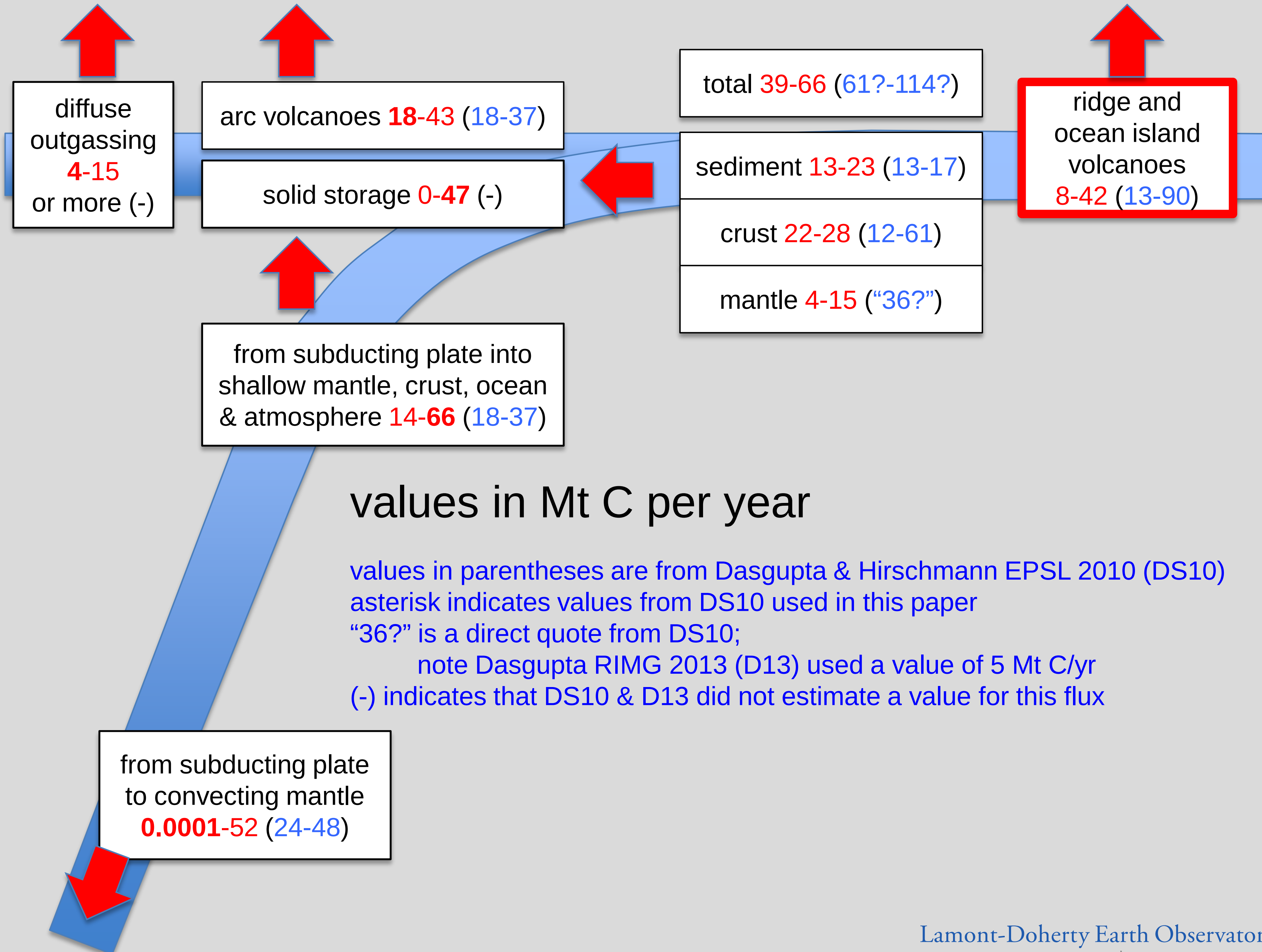

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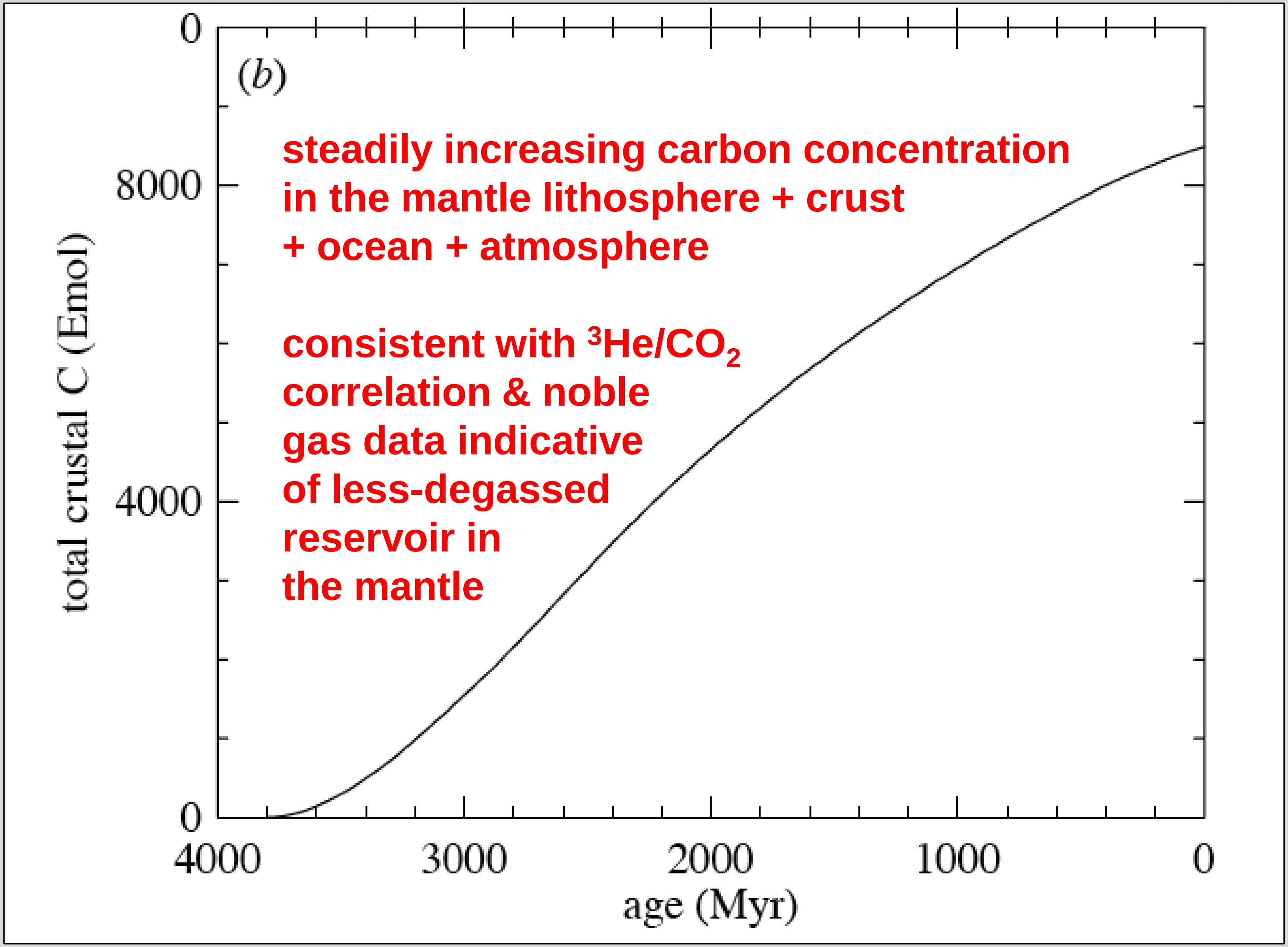
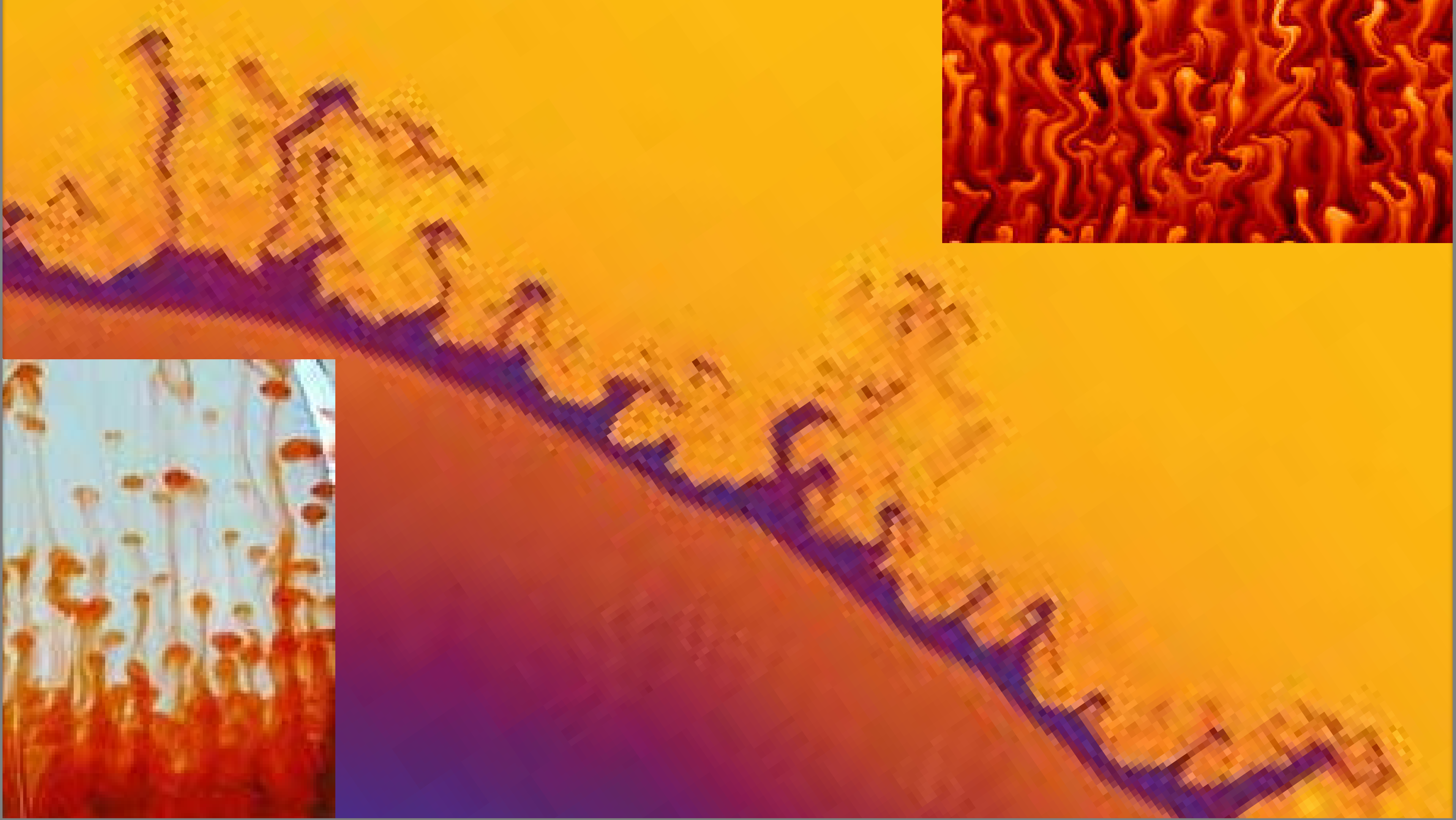
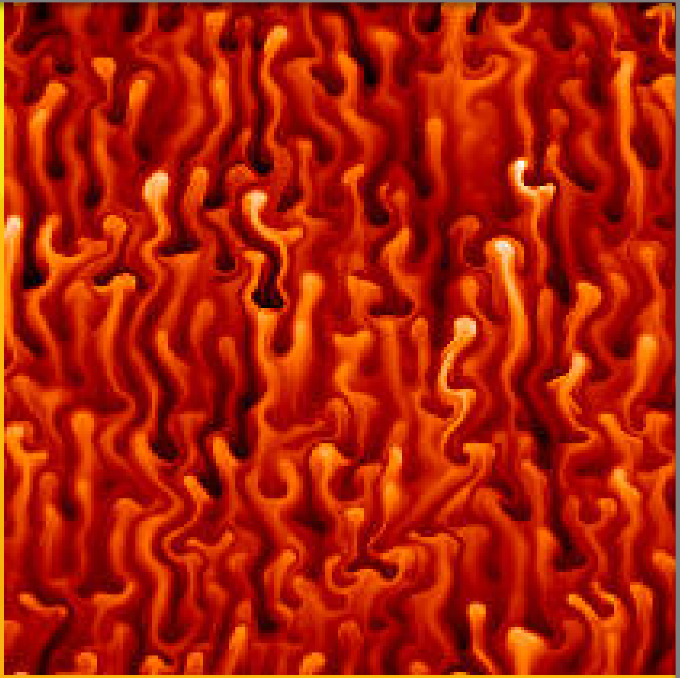
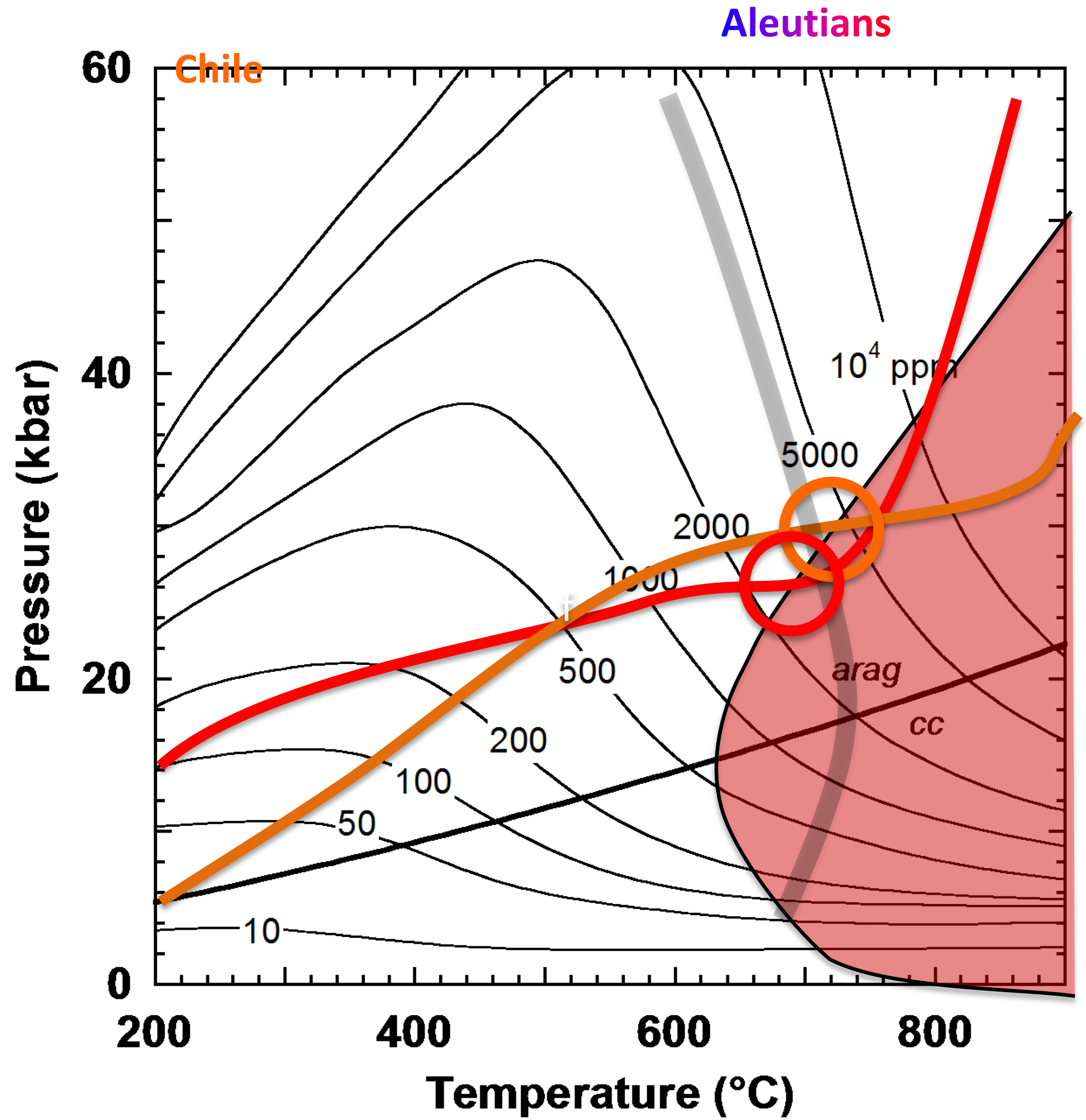


Hayes & Waldbauer PTRSL-B 2006; Marty et al. RIMG 2013

thank you for
your attention



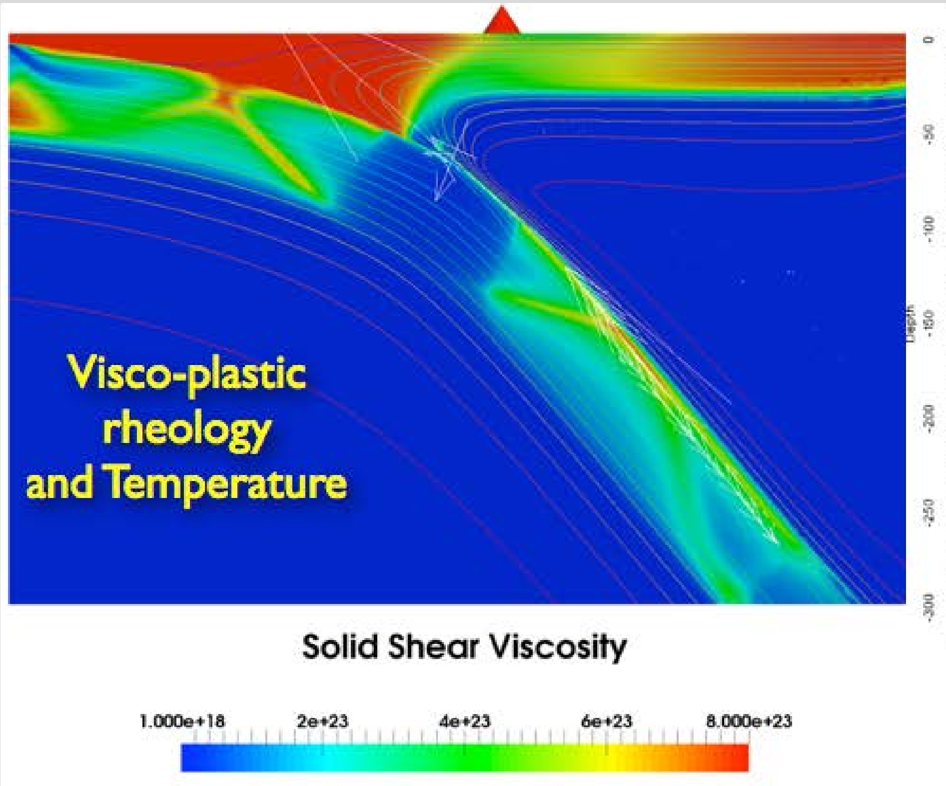


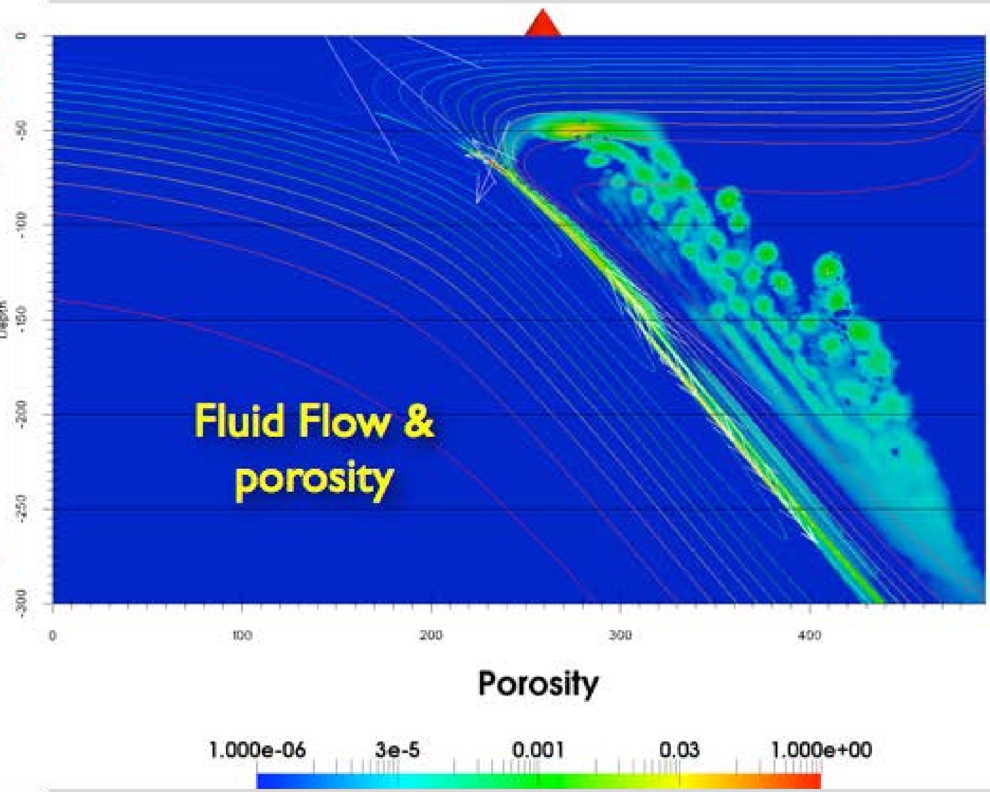


Aleutians
Chile
60
40
20
0
Pressure (kbar)
200
400
600
800
Temperature (°C)
10^4 ppm
5000
2000
1000
500
200
100
50
10
arag
cc

TerraFERMA Examples

New subduction zone models

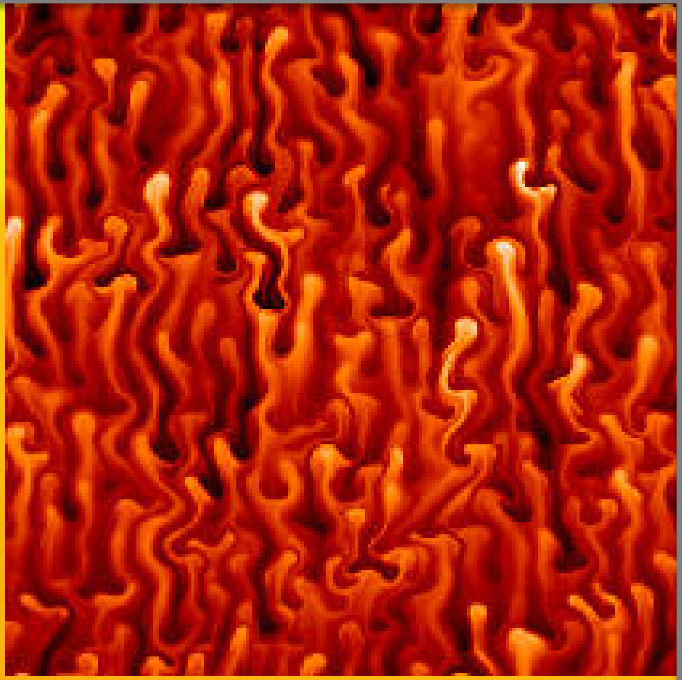


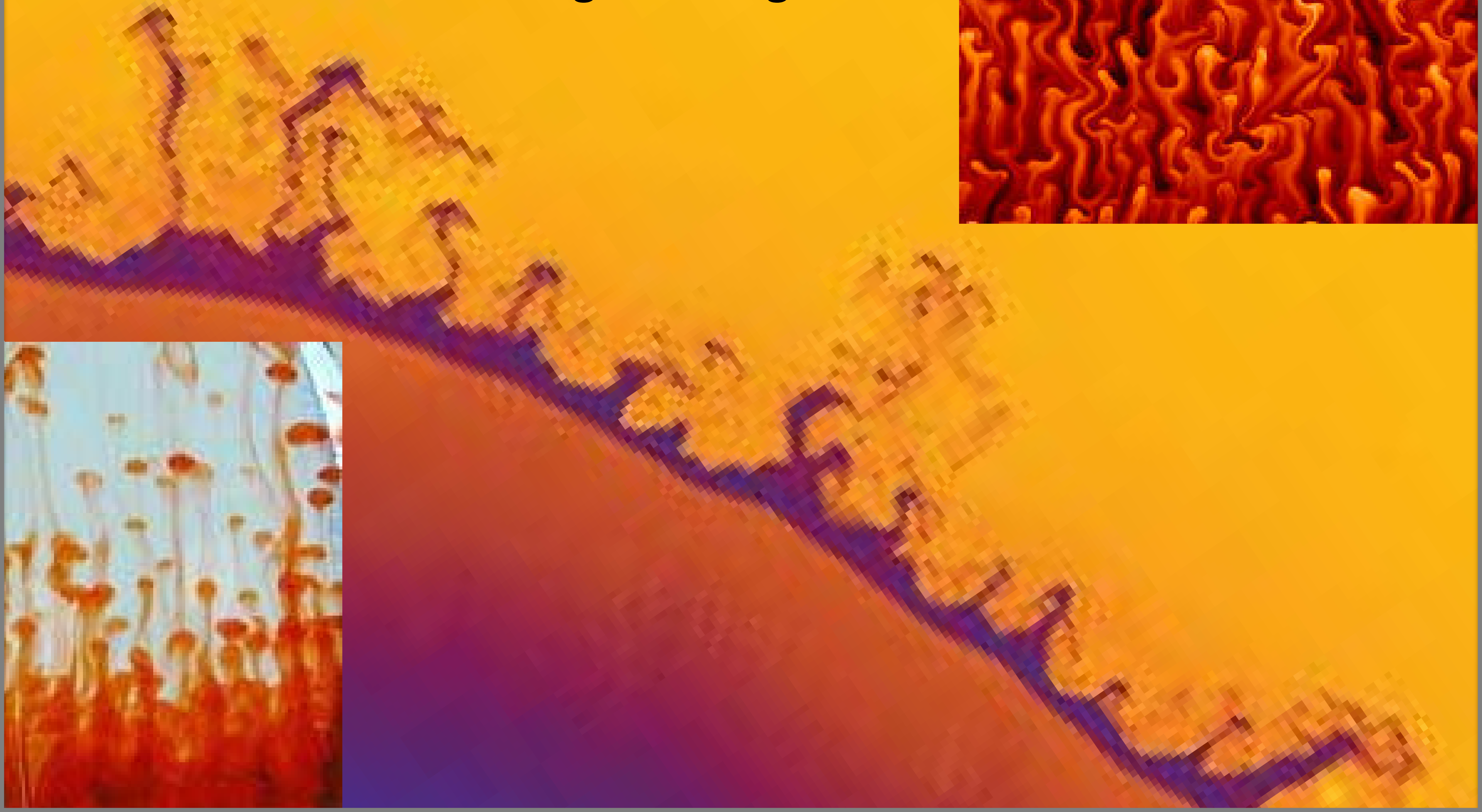


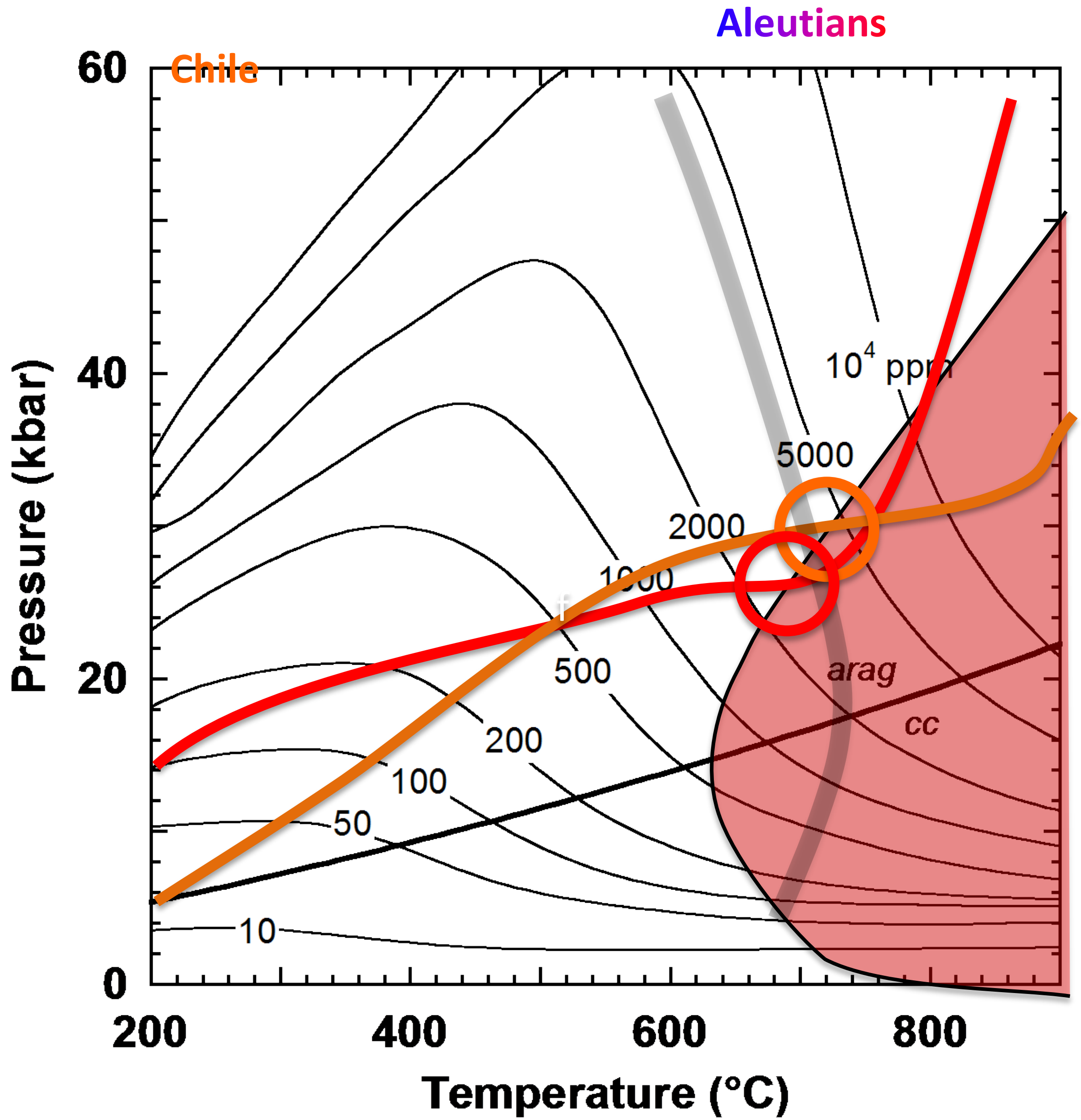
- Slab geometry from data (here, Alaska Peninsula van Keken et al 2011)
- Visco-plastic rheology - diffusion creep plus von-mises plasticity
- Similar focusing behavior

carbon fluxes in subduction zones: what goes down, mostly comes up

Peter Kelemen & Craig Manning



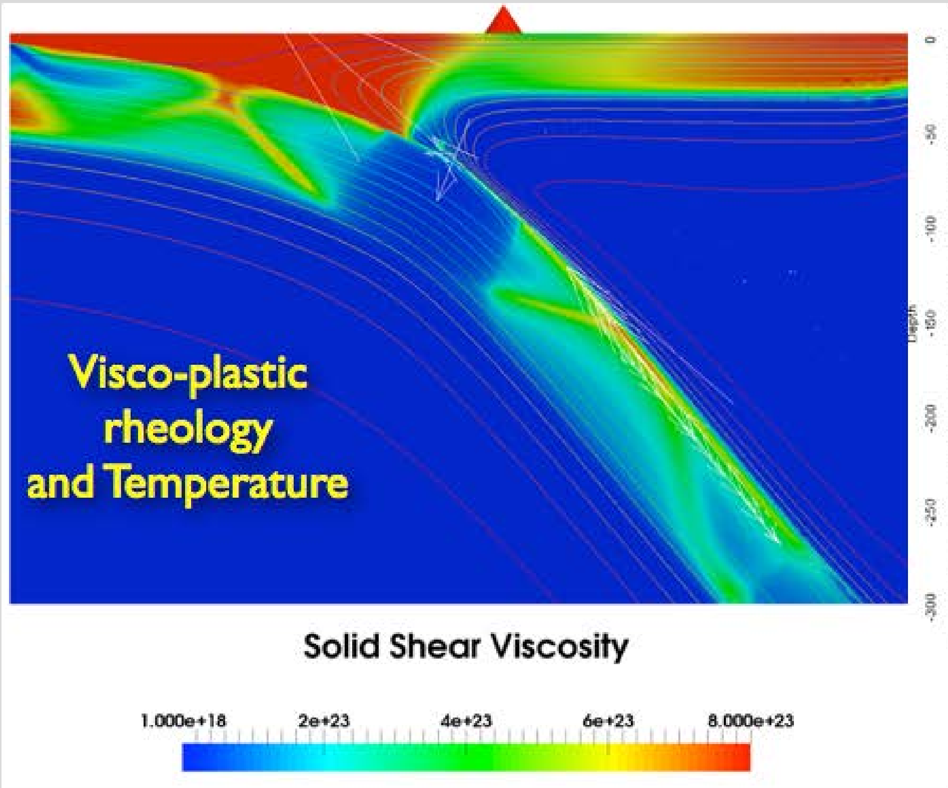


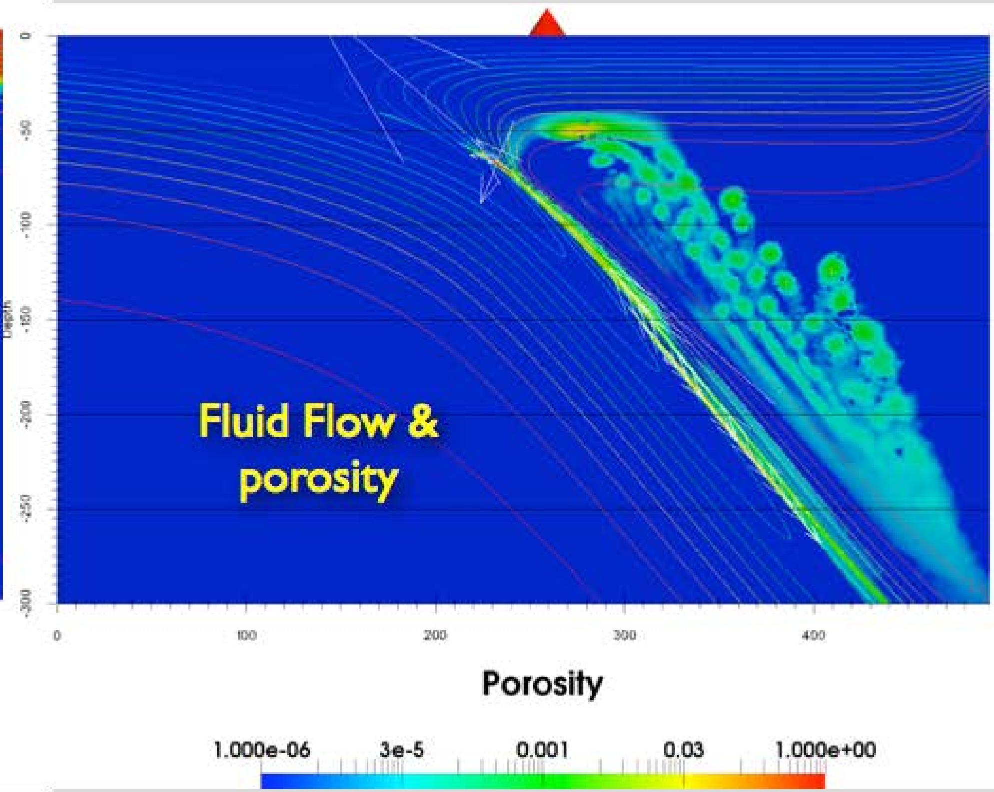


Aleutians
Chile
60
40
20
0
Pressure (kbar)
200
400
600
800
Temperature (°C)
10⁴ ppm
5000
2000
1000
500
200
100
50
10
arag
cc

TerraFERMA Examples

New subduction zone models





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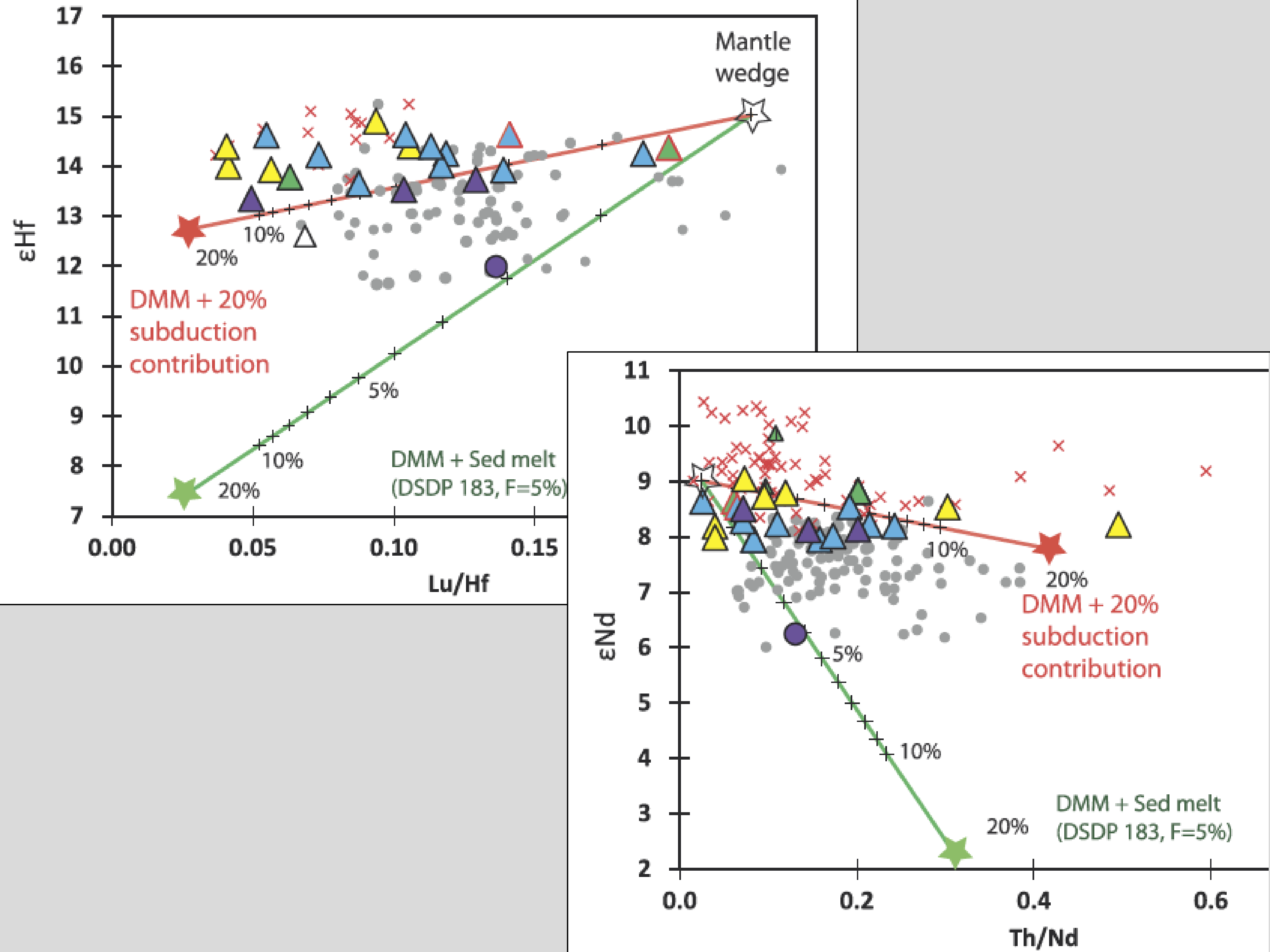
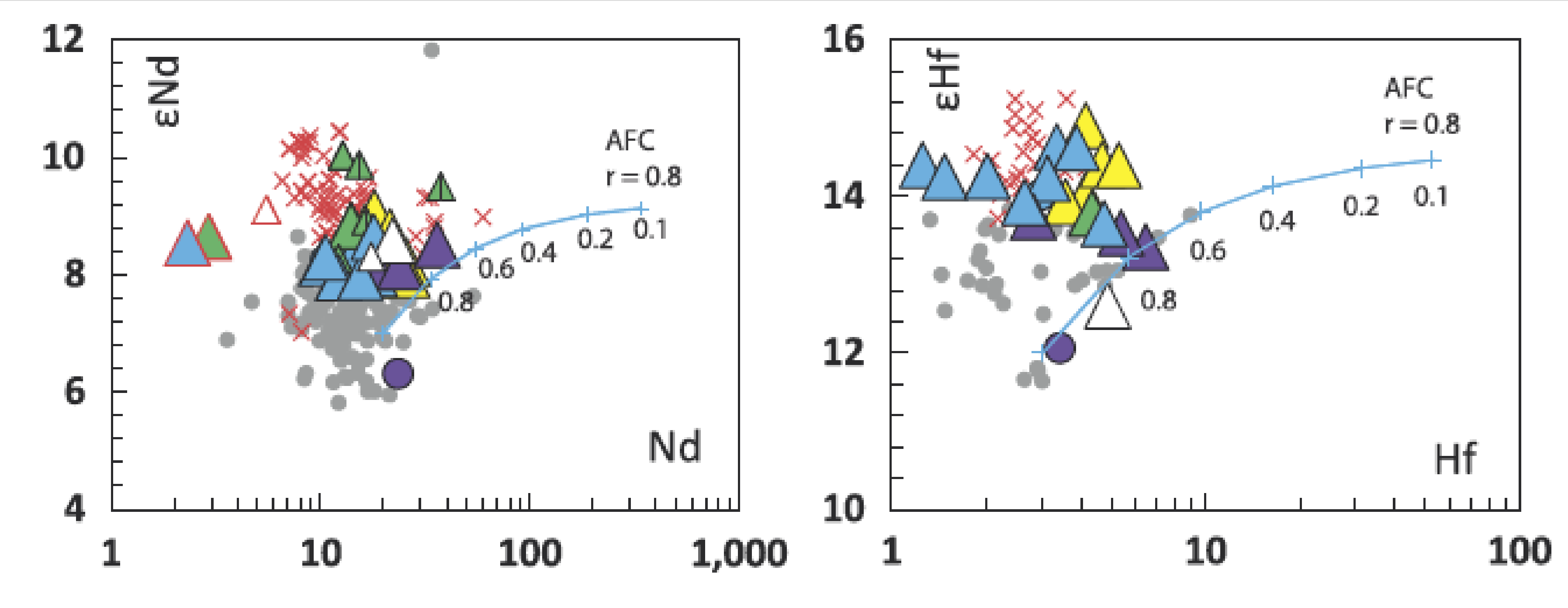
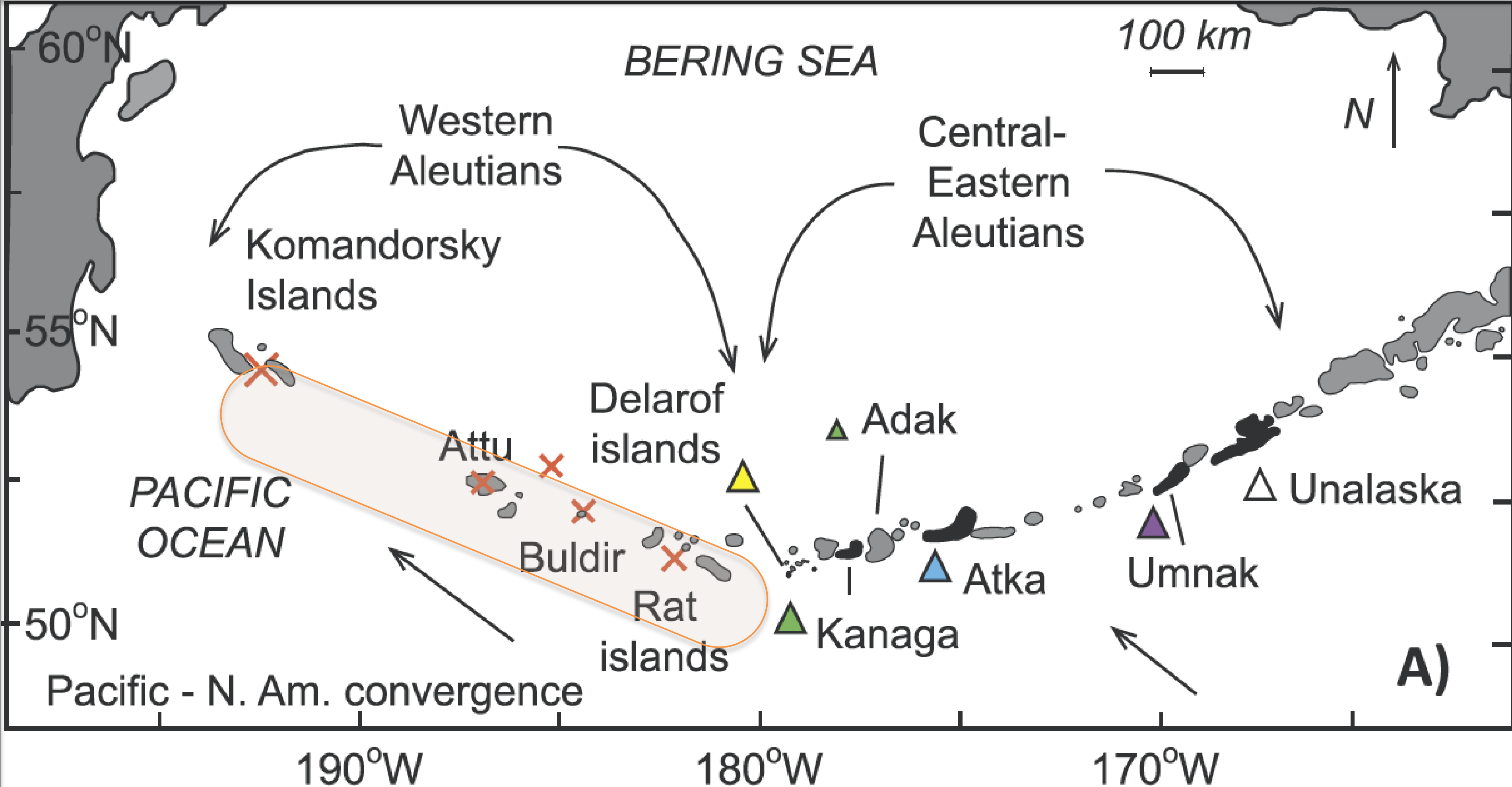


Mantle wedge
εHf
Lu/Hf
10%
20%
DMM + 20% subduction contribution
5%
10%
20%
DMM + Sed melt (DSDP 183, F=5%)
εNd
Th/Nd
10%
20%
DMM + 20% subduction contribution
5%
10%
20%
DMM + Sed melt (DSDP 183, F=5%)



εNd
Nd
AFC
r = 0.8
0.1
0.2
0.4
0.6
0.8
12
10
8
6
4
1
10
100
1,000
εHf
Hf
AFC
r = 0.8
0.1
0.2
0.4
0.6
0.8
16
14
12
10
1
10
100



systematically distinct sources for Aleutian plutons and lavas

Merry Cai, Matt Rioux, Peter Kelemen & Steve Goldstein

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