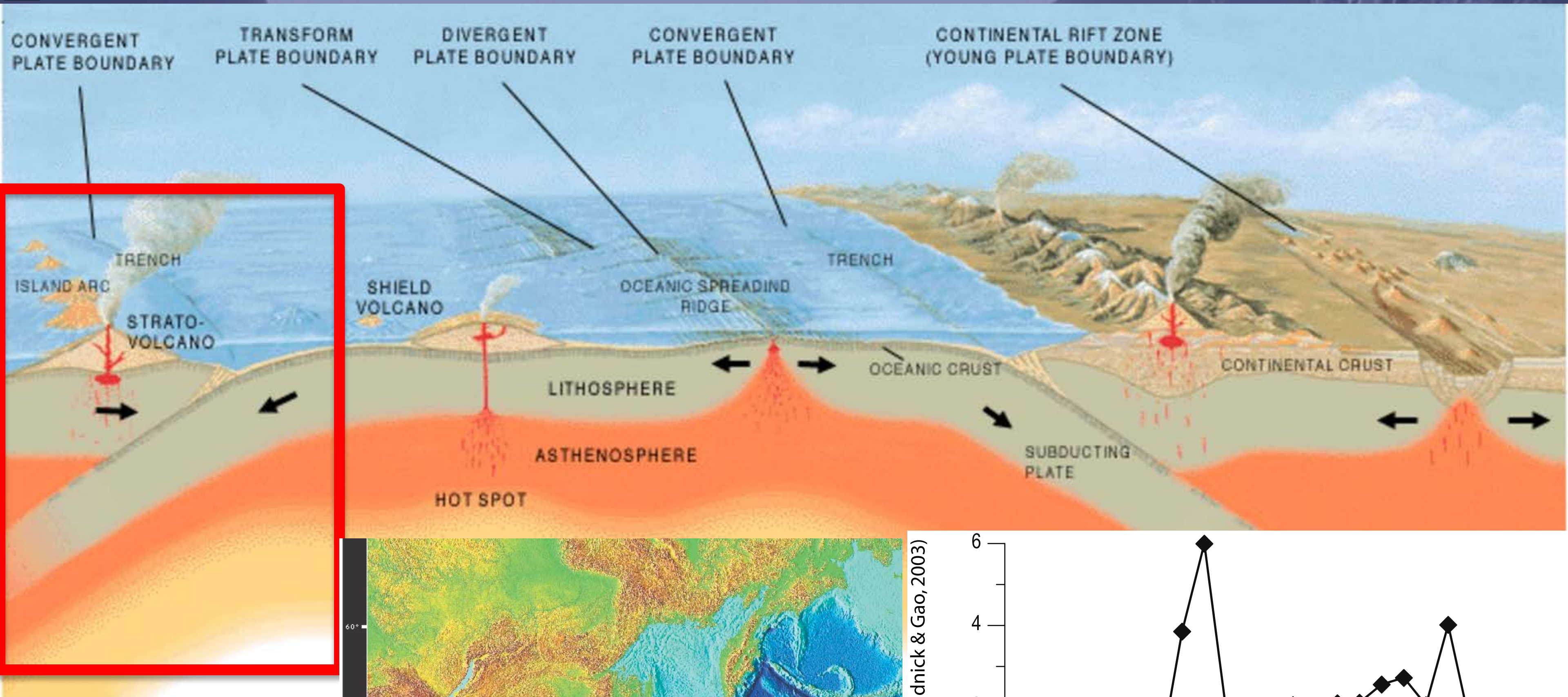
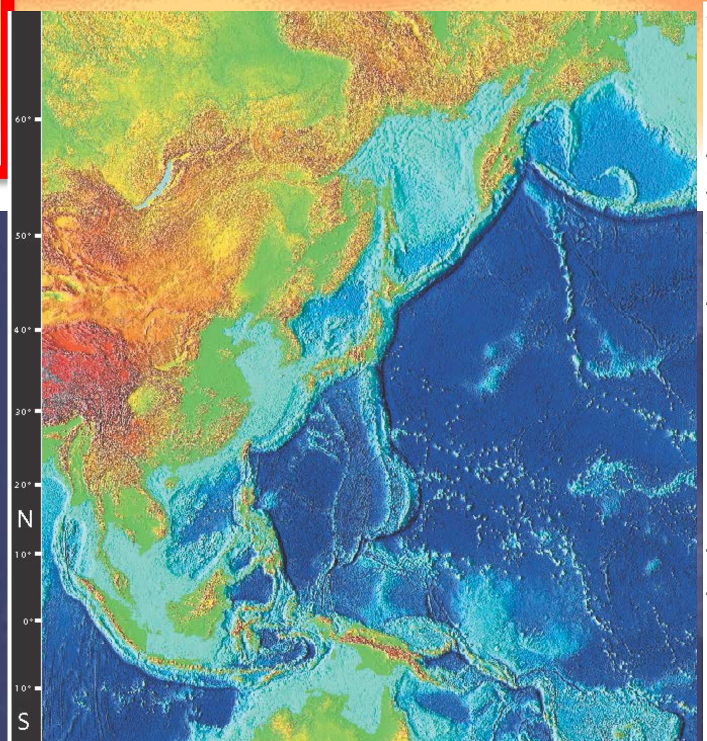
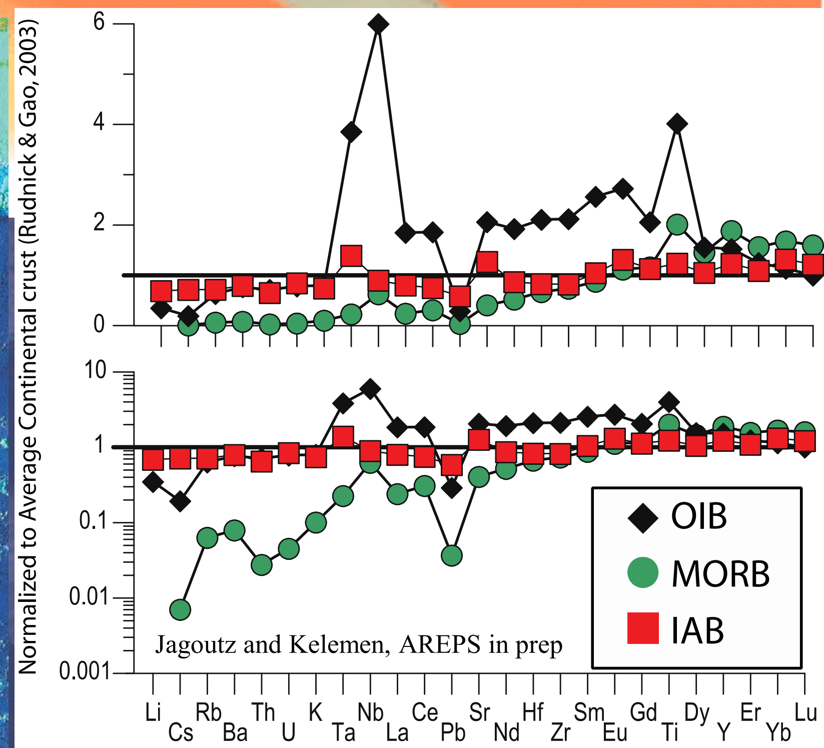
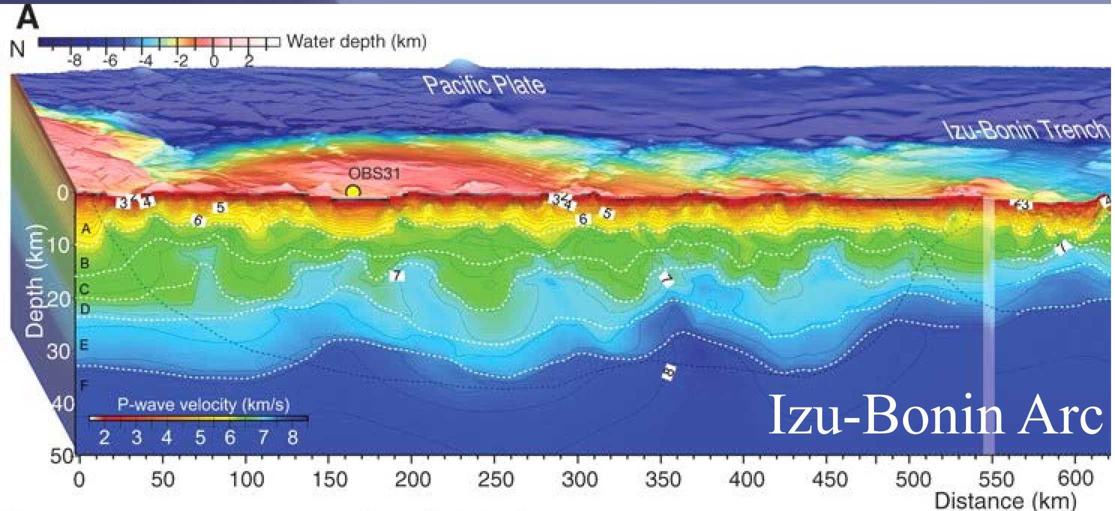
“The formation of continental crust in arcs: The seismological perspective”

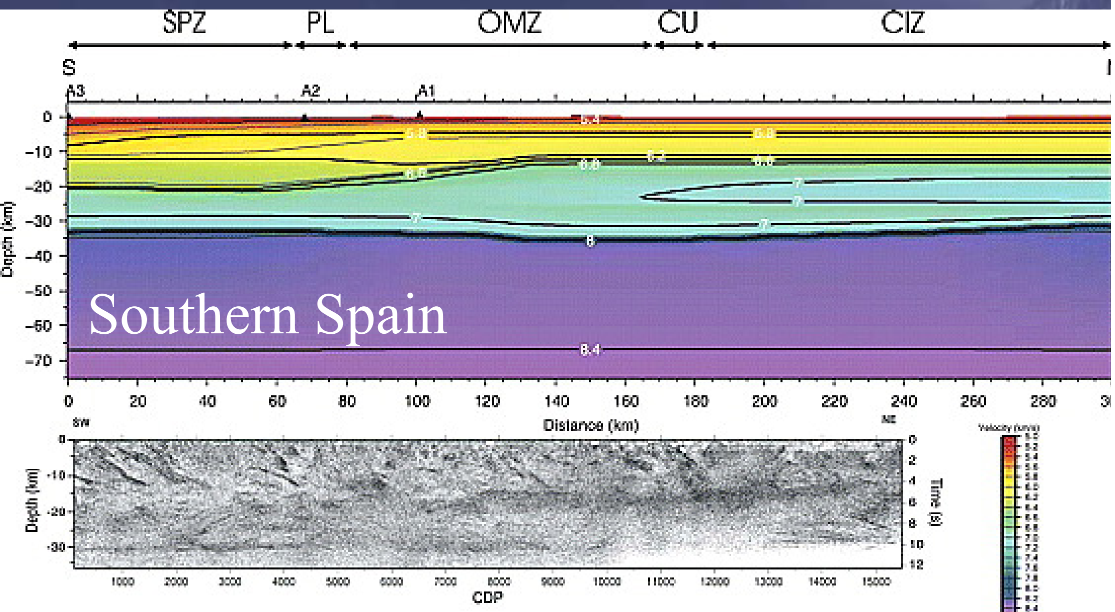
- Oliver Jagoutz (MIT)
- Mark Behn (WHOI)
- Peter Kelemen (LDEO)

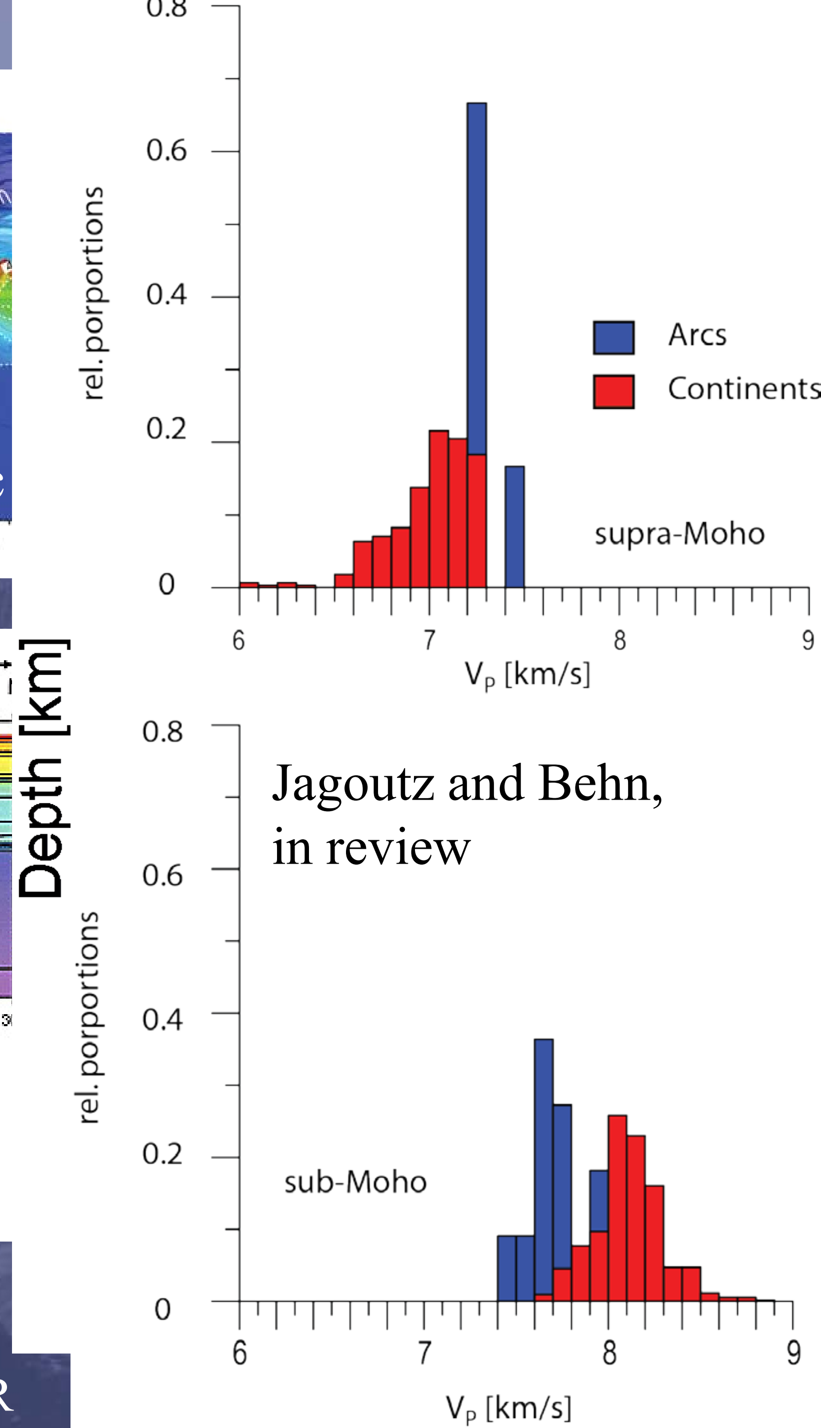

CONVERGENT PLATE BOUNDARY
TRANSFORM PLATE BOUNDARY
DIVERGENT PLATE BOUNDARY
CONVERGENT PLATE BOUNDARY
CONTINENTAL RIFT ZONE (YOUNG PLATE BOUNDARY)
TRENCH
ISLAND ARC
STRATO-VOLCANO
SHIELD VOLCANO
OCEANIC SPREADING RIDGE
TRENCH
OCEANIC CRUST
CONTINENTAL CRUST
LITHOSPHERE
ASTHENOSPHERE
HOT SPOT
SUBDUCTING PLATE


N
S

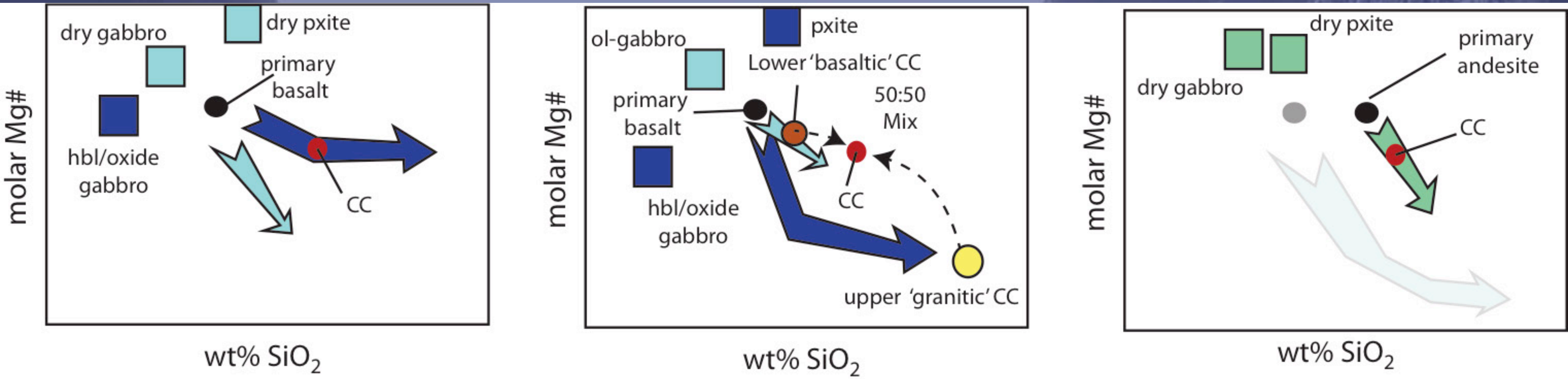

Normalized to Average Continental crust (Rudnick & Gao, 2003)
6
4
2
0
10
1
0.1
0.01
0.001
Li Cs Rb Ba Th U K Ta Nb La Ce Pb Sr Nd Hf Zr Sm Eu Gd Ti Dy Y Er Yb Lu
OIB
MORB
IAB
Jagoutz and Kelemen, AREPS in prep

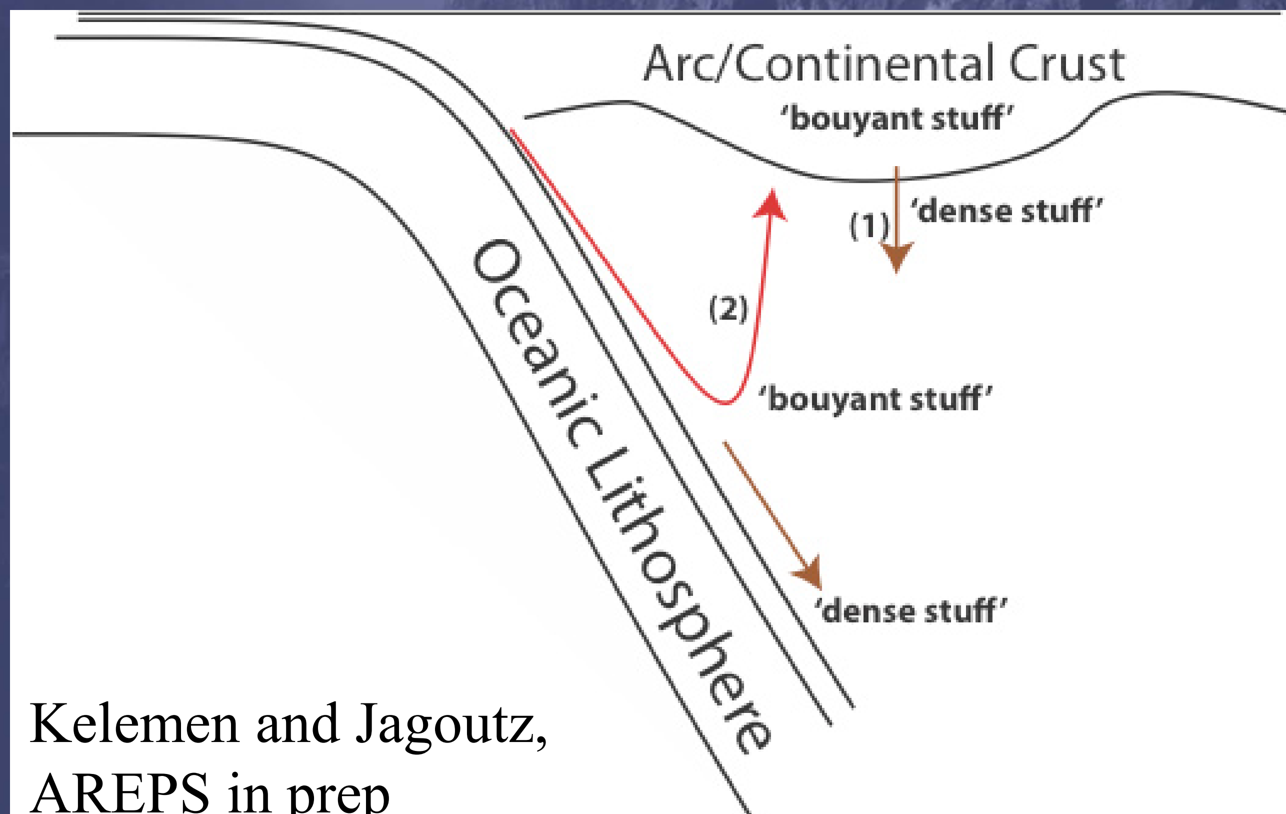






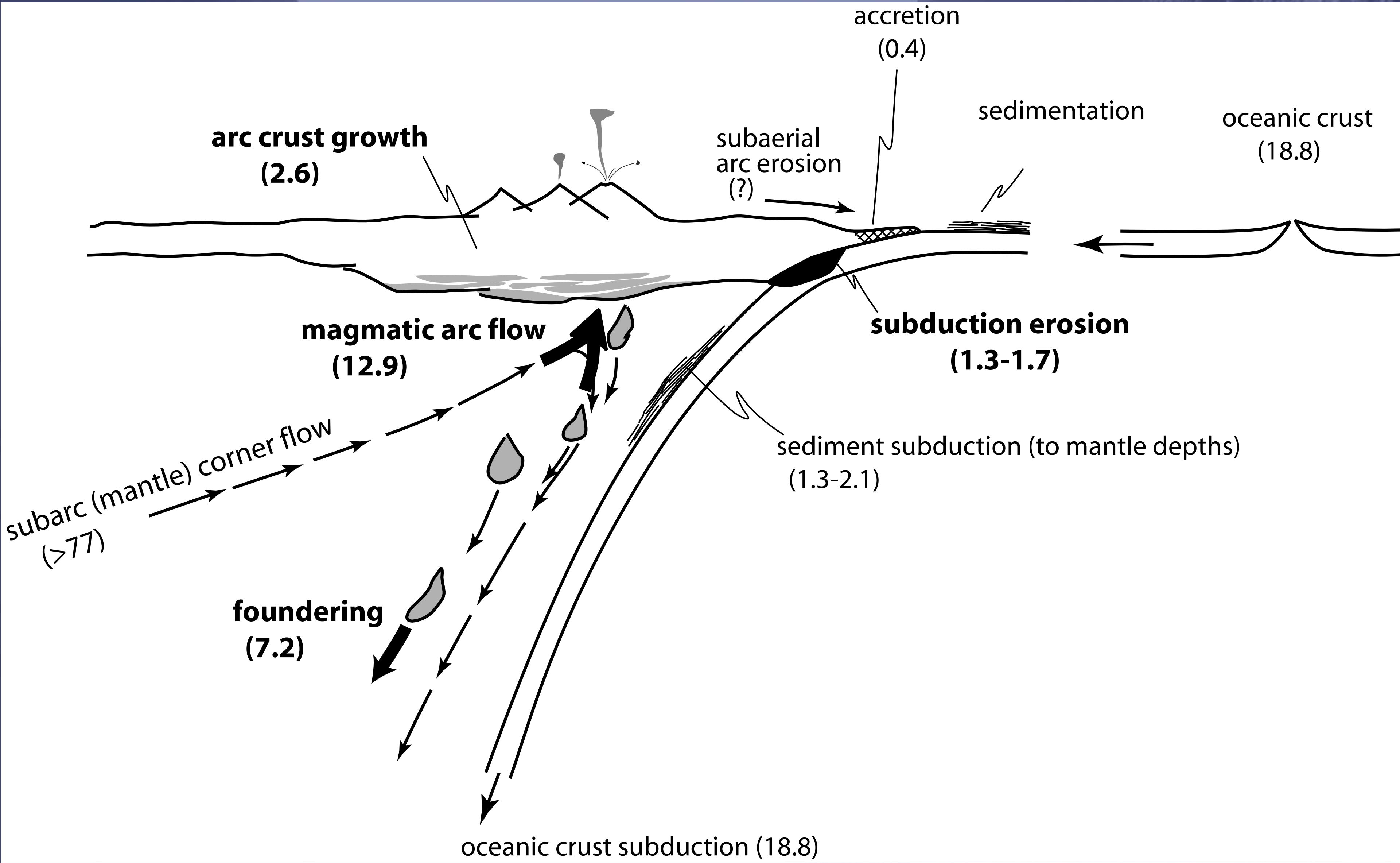
Kodaira et al, 2007 Geology; Palomeras et al, 2009, JGR





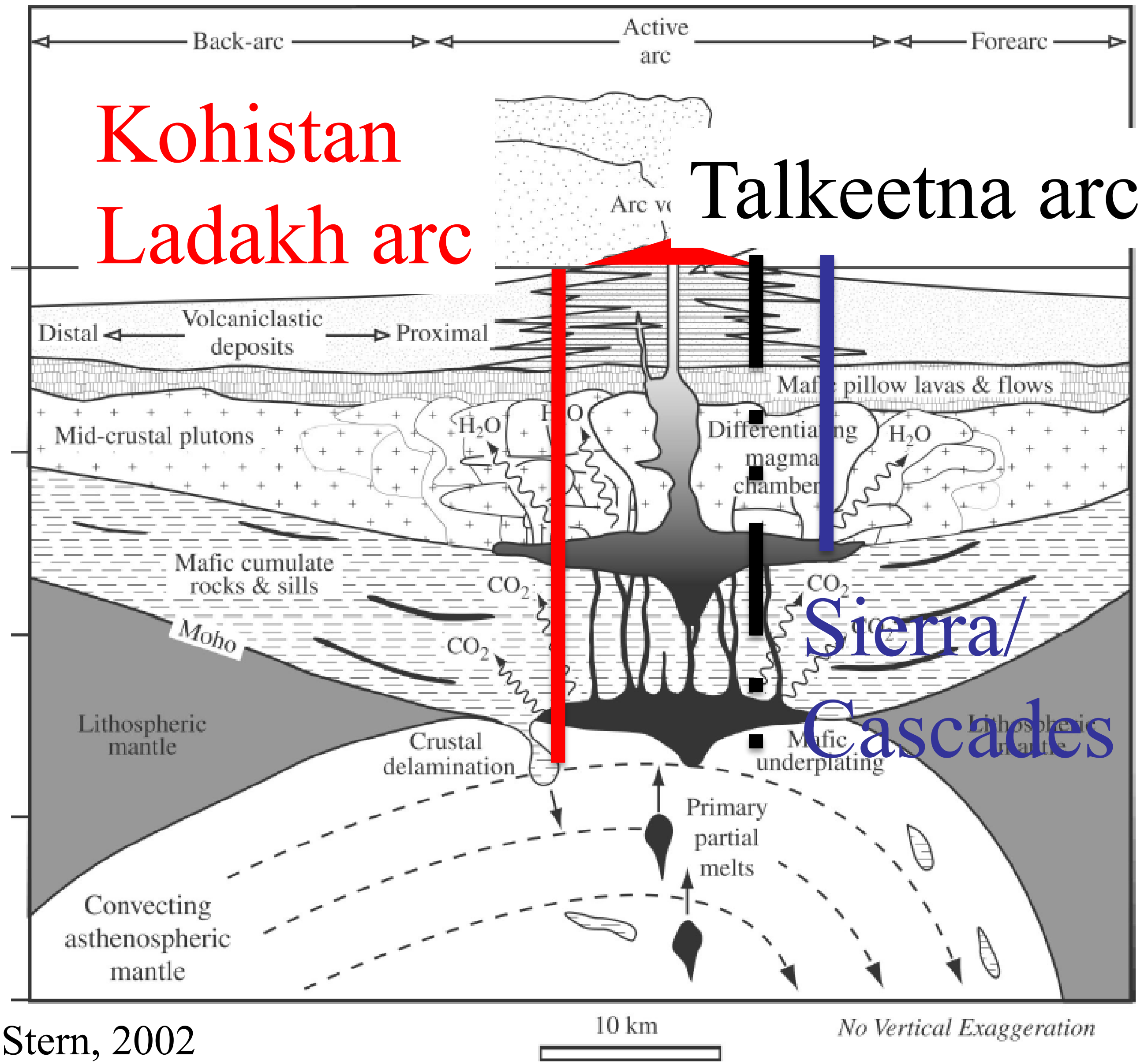
Kelemen and Jagoutz, AREPS in prep

Subduction zone mass balance [km^3/a]

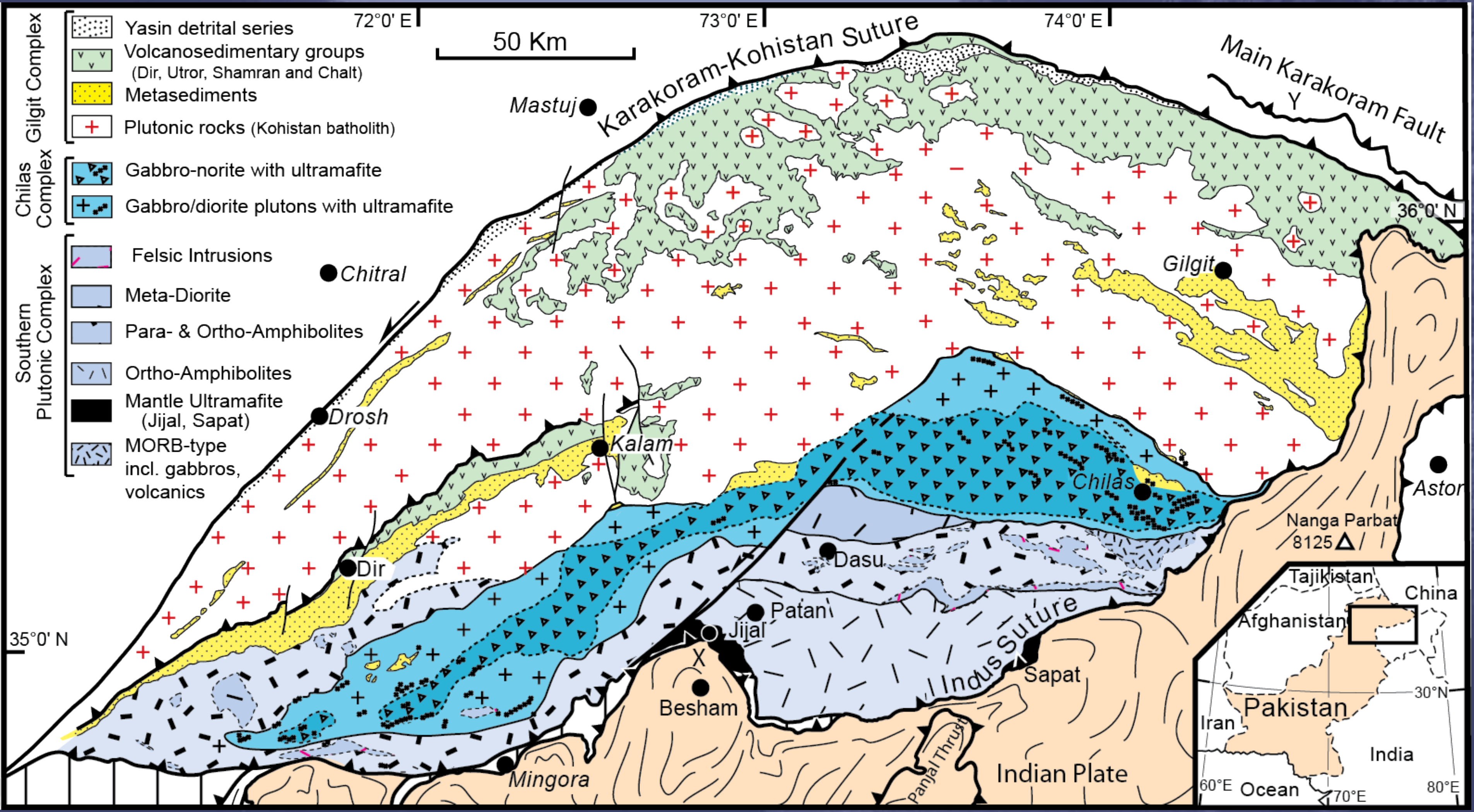


Jagoutz and Schmidt, 2013, EPSL

Exposed arc sections

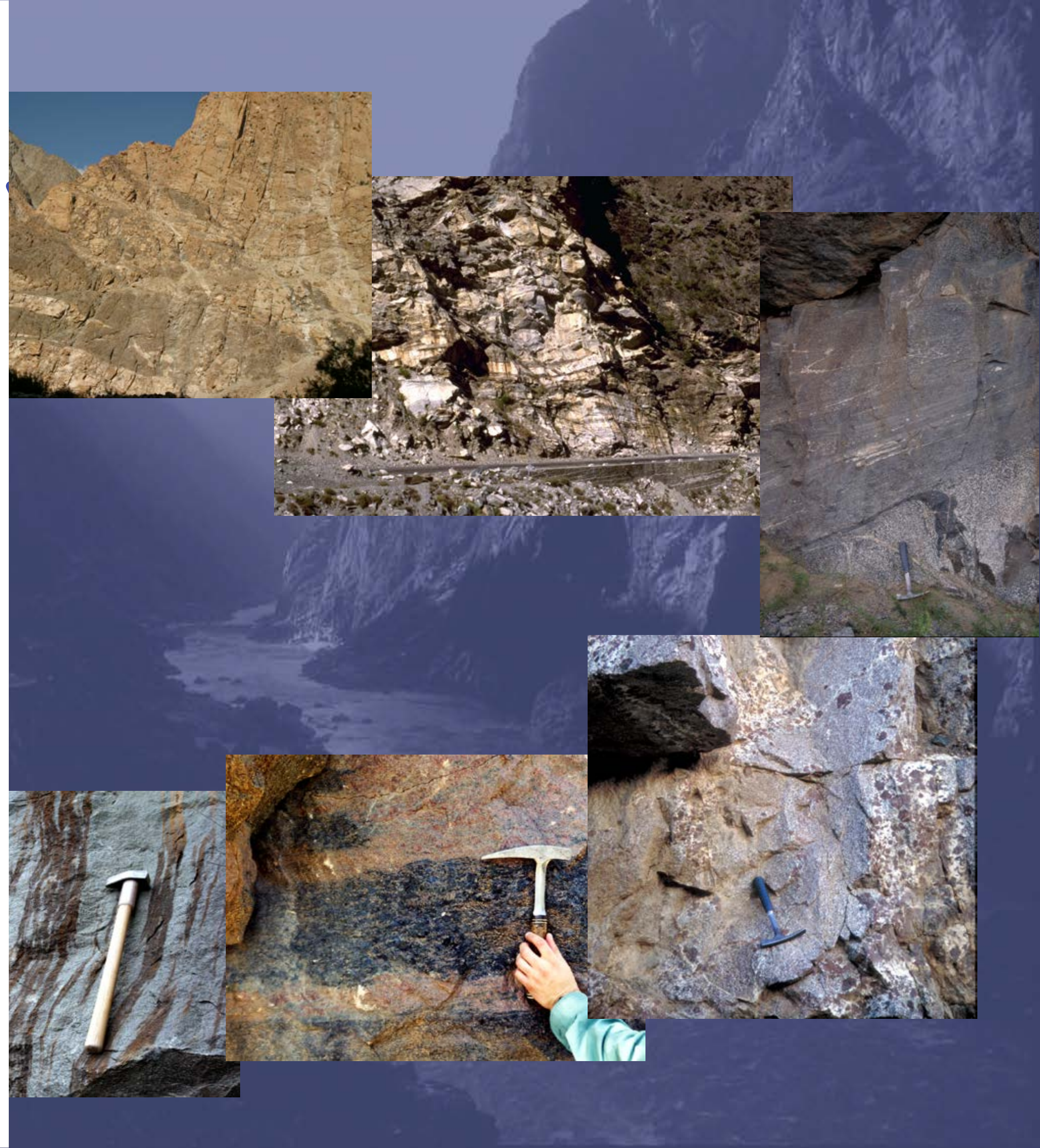


Stern, 2002

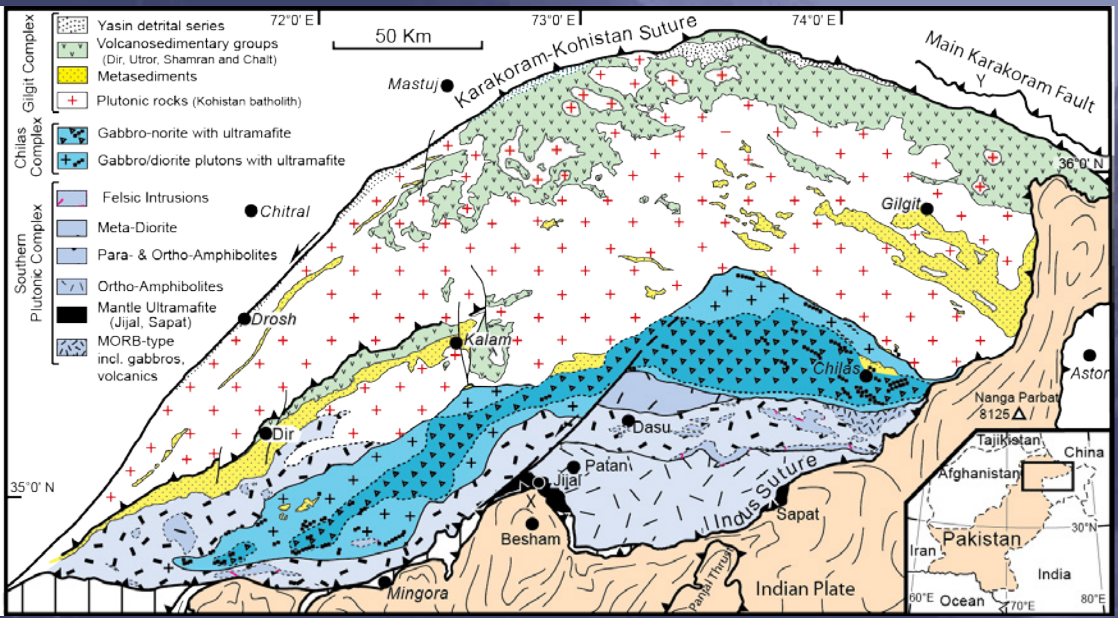


Jagoutz et al., 2011, EPSL


Depth (km)



How to ‘translate’ an exposed arc section



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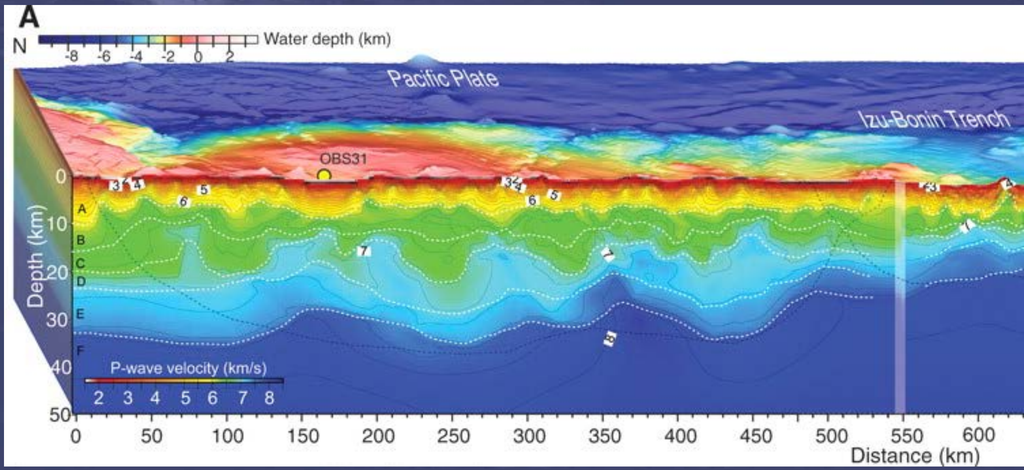
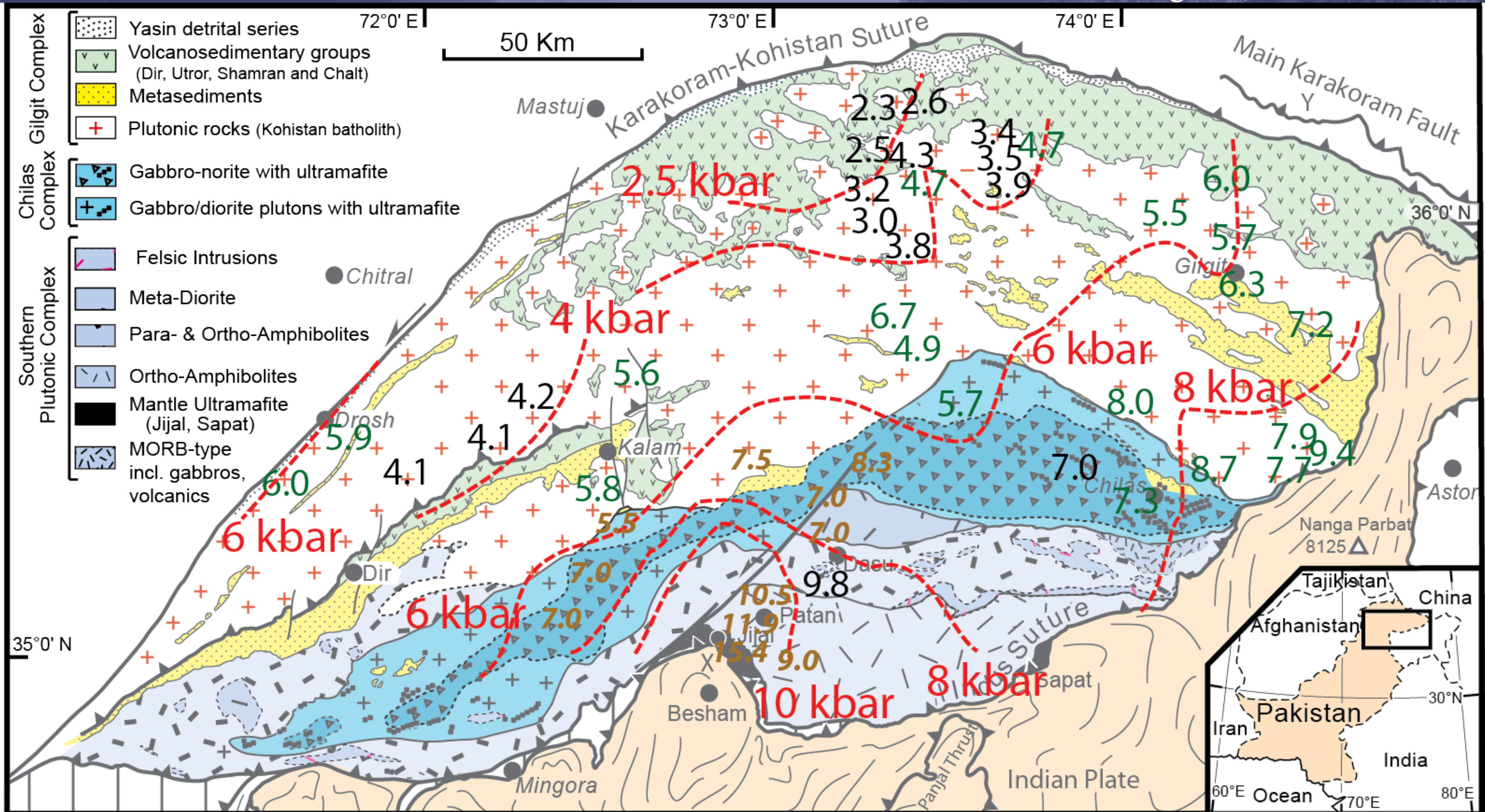
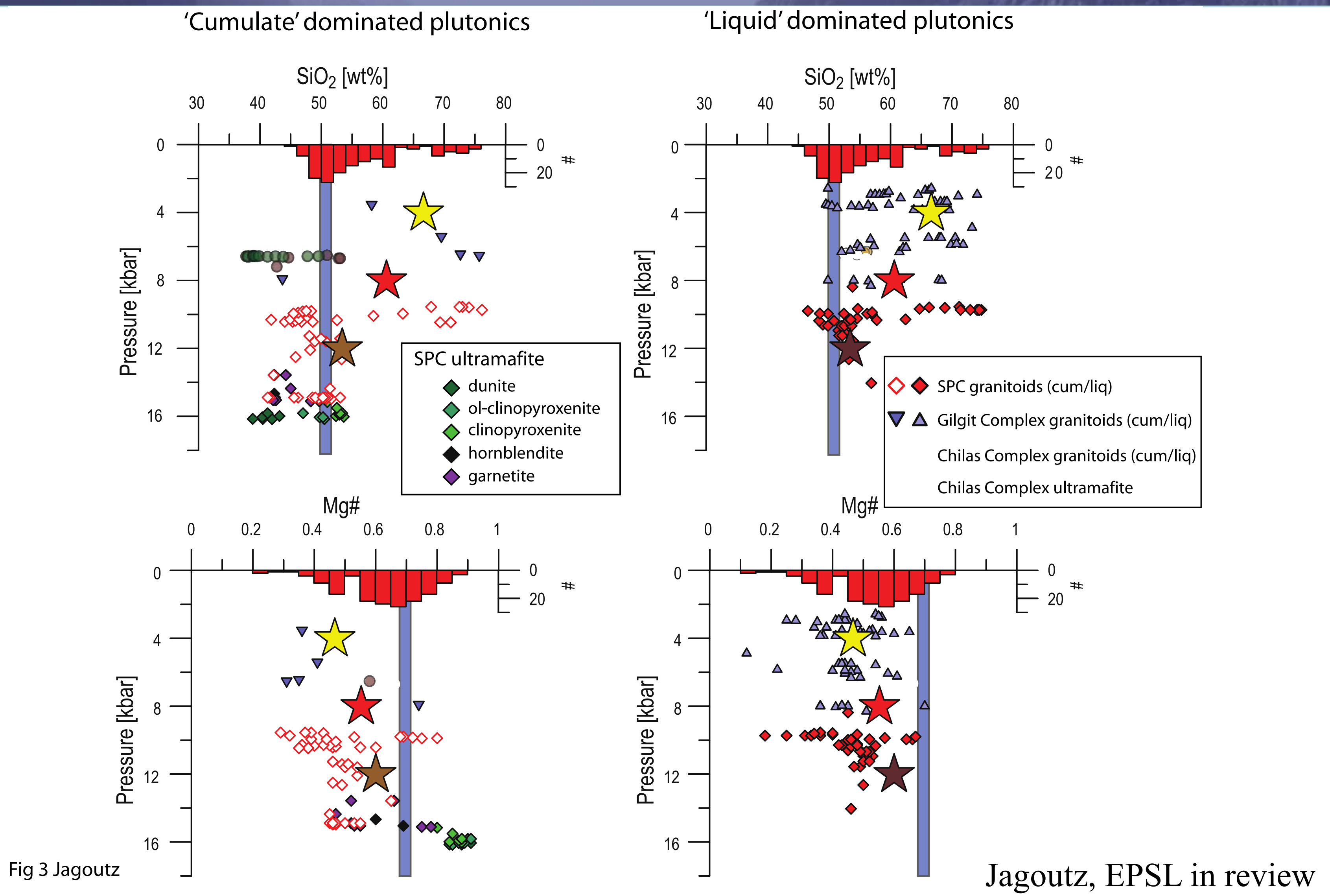


How to 'translate' an exposed arc section

Jagoutz, EPSL in review



Composition vs Depth



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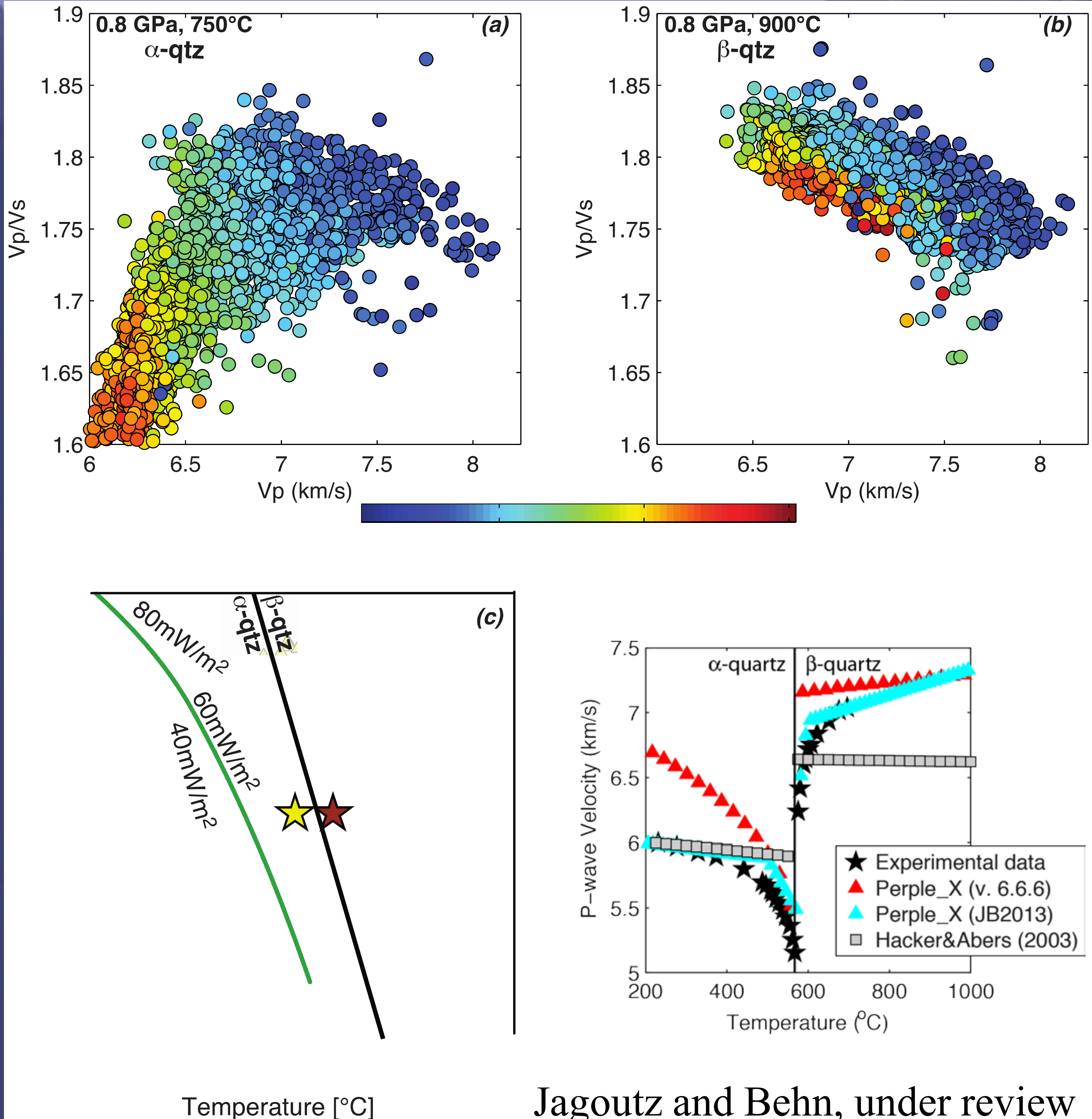
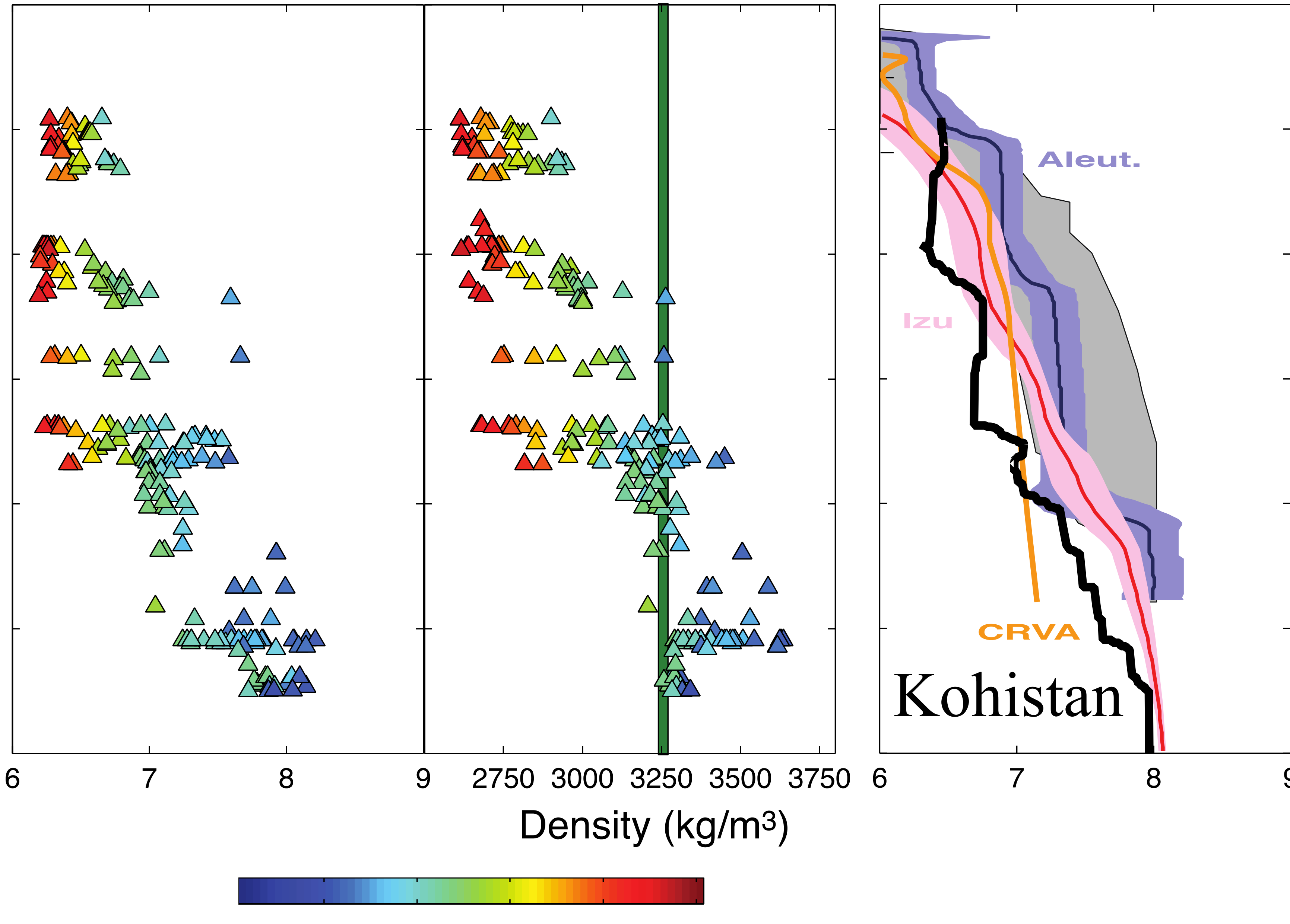
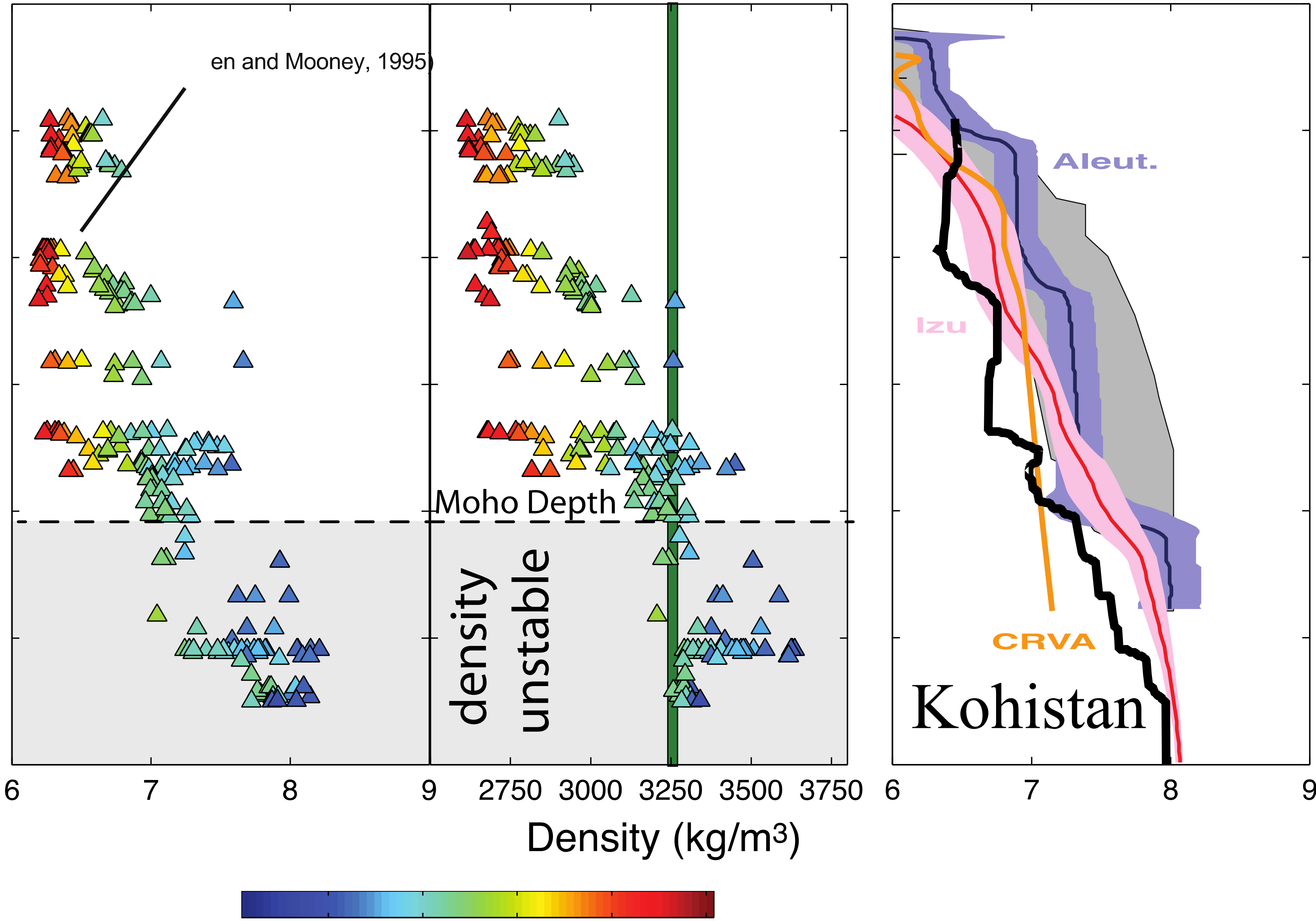


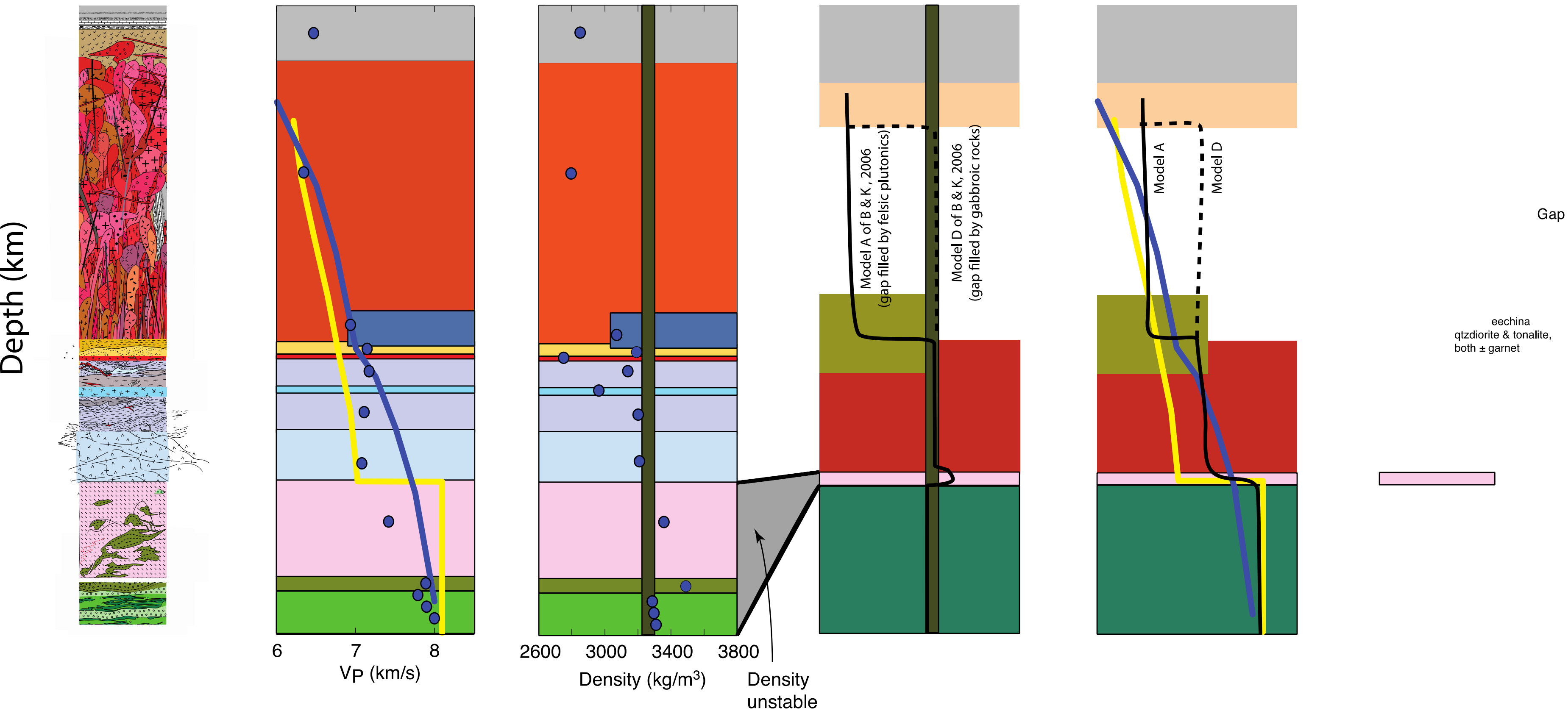
Jagoutz and Behn, under review



Jagoutz and Behn, under review



Jagoutz and Behn, under review



Jagoutz and Behn, under review

Magmatic growth of a cumulate layer

$$h = q\alpha t$$

h = Cumulate layer thickness
t = time
q = magma flux
α = fractionation factor

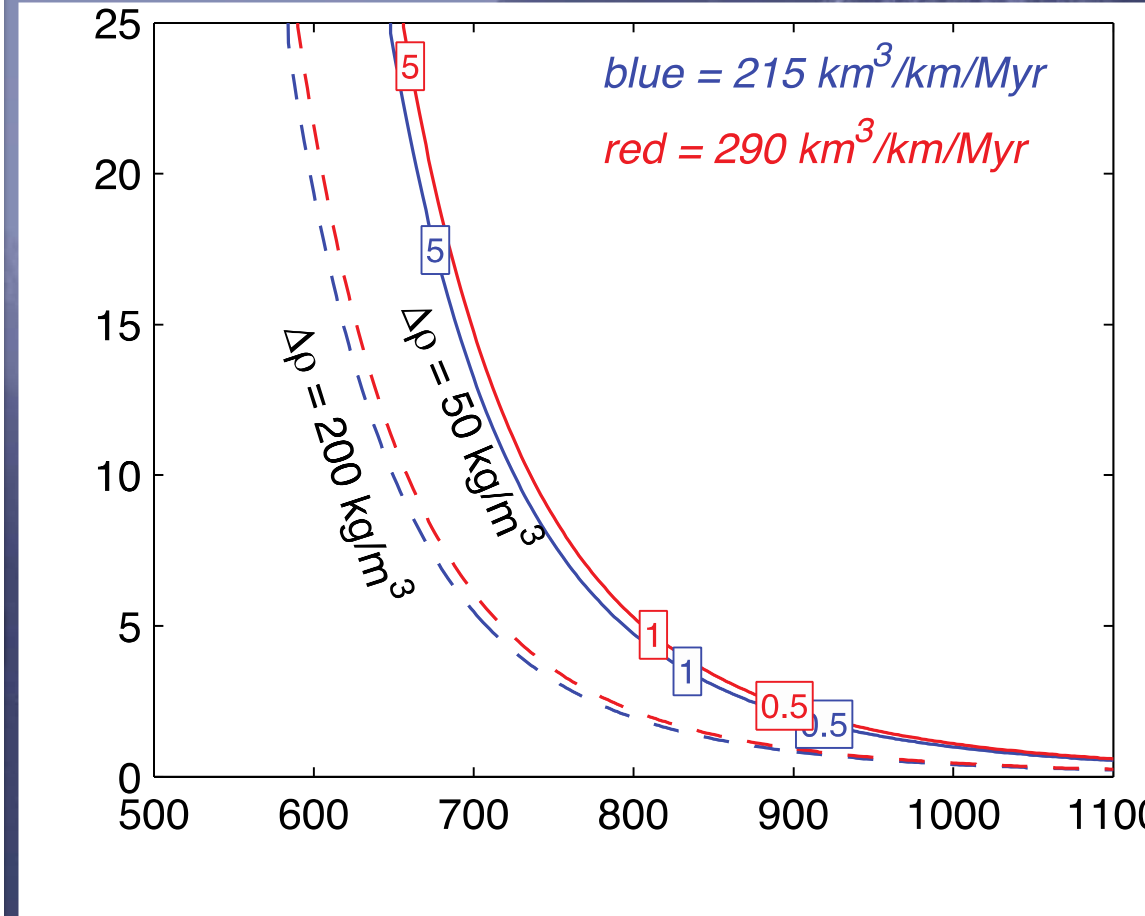
Instability growth rates

(after Jull and Kelemen, 2001)

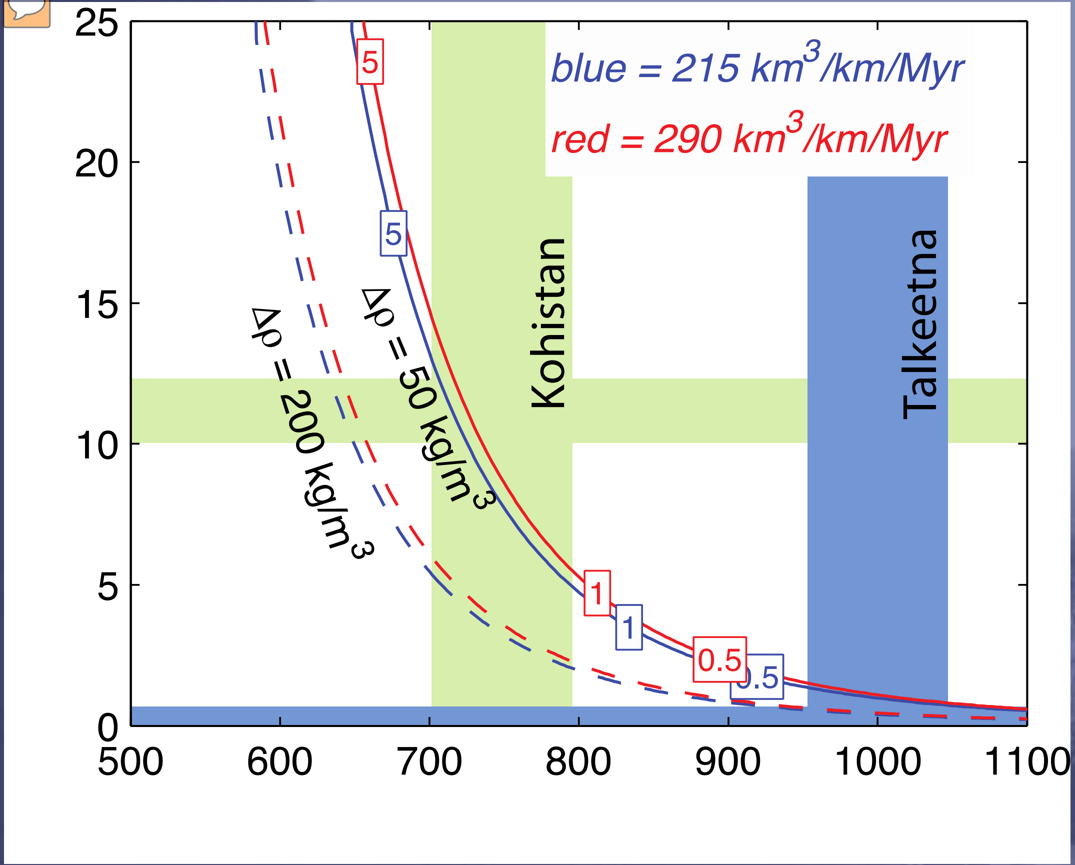
$$t_b = \left(\frac{n}{C'}\right)^n \frac{Z_0^{'(1-n)}}{n-1} S$$

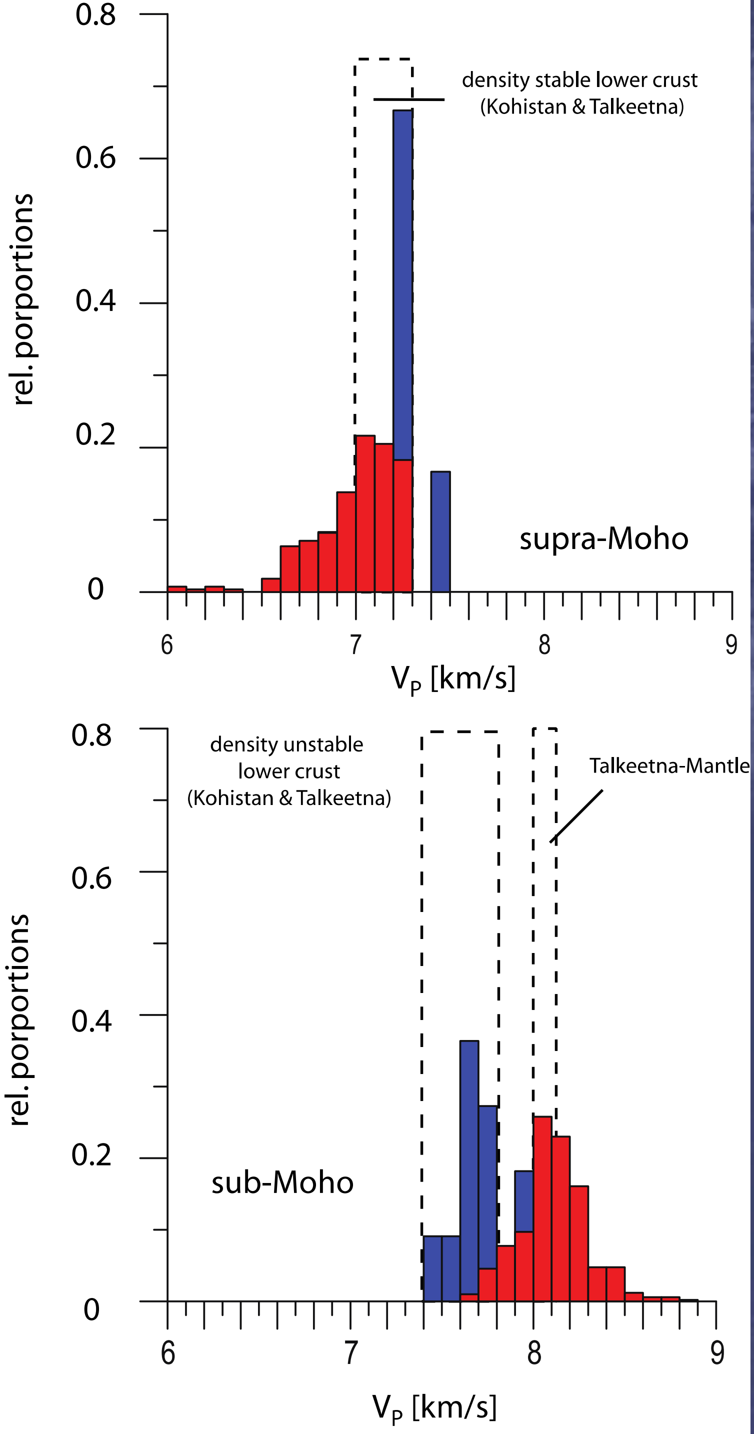
$$S = \left(\frac{B}{2\Delta\rho g h}\right)^n$$

$$B = A^{-1/n} \exp\left(\frac{Q}{nRT}\right)$$



Jagoutz and Behn, under review





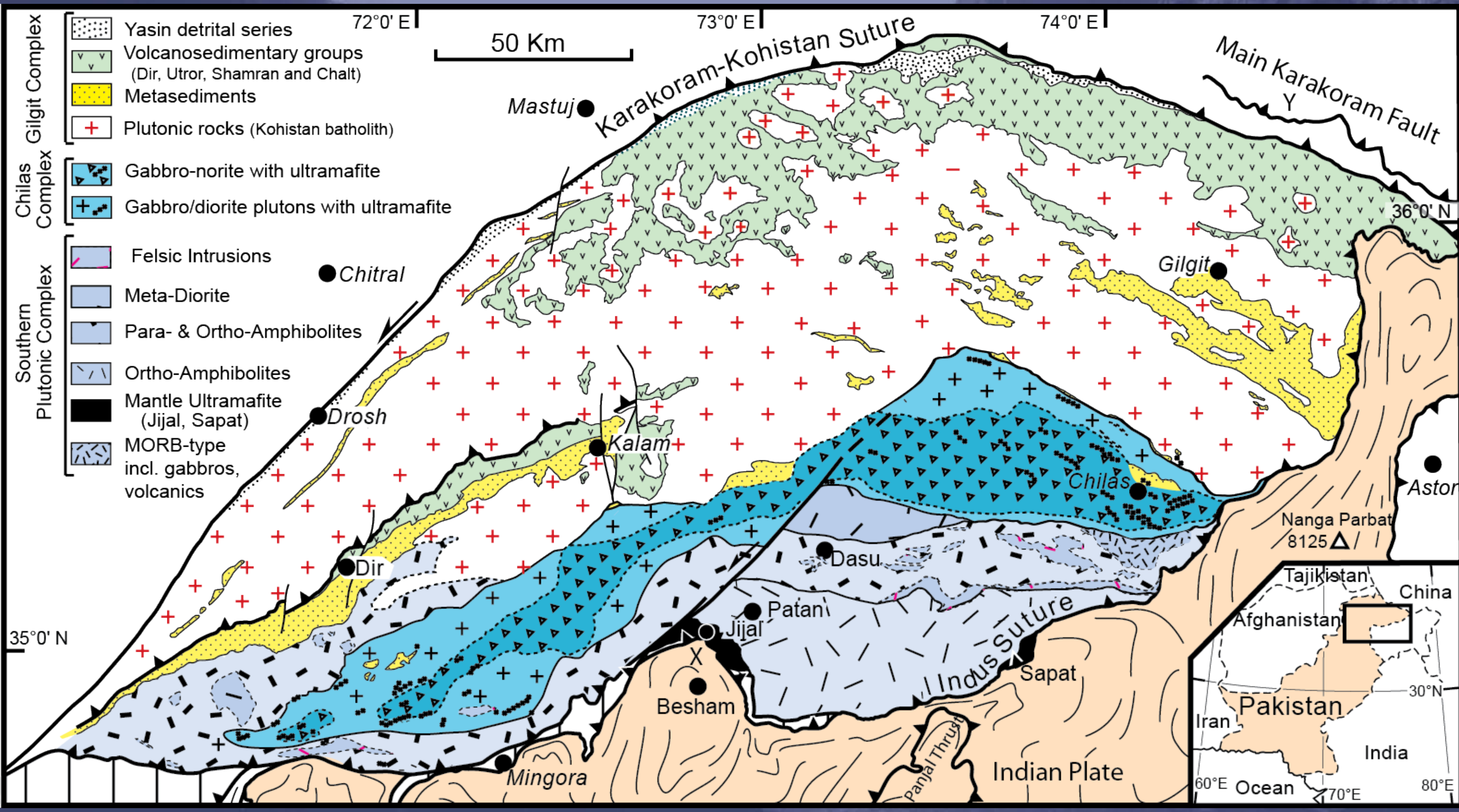
Jagoutz and Behn,
under review

Conclusions

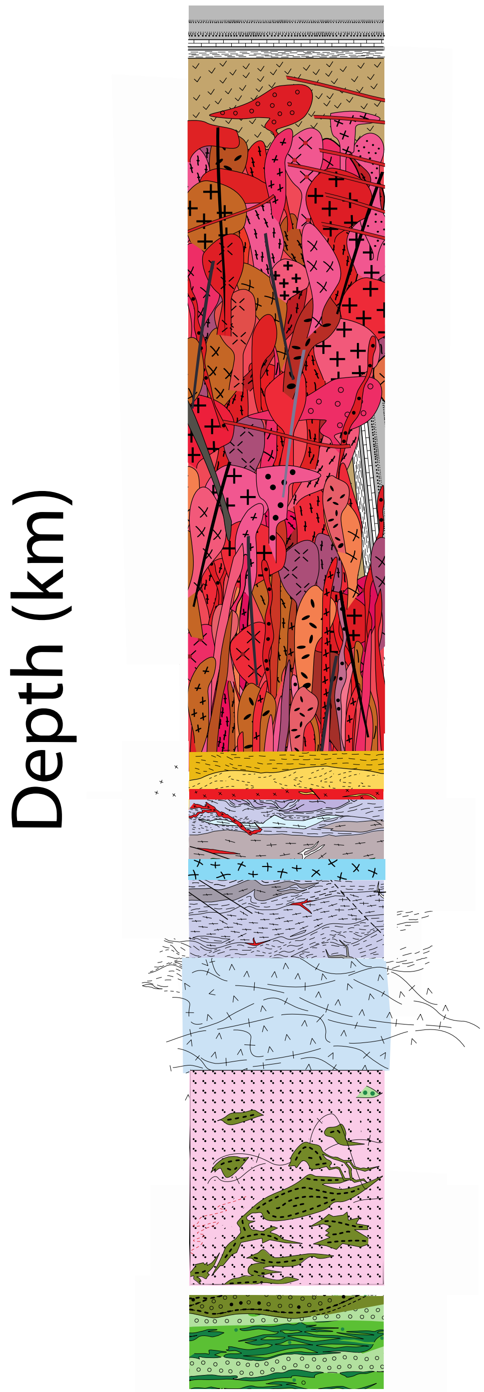
- Foundering of the density unstable lower arc crust can explain the location and the characteristics of the continental Moho

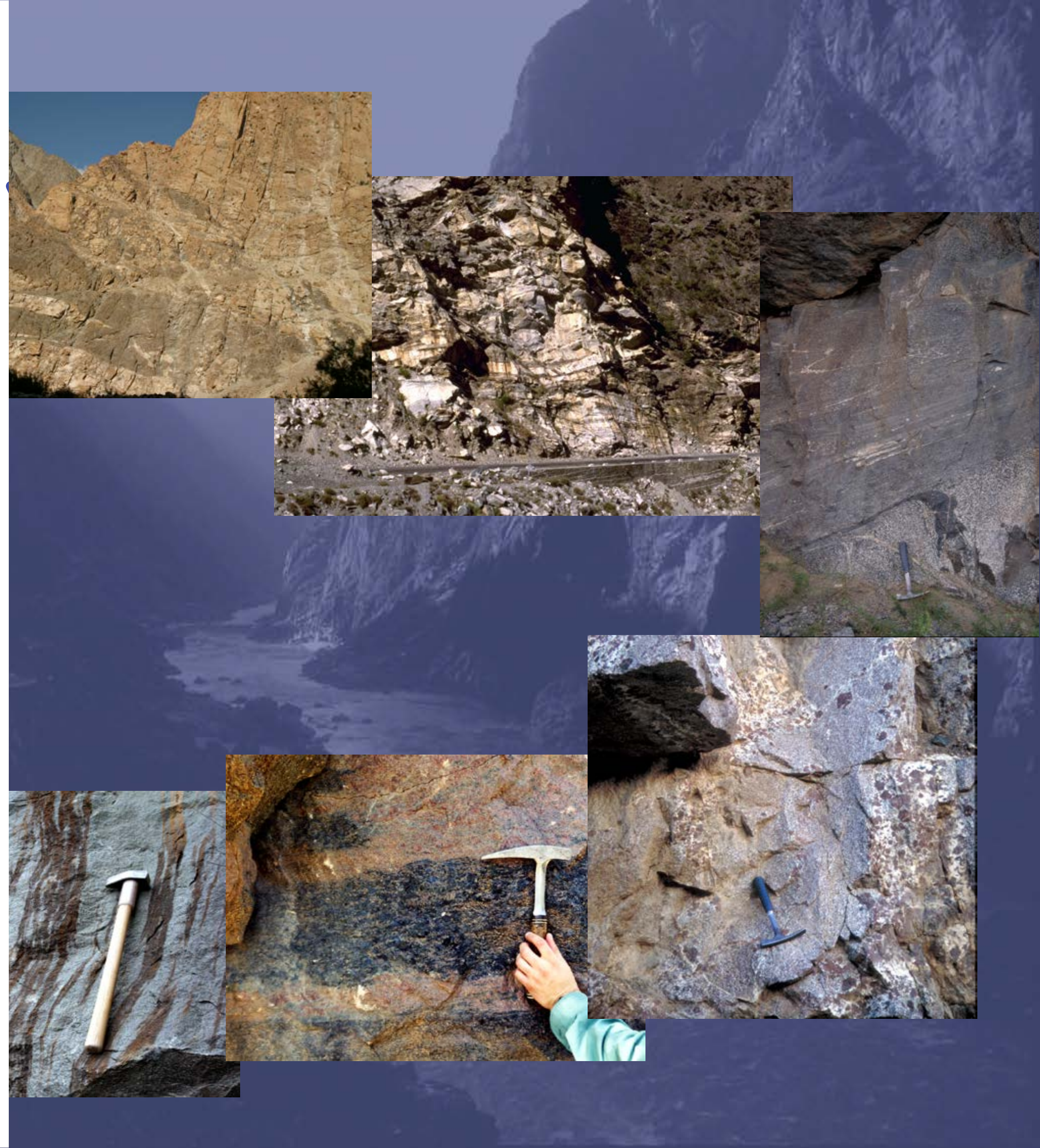
Conclusions

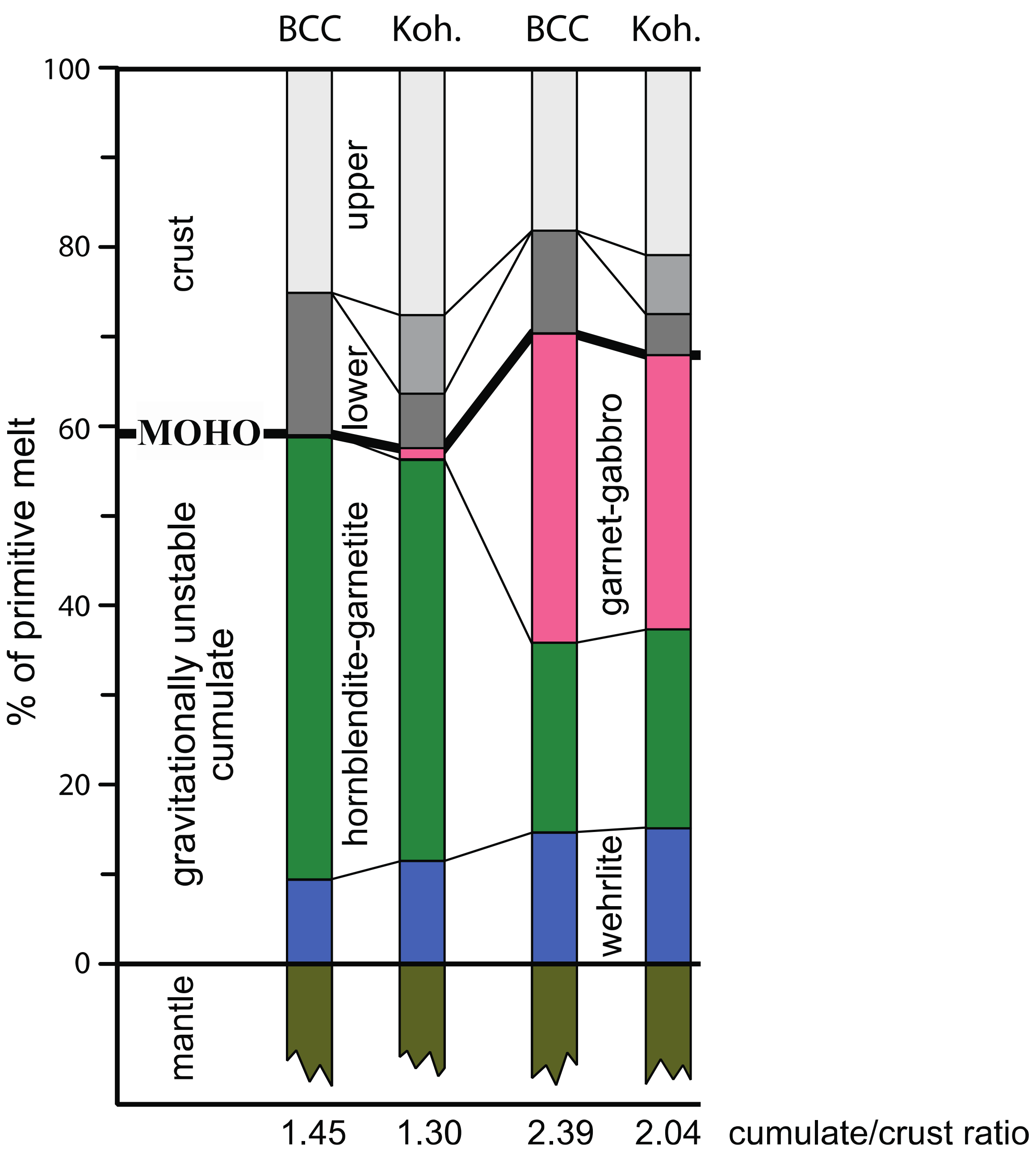
- Continental crust can be formed in oceanic arcs
- Foundering of density unstable lower crust is an essential mechanism :
  - The composition of the CC
  - The location and characteristics of the CC Moho
  - Influence on the global 'mantle zoo'



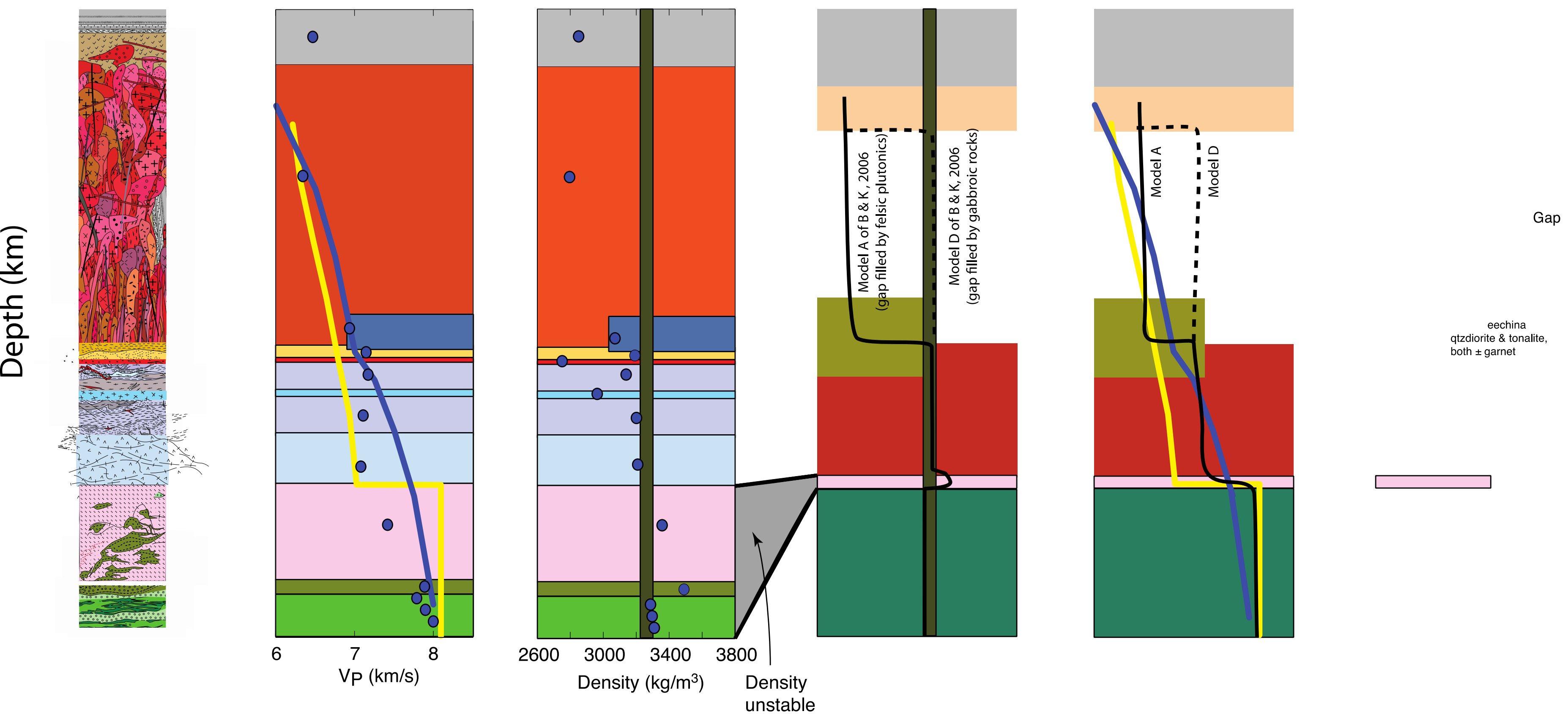
Jagoutz et al., 2011, EPSL


Depth (km)

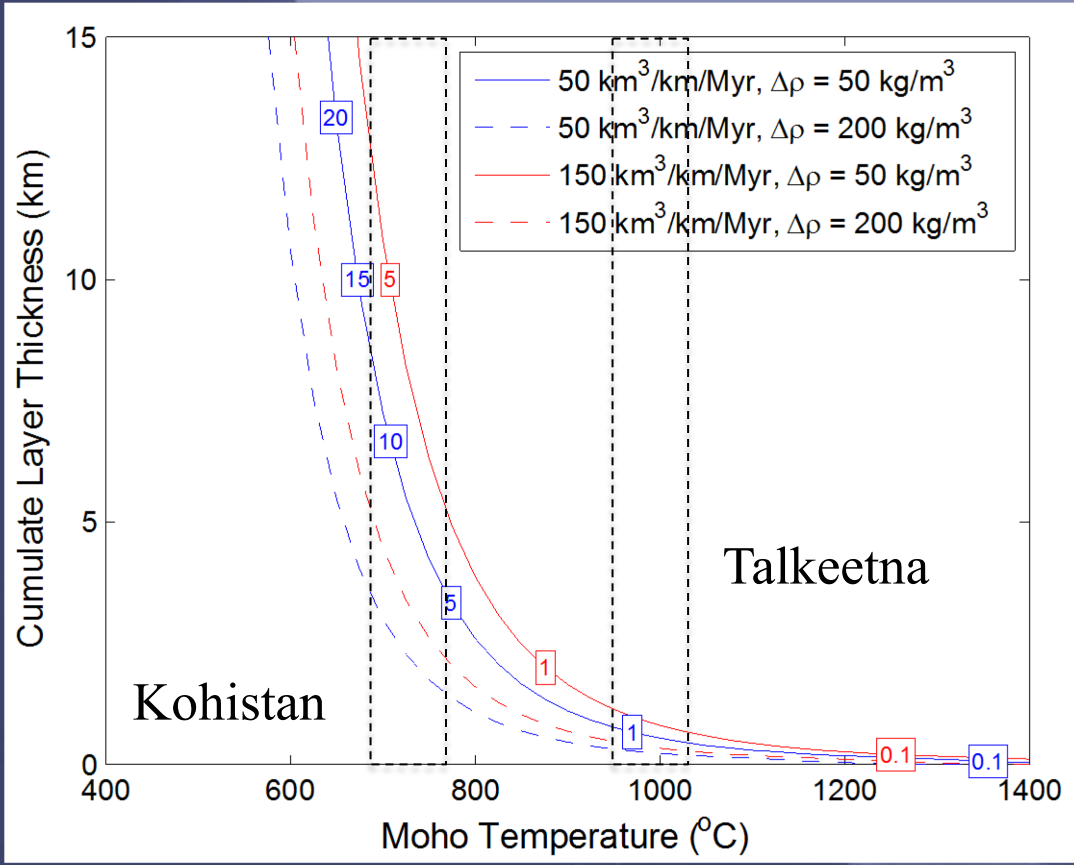


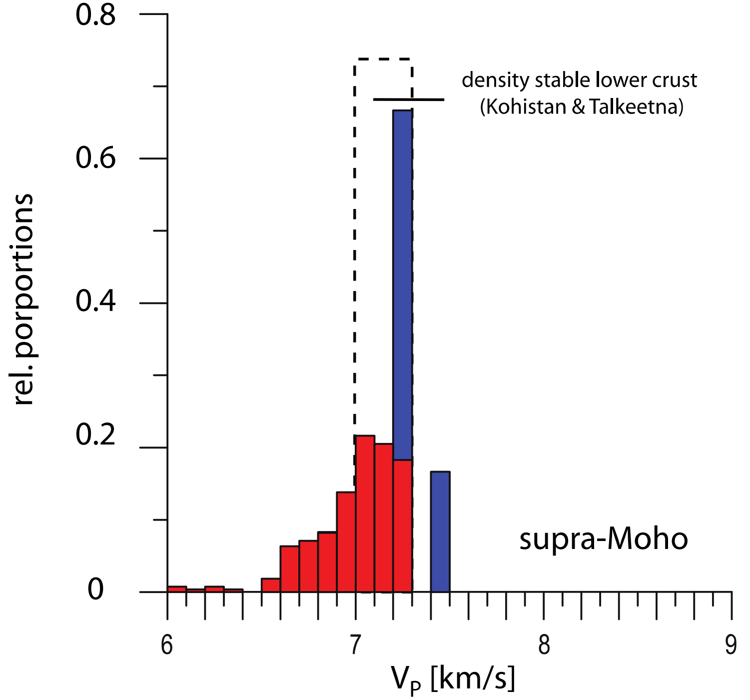


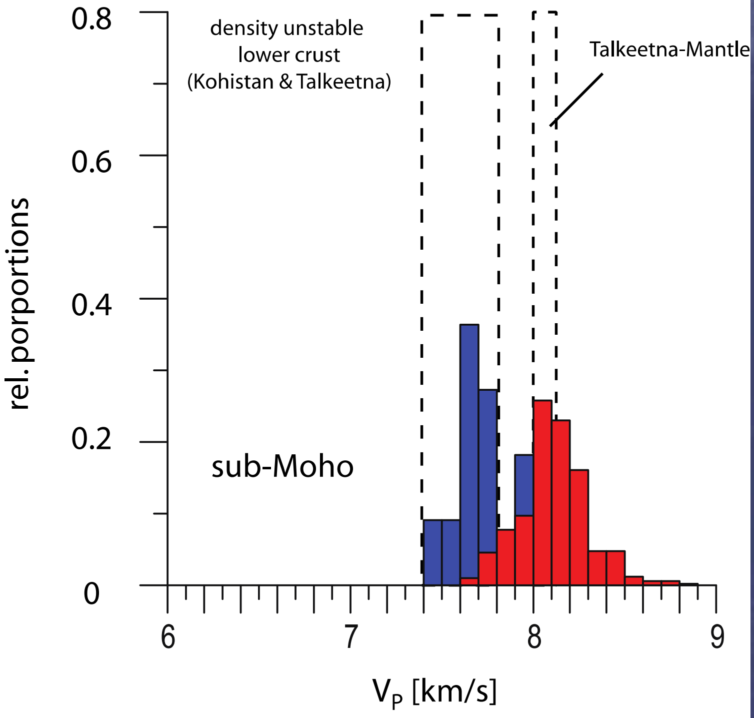
Schmidt and Jagoutz, EPSL accepted



Jagoutz and Behn, in prep

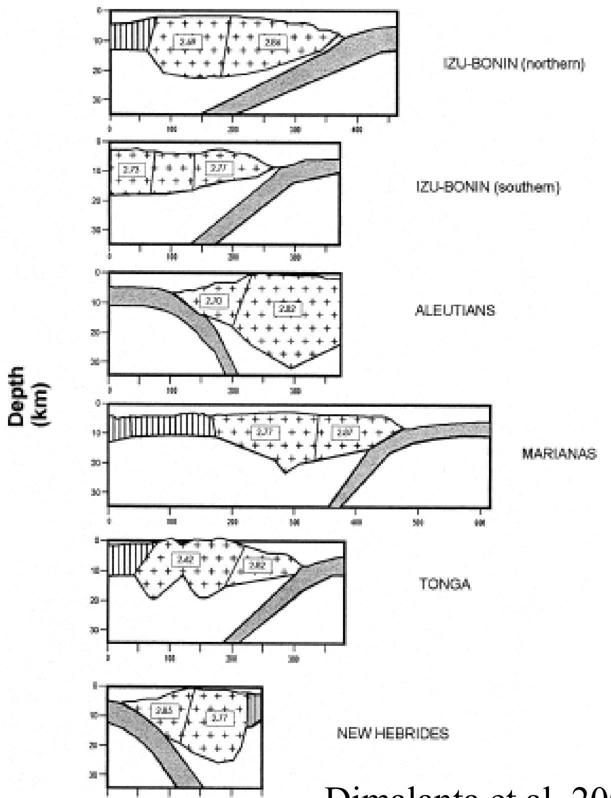






Jagoutz and Behn, in prep

The problem



Dimalanta et al. 2002

Arc production rate
~ 1.5-7 km^3/a

If $C_{arc} = C_{parcmelt}$

$\Rightarrow$Arc production rate=Arc magma flux

Else

Arc production rate=
Arc magma flux-delamination flux
and
$yC_{arc}=xC_{parcmelt}-(1-x)C_{delaminat}$

We need:
C_{arc}, $C_{delaminat}$, $C_{parcmelt,}$ x

Take home messages

- A ‘hidden’ mass flux at the mantle-crust interface in arc exist that has a similar magnitude as the subduction of oceanic crust

- Foundering of the density unstable lower arc crust can explain the location and the characteristics of the continental Moho

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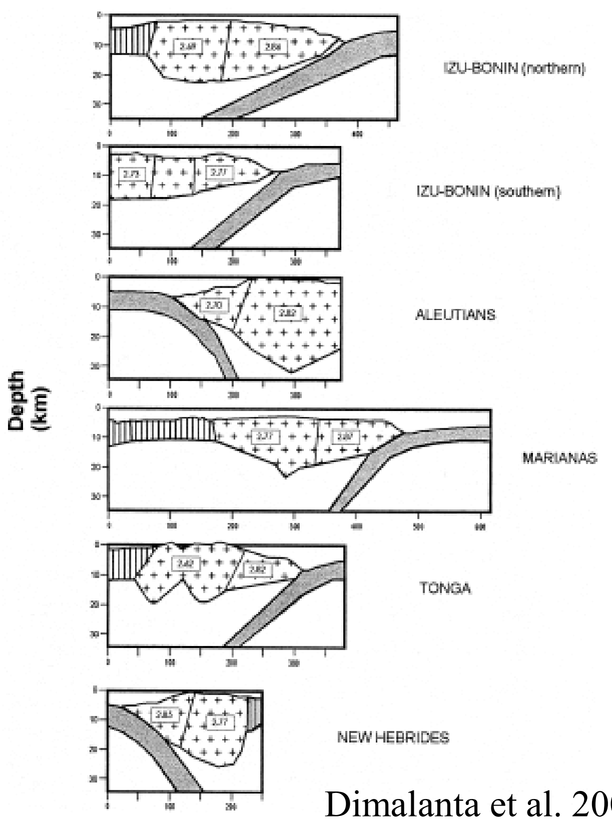

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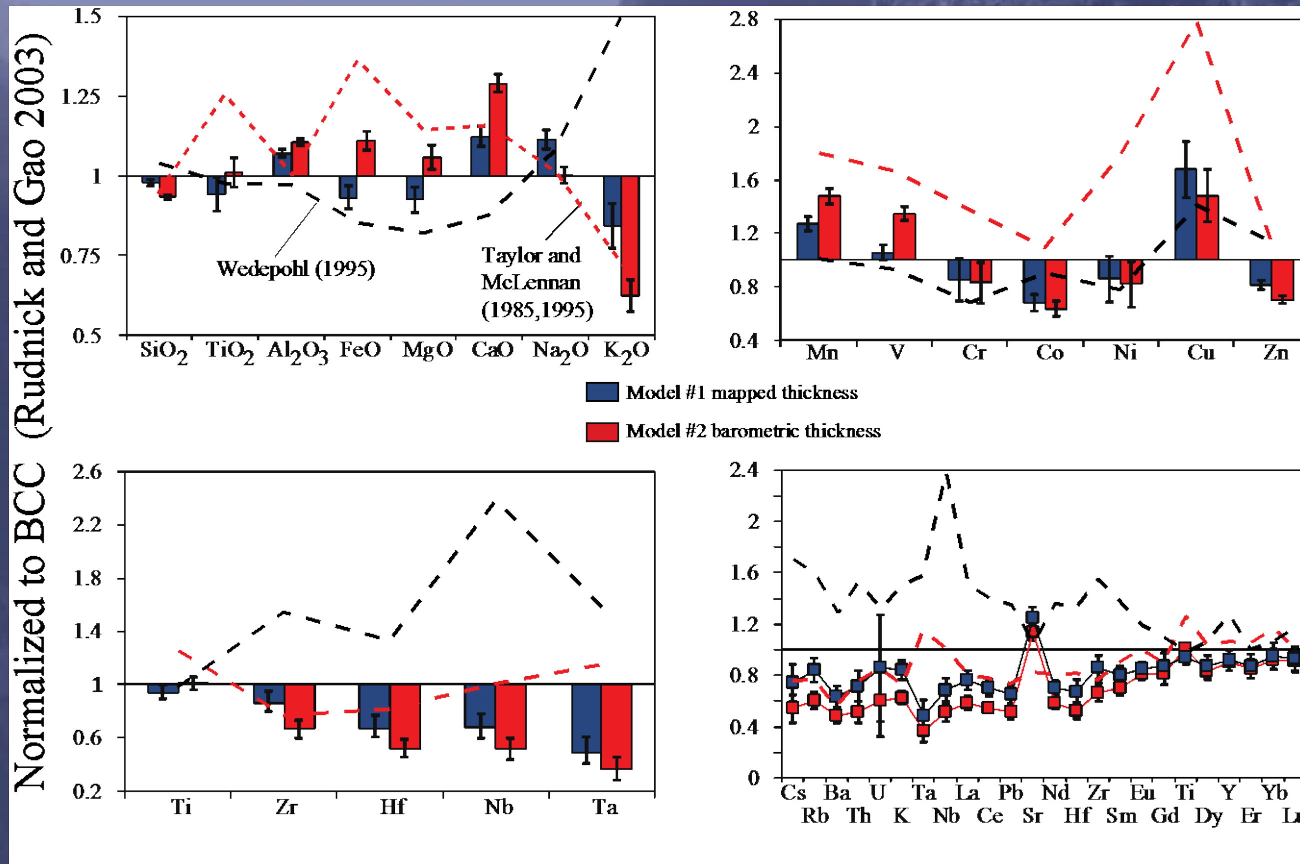
<u>Step 1:</u> modern mature island **arc crust** (= the Kohistan) **is similar to continental crust**

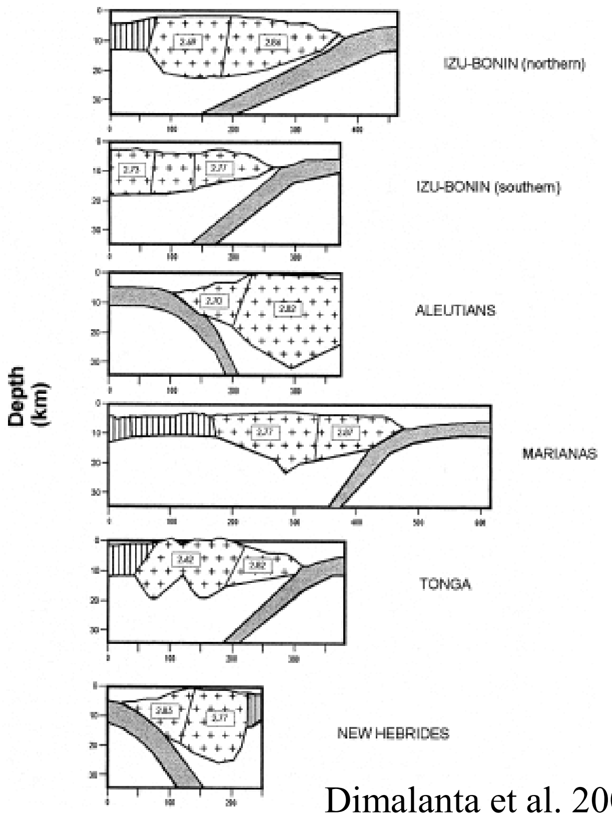
	bulk crust	
	Kohistan arc	continental
	Koh-m#1	RG
SiO_2 (wt%)	59.3	60.6
TiO_2	0.68	0.72
Al_2O_3	17.0	15.9
FeO^T	6.26	6.71
MnO	0.13	0.10
MgO	4.32	4.66
CaO	7.21	6.41
Na_2O	3.42	3.07
K_2O	1.52	1.81
P_2O_5	0.19	0.13
$X_{Mg}{}^{b}$	0.552	0.553



Rudnick+Gao (2003)

Jagoutz+Schmidt (2012)

The problem



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Step 2: primitive (basaltic calc-alkaline/tholeiitic) **mantle melts in arcs**

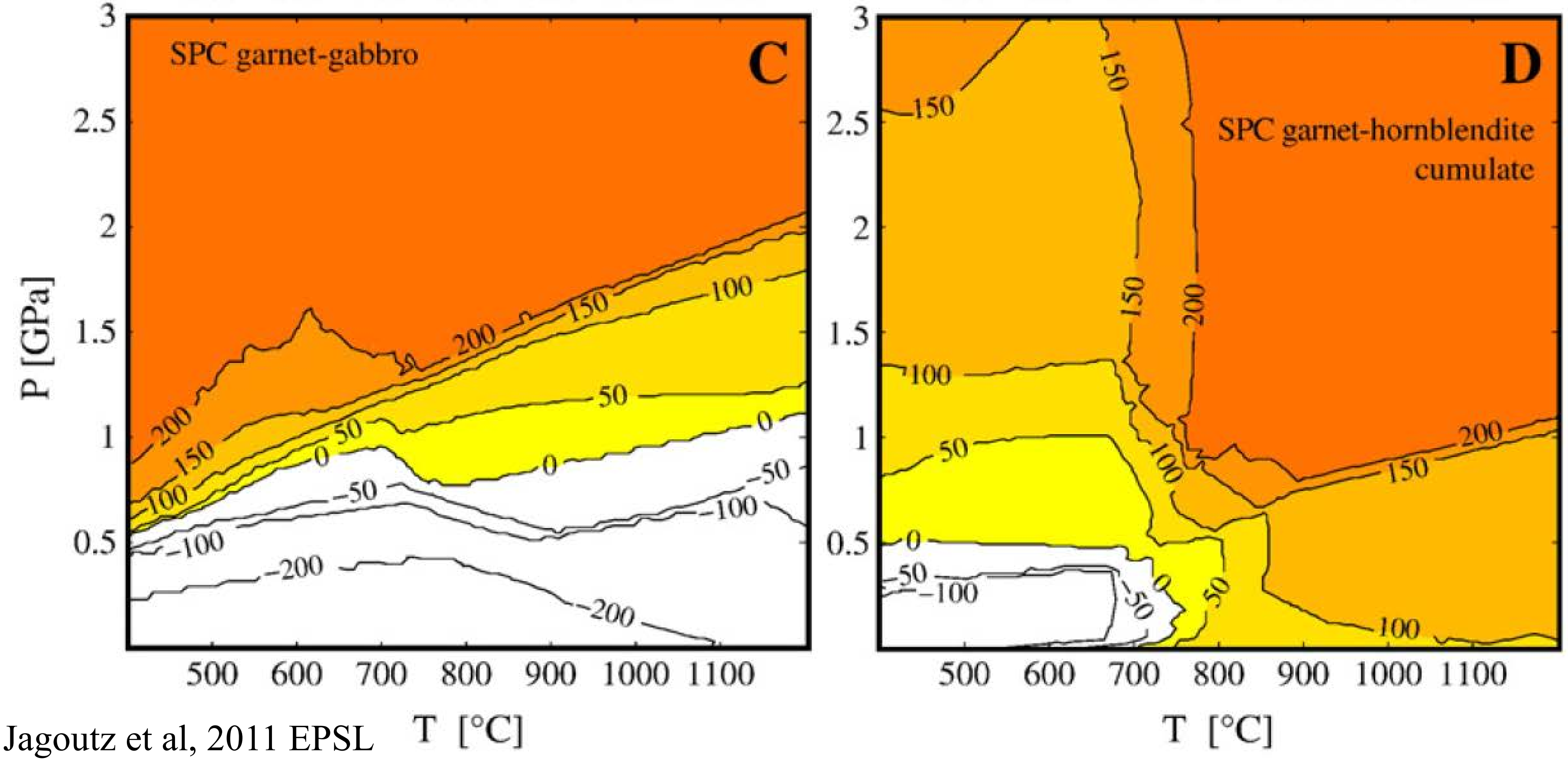
Compilation of primitive volcanics from GEOROC data base (Mainz)

	calc-alkaline / tholeiitic									
	Aleutians	**Bismark**	**Kuriles**	**Marianas**	**Tonga**	**Vanuatu**	**Yap**	**Palau**	**Kohistan**	**average**
n	*12*	*9*	*14*	*20*	*13*	*31*	*4*	*13*	*10*	
SiO_2 (wt%)	49.8	50.5	51.5	50.2	49.3	49.4	49.5	51.2	50.7	**50.2**
TiO_2	0.75	0.99	0.83	0.91	0.60	0.69	0.59	0.60	0.80	**0.8**
Al_2O_3	15.7	14.9	14.7	15.7	12.0	12.9	15.2	16.5	15.6	**14.8**
FeO^{tot}	8.8	9.0	8.8	8.1	9.3	9.6	8.6	7.9	8.6	**8.8**
MnO	0.16	0.17	0.16	0.13	0.18	0.19	0.17	0.16	0.14	**0.2**
MgO	11.1	10.9	10.9	10.9	13.4	12.7	11.1	10.7	10.9	**11.4**
CaO	10.5	11.1	9.9	11.3	10.5	11.1	12.9	9.9	9.9	**10.8**
Na_2O	2.4	2.2	2.3	2.3	2.1	2.0	1.7	2.6	2.4	**2.2**
K_2O	0.70	0.31	0.83	0.37	2.12	0.98	0.18	0.28	0.61	**0.7**
P_2O_5	0.13	0.11	0.14	0.12	0.46	0.20	0.05	0.07	0.19	**0.2**
$X_{Mg}{}^{b}$	0.691	0.684	0.687	0.705	0.718	0.702	0.697	0.707	0.693	**0.7**
Cr (ppm)	611	545	647	456	697	666	507	689	512	**592**
Ni	208	213	196	240	300	242	153	207	167	**214**

X_{Mg} = 0.65-0.74
Ni = 150-500
Cr = 300-1100

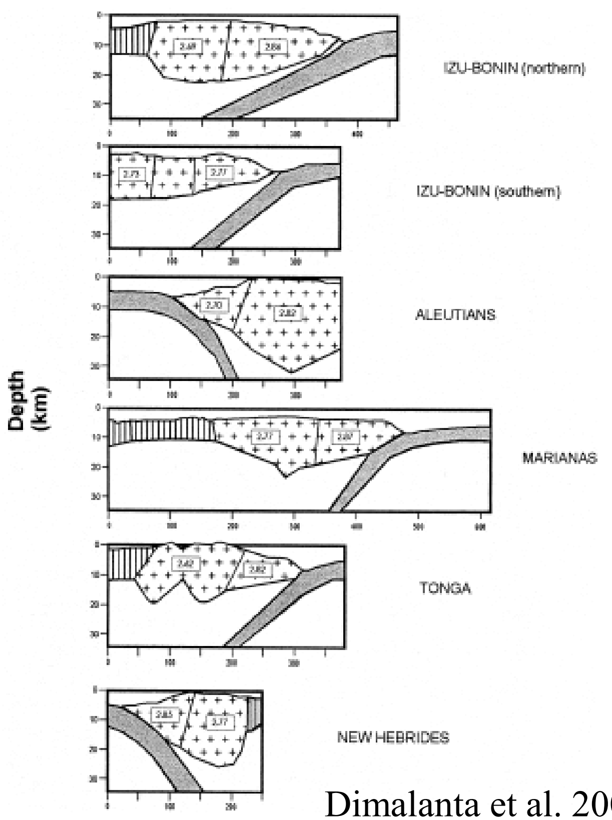
Tonga, Marianas and Aleutians also have primitive high-Mg andesites

$\Delta\rho$ cumulate – primitive mantle (kg/m^3)



Jagoutz et al, 2011 EPSL

The problem



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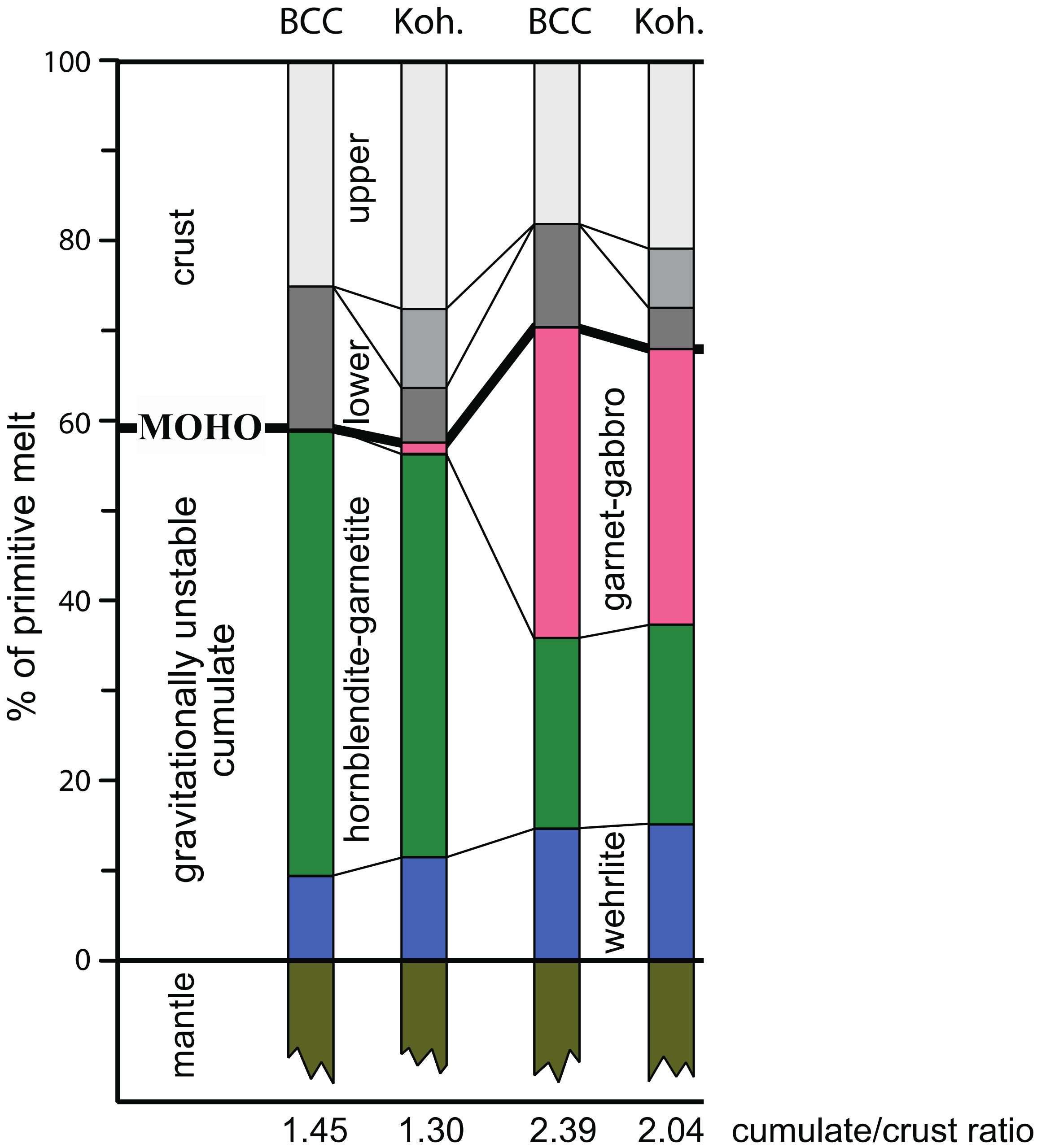
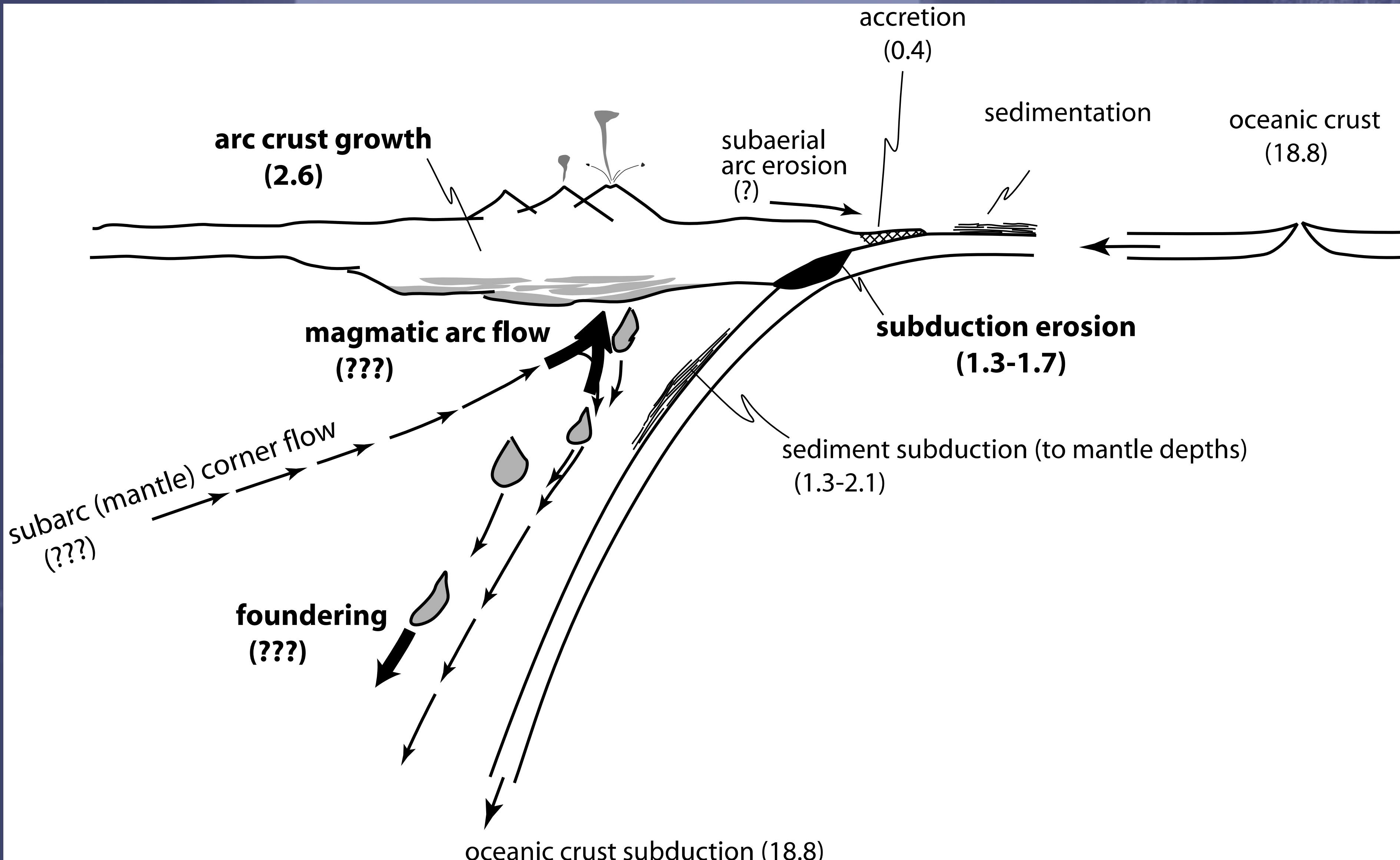
Simple global mass balance

	continental crust		primitive arc melts			
	Kohistan	Rudnick+Gao	Kuriles	Kohistan	Aleutians	Mariannas
			calc-alkaline/tholeiitic		alkaline	boninite
Major elements [wt%]						
SiO2	**56.94**	60.60	51.50	50.72	45.41	56.68
TiO2	**0.73**	0.72	0.82	0.80	2.42	0.34
Cr2O3	**0.00**	0.00	0.10	0.06	0.06	0.09
Al2O3	**17.17**	15.90	14.74	15.67	13.17	14.08
DFeO	**7.58**	6.71	8.82	8.60	11.06	7.63
MnO	**0.15**	0.10	0.16	0.14	0.18	0.15
MgO	**4.96**	4.66	10.93	10.87	12.62	10.42
CaO	**8.02**	6.41	9.85	9.88	9.88	7.94
Na2O	**3.09**	3.07	2.25	2.43	3.49	2.00
K2O	**1.19**	1.81	0.78	0.61	1.30	0.67
P2O	**0.17**	0.13	0.14	0.19	0.49	0.06
Total	**100.0**					
Mg#	**0.54**	**0.55**	0.69	0.69	0.67	0.71
		Kohistan				
		wherlite	15.5	17.7	-4.1	12.5
		hblgrtt	14.5	7.0	215	74.0
		gabbro	28.9	45.4	239	-59.1
		Koh.crust	41.0	29.9	129	72.6
		r^2	**0.84**	**2.6**	**6.5**	**50**
		RG				
		wherlite	16.5	19.3	-3.4	13.0
		hblgrtt	1.0	-8.7	190	58.7
		gabbro	59.2	75.2	-166	-16.6
		RG-crust	23.2	14.3	80.3	44.9
		r^2	**1.2**	**3.1**	**9.2**	**49**



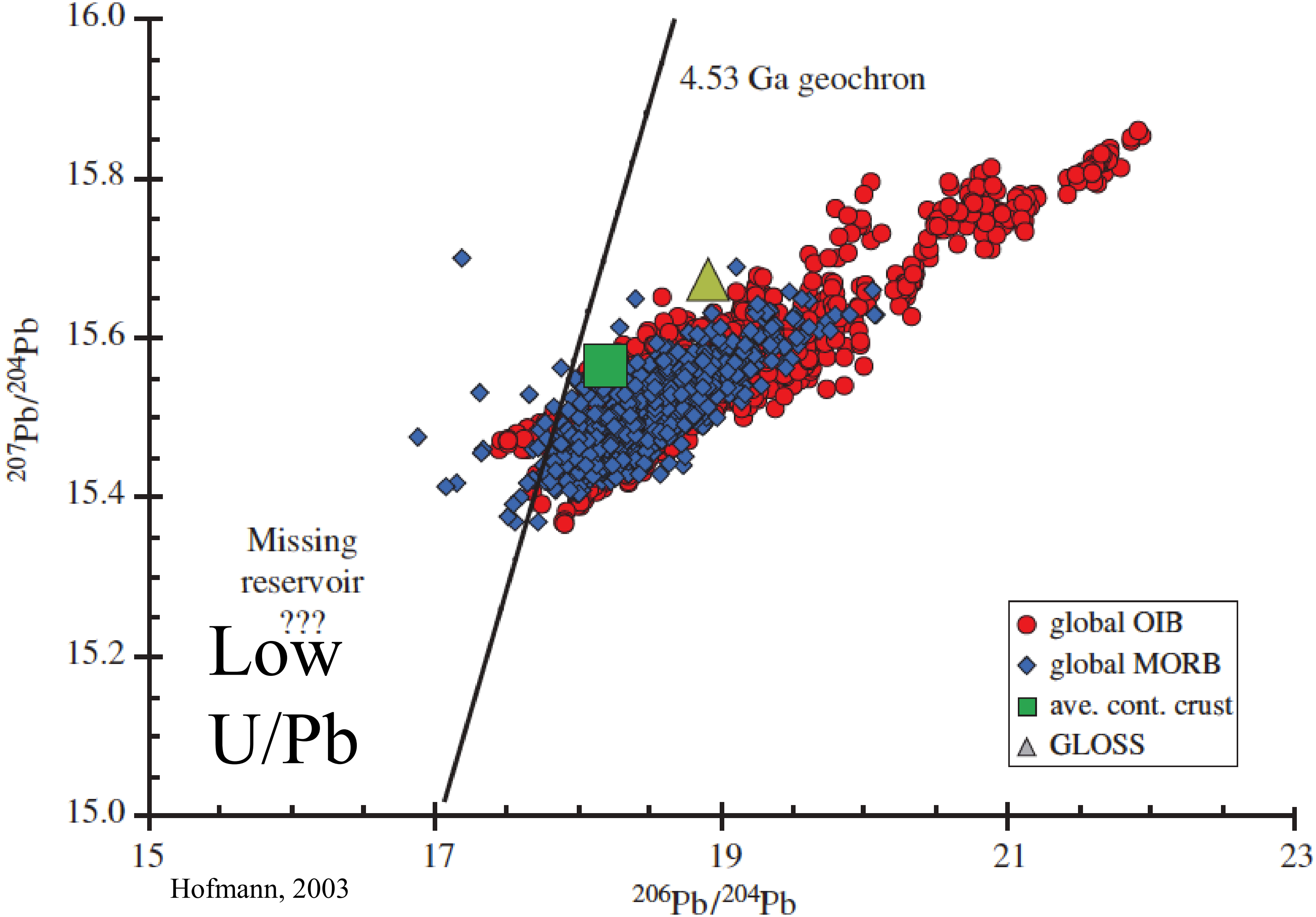
Schmidt and Jagoutz, 2013 EPSL

Subduction zone mass balance [km^3/a]

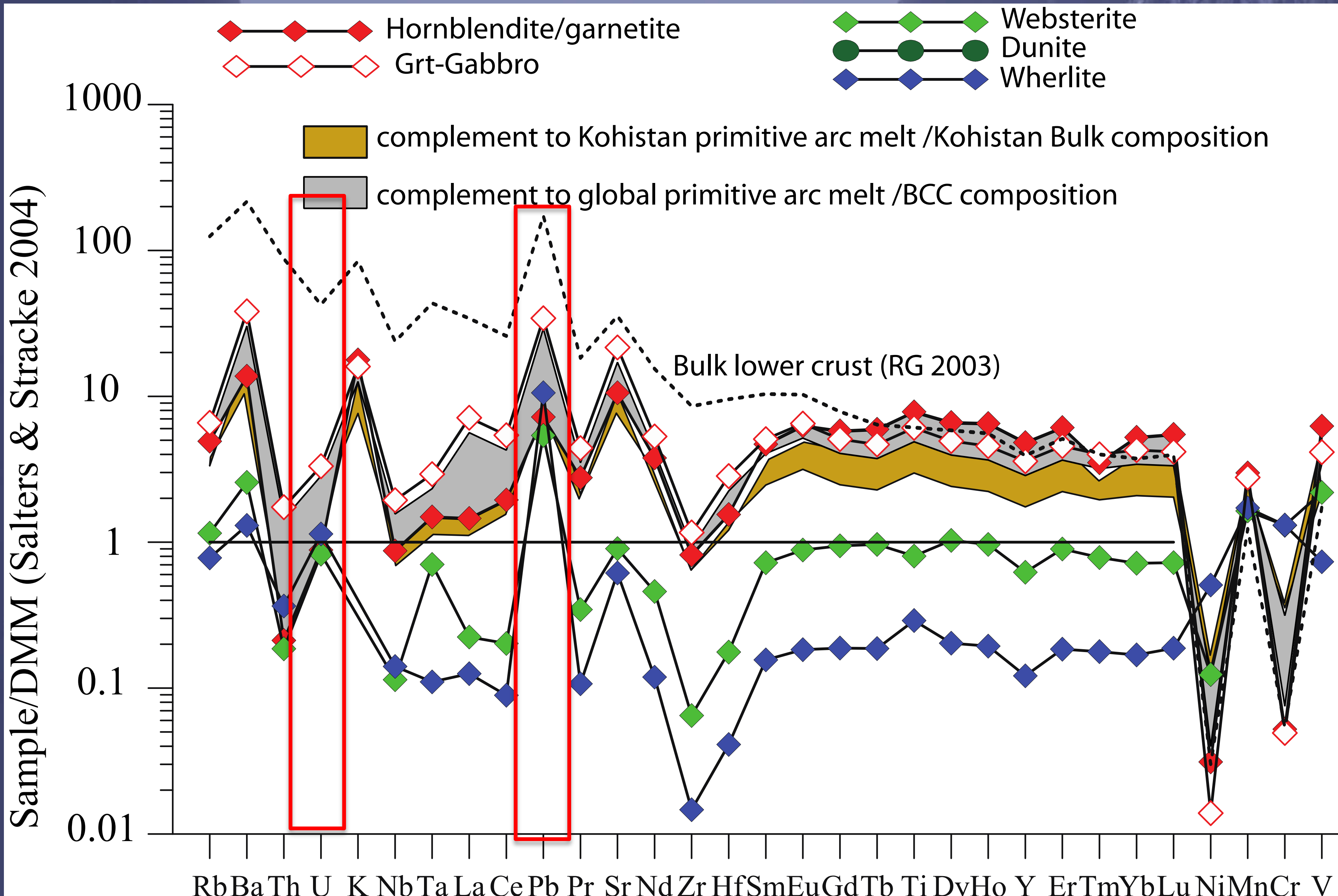


Schmidt and Jagoutz, EPSL accepted

Important reservoir for the Pb paradox ?



Hofmann, 2003



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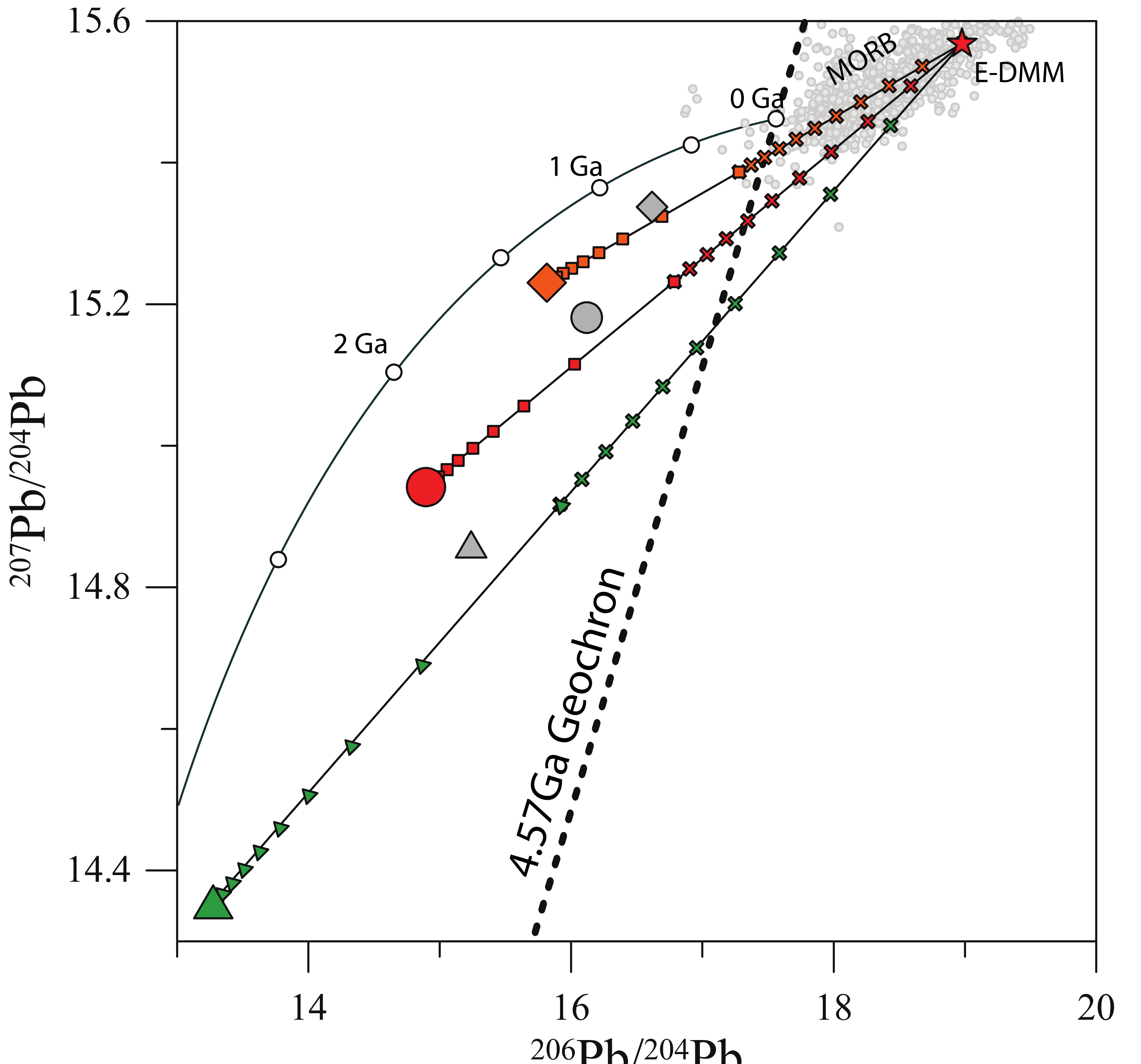

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Take home messages

- A ‘hidden’ mass flux at the mantle crust interface in arc exist that has a similar magnitude as the subduction of oceanic crust

- **Foundering of the density unstable lower arc crust can explain the location and the characteristics of the continental Moho**