Constraints on the deep water cycle based on volcanic and hydrothermal gas emissions

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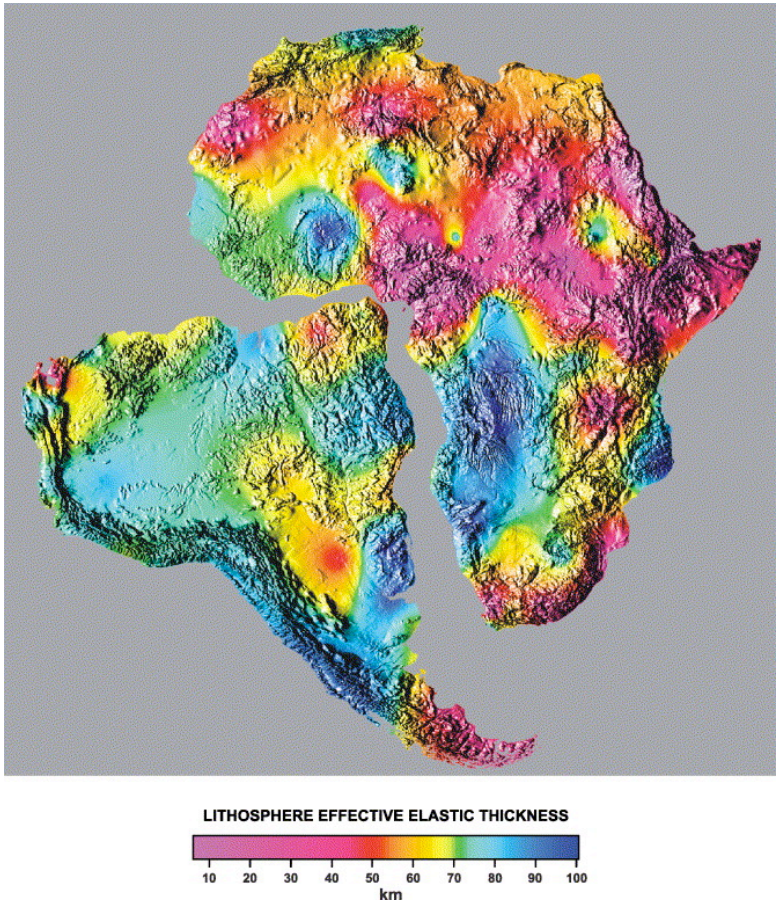
One of the key features of Earth's surface geology is the near constancy of continental freeboard through geologic time (Wise 1974).

This reflects a steady budget of surface H_2O relative to H_2O stored in the mantle.

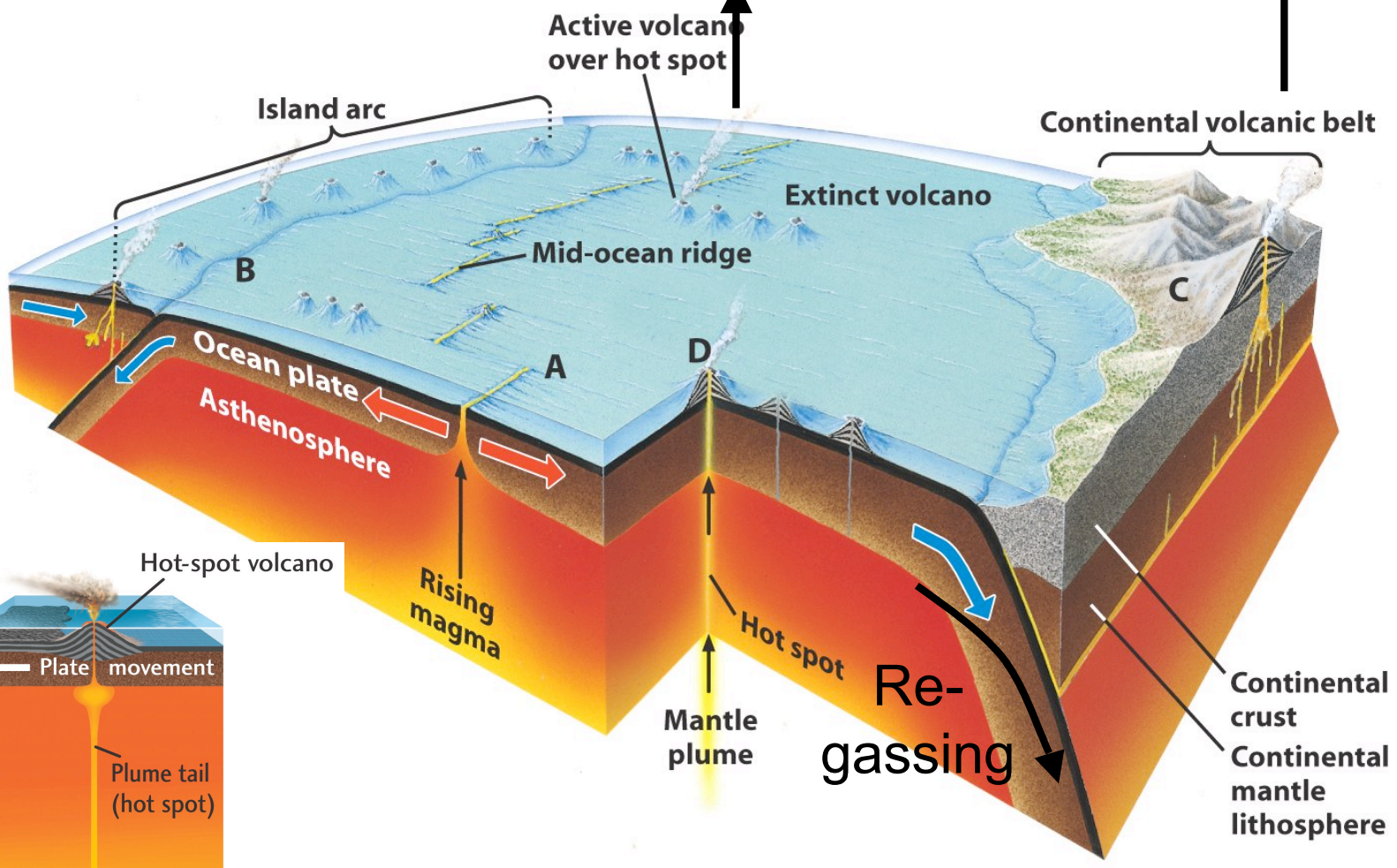
-Interesting considering that the H_2O in the oceans could be a modest fraction of the total terrestrial H_2O budget (0.25 to 4 x the oceans in mantle).
- However, rate of subduction of H_2O is sufficient to desiccate the oceans in 1–2 Ga (Ito et al. 1983).

SO: fluxes of H_2O into the deep mantle must be closely in balance with degassing at ridges and regassing at subduction zones (McGovern & Schubert 1989, Rüpke et al. 2004).

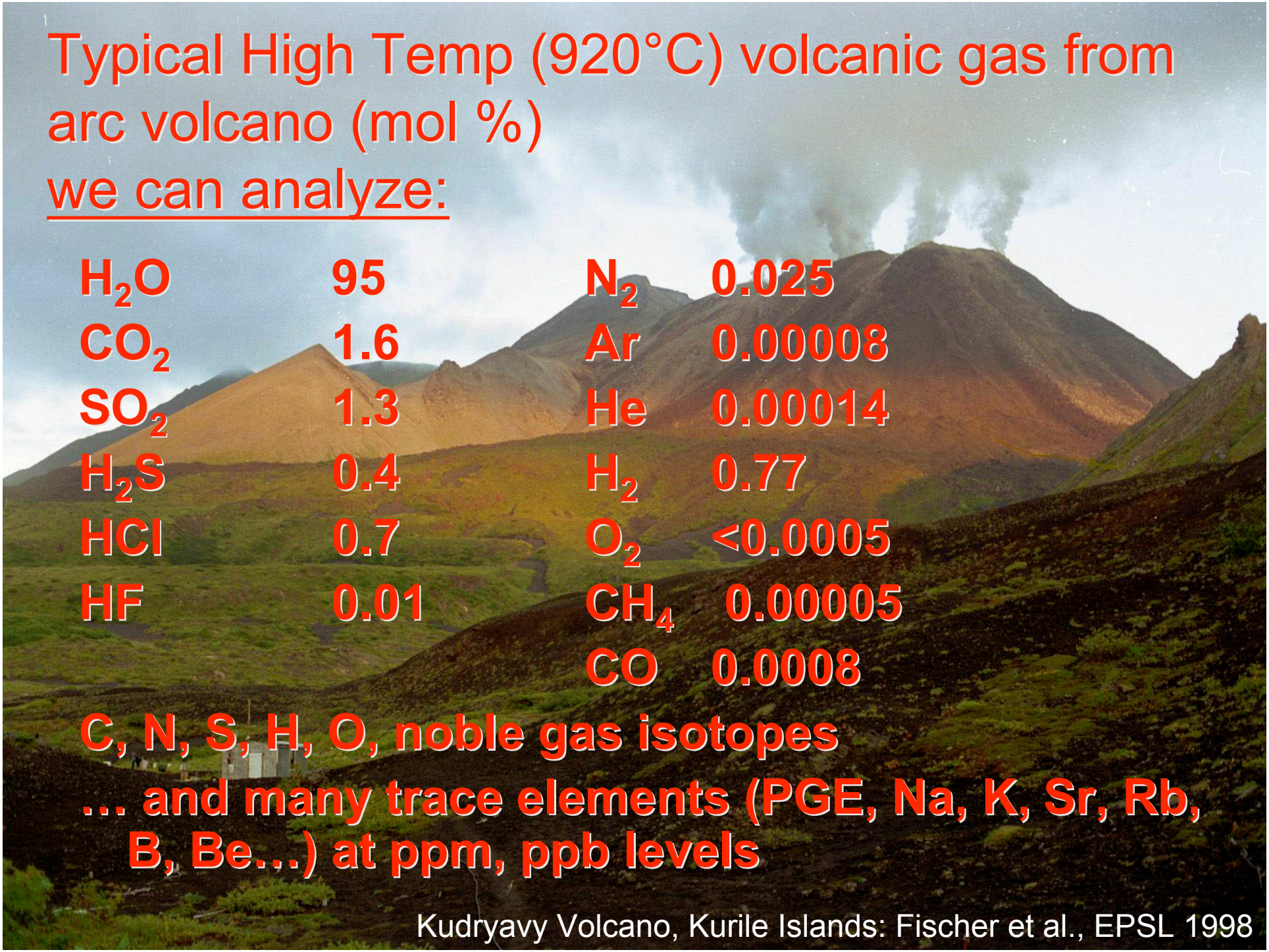


Ridge/hot spot water flux

Arc water flux



Ridge + Hotspot flux ~ Re-gassing flux



Typical High Temp (920°C) volcanic gas from arc volcano (mol %) we can analyze:

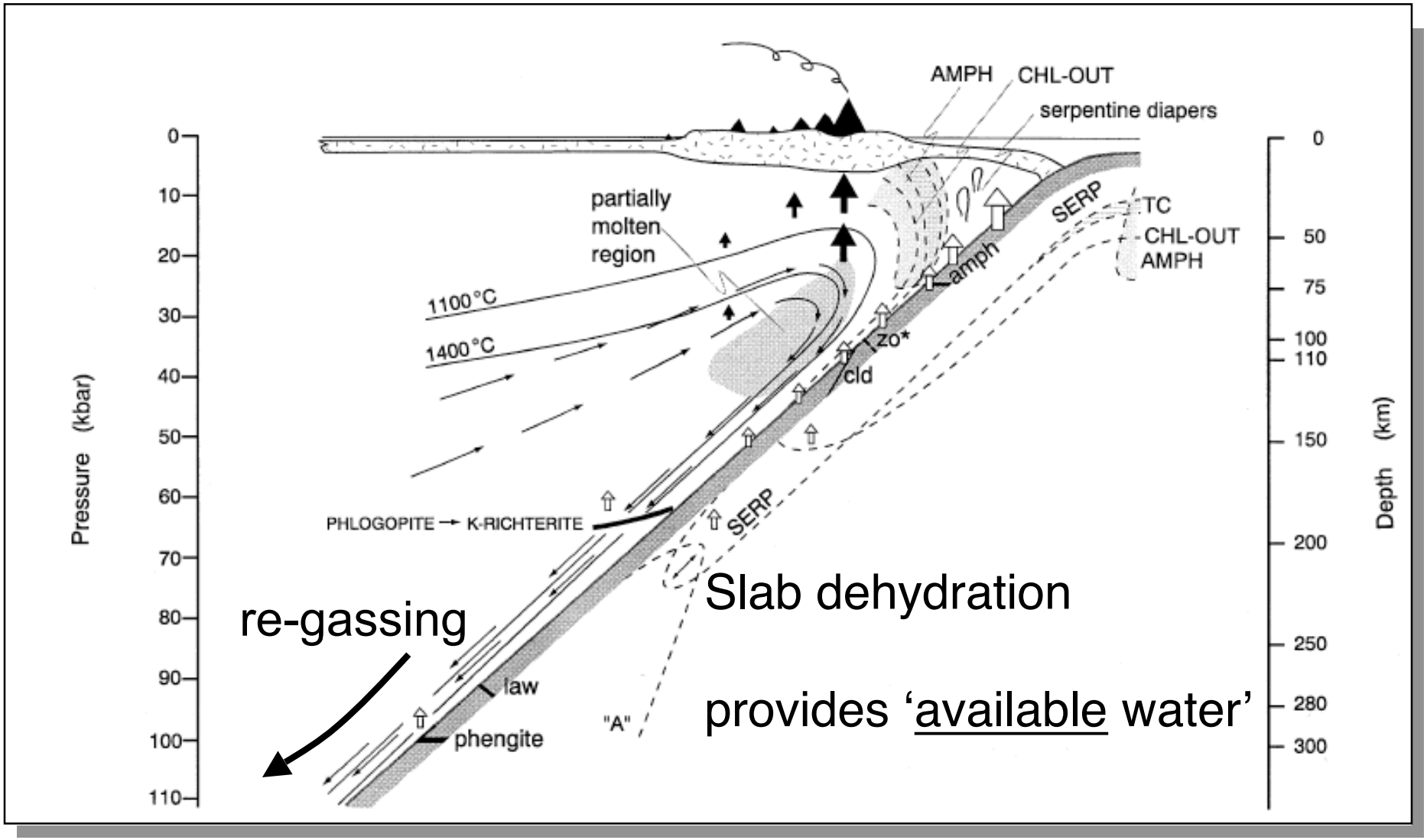
H_2O	95	N_2	0.025
CO_2	1.6	Ar	0.00008
SO_2	1.3	He	0.00014
H_2S	0.4	H_2	0.77
HCl	0.7	O_2	<0.0005
HF	0.01	CH_4	0.00005
		CO	0.0008

C, N, S, H, O, noble gas isotopes

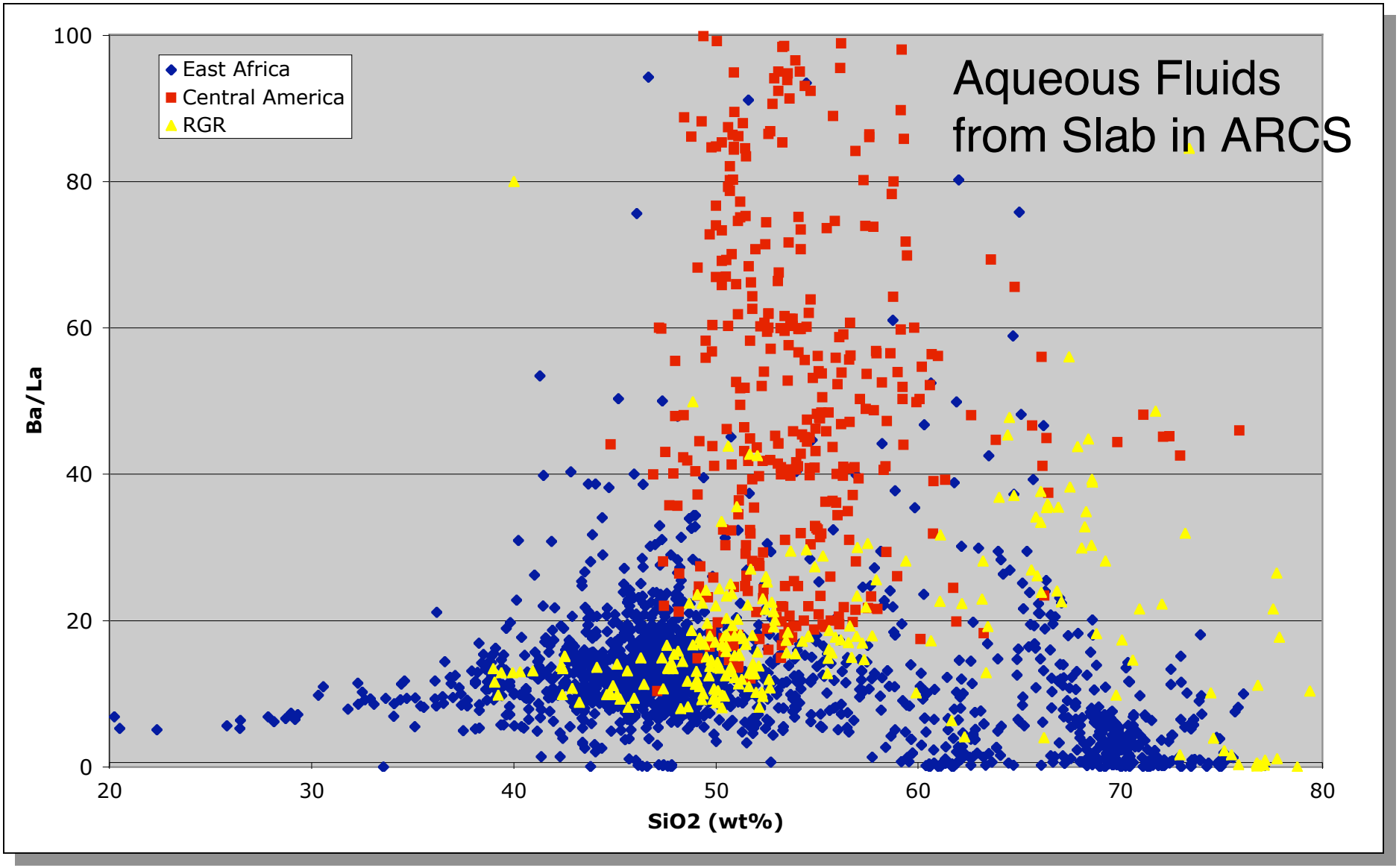
… and many trace elements (PGE, Na, K, Sr, Rb, B, Be…) at ppm, ppb levels

Kudryavy Volcano, Kurile Islands: Fischer et al., EPSL 1998

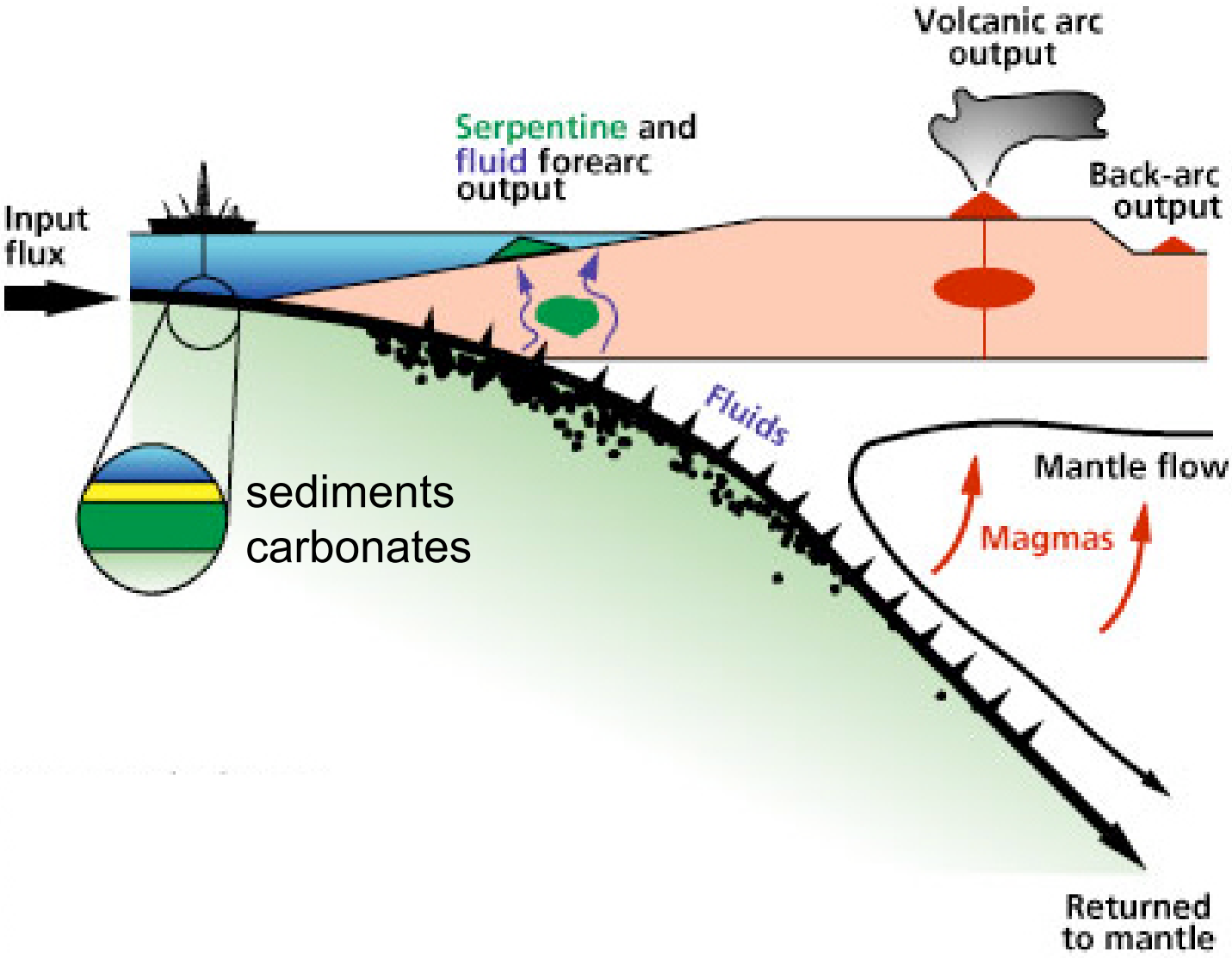
In Arcs fluids come from the slab

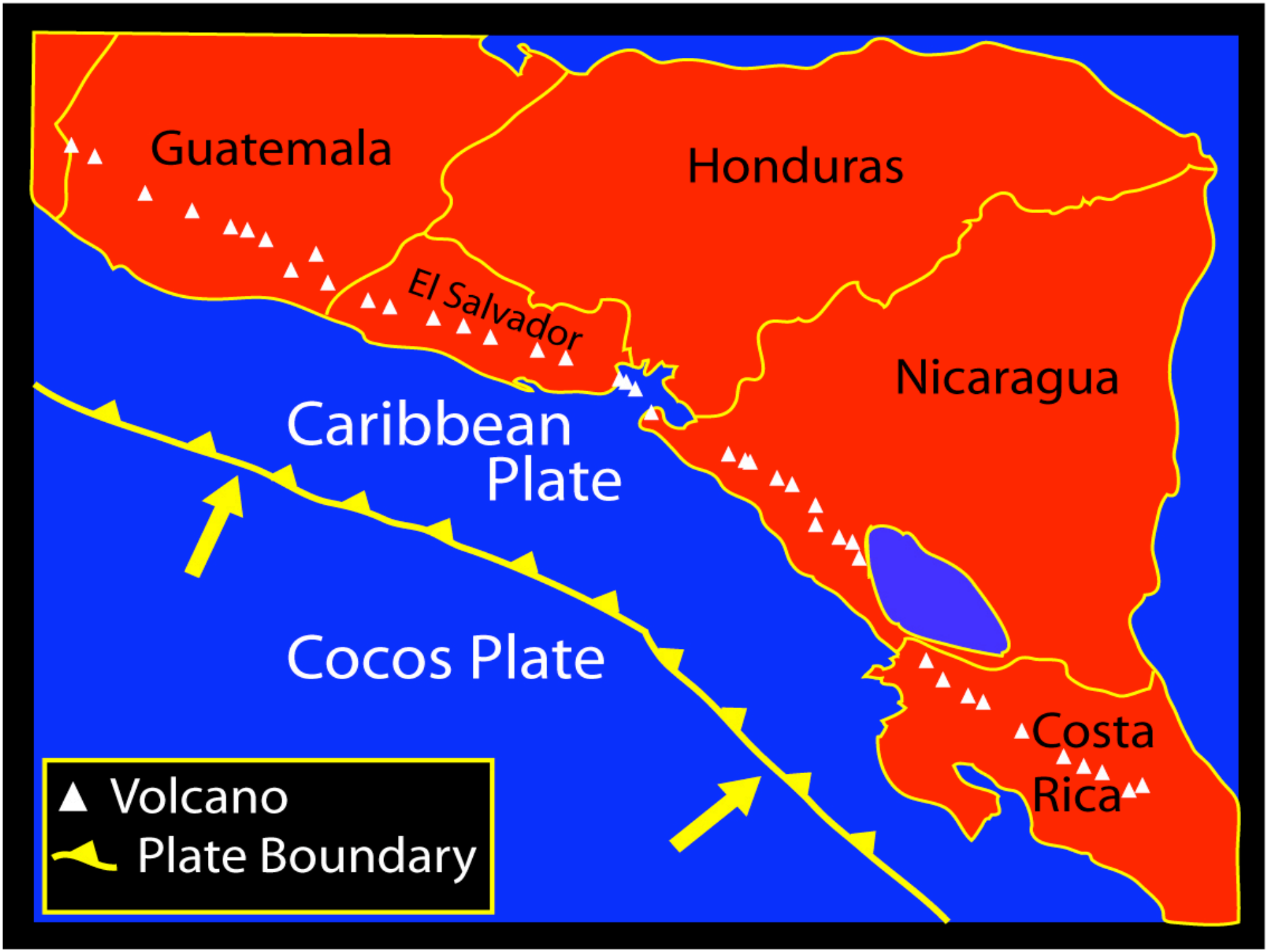


Schmidt+Poli, 1998



Georoc database and Mike Carr's data base

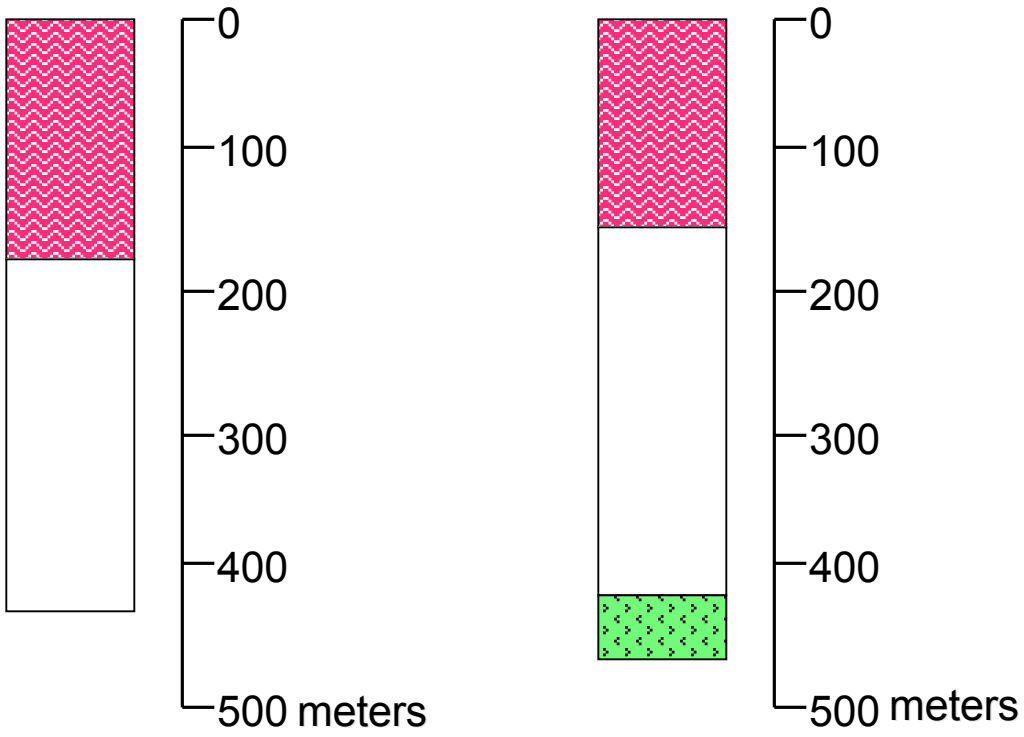

Volcanic arc output
Serpentine and fluid forearc output
Back-arc output
Input flux
Fluids
Mantle flow
Magmas
sediments
carbonates
Returned to mantle


Guatemala
Honduras
El Salvador
Nicaragua
Caribbean Plate
Cocos Plate
Costa Rica
Volcano
Plate Boundary

Sediment lithology:

Site 495
Guatemala

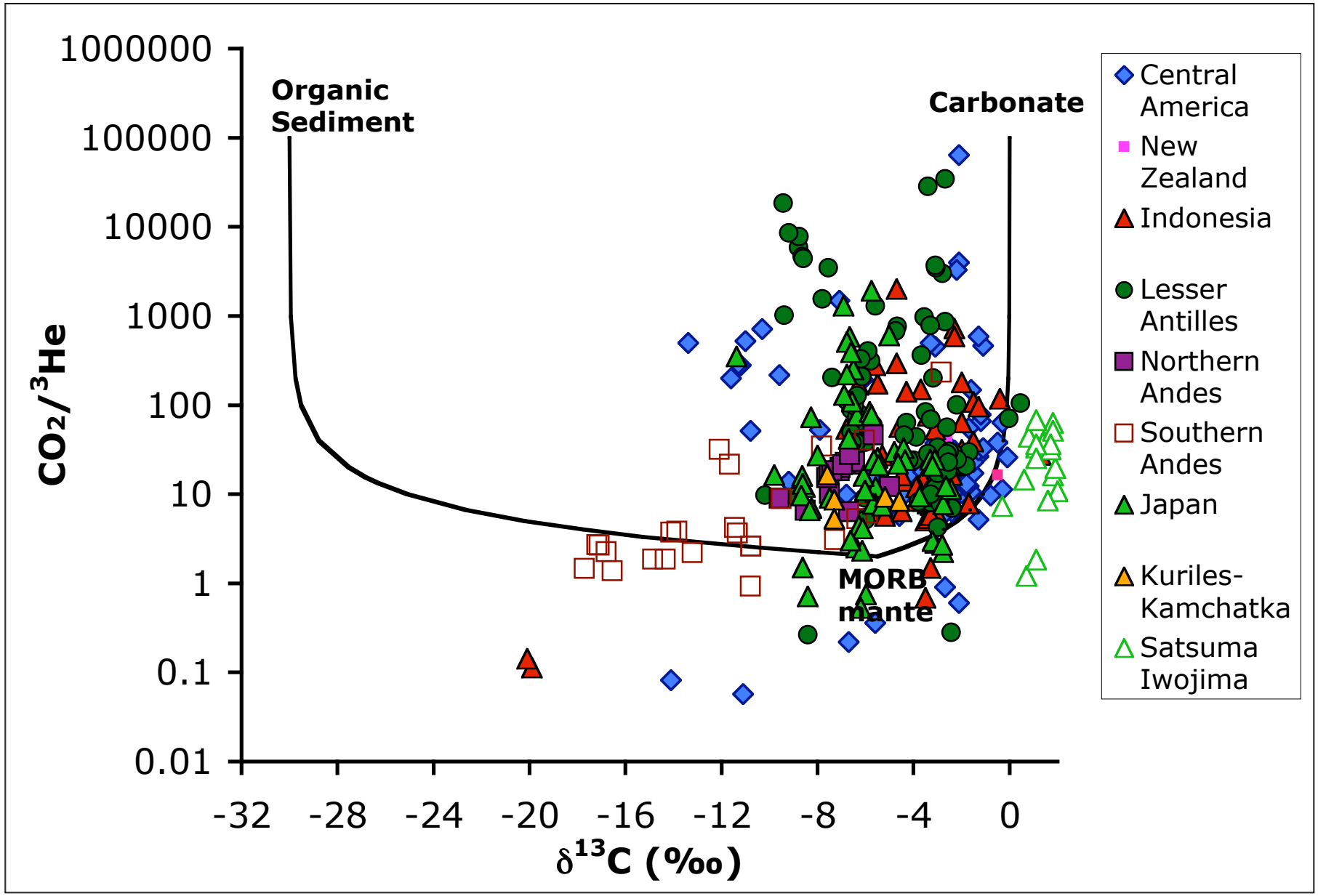
Site 1039
Costa Rica



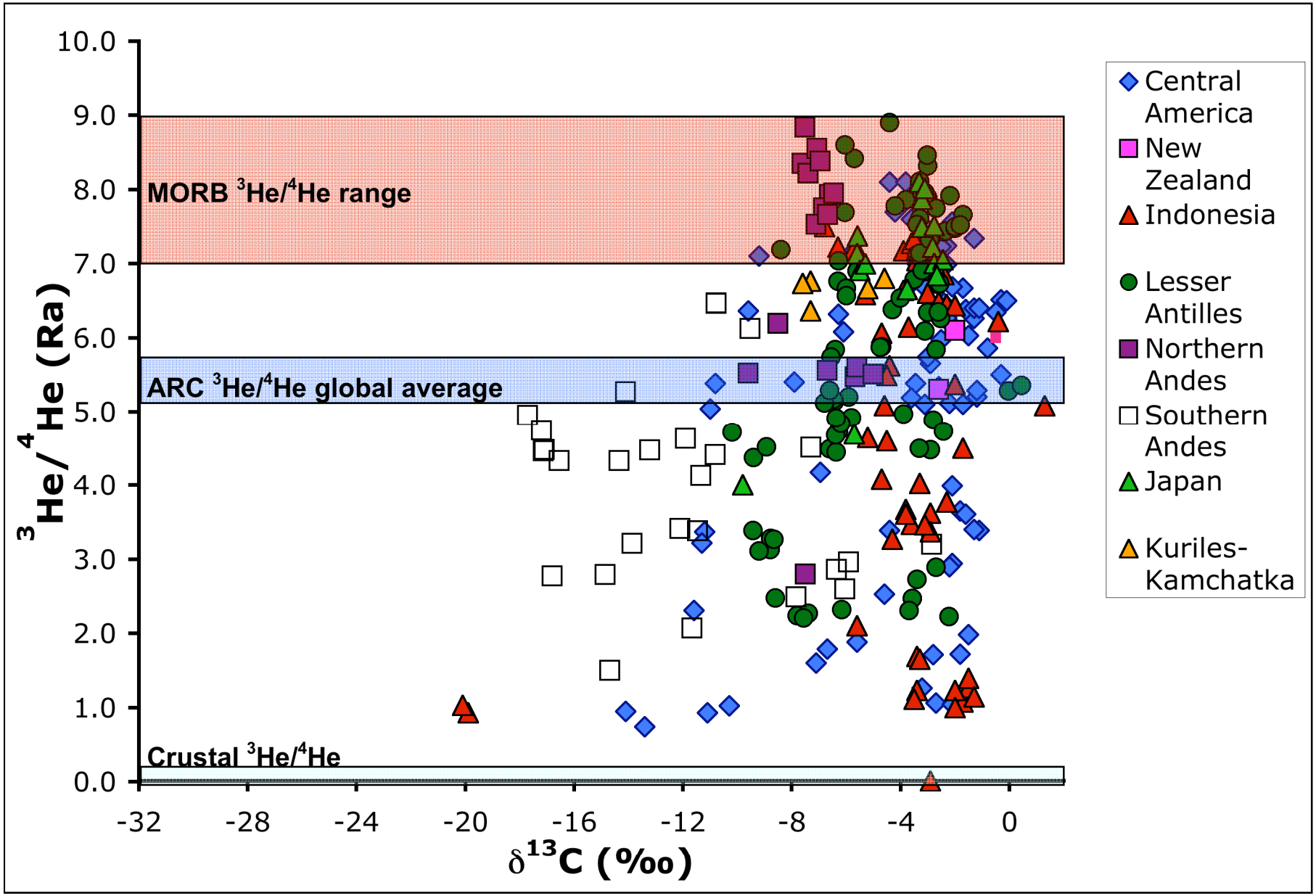
Hemi-pelagic
diatom-rich mud

Pelagic
Carbonates

Pyroxene Gabbro



after Sano and Marty (1995); from Oppenheimer, Fischer, Scaillet (in press)



from Oppenheimer, Fischer, Scaillet (in press)

Carbon imbalance at arcs

Arc	H_2O OUT/ IN total	OUT/ IN avail.	CO_2 sed OUT/ org IN	L OUT/ Car IN	L OUT/ (CAR+CRUST) IN	N_2 exc. OUT/ (SED+CRUST) IN
Antilles	5.54	46.35	0.13	23.17	0.90	1.22
Andes	83.71	482.94	0.37	1.86	1.18	1.58
Central America +Mexico	11.16	56.54	0.08	0.20	0.26	0.13
Alaska-Aleutians	0.27	1.76		>1		0.02
Kamchatka-Kuriles	0.33	2.71	0.00	>1	0.01	0.06
Japan	37.53	298.45	0.20	>1	1.63	6.55
Phillipines	63.93	311.61				0.32
Indonesia	0.34	2.91	0.00	640.92	0.04	0.03
New Zealand	304.88	1813.66	0.44	>1	6.03	4.58
Average Ratios	56.41	335.21	0.18	166.54	1.44	1.61
STD	98.09	581.25	0.17	316.43	2.12	2.36

Hilton, Fischer, Marty (2002)

Water imbalance at arcs: out flux >> in flux

Arc	H_2O OUT/ IN total	H_2O OUT/ IN avail.	CO_2 sed OUT/ org IN	CO_2 L OUT/ Car IN	CO_2 L OUT/ (CAR+CRUST) IN	N_2 exc. OUT/ (SED+CRUST) IN
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Uses H_2O/CO_2 of 50 in fumaroles and CO_2 flux

Hilton, Fischer, Marty (2002)

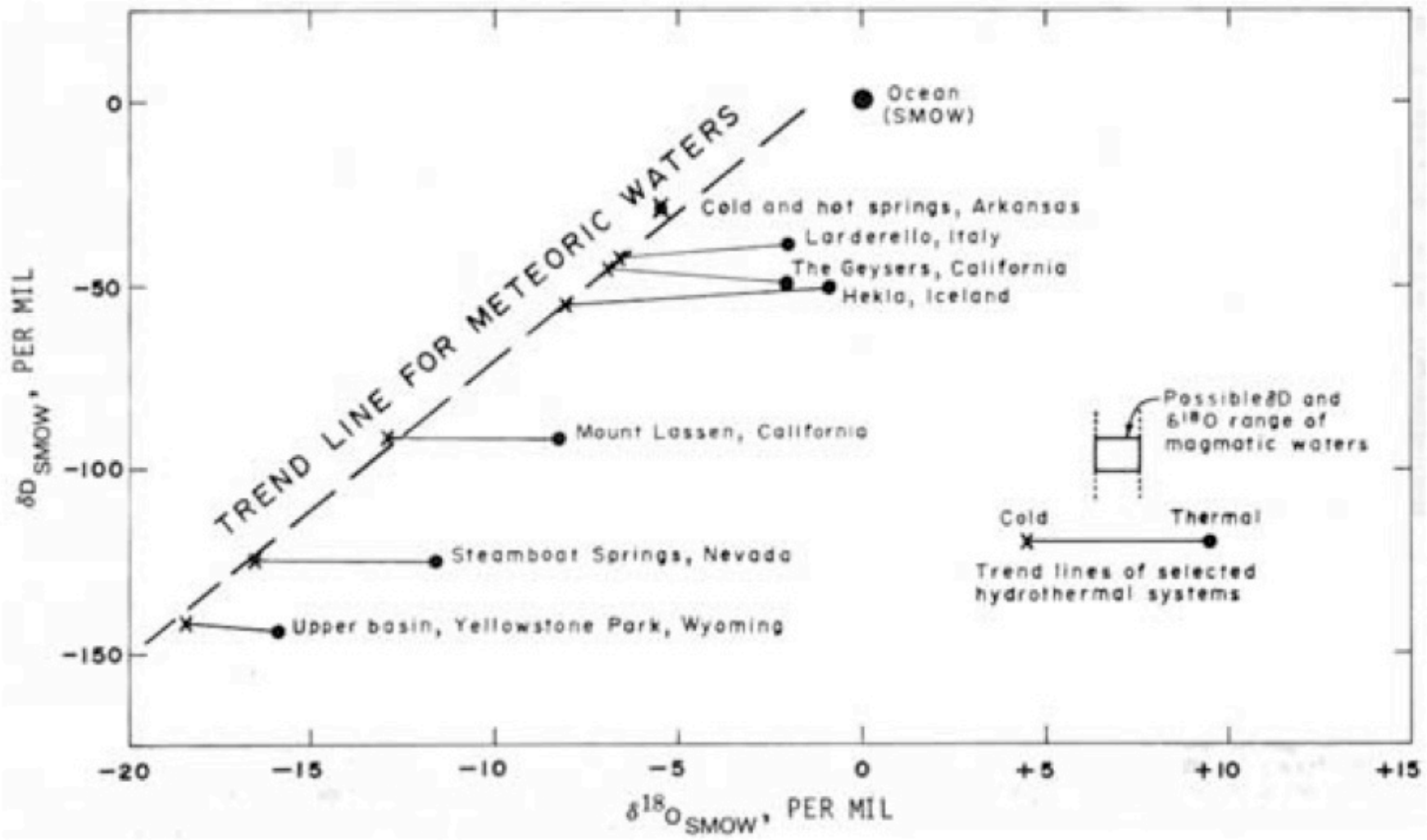
More recent estimate of water flux from arcs using H_2O/SO_2 ratio of high temperature fumaroles of individual arcs gives

Arc water out flux of 2-4 x 10^{13} mol/yr.

About 1 x10^{14}mol/yr is subducted globally

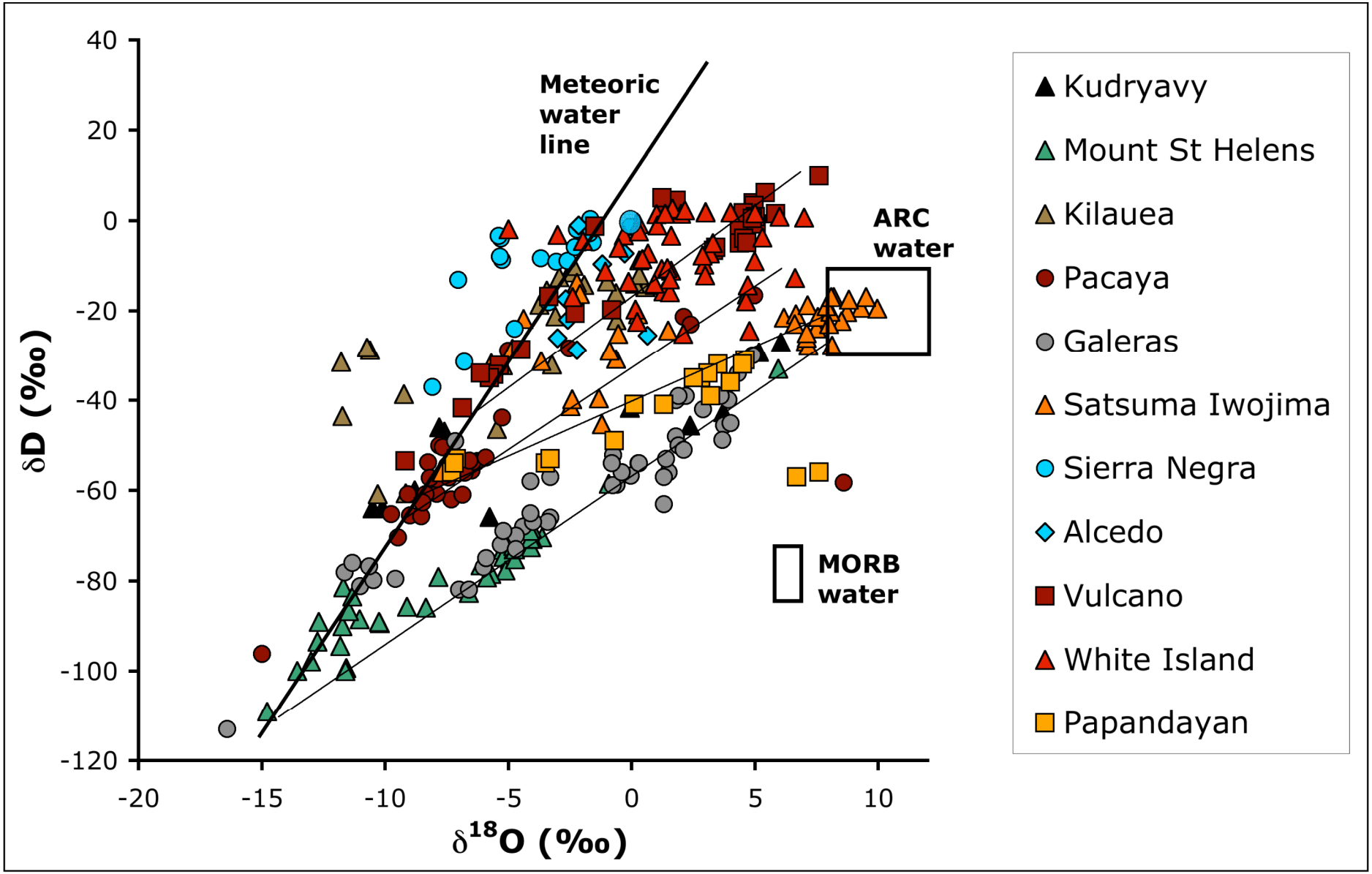
and 2-7 10^{13} mol/yr is available for arc magma generation

Fischer, Geo Chem. J. 2008



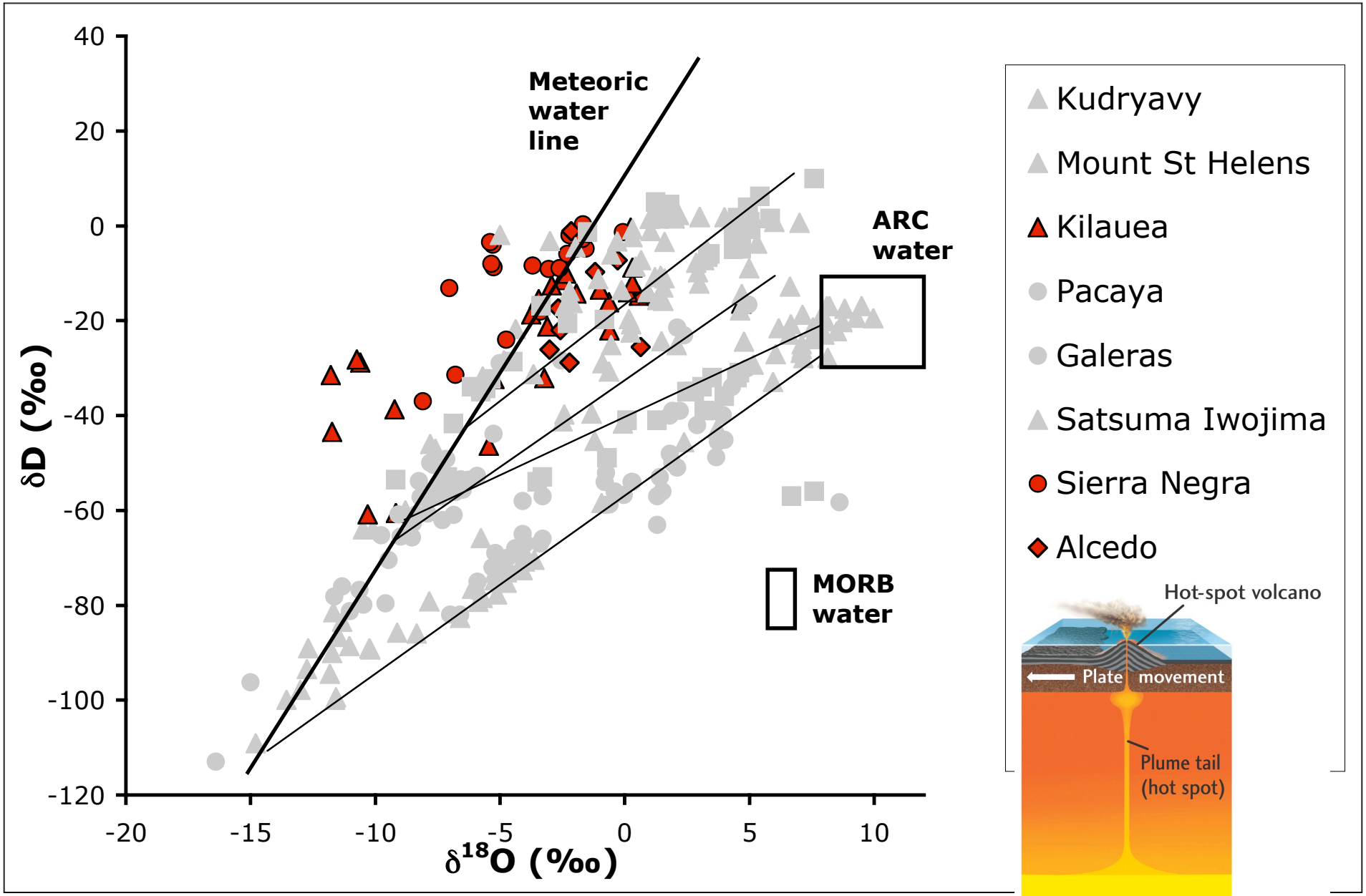
Craig and others 1960's, 70's, 80's

All hydrothermal waters are shifted meteoric waters



After Giggenbach 1992 and Taran 1992

from Oppenheimer, Fischer, Scaillet (in press)



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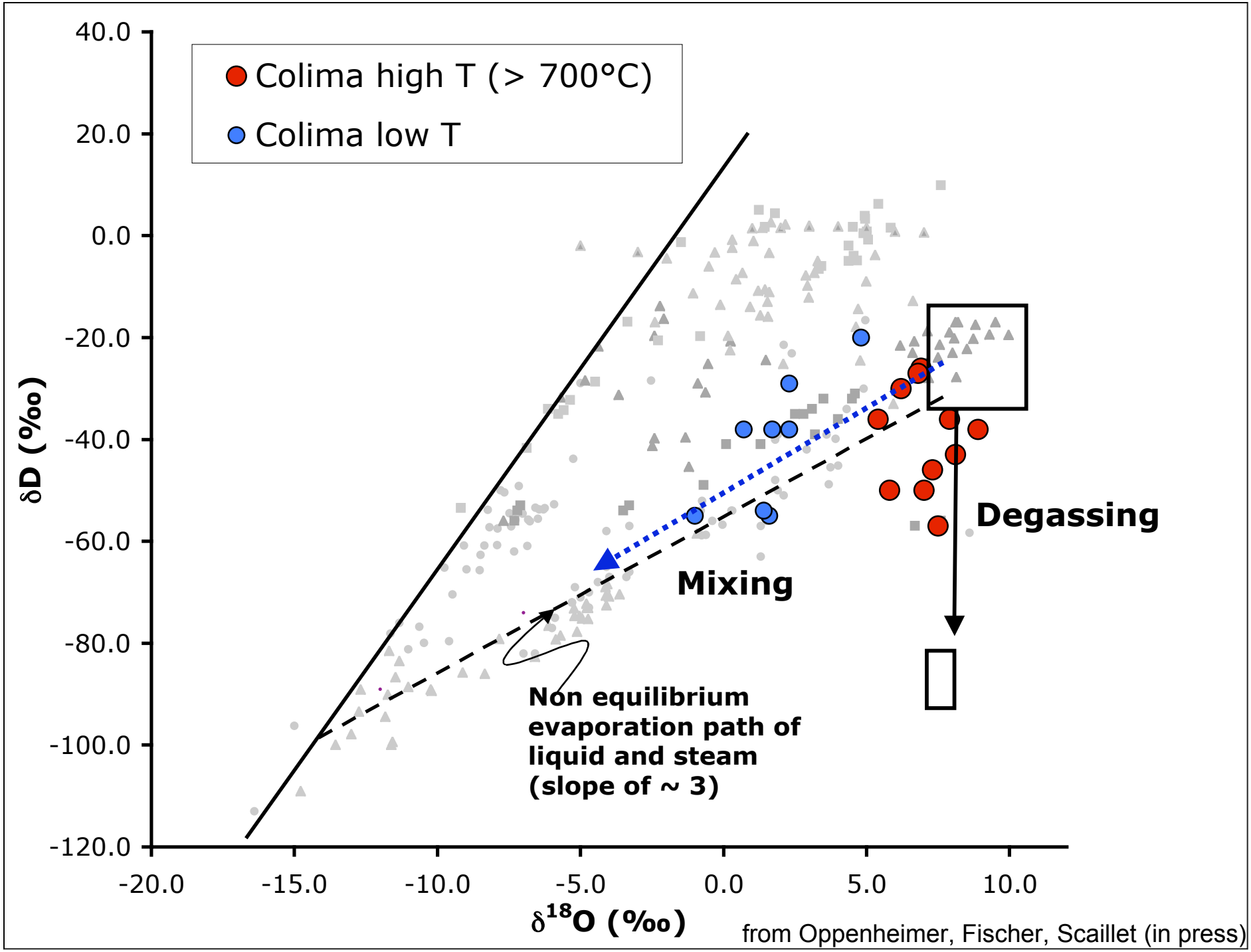
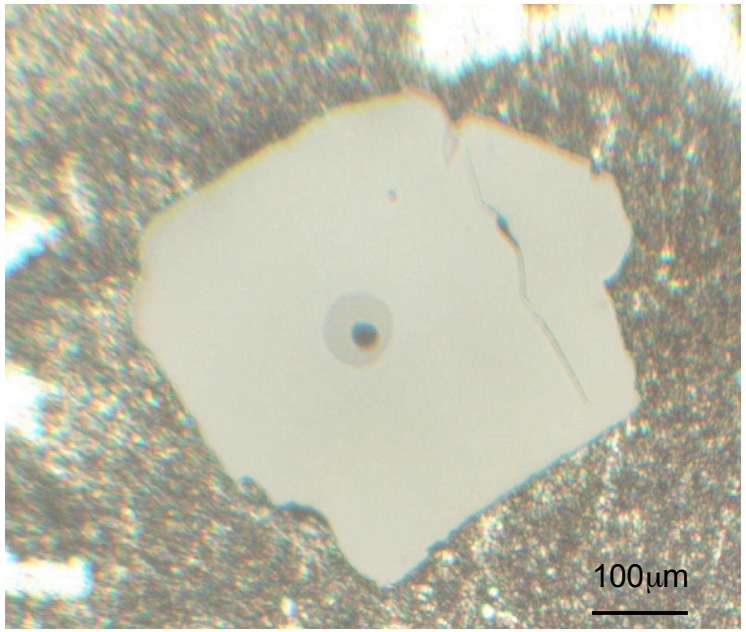

Colima high T (> 700°C)
Colima low T
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
δD (‰)
-20.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
δ18O (‰)
Mixing
Degassing
Non equilibrium
evaporation path of
liquid and steam
(slope of ~ 3)
from Oppenheimer, Fischer, Scaillet (in press)

Melt inclusions: pre-eruptive melt volatile contents

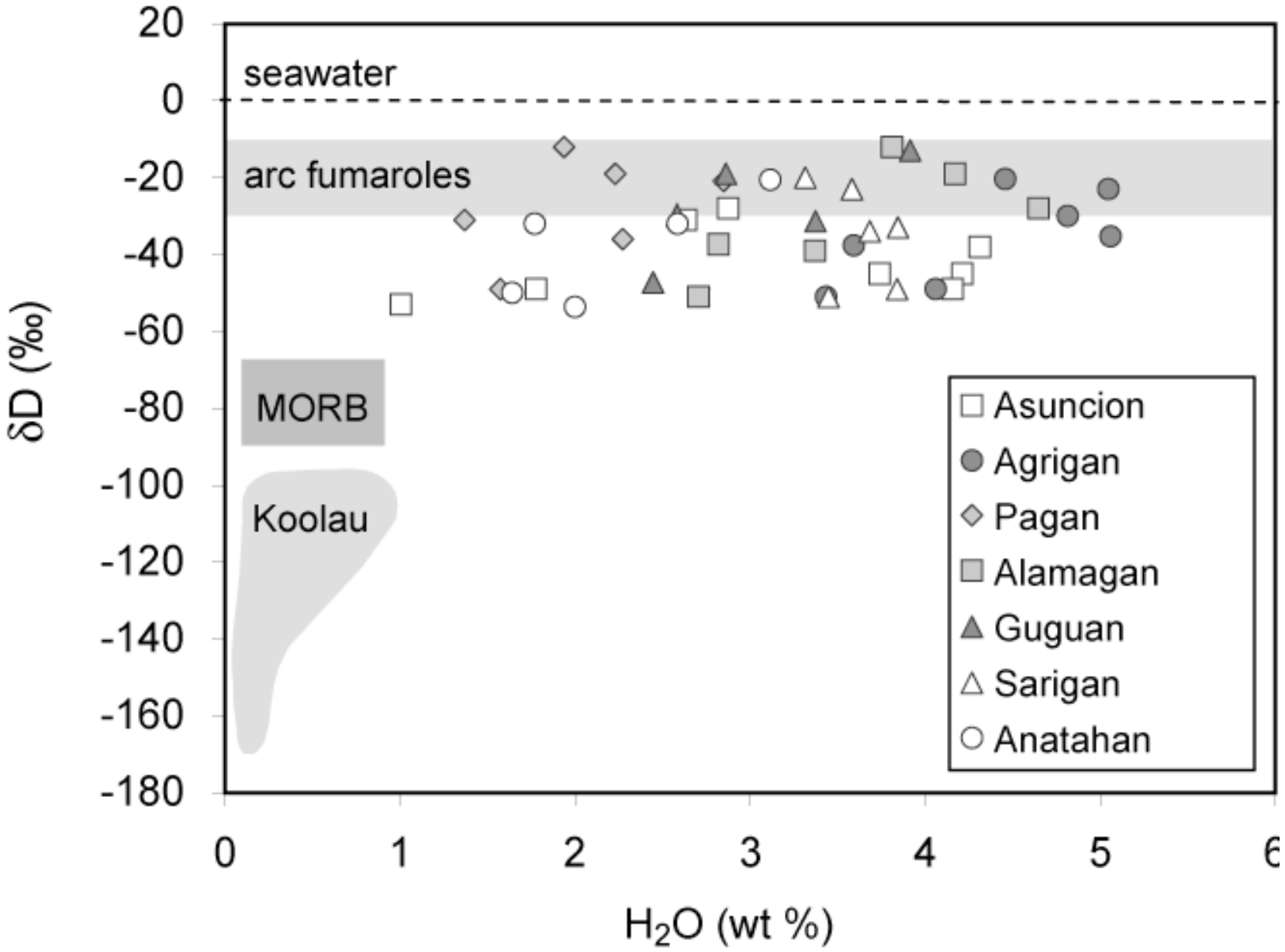
Allow for assessment of pre-eruptive melt composition since they are assumed to be less susceptible to degassing and contamination

Olivine-hosted melt inclusions in recently-erupted tephras from Marianas Arc Volcanoes

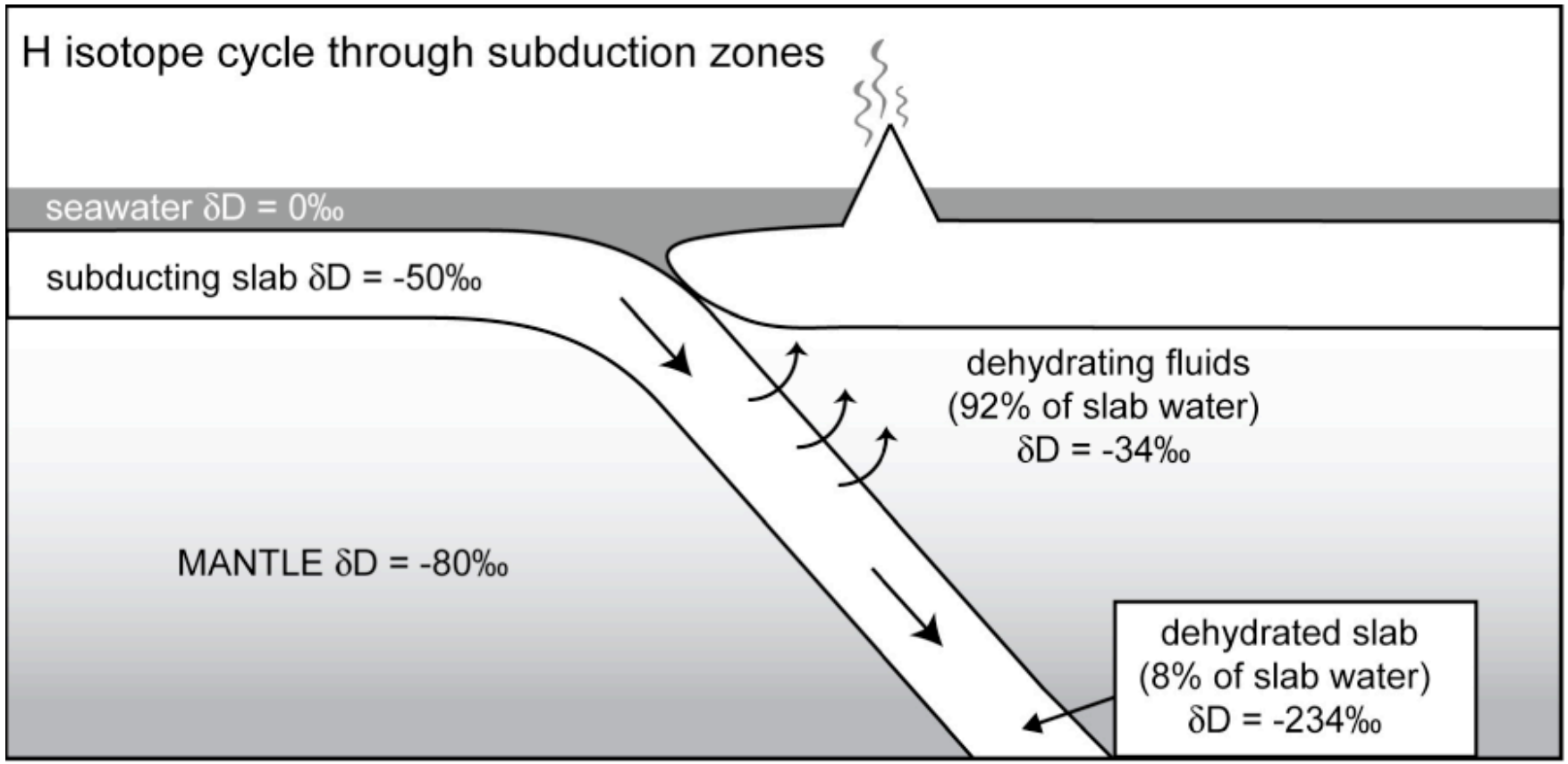


Shaw et al., 2008

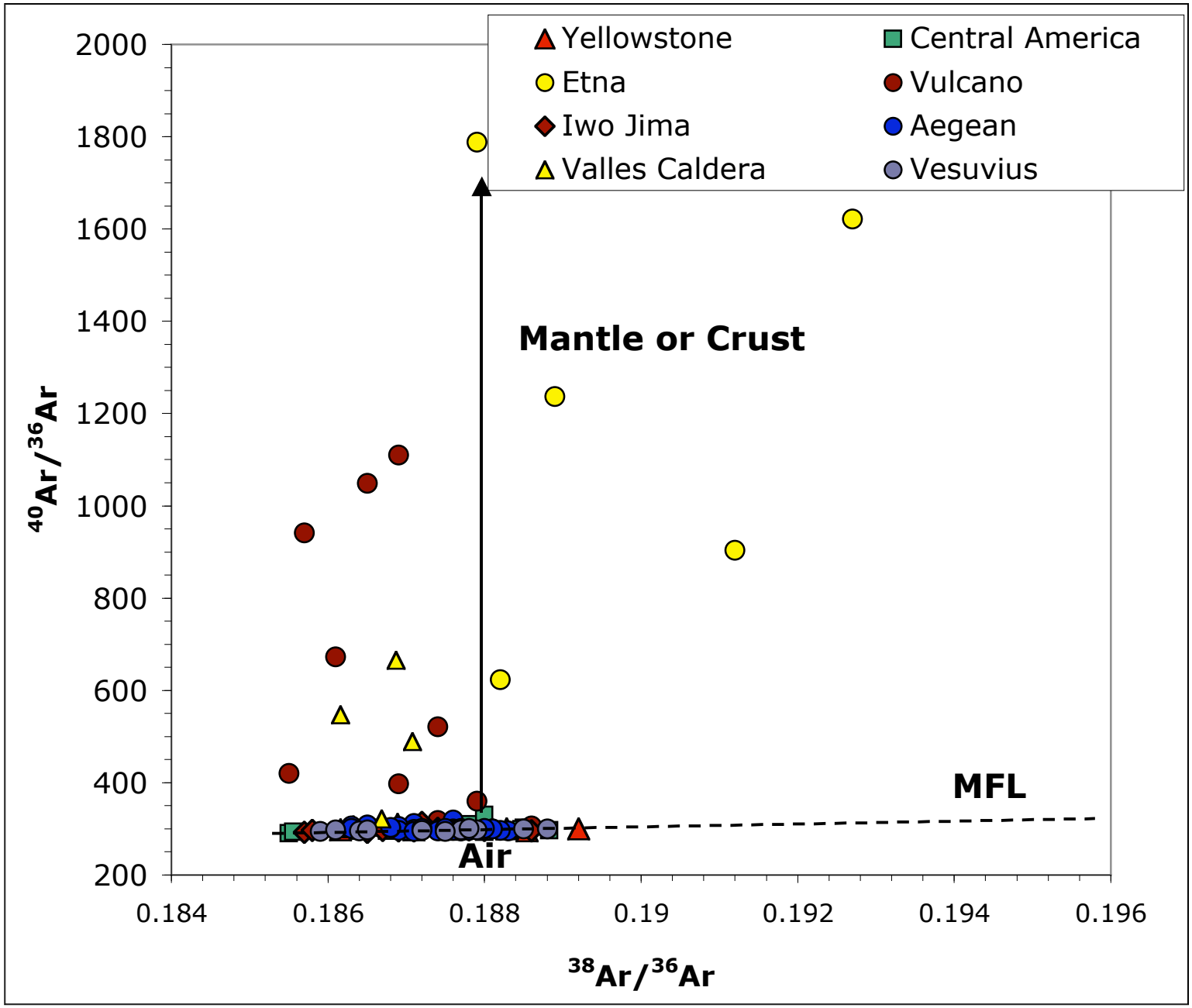
Melt inclusions: Marianas Arc



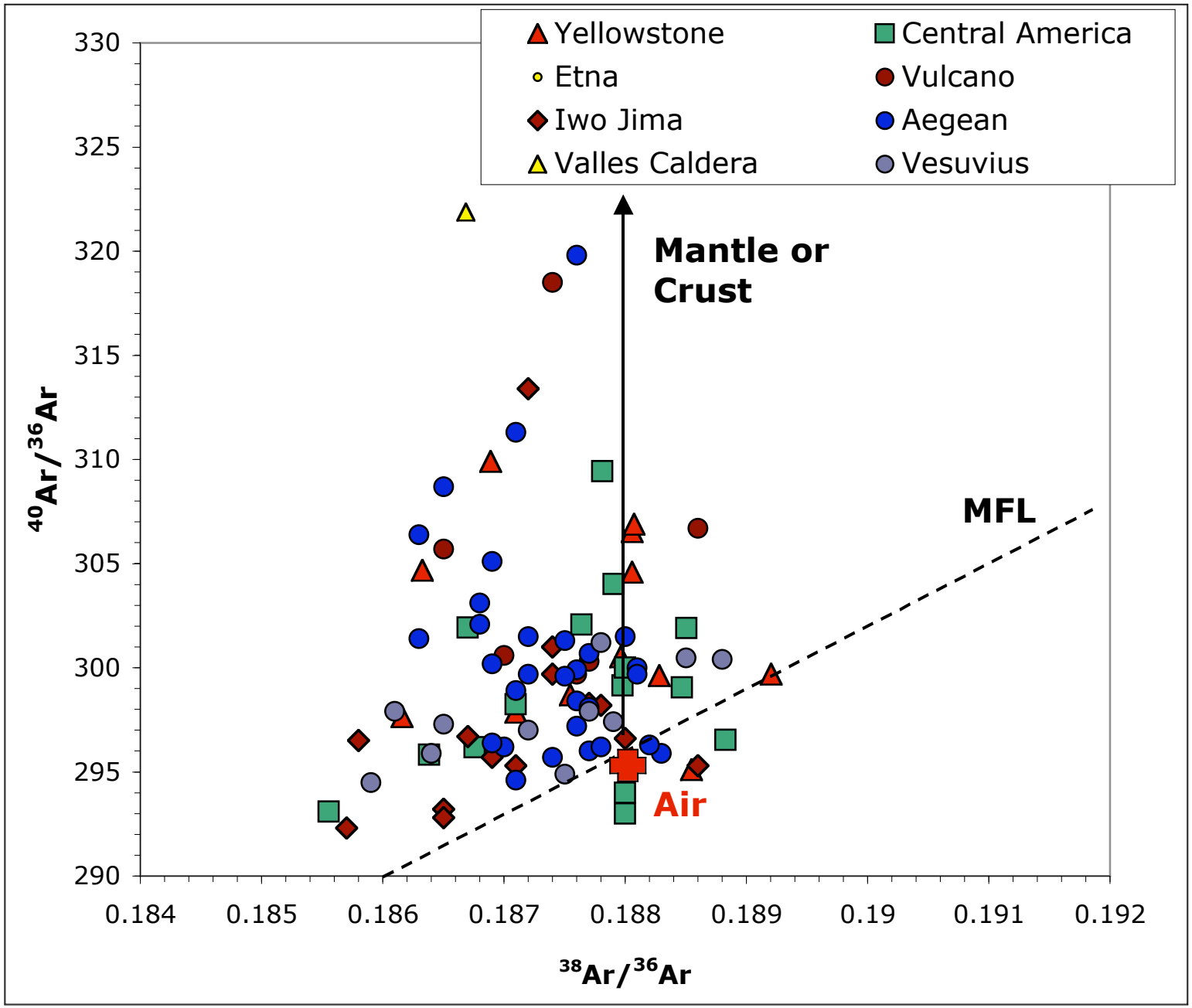
Shaw, Hauri, Fischer et al. EPSL 2008



Shaw, Hauri, Fischer et al. EPSL 2008

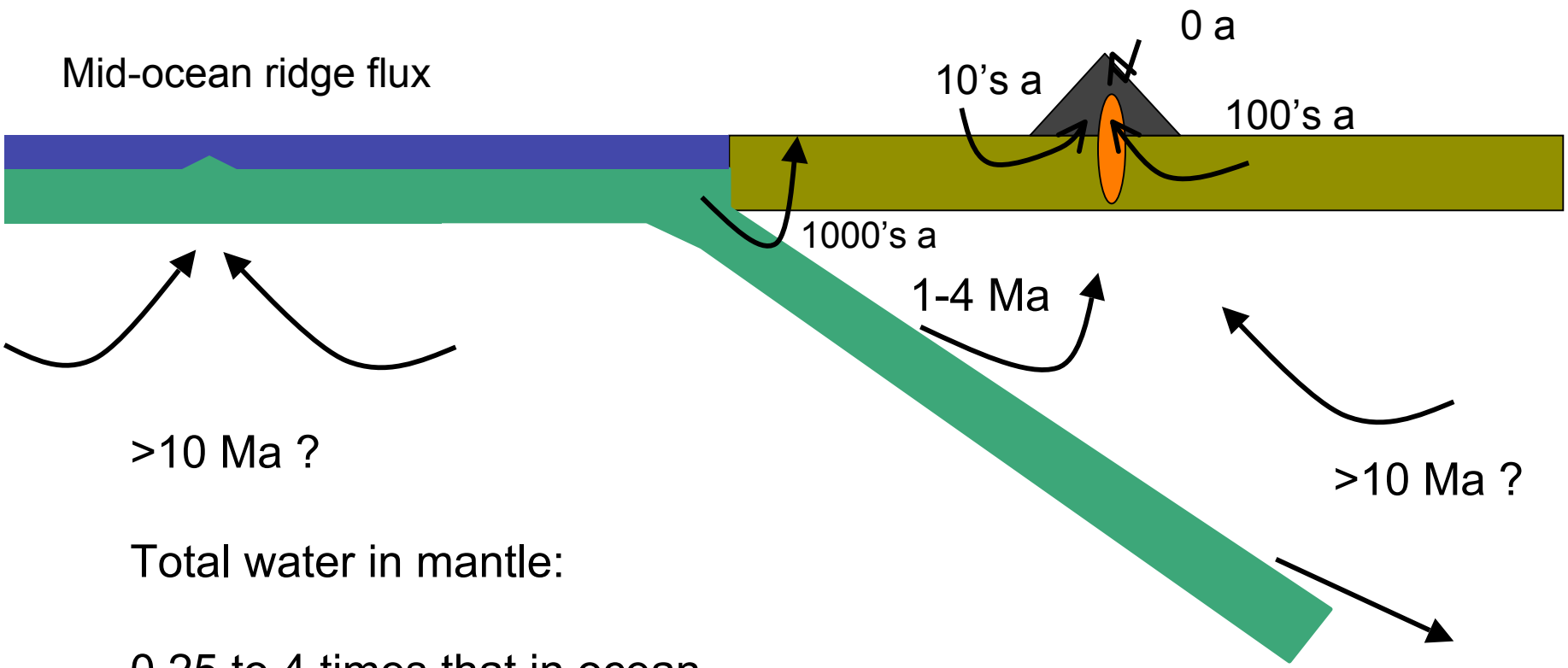


from Sano and Fischer (in press)



from Sano and Fischer (in press)

Towards a better understanding of the deep water cycle:



Total water in mantle:

0.25 to 4 times that in ocean

re-gassing of mantle