Sampling and interpretations of volcanic gases

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‘Volcanic Gases’

volcanic - magmatic - hydrothermal

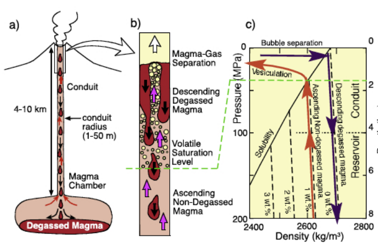
fumaroles, bubbling springs, plumes, geothermal wells, diffuse emissions

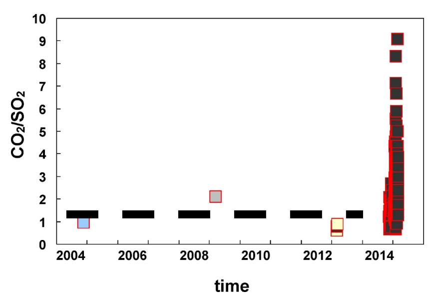
‘Tectonic Gases’

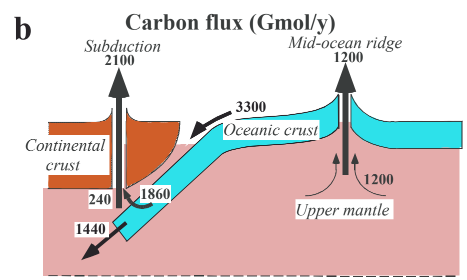
not related to volcanoes

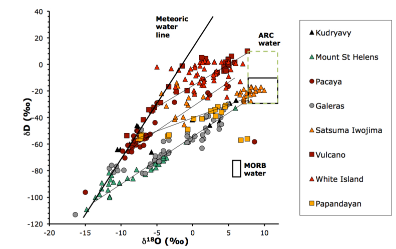
fumaroles, bubbling springs, geothermal wells, diffuse emissions

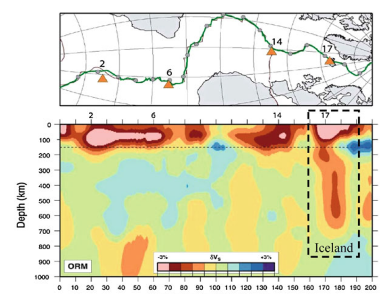
volcanic/tectonic gases



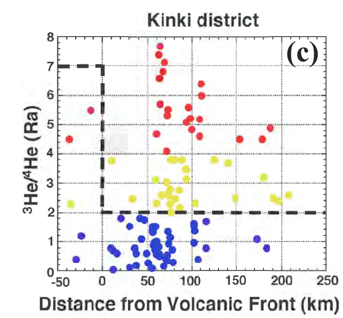




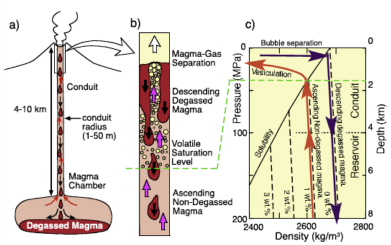


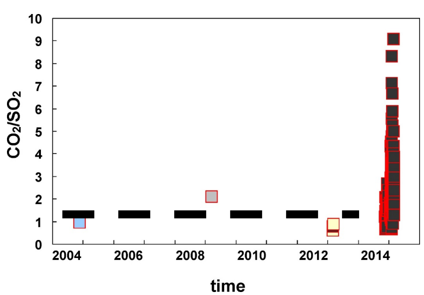


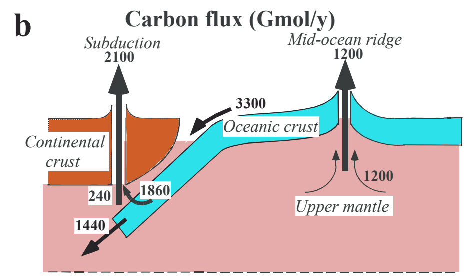
(c) S-wave tomographic image along the Mid-Atlantic Ridge

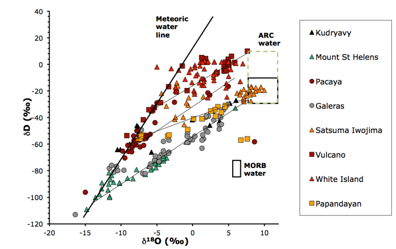


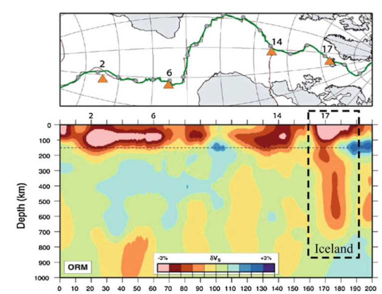
volcanic/tectonic gases











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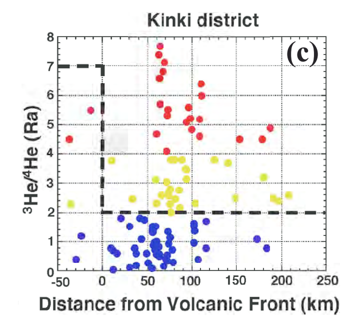
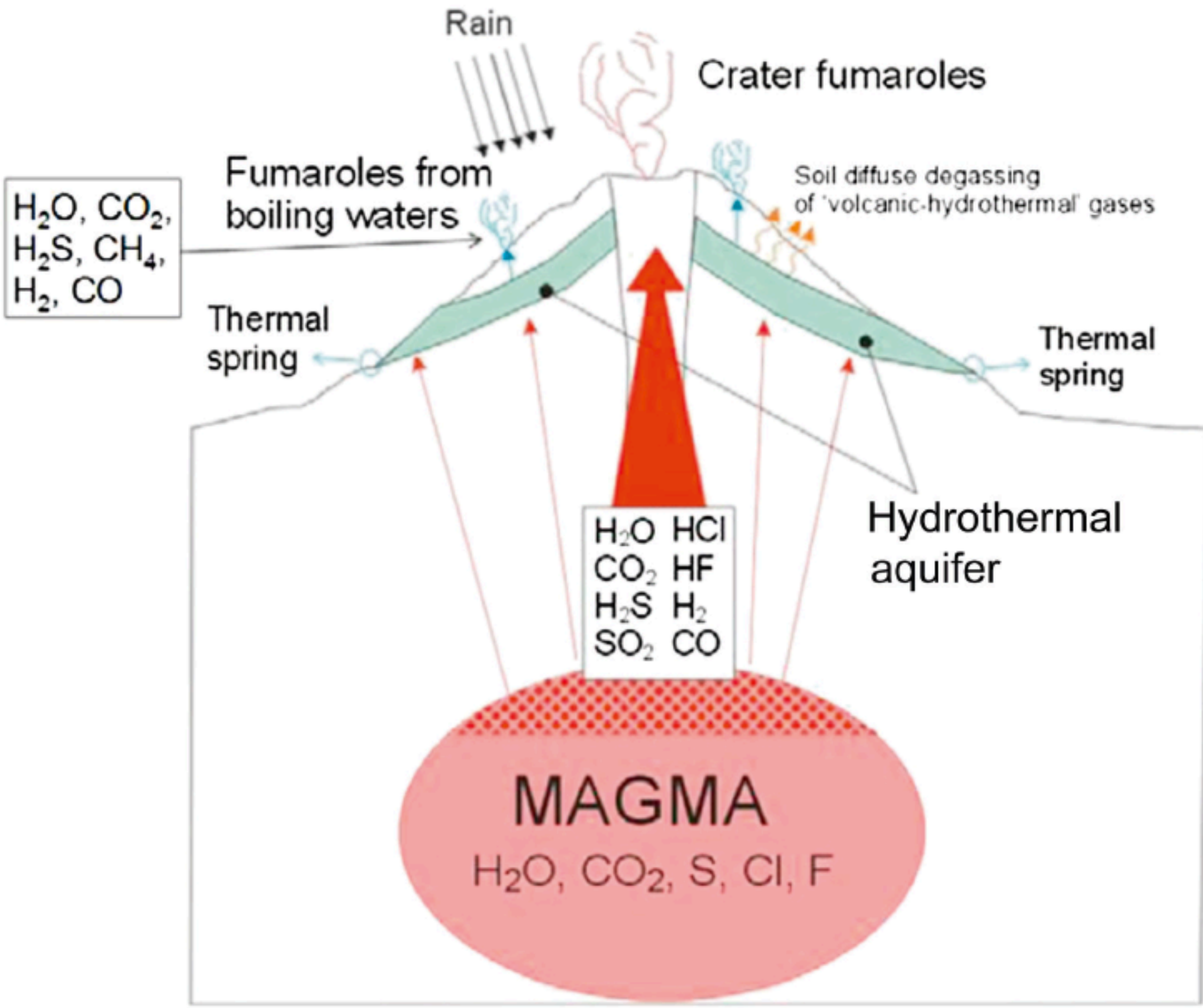
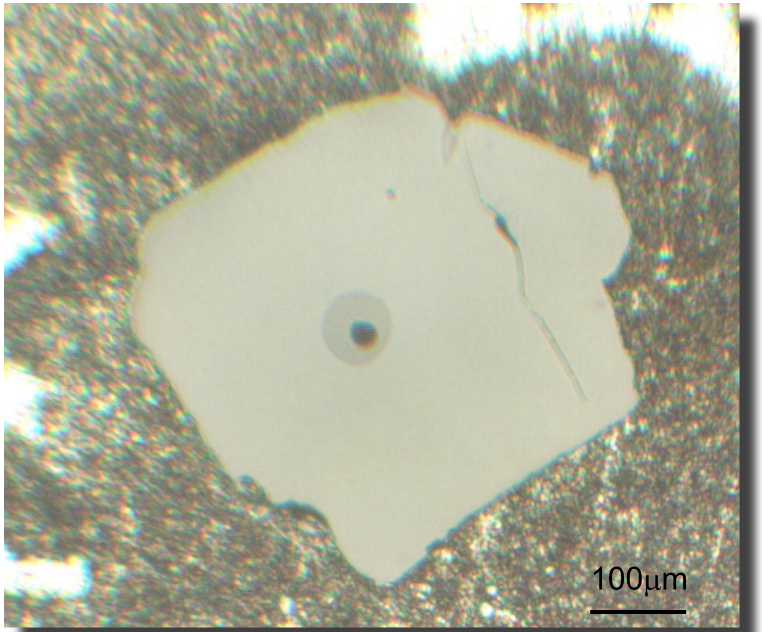




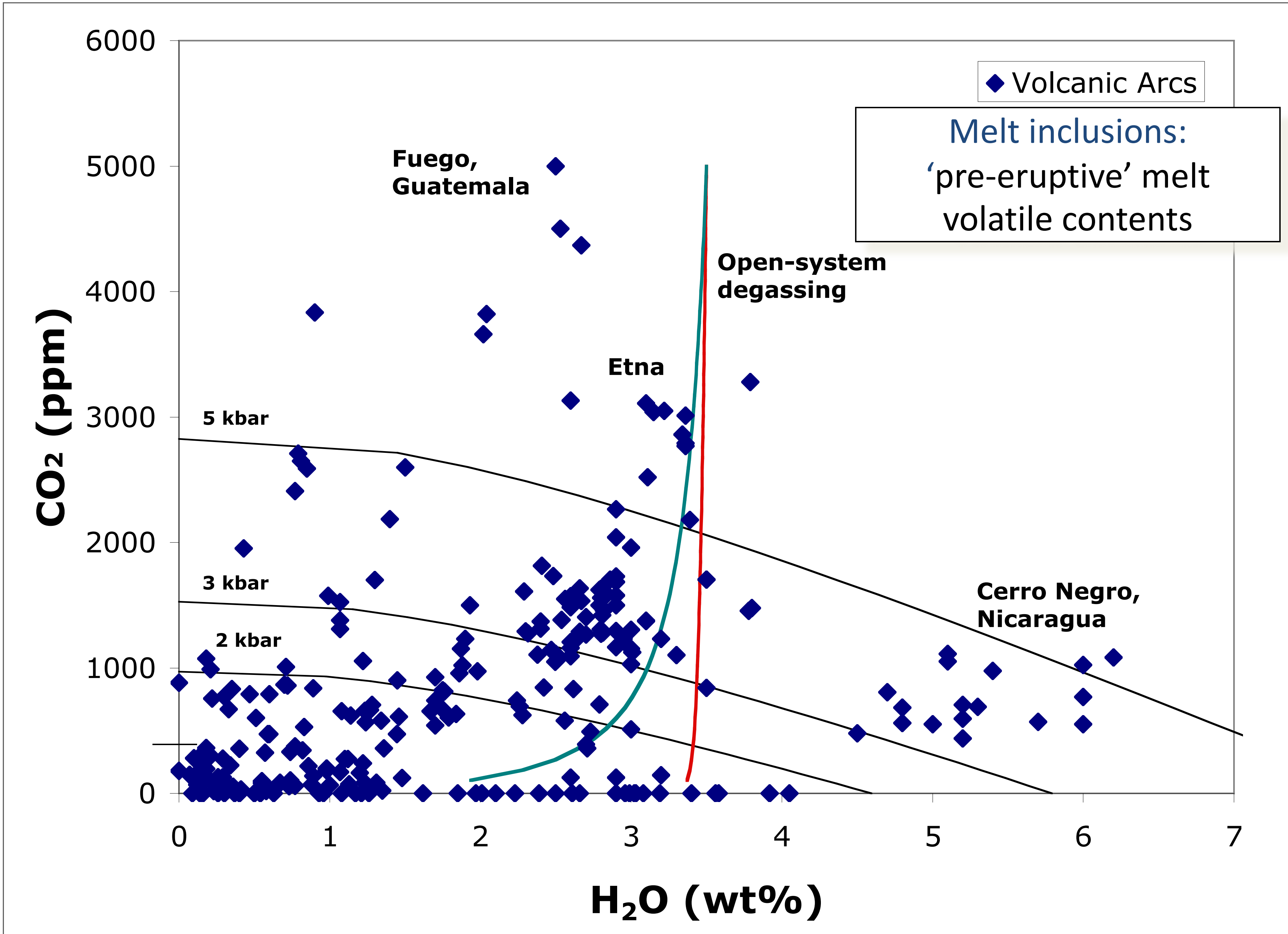
Fischer and Chiodini, 2015

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 than glasses



Photos: Alison Shaw, WHOI

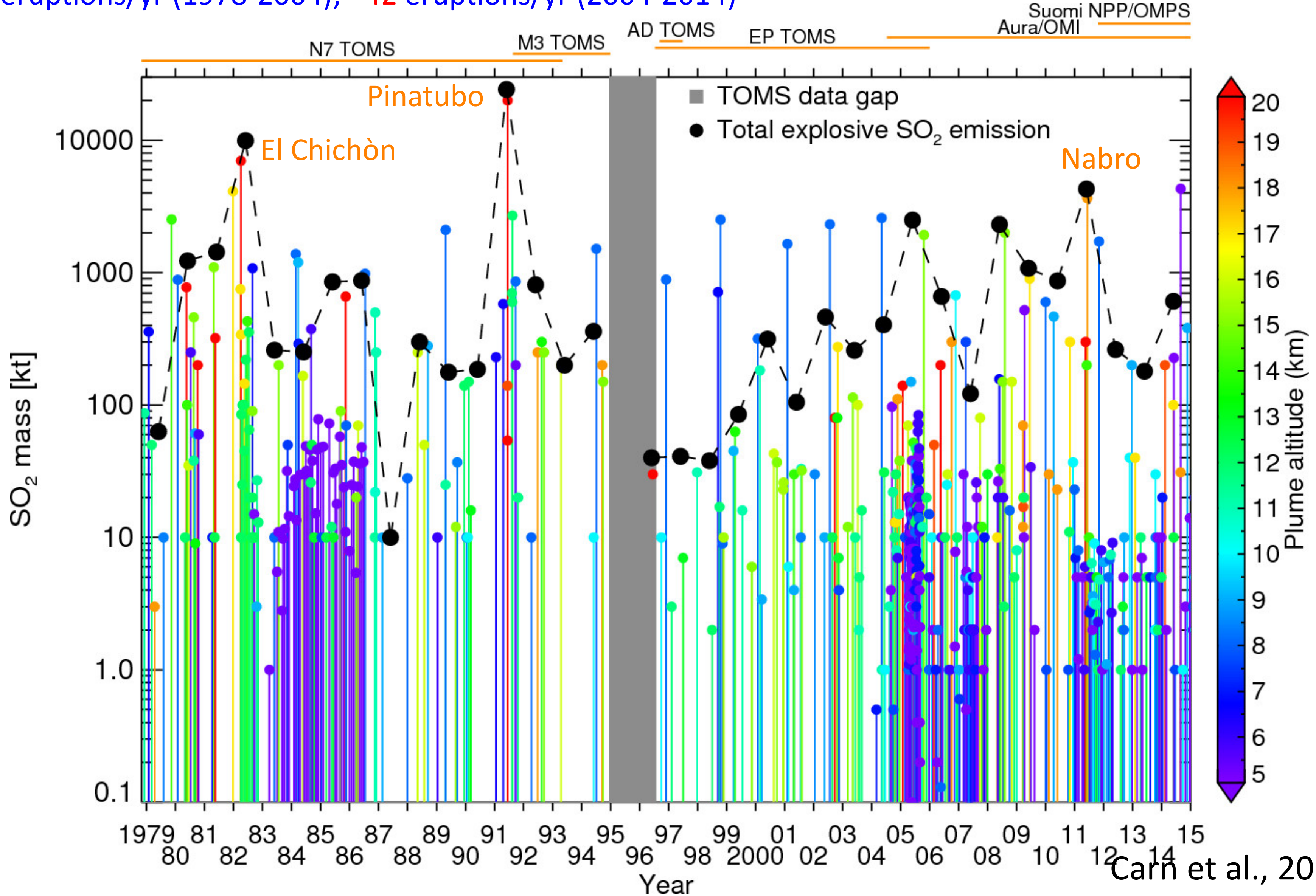


Georoc database and Roggensack et al., 2001

Eruptive volcanic SO_2 emissions (1978 – 2015)

650 eruptions; 100 Tg total SO_2; mean 0.16 Tg; 1σ = 0.9 Tg
~8 eruptions/yr (1978-2004); ~42 eruptions/yr (2004-2014)

[Bluth et al., 1993; Carn et al., 2003, 2015, in prep.]



Carn et al., 2017

Excess Sulfur first recognized at Fuego

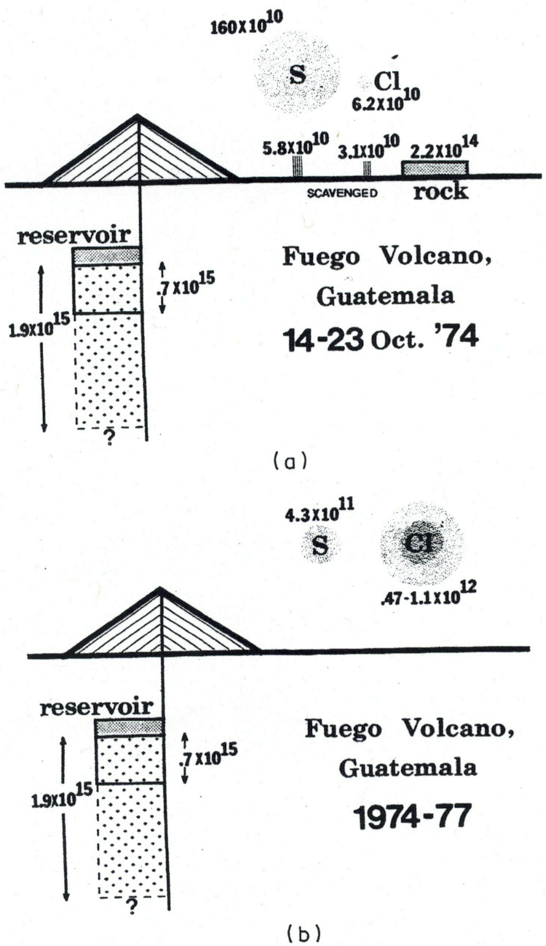
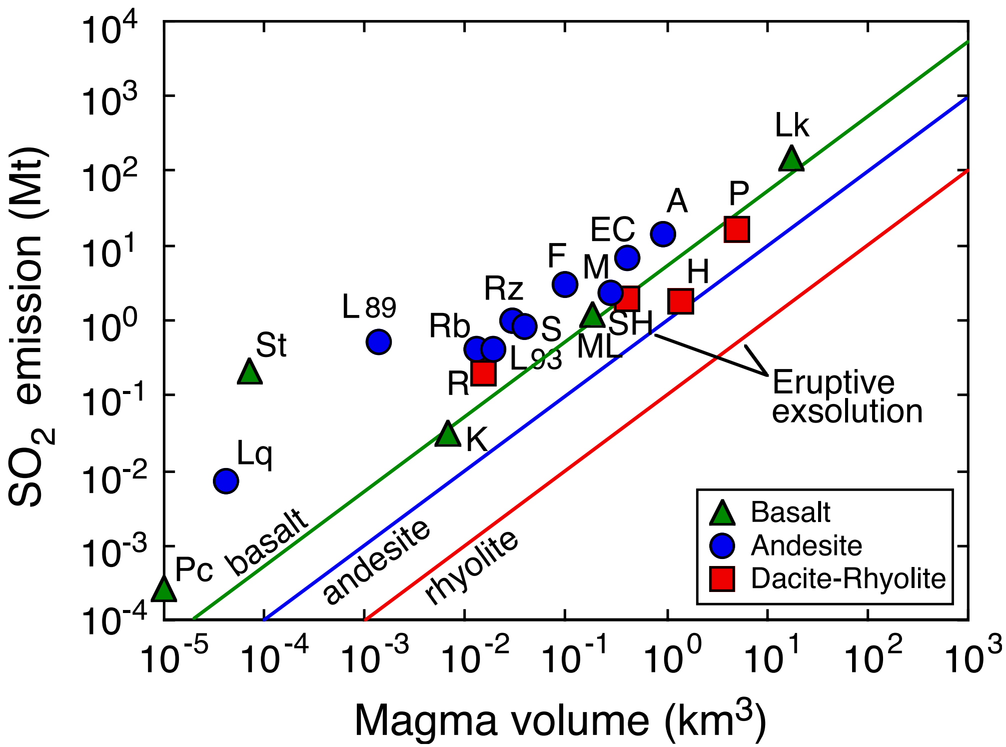


Fig. 2 Schematic diagram to represent the masses of S and Cl degassing from Fuego volcano and the magma masses required to account for them. (a) October 1974 explosive eruption; (b) 1974–77 passive degassing following eruption. All numbers given are in grams

Rose et al., 1982 recognized that 5 times more magma degassed just prior and during the 1974 eruption of Fuego, Guatemala than what can be attributed to erupted magma.

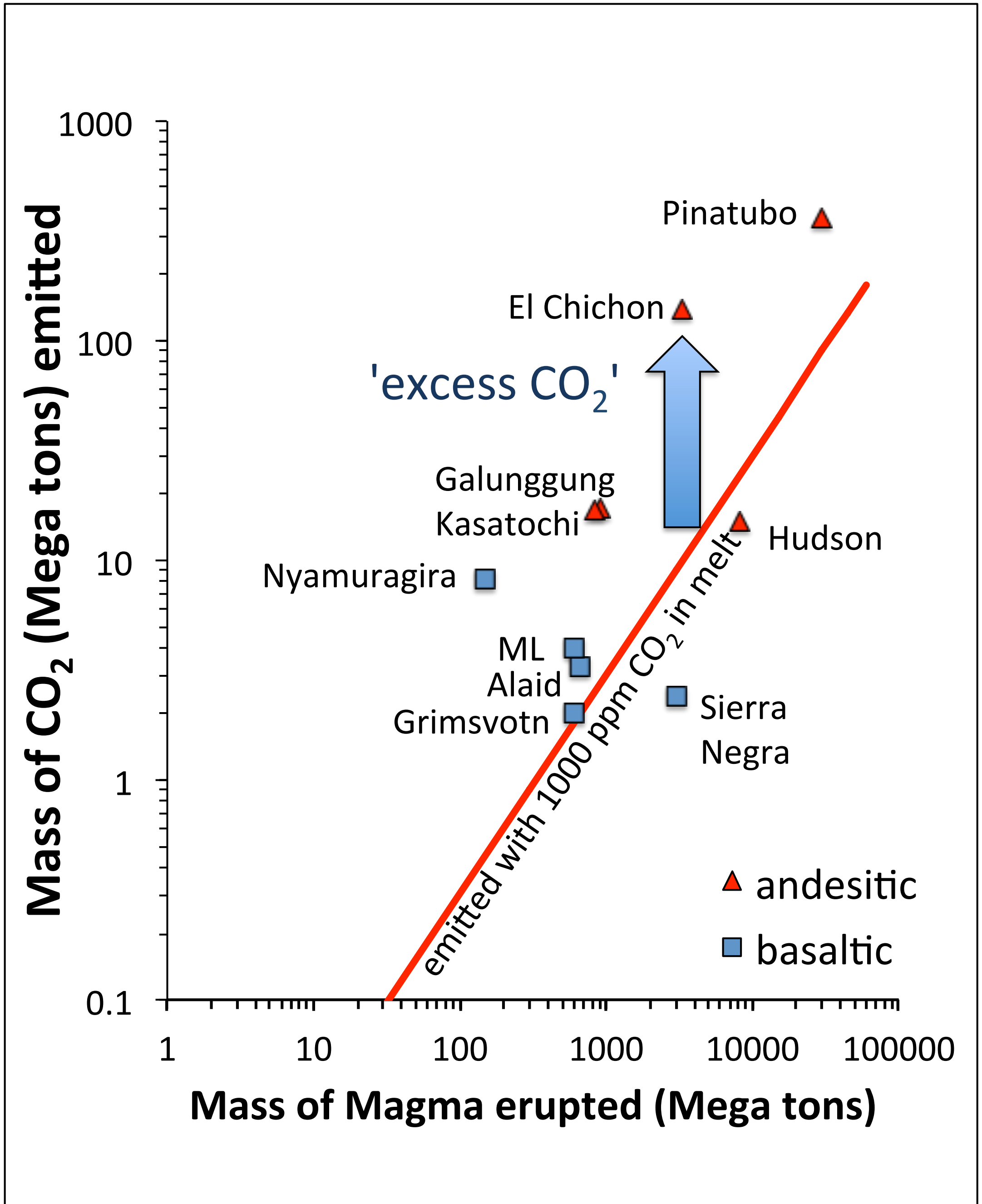
Rose, Stoiber and Malinconico, 1982

The Excess Sulfur 'problem'



More SO_2 erupted into atmosphere than what can be dissolved in erupted magma (factor of 10 – 100)

From: Wallace 2005



CO_2 flux requires

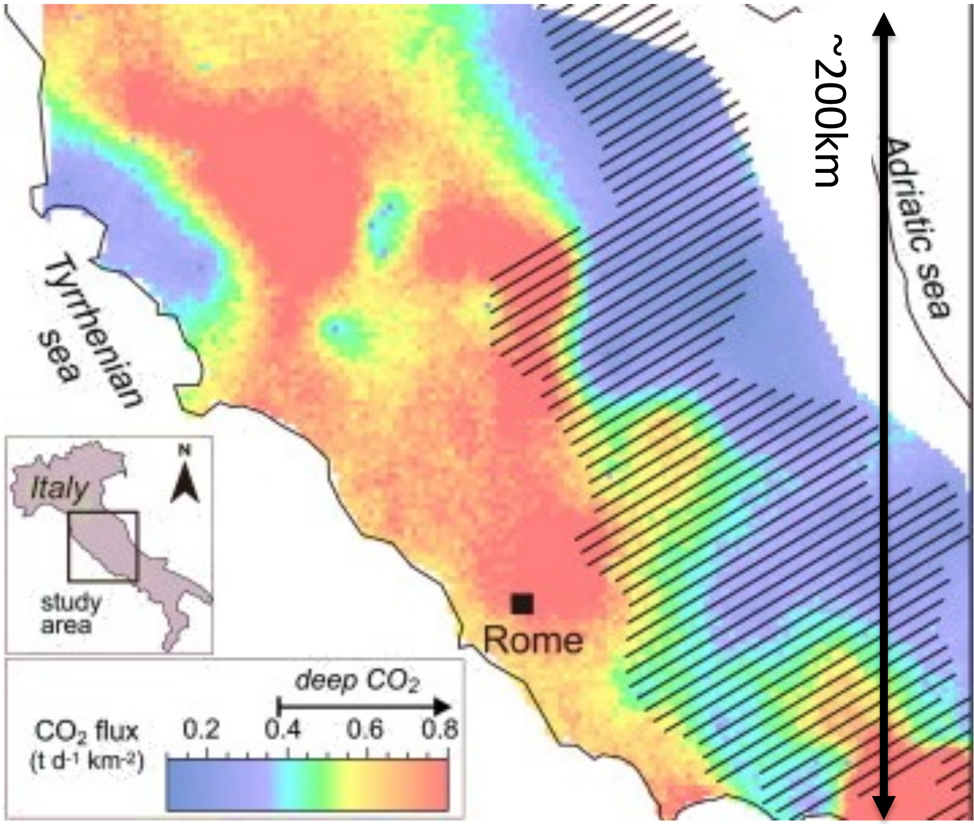
SO_2 flux and eruption C/S

Fischer and de Moor, 2014 AGU

BUT poorly constrained – needs to be re-done with new data

Passive Degassing from a volcano
i.e. during non-eruptive periods

Diffuse Degassing from a volcano
or region



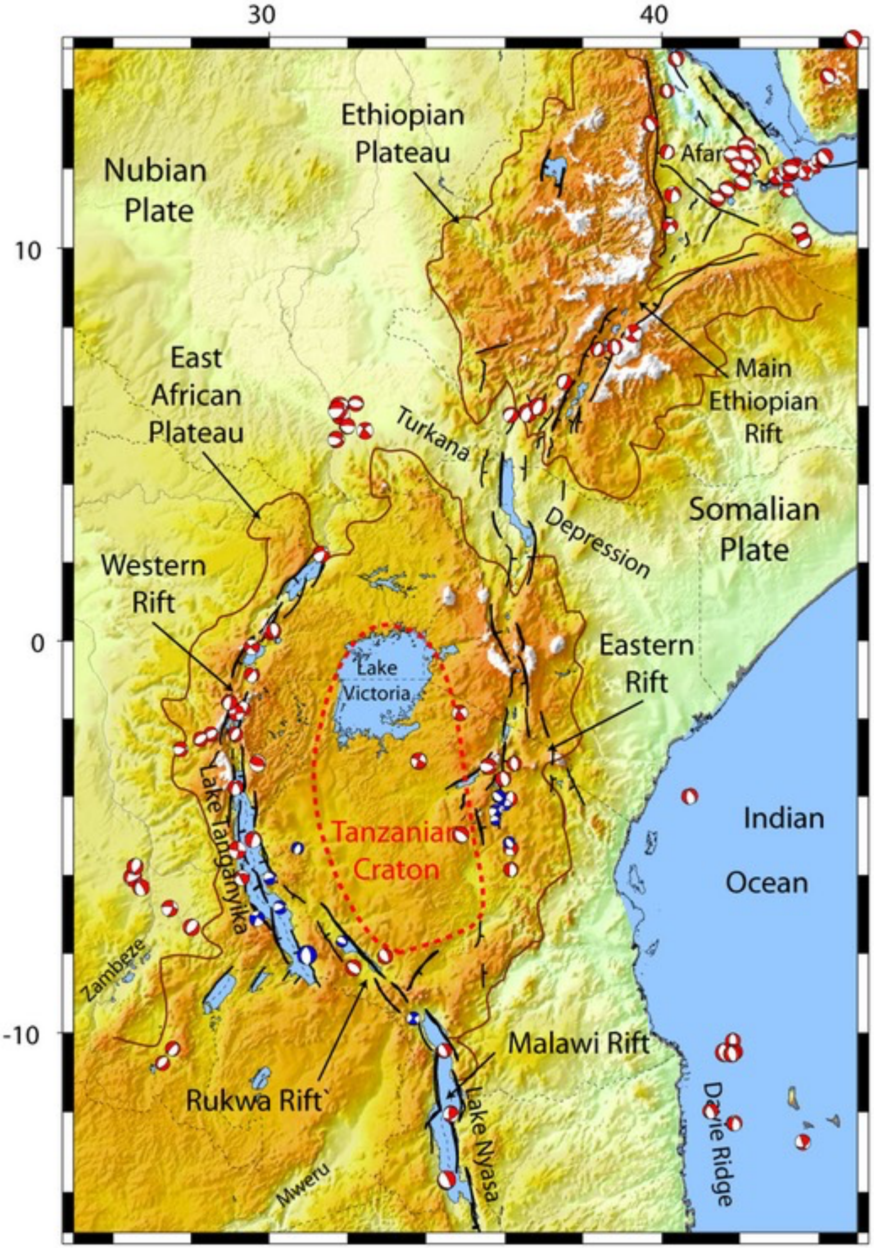
From ISS (NASA)

Etna 3 Mt CO_2/yr

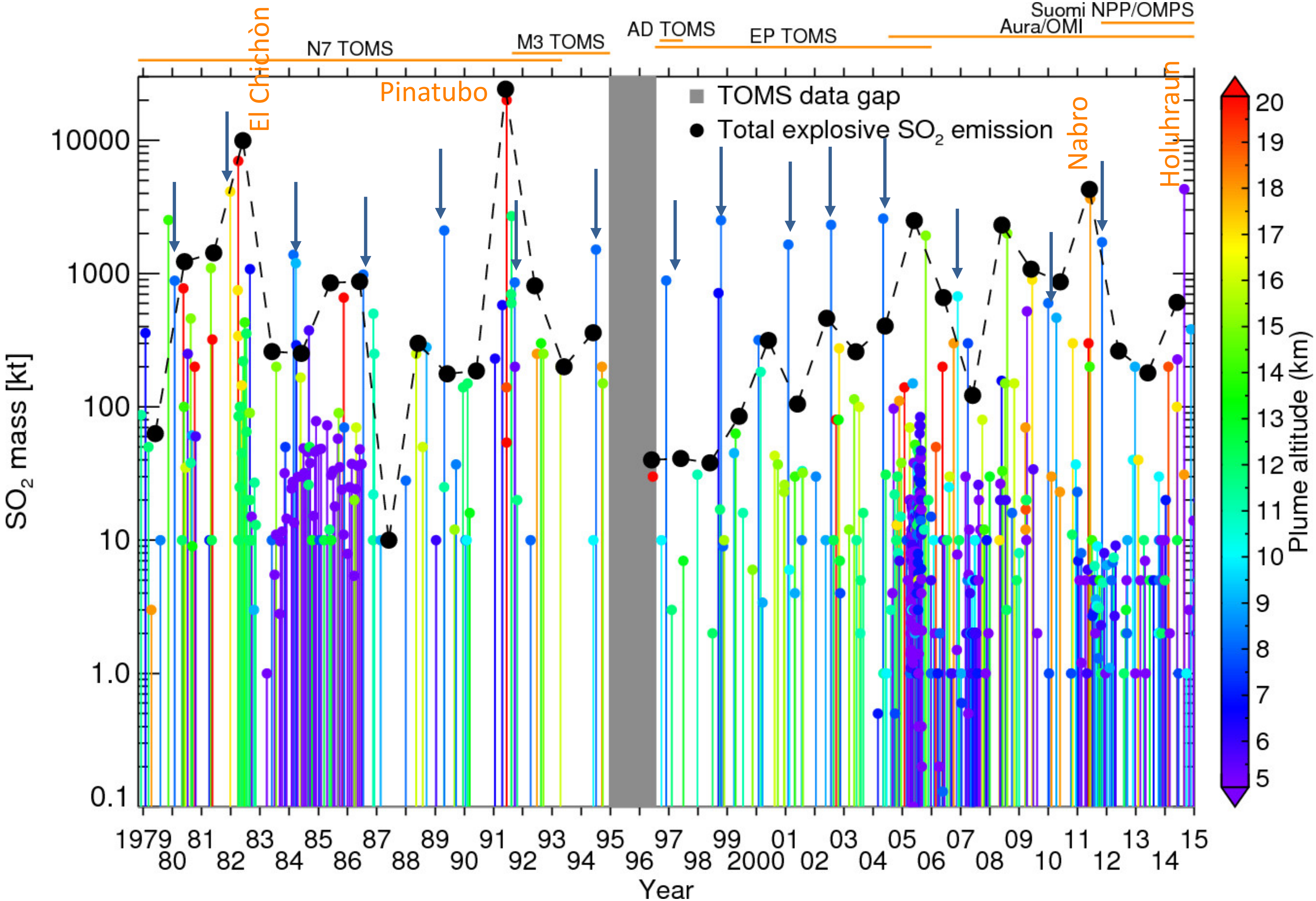
2 Mt CO_2/yr in this region

Chiodini et al., 2013

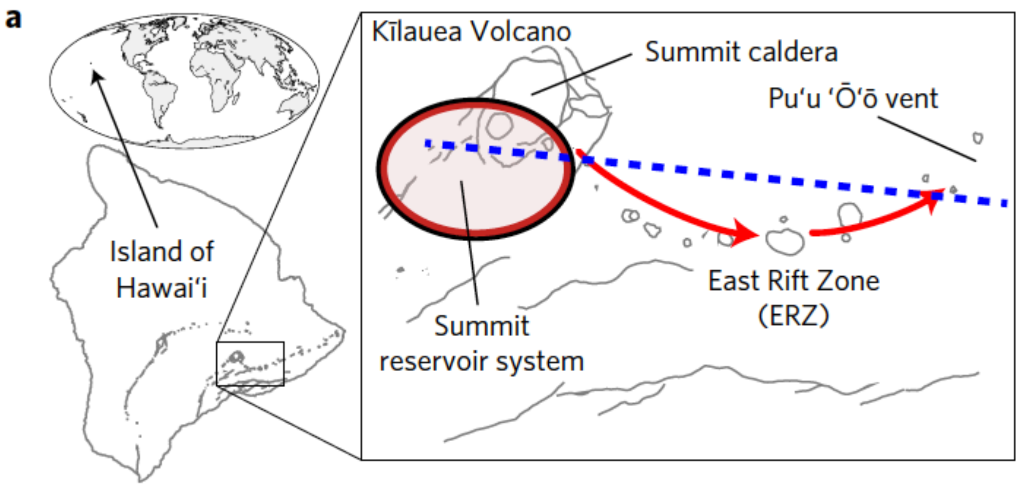
Nyamuragira/Niragongo



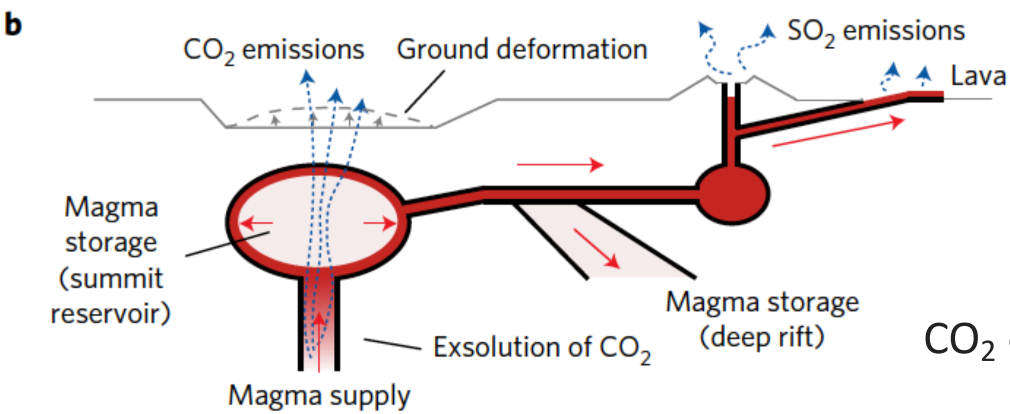
Eruptive volcanic SO_2 emissions (1978 – 2015) – Satellite data



Carn et al. 2015



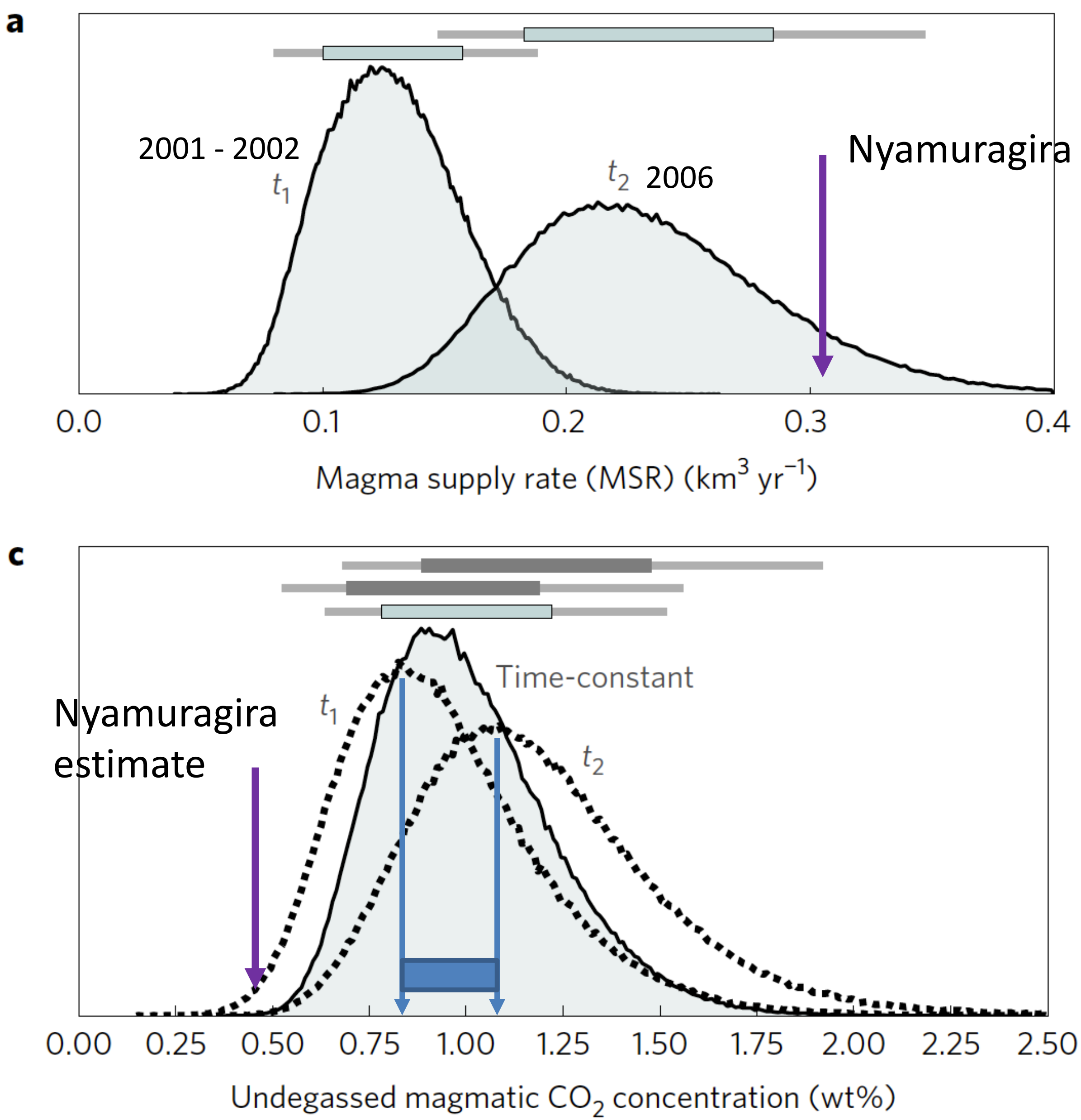
Kilauea 2018, Wikipedia



Model computes CO_2 emission rates from magma supply rates and undegassed C concentrations

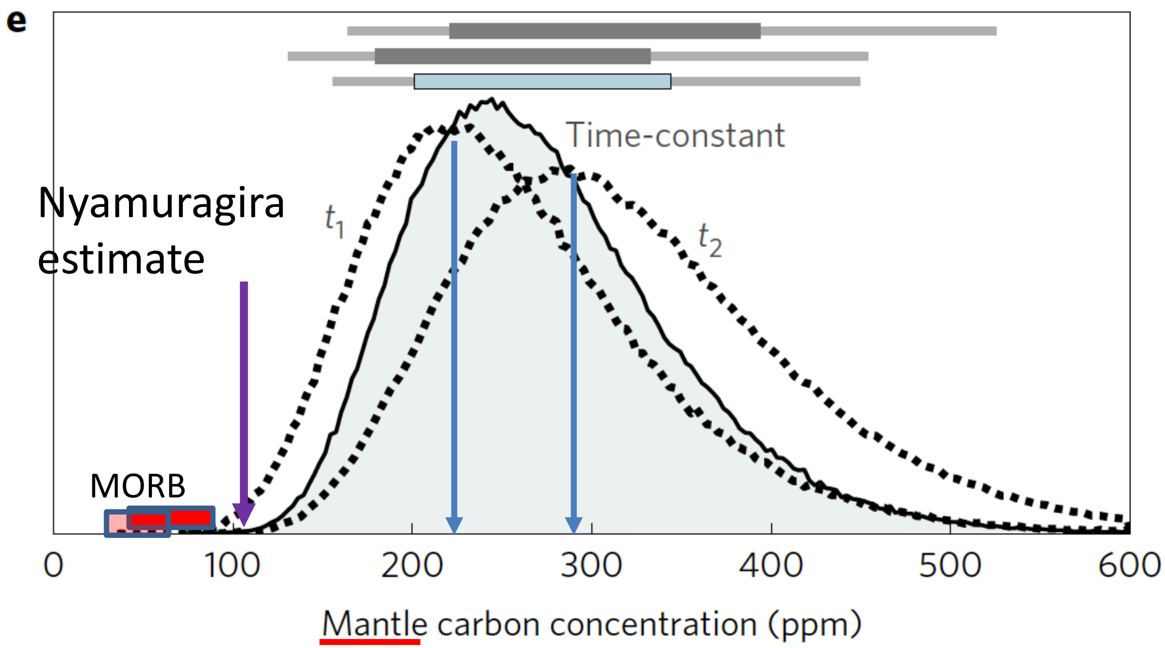
CO_2 emission rates used 8,400 ± 1,500 t d^{-1}

Anderson and Poland 2017



CO_2 saturated at ~ 30 to 40 km depth at Kilauea

Anderson and Poland 2017



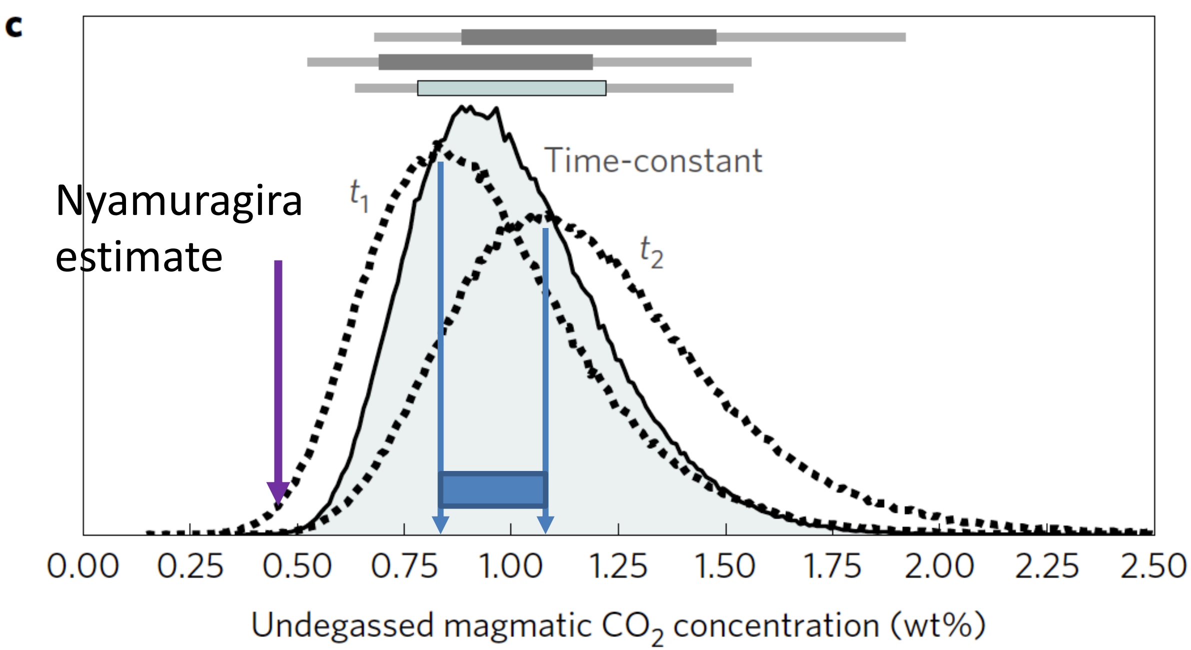
Use 10 ± 1.5 % melt fraction and C = 0.273 CO_2 to get mantle C

Average DMM

Saal et al, 2002 ~ 80 ppm C

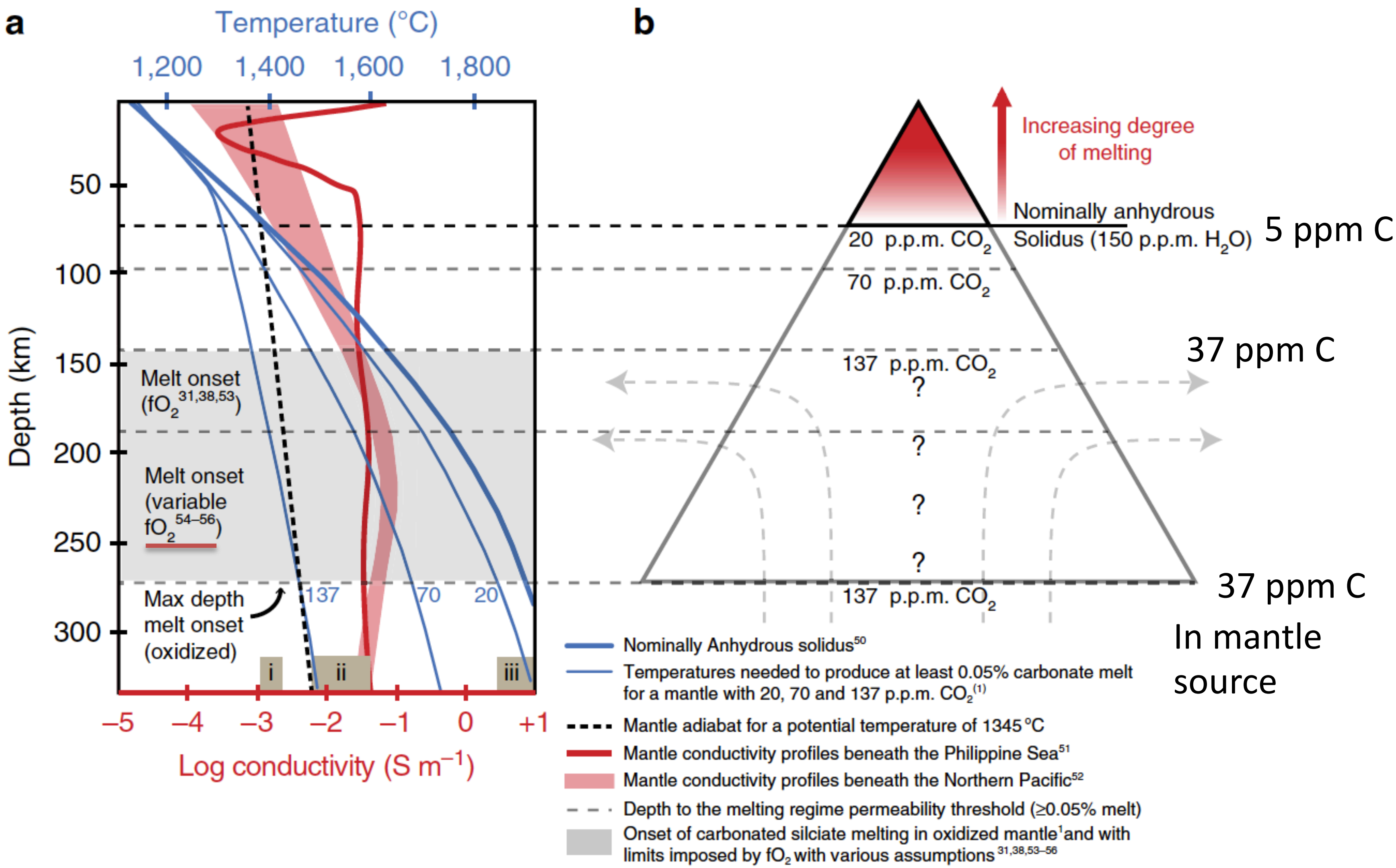
Le Voyer et al., 2017

average 37.4 ± 14.7 ppm C



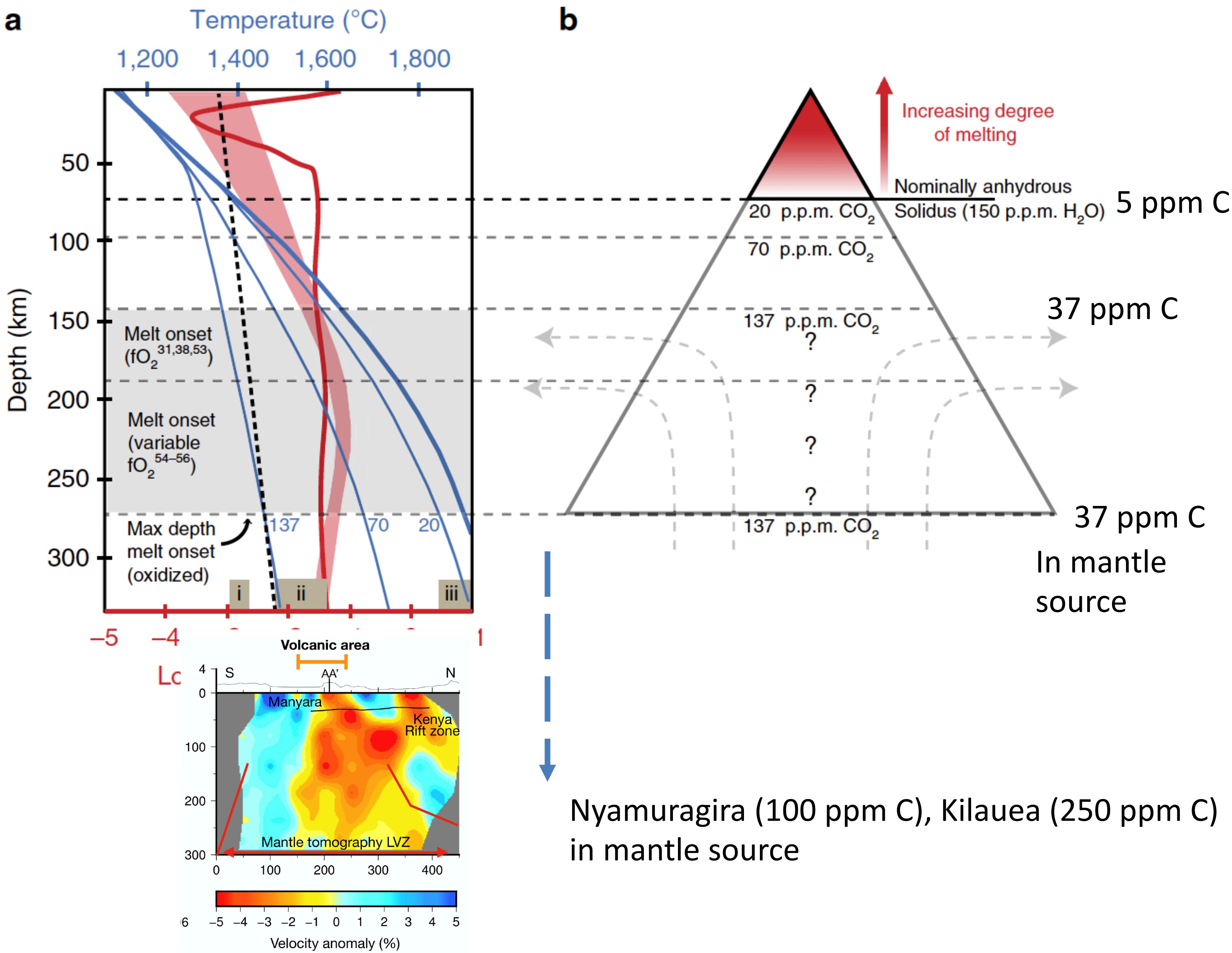
(5.5 to 327 ppm total range BUT questioned by Jones, Kurz et al., 2019 EPSL 2019)

Anderson and Poland 2017

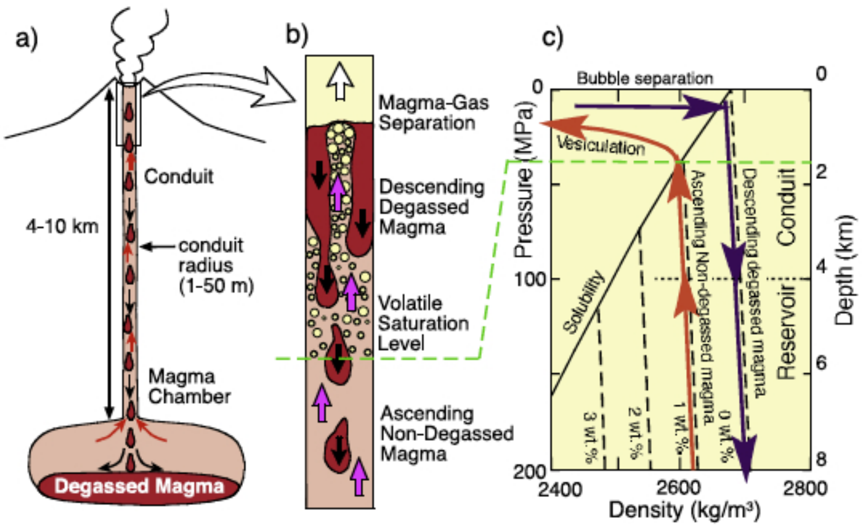


-> f_{O2} and mantle CO_2 content important for melting

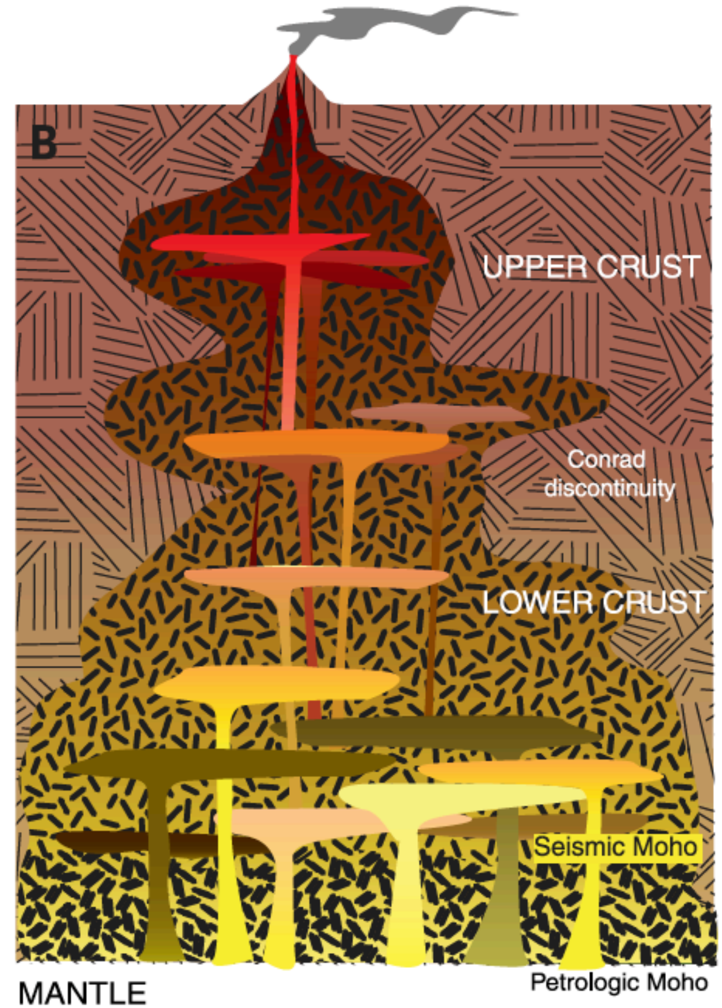
Le Voyer et al., 2017



a
Temperature (°C)
1,200
1,400
1,600
1,800
Depth (km)
50
100
150
200
250
300
Melt onset
(fO_2 31,38,53)
Melt onset
(variable
fO_2 54–56)
Max depth
melt onset
(oxidized)
137
70
20
i
ii
iii
–5
–4
Volcanic area
S
AA'
N
Manyara
Kenya
Rift zone
Mantle tomography LVZ
0
100
200
300
400
–5 –4 –3 –2 –1 0 1 2 3 4 5
Velocity anomaly (%)
b
Increasing degree
of melting
Nominally anhydrous
Solidus (150 p.p.m. H_2O)
20 p.p.m. CO_2
70 p.p.m. CO_2
137 p.p.m. CO_2
?
?
?
?
137 p.p.m. CO_2
5 ppm C
37 ppm C
37 ppm C
In mantle
source
Nyamuragira (100 ppm C), Kilauea (250 ppm C)
in mantle source



Shinohara 2008



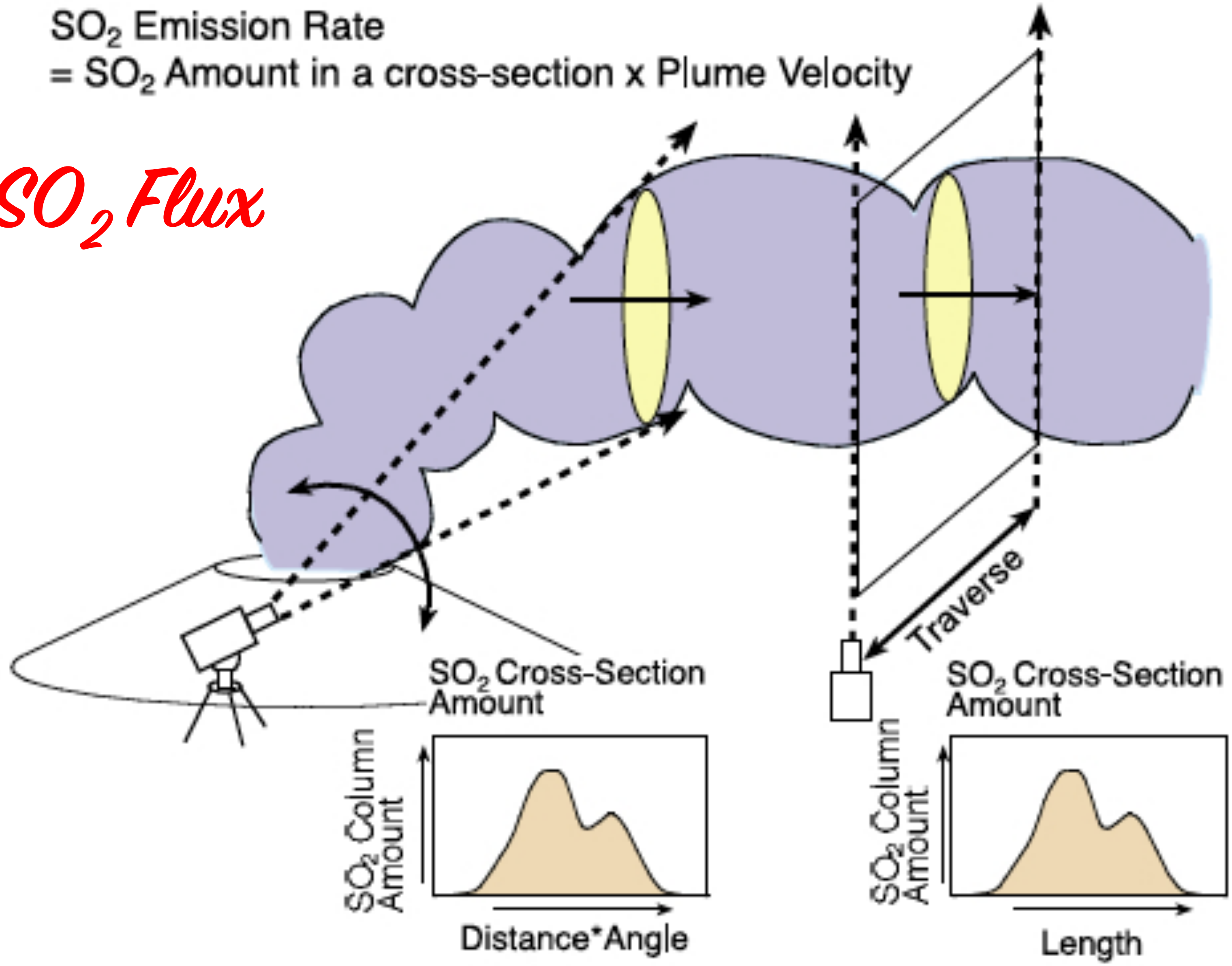
Cashman et al., 2017

Network for Observation of Volcanic and Atmospheric Change (NOVAC)

http://www.novac-project.eu/

SO_2 Flux

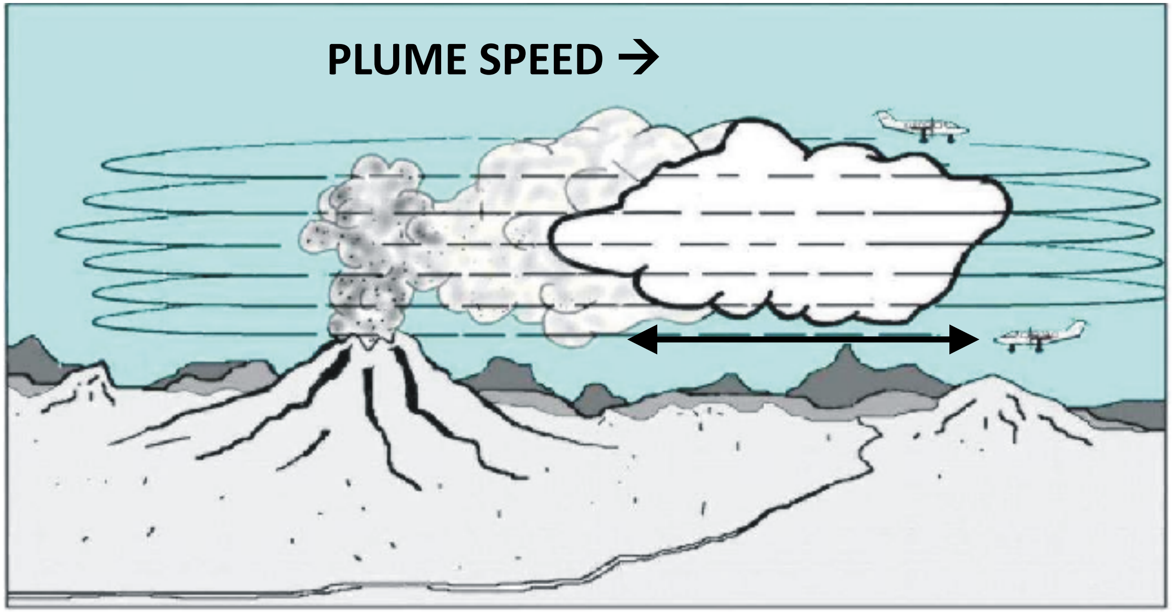
SO_2 Emission Rate
= SO_2 Amount in a cross-section x Plume Velocity

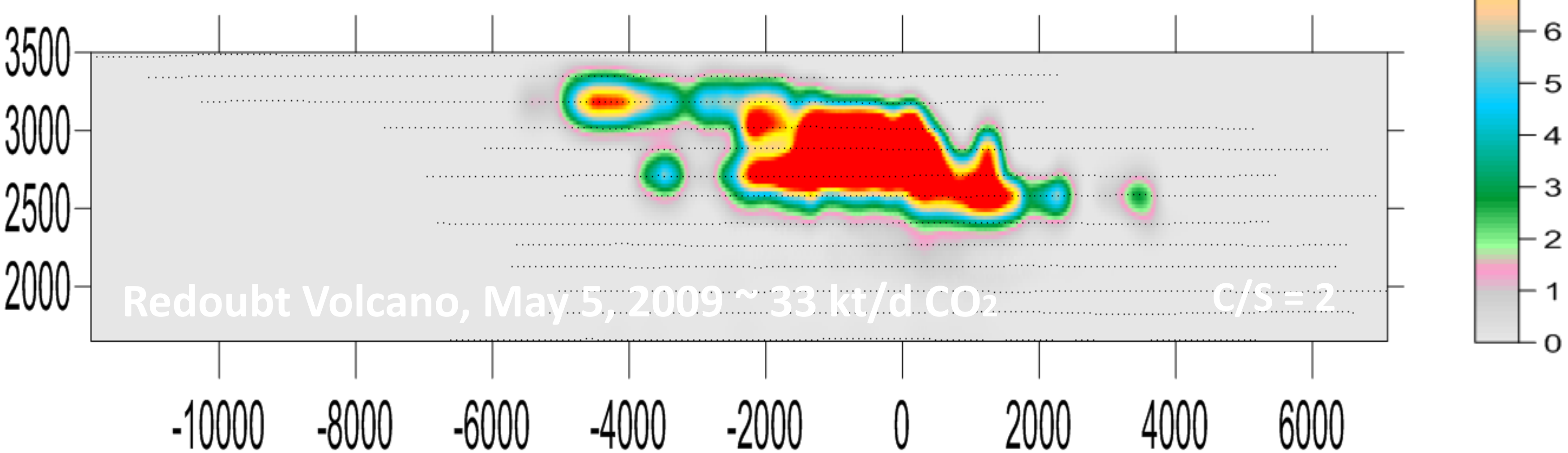


Shinohara 2008

Airborne Method

CO_2 Flux



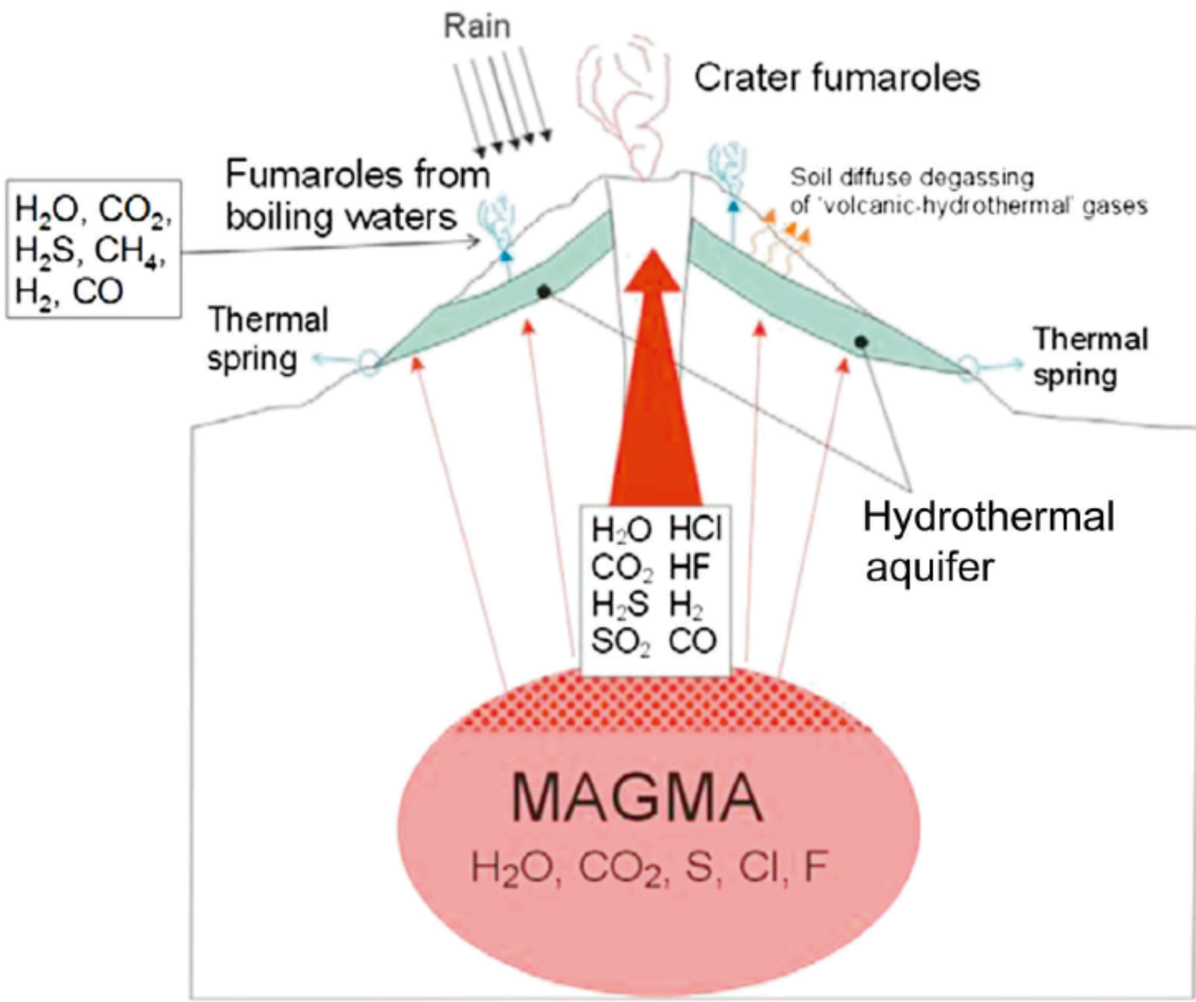


Typical High Temp (950°C) arc volcanic gas (~mol %)

H_2O	95	N_2	0.025
CO_2	1.6	Ar	0.001
SO_2	1.3	He	0.00014
H_2S	0.4	H_2	0.770
HCl	0.7	O_2	<0.0005
HF	0.01	CH_4	0.00005
		CO	0.0008

C, N, S, H, O, He, Ar isotopes

Fischer et al., 1998 EPSL


Rain
Crater fumaroles
H_2O, CO_2, H_2S, CH_4, H_2, CO
Fumaroles from boiling waters
Soil diffuse degassing of 'volcanic-hydrothermal' gases
Thermal spring
Thermal spring
H_2O HCl
CO_2 HF
H_2S H_2
SO_2 CO
Hydrothermal aquifer
MAGMA
H_2O, CO_2, S, Cl, F

Key Gas Reactions

$CO + 0.5\ O_2 = CO_2$

$$\xrightarrow{\text{K's and T}} fO_2$$

$H_2 + 0.5\ O_2 = H_2O$

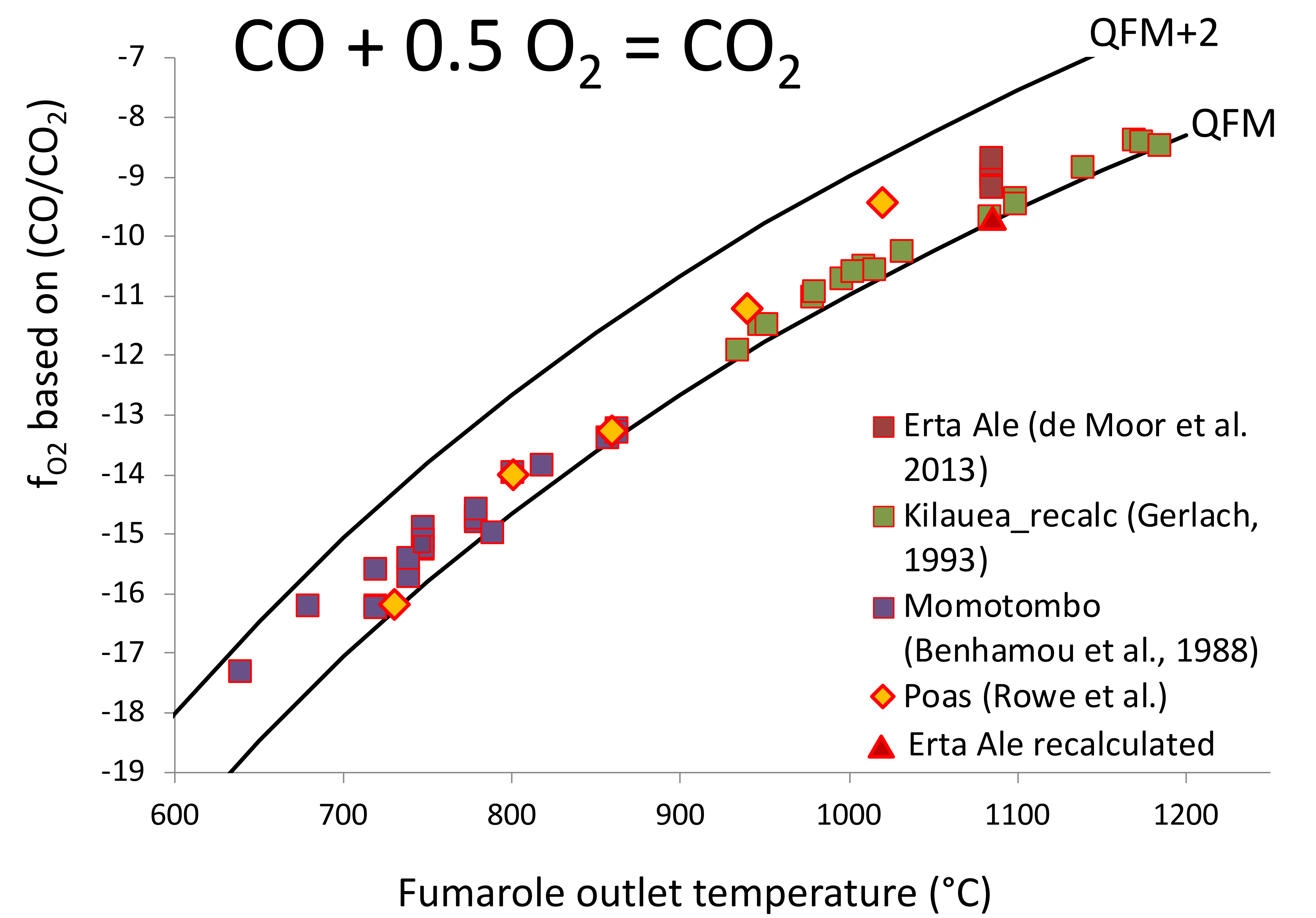
Key Gas Reactions

$$CO + 0.5\ O_2 = CO_2$$

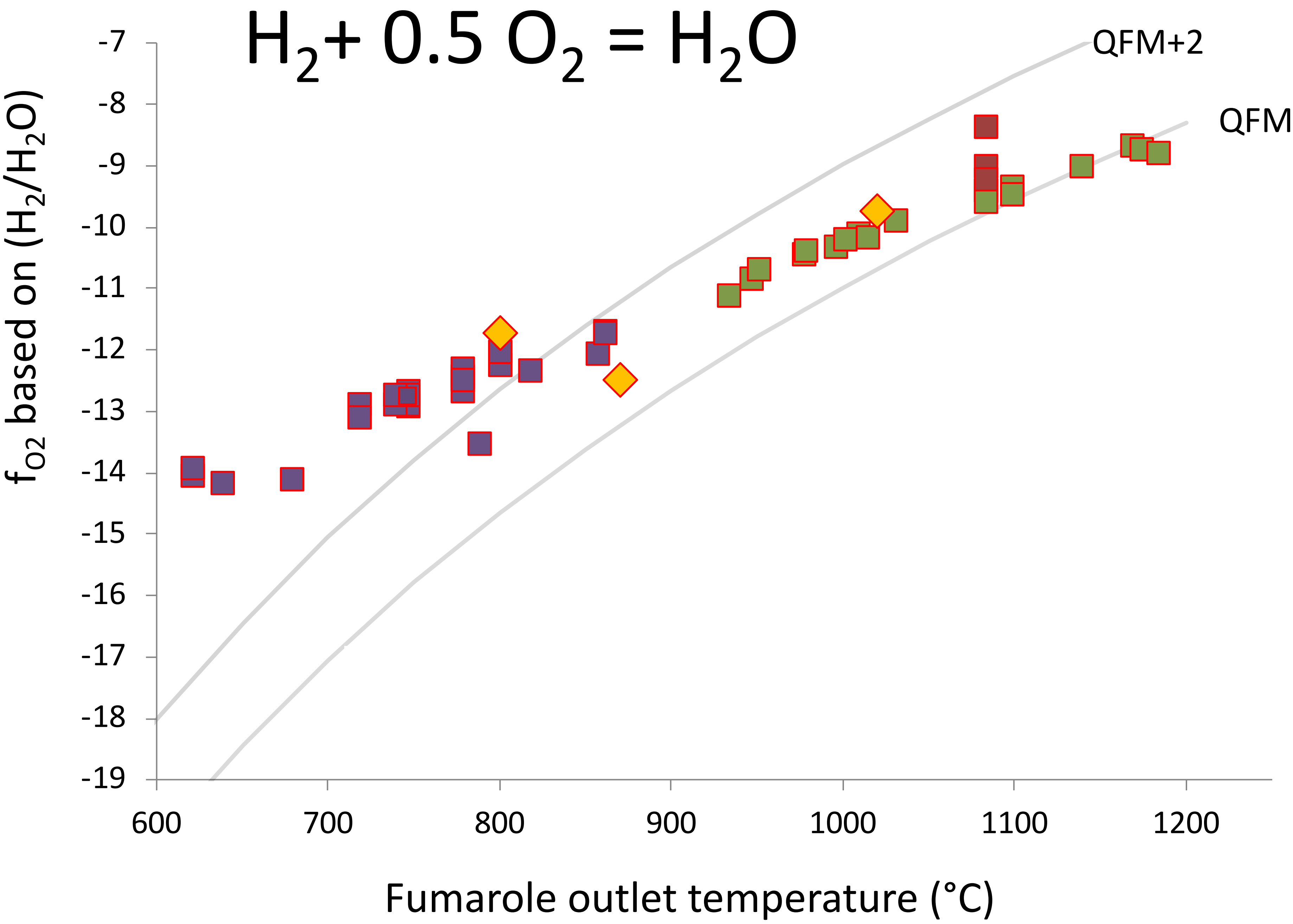
$$\xrightarrow{\text{K's and T}} fO_2$$

$$H_2 + 0.5\ O_2 = H_2O$$

Air contamination during sampling or close to surface
Use N_2/Ar and N_2/O_2 ratios to correct



$CO + 0.5\ O_2 = CO_2$
QFM+2
QFM
f_{O2} based on (CO/CO_2)
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
600
700
800
900
1000
1100
1200
Fumarole outlet temperature (°C)
Erta Ale (de Moor et al. 2013)
Kilauea_recalc (Gerlach, 1993)
Momotombo (Benhamou et al., 1988)
Poas (Rowe et al.)
Erta Ale recalculated

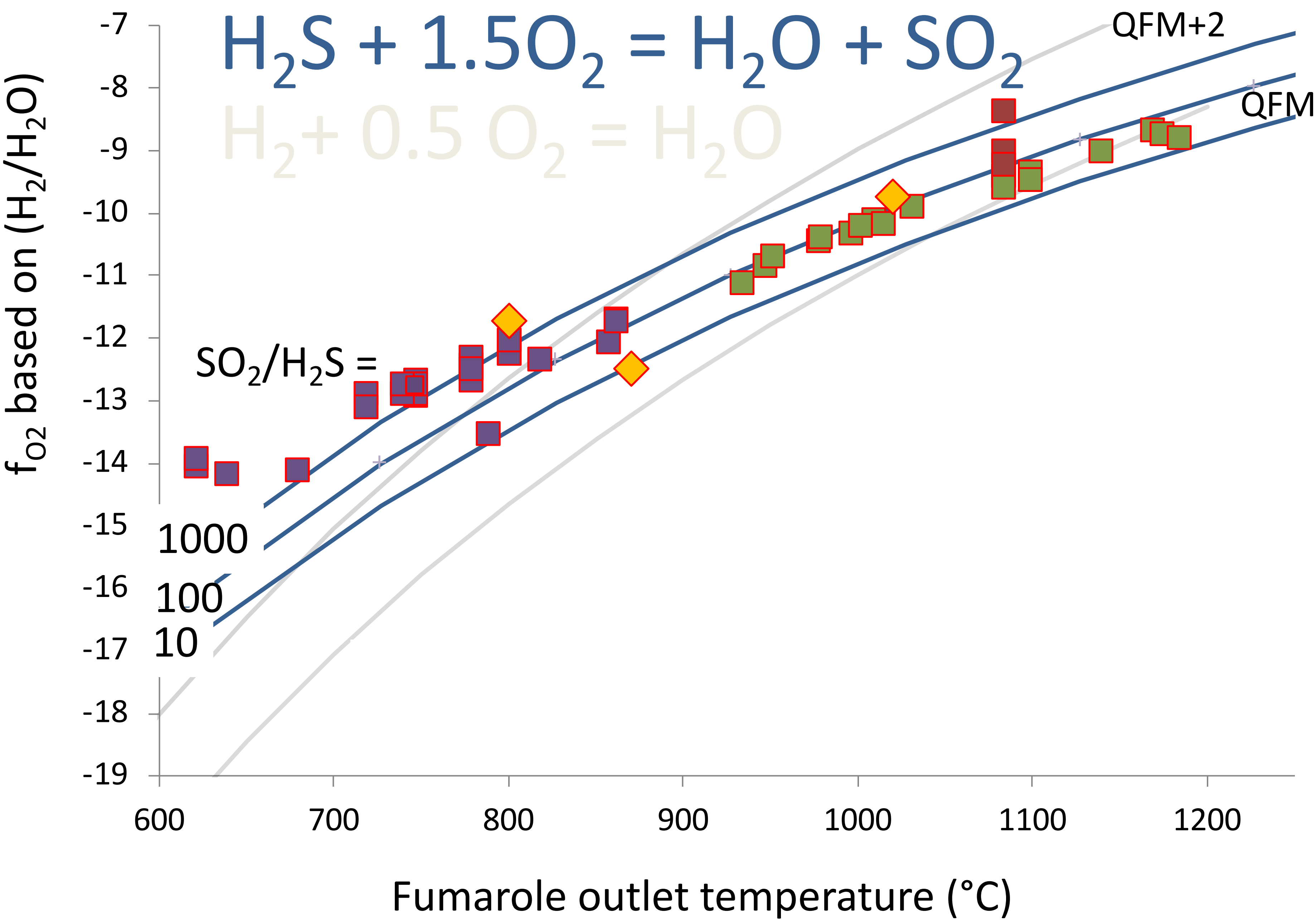


$H_2 + 0.5\ O_2 = H_2O$
QFM+2
QFM
f_{O2} based on (H_2/H_2O)
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
600
700
800
900
1000
1100
1200
Fumarole outlet temperature (°C)

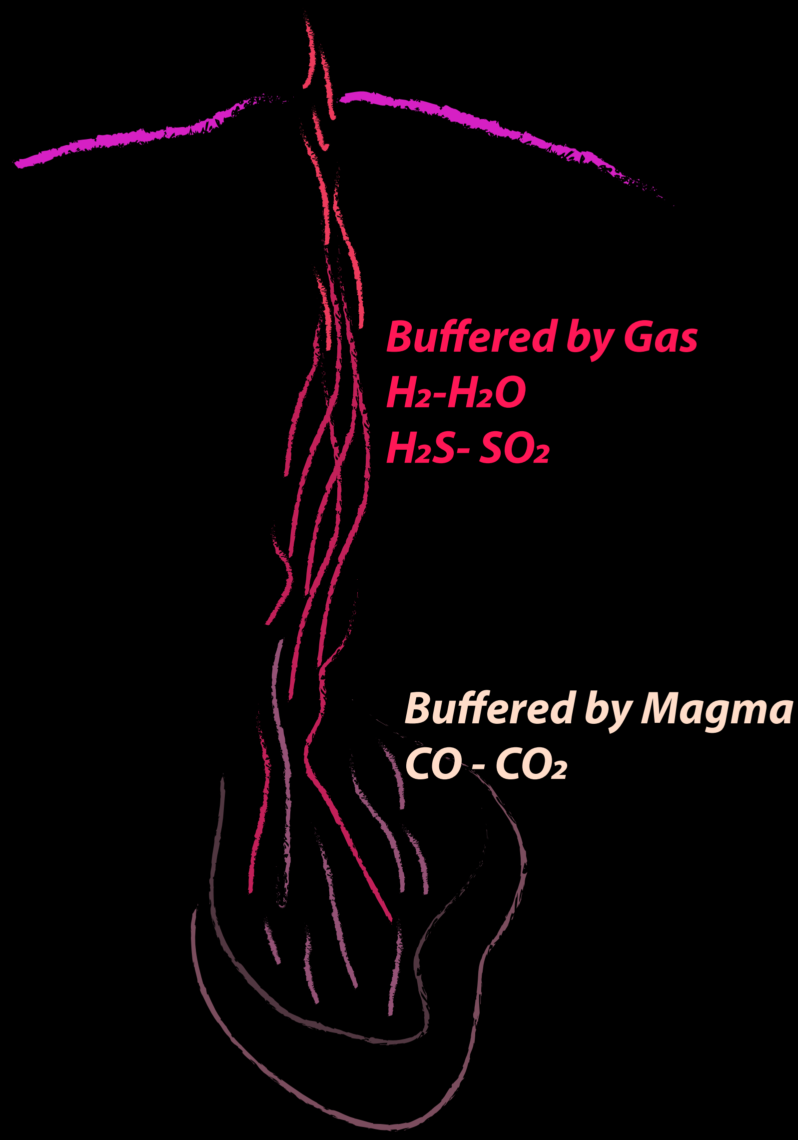
$$H_2S + 1.5O_2 = H_2O + SO_2$$

$$H_2 + 0.5\ O_2 = H_2O$$

$$\longrightarrow fO_2$$

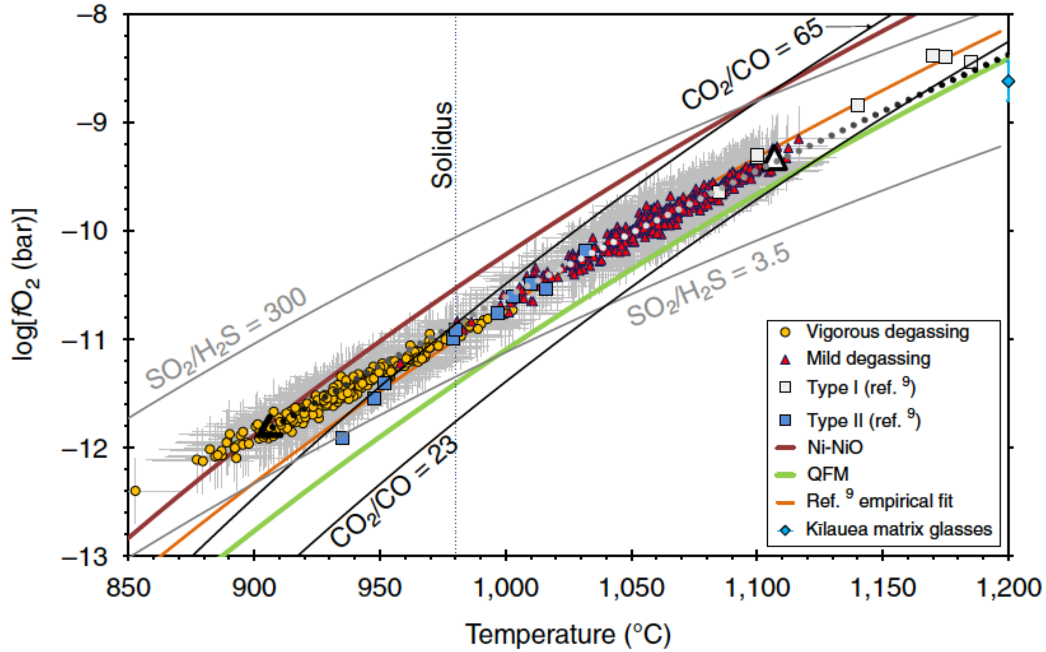


$H_2S + 1.5O_2 = H_2O + SO_2$
$H_2 + 0.5\ O_2 = H_2O$
QFM+2
QFM
$SO_2/H_2S =$
1000
100
10
f_{O2} based on (H_2/H_2O)
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
600
700
800
900
1000
1100
1200
Fumarole outlet temperature (°C)



Buffered by Gas
H_2-H_2O
H_2S- SO_2
Buffered by Magma
CO - CO_2

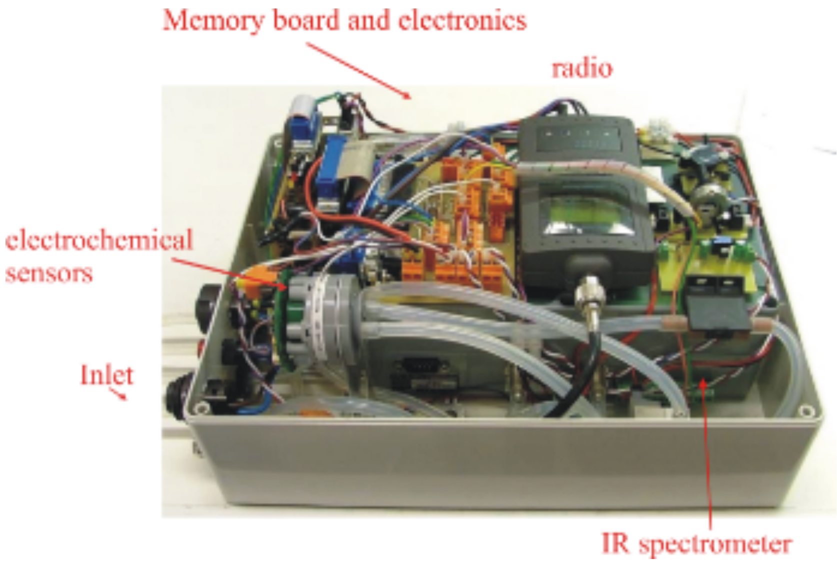
Open-Path FTIR measurements at Kilauea

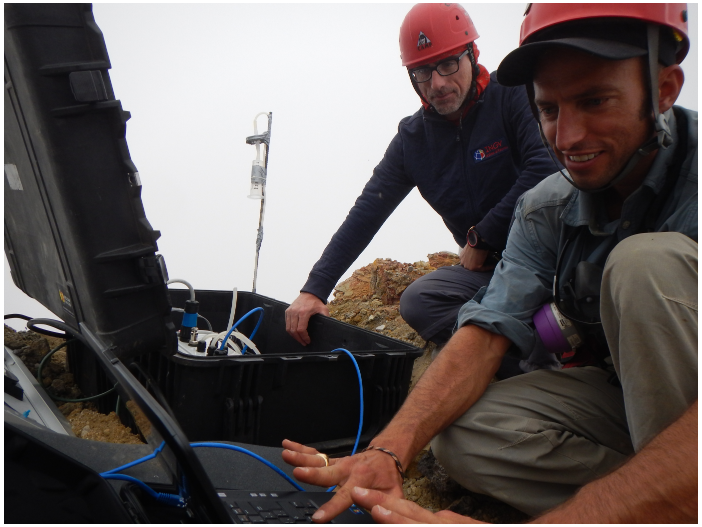


Fast-rising bubbles during vigorous degassing cool adiabatically, and lose the redox signature of their associated melts.

Oppenheimer et al., 2018

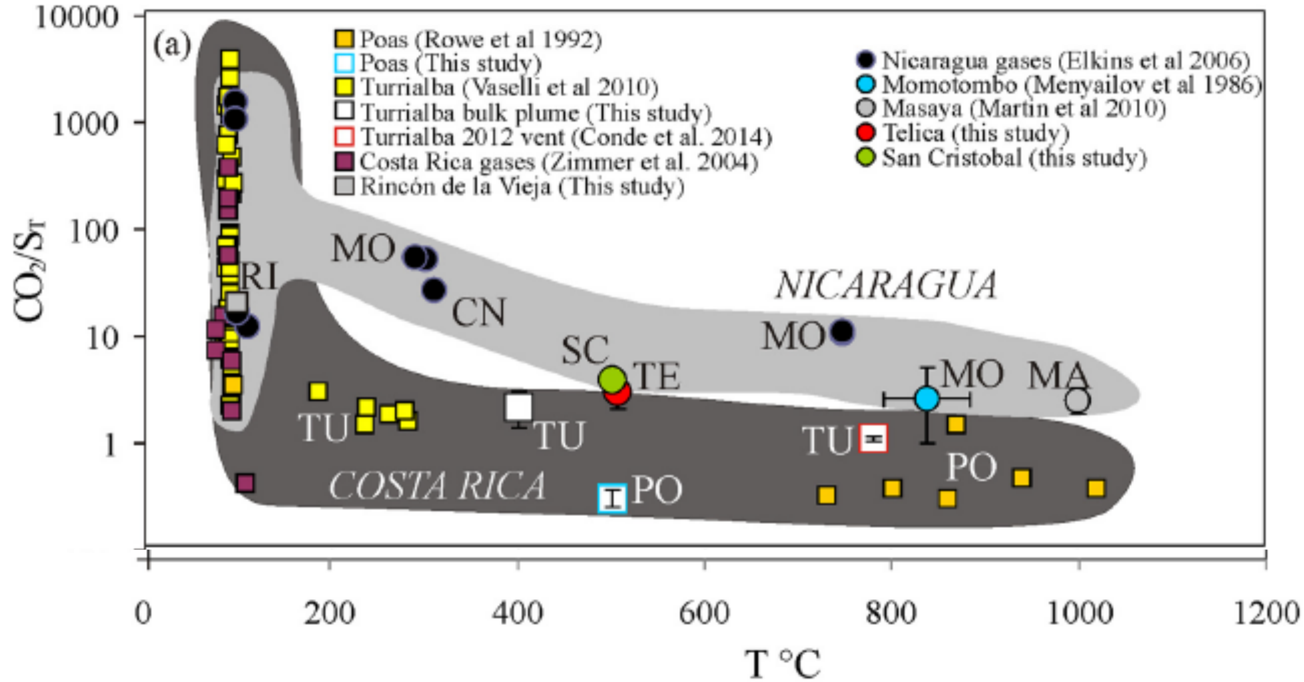
Permanent gas monitoring network
multiGAS for CO_2, SO_2, H_2O, H_2 in plume - > gas ratios

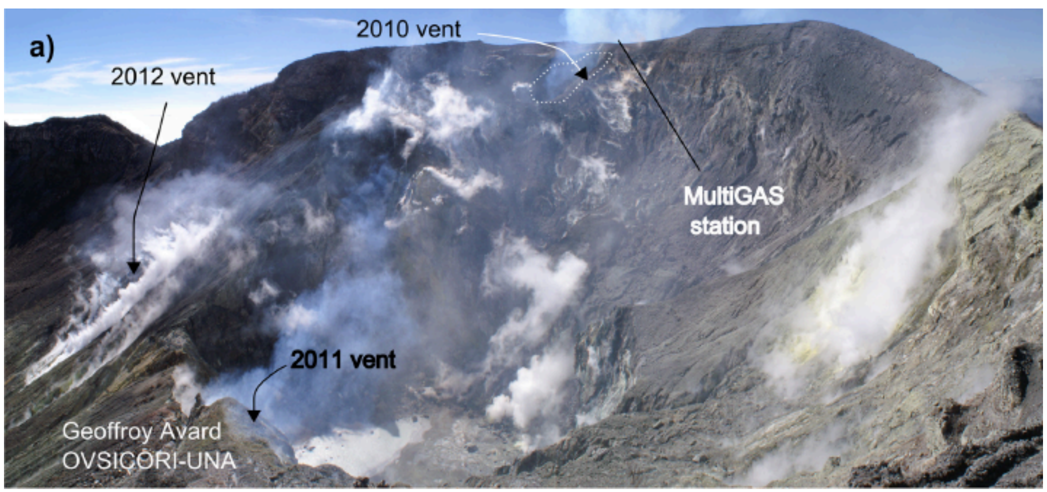




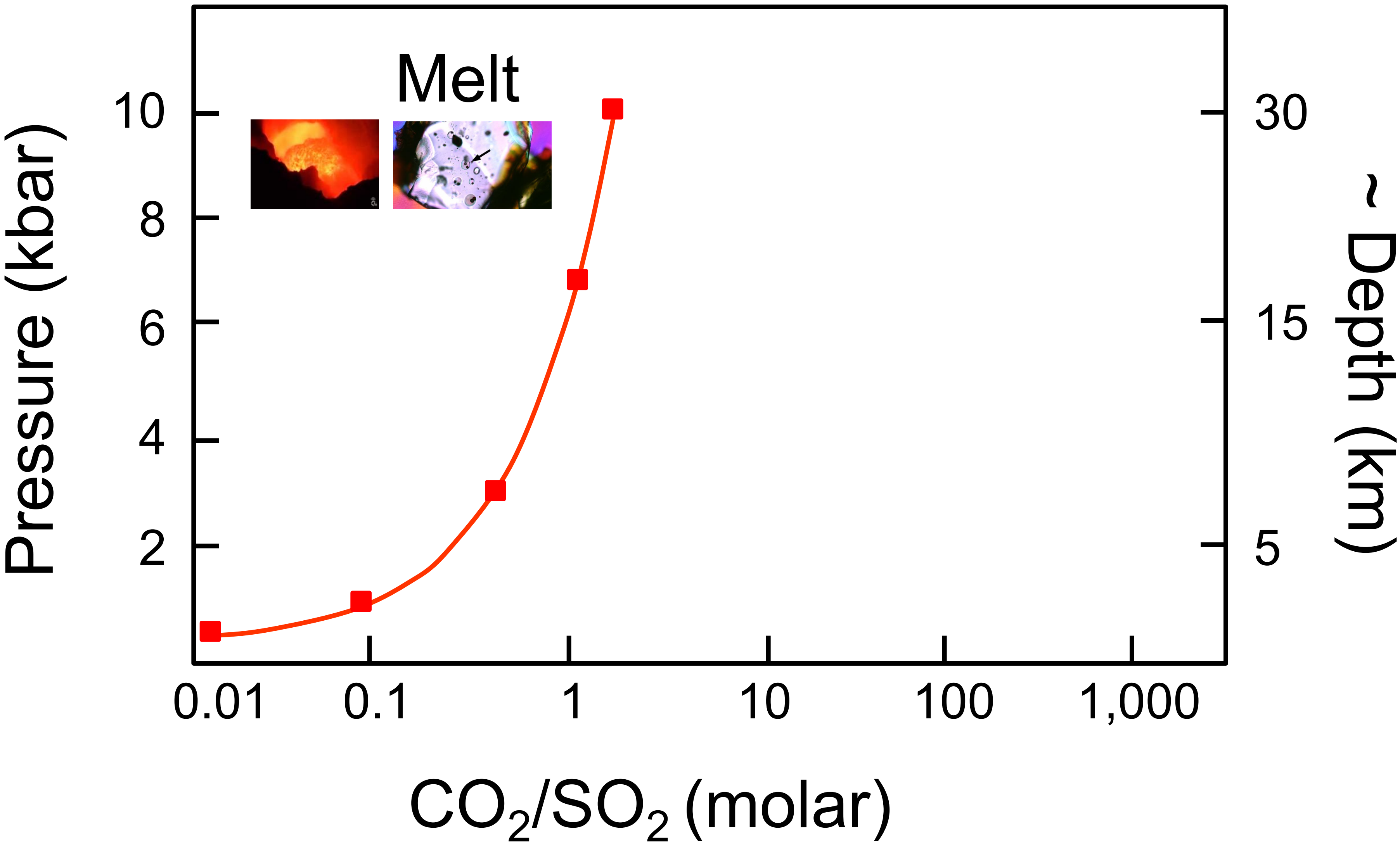
DEEP CARBON OBSERVATORY

DECADE

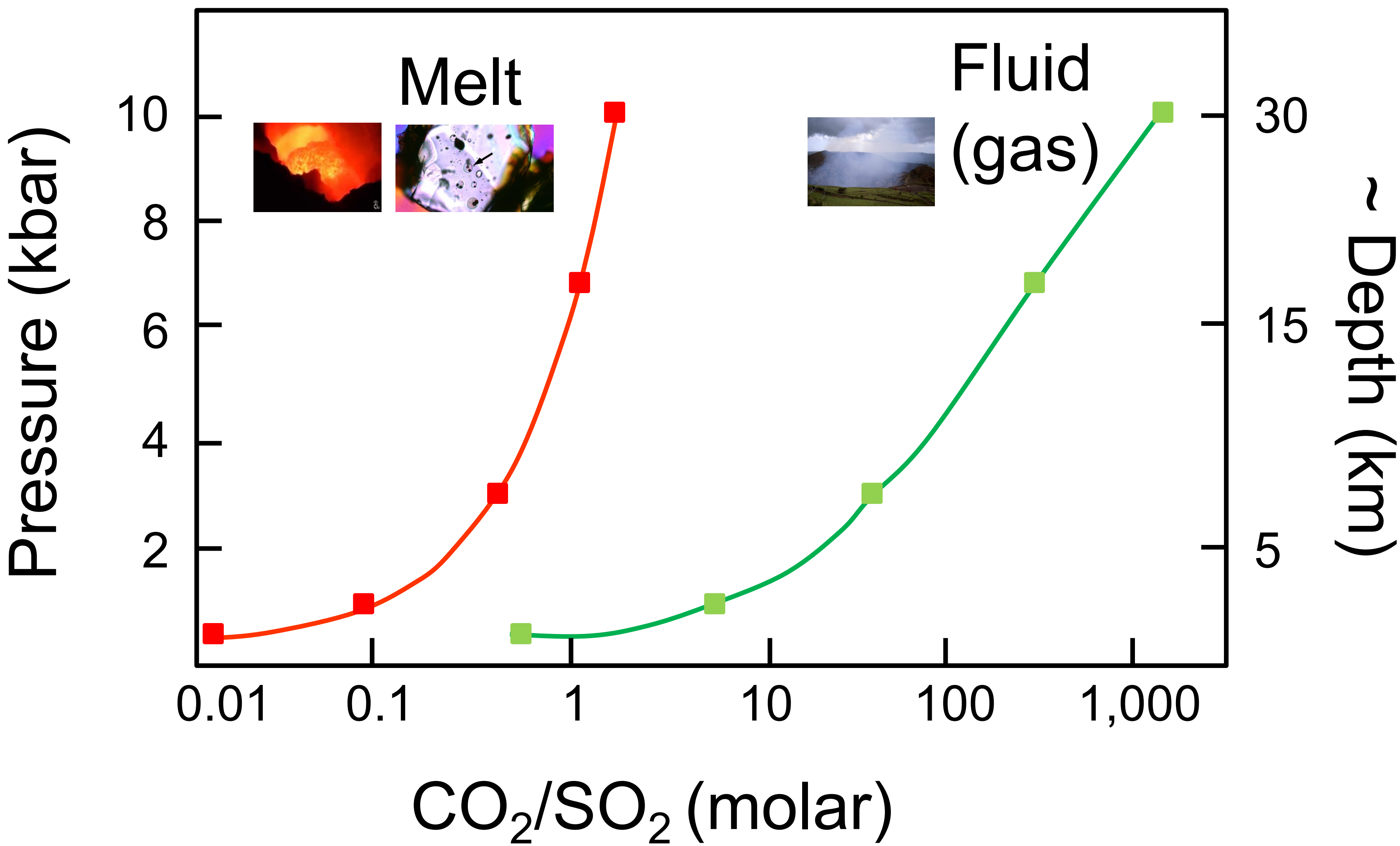




Aiuppa et al., 2014



mod. from: Scaillet and Pichavant, 2005



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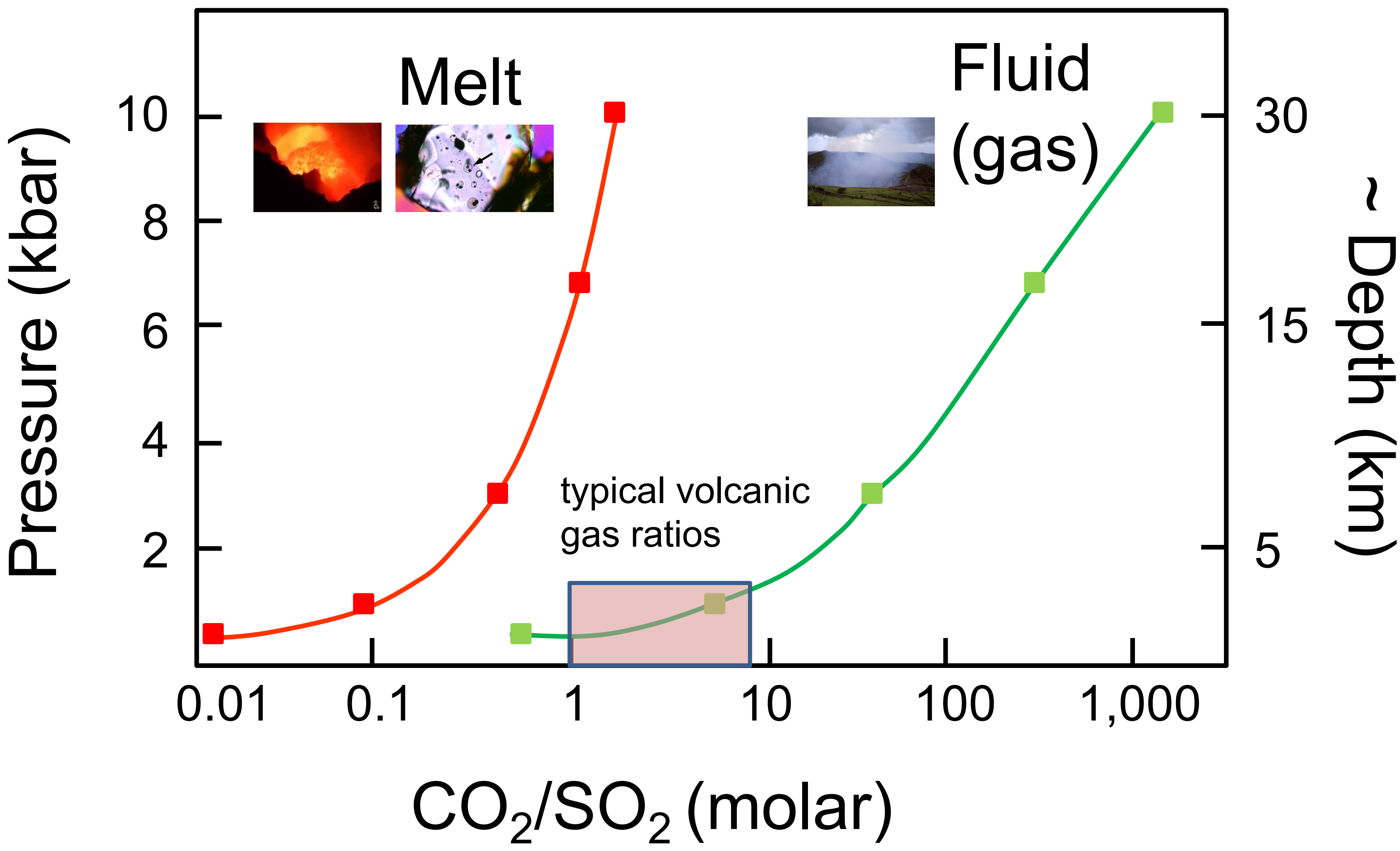

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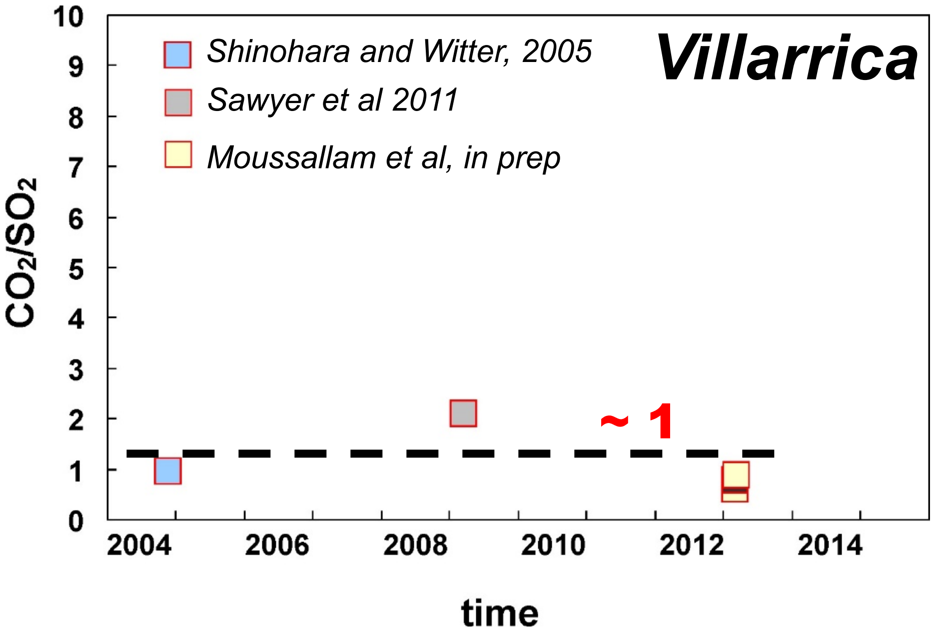
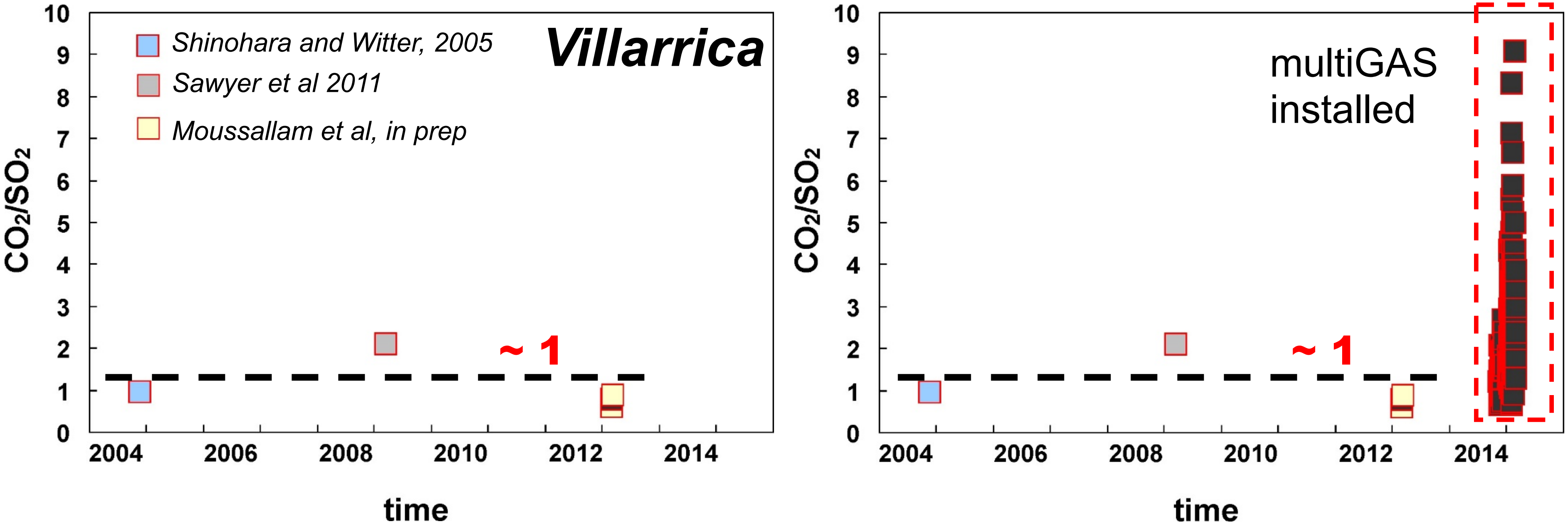


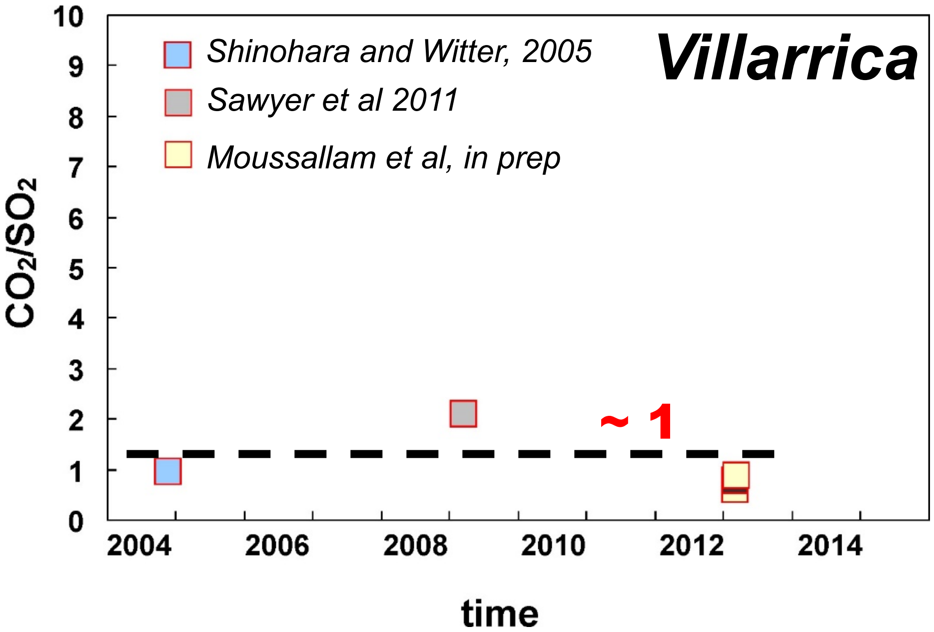
Villarrica

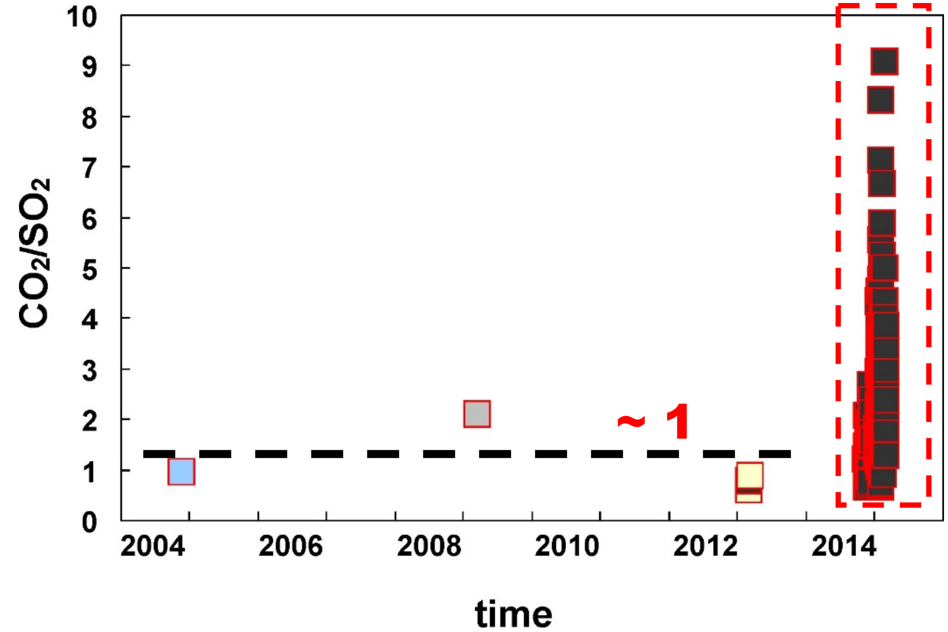
November 2014

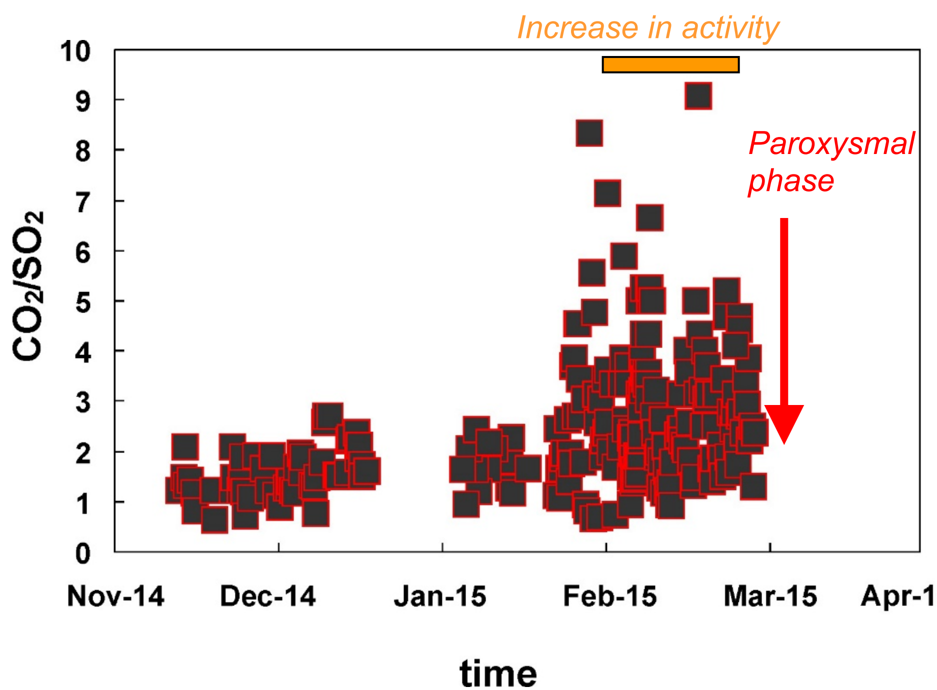
Aiuppa et al, 2017 G3



Aiuppa et al, 2017 G3



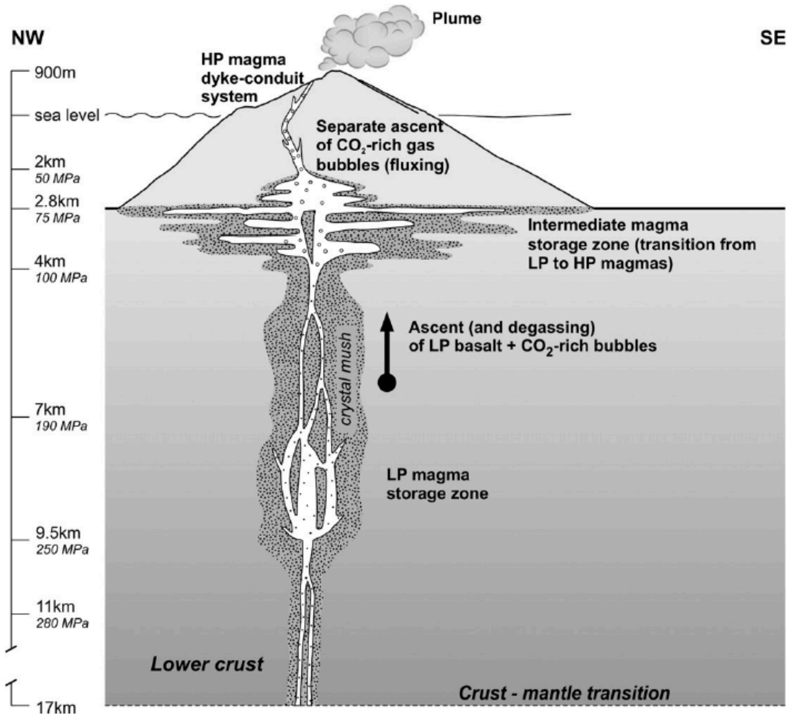


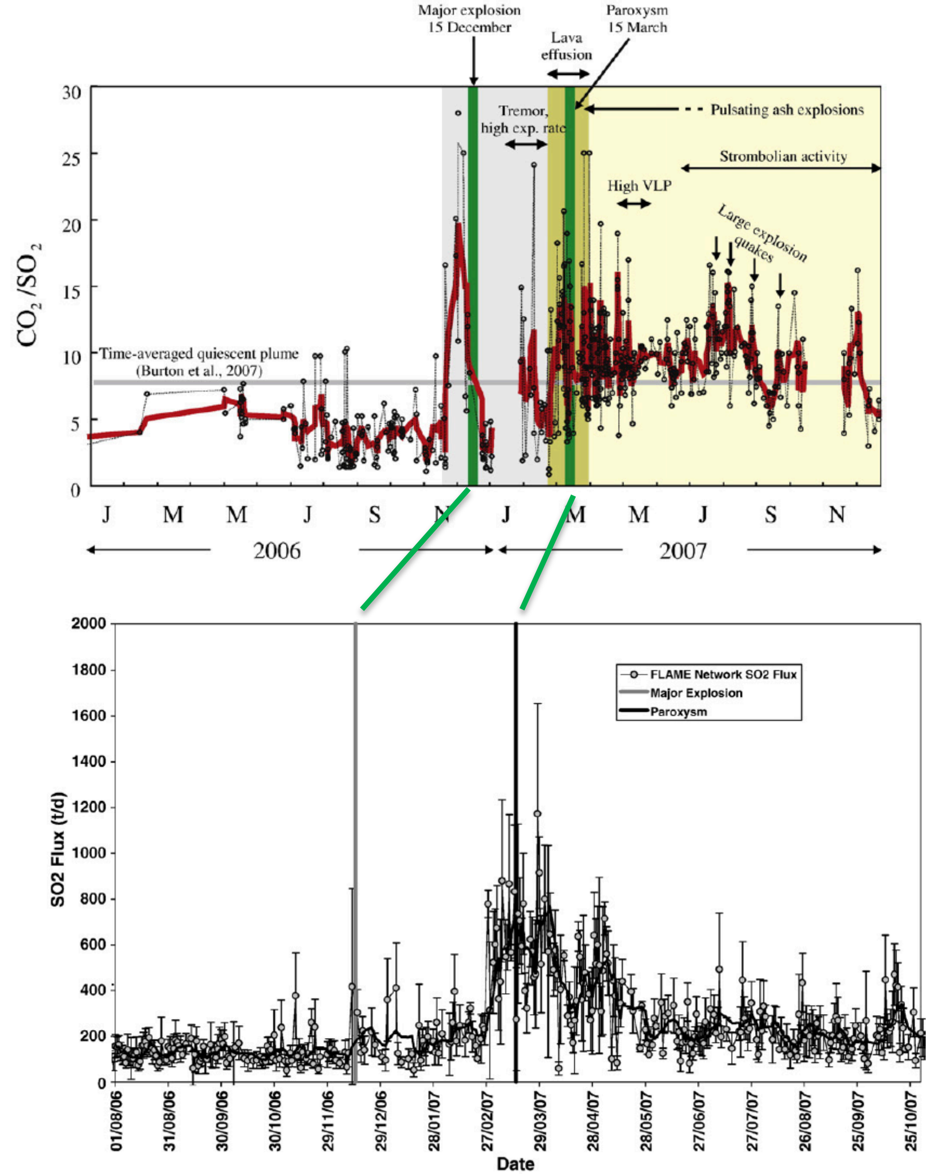


DECADE

Aiuppa et al, 2017 G3

Stromboli

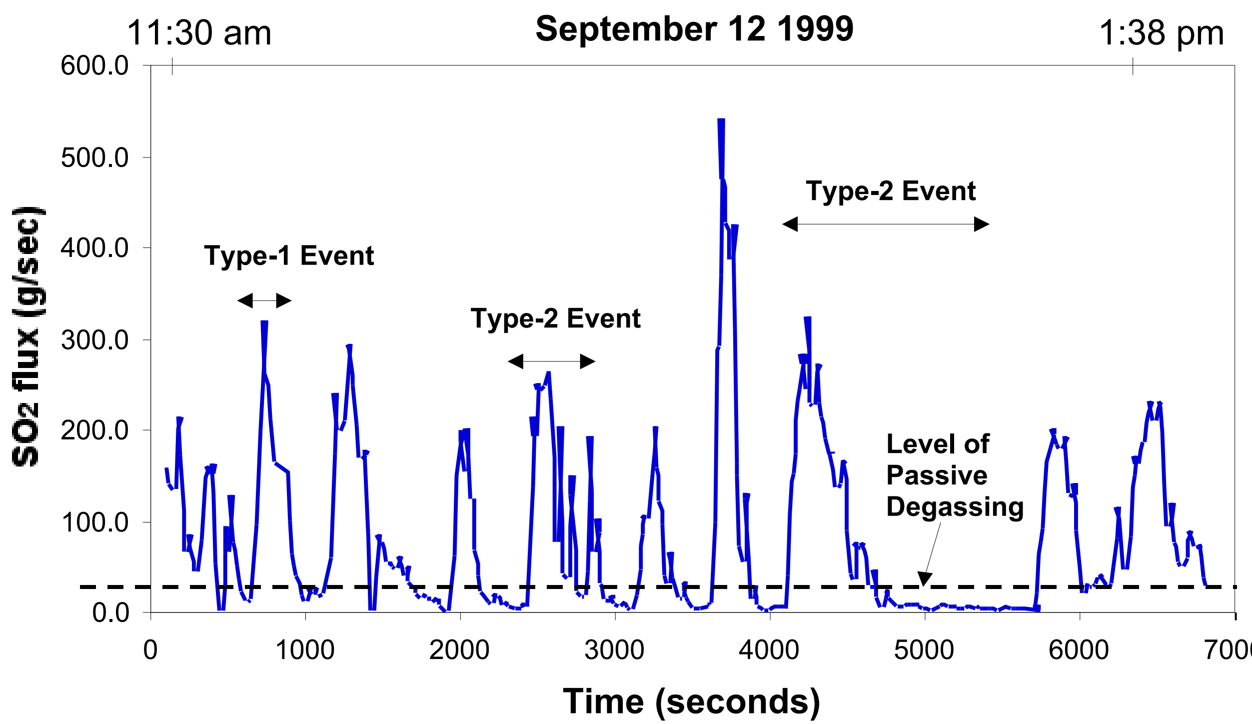




Aiuppa et al., 2009, 2010
Burton et al., 2009

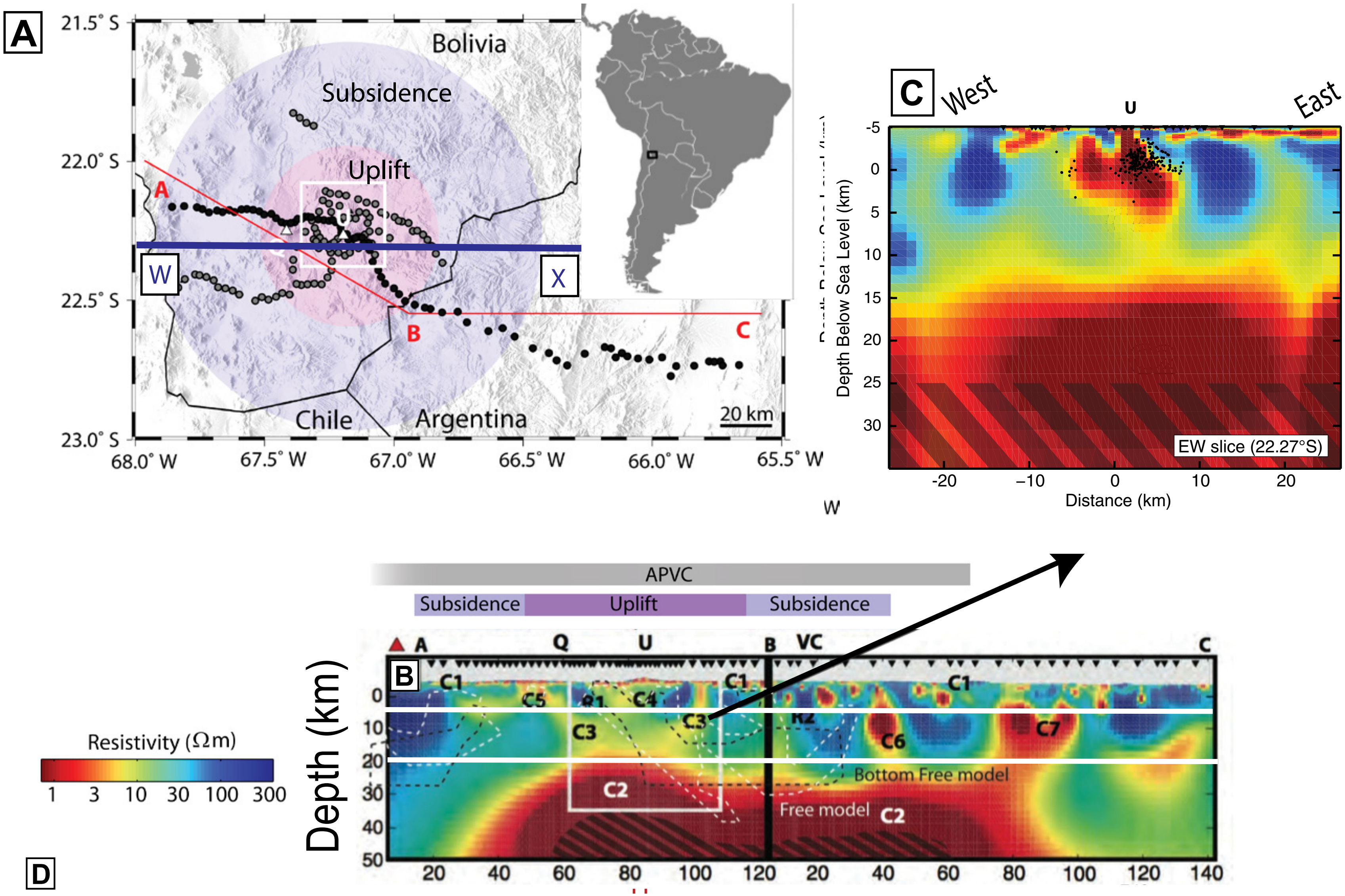
Ash blasts at Karymsky: SO_2 Flux Variations – conduit obstruction

Photo: Inguaggiato, 2010

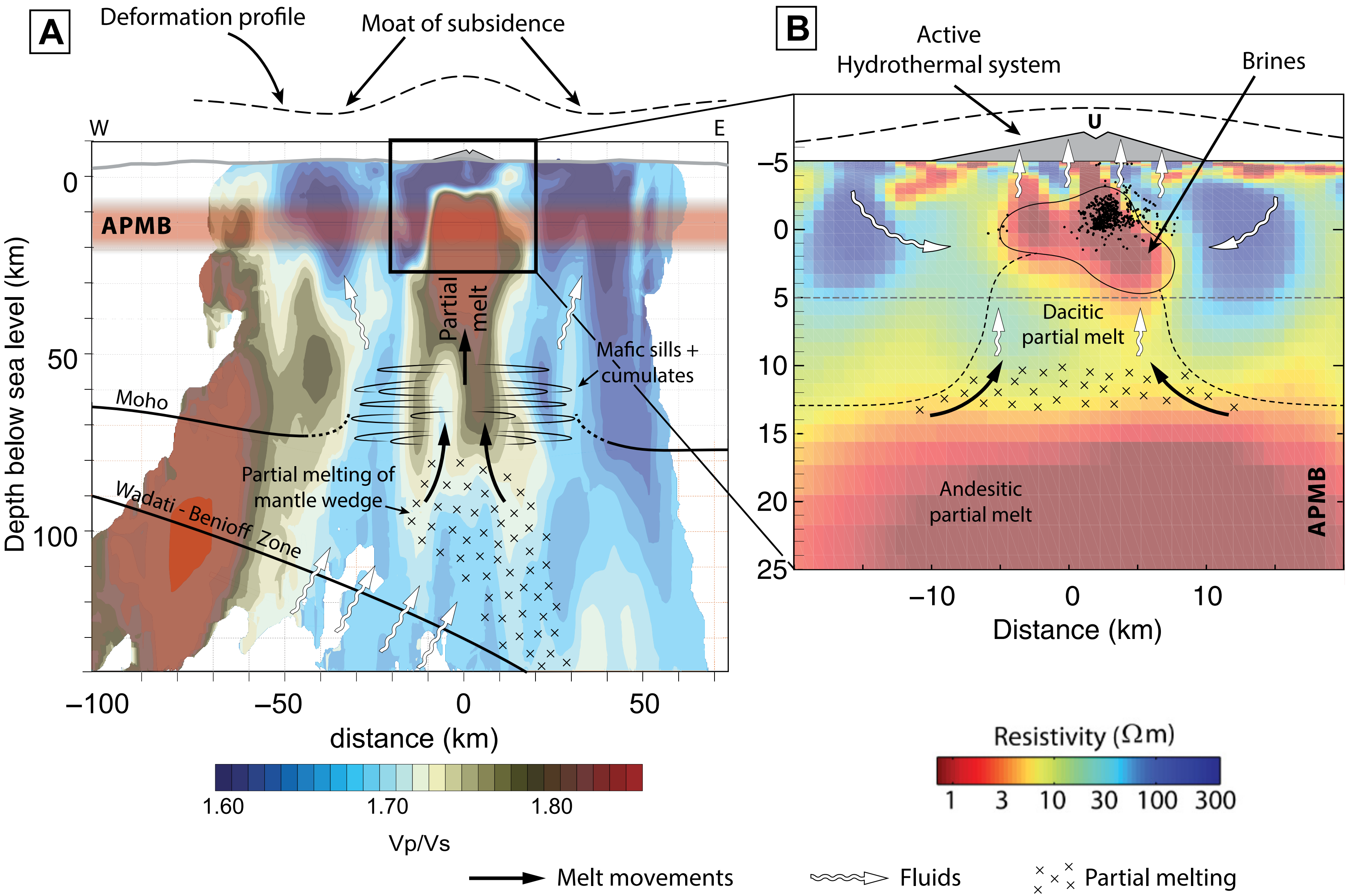


Fischer et al., 2002

"The Whopper" - Bergantz, CIDER 2019

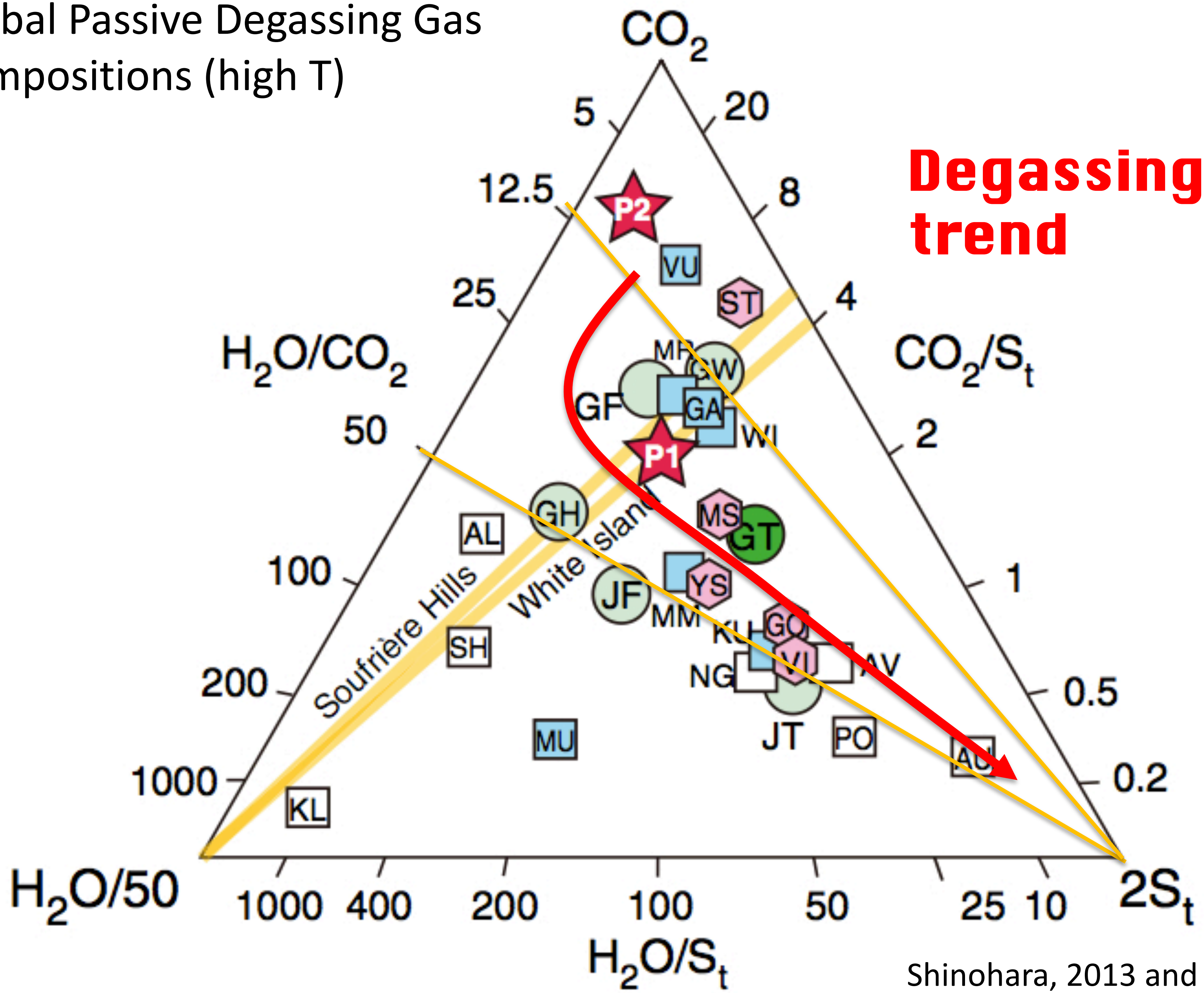


Pritchard et al., 2018



Pritchard et al., 2018

Global Passive Degassing Gas Compositions (high T)



Shinohara, 2013 and refs

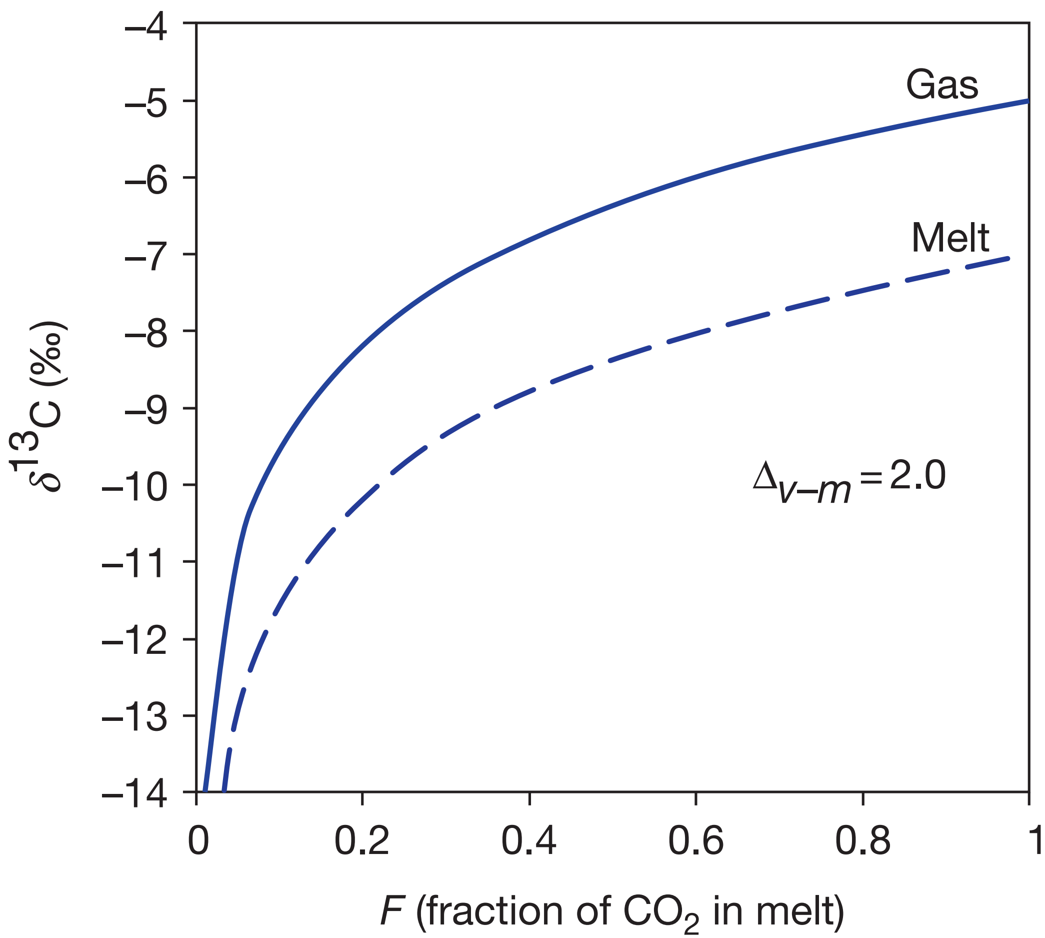
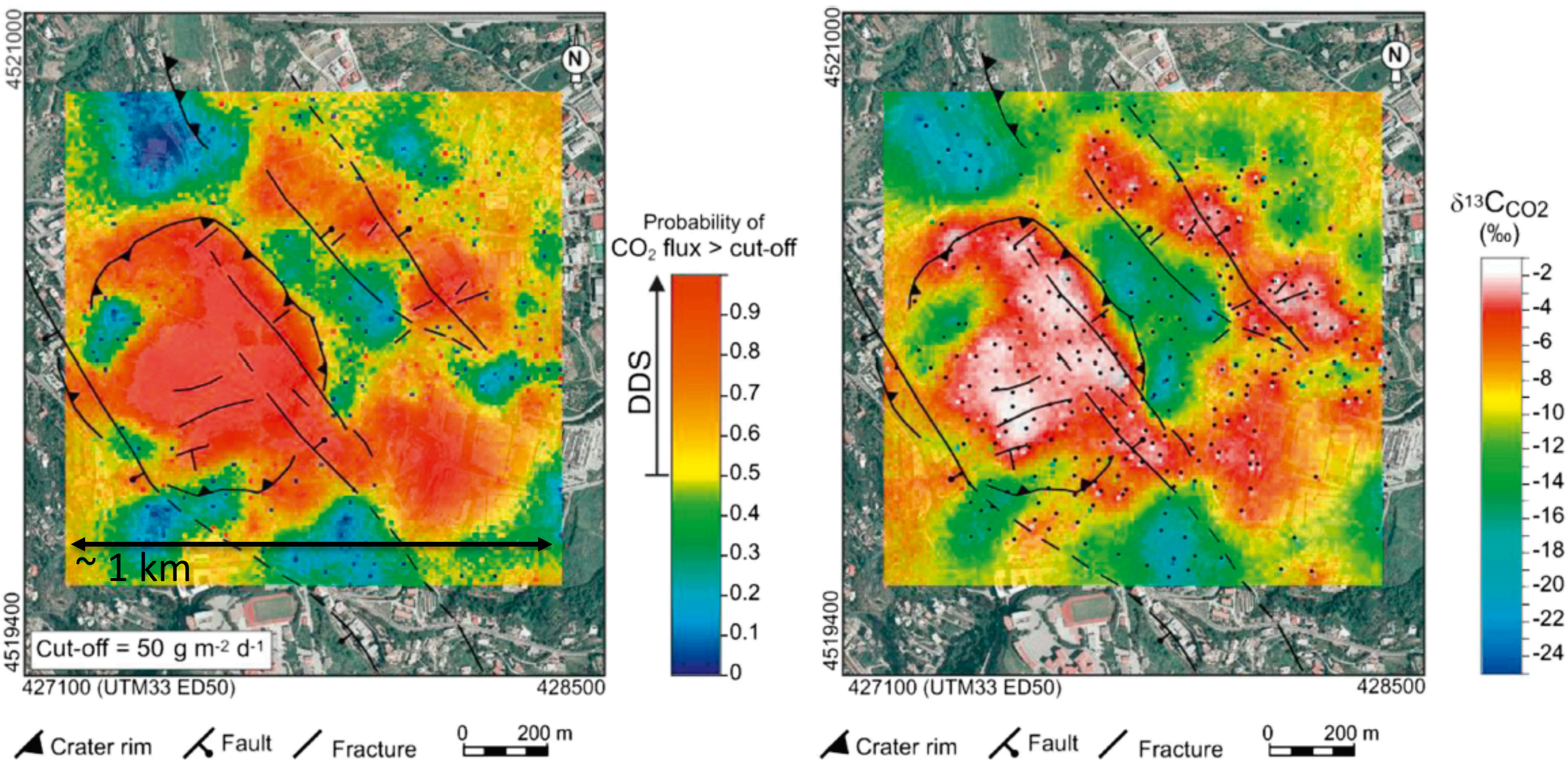


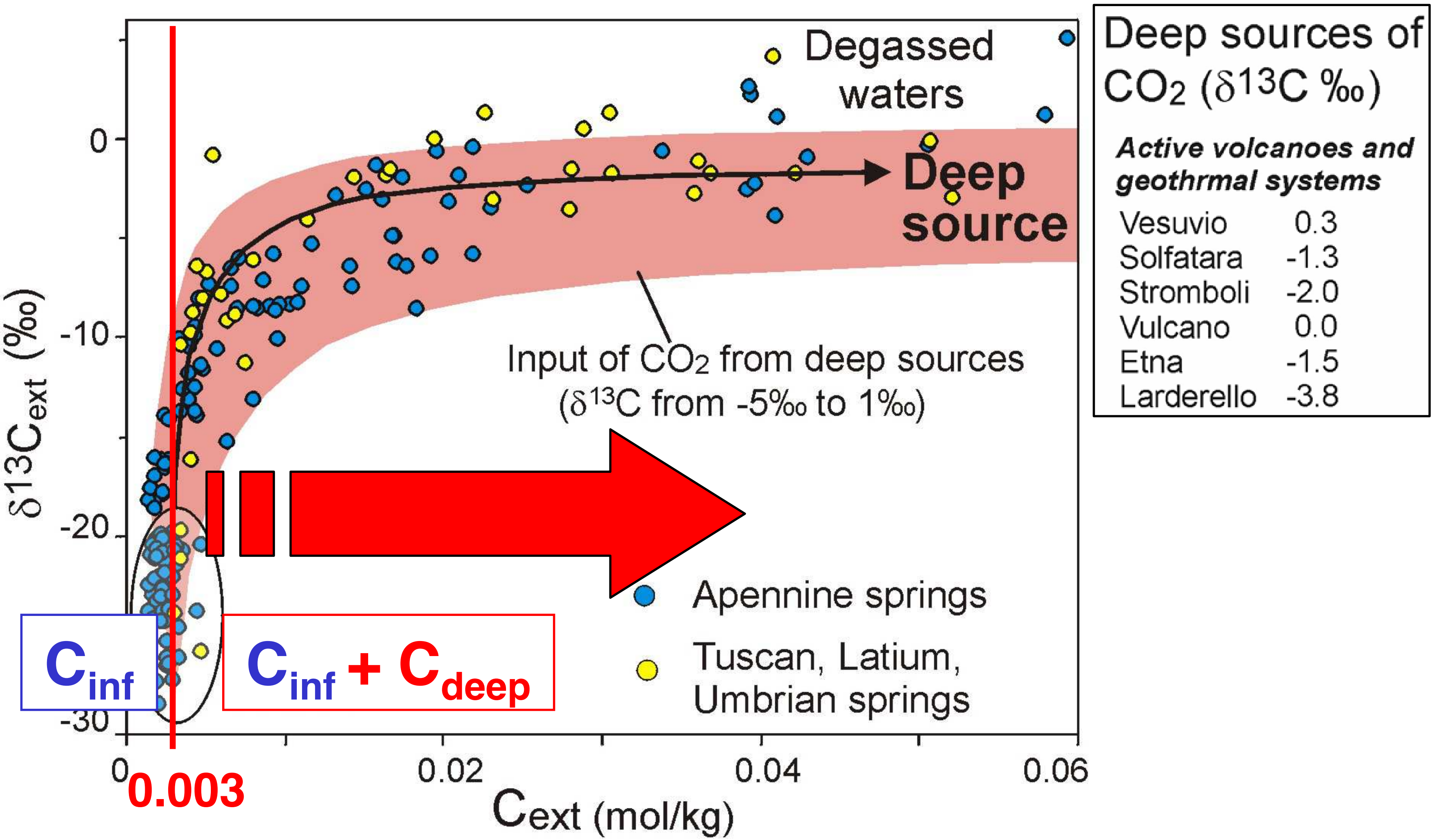
Table 8 Carbon isotope fractionation factors for silicic liquids

Melt	*Melt species*	*Δ_{v-m} (‰)*	T *(°C)*	*References*
CO_2				
Basalt	CO_3^{2-}	4.3 (±0.4)	1120–1280	Javoy et al. (1978)
Basalt	CO_3^{2-}	2.0 (±0.2)	1200–1400	Mattey (1991)
Rhyolite	CO_2	0.0 (±0.2)	800–1200	Blank et al. (1993)
H_2O				

Diffuse CO_2 degassing



Fischer and Chiodini, 2015

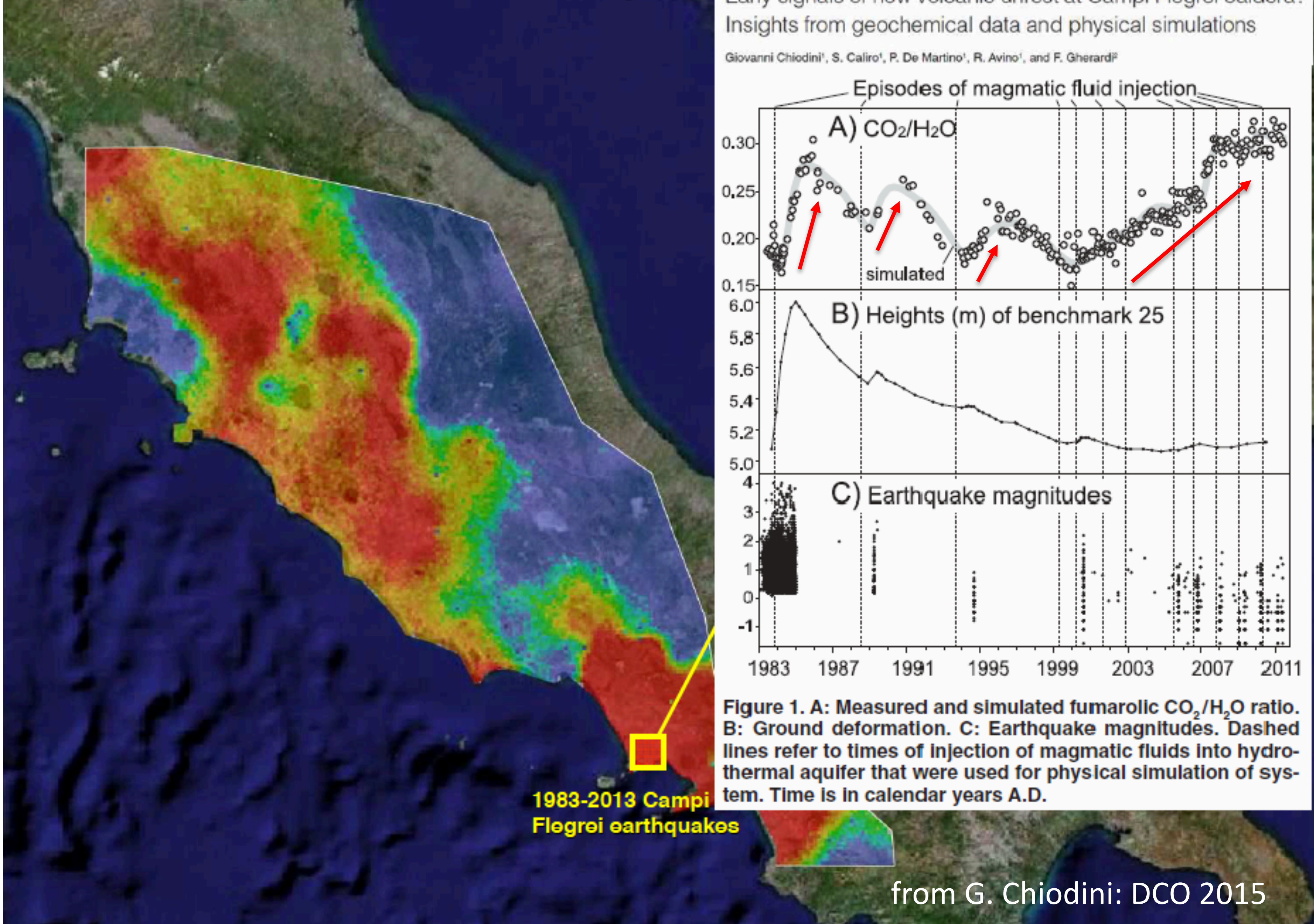


C_{inf}= C infiltration (organic sources)

$C_{ext} = C_{inf} + C_{deep}$

Chiodini DCO meeting 2015

4. Earth degassing and seismicity



ABOVE: New frontiers for volcanic gas sampling

DEEP CARBON OBSERVATORY

https://deepcarbon.net/dco-above-expedition-updates-field

From Emma Liu and ABOVE group