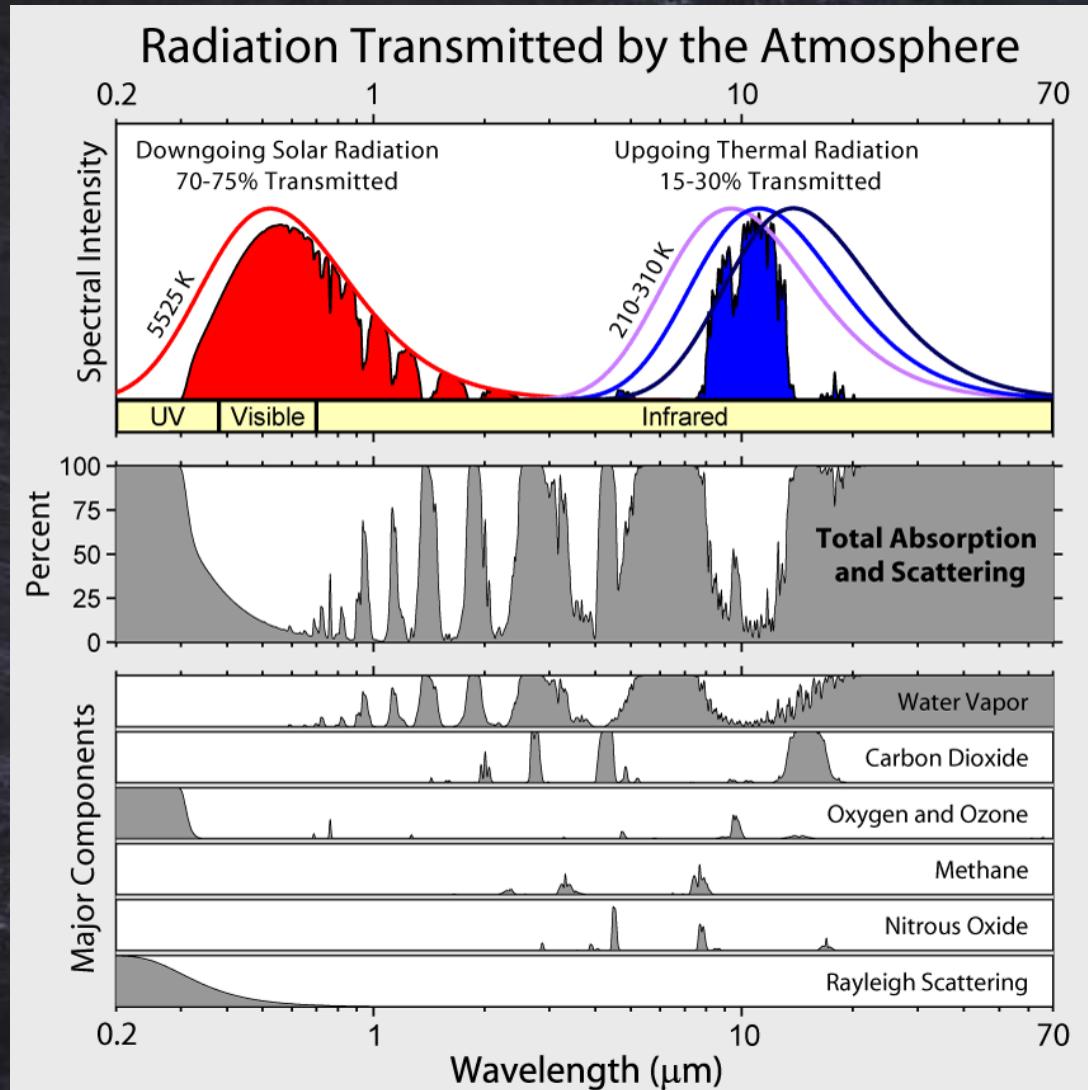
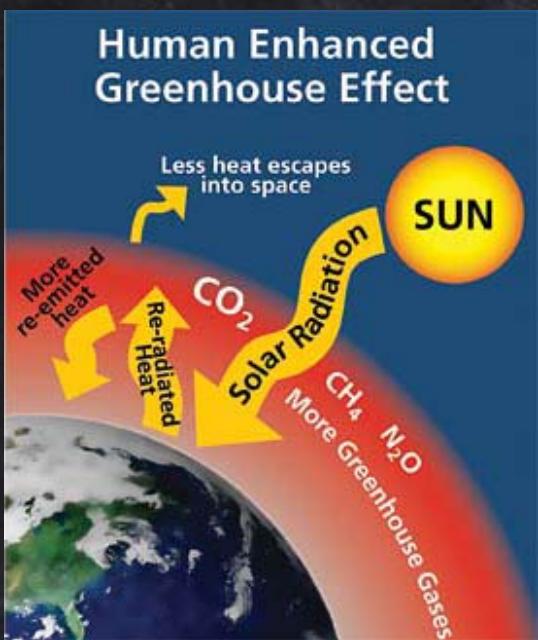
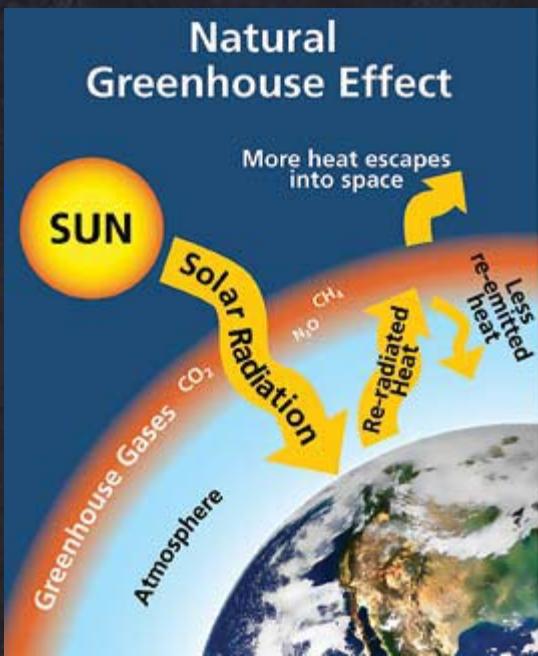


# MOUNTAIN BUILDING AND CARBON CYCLE – A PETROLOGIC PERSPECTIVE OF DEEP EARTH- CLIMATE FEEDBACK

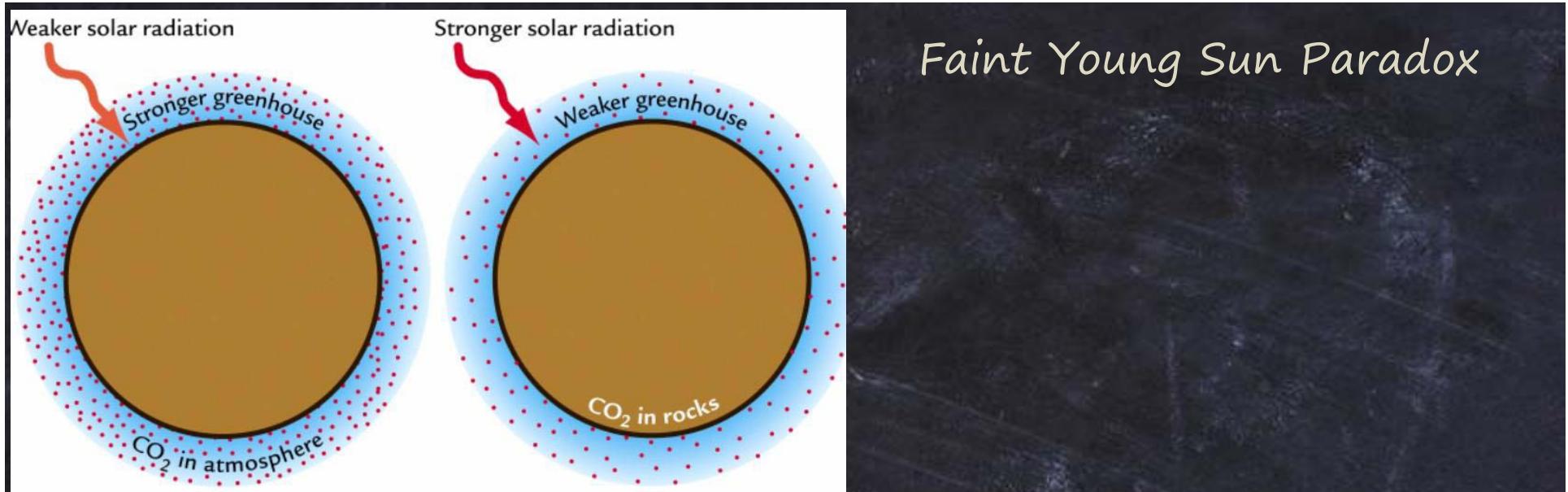


Rajdeep Dasgupta

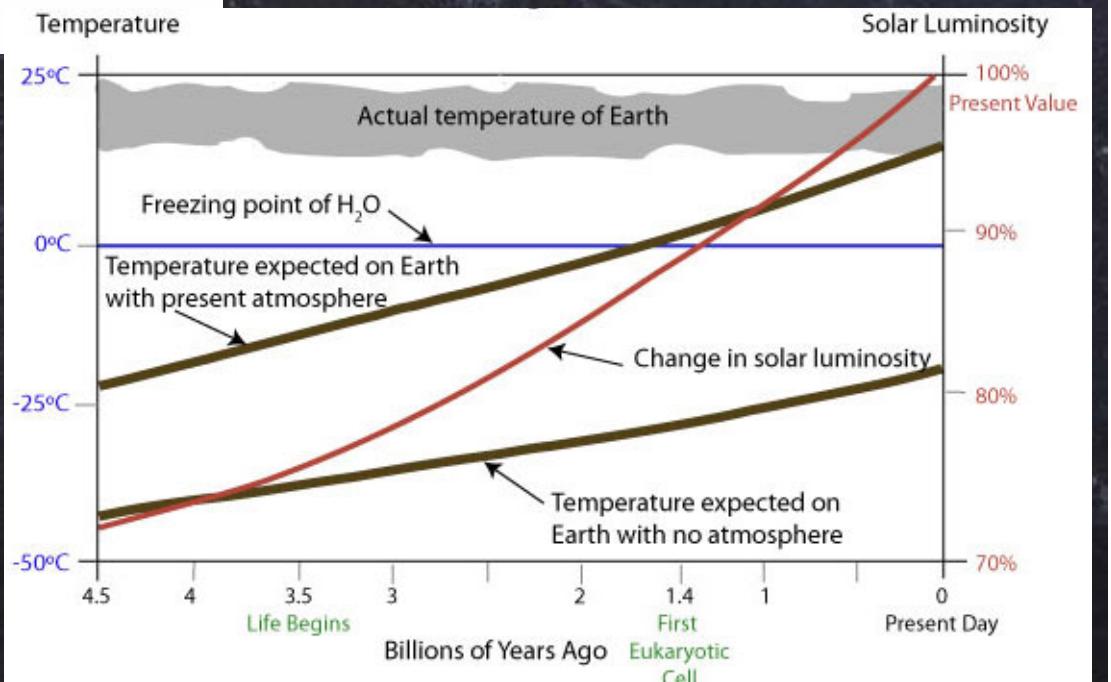
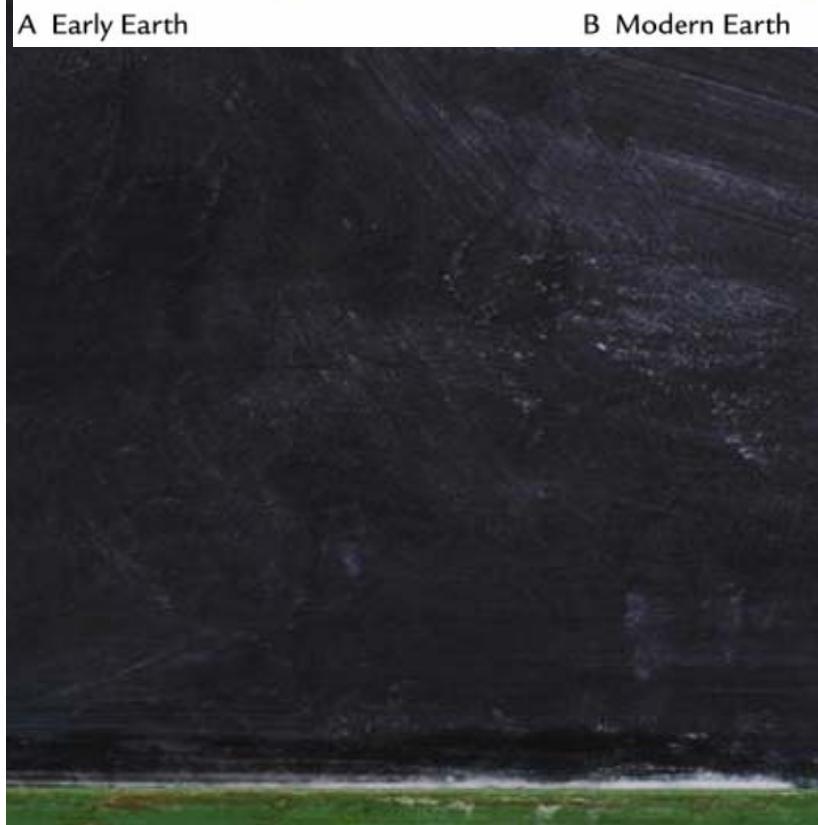
# Greenhouse gases and climate



[http://en.wikipedia.org/wiki/Greenhouse\\_gas](http://en.wikipedia.org/wiki/Greenhouse_gas)



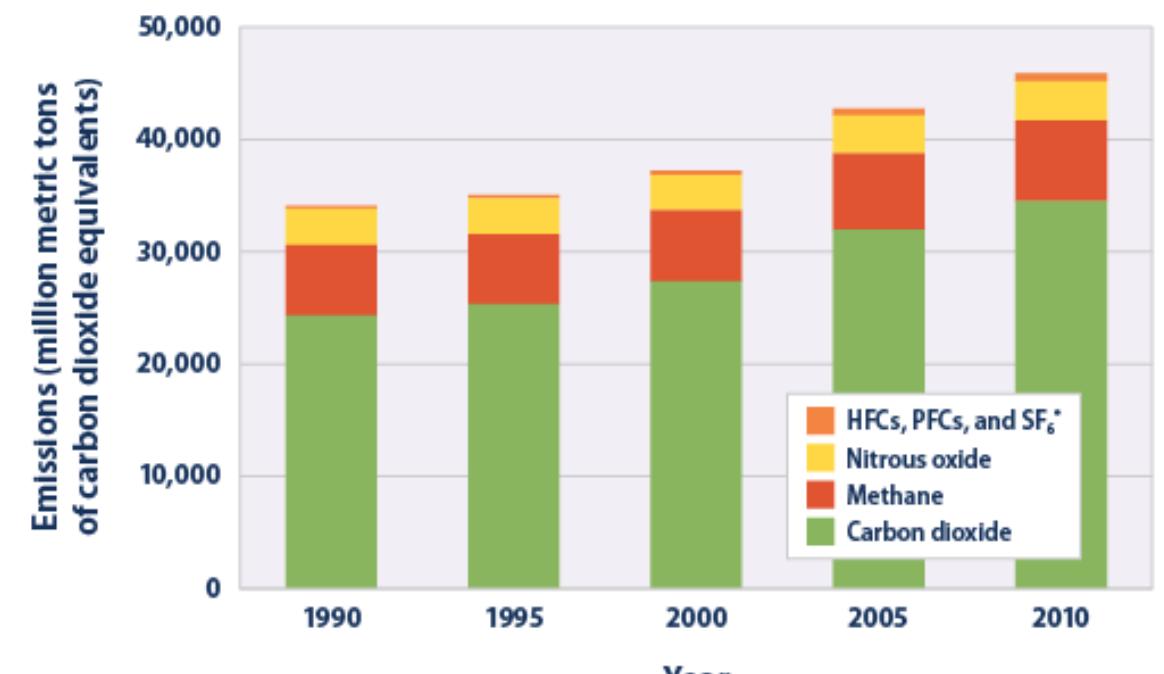
## Faint Young Sun Paradox



Even though the Sun was about 30% dimmer than it is now,  
the temperature on Earth has been more or less stable.

# $CO_2$ Emission

Figure 1. Global Greenhouse Gas Emissions by Gas, 1990–2010

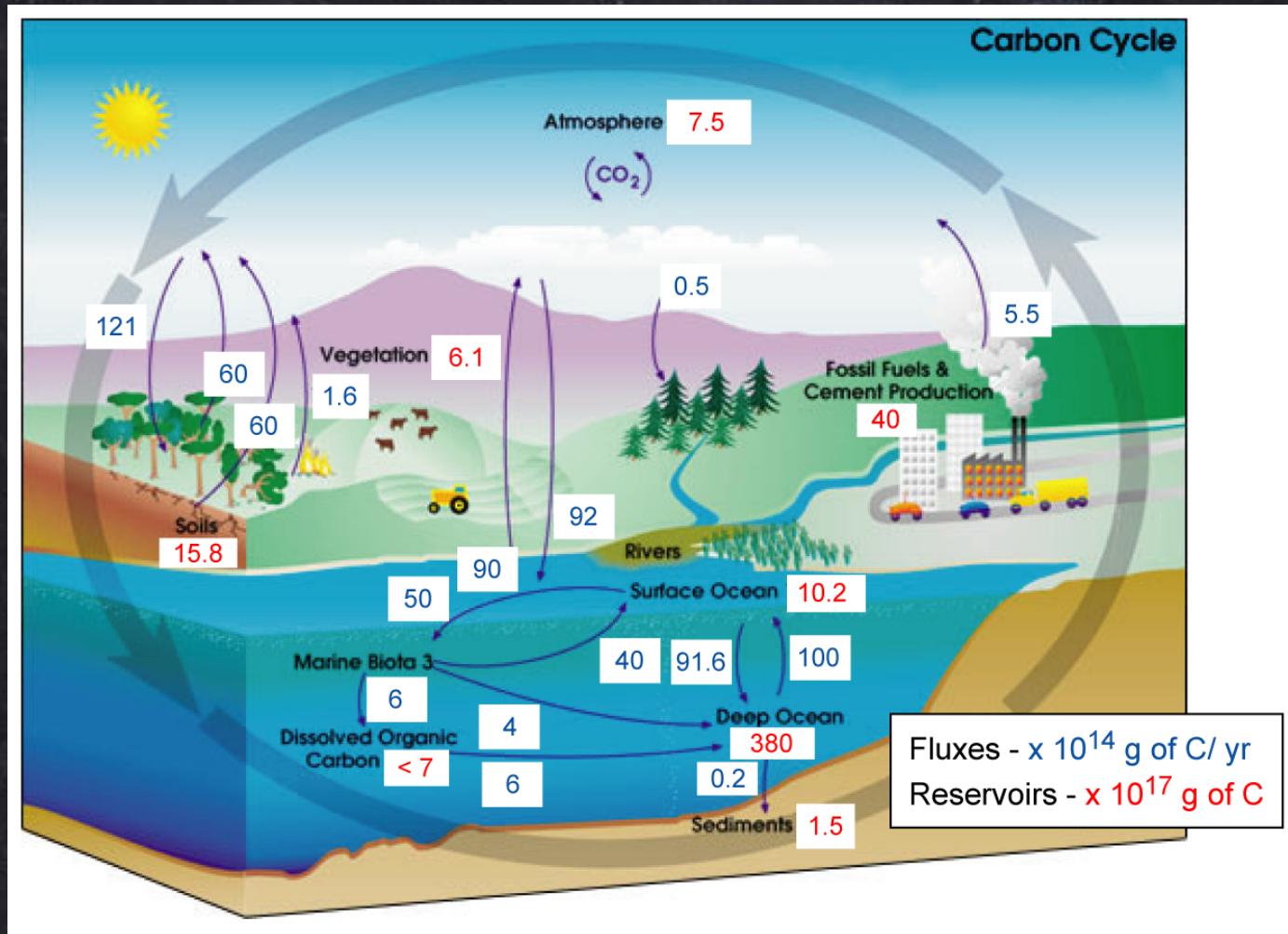


epa.gov

Global  $CO_2$  emission

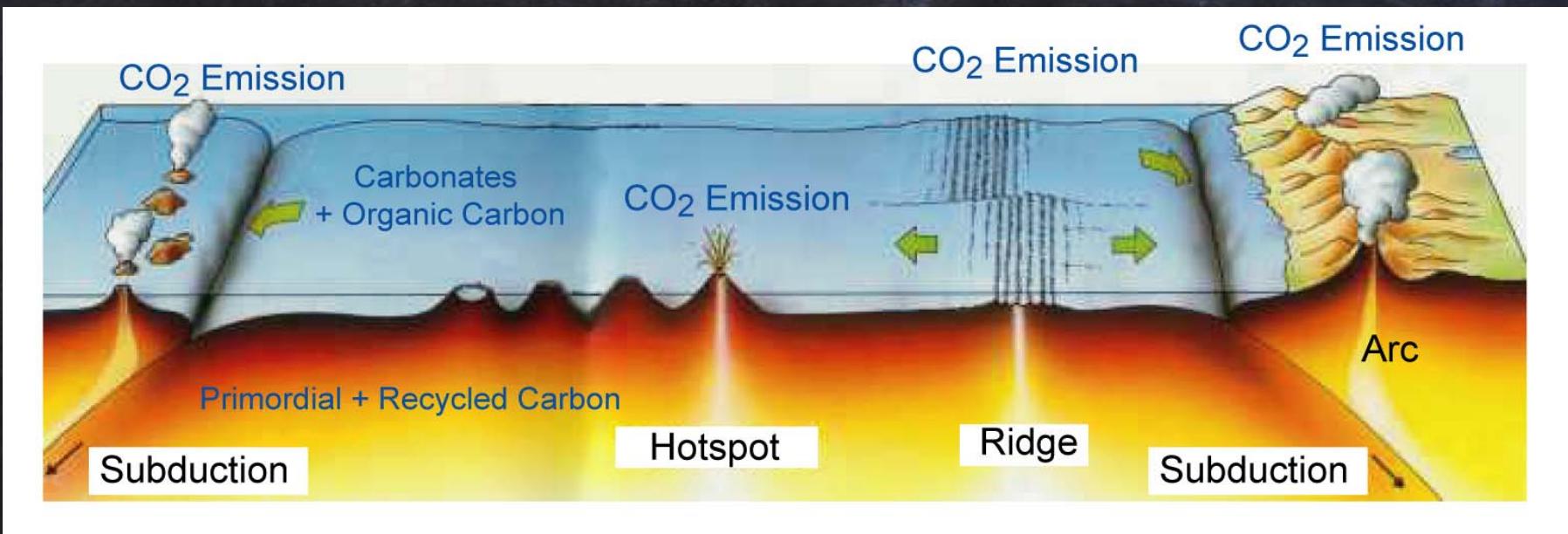
$$\sim 40 \times 10^9 \text{ tons } CO_2/y = 3.6 \times 10^{16} \text{ g } CO_2/y = 9.8 \times 10^{15} \text{ g C/y}$$

# Short-term Carbon Cycle

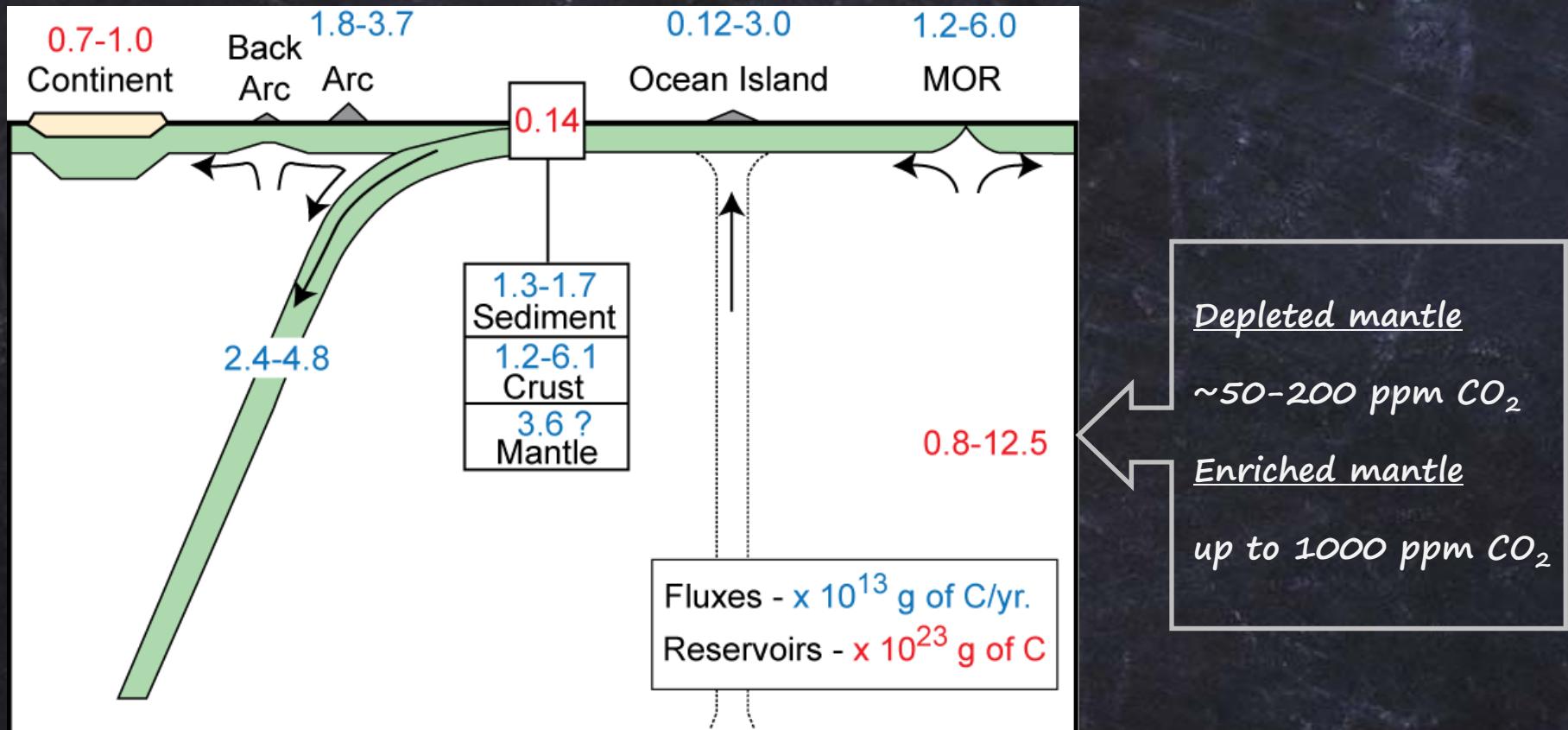


<http://earthobservatory.nasa.gov/Library/CarbonCycle>

# Volcanic Emission of $CO_2$ and Carbon Recycling



# Long-term Carbon Cycle



Volcanic CO<sub>2</sub> flux is ~2 orders of magnitude less than CO<sub>2</sub> emission by surficial carbon cycle

# Estimating Volcanic Flux and Mantle Budget of CO<sub>2</sub>

- Direct measurement of CO<sub>2</sub> in mantle derived melts/ glasses (MORB, OIB, Arc Lavas and melt inclusions)  
(e.g., Dixon et al., 1997; Bureau et al., 1998)
- Direct measurement of CO<sub>2</sub> in mantle-derived fluids (trapped gas bubbles in basalts, hydrothermal vent fluids, plumes) and gases  
(e.g., Aubaud et al., 2005)



$$\frac{C_L}{C_o} = \frac{1}{F + D - FD}$$

Concentration in the melt →  $C_L$

Concentration in the mantle source →  $C_o$

Melt fraction/extent of melting

Bulk Partition Coefficient

The equation shows the relationship between the concentration of CO<sub>2</sub> in the melt ( $C_L$ ) and the concentration in the mantle source ( $C_o$ ). It includes terms for the melt fraction ( $F$ ), the extent of melting ( $D$ ), and the bulk partition coefficient ( $FD$ ). A blue arrow points from the term  $1$  to the right side of the equation, and another blue arrow points from the term  $FD$  to the left side of the equation.

# *Challenge for CO<sub>2</sub>*

## *CO<sub>2</sub> Solubility in Silicate Melt*

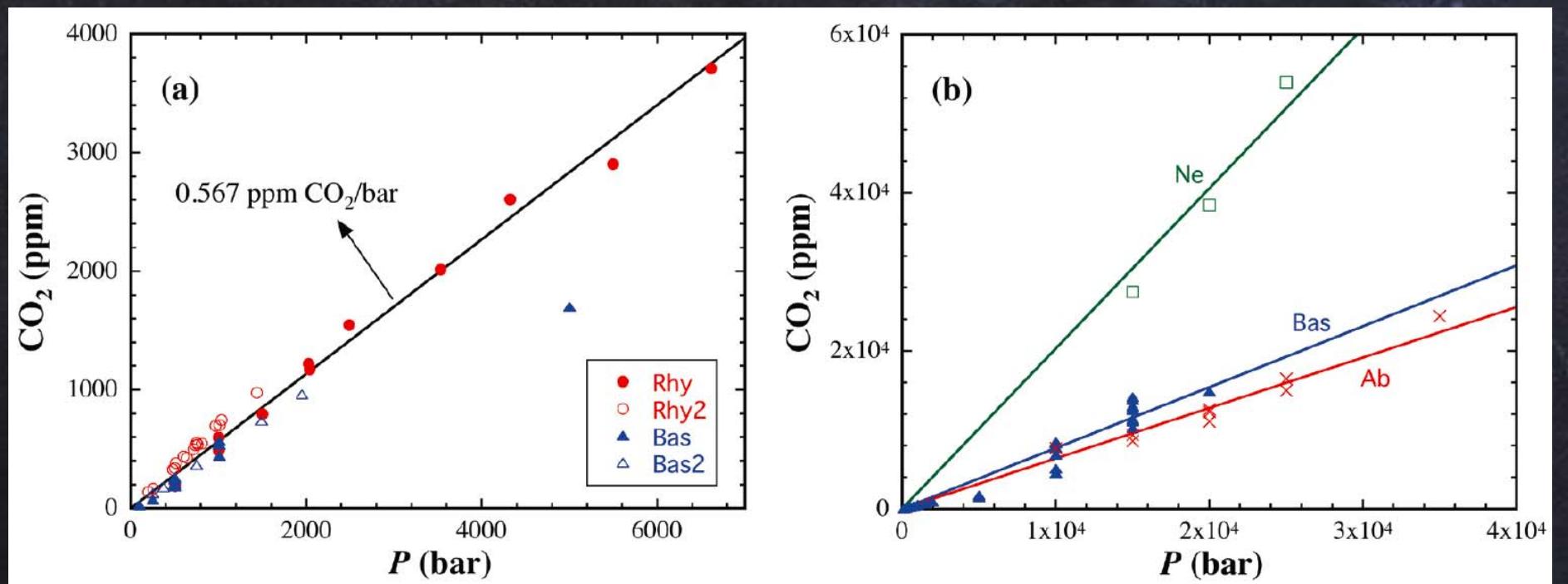
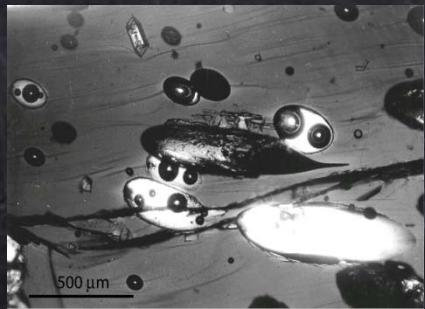


Figure from *Ni and Keppler (2013)*

# Estimating Volcanic Flux and Mantle Budget of $CO_2$

- Measurement of  $CO_2$ /Incompatible element ratio in glasses, fluids, gases and independent estimate of mantle  $He$  or  $Nb$  or  $U$  etc.



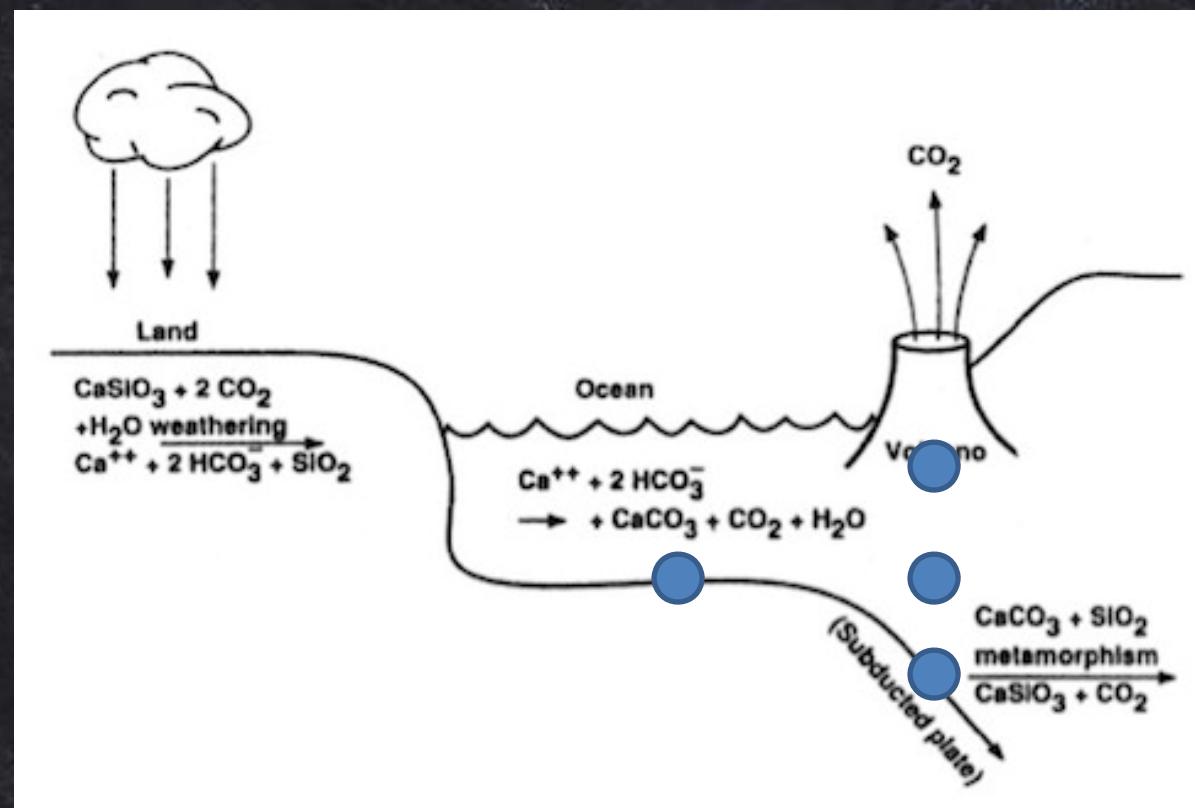
$CO_2/^{3}He$ ,  $CO_2/^{4}He$  (e.g., Trull et al., 1993; Marty and Tolstikhin, 1998; Shaw et al., 2003; Resing et al., 2004)

$CO_2/Ar$  (e.g., Tingle, 1998; Cartigny et al., 2001)

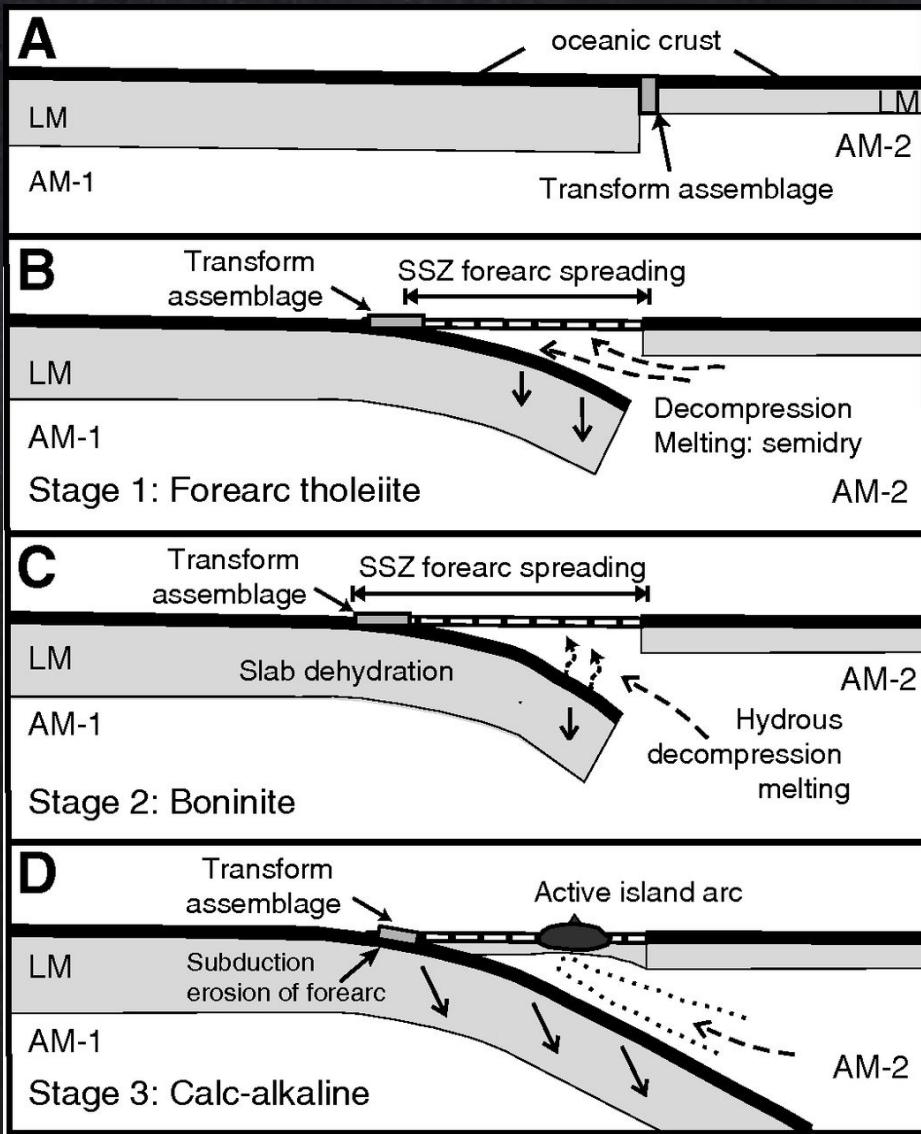
$CO_2/Nb$  (e.g., Saal et al., 2002; Cartigny et al., 2008)

$CO_2/U$  or  $CO_2/Th$  (e.g., Rosenthal et al., 2015)

$CO_2/Cl$  (e.g., Saal et al., 2002)



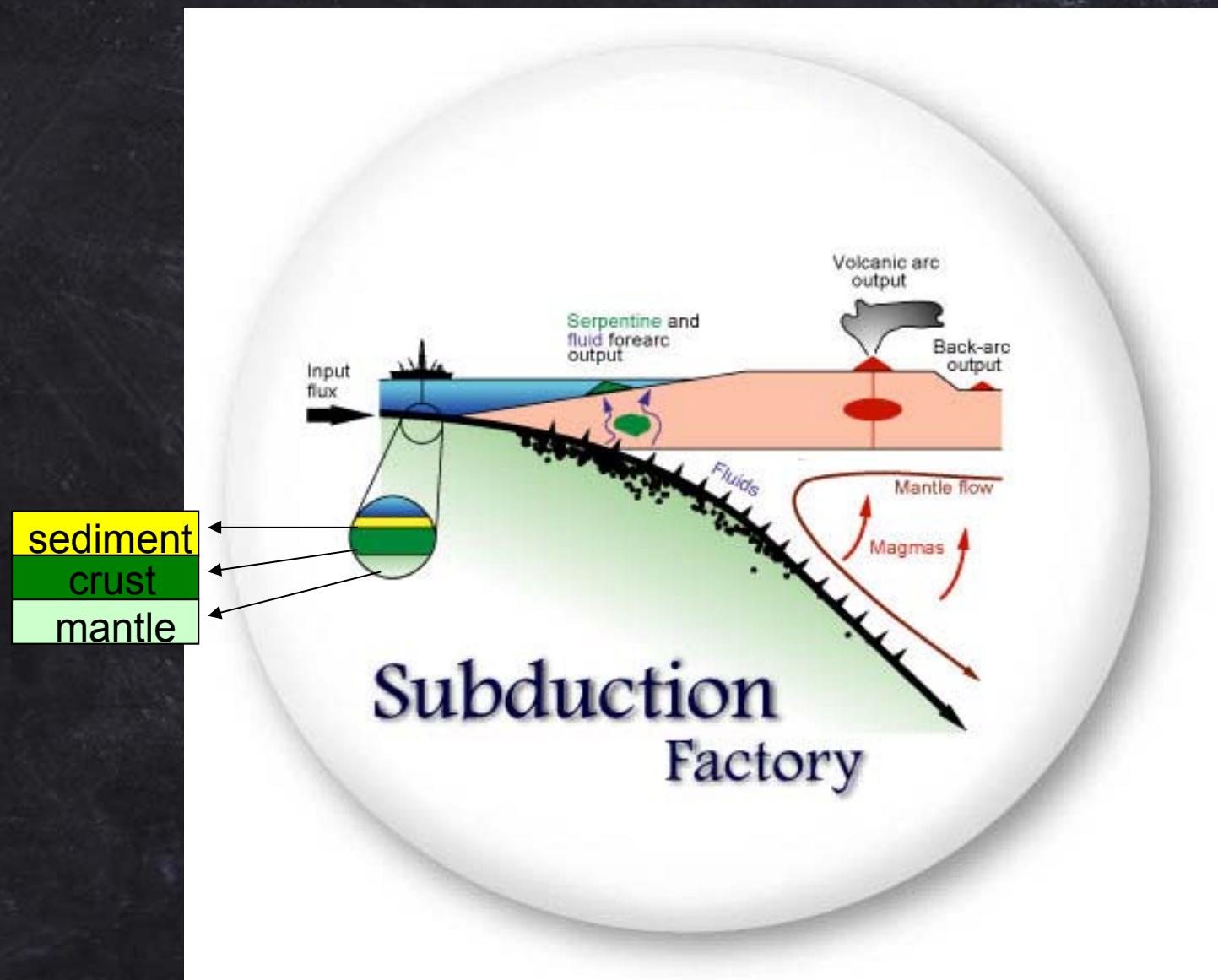
*Kasting and Catlin (2003)*



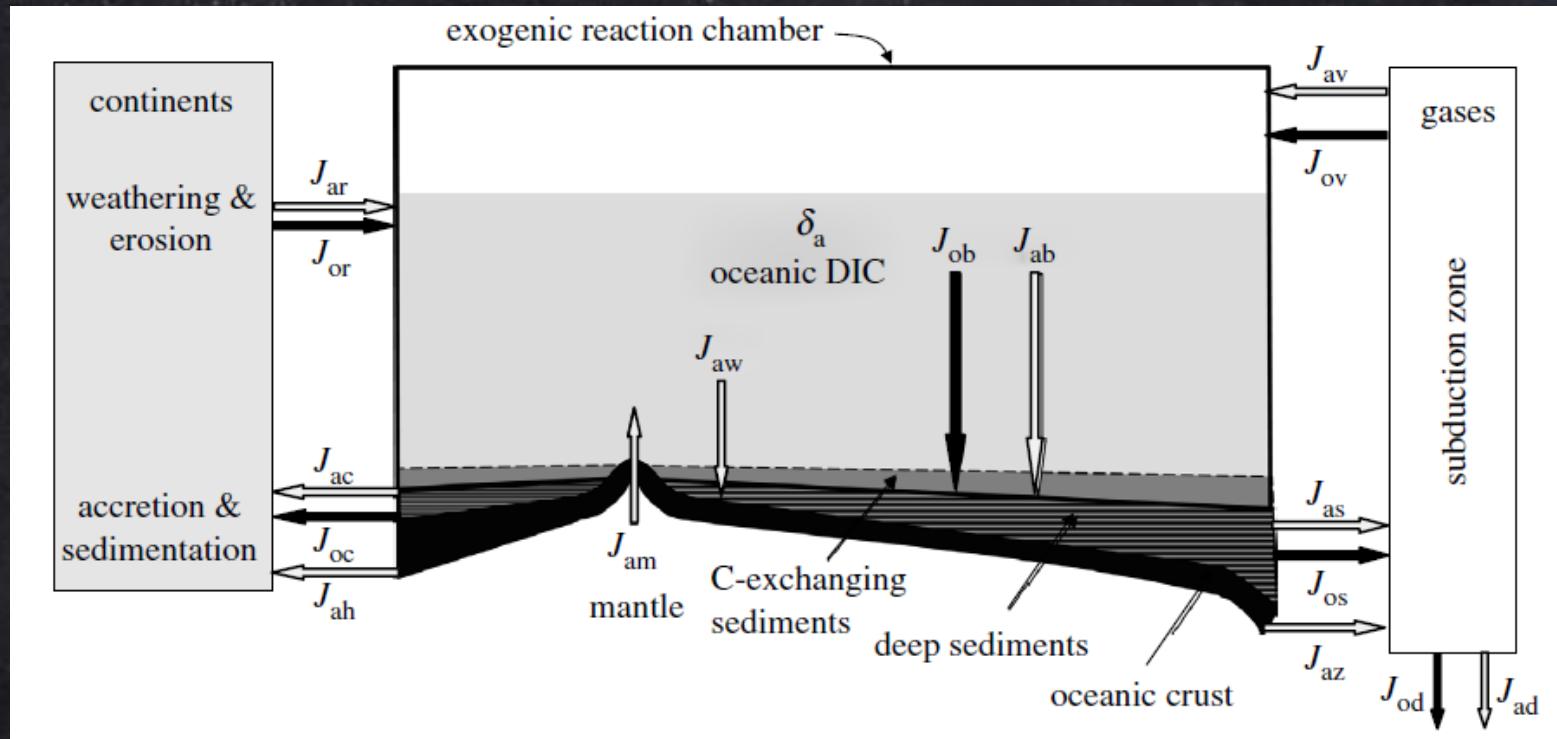
Initiation of subduction +  
formation and evolution of  
volcanic arc

The magmatic  
contribution to volatile  
flux may change through  
the evolution of arcs

## Development and growth of arc (mountain building)



*Hayes and Waldbauer (2006)*



*Input to Ocean-Atmosphere*

*Removal from Ocean-Atmosphere*

$$J_{am} + J_{ar} + J_{or} + J_{av} + J_{ov} = J_{ab} + J_{ob} + J_{aw}$$

↓                    ↓                    ↓                    ↓                    ↓                    ↓  
 Mantle C      Weathering-      C released from      Burial of      Burial of      Sea-floor  
 degassing      induced release      subducting slab      carbonate      Org C      alteration of  
 of continental C

# Approaches

Inverse  
Approach

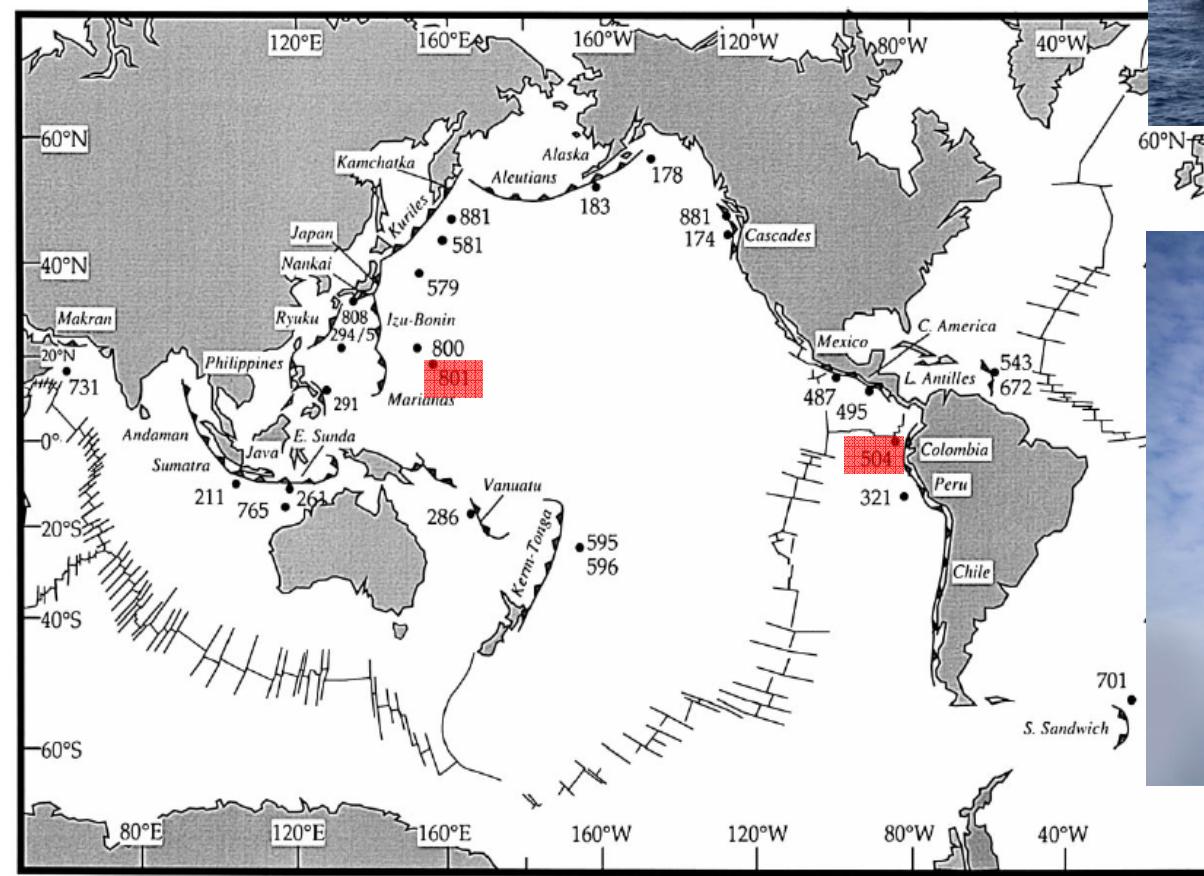
- Constraints on slab input and arc output
- Thermodynamic modeling (Gibbs free energy minimization) of metamorphic devolatilization of various subducting lithologies

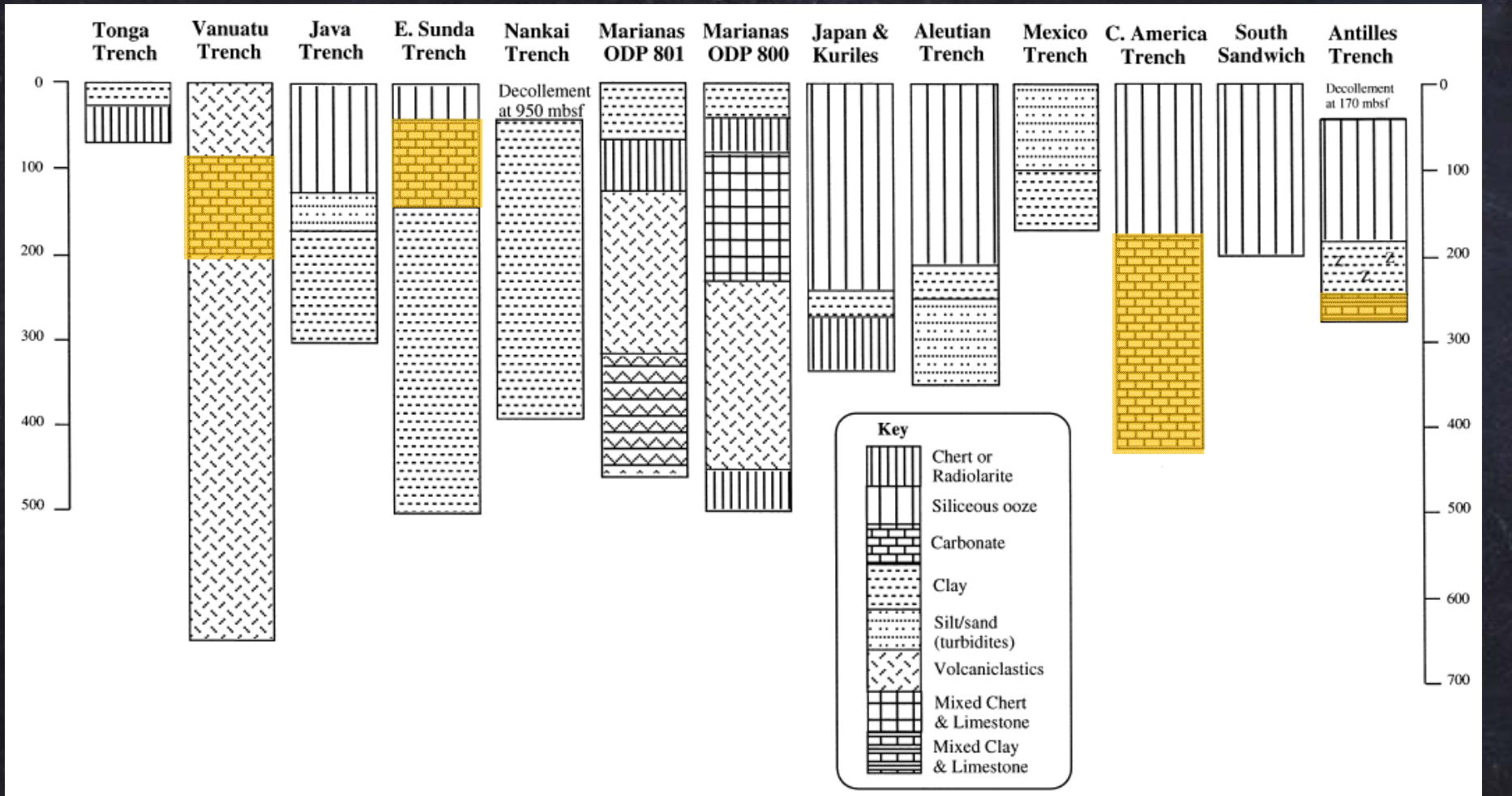
Forward  
Approach

Perple\_X, Thermo-Calc

- Laboratory experiments constraining devolatilization and melting of subducting lithologies

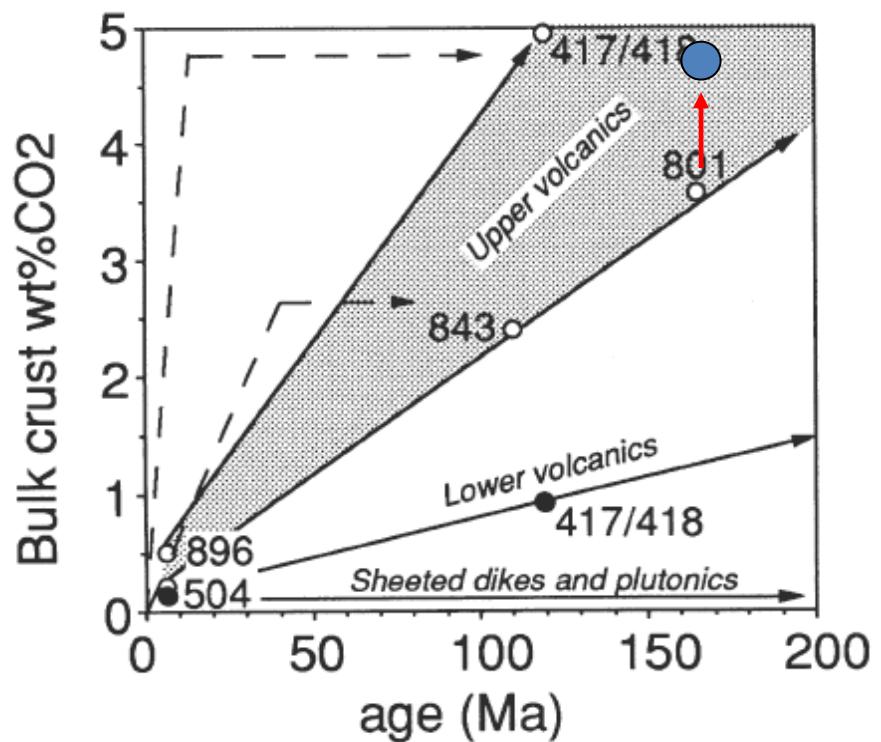
*Estimating*  $J_{ab} + J_{ob} + J_{aw}$





*Plank and Langmuir (1998)*

# *Carbonation of ocean floor basalts*



(Alt & Teagle, 1999; Kelley et al., 2005)

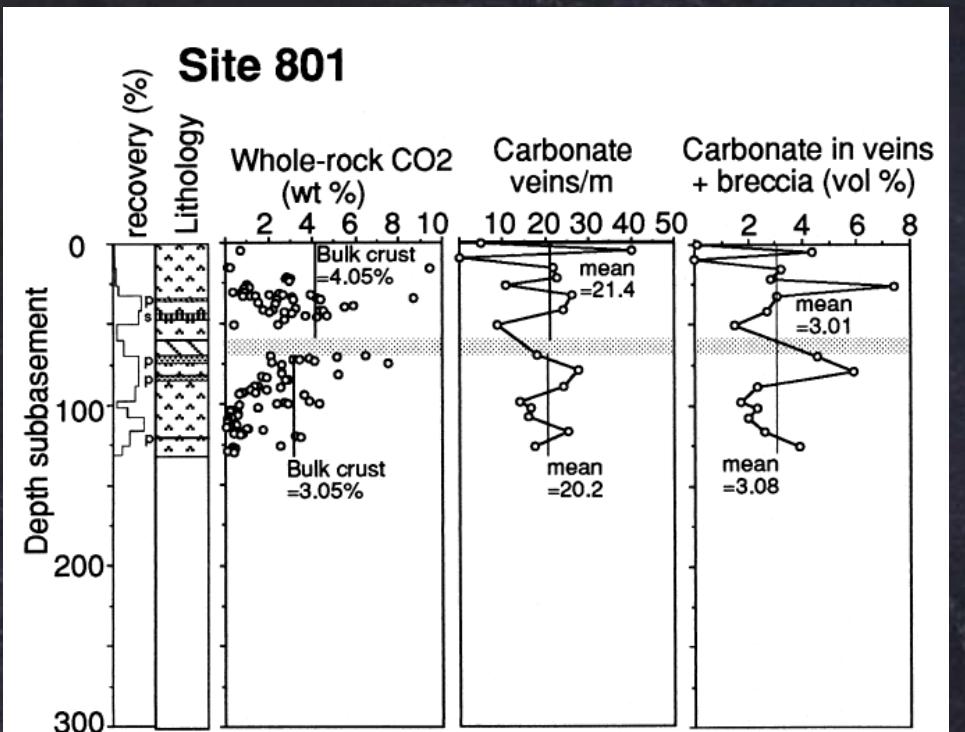


Table 1. Bulk CO<sub>2</sub> content of altered ocean crust.

*sediment*



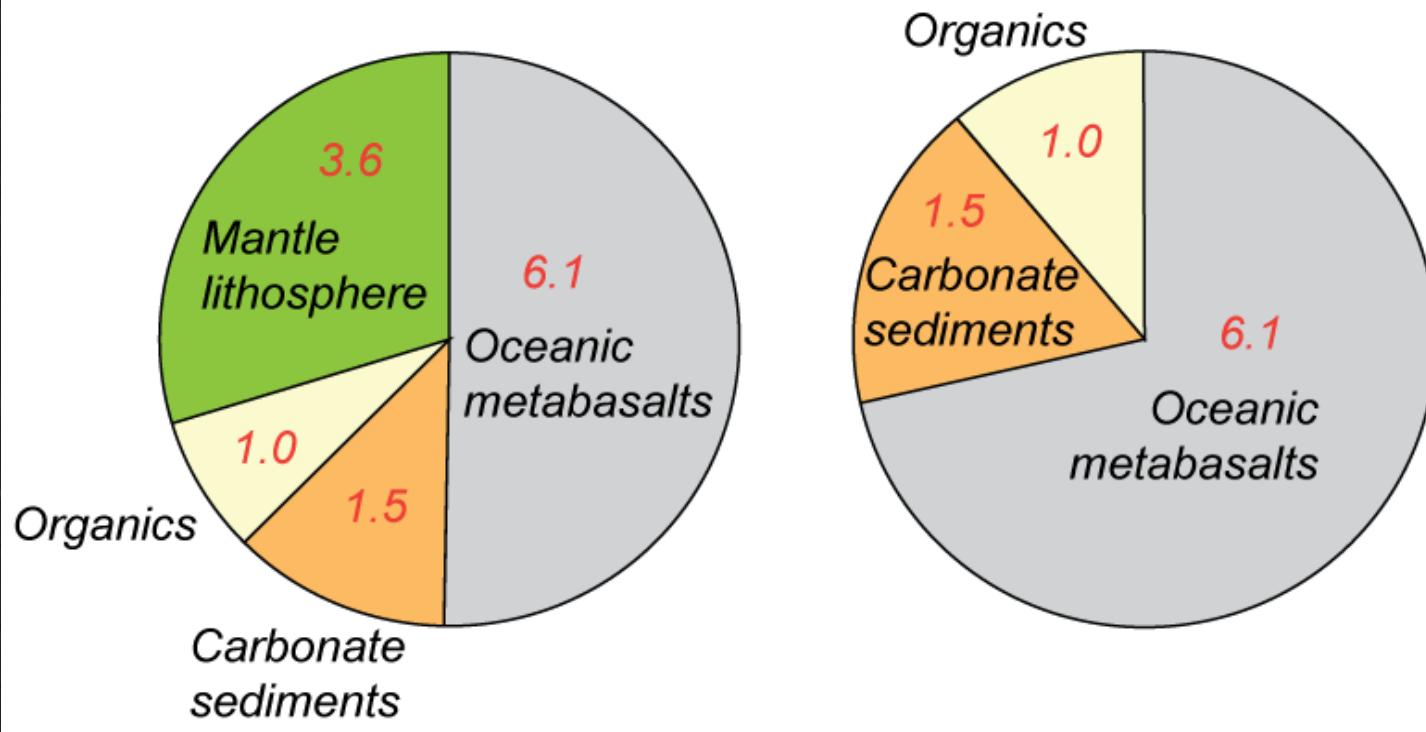
*basalt*



*peridotite*

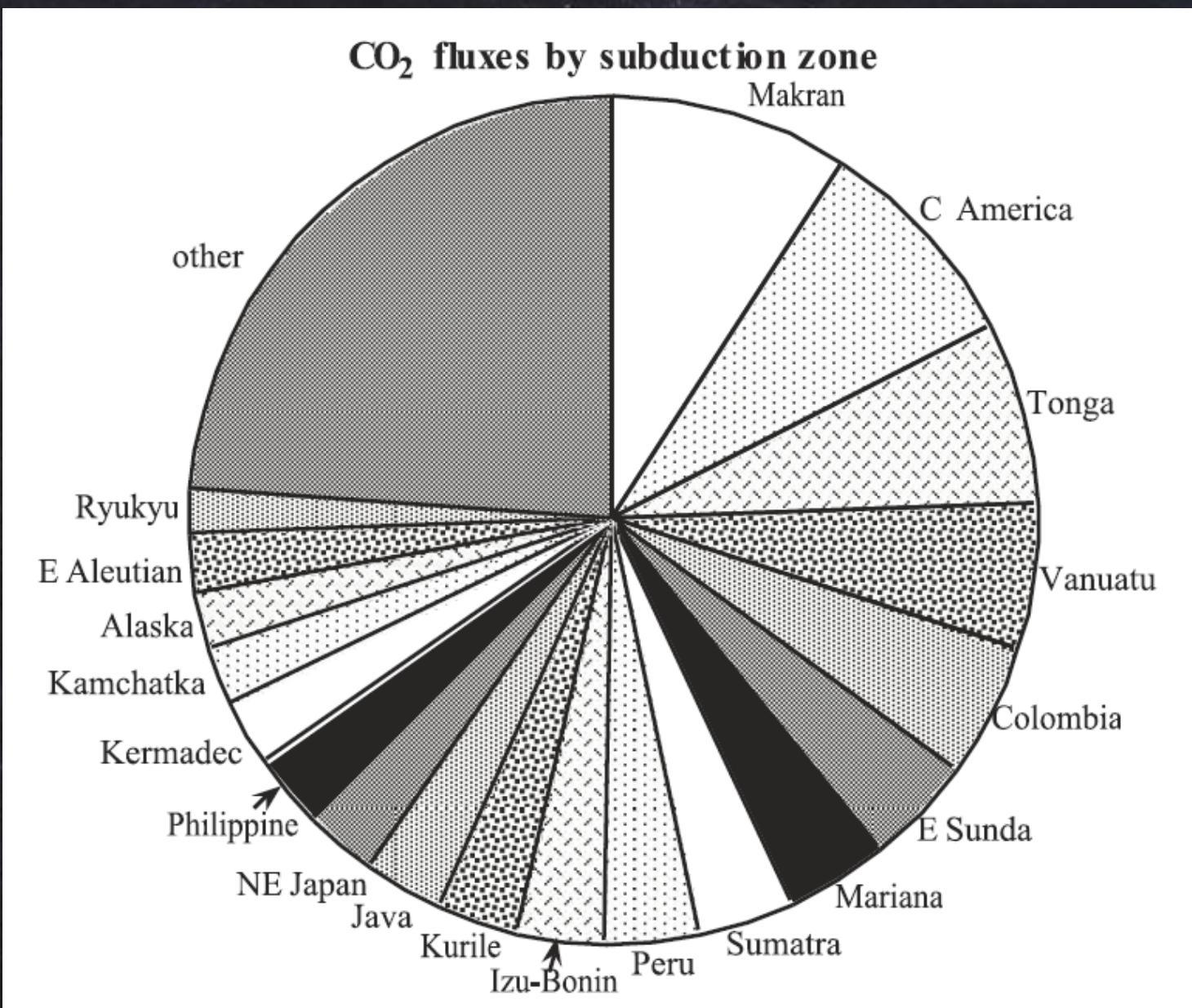


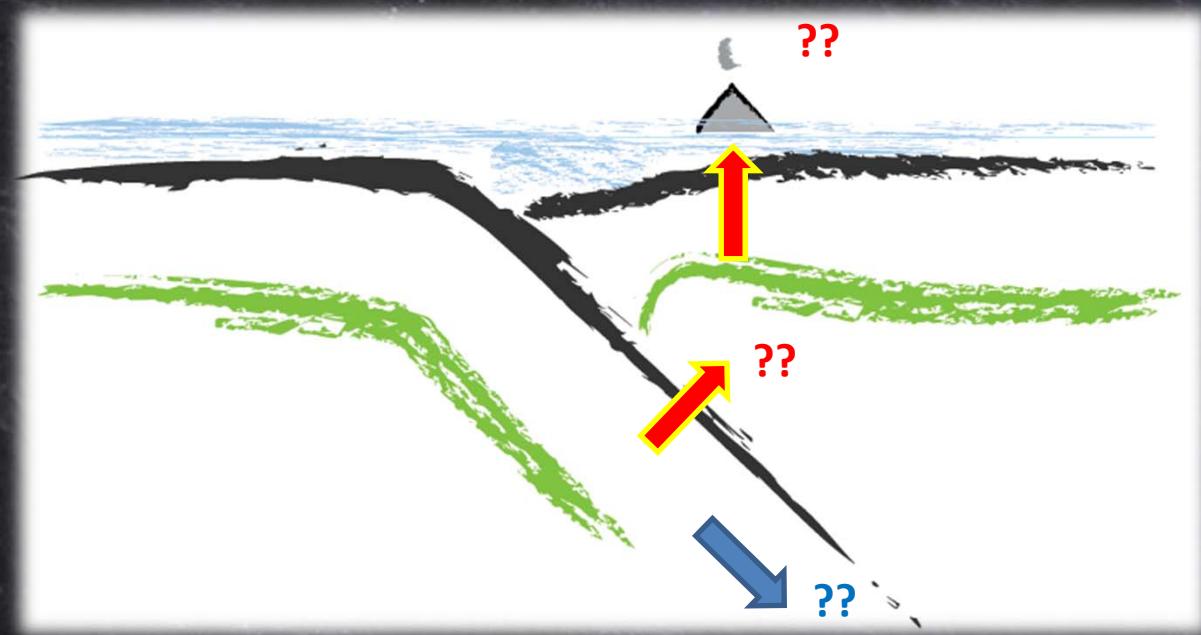
*Mass flux of subducting Carbon (x 10<sup>13</sup> g/yr)*



(Sciutto and Ottonello, 1995; Kerrick & Connolly, 2001; Sleep and Zahnle, 2001; Jarrard, 2003; Alt, 2004)

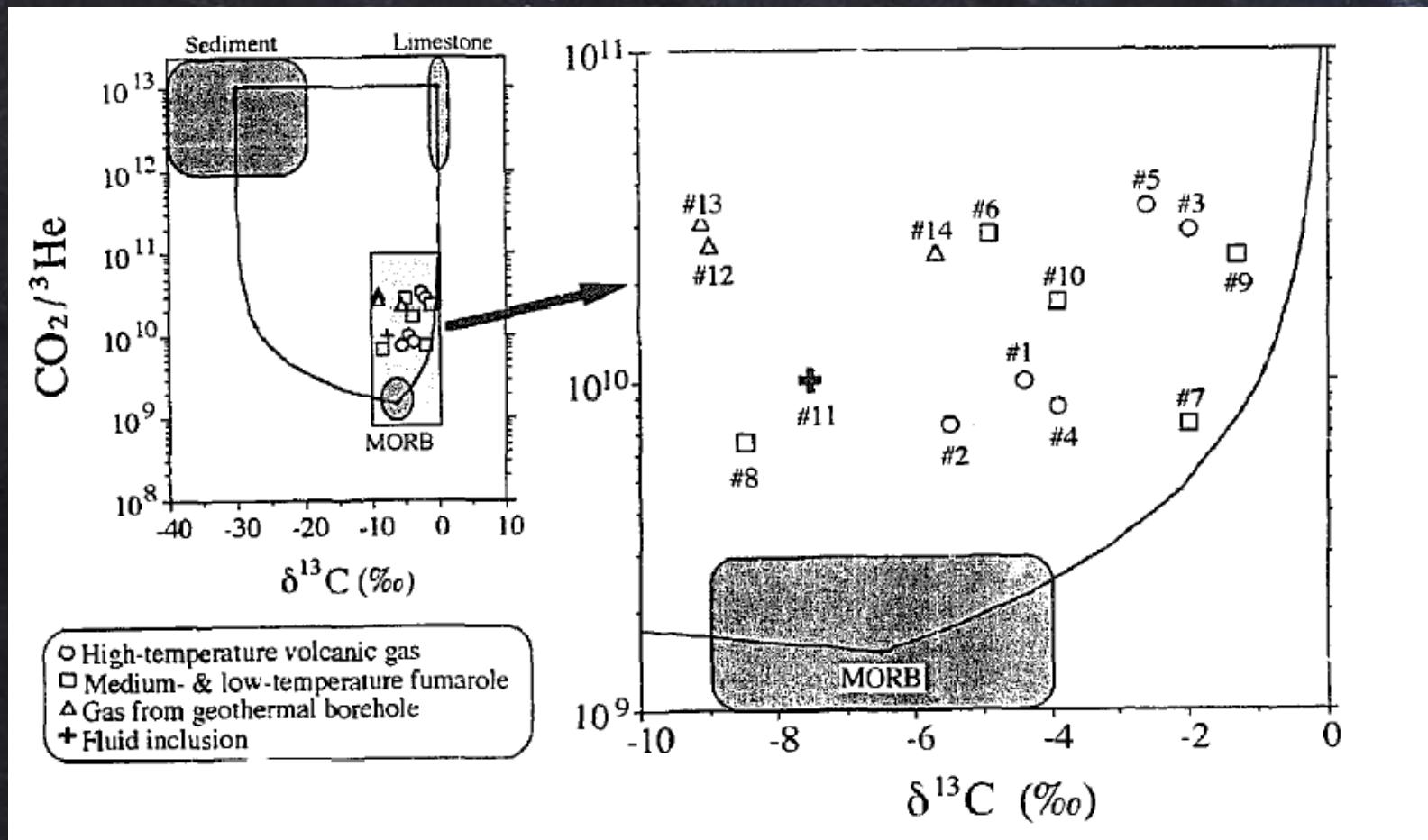
*Jarrard (2003)*



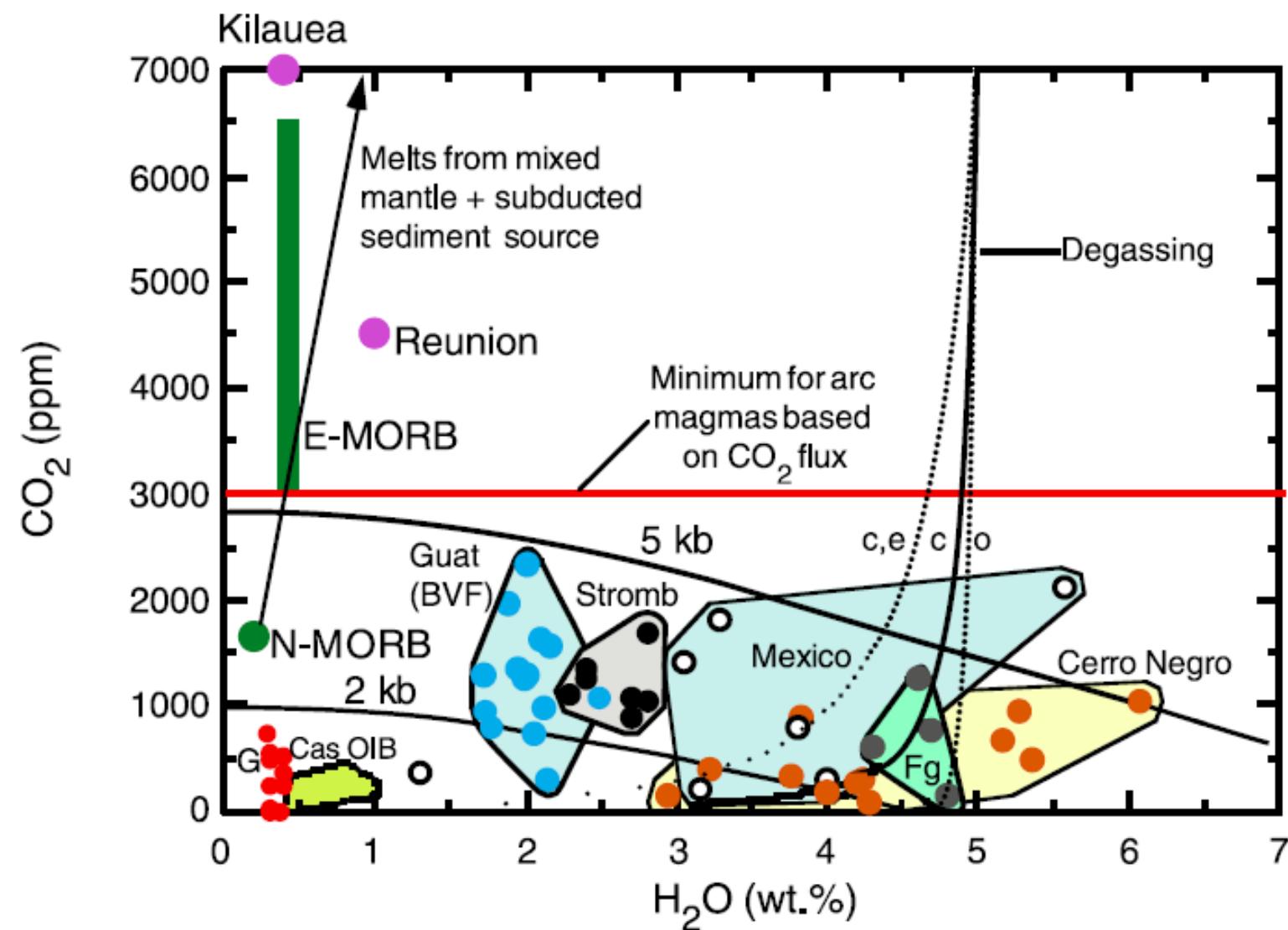


# Constraints on slab input and arc output

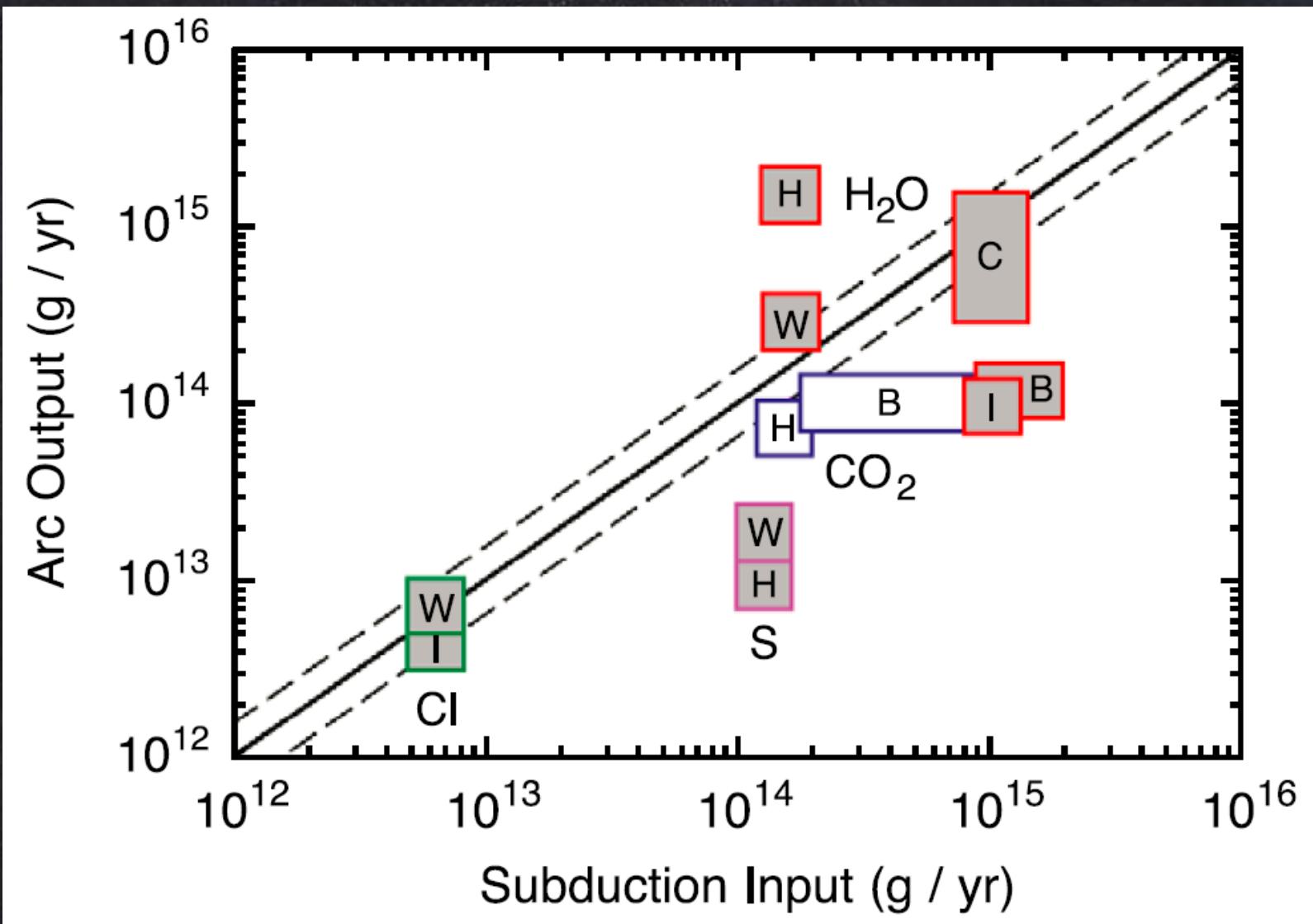
## Carbon isotope chemistry of arcs



Sano and Marty (1995)



Wallace (2005)



Wallace (2005)

- Thermodynamic modeling  
(Gibbs free energy minimization) of  
metamorphic devolatilization of  
various subducting lithologies

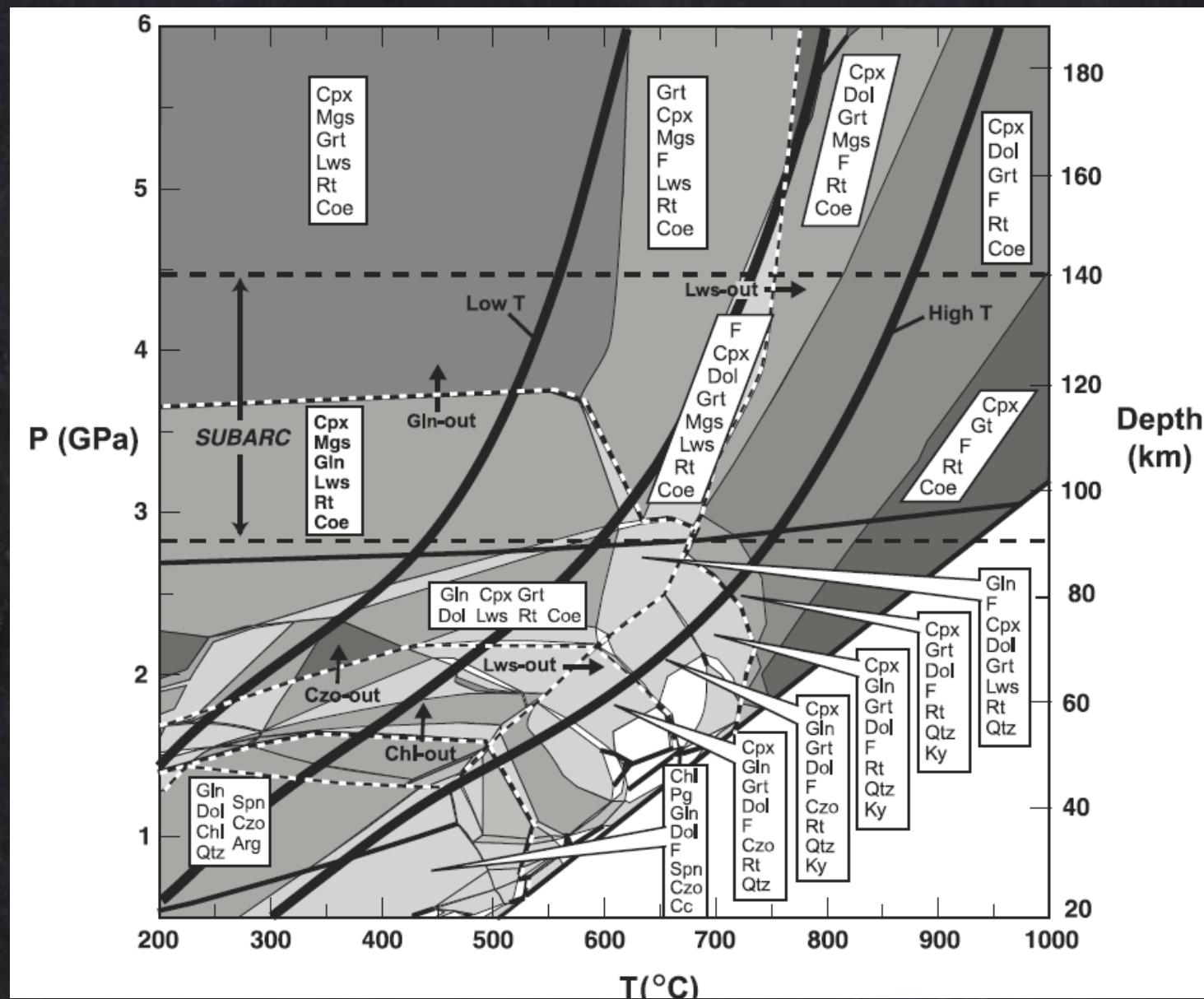
Perple\_X

Kerrick and Connolly (2001)

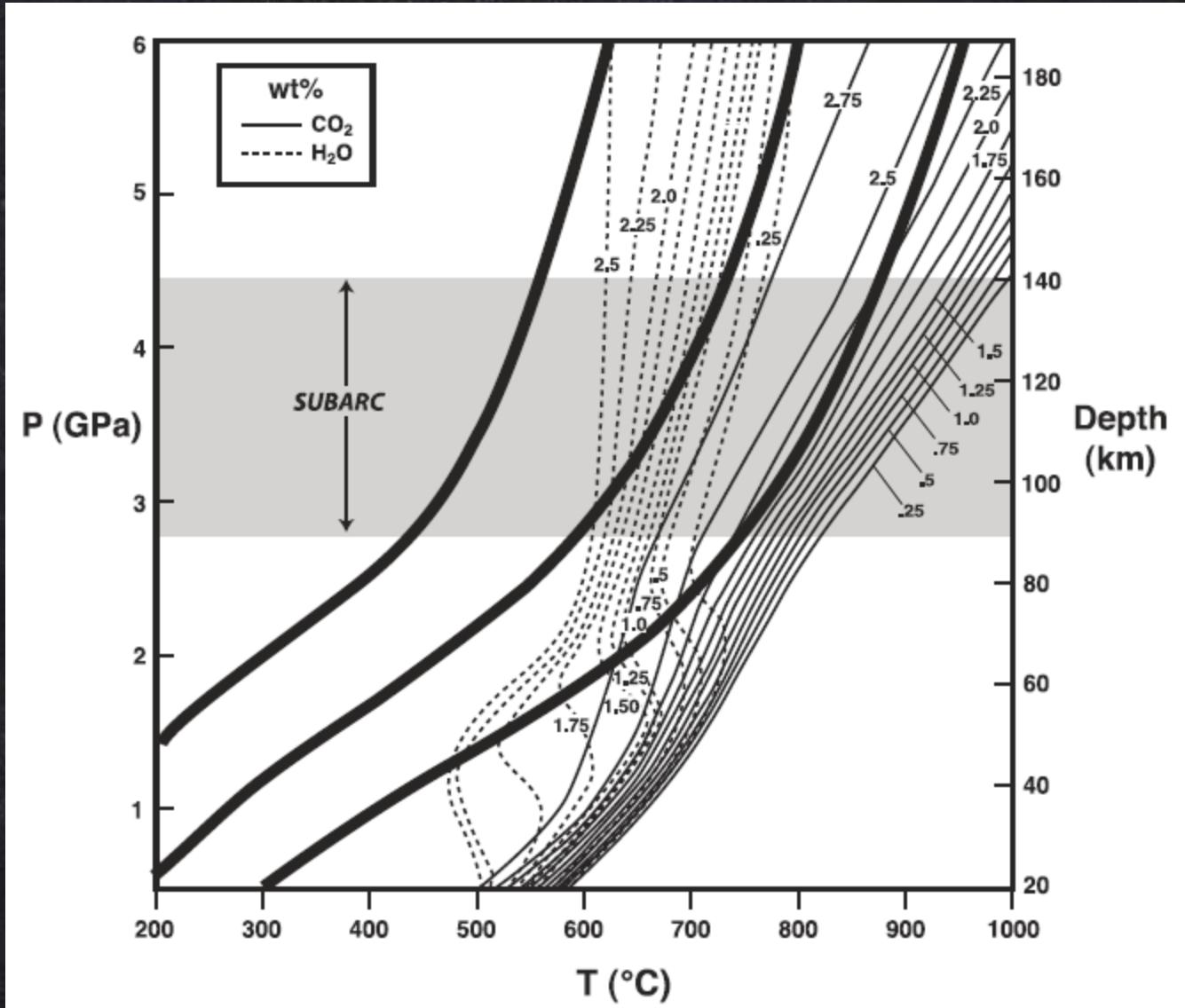
Chemical composition (wt%) of average MOR metabasalt  
(‘Super Composite’ from [7])

SiO <sub>2</sub>	45.8
TiO <sub>2</sub>	1.12
Al <sub>2</sub> O <sub>3</sub>	15.53
Fe <sub>2</sub> O <sub>3</sub>	10.02
MnO	0.17
MgO	6.66
CaO	12.88
Na <sub>2</sub> O	2.07
K <sub>2</sub> O	0.56
P <sub>2</sub> O <sub>5</sub>	0.11
H <sub>2</sub> O	2.68
CO <sub>2</sub>	2.95
Total	100.61

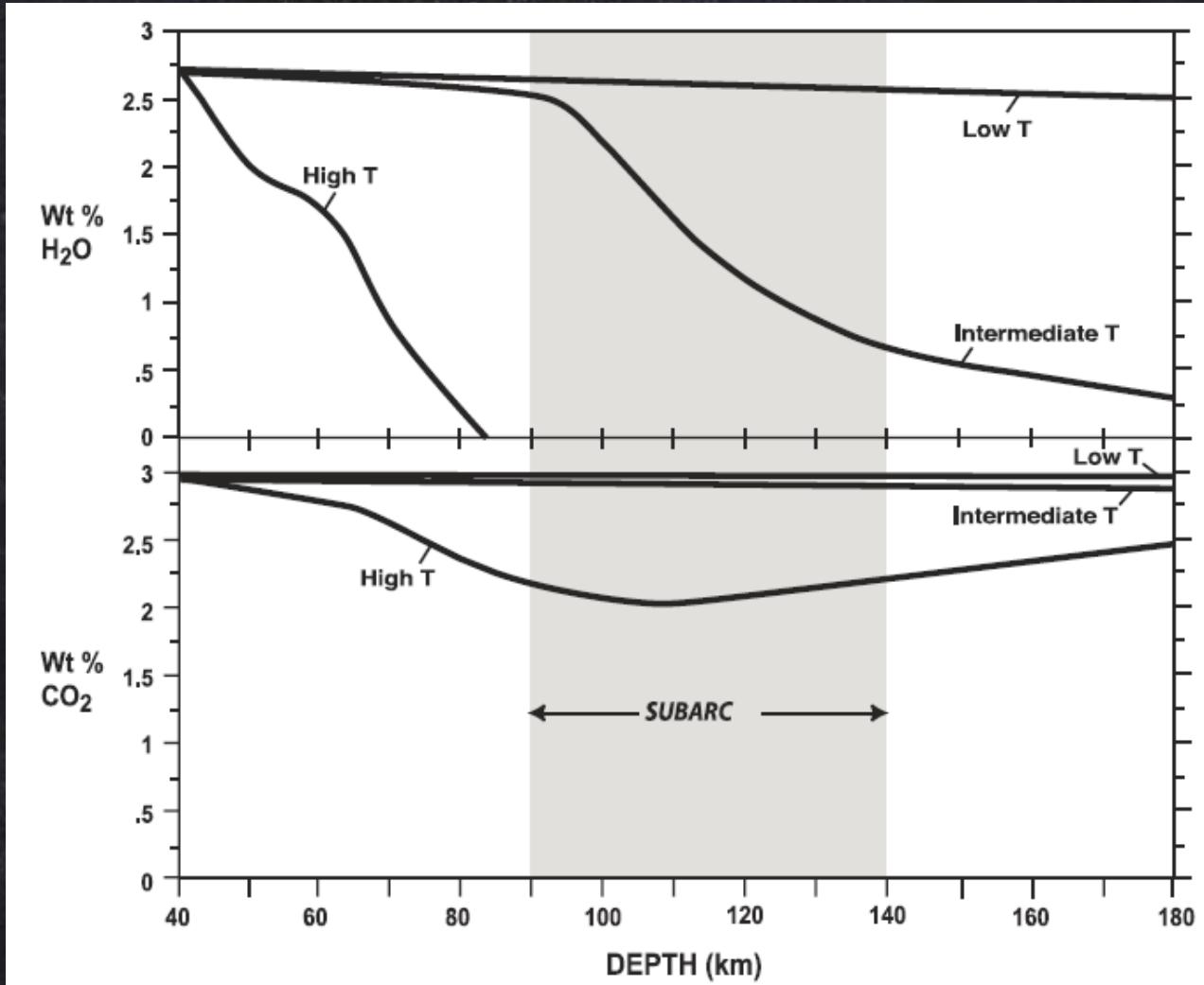
Composition of altered oceanic crust (top few hundred meters)



Kerrick and Connolly (2001)



Kerrick and Connolly (2001)



*Kerrick and Connolly (2001)*

## Newer models of subduction zone thermal structure

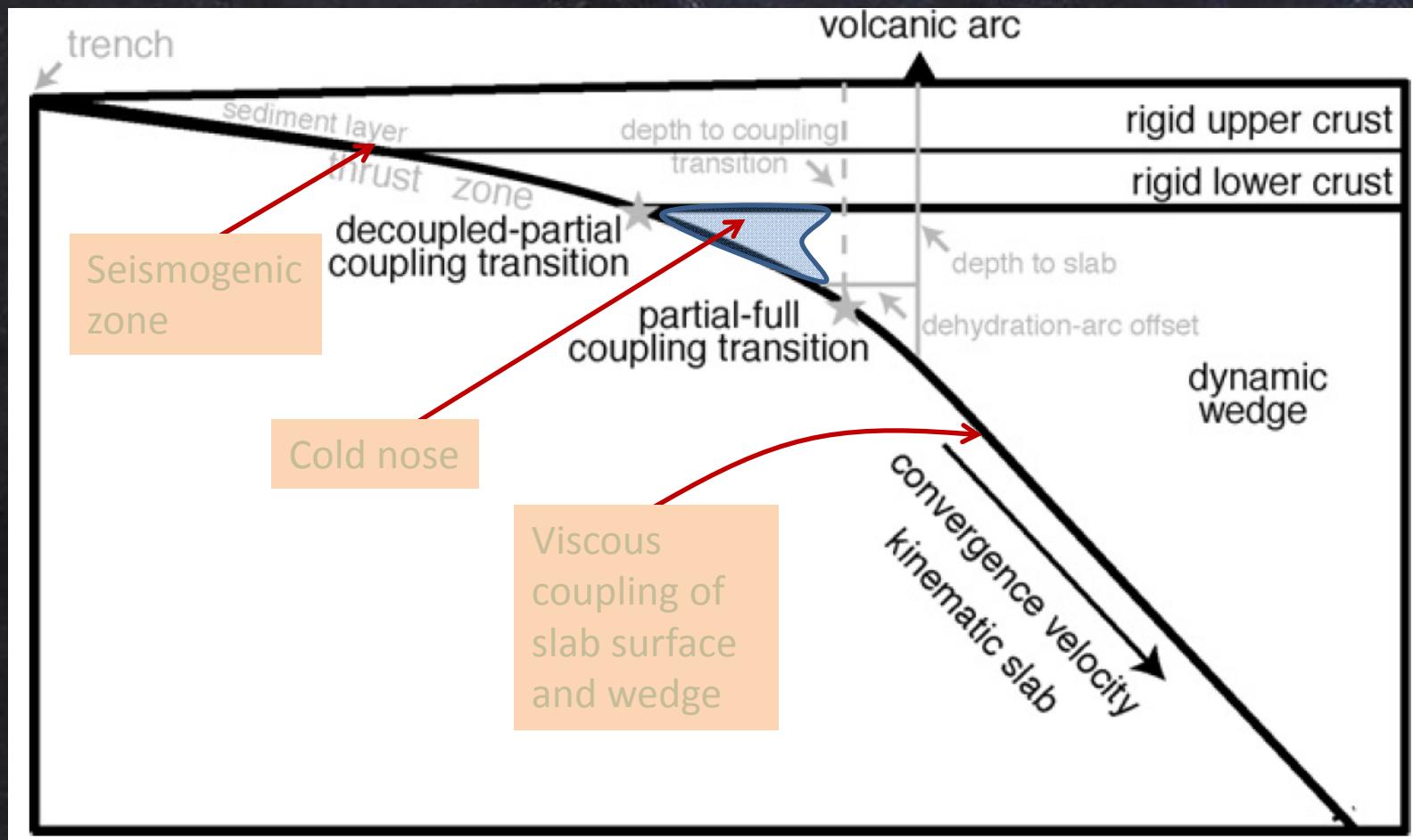
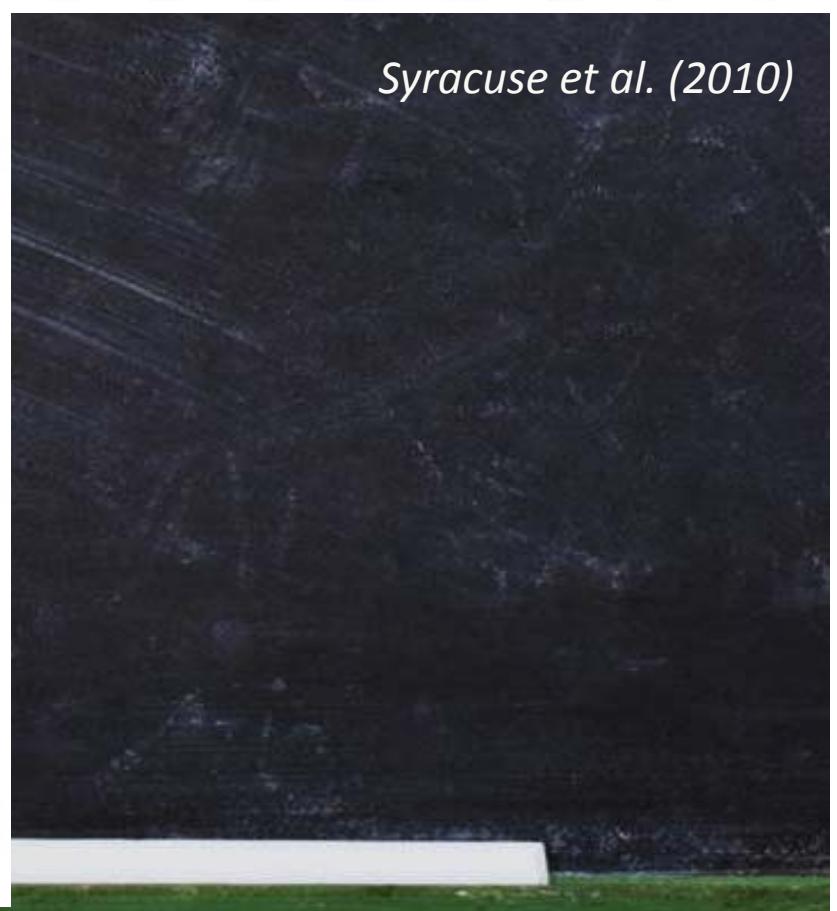
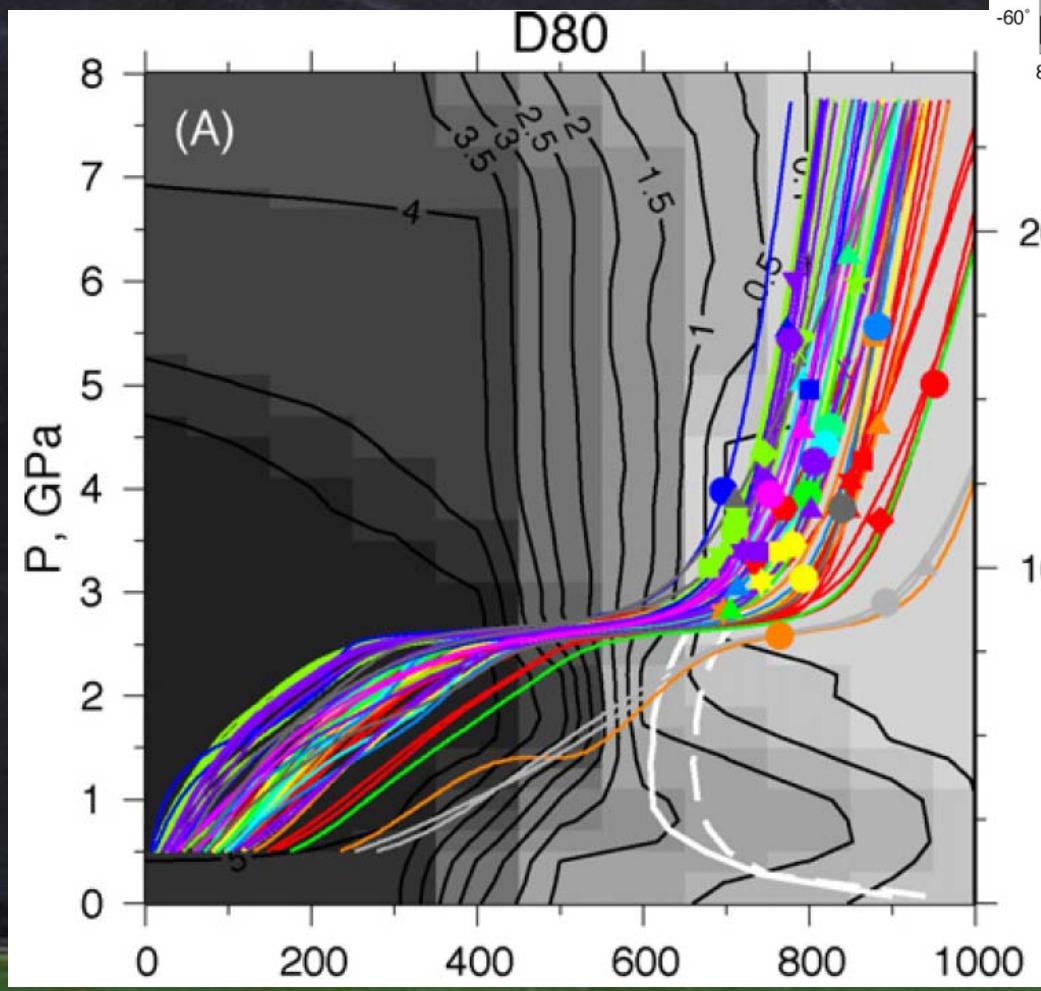
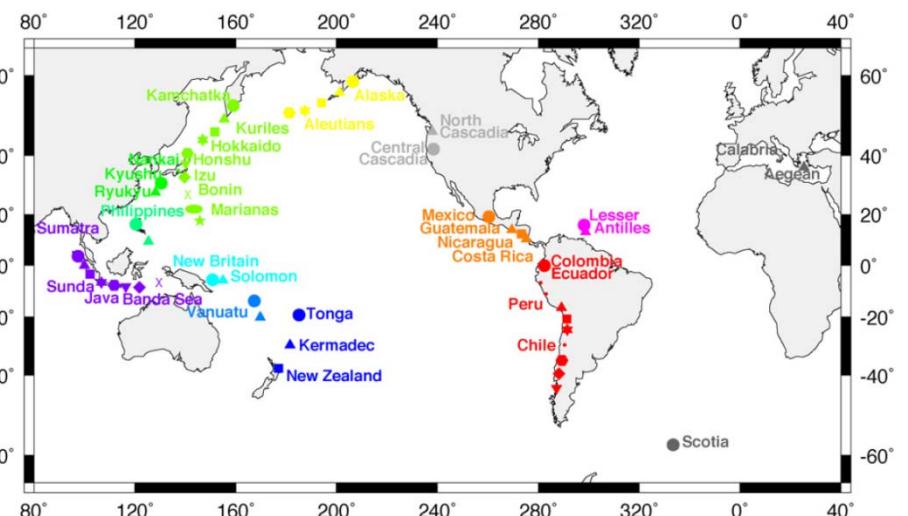
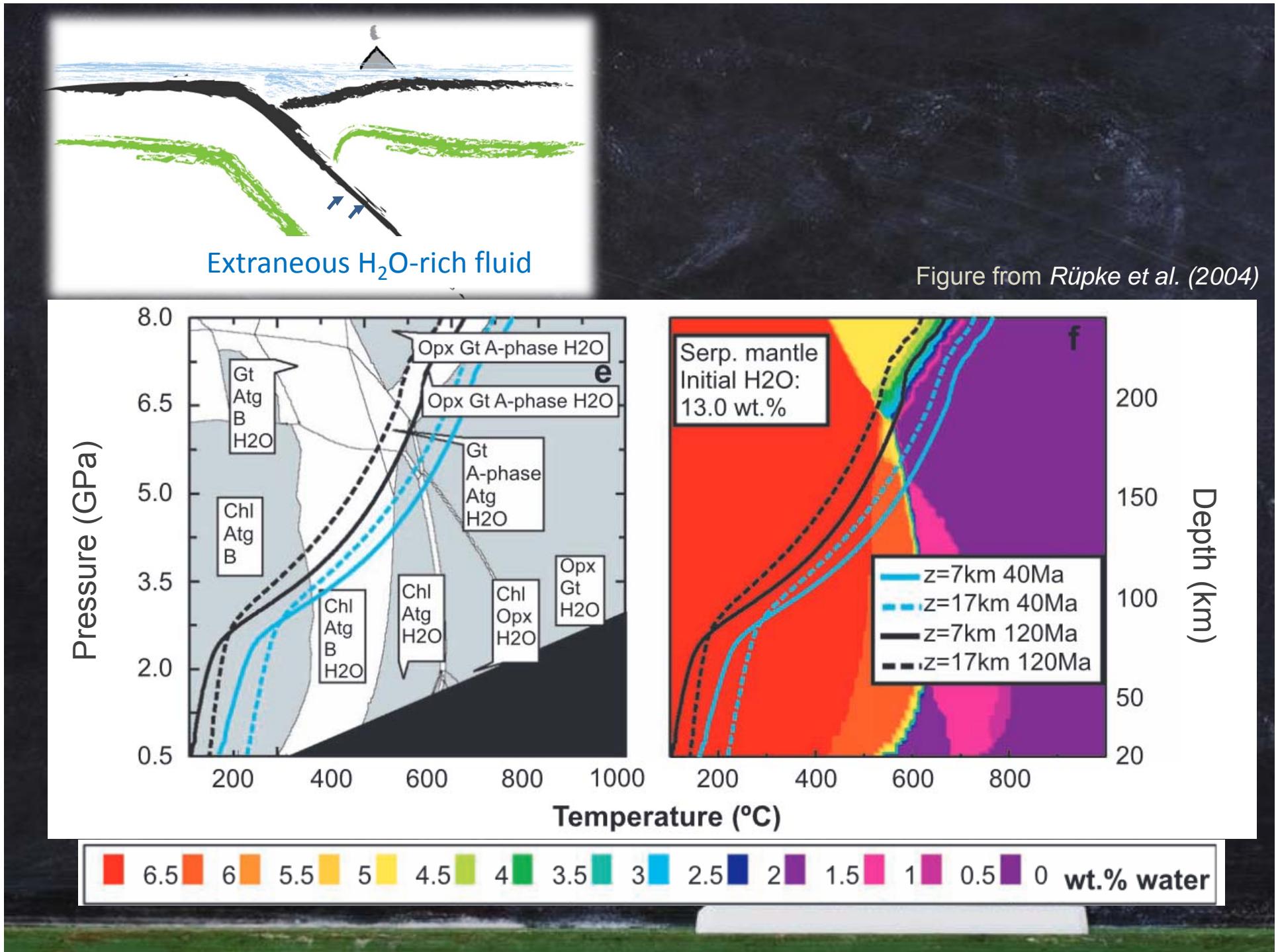


Figure modified from *Syracuse et al. (2010)*

# Slab surface $P$ - $T$ paths with temperature and stress-dependent rheology of mantle wedge





- Fluid infiltration induced decarbonation of basalts and sediments

(Molina and Poli, 2000; Connolly, 2005; Gormann et al., 2006; Poli et al., 2009)

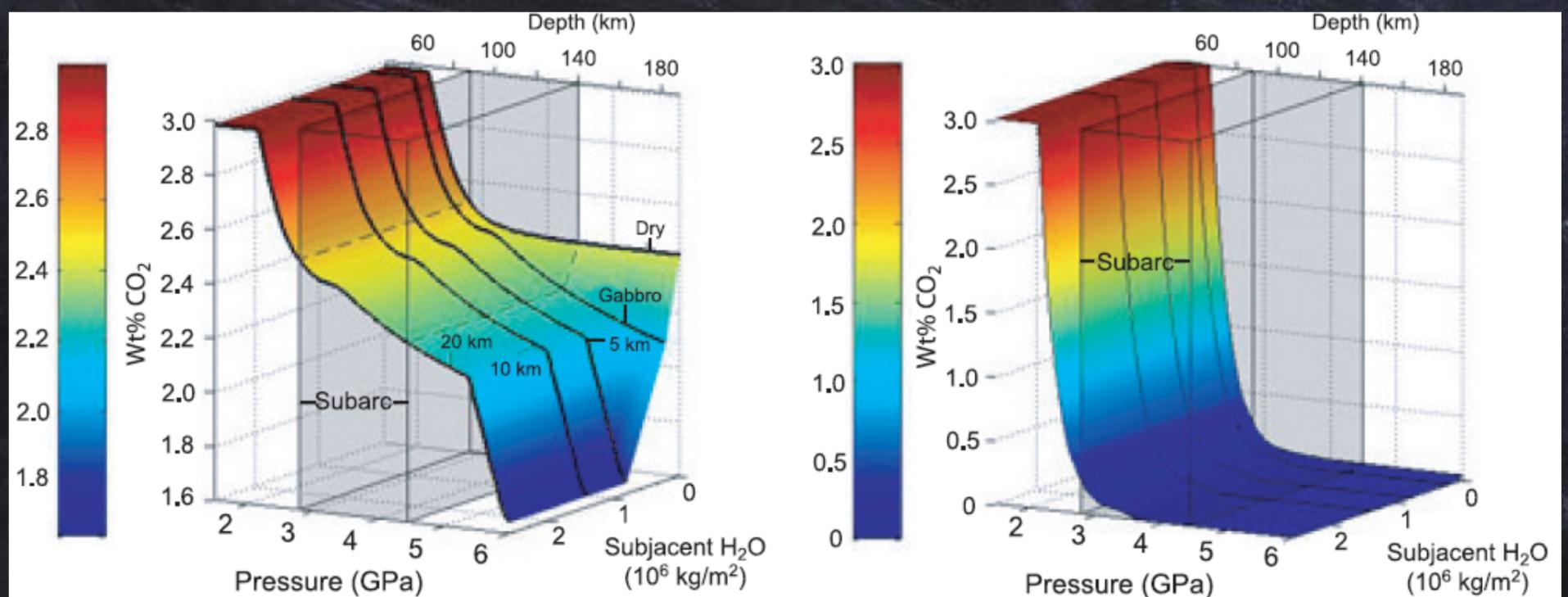


Figure from Gormann et al. (2006)