METAMORPHIC CO₂ PRODUCTION: A NEGLECTED CONTRIBUTION TO GLOBAL CARBON MODELS

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Why does it matter?
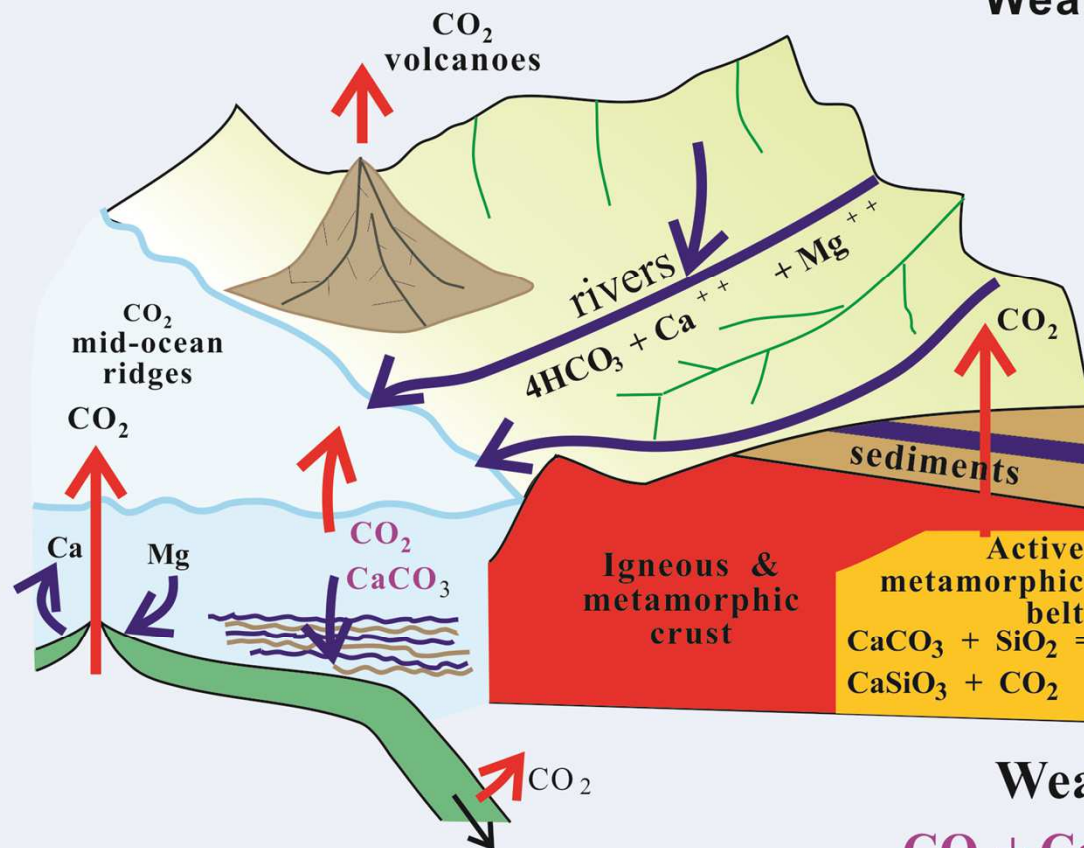
1) what is solid Earth CO_2 degassing flux?
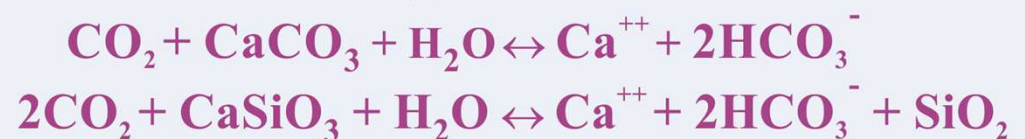
Weathering Flux: mole $CO_2 \cdot a^{-1}$

Gaillardet et al., 1999
Carbonate 12.3×10^{12}
Silicate 11.7×10^{12}
CO_2 consumed ~ 6×10^{12}

Rivers: Poorly sampled
Silicate/carbonate?
short term variations
Ocean crust?

Weathering Reactions

$$CO_2 + CaCO_3 + H_2O \leftrightarrow Ca^{++} + 2HCO_3^-$$

$$2CO_2 + CaSiO_3 + H_2O \leftrightarrow Ca^{++} + 2HCO_3^- + SiO_2$$

Solid Earth CO_2 Output Fluxes: 10^{12} mol/yr

Mid-ocean ridges:

Marty & Tolstikhin (1998)	2.2 ± 0.9
Dasgupta & Hirschman (2010)	3^{+3}_{-2}

Subduction zones:

Marty & Tolstikhin (1998)	2.5
Dasgupta & Hirschman (2010)	2.3 ± 0.8
Jonhston et al. (2011)	1.9

Plumes

Mjelde (2010)	1.3
Dasgupta & Hirschman (2010)	1
Total	$6^{+4.5}_{-3.2}$
Gerlach (2011) *total*	3.5 to 6

Global CO_2 weathering (river data): 6 (3 to 12?)
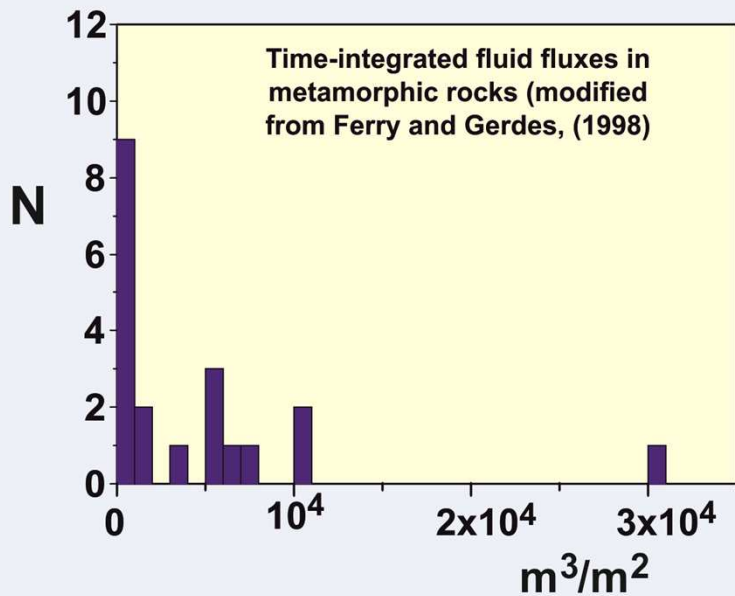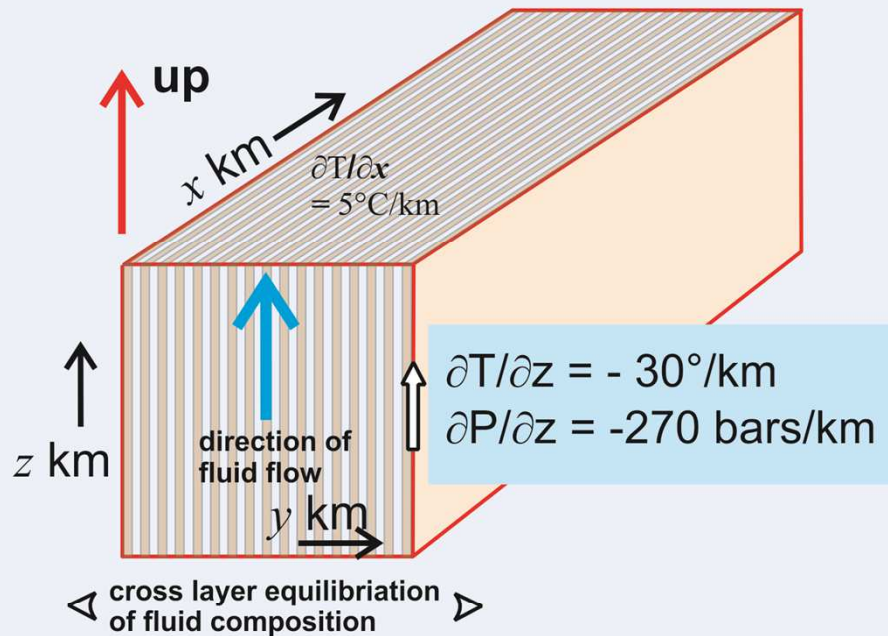
Metamorphic (by difference) $0^{+4.4}_{-7.5}$
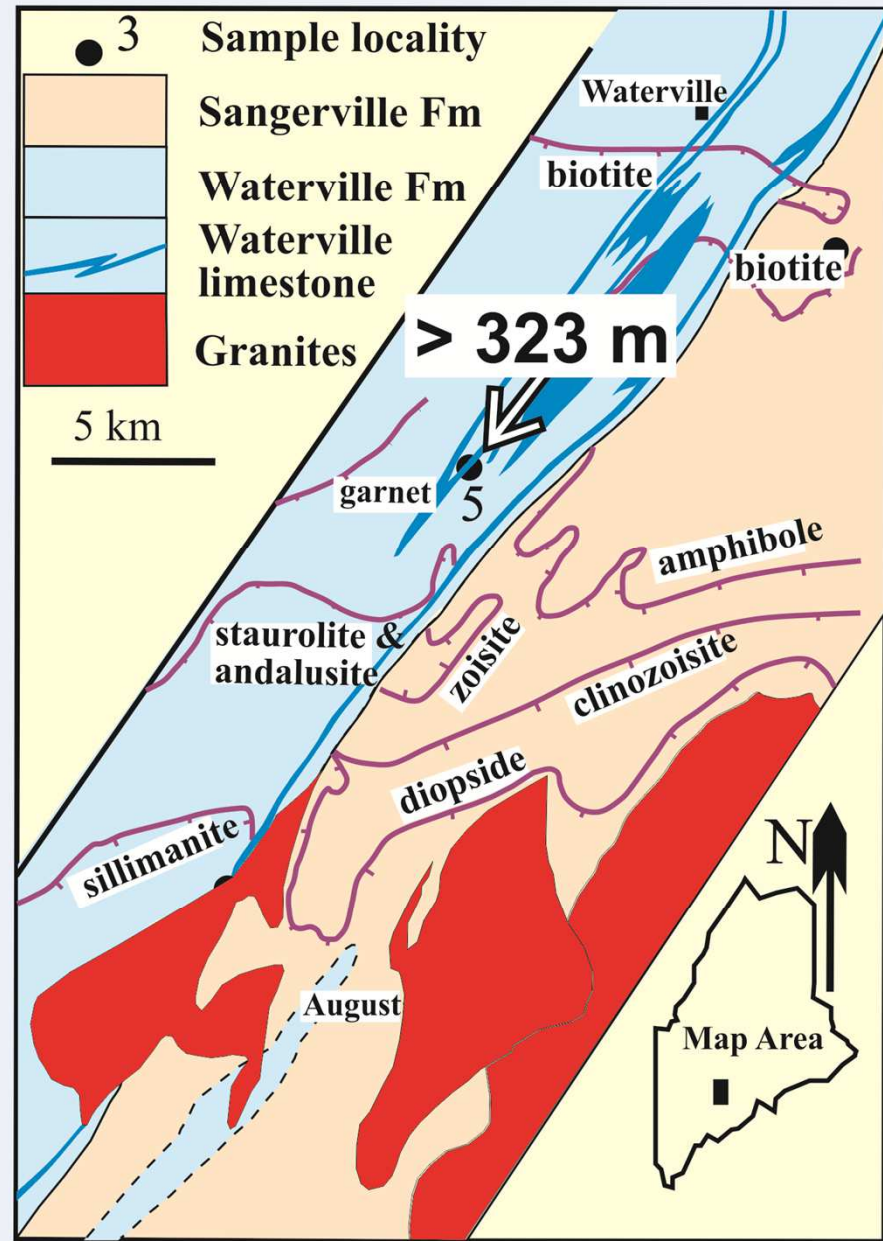
Metamorphic degassing – Himalayas
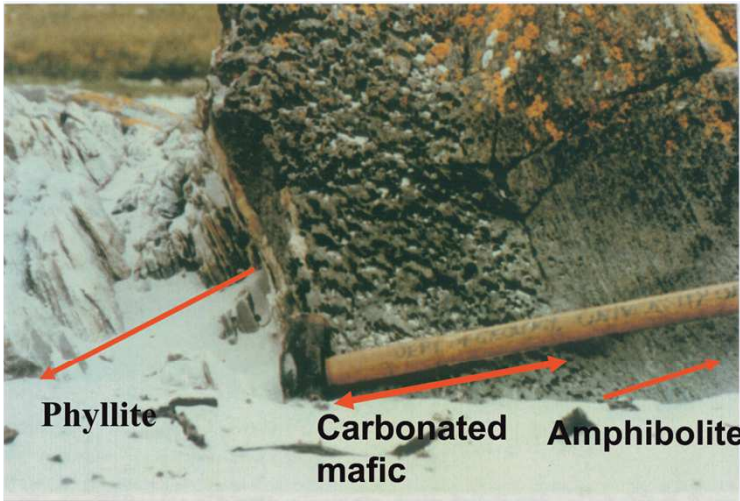
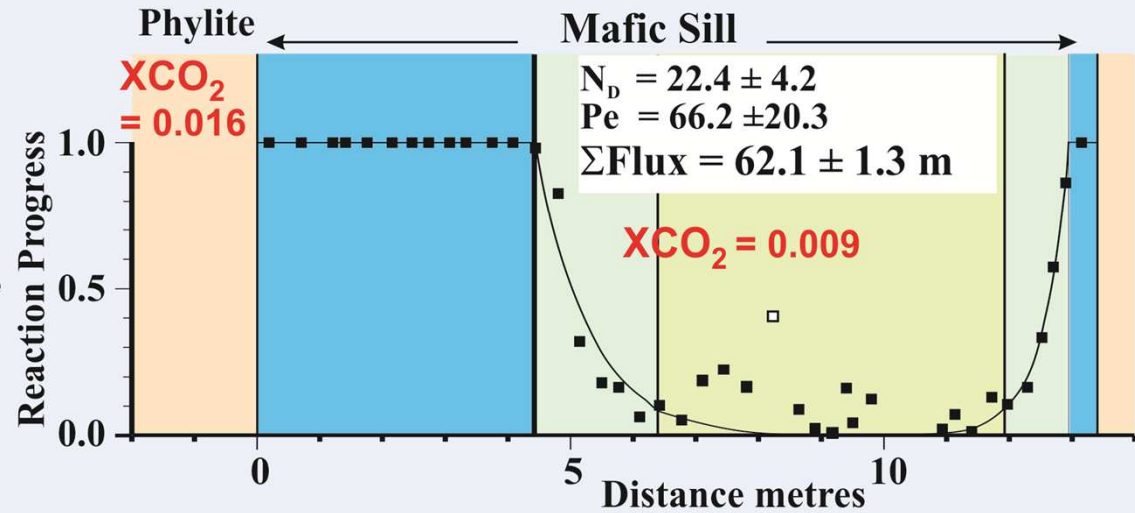**Metamorphic degassing – Himalayas**

Metamorphic Fluid Fluxes

South-central Maine after Ferry et al. (2013)

up

x km

$\partial T/\partial x$ = 5°C/km

z km

direction of fluid flow

$\partial T/\partial z$ = - 30°/km
$\partial P/\partial z$ = -270 bars/km

y km

◁ cross layer equilibriation of fluid composition ▷

Time-integrated fluid fluxes in metamorphic rocks (modified from Ferry and Gerdes, (1998)

N

12
10
8
6
4
2
0

0   10^4 2×10^4 3×10^4

m^3/m^2

3   Sample locality

Sangerville Fm

Waterville Fm

Waterville limestone

Granites

5 km

> 323 m

Waterville

biotite

biotite

garnet   5

amphibole

staurolite & andalusite

zoisite

clinozoisite

diopside

sillimanite

August

N

Map Area

Carbonation Reaction in Metabasite Sills

Phyllite

Carbonated mafic

Amphibolite

Skelton - fluids fluxes in the Dalradian,
S. W. Highlands e.g. Skelton et al., (1997)

Phylite ← Mafic Sill →

$XCO_2 = 0.016$

$N_D = 22.4 \pm 4.2$
$Pe = 66.2 \pm 20.3$
$\Sigma Flux = 62.1 \pm 1.3$ m

$XCO_2 = 0.009$

Reaction Progress

Distance metres

Loch Awe Syncline

Ardrishaig Anticlyne

Port Cill Maluaig Shear Zone

C — C'

2 km
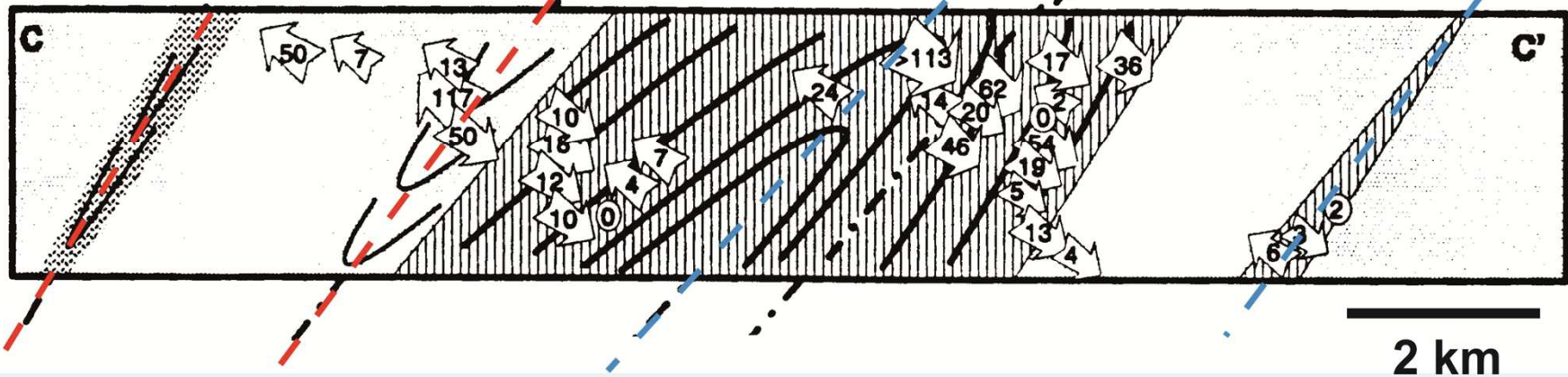
Flow up and out of antiforms: dubious correction for dip.

Assume orogen area 2500 km x 200 km = 5x10^5 km^2

Dalradian: Fluxes > 83 m, XCO$_2$ = 0.016, over 20,000 yrs

Duration of fluid flow event: 10^4 10^5 10^6 10^7 years

Orogen output: 4.4   0.4   0.04   0.004 (x10^{12} mol/yr)

Maine/Vermont: Fluxes > 323, 210 m, XCO$_2$ = 0.163, 0.229

Duration of fluid flow event: 10^4 10^5 10^6 10^7 years

Orogen output: 100   10   1   0.1 (x10^{12} mol/yr)

PETM event: C input: ~ 40x10^{12} mol/yr over 6000 yrs (Zeebe et al., 2009)

Anthropogenic: 800x10^{12} mol/yr over ?

How else do we measure metamorphic CO_2 Fluxes?

Measure directly (ground fluxes) e.g.   Global flux
        Perrier et al (2009)

Measure hot spring input to rivers + degassing model
        Becker et al. (2008) 0.9×10^{12} mol/yr
        Evans et al. (2008) 2×10^{11} mol/yr

$^{87}Sr/^{86}Sr$ evolution of global sediment mass
        Bickle (1994):

4×10^{15} g/yr rock metamorphosed $\rightarrow 4 \times 10^{12}$ mol/yr CO_2

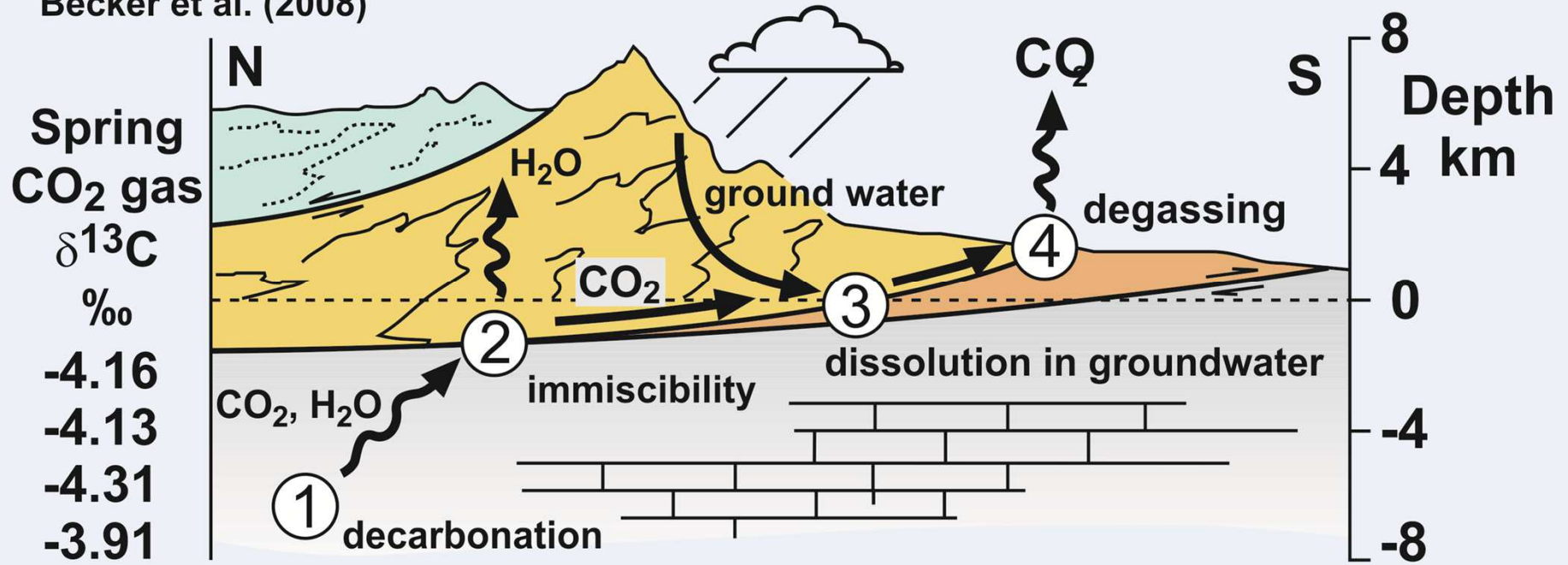Estimate of CO_2 produced from Himalayan orogeny over 50 Myrs:
        Bickle (1996):

2×10^{15} g/yr rock metamorphosed $\rightarrow 2 \times 10^{12}$ mol/yr CO_2
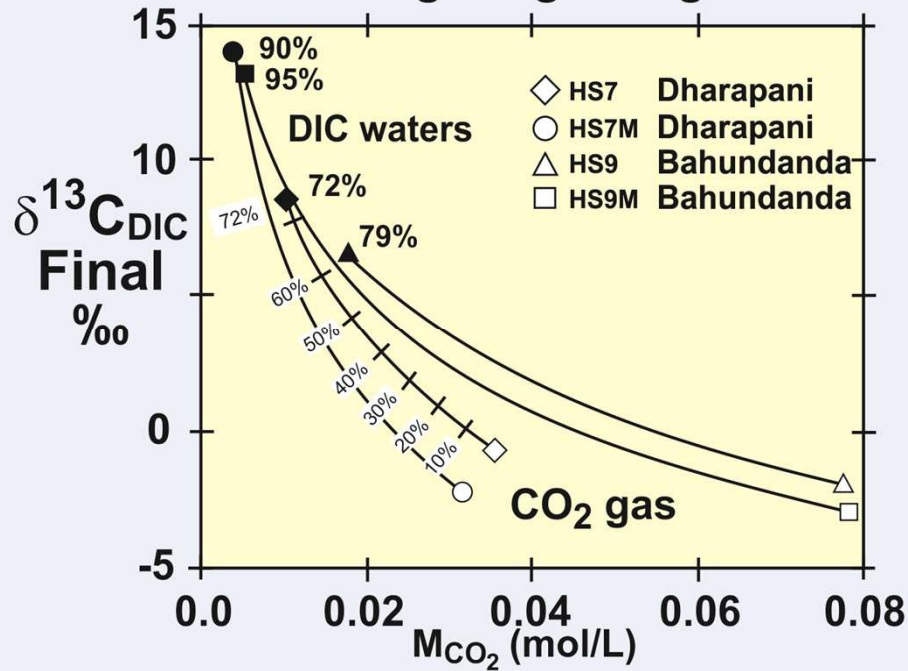
Note Ganges alone carries 0.6×10^{15} g/yr
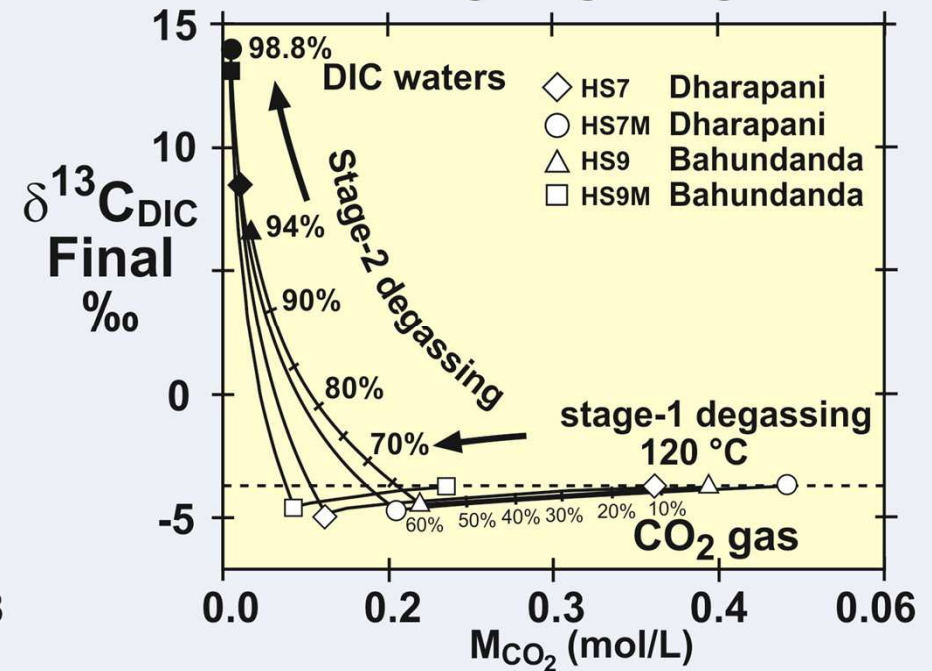
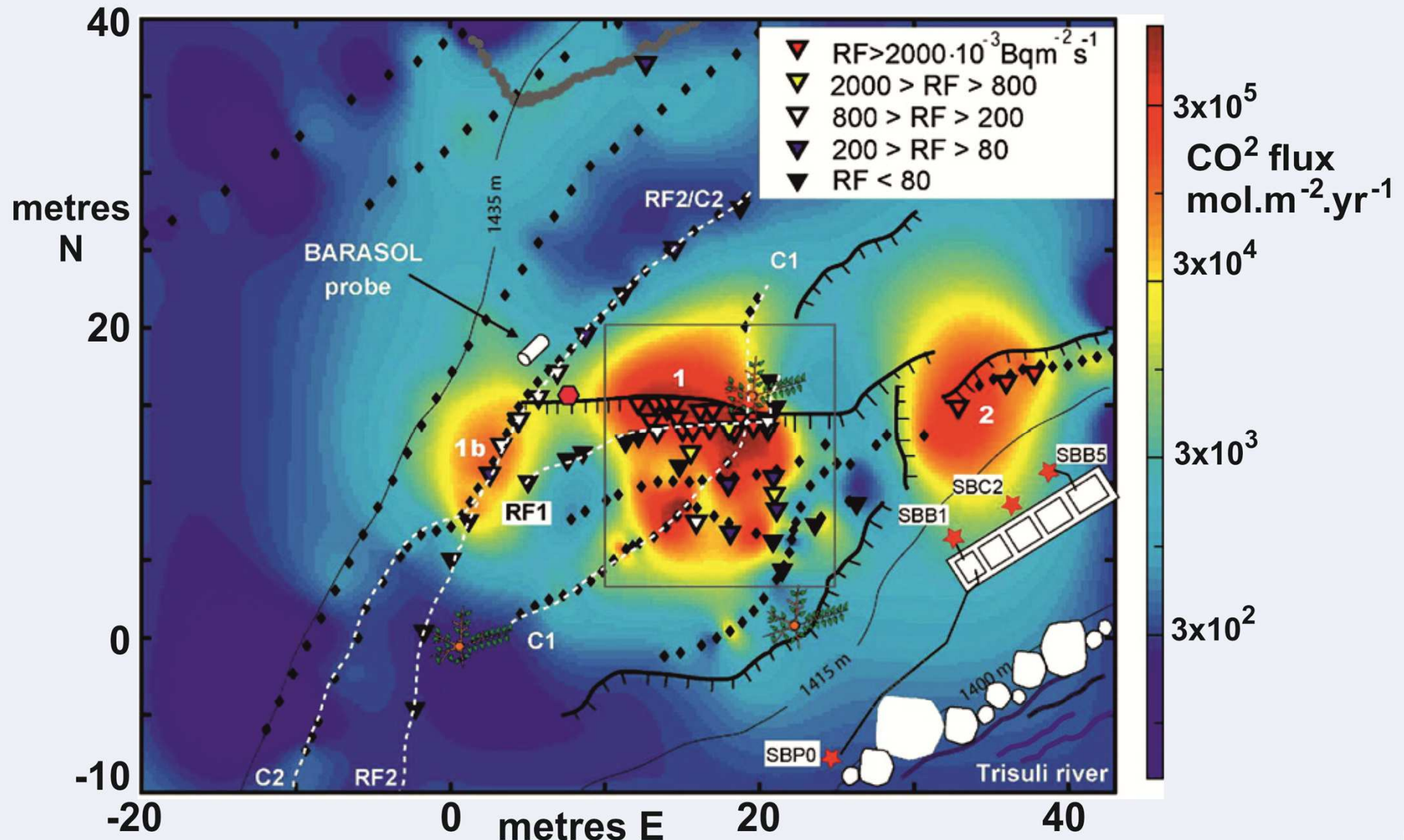Hot spring locations: Evans et al. (2008)
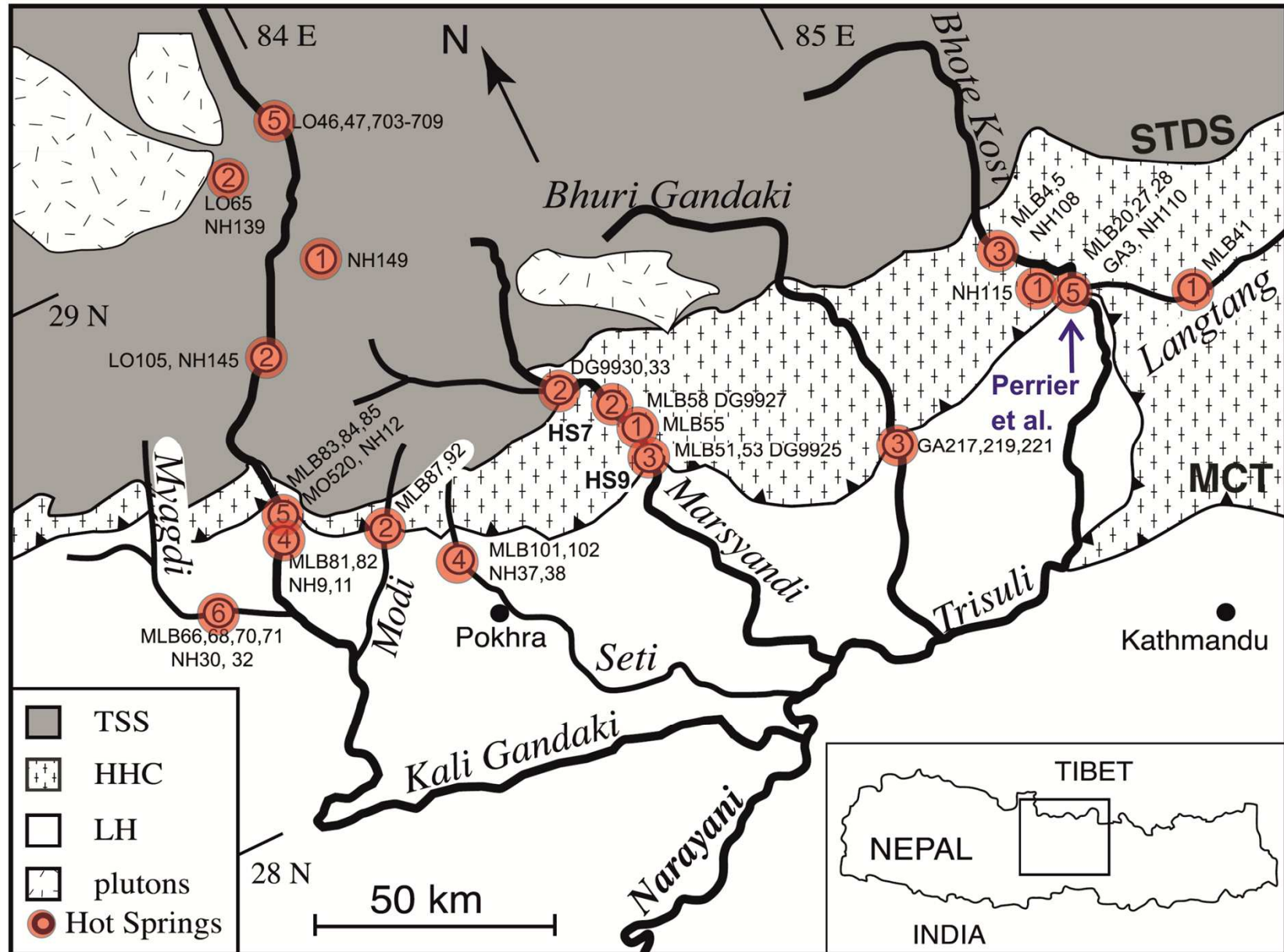
Becker et al. (2008)

Perrier et al. (2009) - direct measurements in Nepal

Ratio gas flux to water bicarbonate flux: 50:1 (ie 98% degassing)

Marsyandi - estimate of metamorphic CO_2 flux

1)   Cl concentration in springs and Cl in river $\rightarrow$ brine flux from springs.

2)   Calculate DIC flux from springs from DIC/Cl ratio in springs.

3)   Calculate CO_2 gas flux from springs from 97% degassing estimate

CO_2 discharge from the Marsyandi (4800 km^2): 5.4×10^9 mol/yr

Extrapolate to whole Himalaya   (5×10^5 km^2) 0.6×10^{12} mol/yr

ie 10% of global CO_2 degassing

Need more data!

Need work on other active metamorphic environments
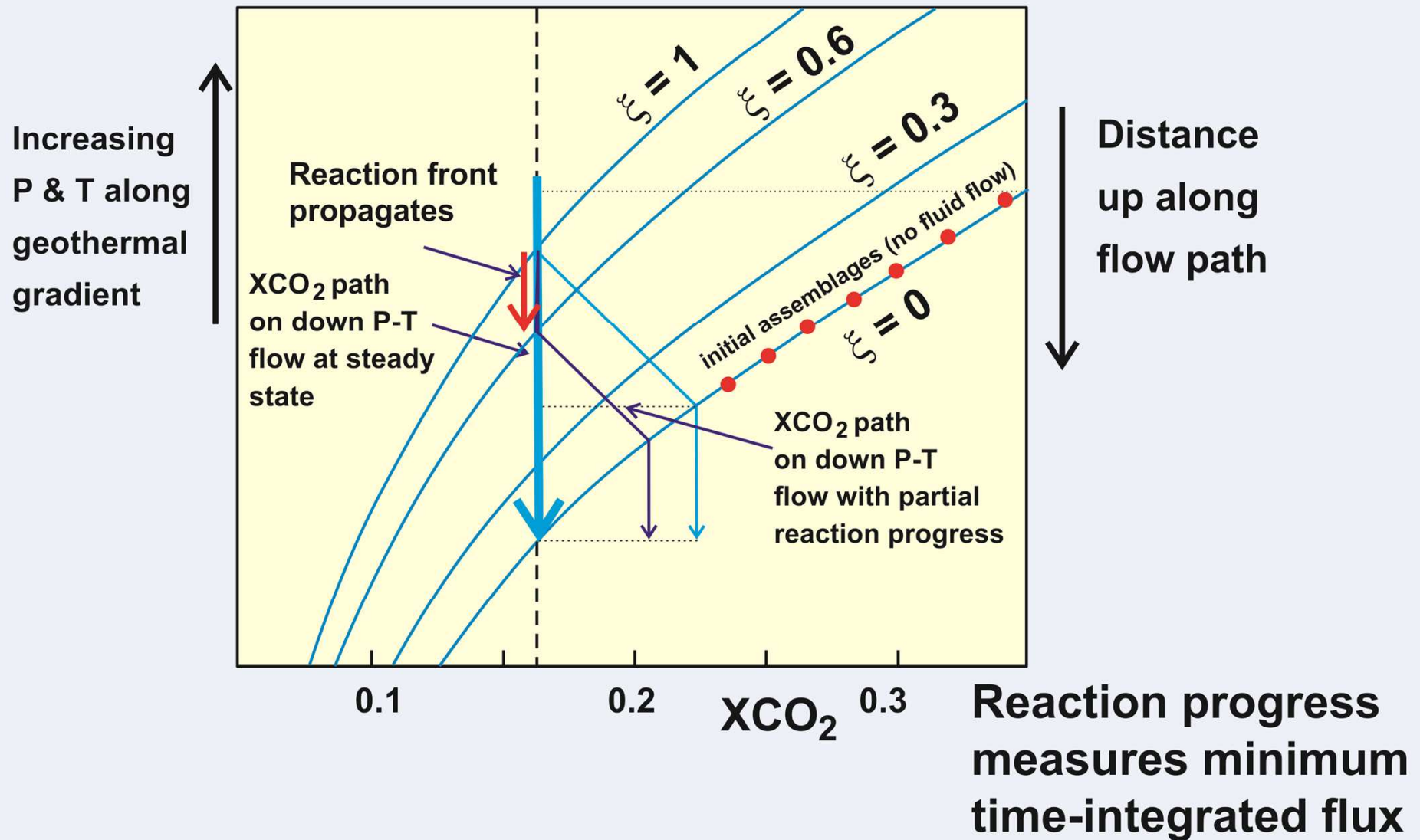
Global metamorphic CO$_2$

fluxes are unknown.