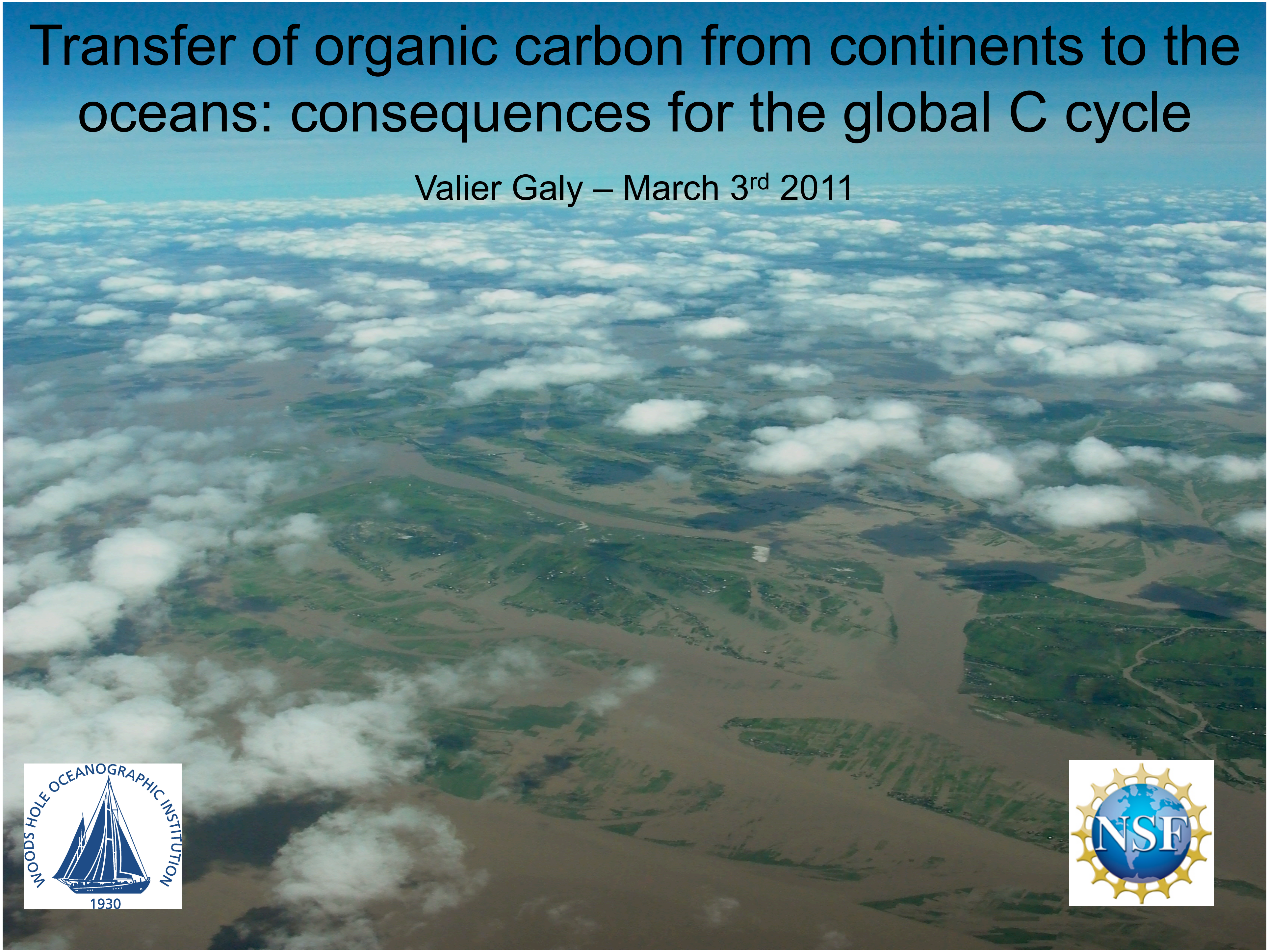
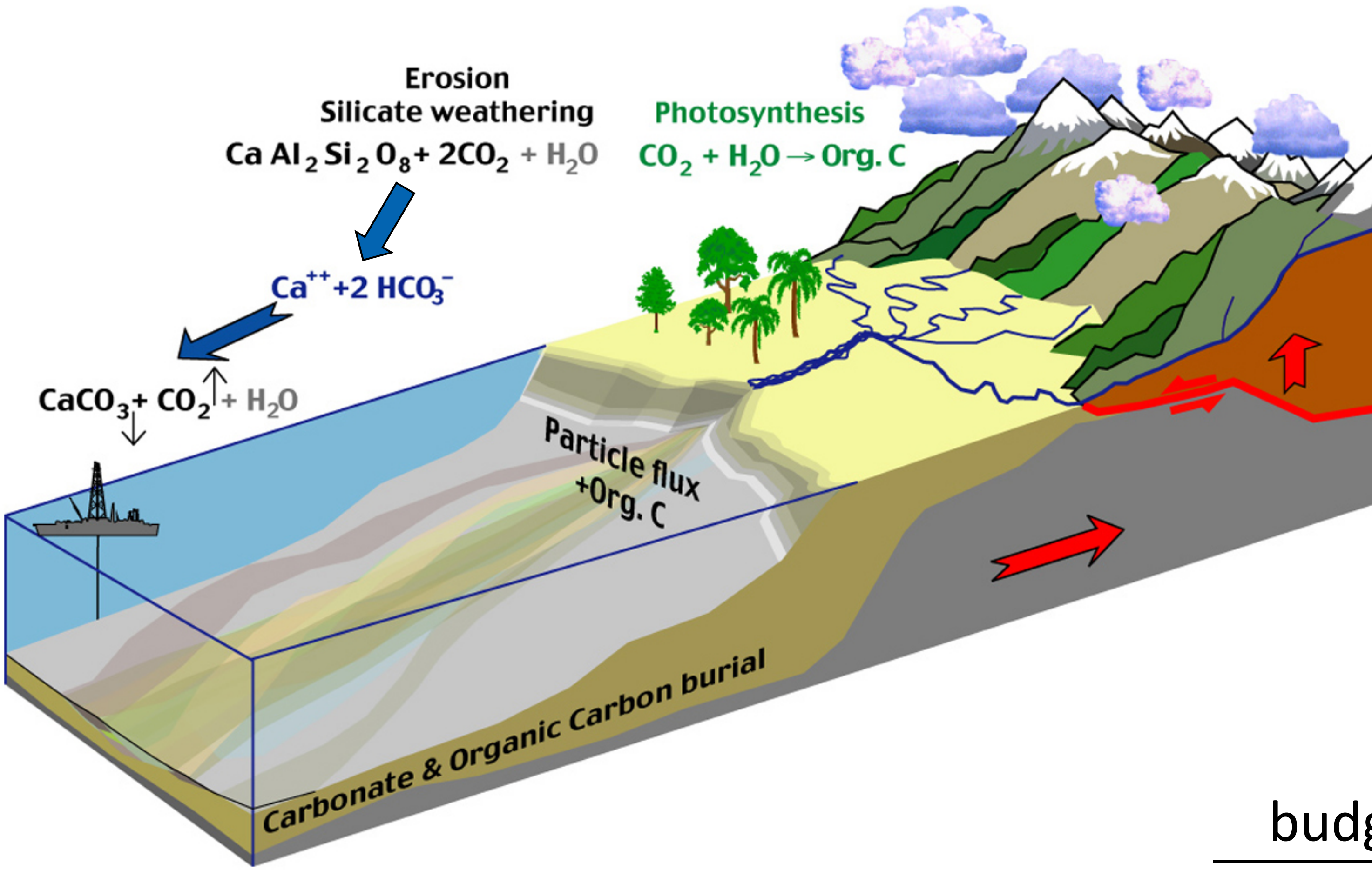
Transfer of organic carbon from continents to the oceans: consequences for the global C cycle

Valier Galy – March 3rd 2011

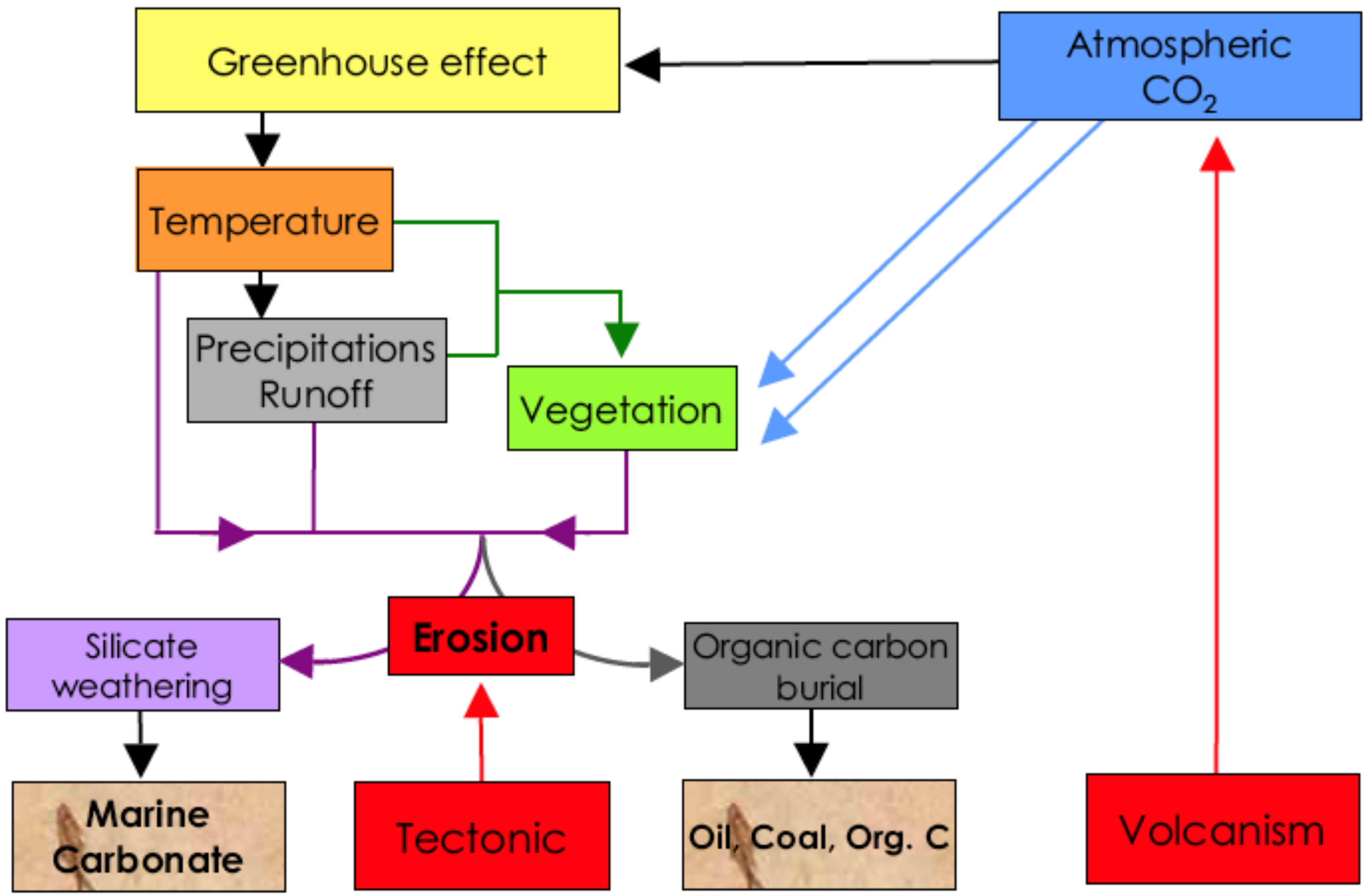


The long term C cycle: a natural climate regulation

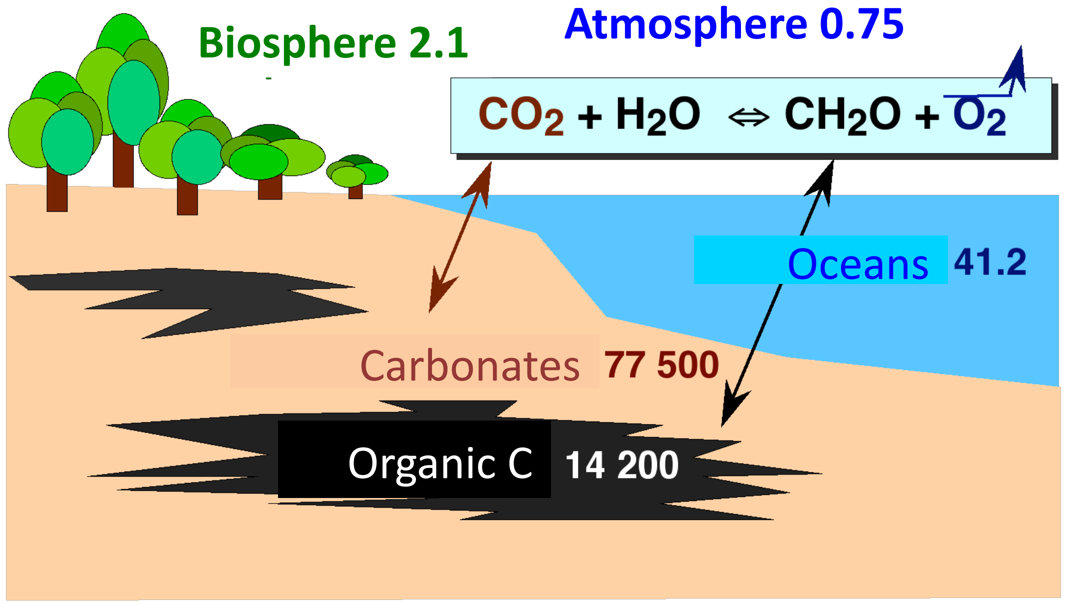


		budget
C_{inorg}	volcanism and metamorphism	CO_2 ↑
	silicate weathering + carbonate precipitation	CO_2 ↓
C_{org}	photosynthesis + organic carbon burial	CO_2 ↓ O_2 ↑
	oxidation of sedimentary organic carbon	CO_2 ↑ O_2 ↓

Global climate regultion: Walker's hypothesis (1981)



Where is C being currently stored?

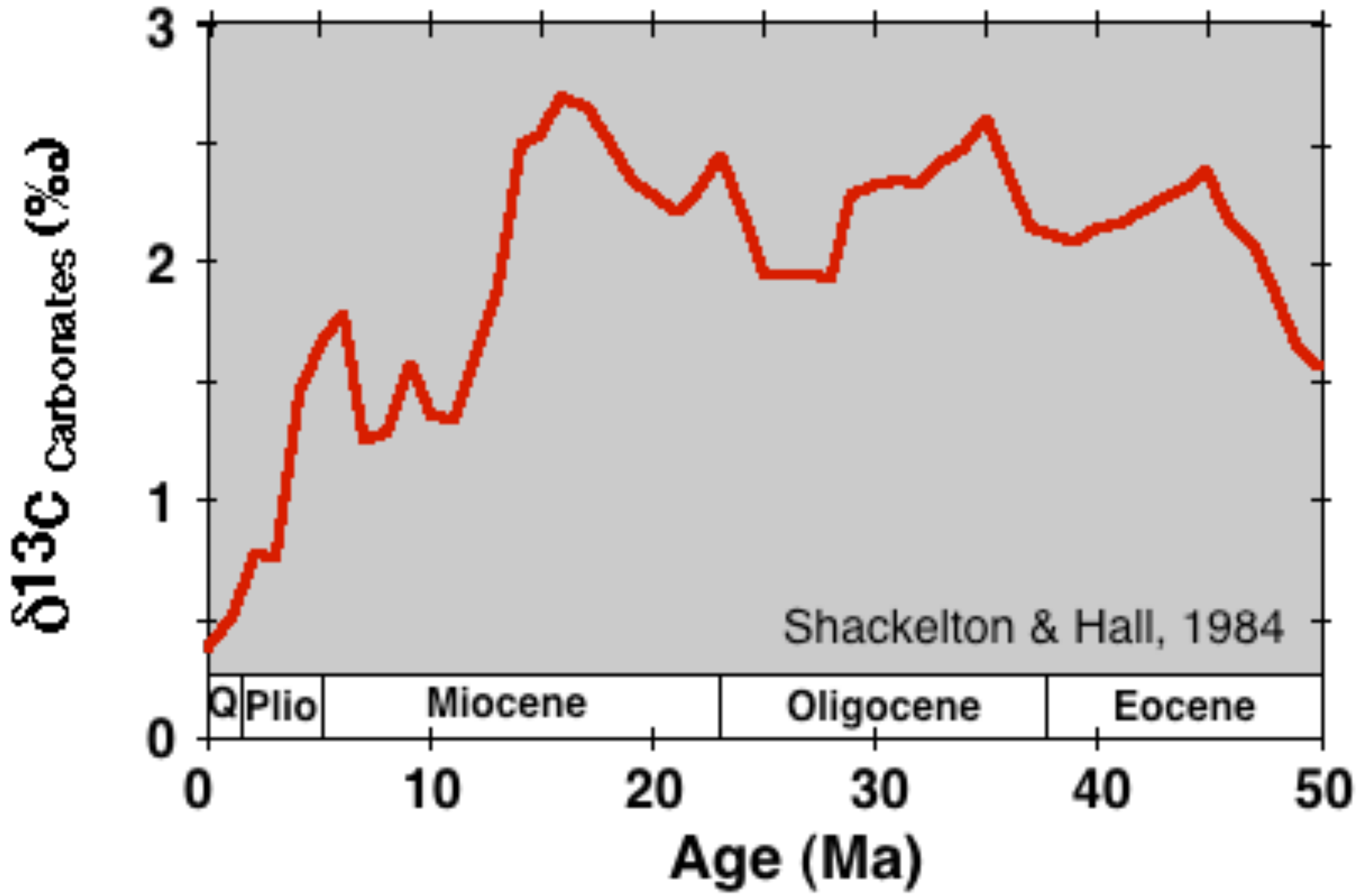


Main reservoirs of C (10^{12} tons)

Large crustal long term reservoir

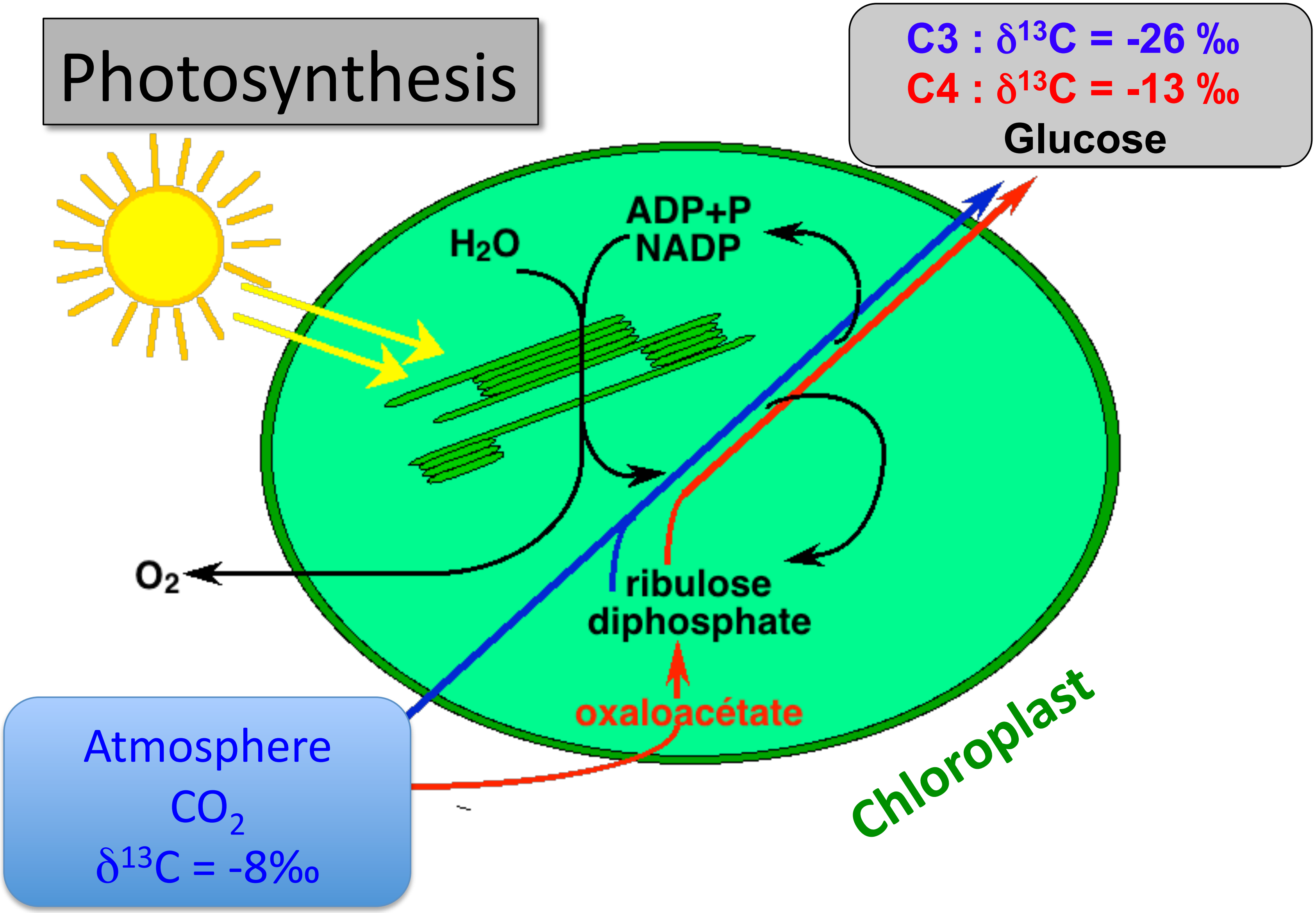
Small short term atmosphere-biosphere-hydrosphere reservoir

The long-term record of carbon burial



Long term variations of the isotopic composition of marine carbonates: what does it mean?

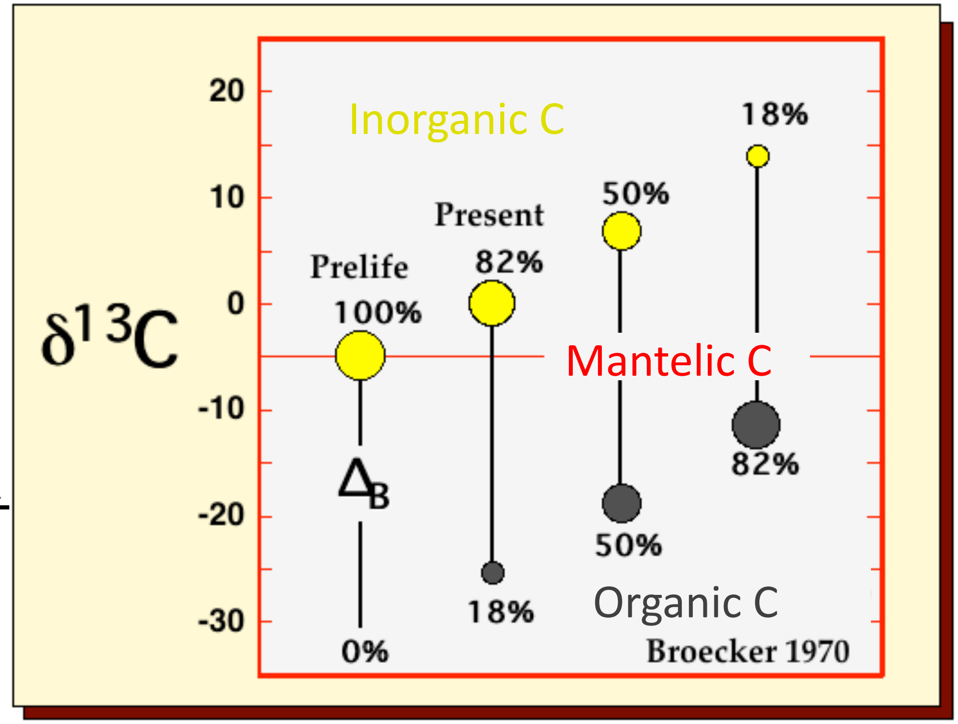
Photosynthetic isotopic fractionation



Mass balance calculations

$$\frac{dM_{org}}{dt} = J_{bur} X_{org}^{bur} - J_{er} X_{org}^{er}$$

$$\frac{dM_{org}}{dt} = J_{er} \cdot \left(X_{org}^{bur} - X_{org}^{er} \right) \cong \frac{dO_2}{dt} \cong -\frac{dCO_2}{dt}$$

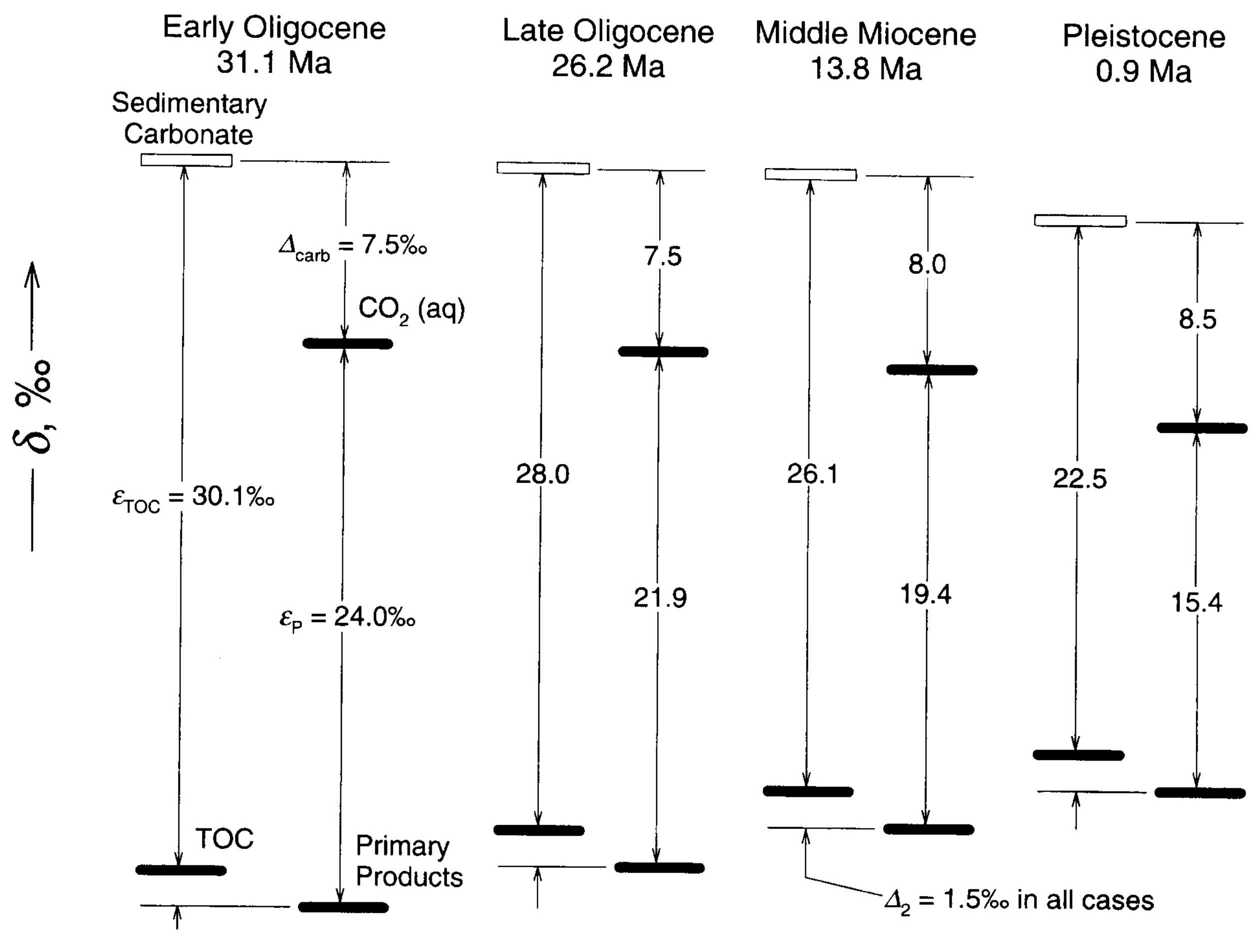


$$X_{org} = \frac{\delta_{carb} - \delta_{ave}}{\Delta_B}$$

$$\Delta_B = \delta_{carb} - \delta_{TOC}$$

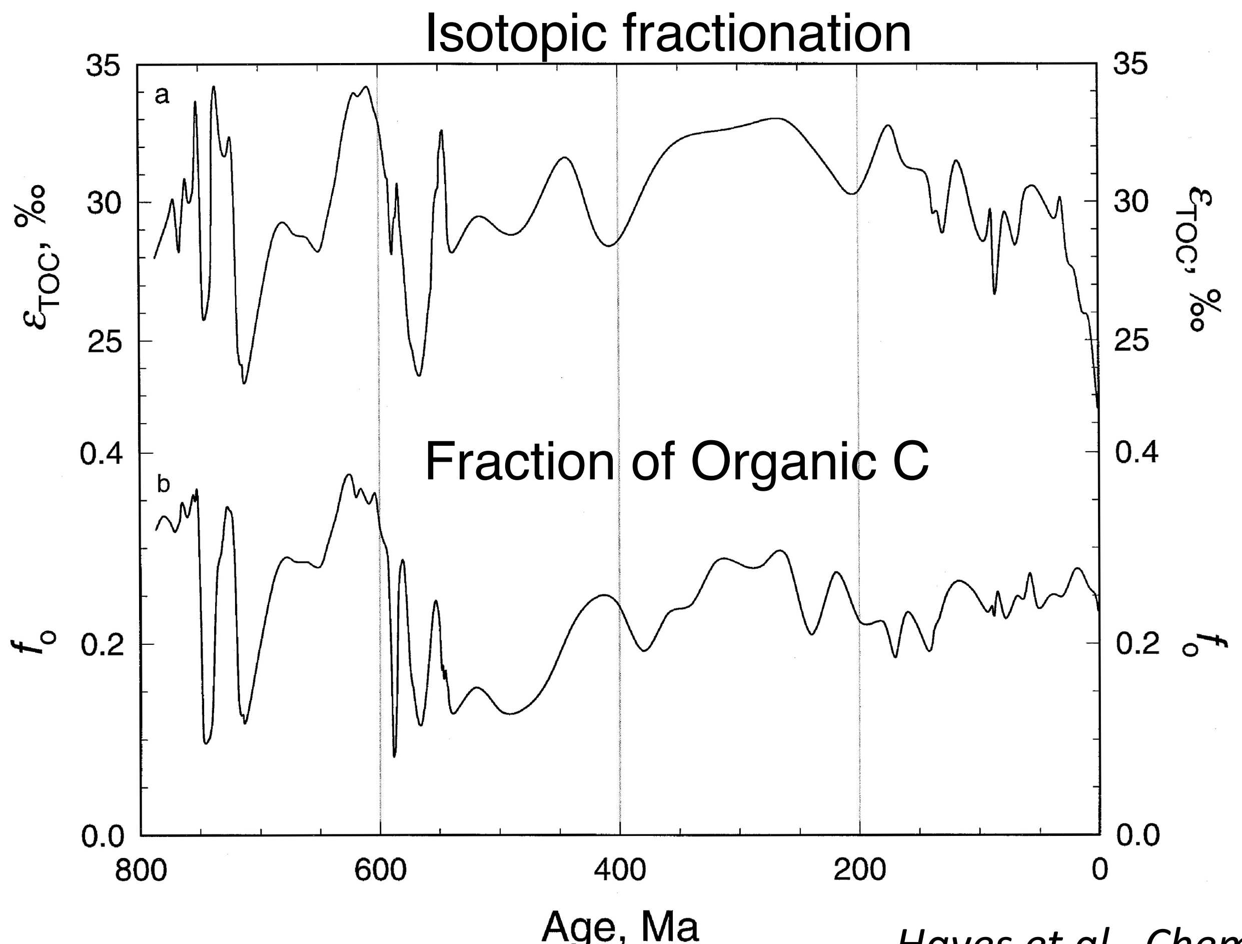
Derry and France-Lanord, Paleoceanogr.,1996

Isotopic fractionation between Inorganic and Organic C



Hayes et al., Chem. Geol., 1999

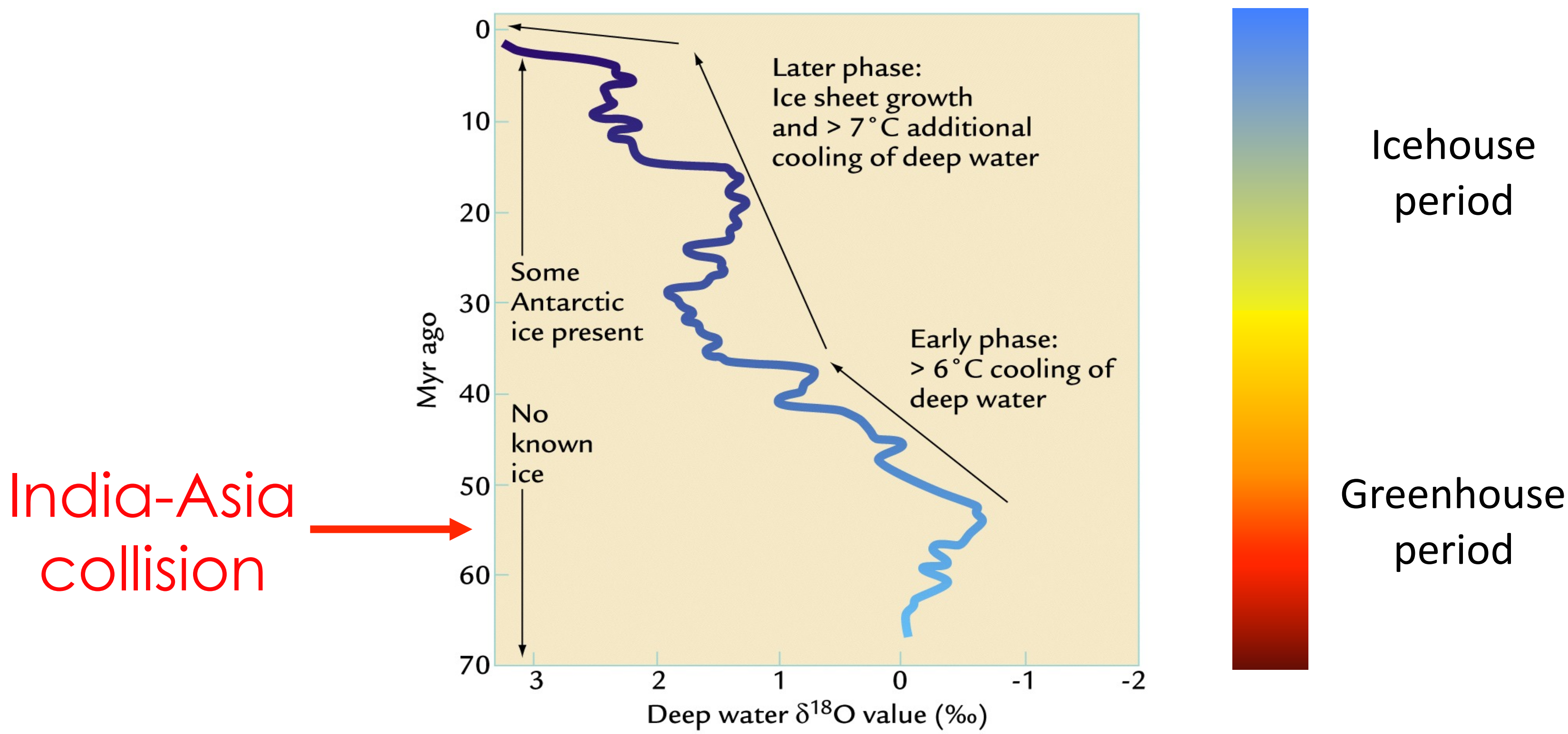
Balance between Inorganic and Organic C burial



Hayes et al., Chem. Geol., 1999

Phanerozoic: 10 to 40% of the total C is stored as organic C

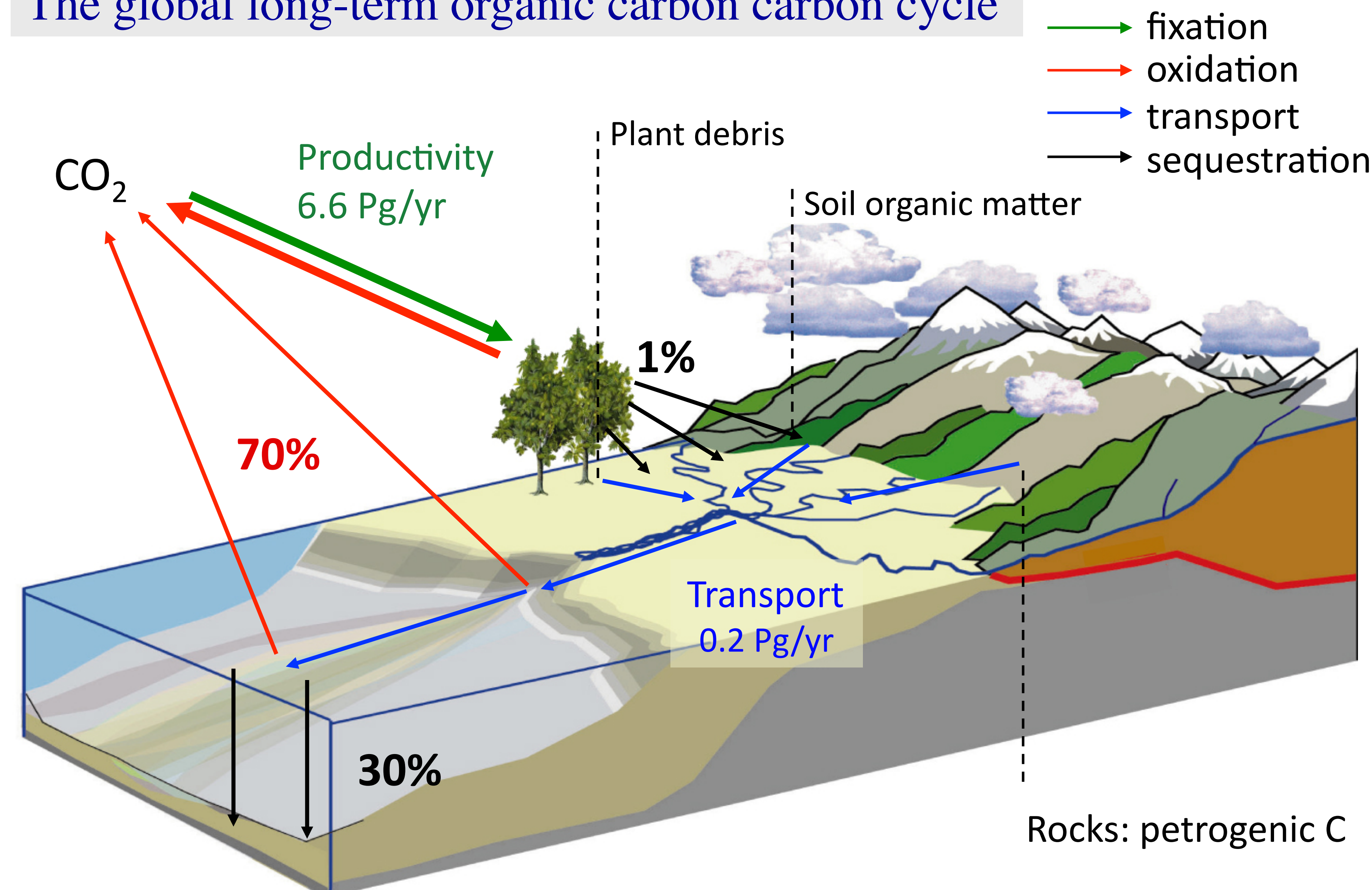
The chilling effect of mountain growth: the Himalayan example



Dramatic impact of Himalayan erosion on Cenozoïc climate ?

- Silicate weathering (e.g. Raymo, 1992) ✘
- C_{org} burial (e.g. France-Lanord et Derry, 1997) ?

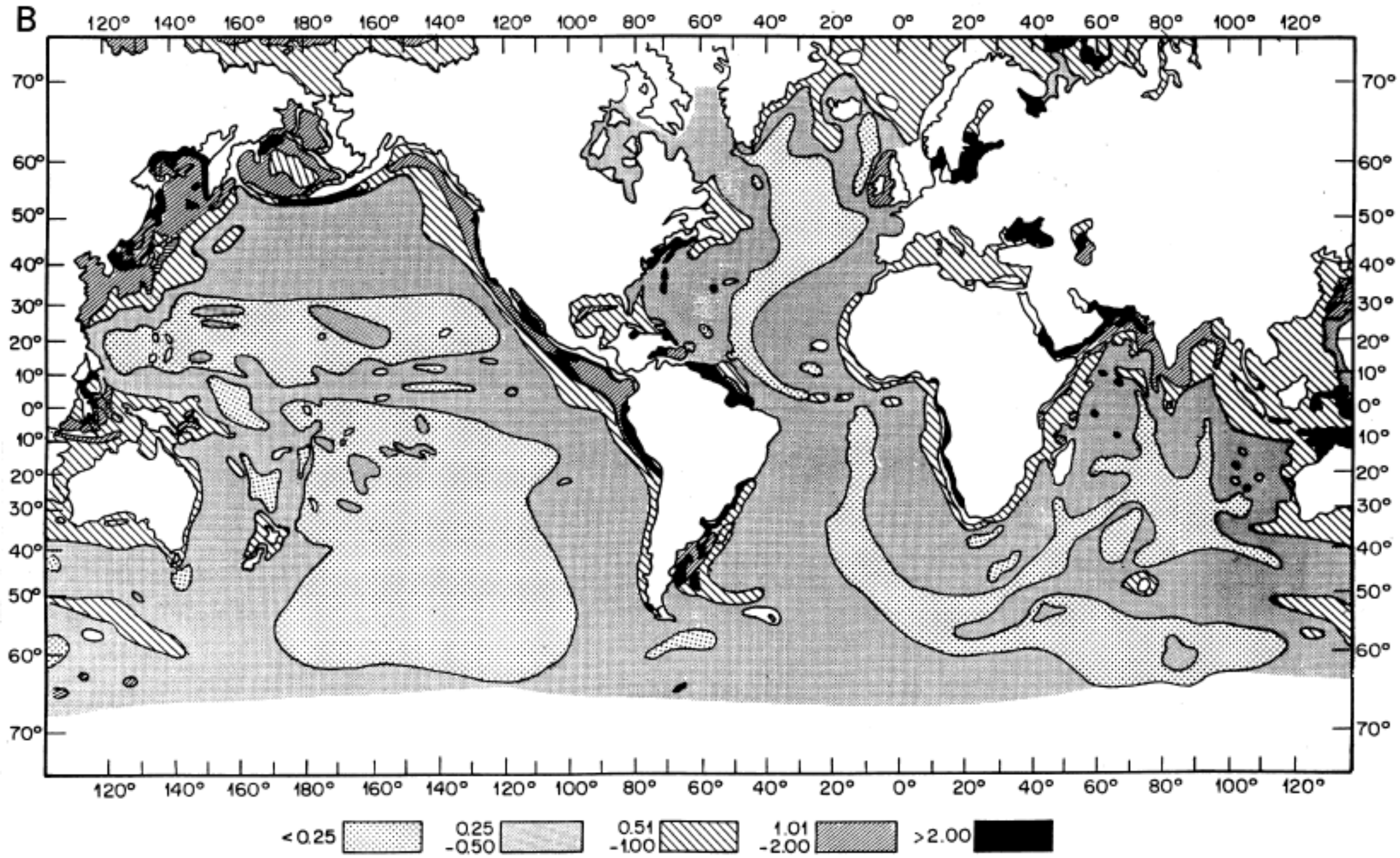
The global long-term organic carbon carbon cycle



Biospheric C burial = CO_2 sink

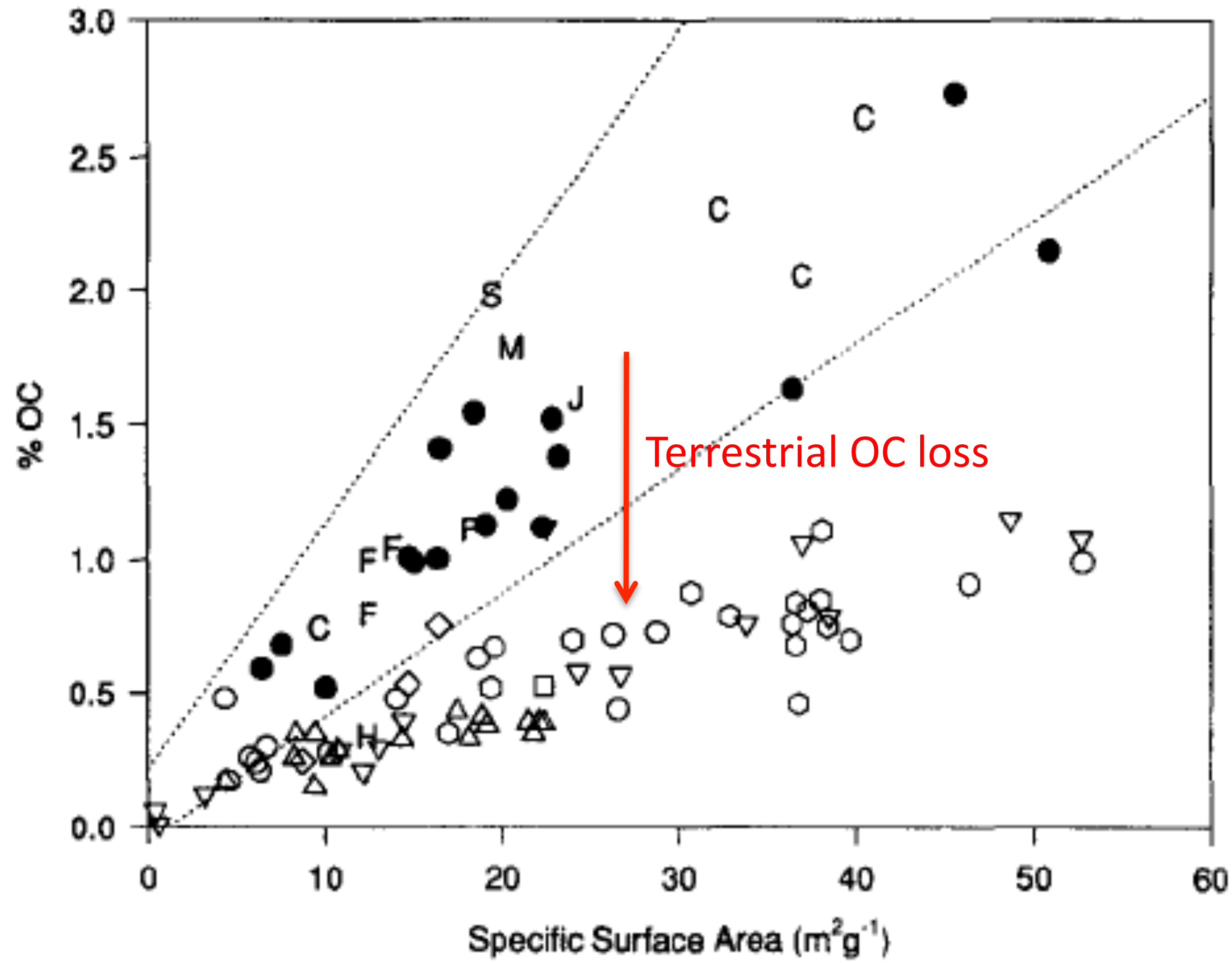
Petrogenic C oxidation = CO_2 source

Where is terrestrial OC buried?



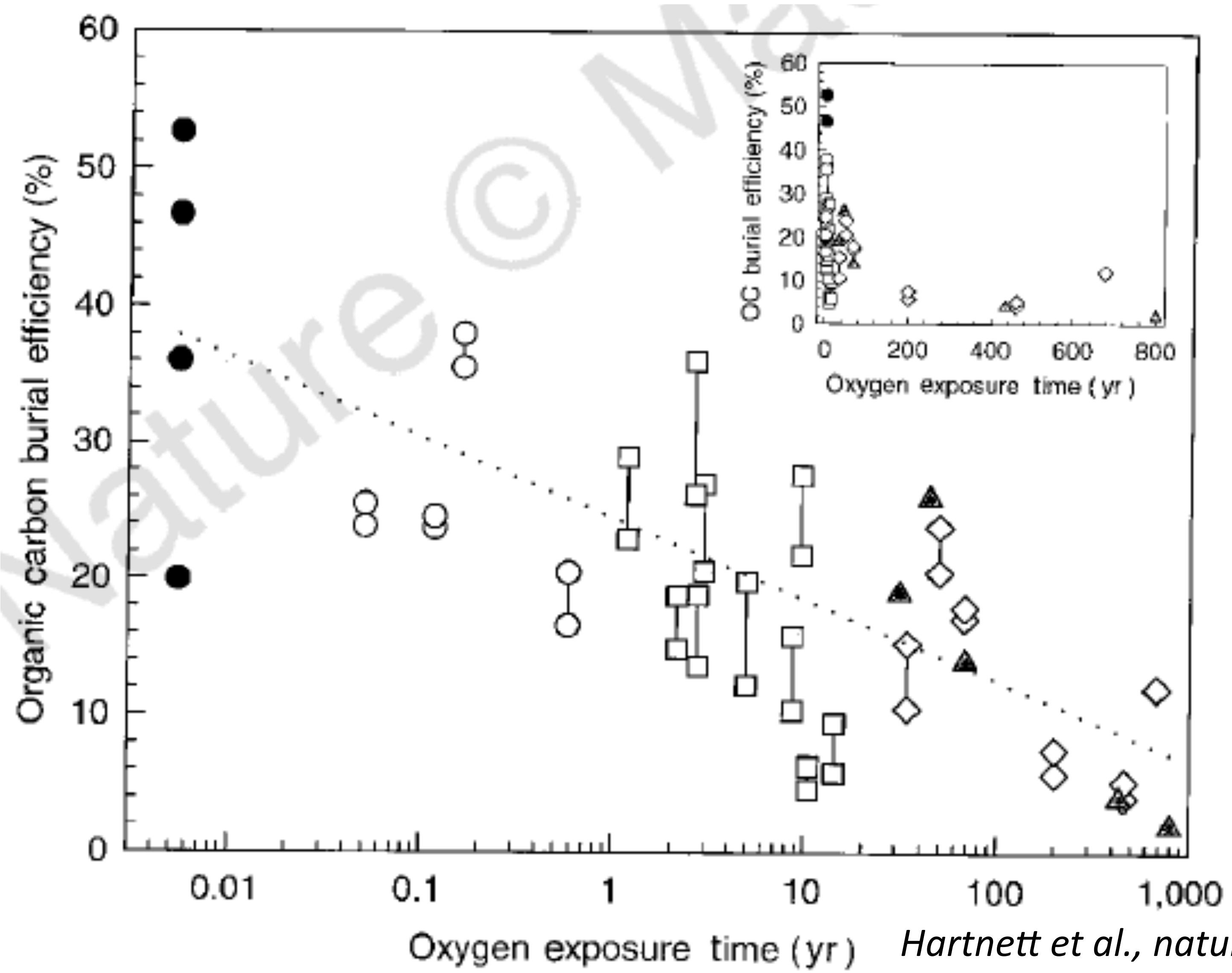
Hedges and Oades, 1997

What is the fate of terrestrial OC in the ocean?



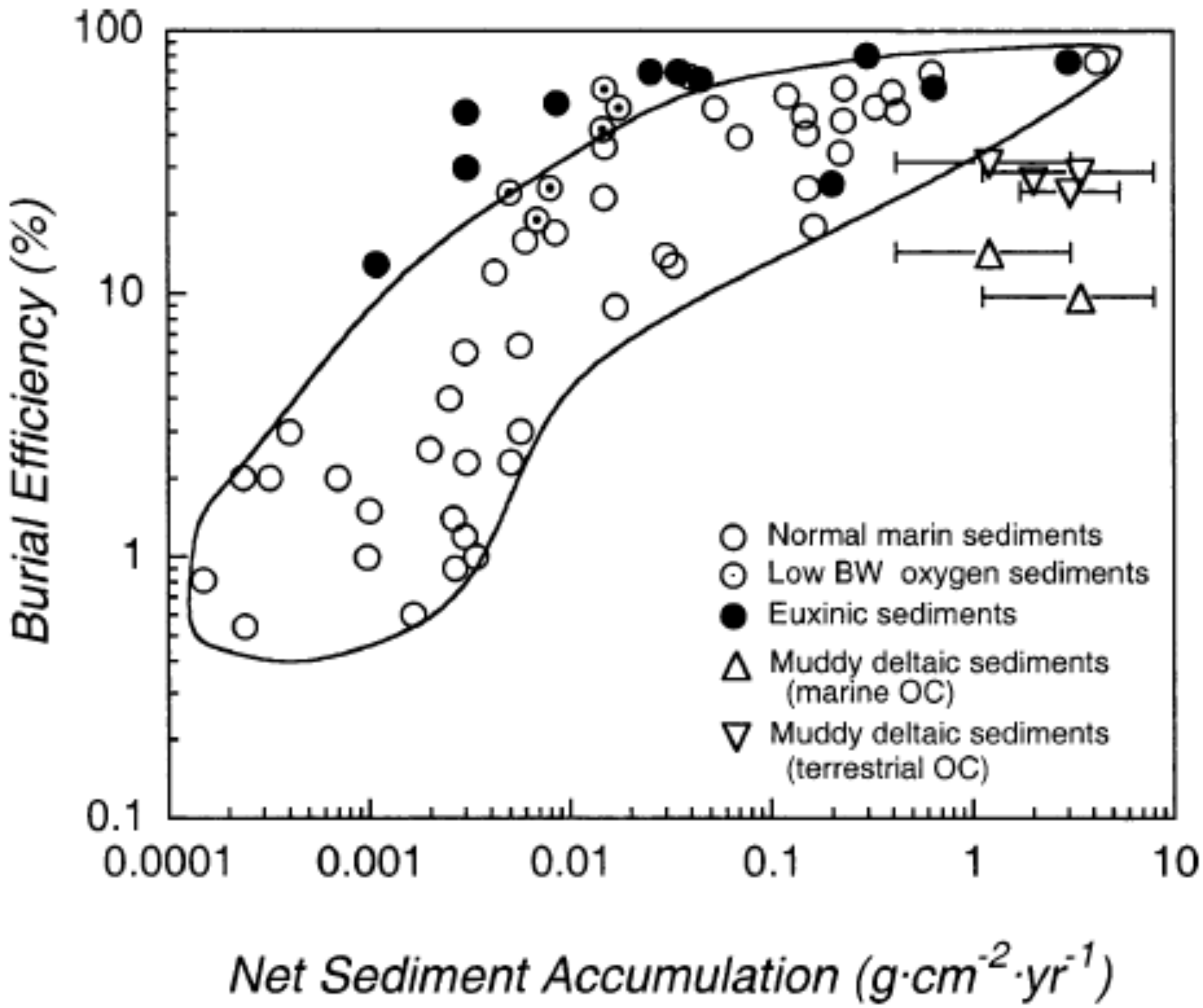
Keil et al., 1997

What controls burial efficiency?



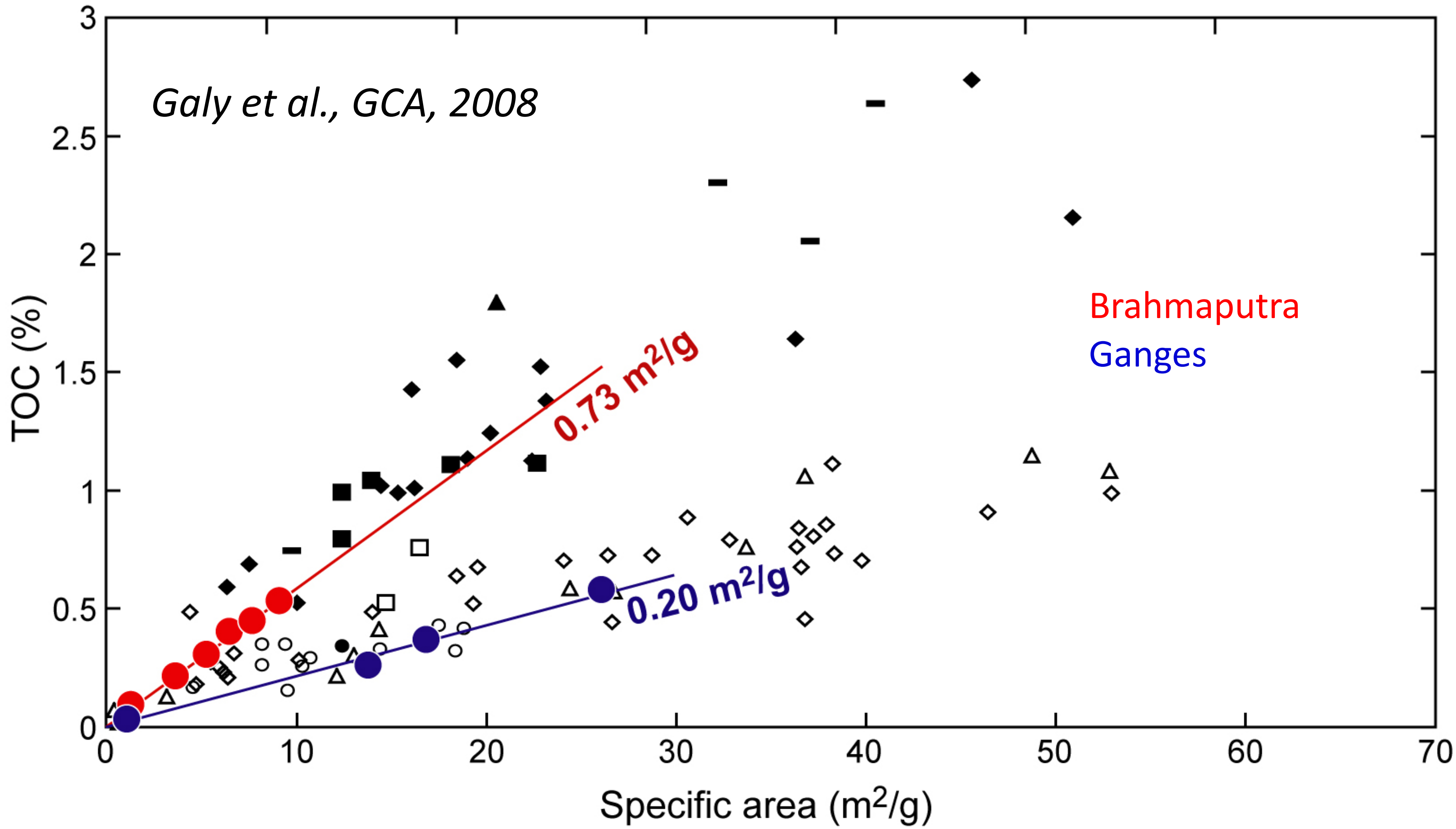
Hartnett et al., nature, 1998

The case of river dominated active margins



Burdige, 2007

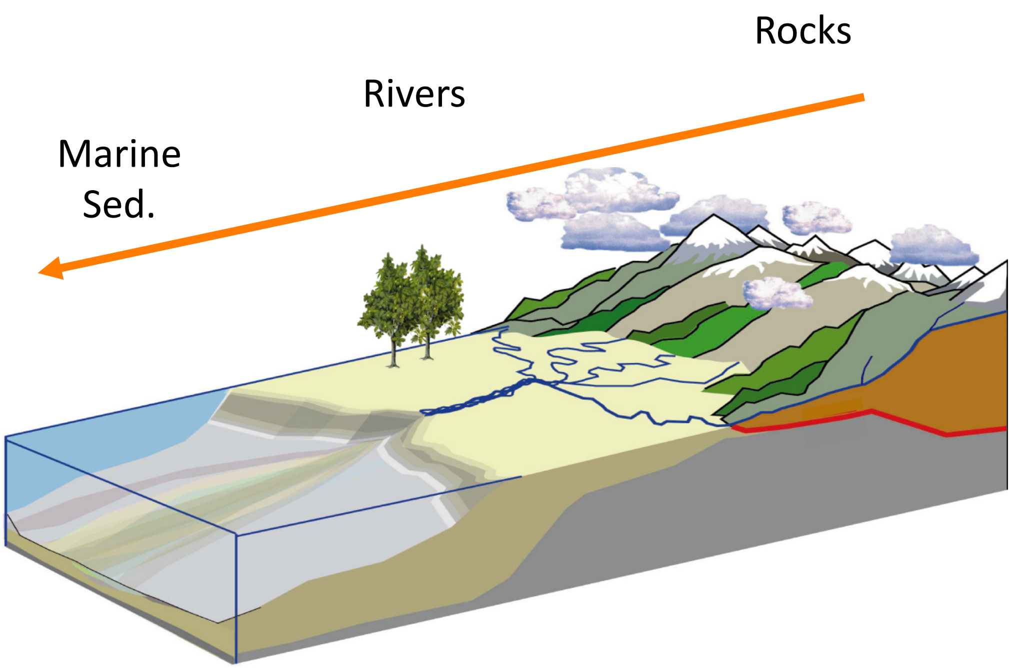
The specific area paradox



Similar TOC, grain size, Al/Si but highly distinct SA

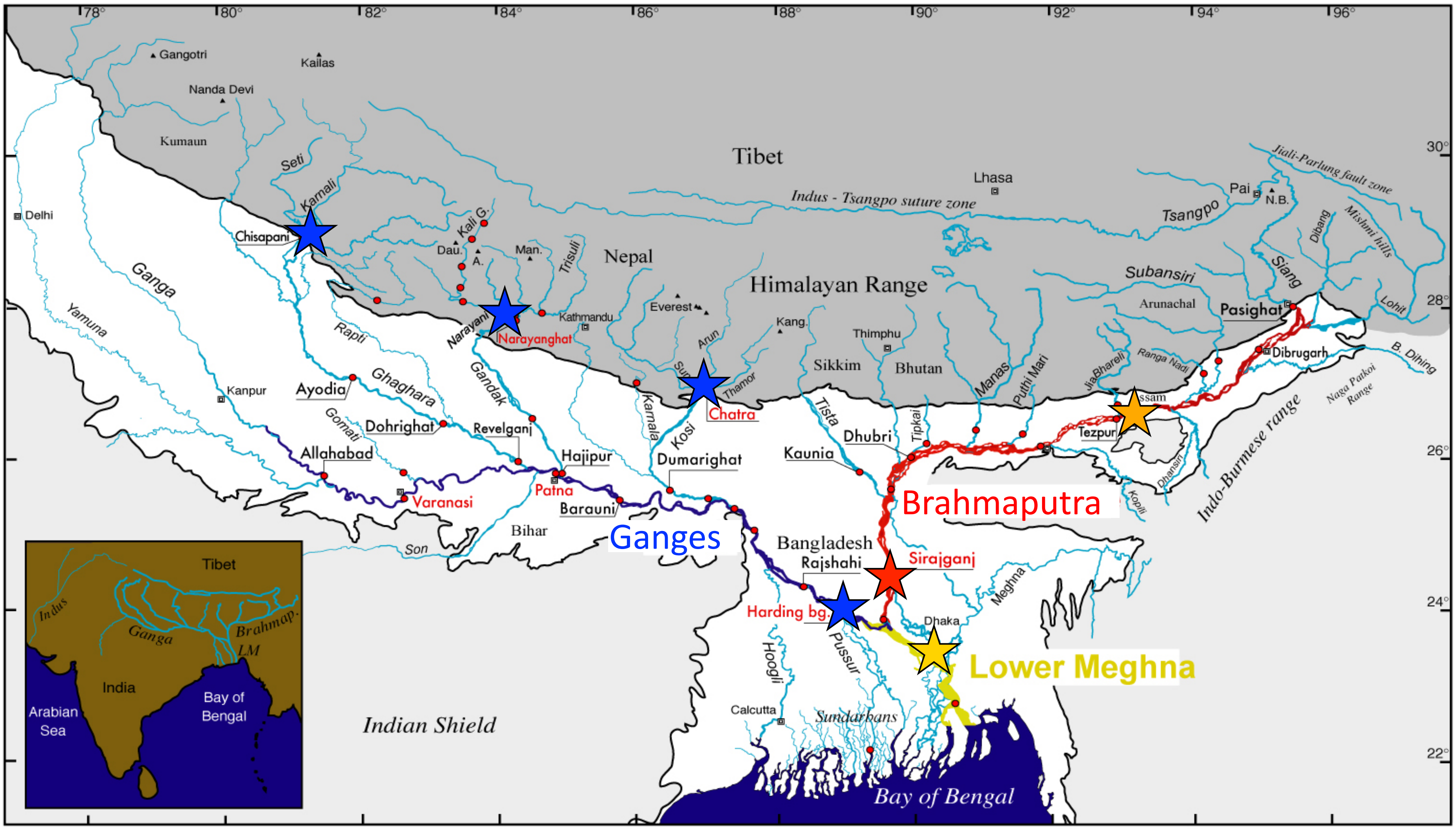
Specific area does not primarily control TOC

Basin scale source to sink approach

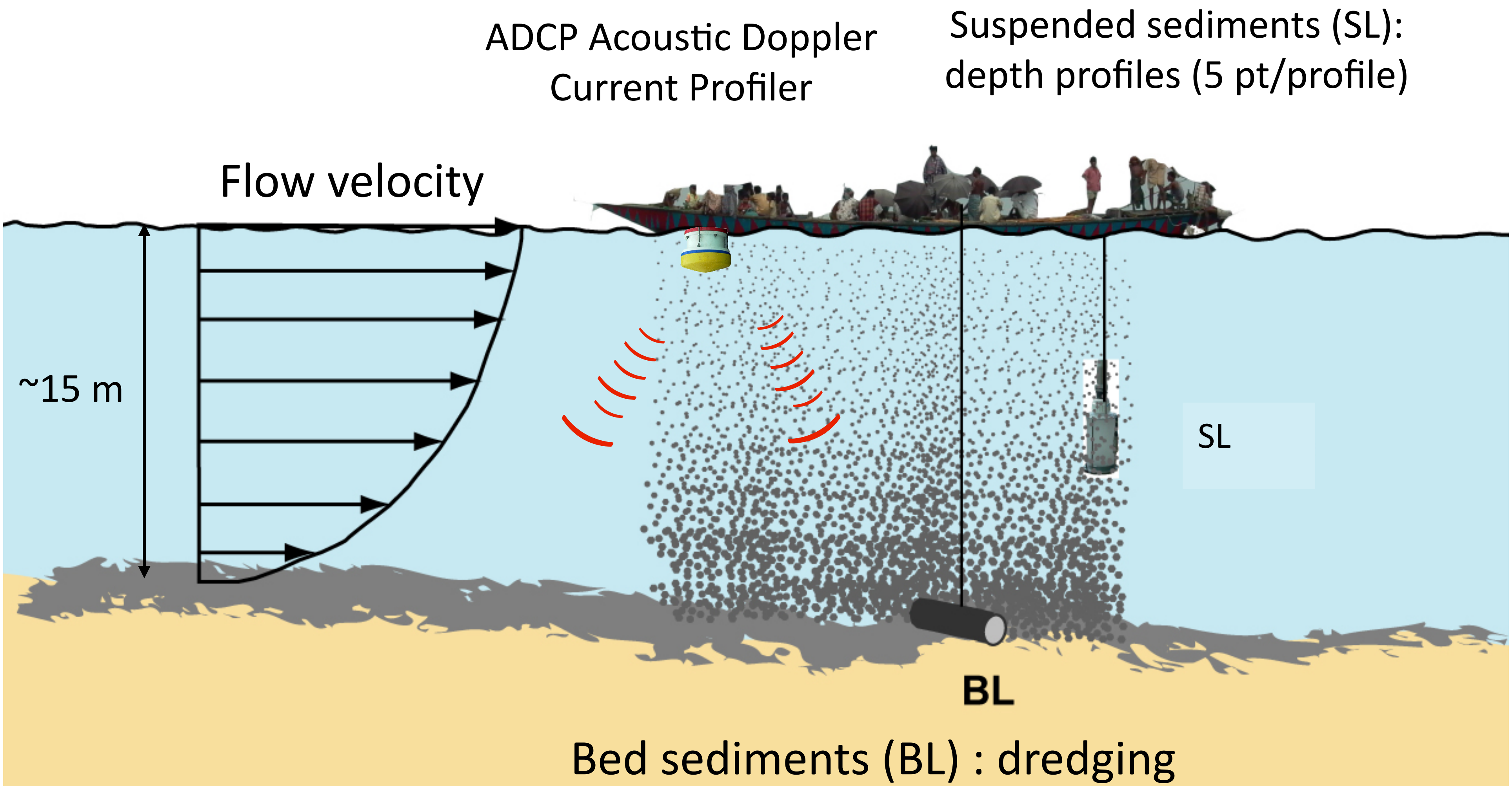


-Basin integrated studies
-Holistic approach
-Comparison modern rivers / marine sedimentary systems
-Conservative tracers

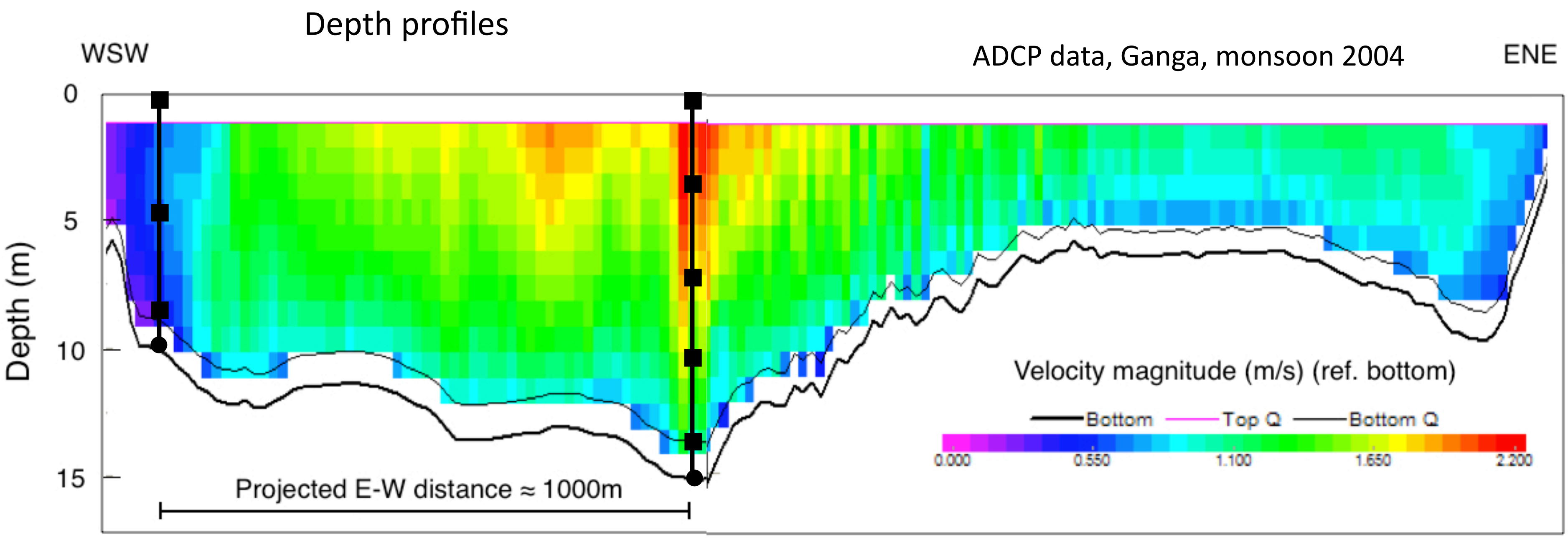
Case study: the Himalayan system



The depth sampling approach

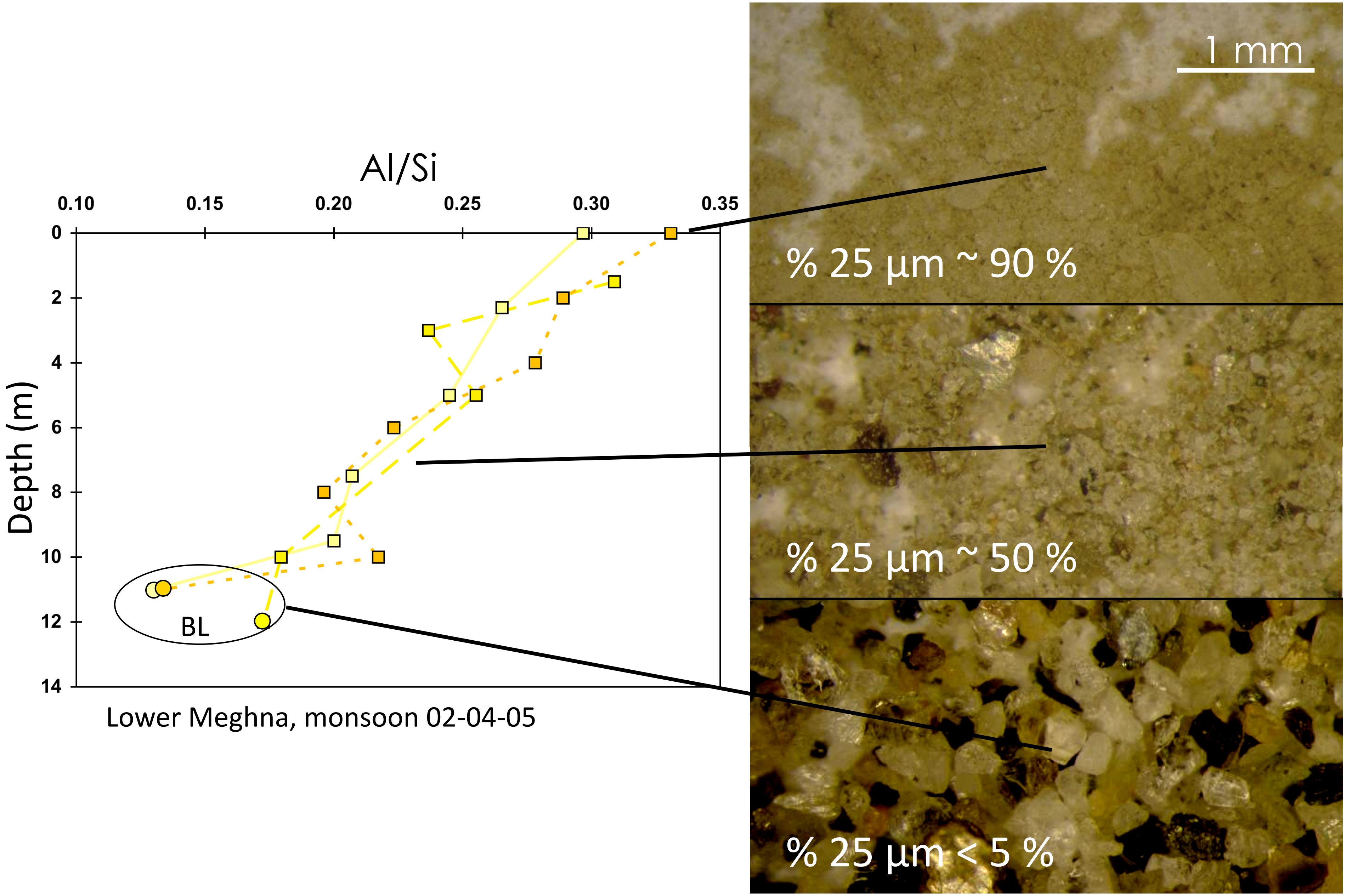


Flow velocity in the river section

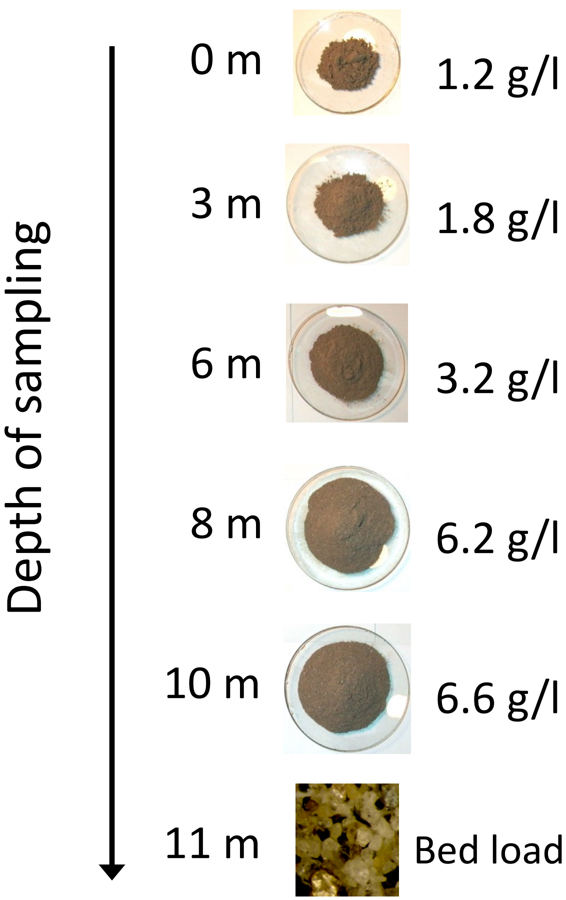


Strong velocity gradients from surface to depth and from centre to edges

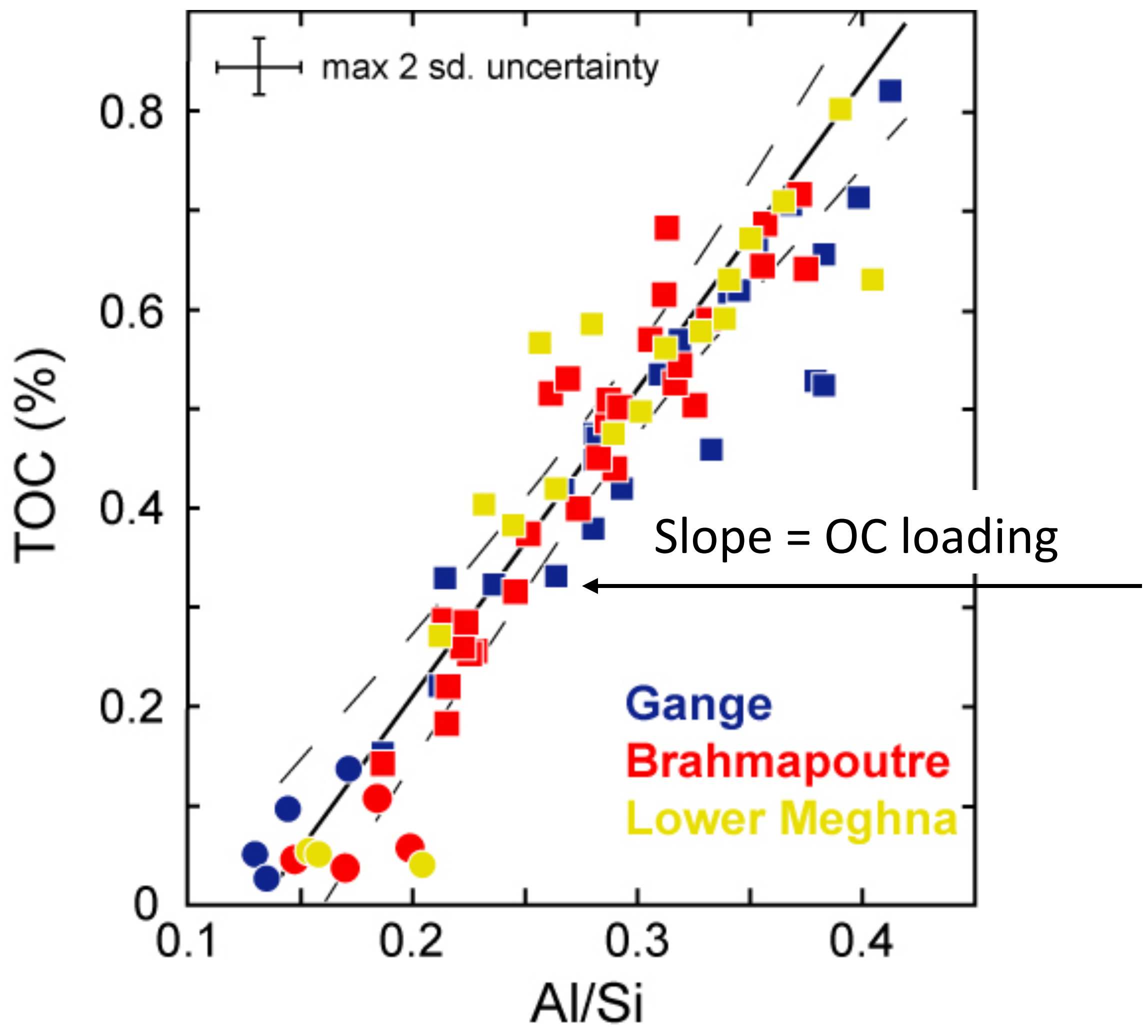
Sediment heterogeneity: chemical composition



Organic Carbon loading

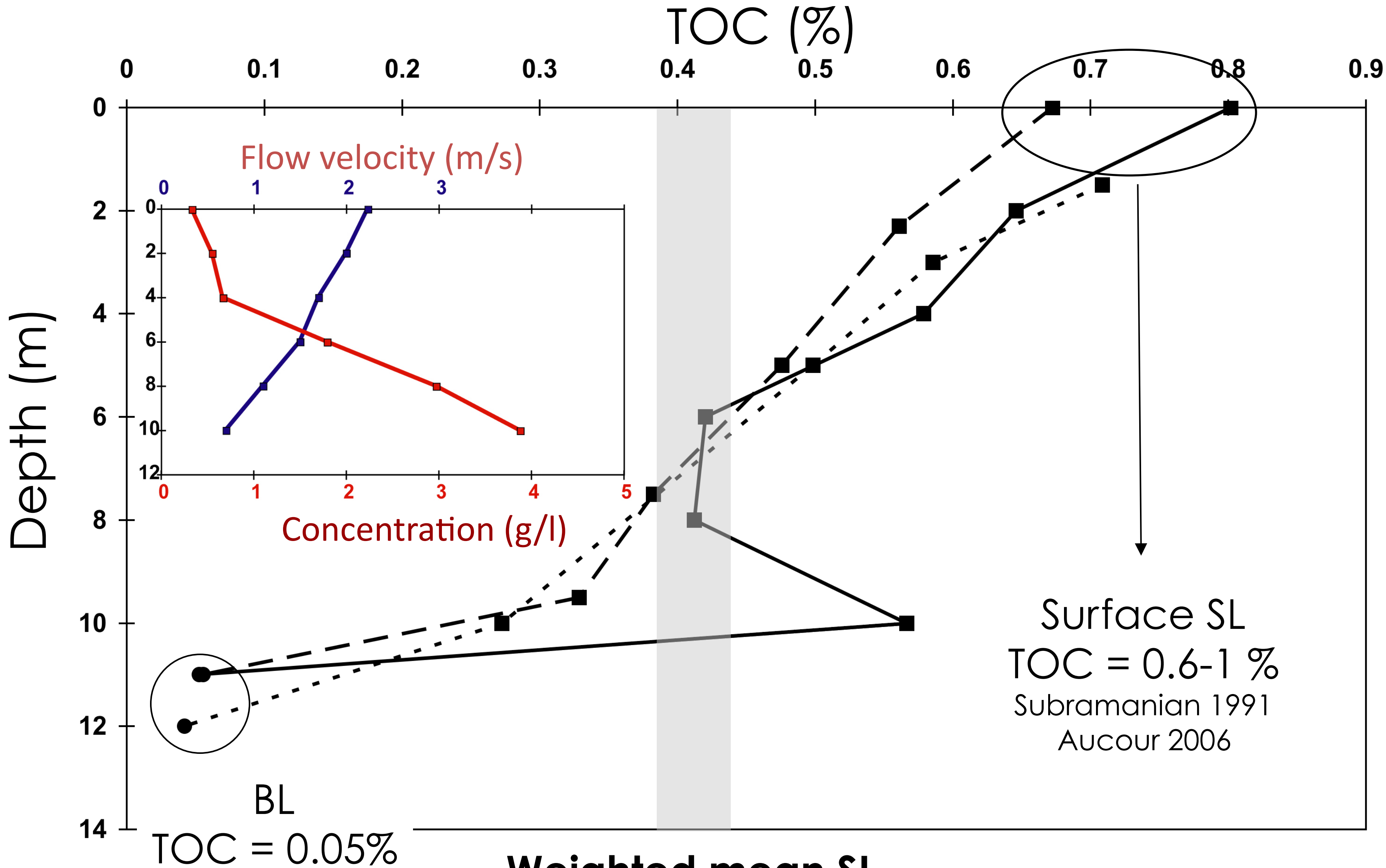


Galy et al., nature, 2007



OC content is controlled by sediment properties

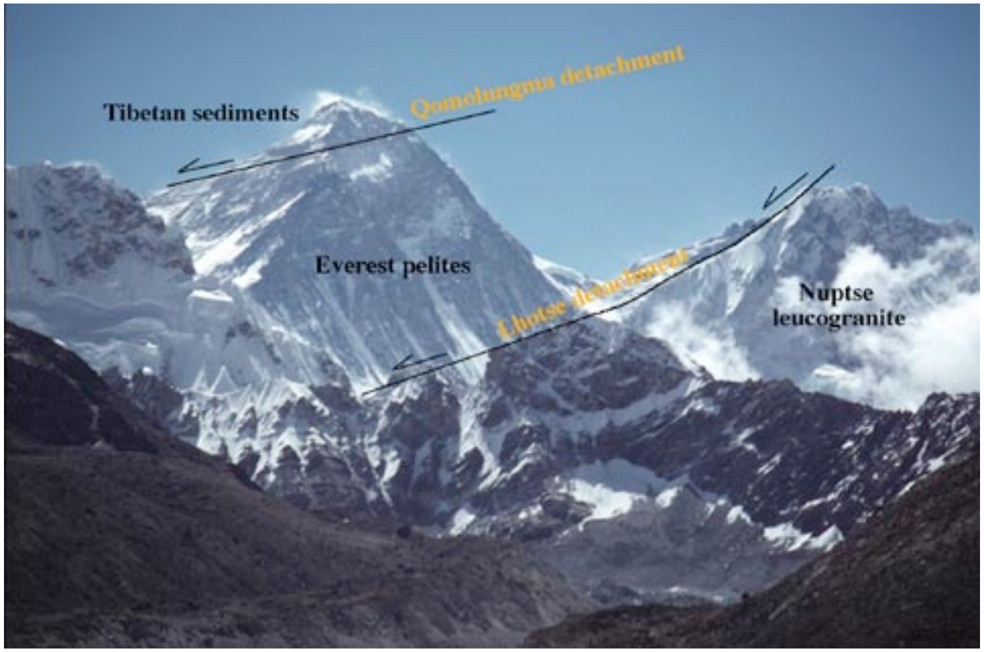
Total OC flux



Weighted mean SL
TOC = 0.42 %

flux of OC ~ **4 x 10^{11} mol/an**

Proportion of petrogenic C: source rocks content

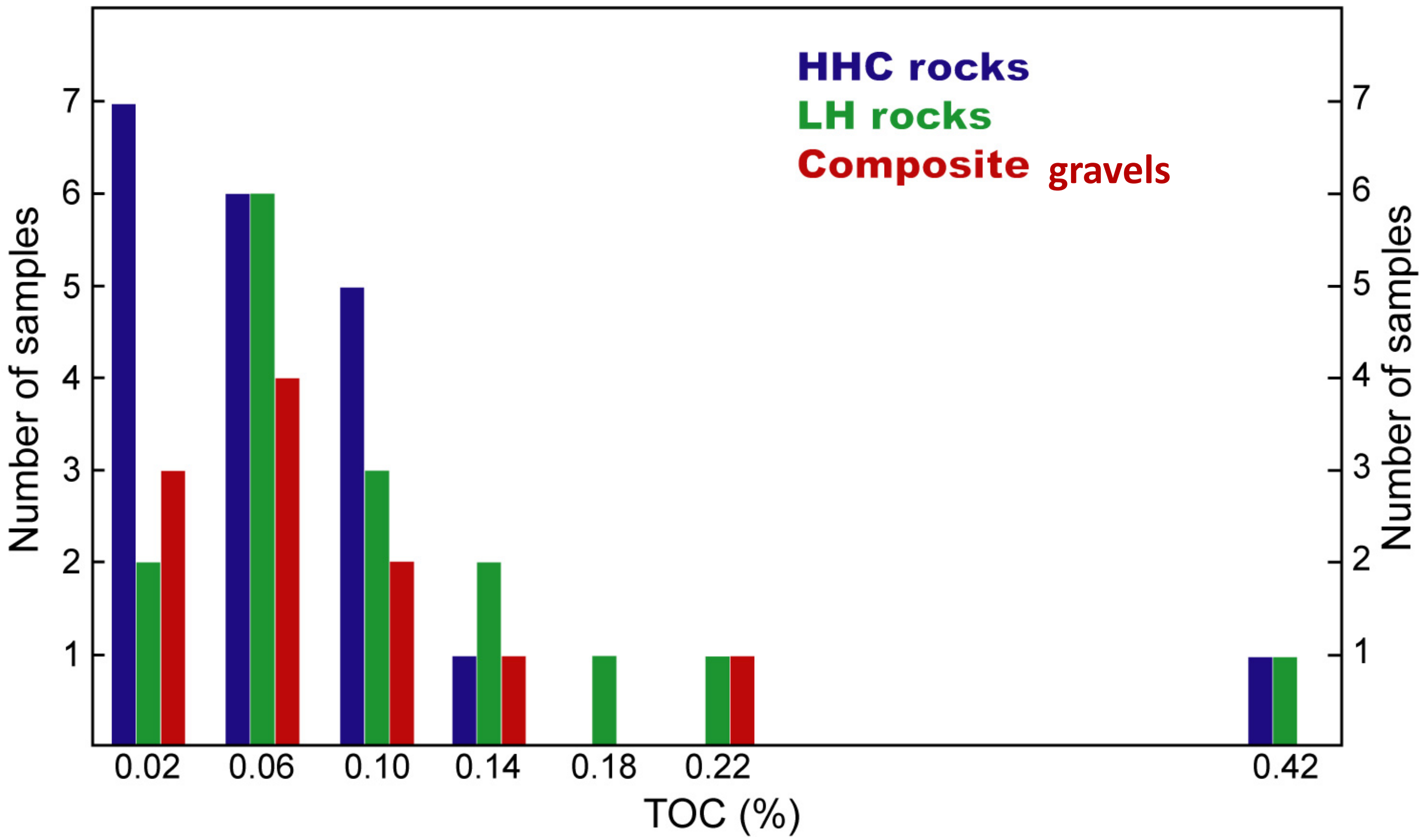


Individual rock samples from different lithologies

Gravels from the bottom of Himalayan rivers integrating a large number of lithologies

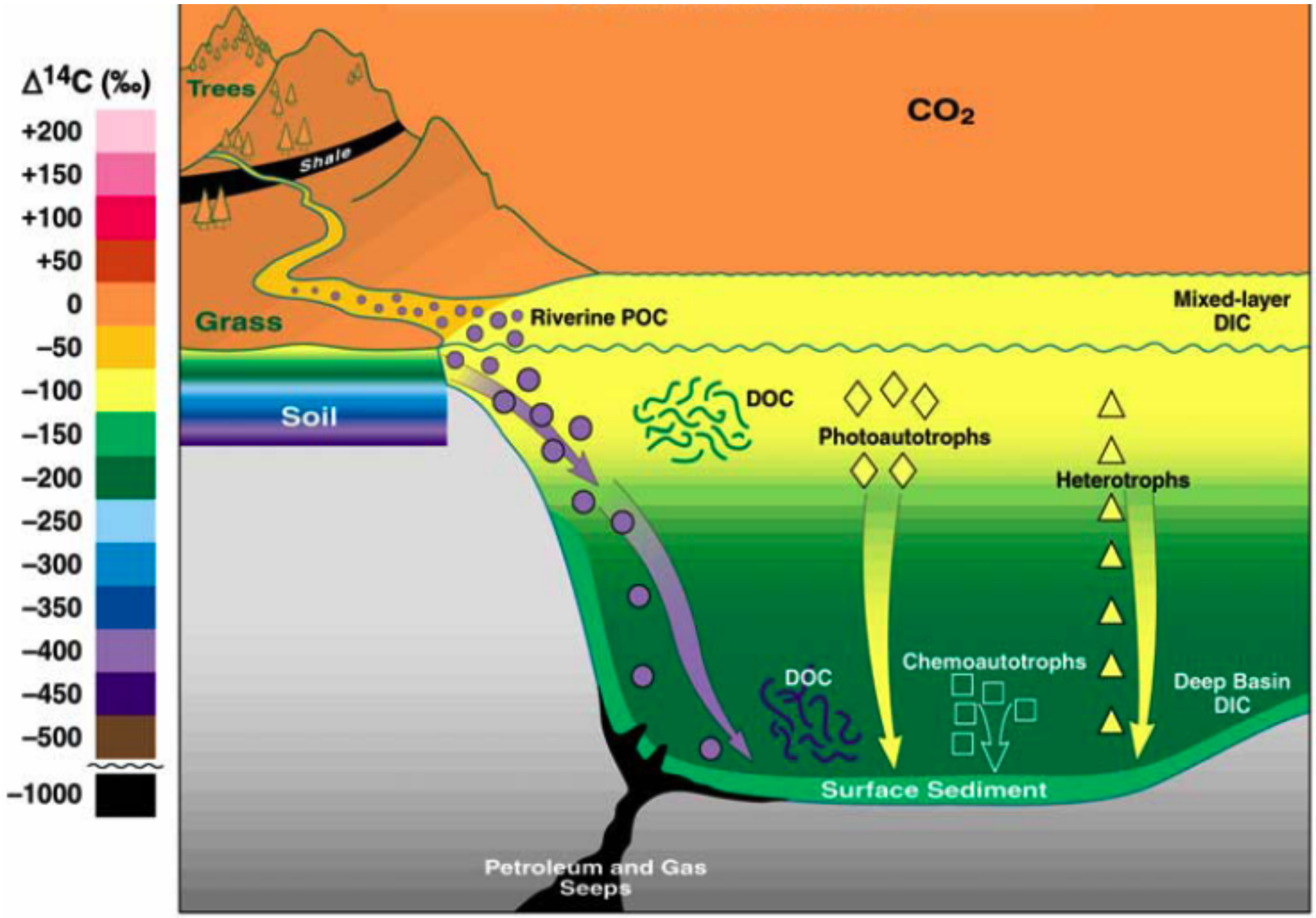
Proportion of petrogenic C: source rocks content

Galy et al., nature, 2007



Himalayan rocks: mean TOC between 0.05 and 0.08%

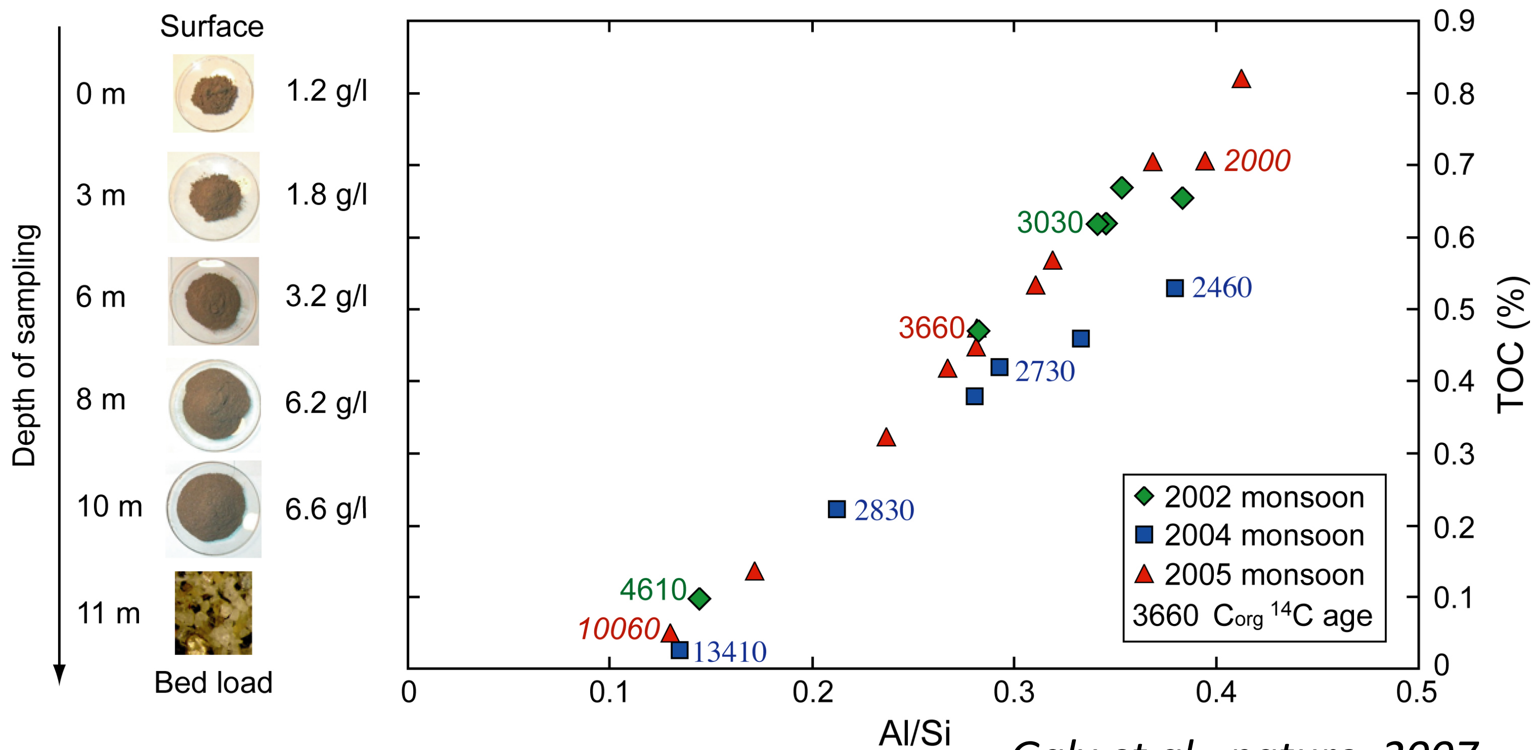
The ^{14}C jumble



Large contrast between petrogenic and biospheric C

Biospheric C is a mixture of young and old components

Quantification of petrogenic C: use of bulk ^{14}C data

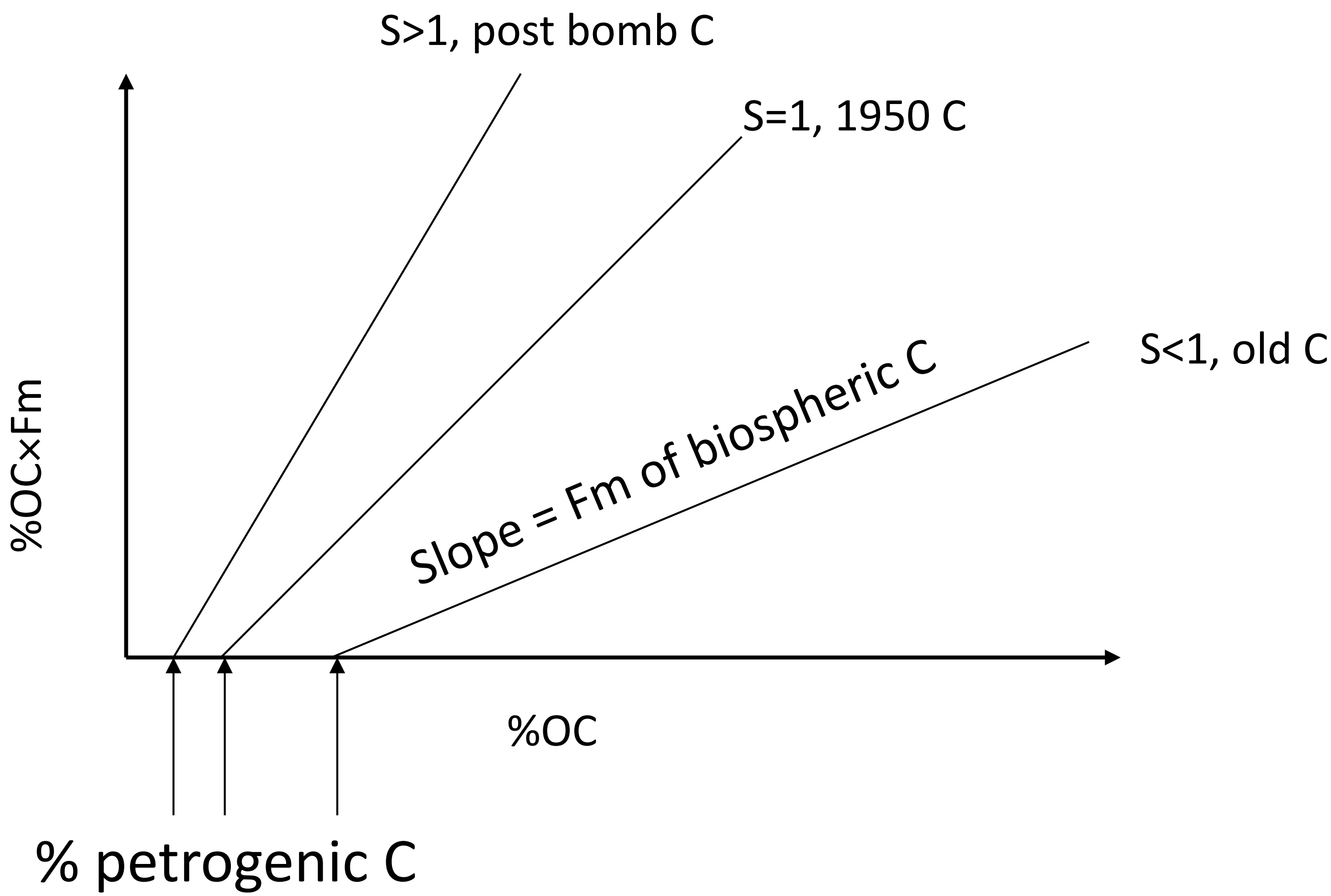


Galy et al., nature, 2007

➢ Binary mixing model:
petrogenic C (^{14}C dead) + biospheric C (contains some ^{14}C)

➢ Hypothesis:
(1) no soils older than de DL of the AMS
(2) all petrogenic C is ^{14}C dead

Quantification of petrogenic C: use of bulk ^{14}C data

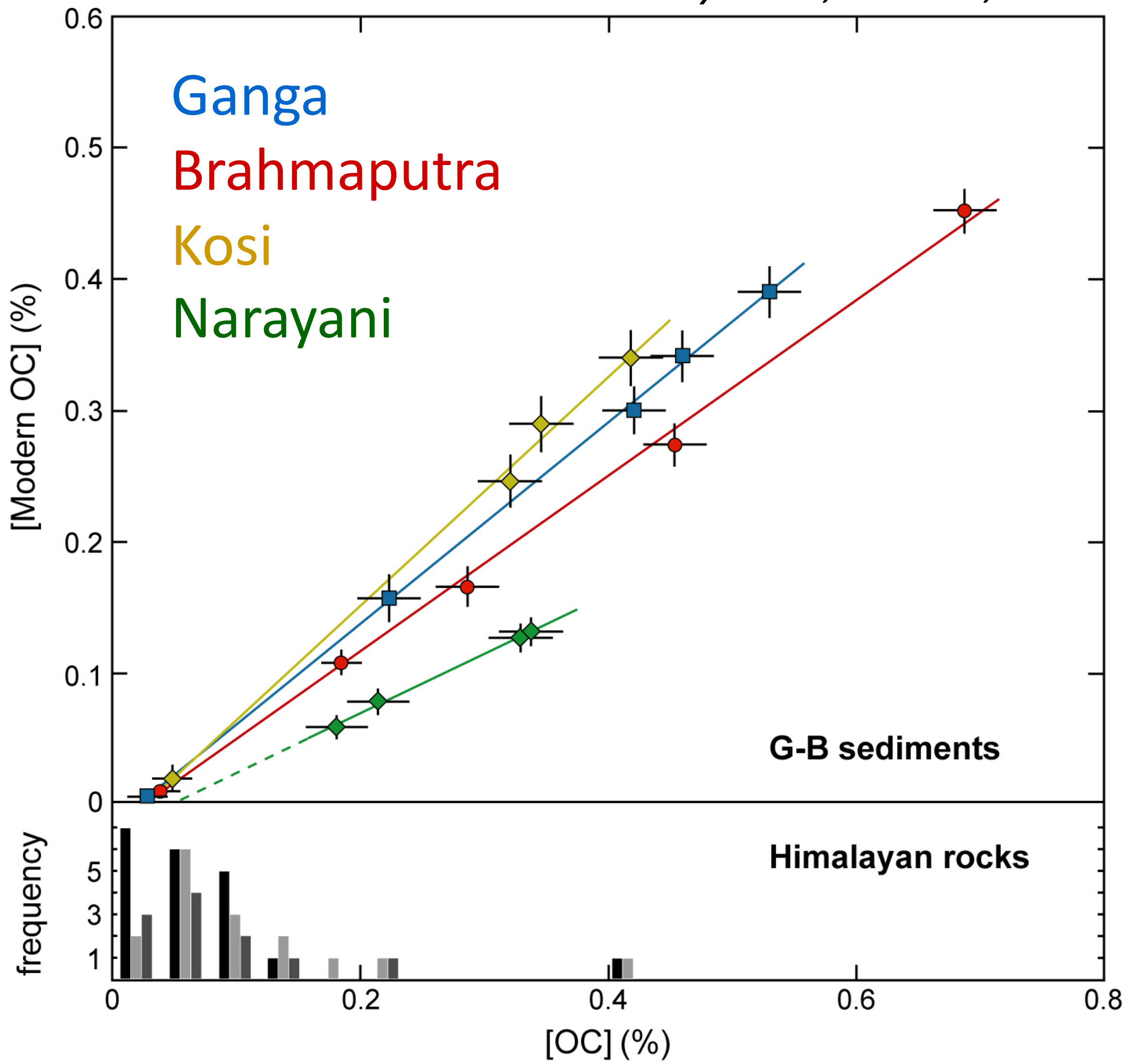


$$\%OC \times Fm = \%OC \times Fm_{biospheric\,C} - \%OC_{petro} \times Fm_{biospheric\,C}$$

Sediments with same amount of petrogenic C and same age of biospheric C plot on linear trends

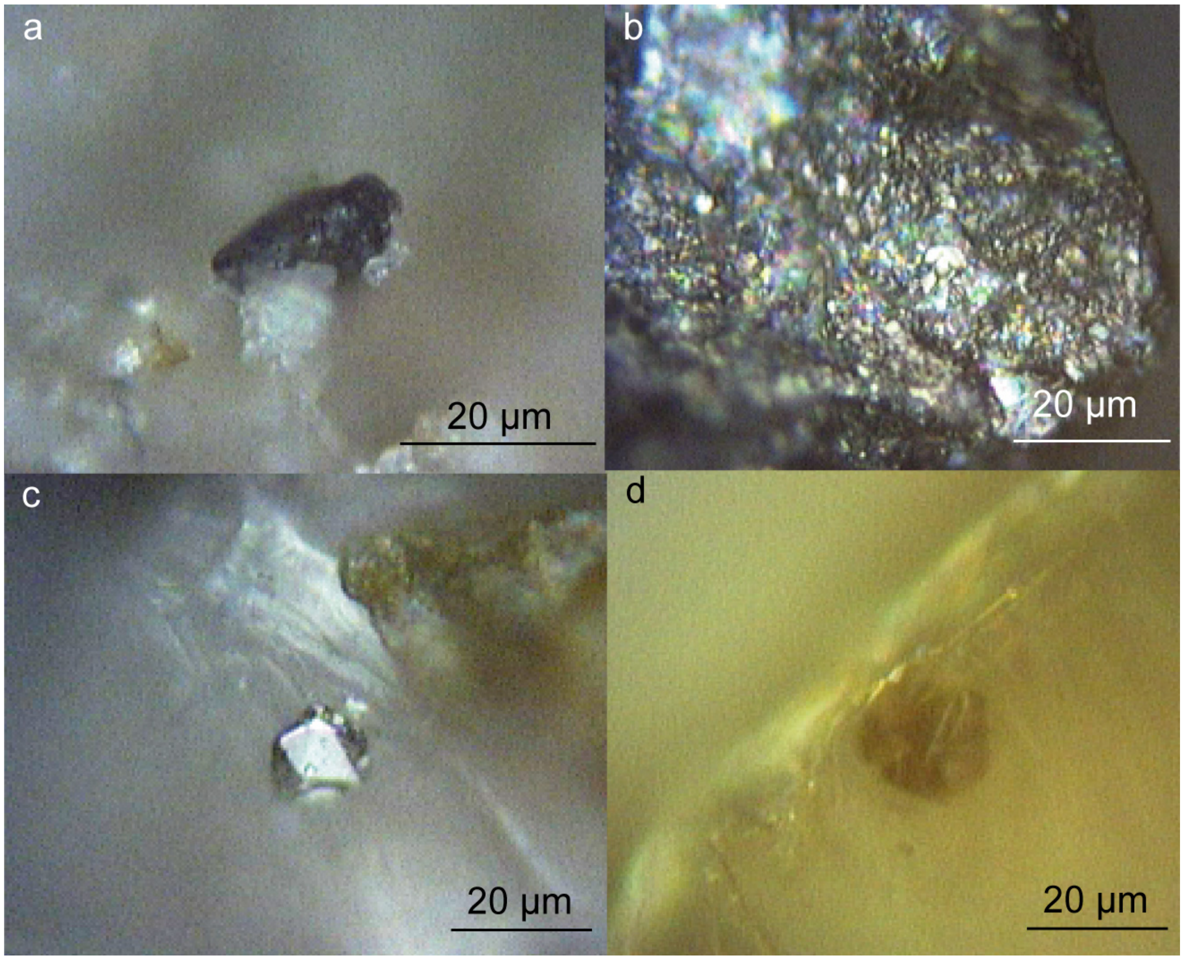
Proportion of petrogenic C: bulk ^{14}C analyses

Galy et al., Science, 2008



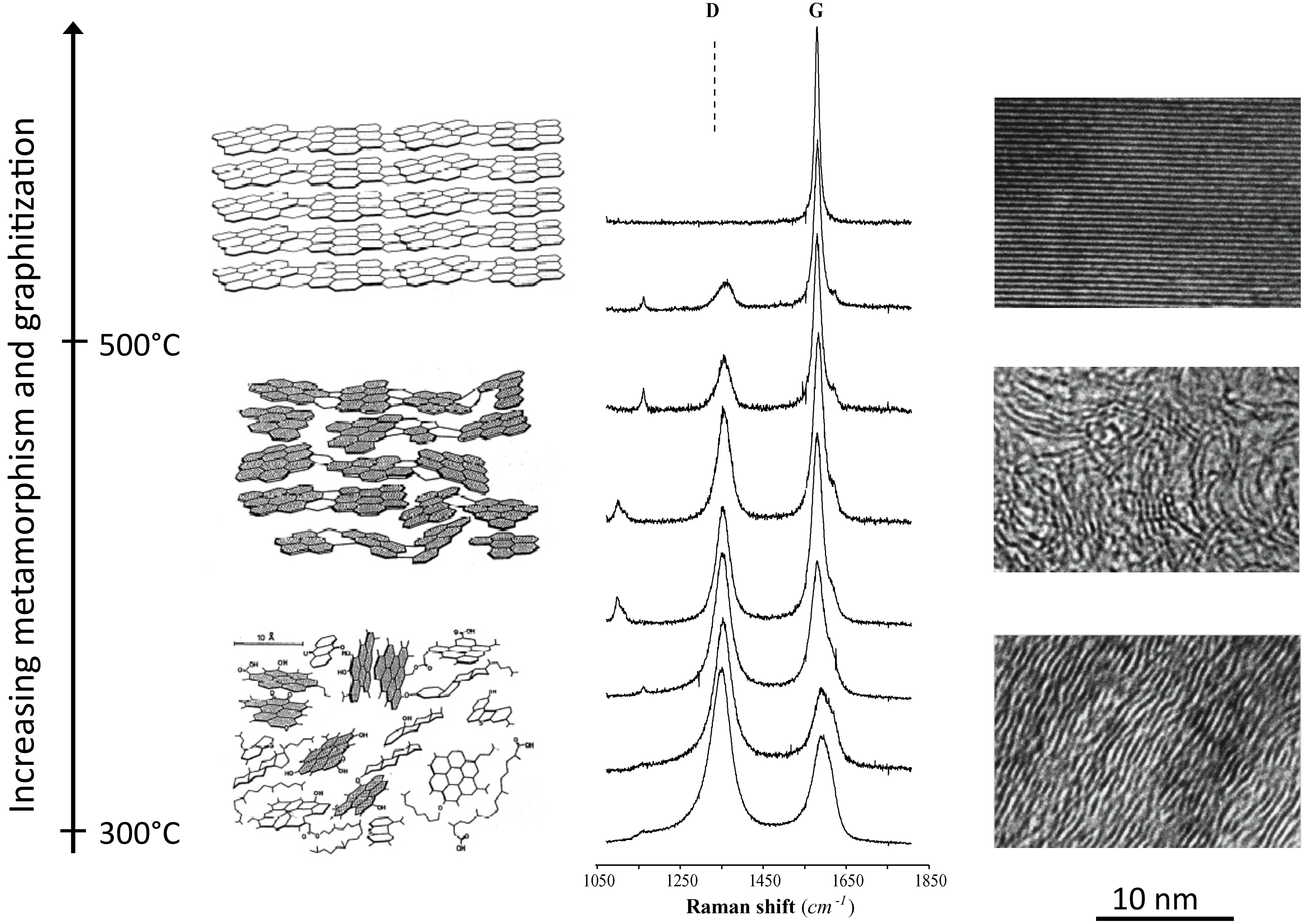
30-50% of petrogenic OC exported to the ocean

What does petrogenic C look like?

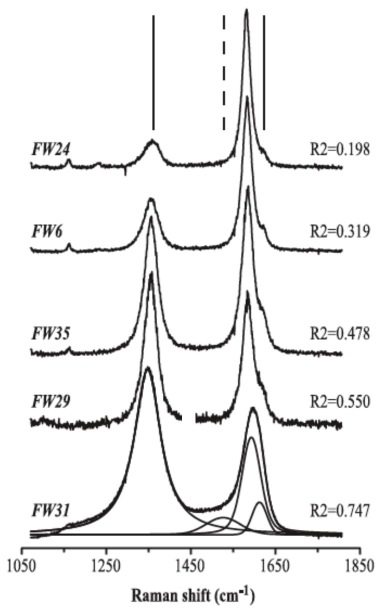


Raman spectroscopy + High resolution TEM imaging

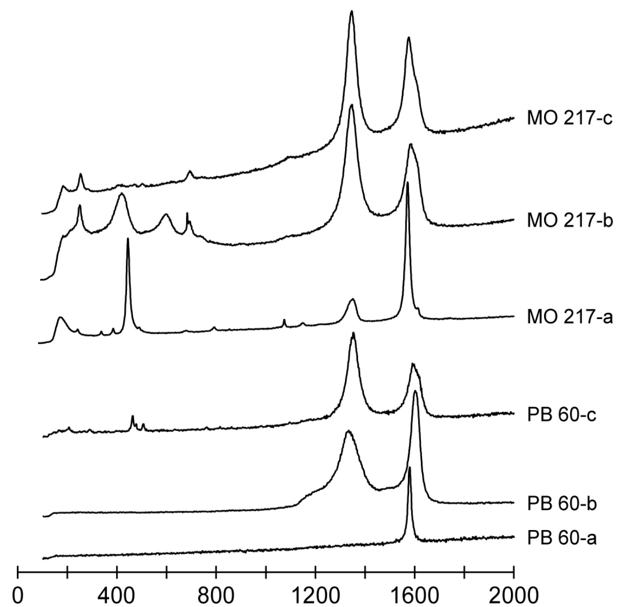
Characterization of petrogenic C: Raman and TEM



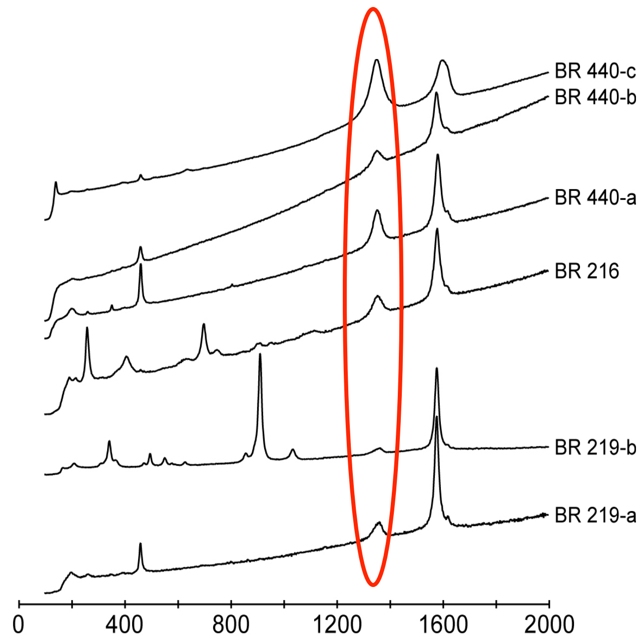
Characterization of petrogenic C: Raman



Rocks



Mountainous rivers



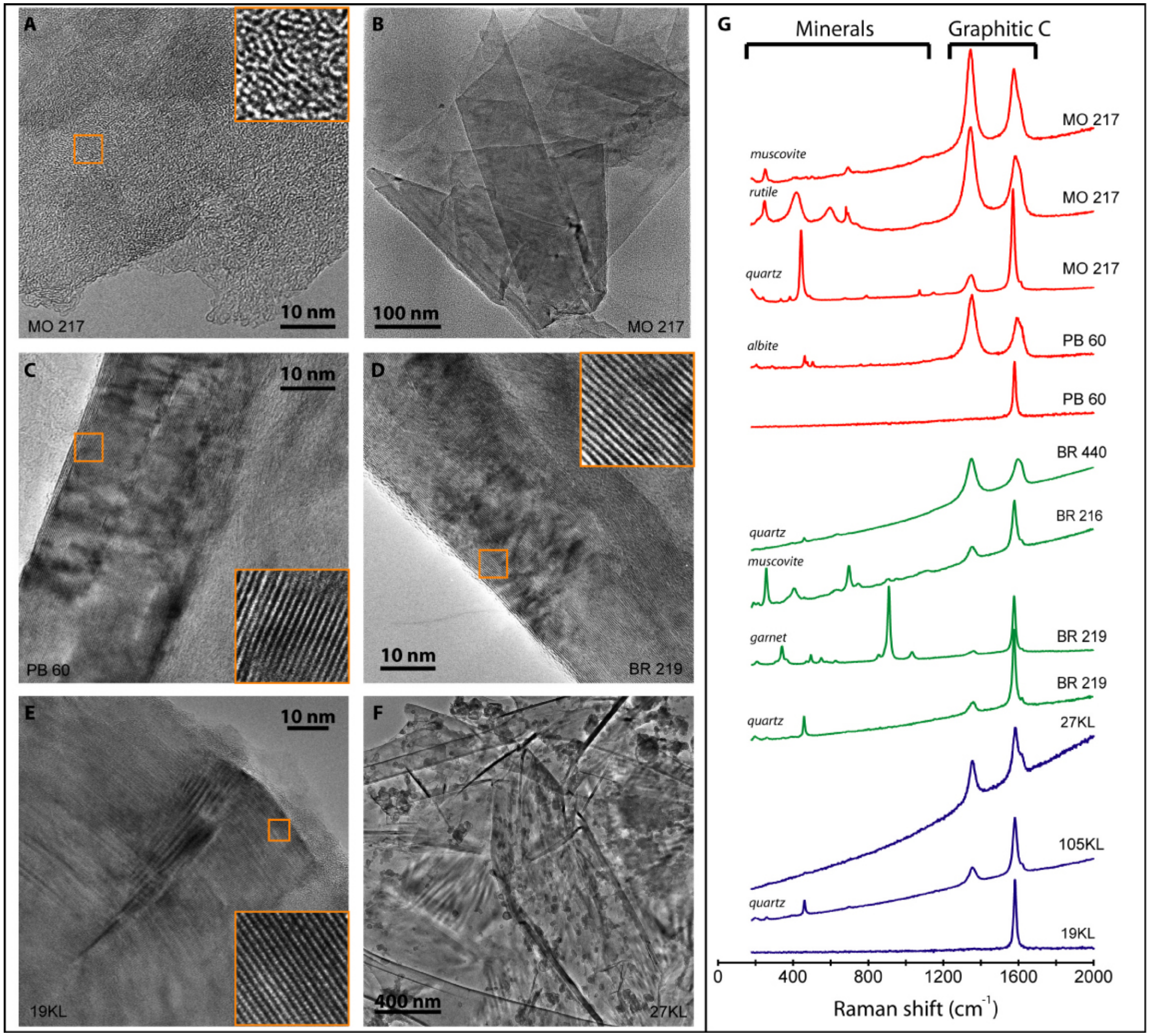
Floodplain rivers

Any type of petro C:
contributions from the different lithologies
reflecting different degree of metamorphism

disappearance of the less organized particles, preservation of highly graphitized C

Characterization of petrogenic C: Raman spectroscopy and TEM

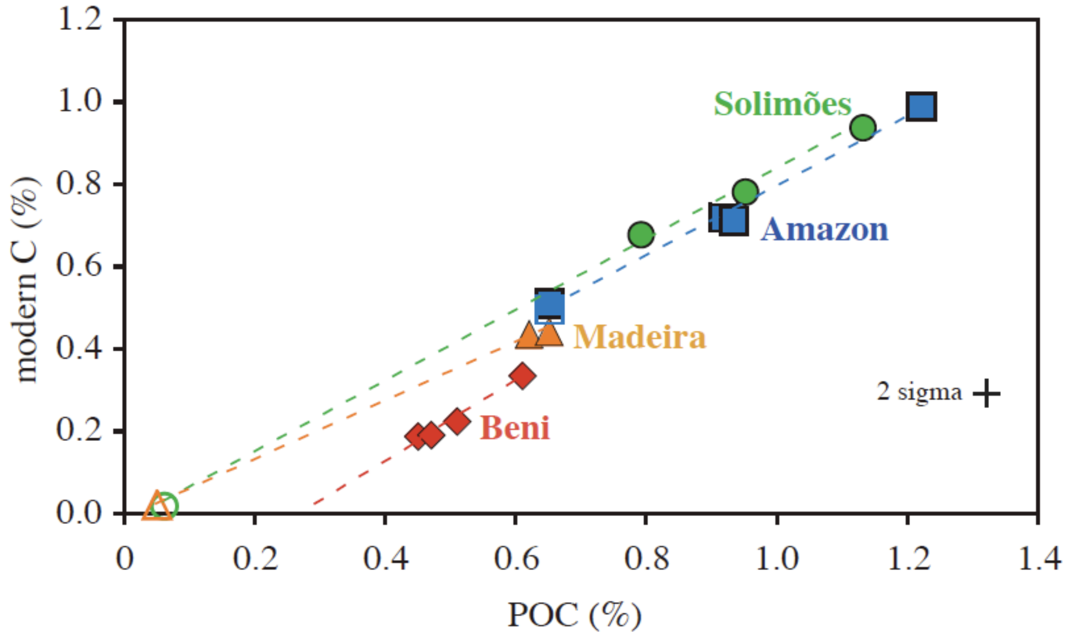
Galy et al., Science, 2008



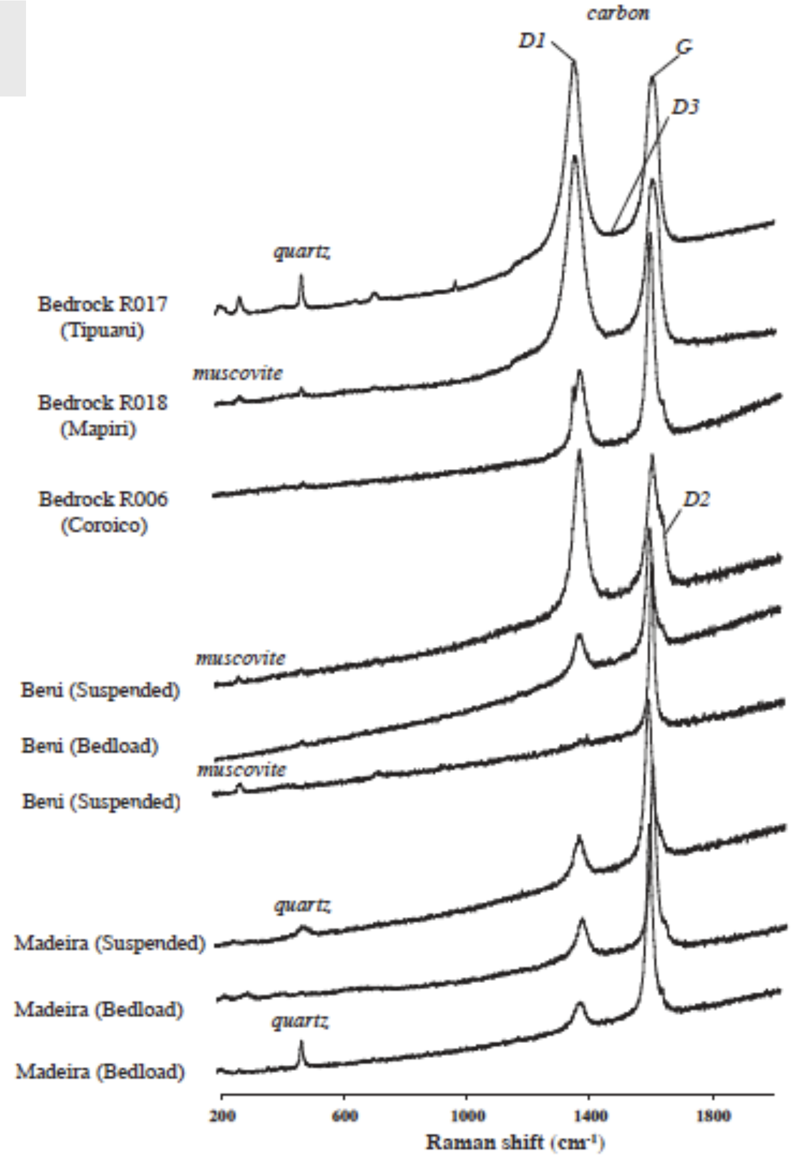
Selective recycling of Graphite during continental erosion

Comparison with the Amazon system

Bouchez, Beyssac, Galy et al., Geology, 2010

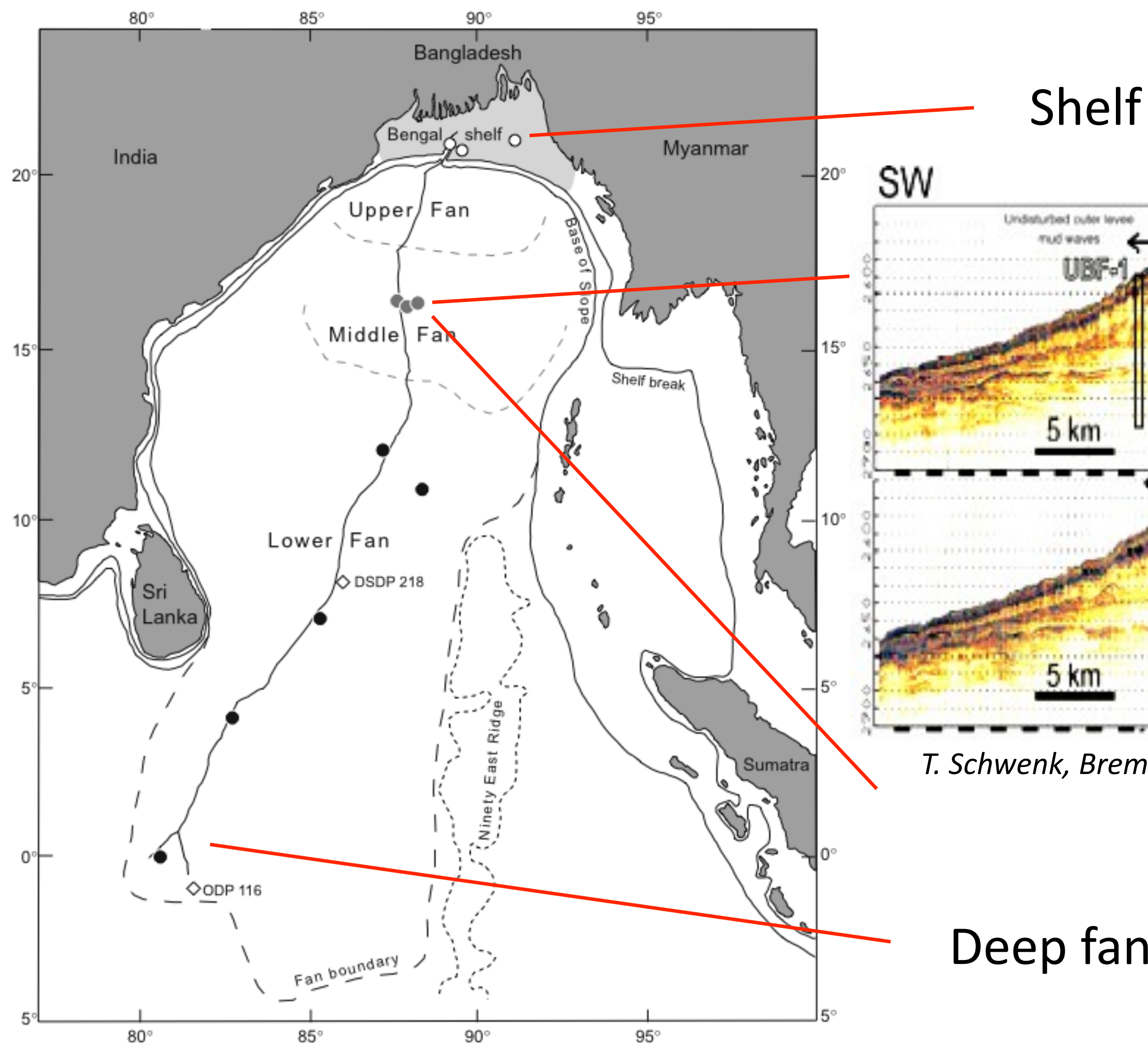


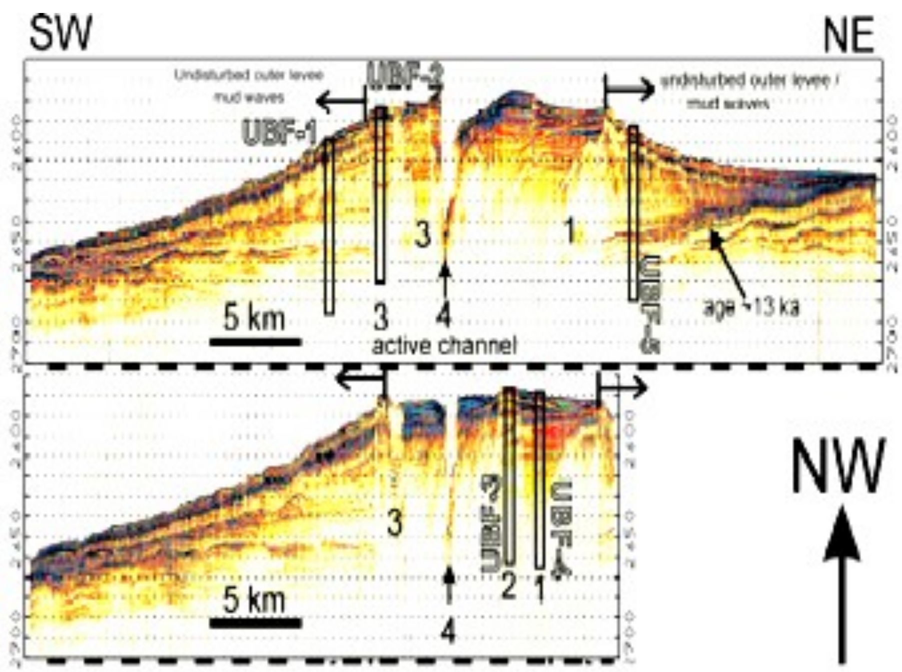
At least 50% of petrogenic C is oxidized in the Madeira basin



Selective preservation of graphitic C

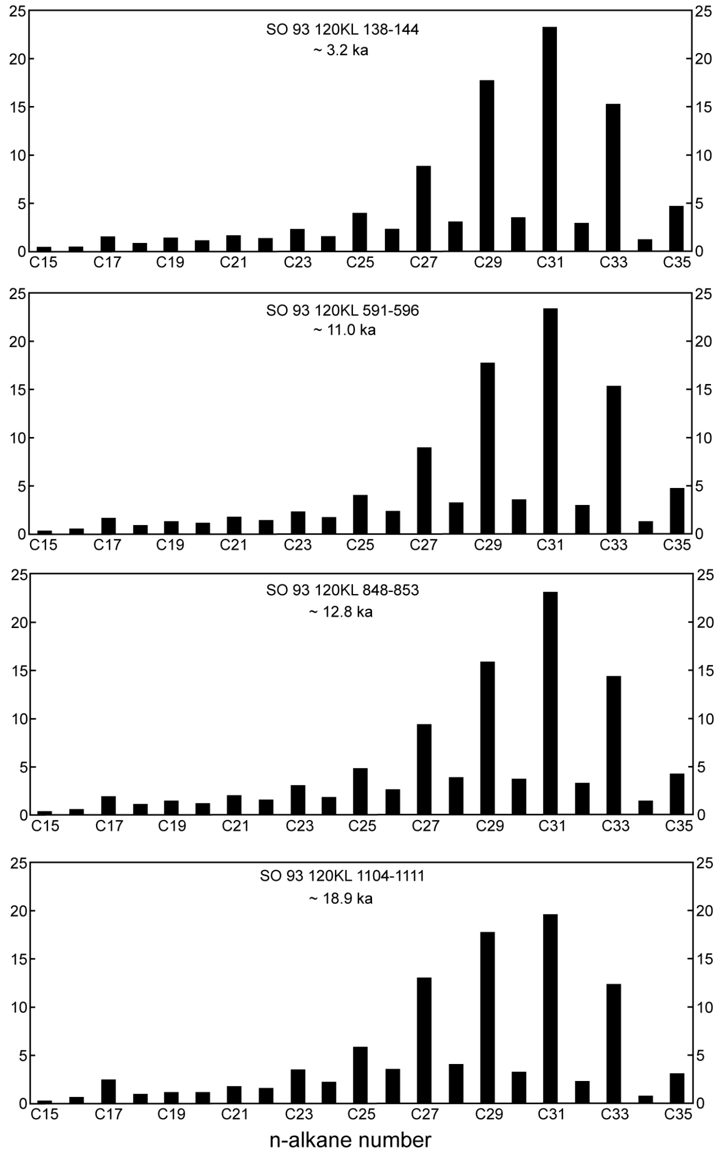
OC burial efficiency in the Bengal Fan



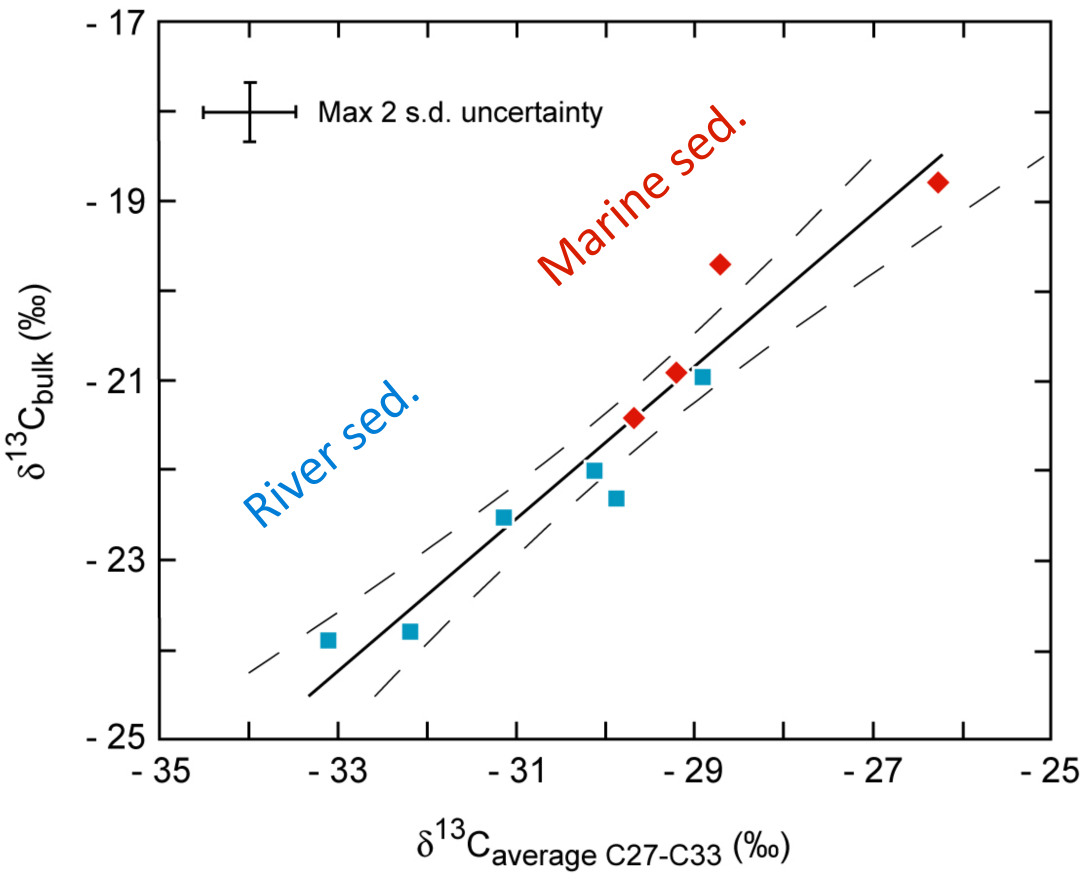


T. Schwenk, Bremen, pers. com.

Source of OC: terrestrial/marine contribution ?

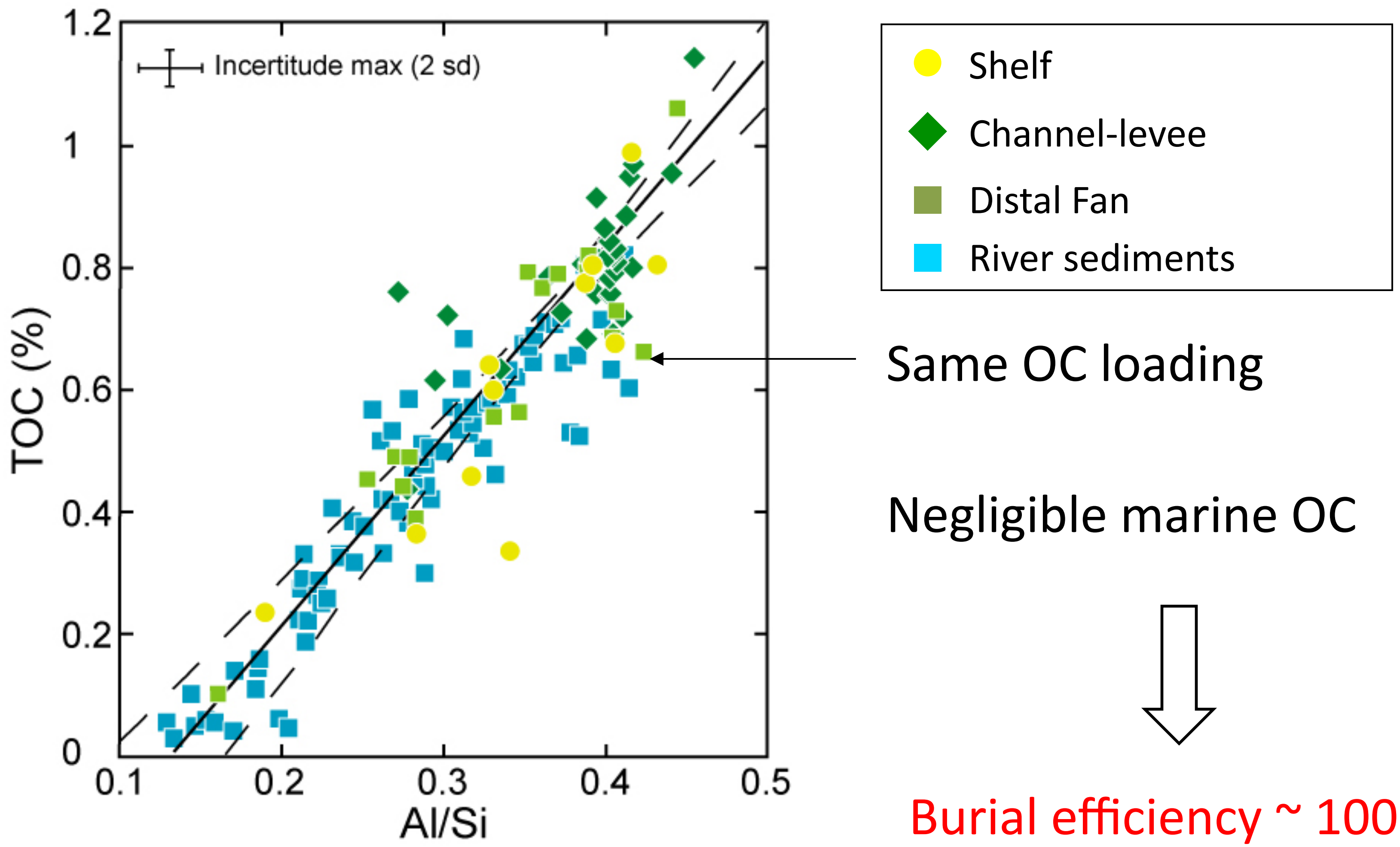


Galy et al., QSR, 2008



Negligible contribution of marine organic carbon

OC preservation



Galy et al., nature, 2007

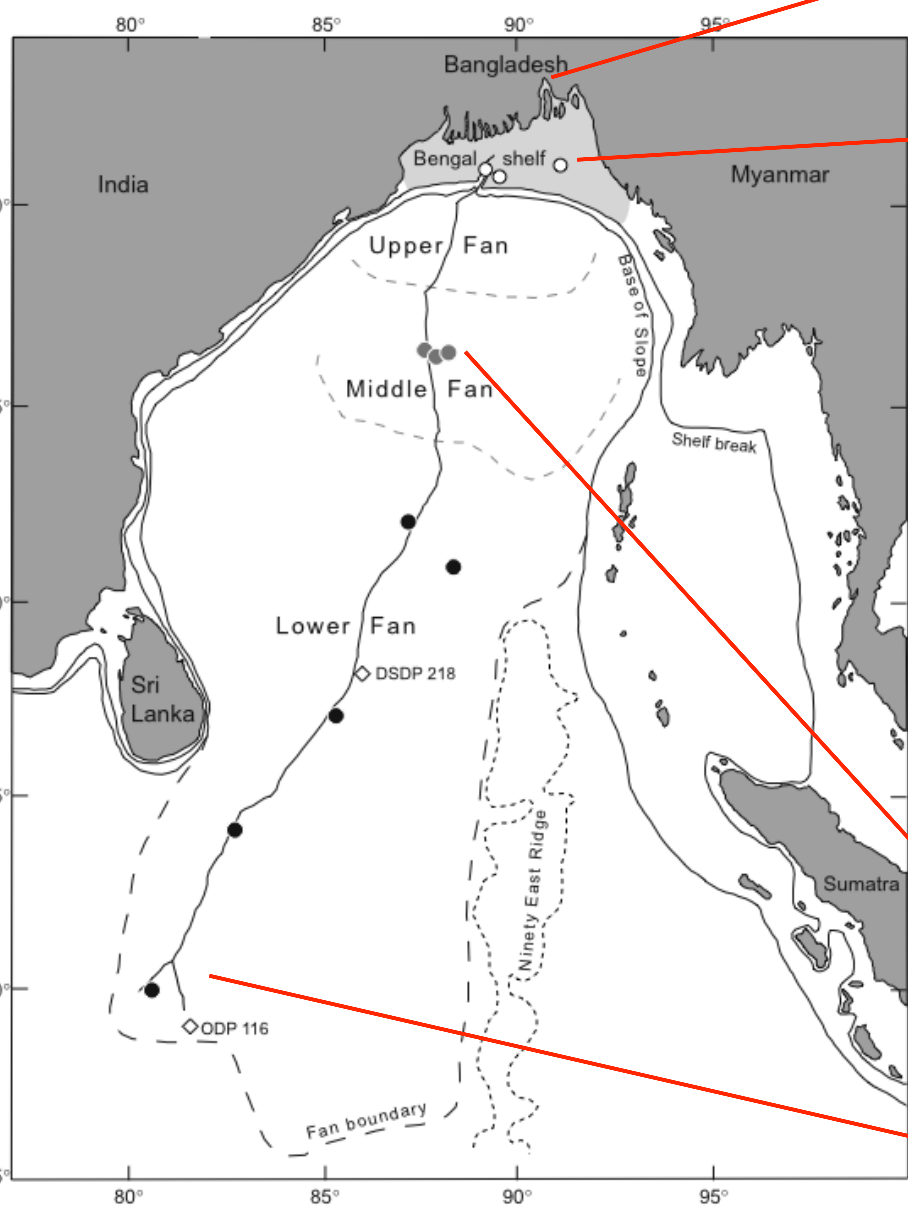
Same OC loading

Negligible marine OC

Burial efficiency ~ 100 %

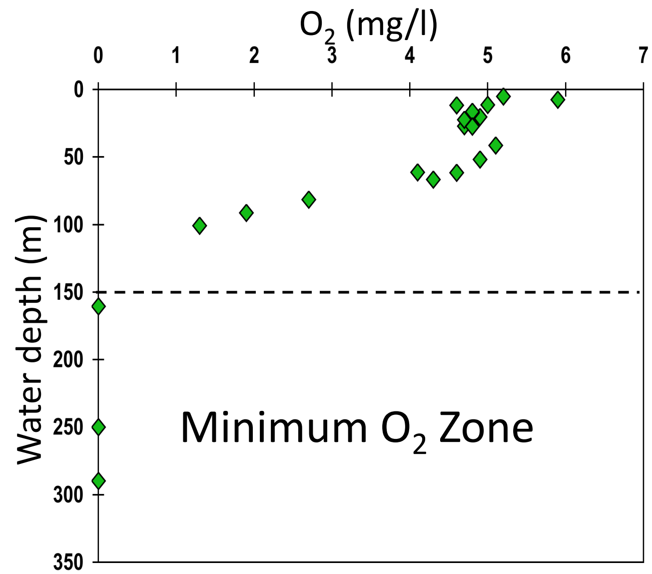
Burial flux of biospheric C ~ **3.1 x 10^{11} mol/an (±0.3) ≈ 10-20% of global flux**

Himalayan system specificity



Himalaya
Very high physical erosion rates
≈ 2.10^{9} tons of sed./yr

Shelf
sed. rates: 1-30 cm/yr

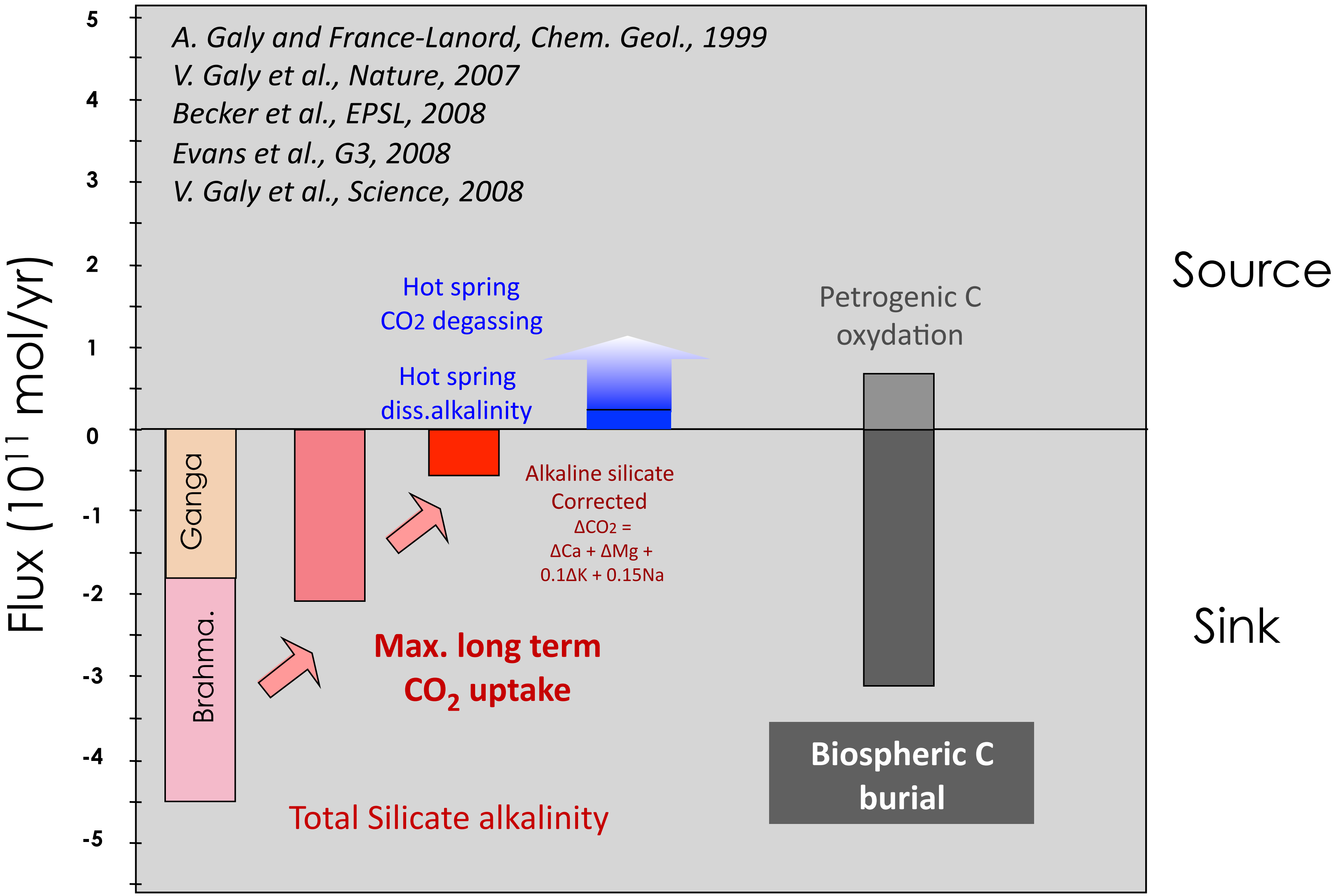


Channel-levee
sed. rates: 1-15 mm/yr
Low O_2 zone

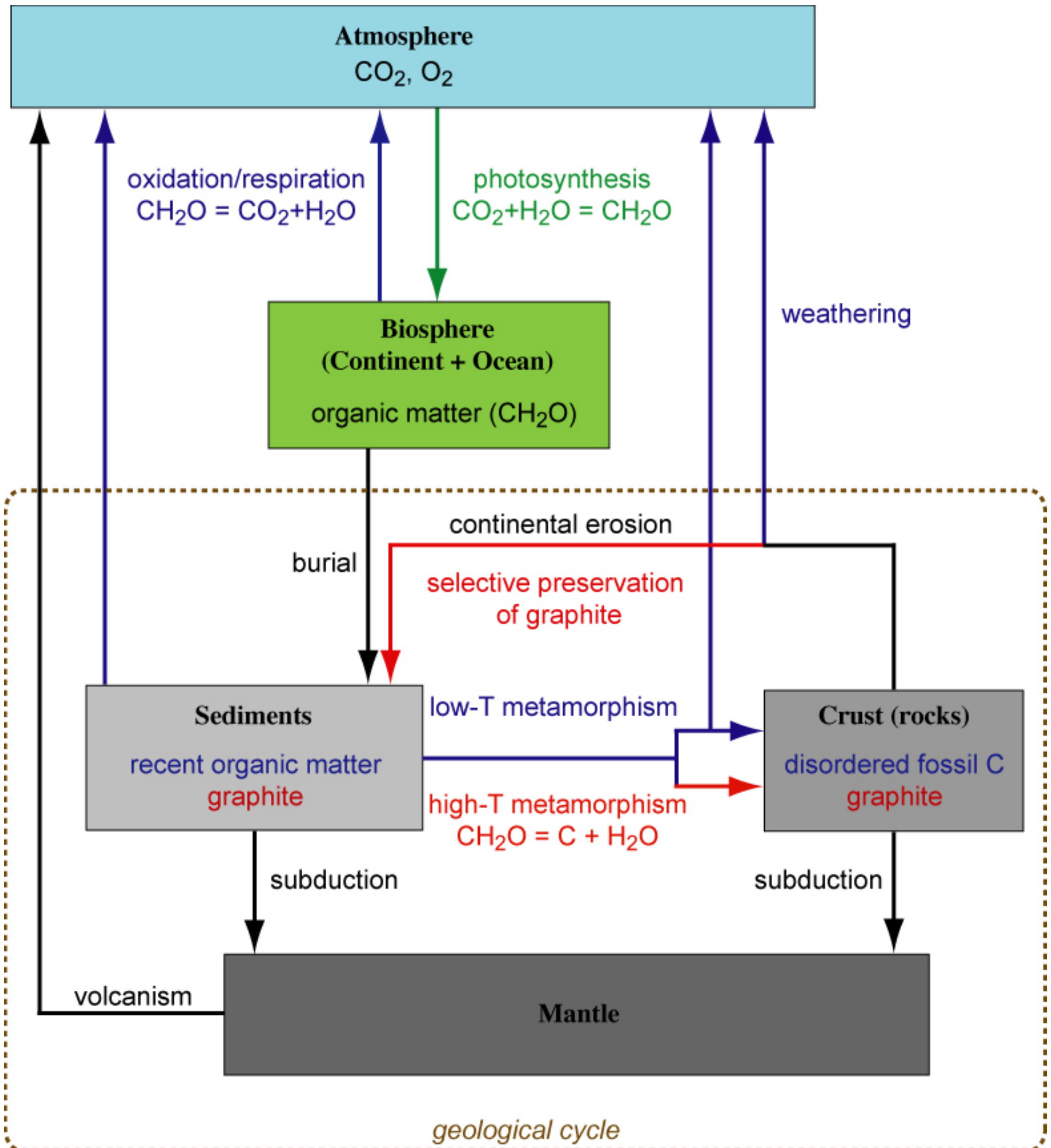
Deep fan (terminal lobes)
Low O_2 zone

Fast transport
Catastrophic events

Himalaya: CO_2 source or sink ?



A new look at the long term C cycle

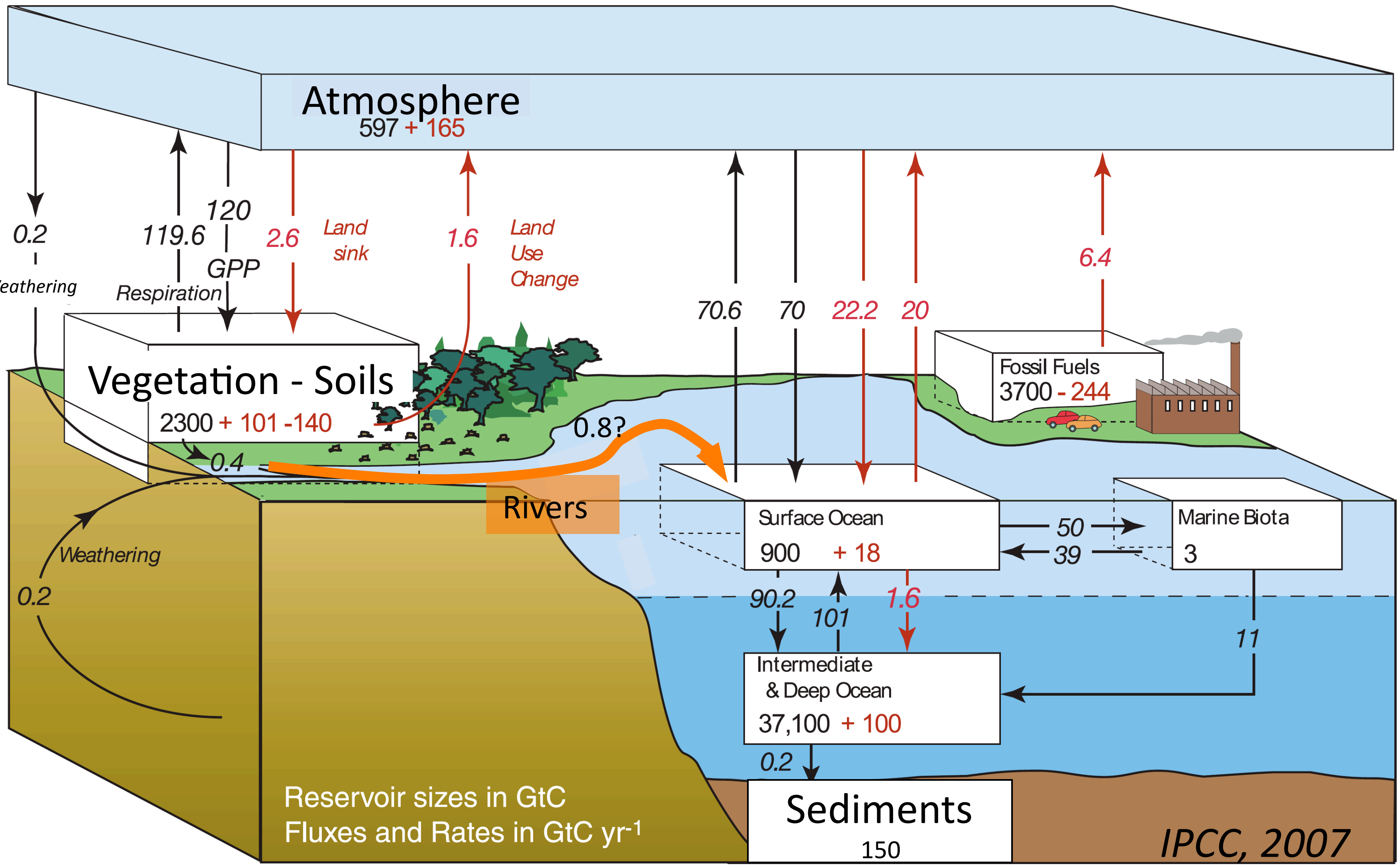


High-T metamorphism lock C into the geological sub-cycle

Burial of biospheric C = net long-term CO_2 sink

Galy et al., Science, 2008

The short term C cycle: sensitivity of the atmospheric reservoir

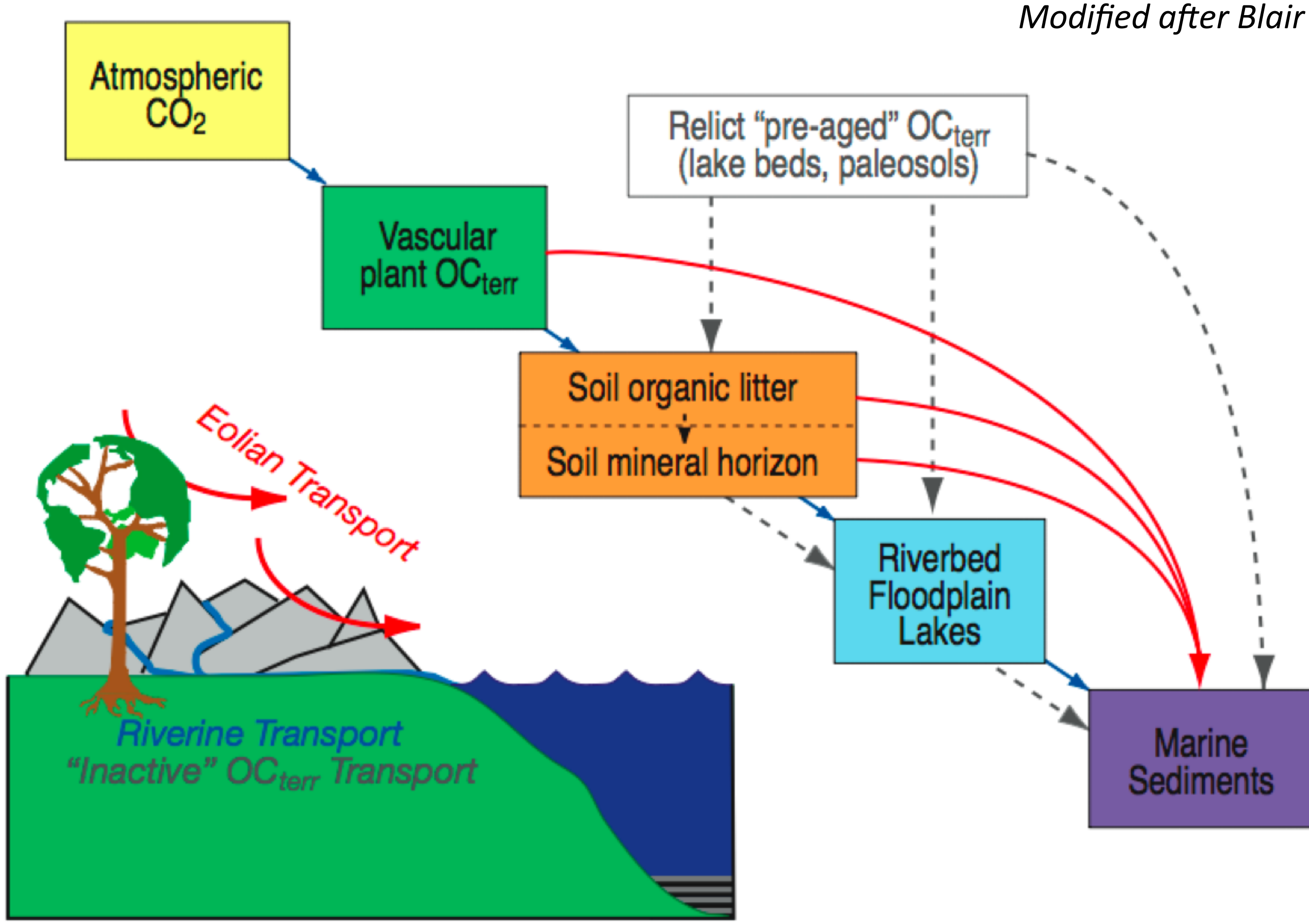


Increase of residence time in continental reservoirs = CO_2 sink

Decrease of residence time in continental reservoirs = CO_2 source

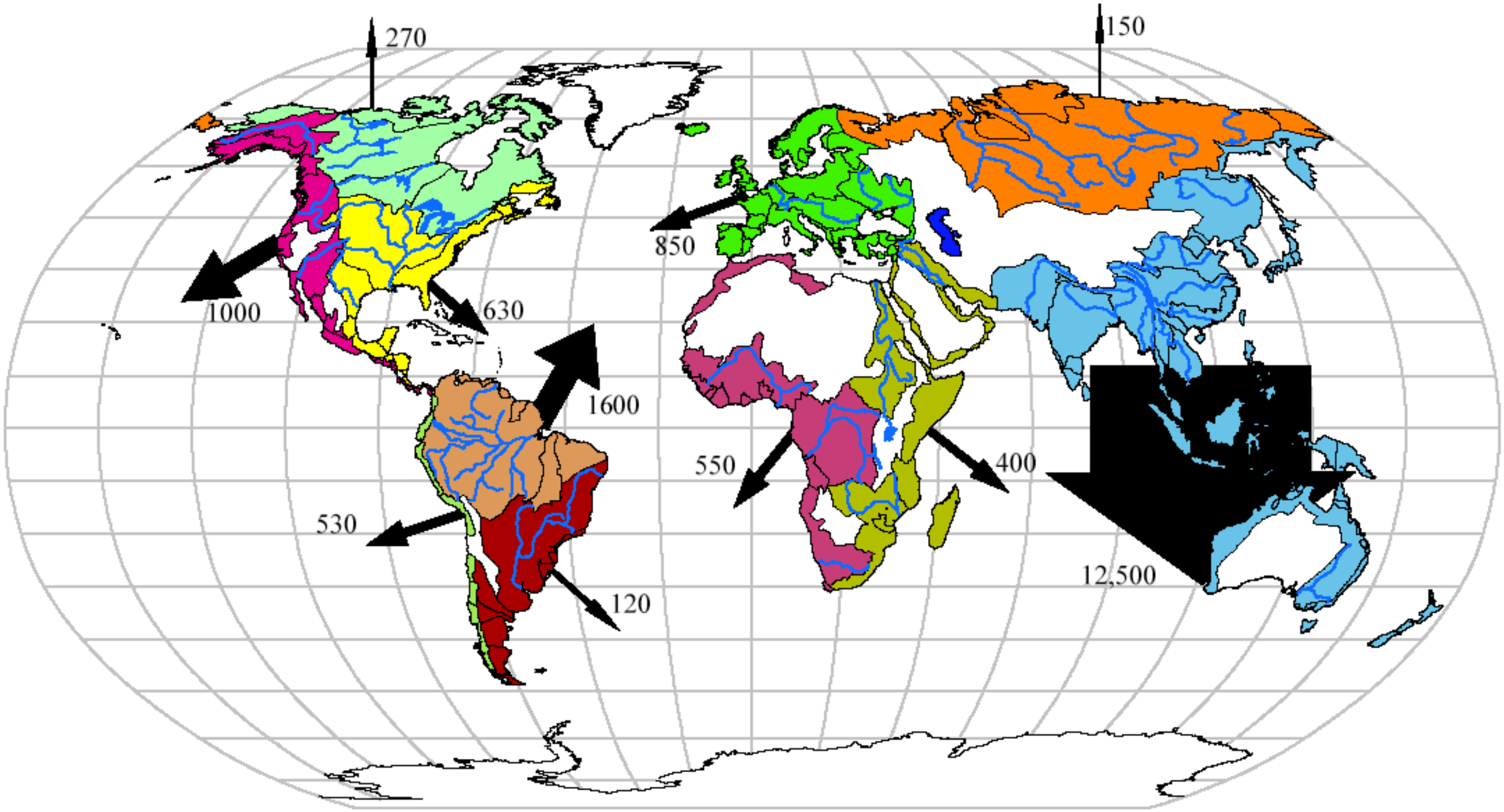
Continental processes of OC recycling

Modified after Blair et al., 2004



Terrestrial OC is affected by several exchange process on its way to the ocean
Consequences for C budget and OC based environmental reconstructions

Sediment flux to the Ocean: the importance of SMRI



Total = 19,000 * 10^6 t/yr

Milliman and Farnsworth, 2011

POC flux to the Ocean: the importance of SMRI

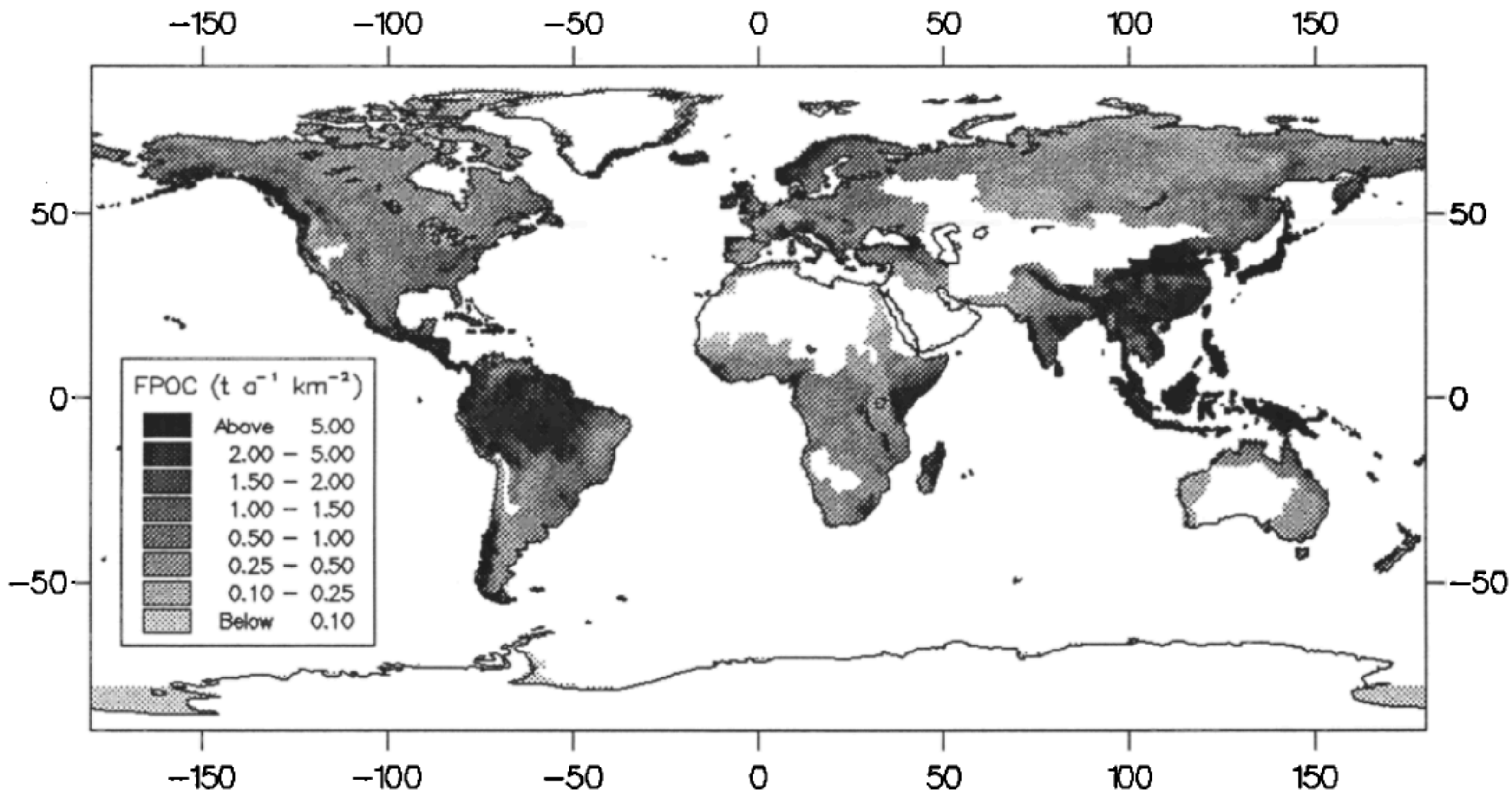
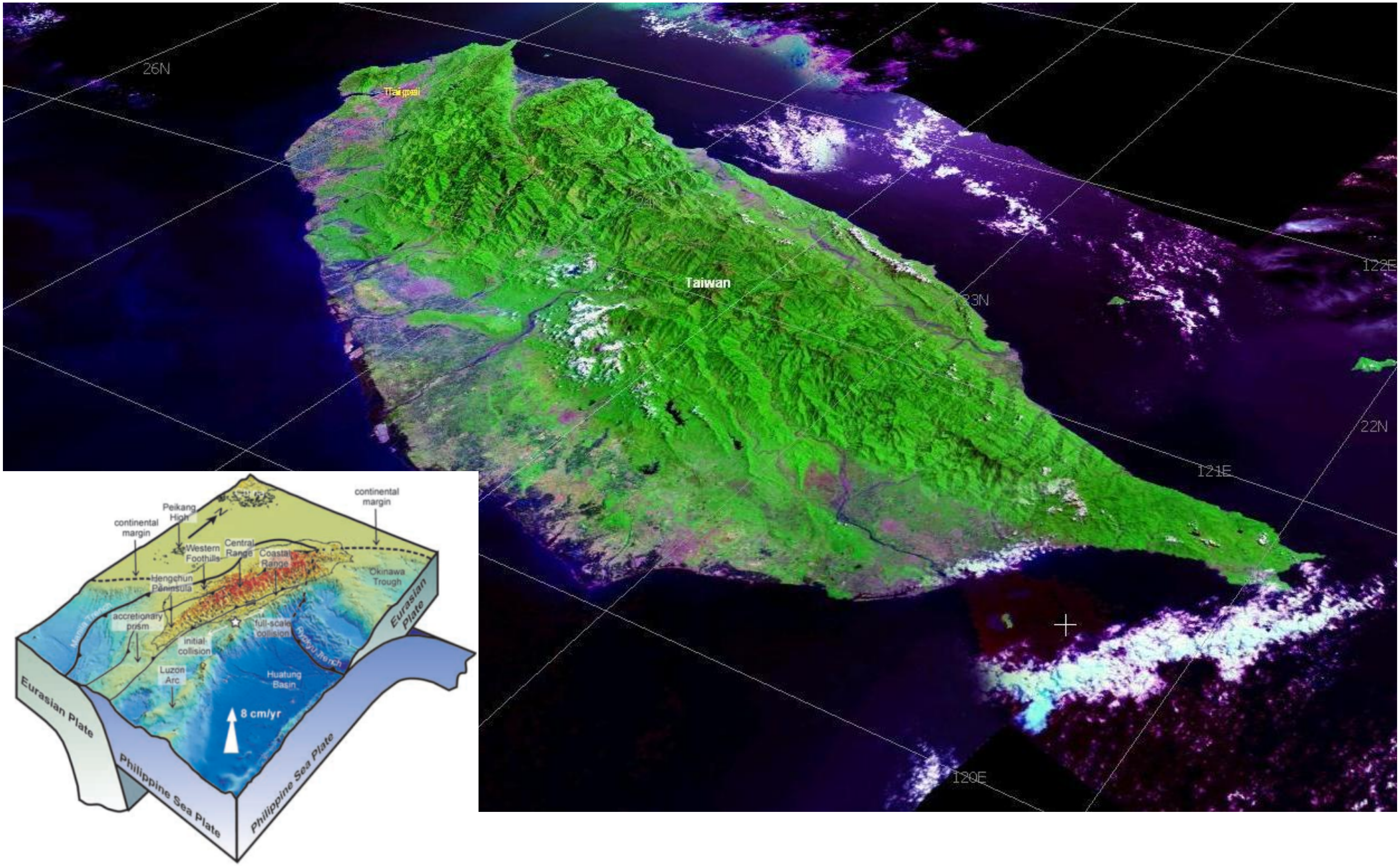


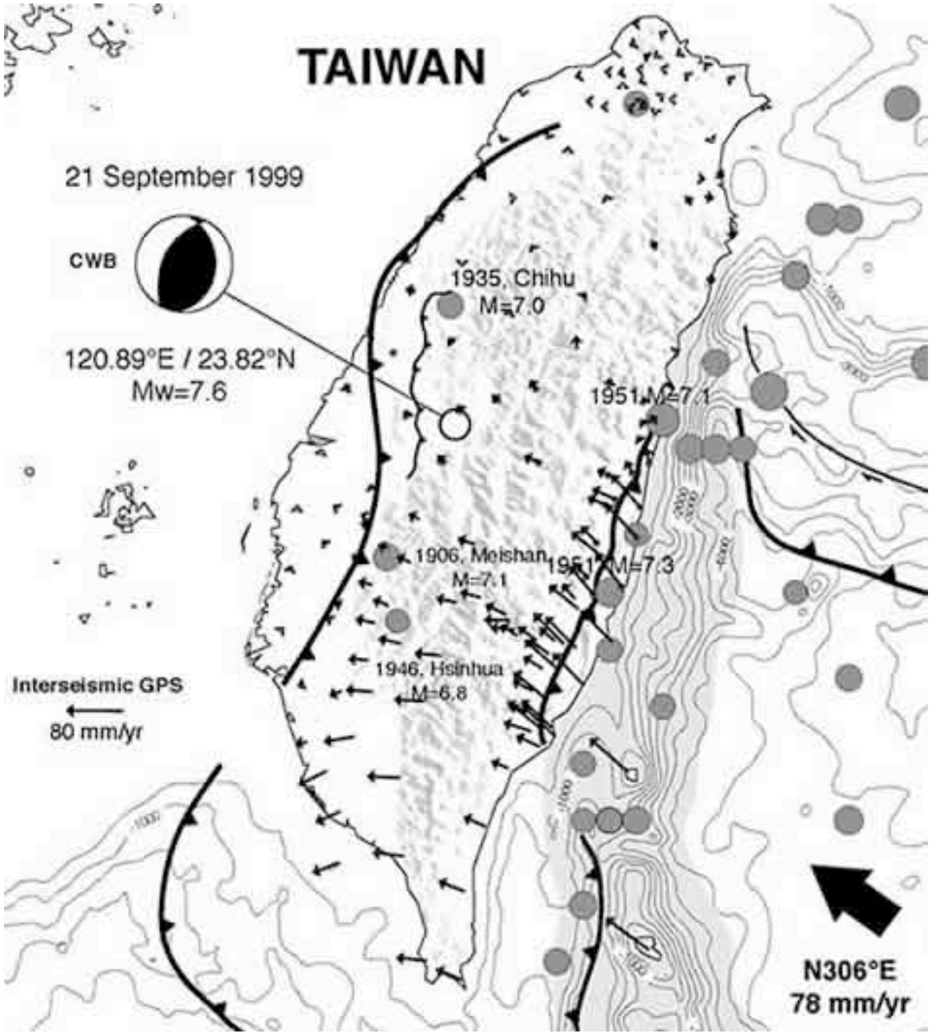
Figure 5b. Estimated continental POC fluxes (tons per square kilometers per year) Endoreic basins and glaciated regions are omitted

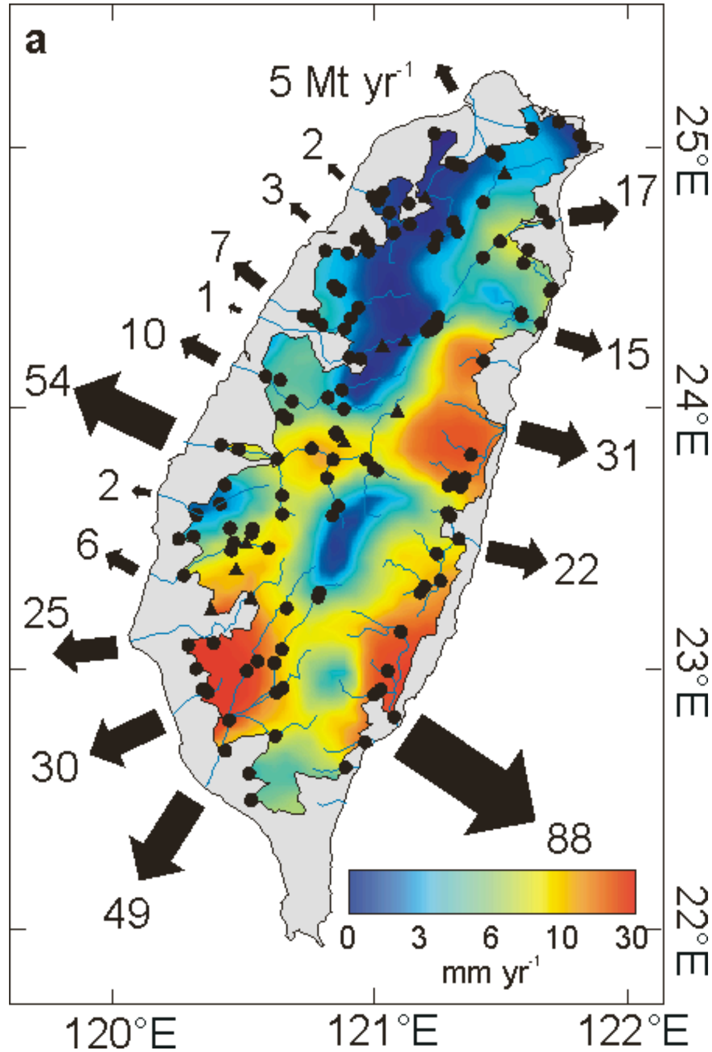
Ludwig et al., GBC, 1996

SMRI example: Taiwan



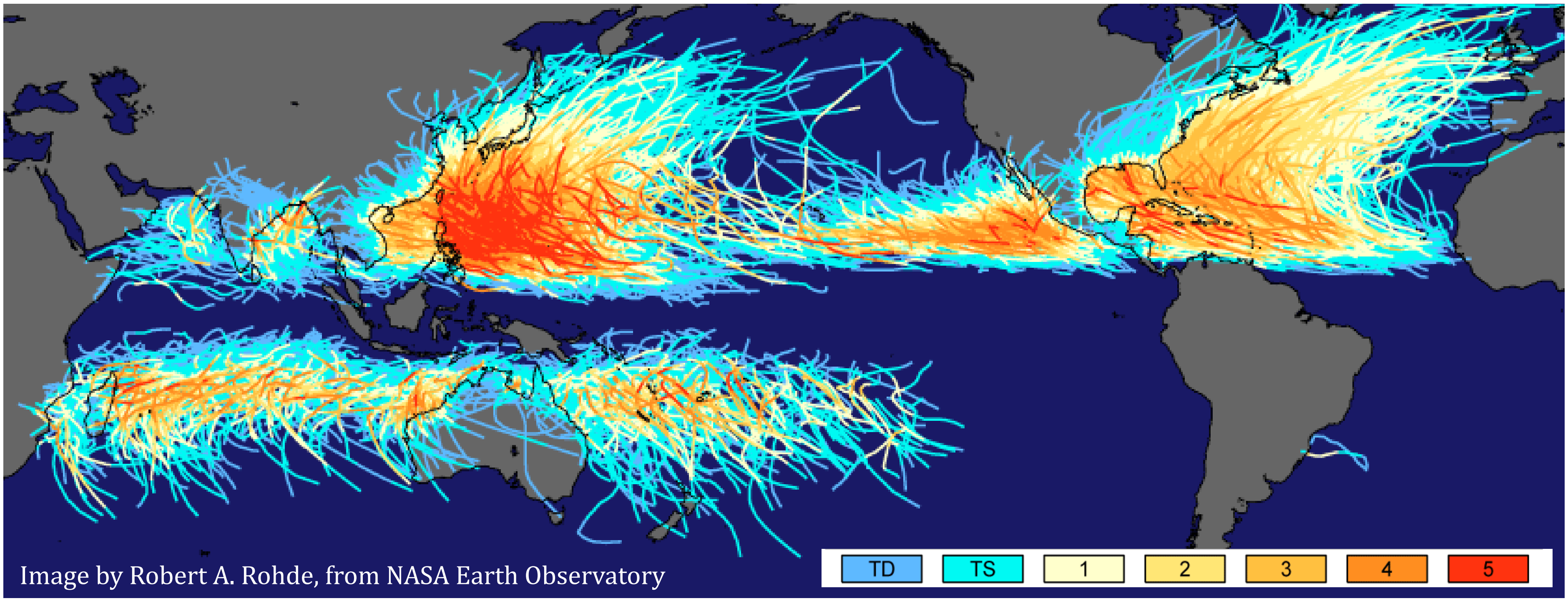
Taiwan: tectonic context





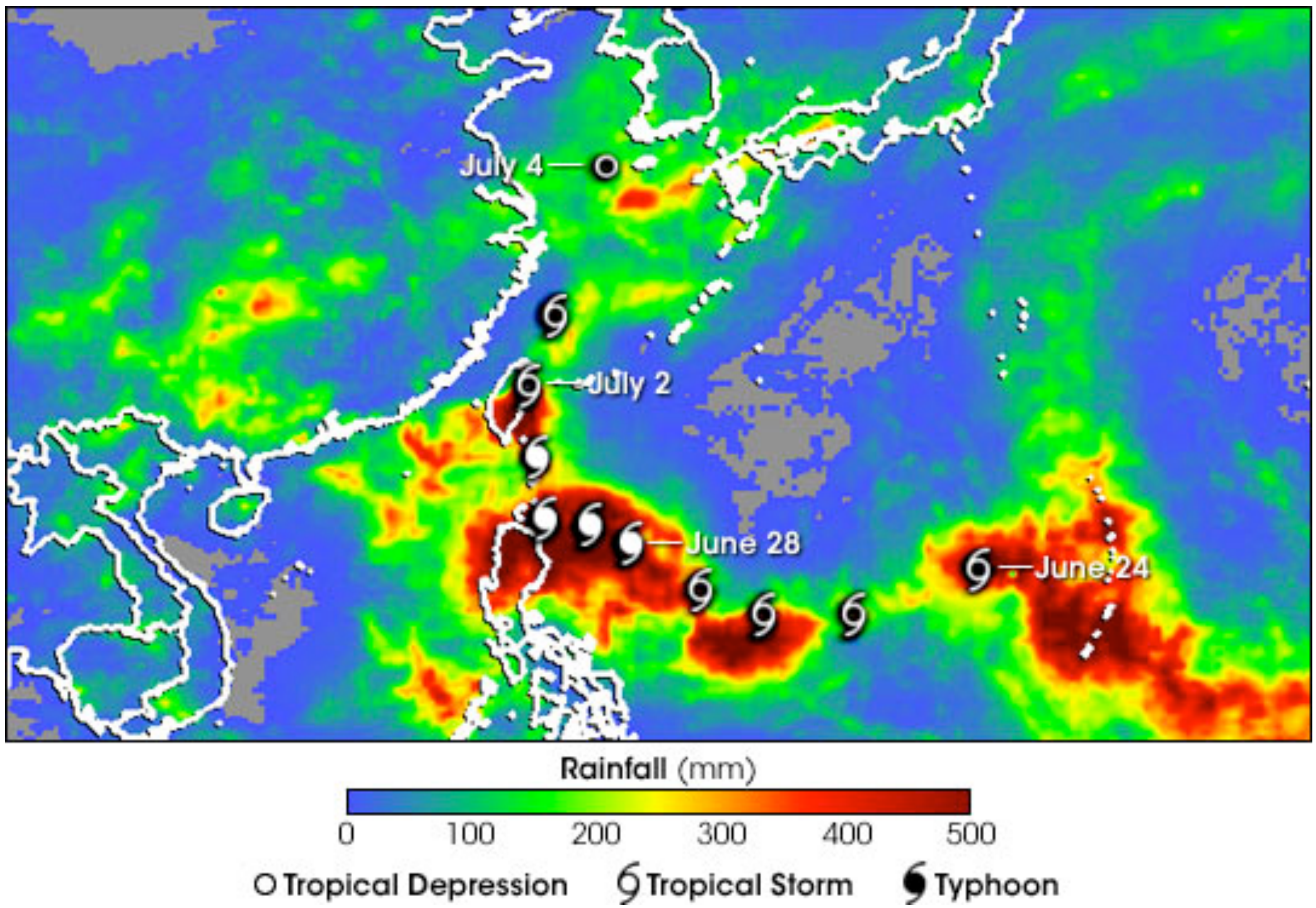
Fast convergence = high relief and fast physical erosion

Taiwan: a strong climate forcing

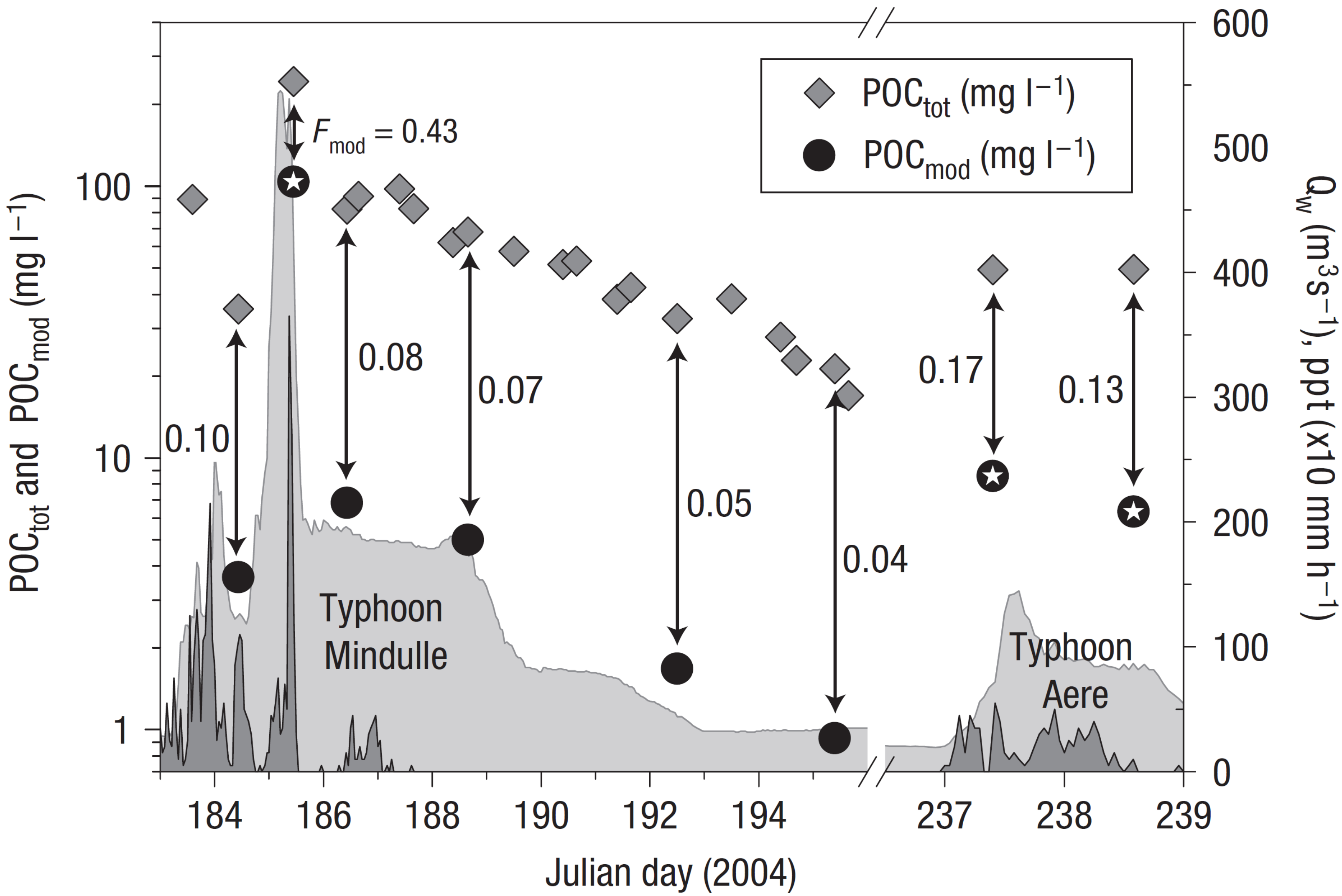


Hurricane pathway and intensity

OC export during extreme events: typhoon Mindulle

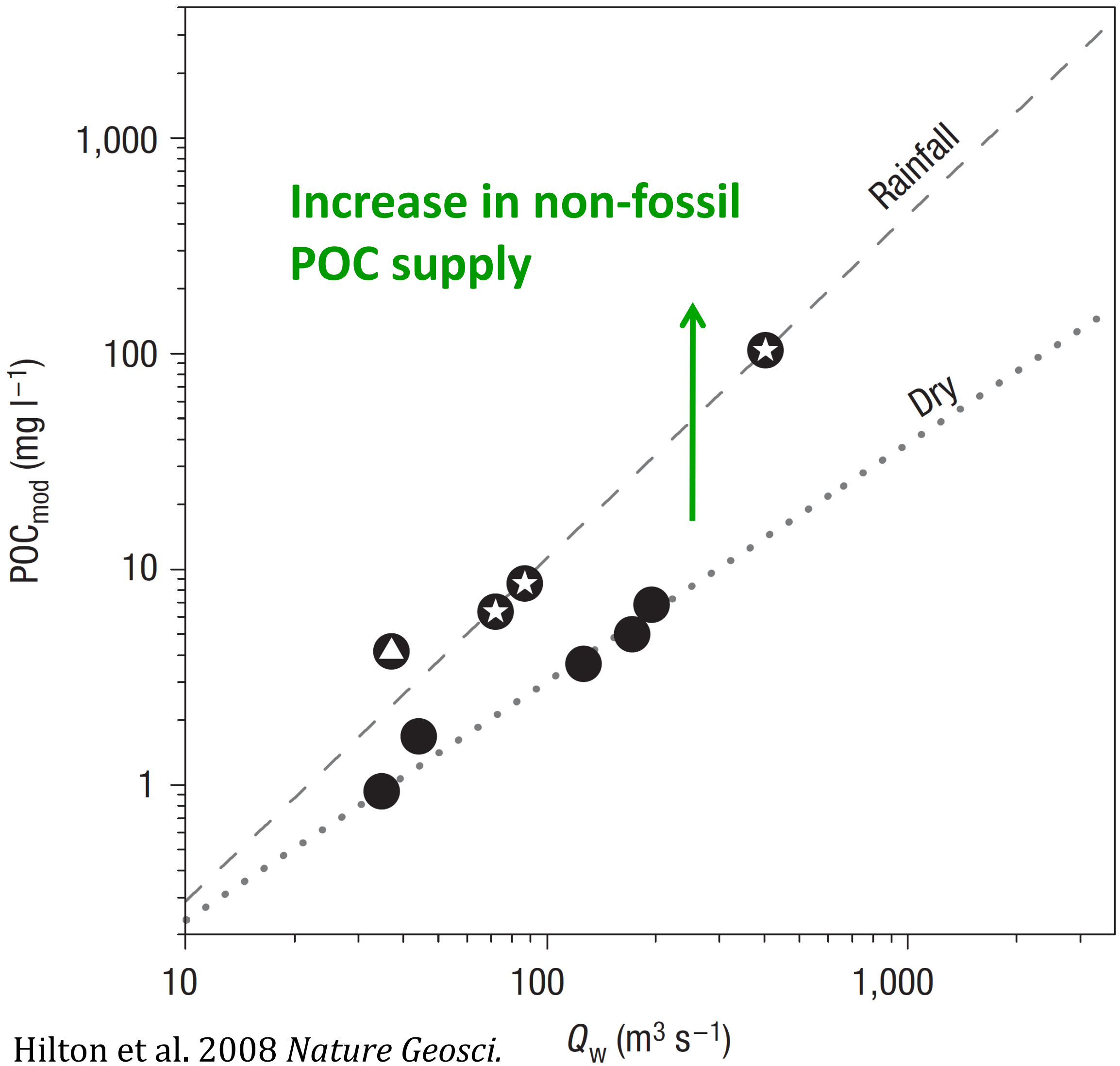


OC export during typhoon Mindulle



Hilton et al., Nature Geo., 2008

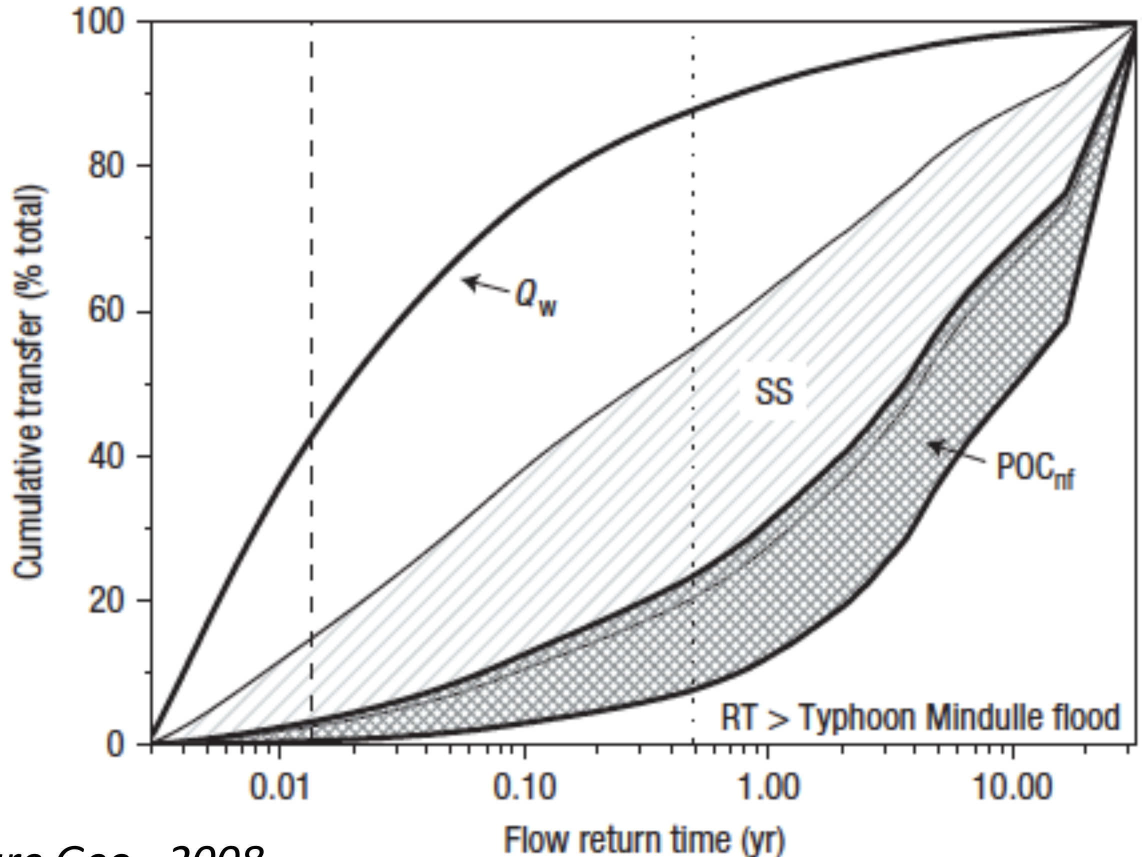
OC export during typhoons



Hilton et al. 2008 *Nature Geosci.*

- Water discharge (Q_w, m^3 s^{-1}) positively correlated with non-fossil POC load.
- Strong climate control on POC transfer

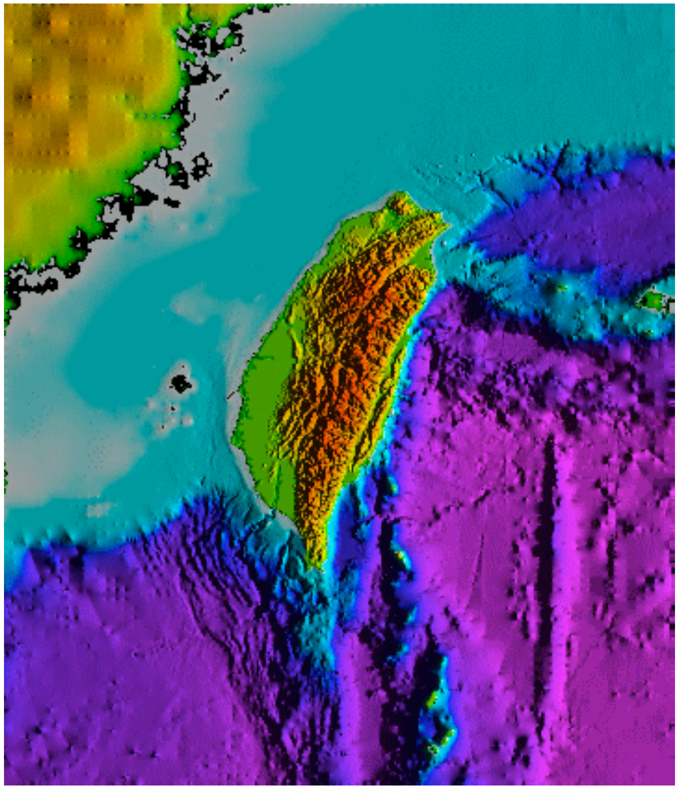
Overall significance of typhoons: a climate control of OC export

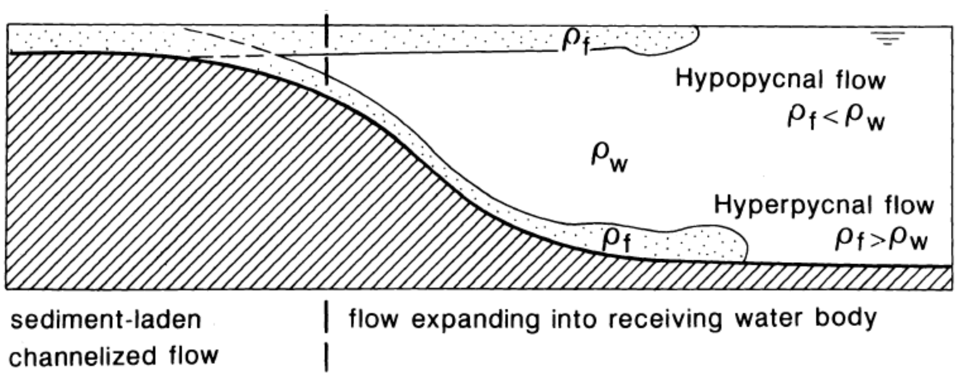


Hilton et al., Nature Geo., 2008

Large typhoons account for most of biospheric C export in Taiwan
Climate controls OC cycling
Negative feedback on atmospheric CO_2?

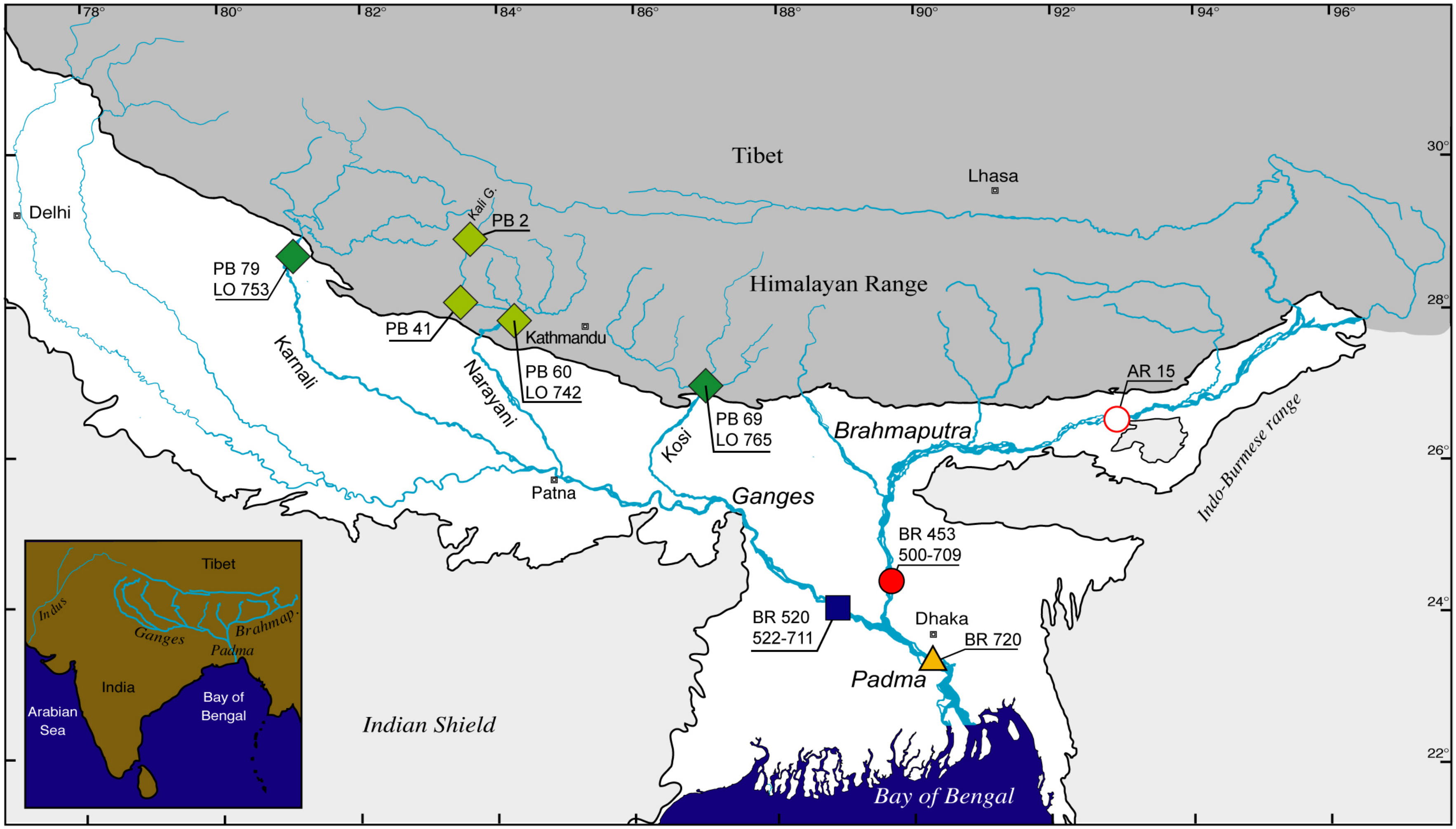
Fate of OC delivered during typhoons to the ocean





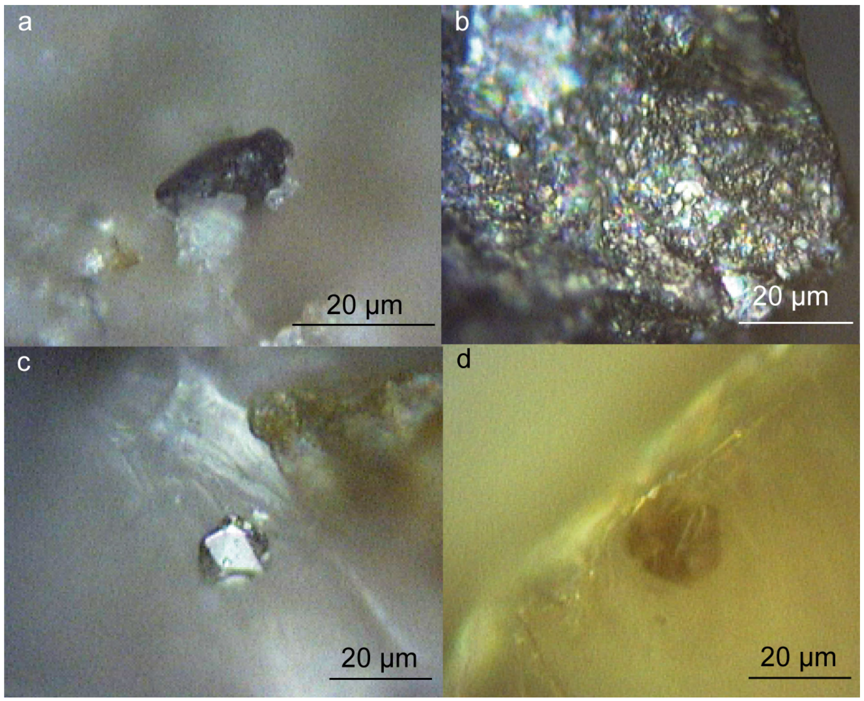
- Lack of well developed floodplain and shelf
- Hyperpycnal flow
- Direct transfer of OC to the deep sea
- High burial efficiency

Large globally significant rivers: the Ganges-Brahmaputra system

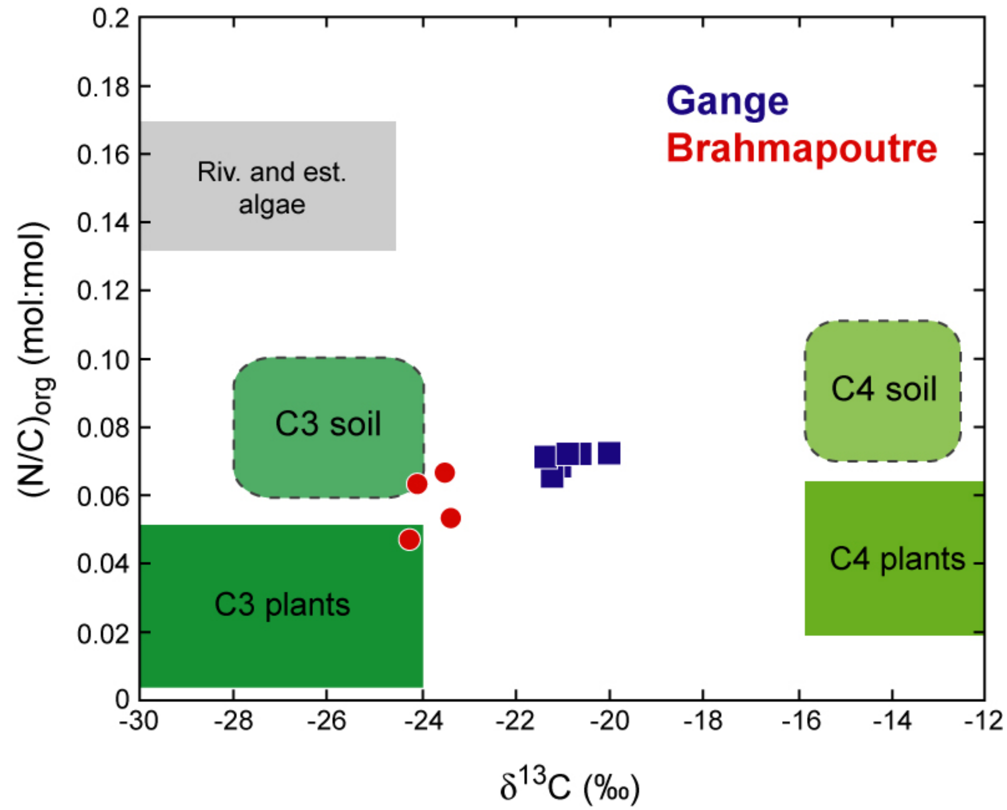


Heterogeneity of the OC pool

Galy, unpublished data



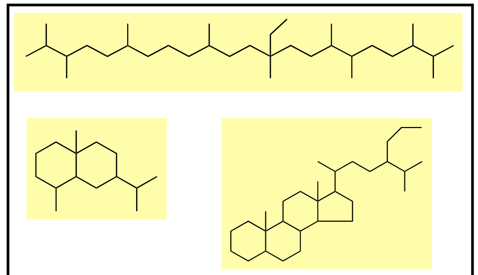
Galy et al., Science 2008



- 30-50% preservation of petrogenic C during erosion
- Complex mixture of C3-C4 vegetation and soil OC

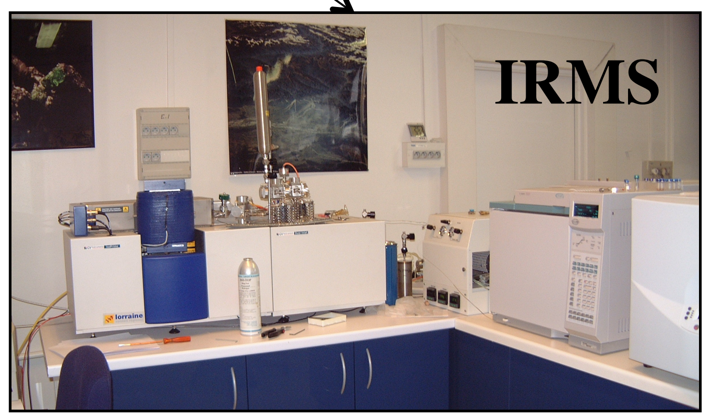
Isotopic analysis of biomarkers

Extraction



Specific markers
Vascular plants

Purification



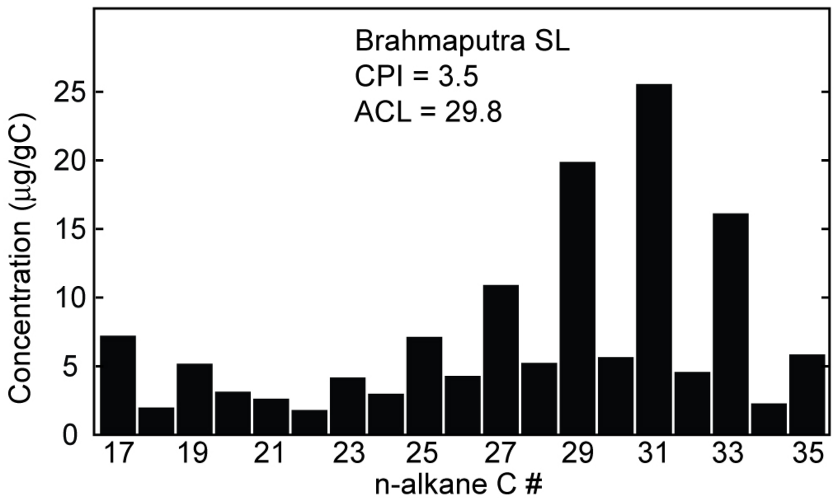
Continuous flow GC-IRMS

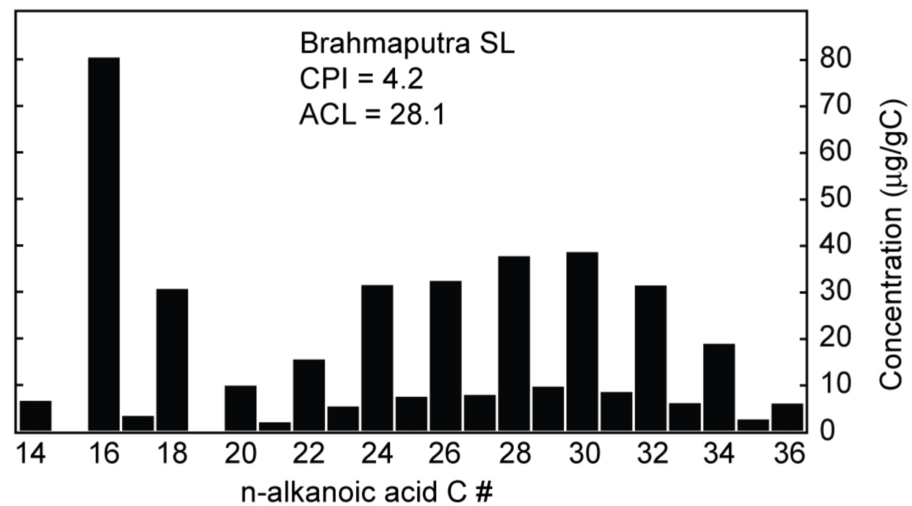
$\delta^{13}C$: source
δD: environmental proxy

Abundance/distribution of plants biomarkers

Suspended Sed.: filtration of up to 210L of water
Dredged bed sediments

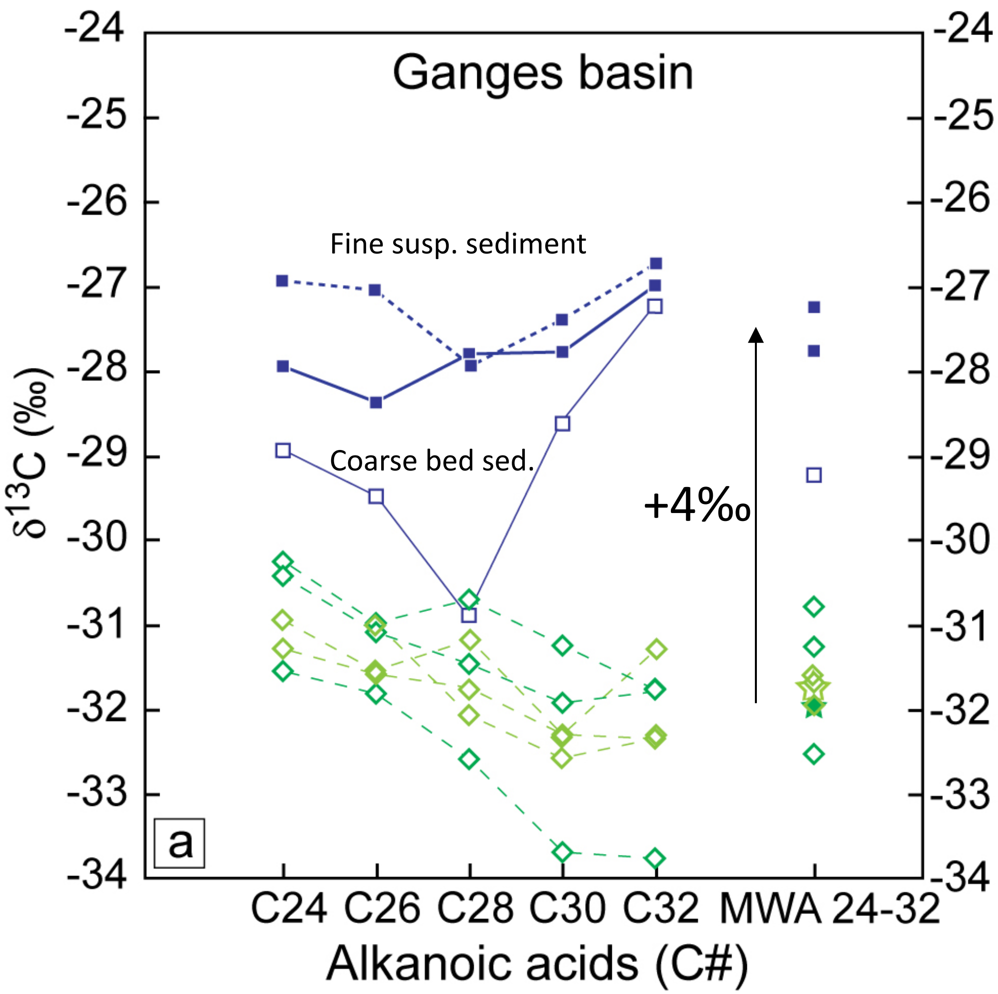
Galy et al., EPSL, in press

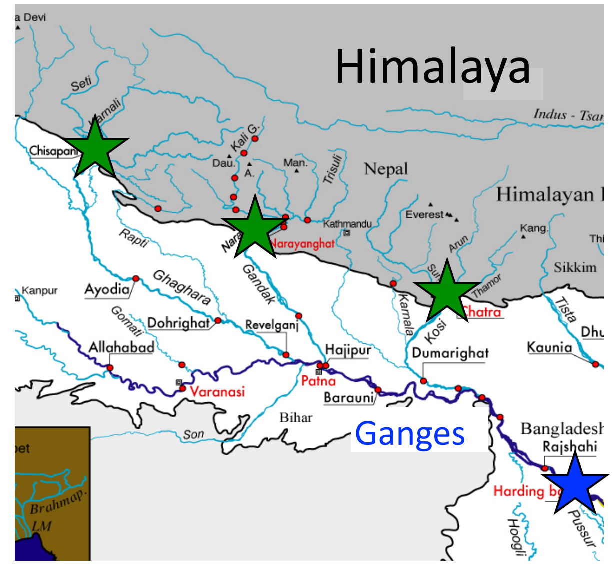




Distributions characteristic of vascular plant inputs
Large amounts suitable for compound specific isotopic analysis

Fate of OC in the Gangetic floodplain

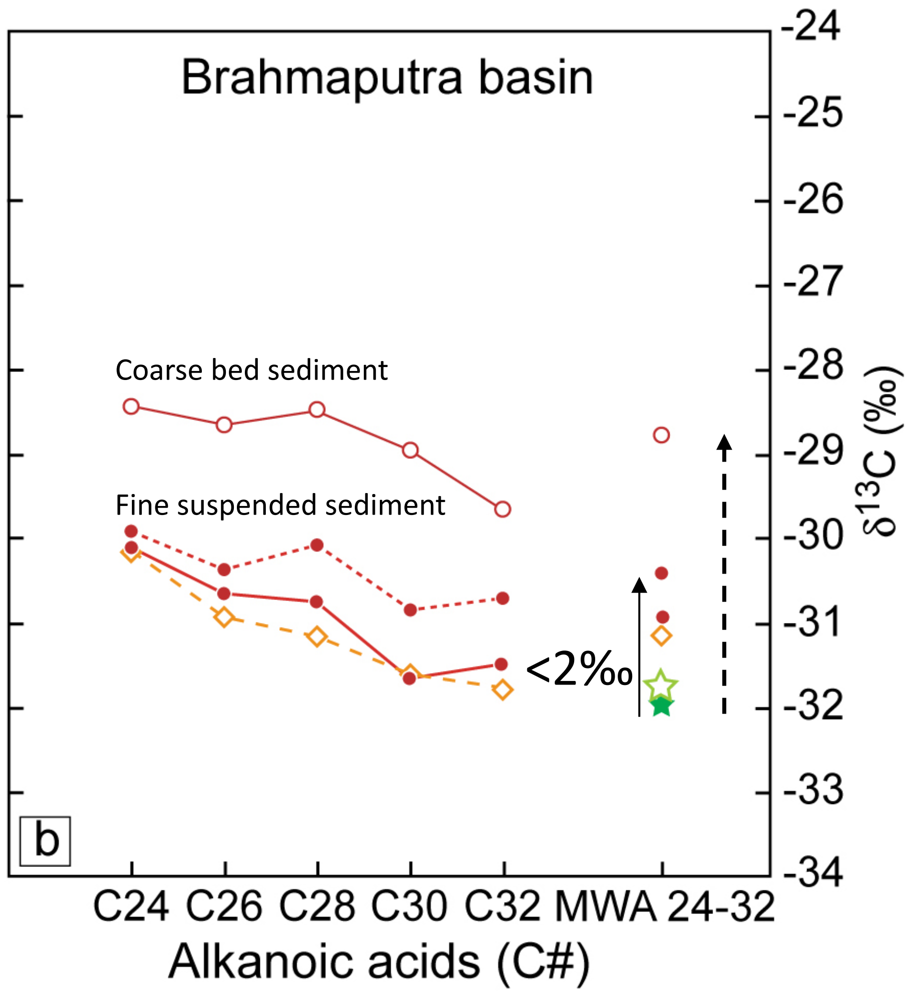


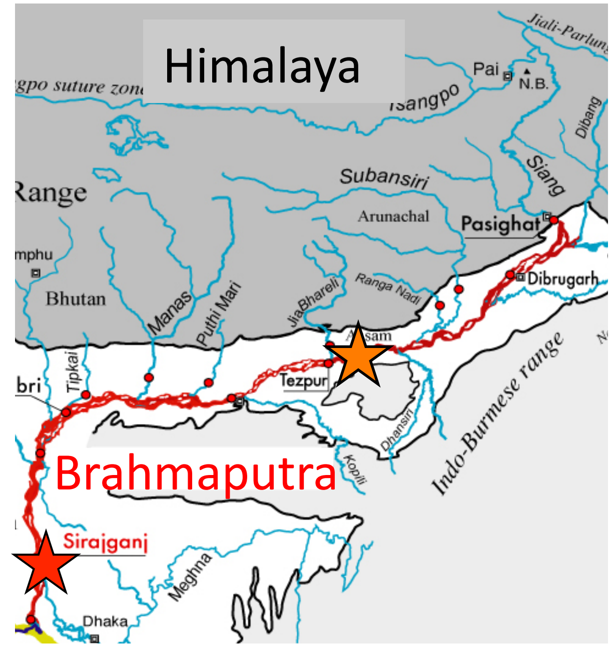


- Replacement of mountainous “C3” OC by plain “C4” OC
- At least 50% of Himalayan OC is oxidised and replaced by floodplain OC

Galy et al., EPSL, in press

Fate of OC in the Brahmaputra basin





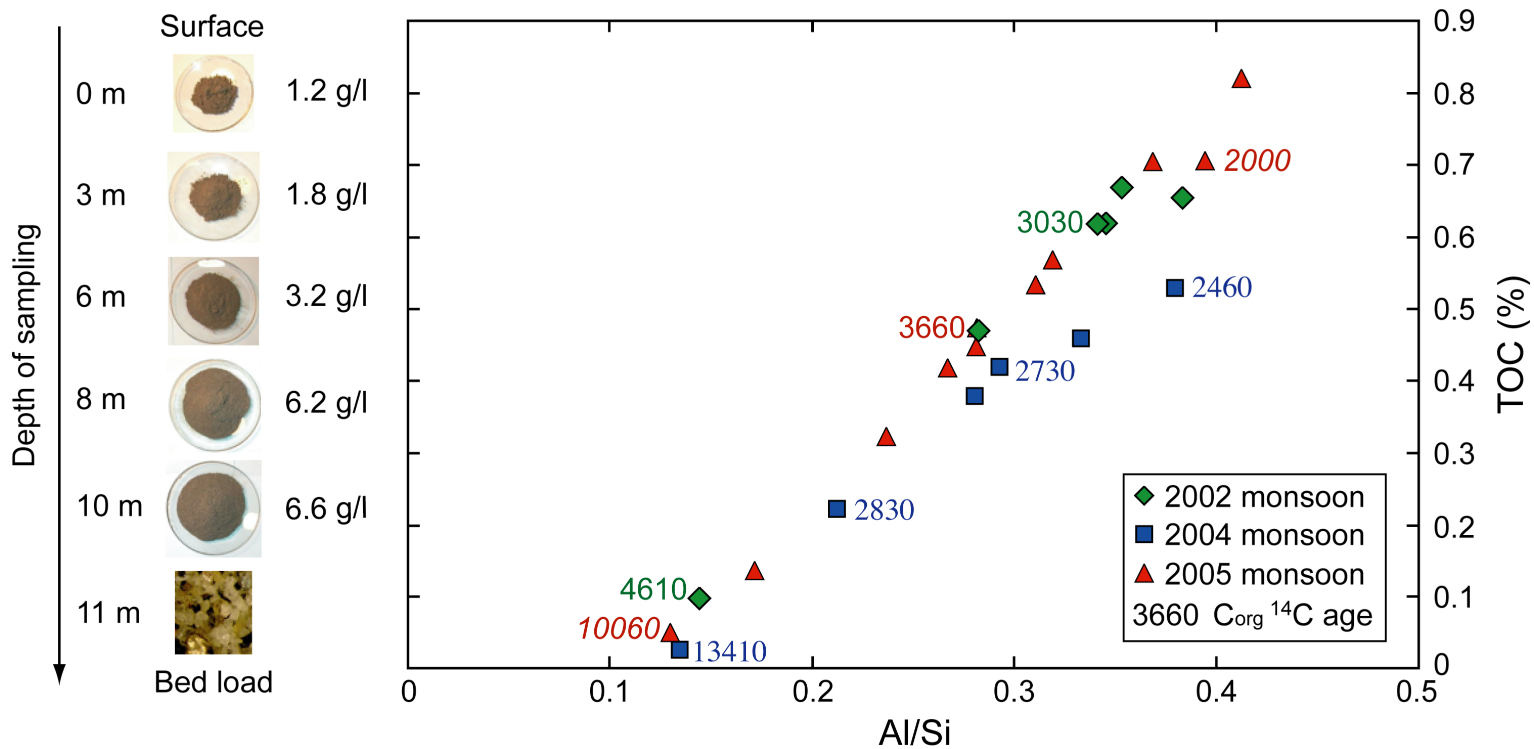
- Differential behaviour of:
  - coarse and fine sediments
  - vegetation debris and "soil" OC
- Slight replacement of "soil" OC in fine sediments
- Huge renewal of vegetation debris in coarse sediments

Galy et al., EPSL, in press

Geomorphologic control of OC fate

Ganges: wide floodplain, meandering river, extensive OC renewal
Brahmaputra: narrow floodplain, braided riv., limited OC renewal

Age of biospheric OC: use of bulk ^{14}C data

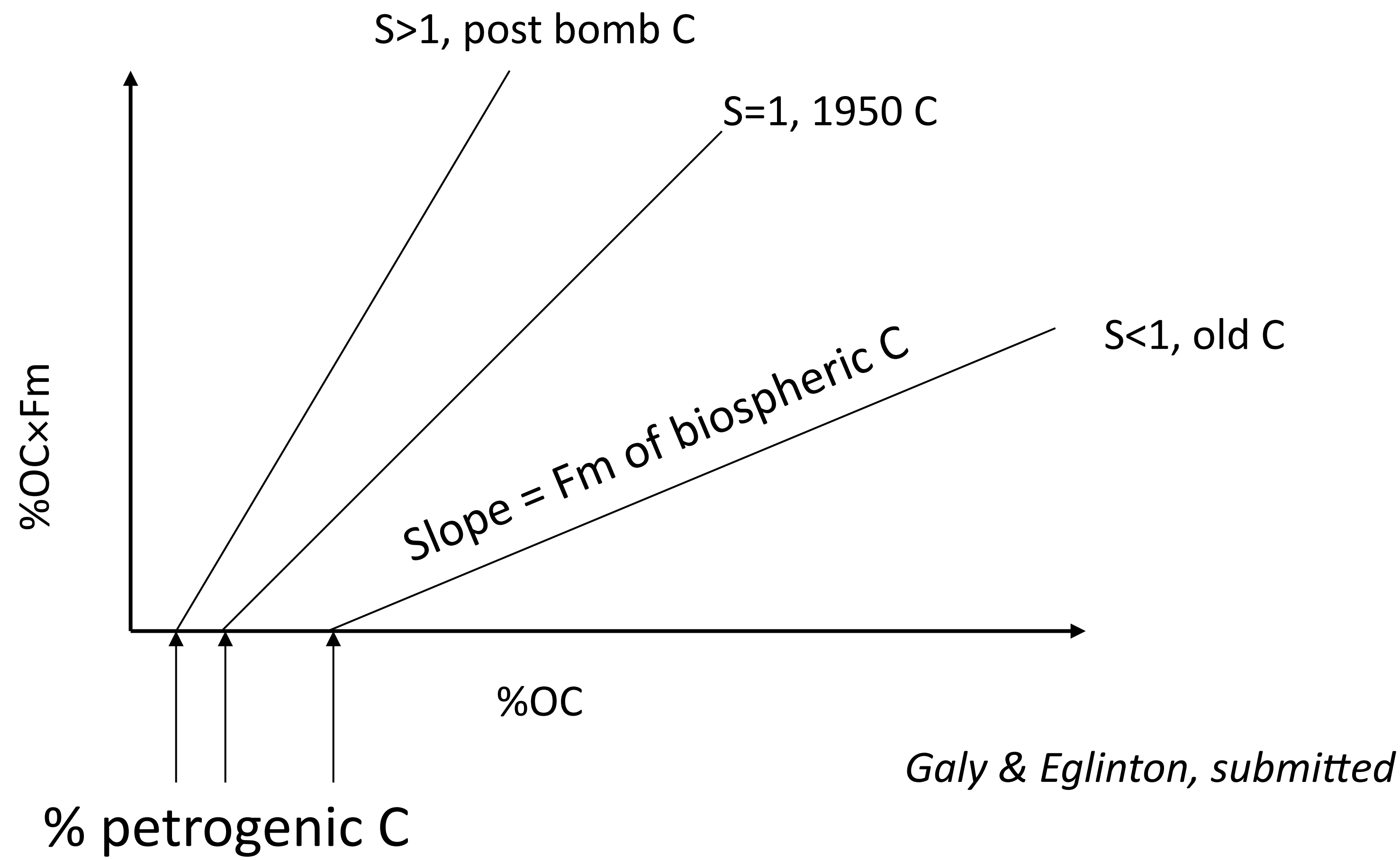


Galy et al., 2007 nature

➢ Binary mixing model:
petrogenic C (^{14}C dead) + biospheric C (contains some ^{14}C)

➢ Hypothesis:
(1) no soils older than de DL of the AMS (≈ 60ka)
(2) all petrogenic C is ^{14}C dead (i.e. no rock formation younger than 60ka)

Age of biospheric OC: use of bulk ^{14}C data

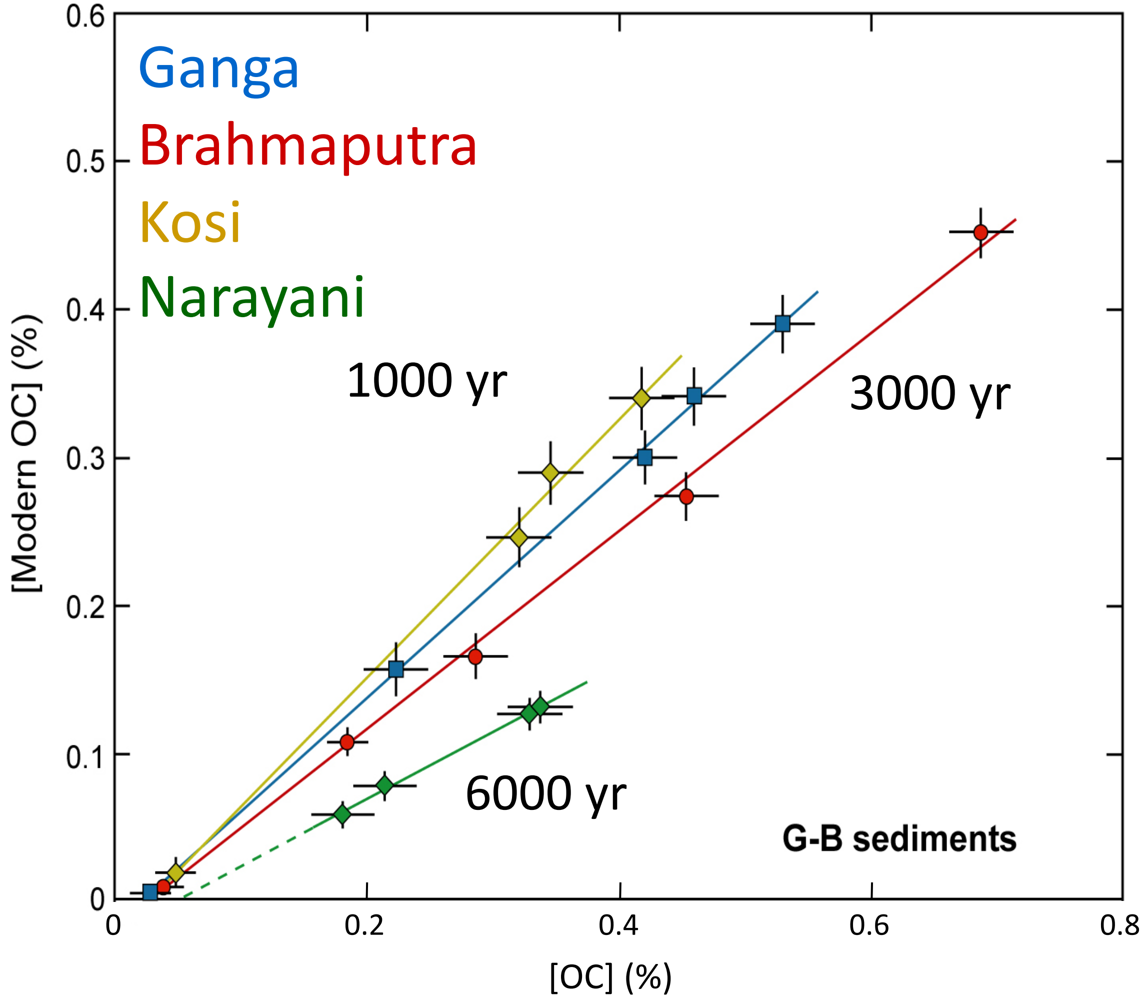


$$\%OC \times Fm = \%OC \times Fm_{biospheric\,C} - \%OC_{petro} \times Fm_{biospheric\,C}$$

Sediments with same amount of petrogenic C and same age of biospheric C plot on linear trends

Residence time of biospheric C in continental reservoirs

Galy & Eglinton submitted



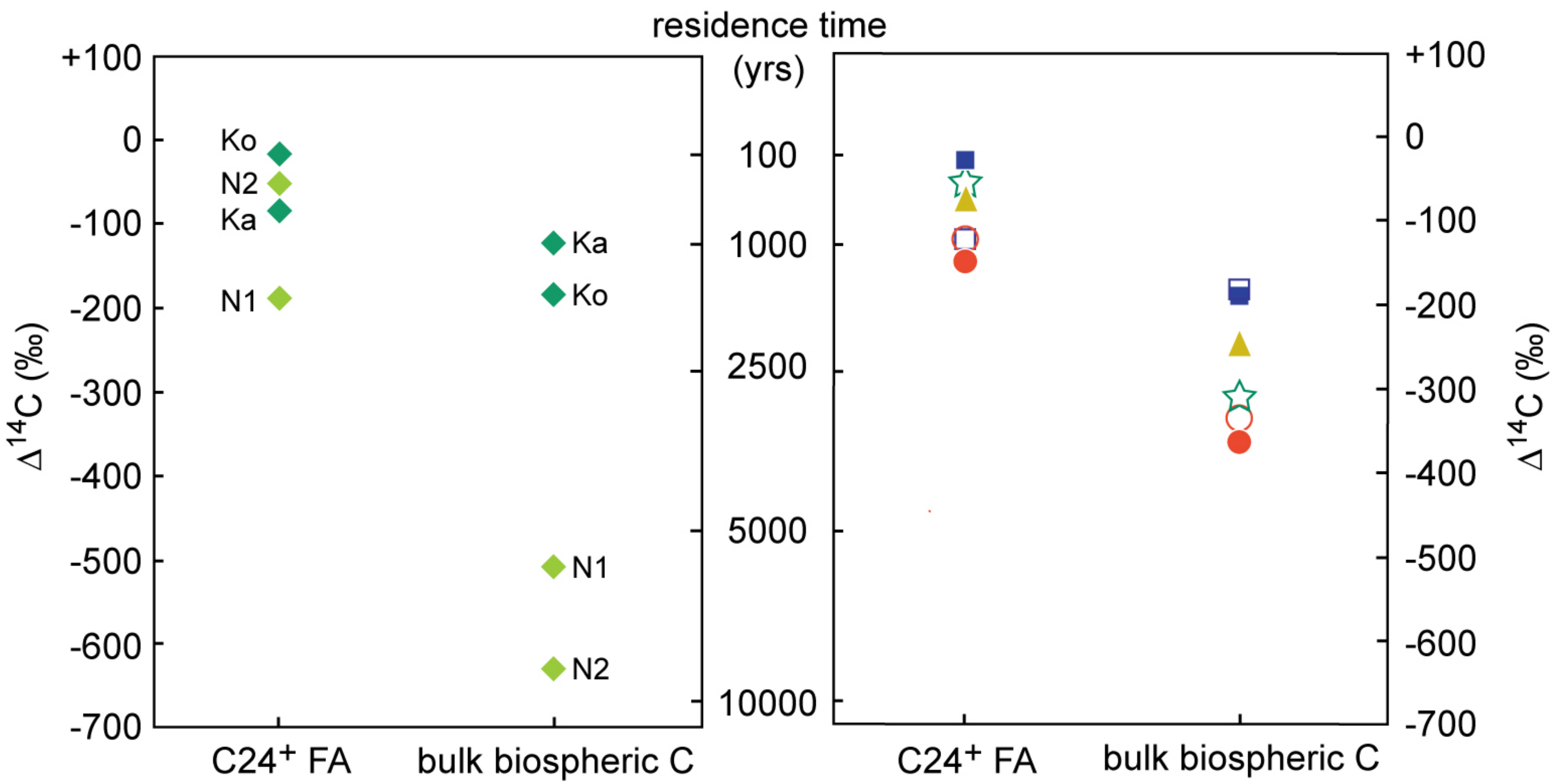
Depth profiles allow the determination of the age of the biospheric OC

Long residence time of biospheric C

Contribution of pre-aged OC in soils

^{14}C composition of vegetation biomarkers

Galy & Eglinton, submitted



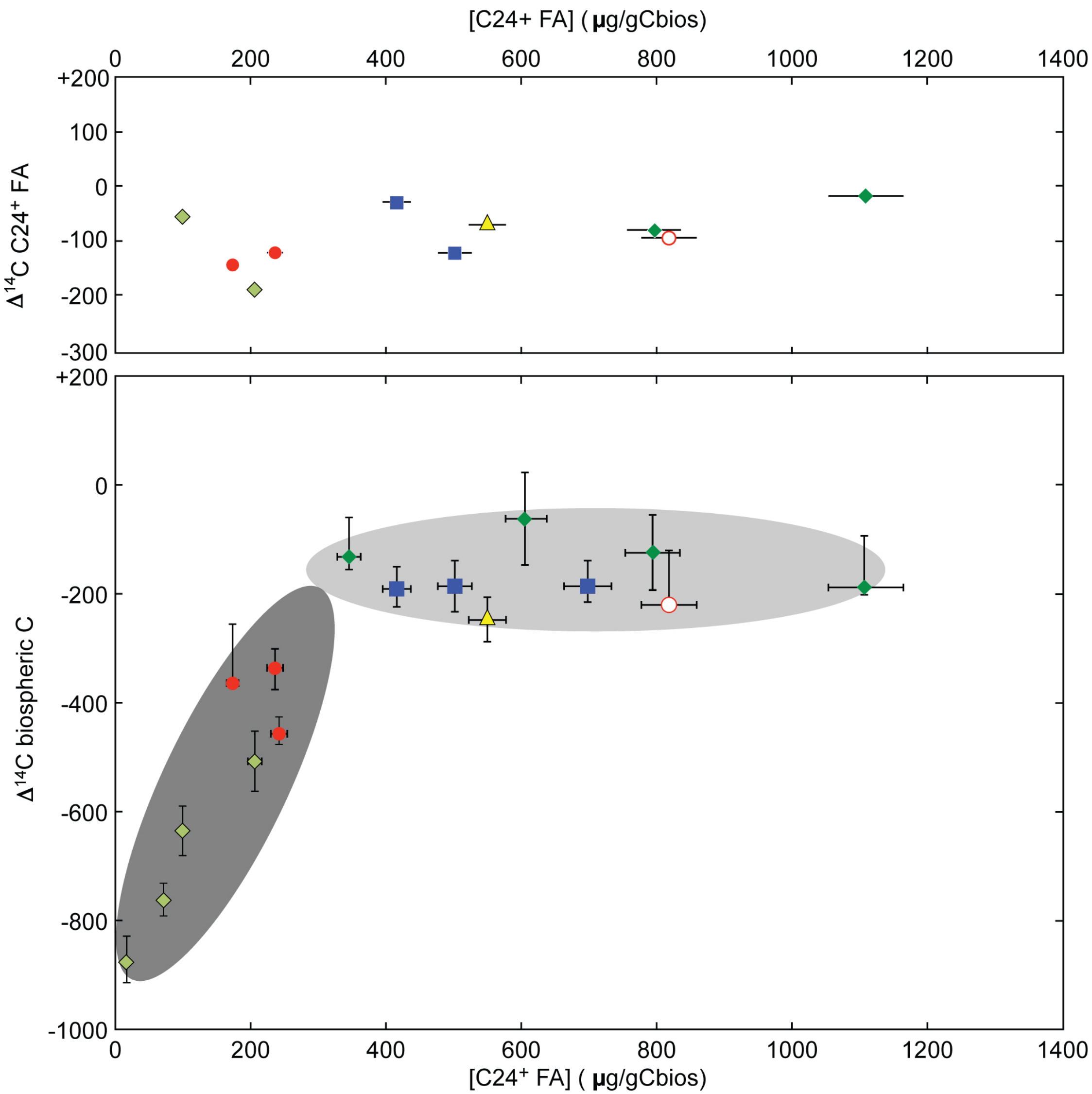
Vascular plants biomarkers are much younger than bulk biospheric C

Residence time of the vegetation component is not homogenous at the basin scale

Presence of a refractory component with longer residence time than bulk biospheric C

Residence time of the refractory component

Galy & Eglinton, submitted



Binary mixing: relatively young labile C + old refractory C

Old component residence time: >15 ka

Response to future warming

CLIMATE CHANGE

PERSPECTIVES

Permafrost and the Global Carbon Budget

Sergey A. Zimov, Edward A. G. Schuur, F. Stuart Chapin III

Science 2006

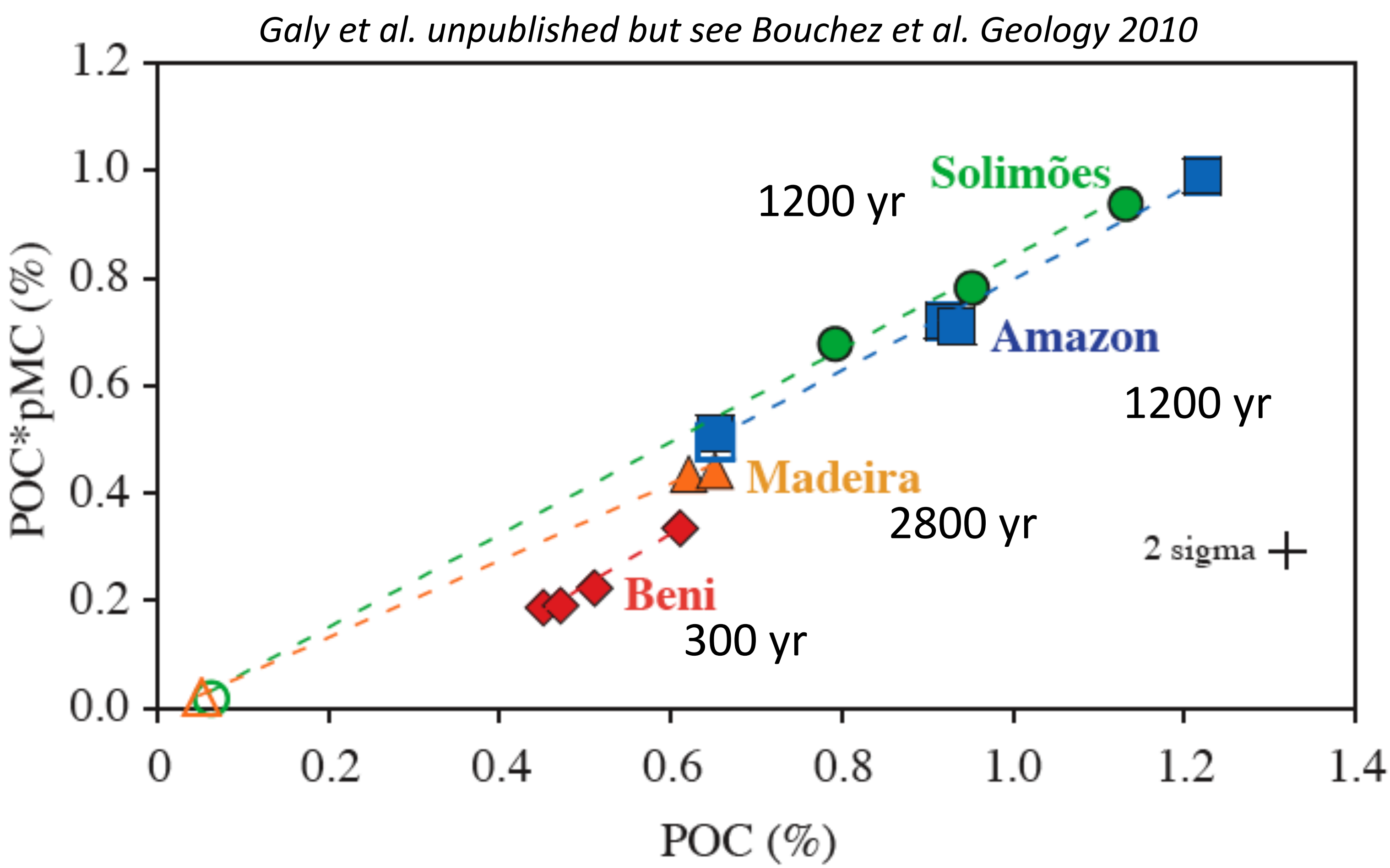
Kolyma river

High latitude: destabilization of permafrost carbon = source of CO_2

Himalayan system: destabilization of old component (decrease of residence time) = source of CO_2

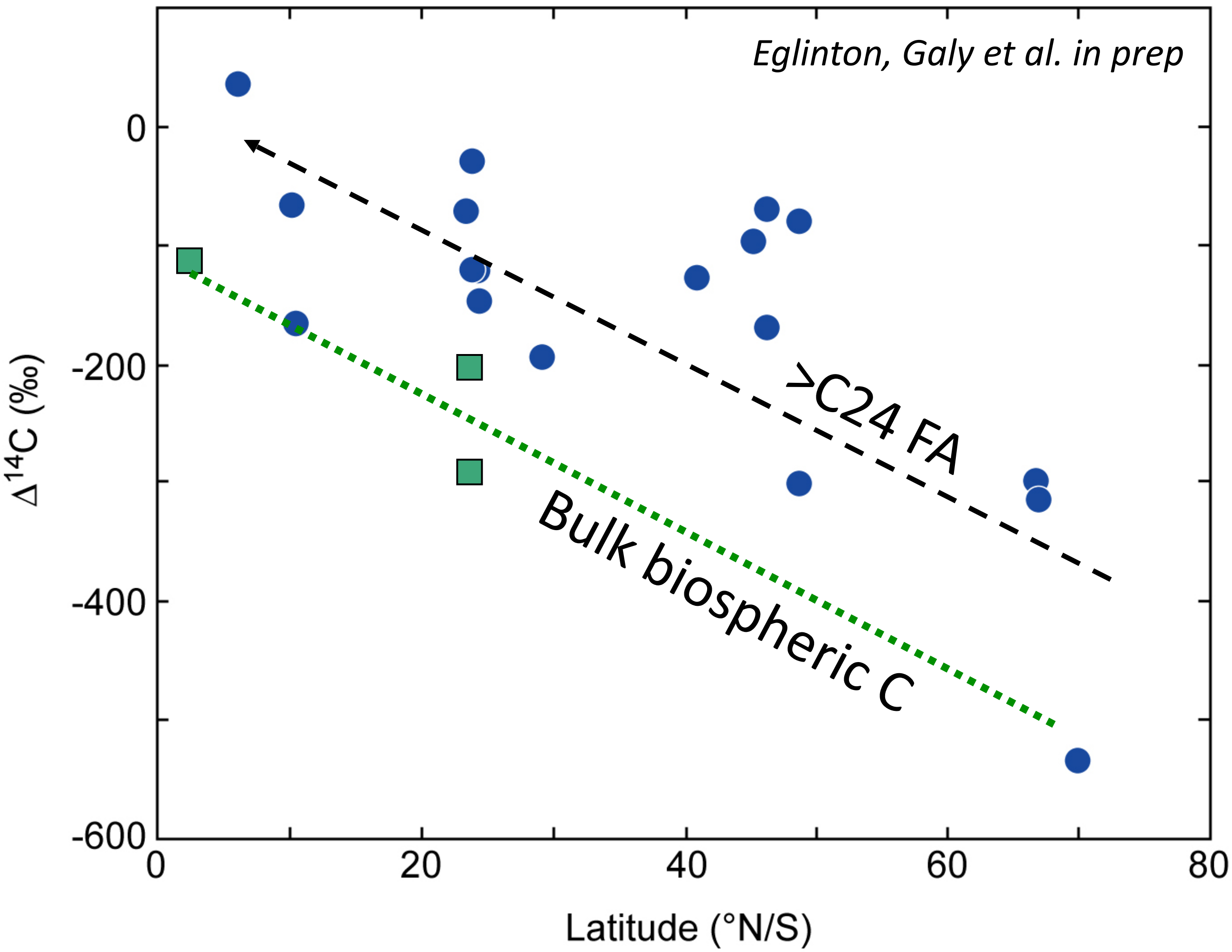
Positive feedback acting at both high and low latitudes (even in fast eroding systems like the Himalaya)

Residence time of biospheric C: the Amazon basin



Surprisingly long residence time in the Amazon floodplain

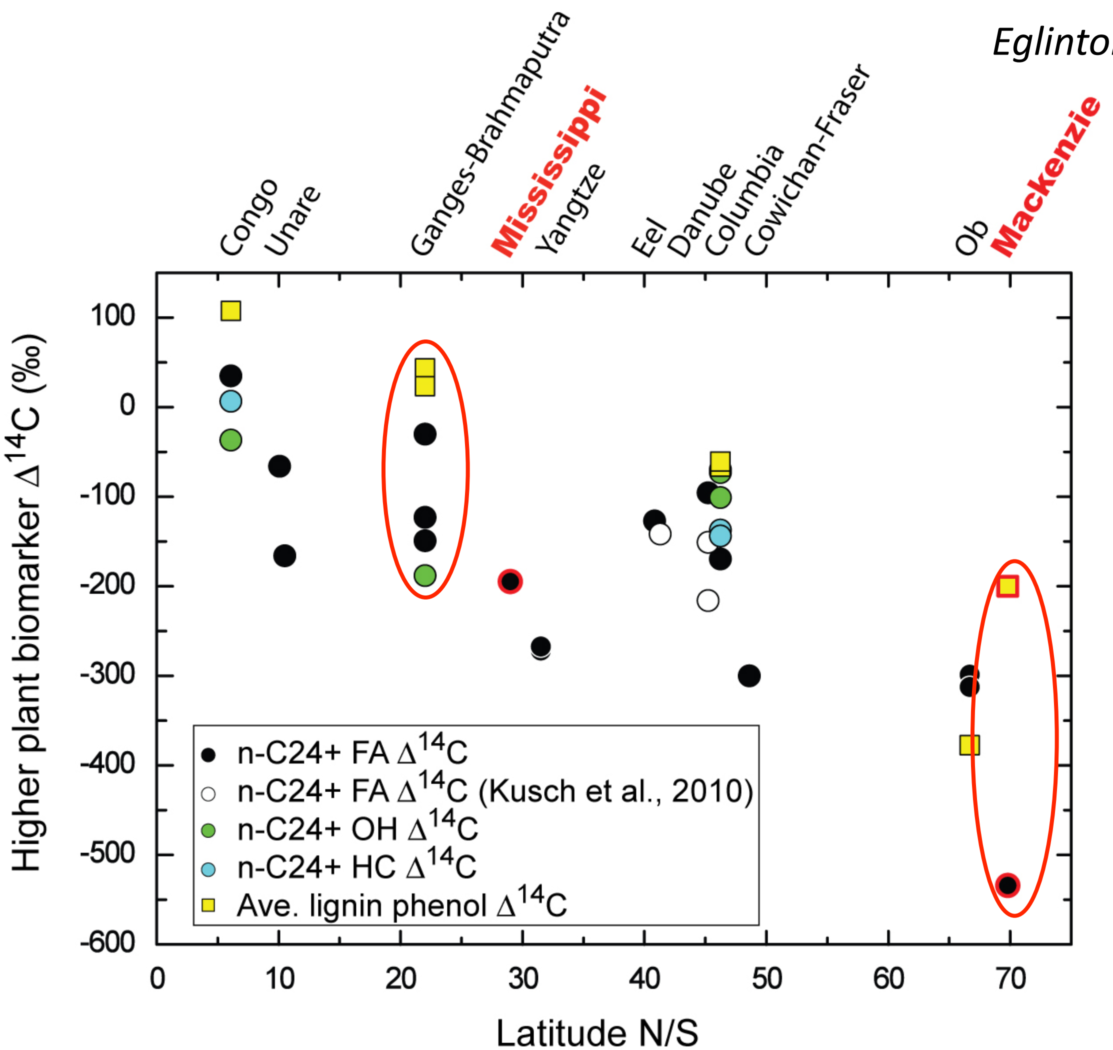
What controls the residence time of biospheric OC?



Latitudinal first order control: climate?

What controls the residence time of biospheric OC?

Eglinton, Galy et al. in prep



Second order controls: geomorphology? Human disturbance?