Carbonation of mantle peridotite: Natural systems, global carbon cycle, engineered capture & storage

Peter Kelemen, Jürg Matter, Greg Hirth,
Craig Manning, Lisa Streit Falk,
and many more

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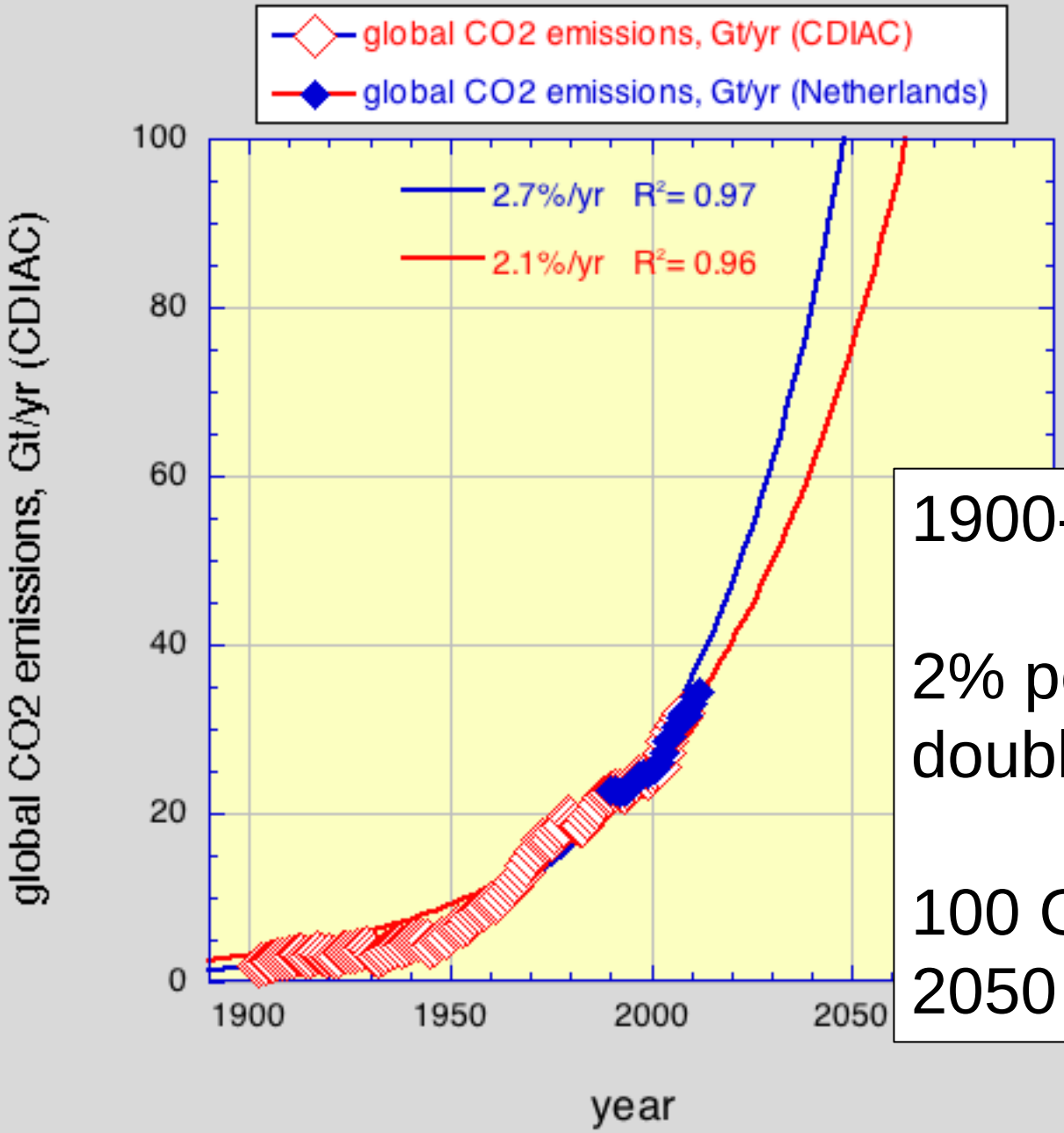

HEADLINE NEWS:
IPCC is shocked …
SHOCKED … that rate of emissions HAS increased in the past decade

1900-2012

2% per year ⇒ doubling time 34 yrs

100 Gt/yr by 2050 to 2060

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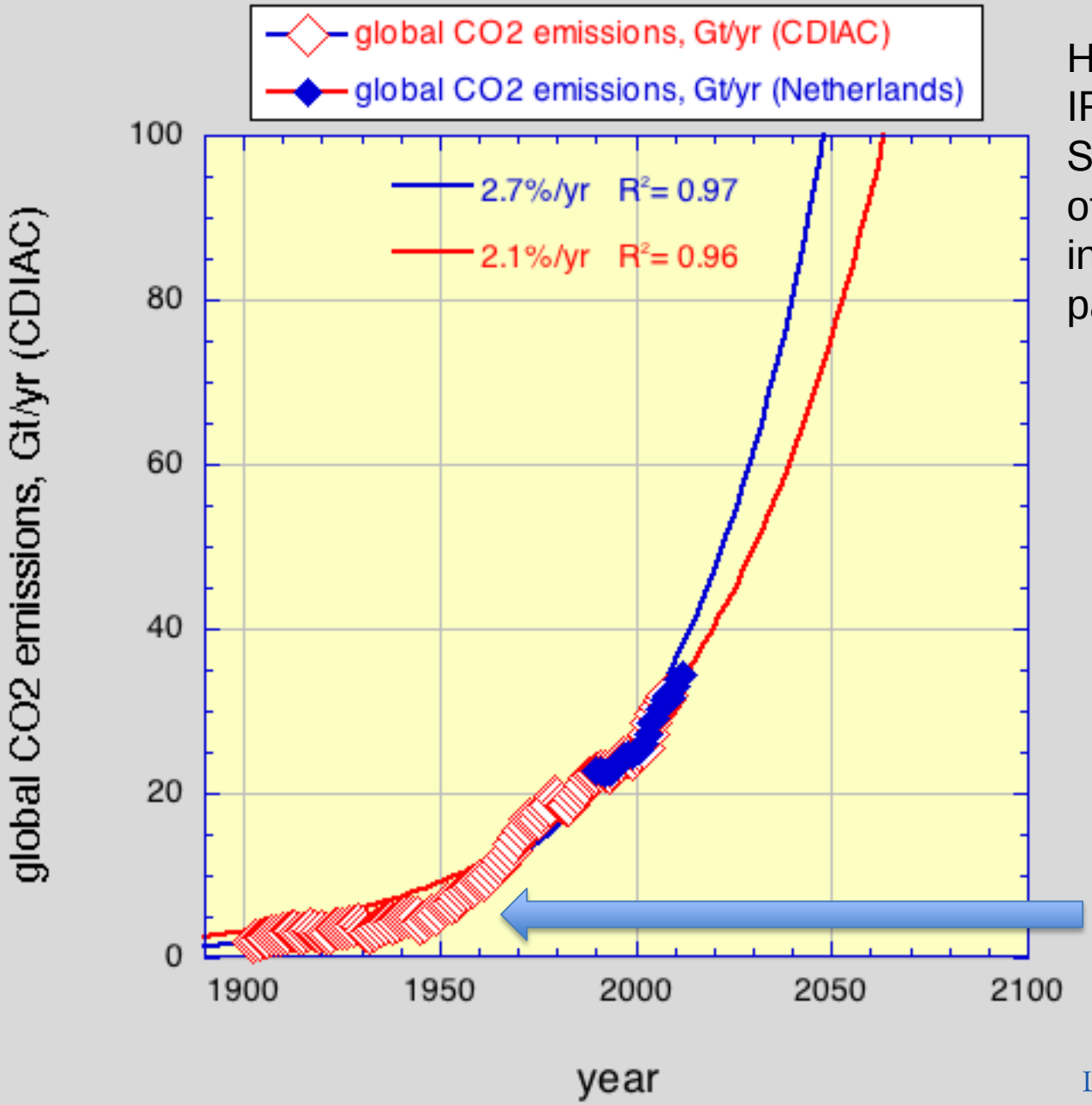

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4Gt ~ oil produced & transported

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London

became world's largest city in 1821

~ 1.4M people

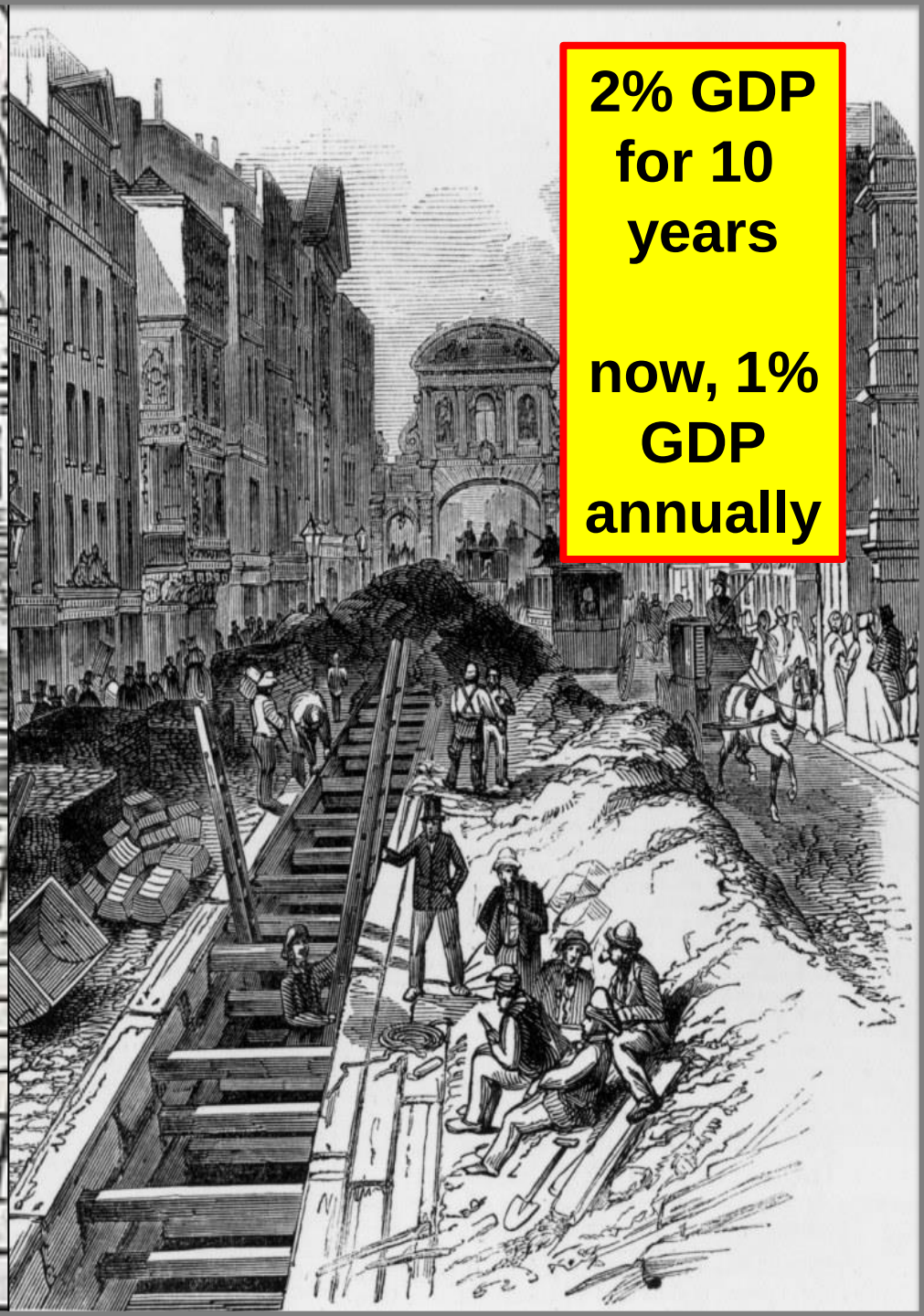
no central sewage disposal

gradually over the threshold

three large cholera outbreaks in first half of 19th century

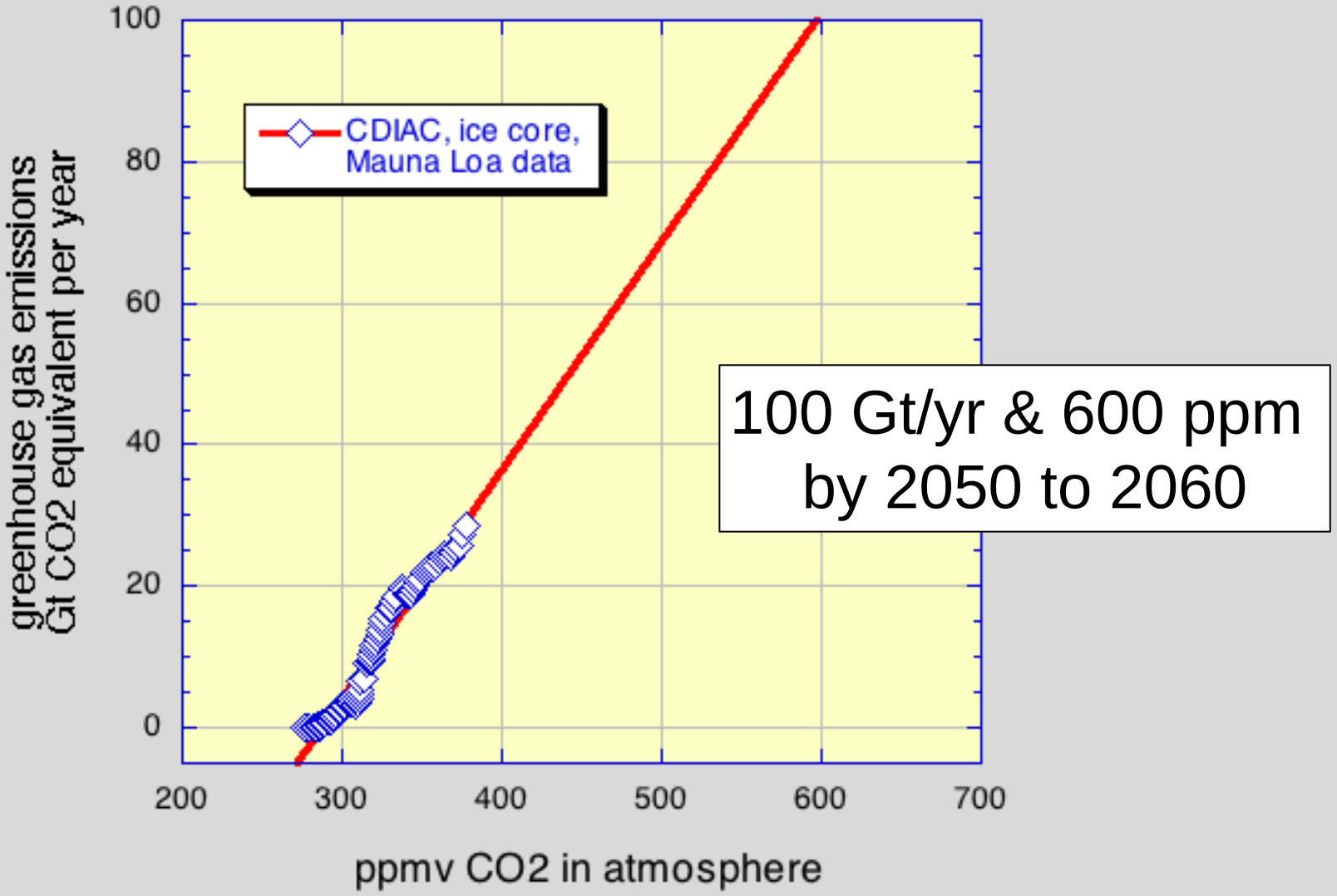
overshoot …

The Great Stink
1858



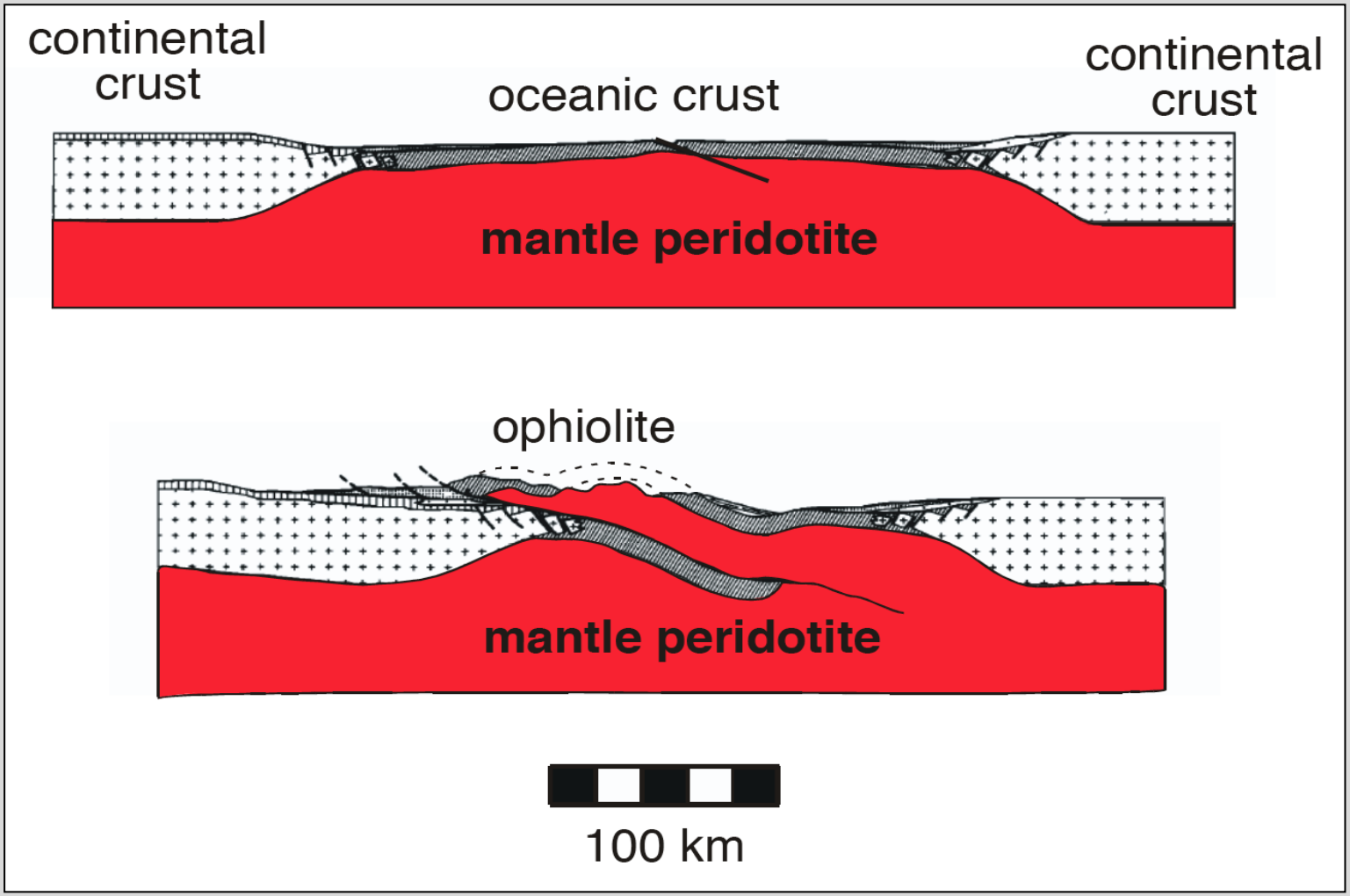
2% GDP for 10 years

now, 1% GDP annually


CDIAC, ice core,
Mauna Loa data
greenhouse gas emissions
Gt CO2 equivalent per year
100
80
60
40
20
0
200
300
400
500
600
700
ppmv CO2 in atmosphere
100 Gt/yr & 600 ppm
by 2050 to 2060

olivine-rich rock (peridotite) near the surface

$$Mg_2SiO_4 + CO_2 = 2MgCO_3 + SiO_2$$



modified from Coleman, Ophiolites, Kluwer, 1977


natural mineral
carbonation
in peridotite

natural mineral carbonation in peridotite

in Oman, 10^4 to 10^5 t/yr
1000 t/km^3/yr, 1 gm/m^3/yr

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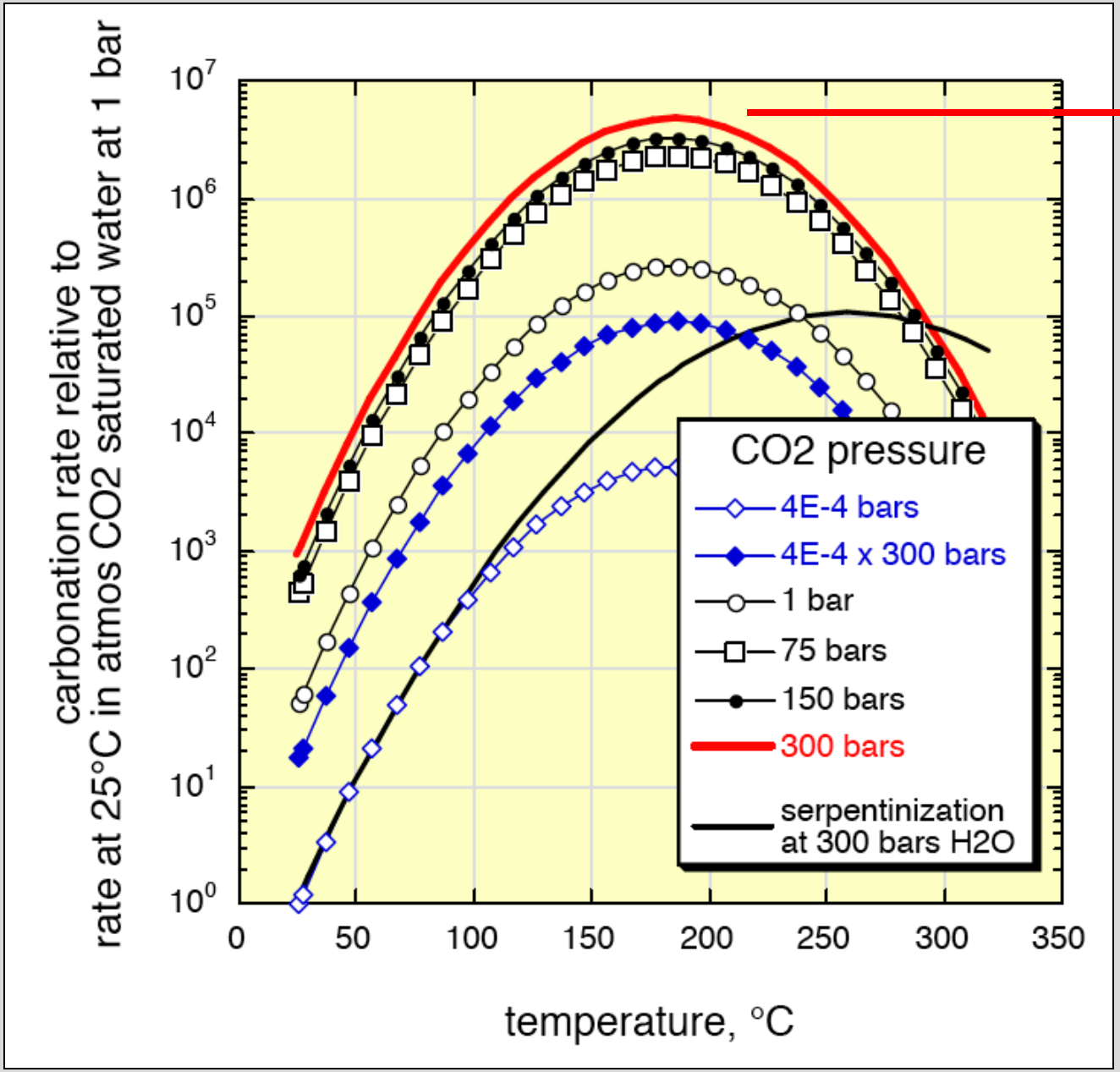
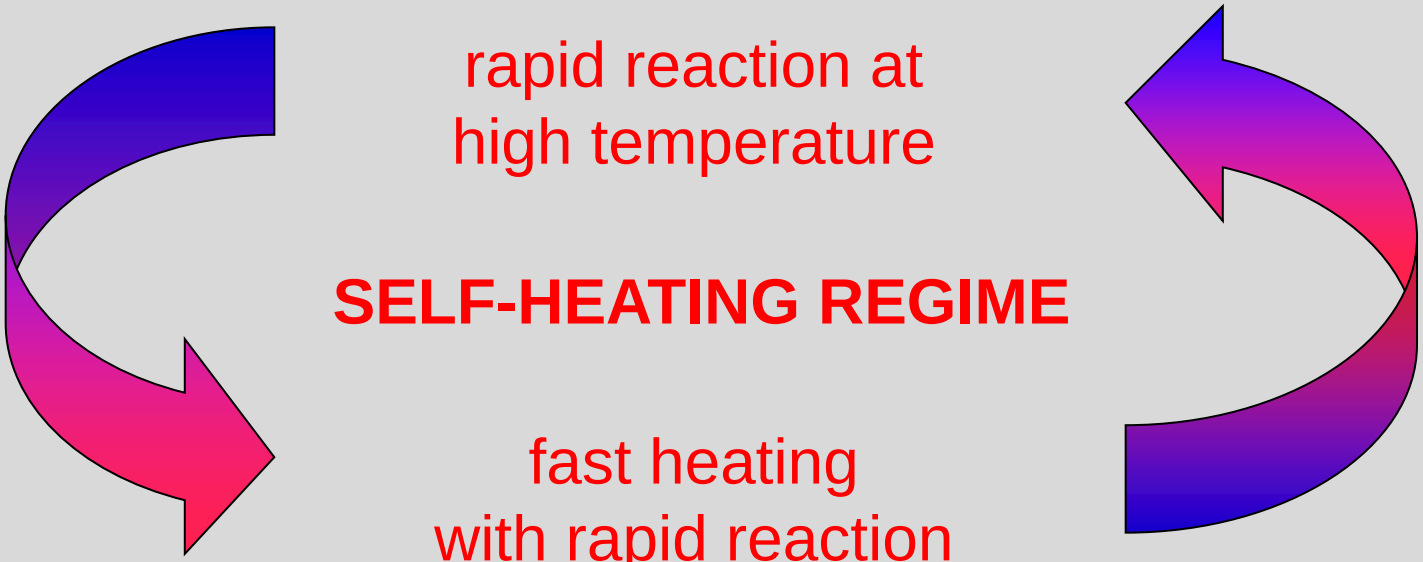


x 10^3 t/km^3/yr
=
~ 1 Gt/km^3/yr

Kelemen & Matter, Proceedings of the National Academy of Sciences, 2008

reactions that condense fluid or gas to form solid usually evolve heat, and increase solid volume



Martin & Fyfe, 1970

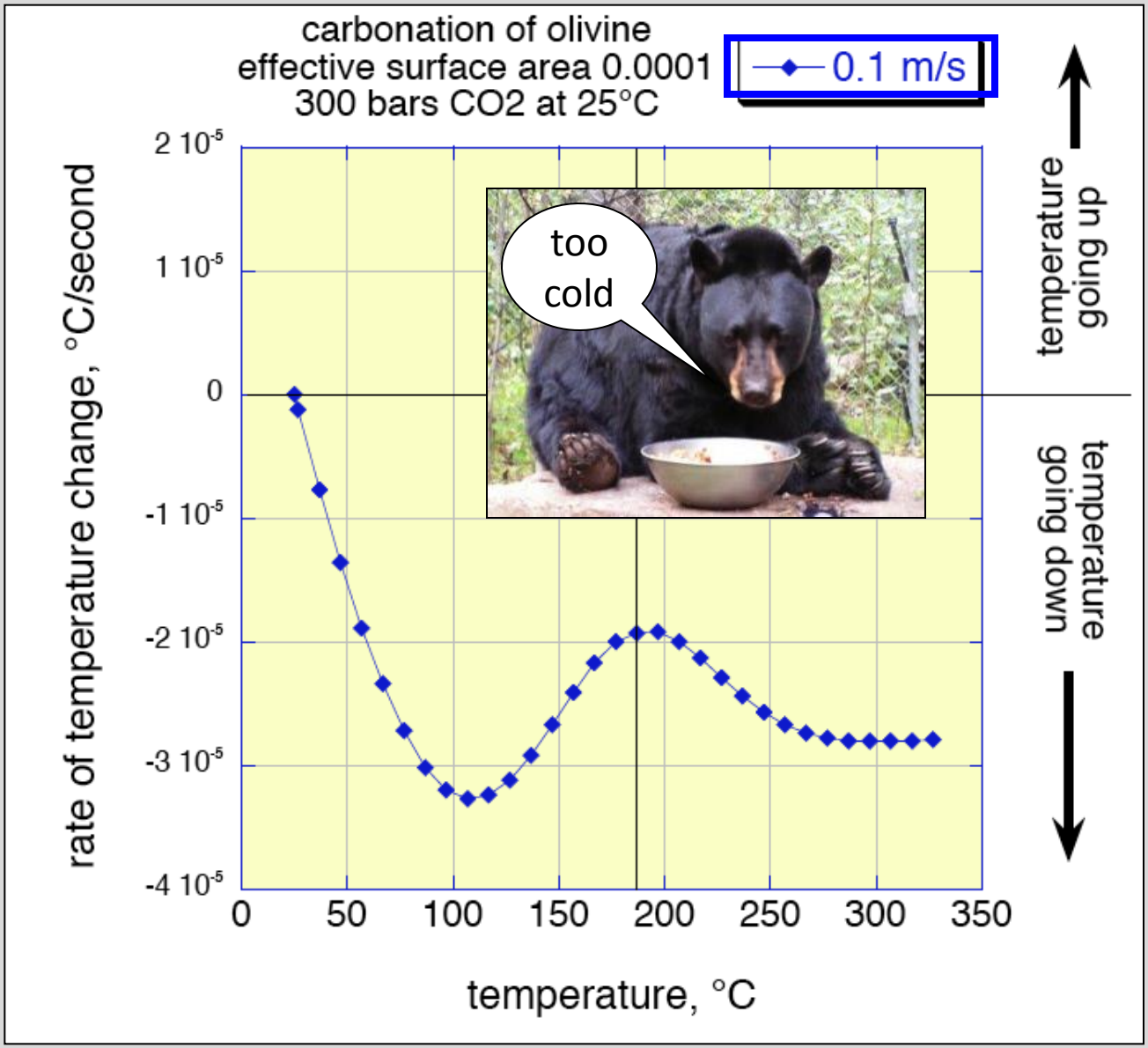
zero-dimensional thermal model

$$dT/dt =$$

$$(T_{in}-T)\, \rho_f\, C_p^f\, \phi\, w/(\rho_s\, C_p^s\, d)$$ advective fluid flow

$$-(T-T_o)\, k/d^2$$ thermal diffusion

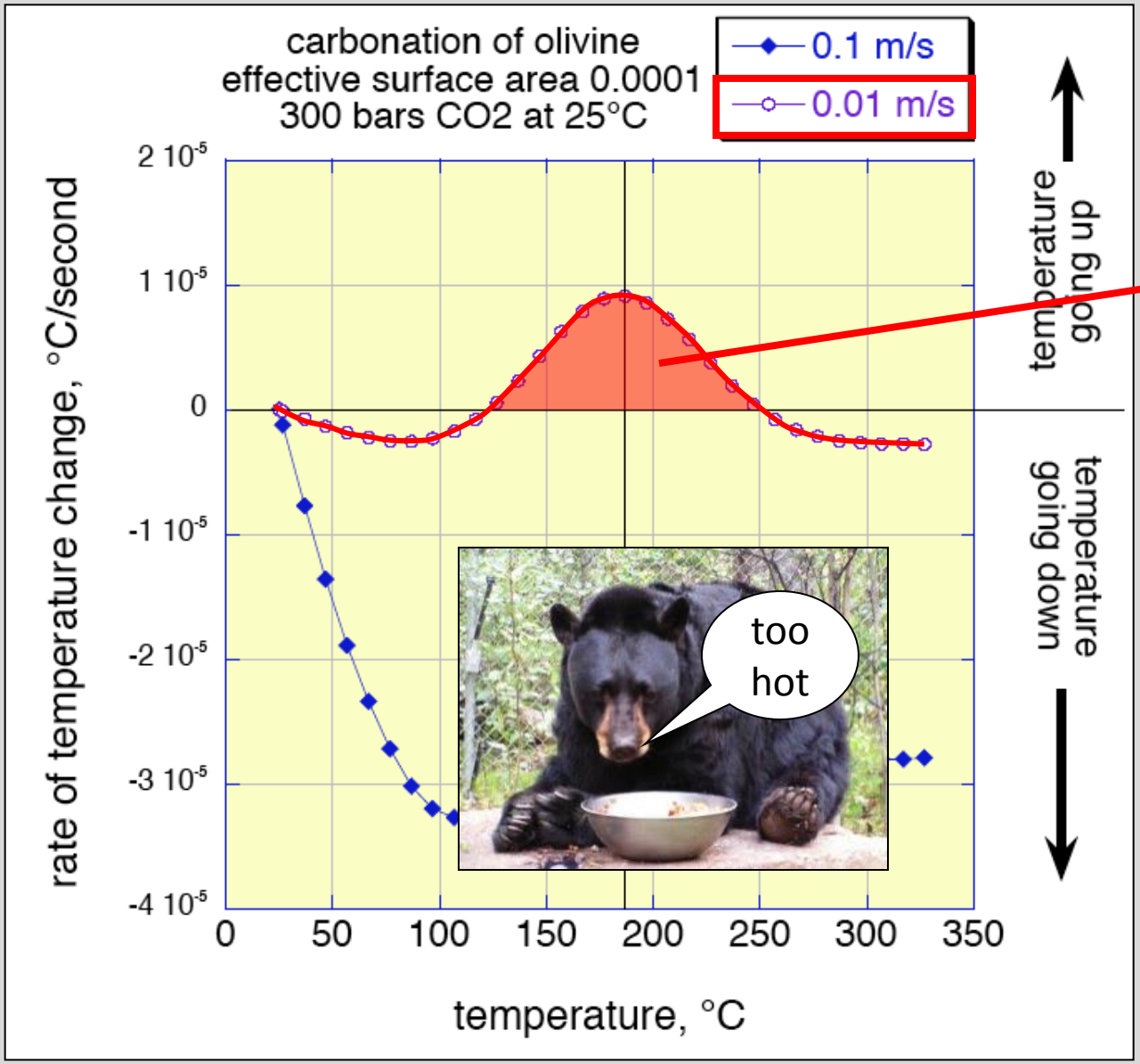
$$+ G(T,P_{CO2})\, A\, \Delta H/[C_p^s(1-\phi)+C_p^f(\phi)]$$ heating from reaction



temperature change
=
cooling from cold fluid
+
cooling to surroundings
+
heating from reaction

here:
rapid flow
⇒ cooling

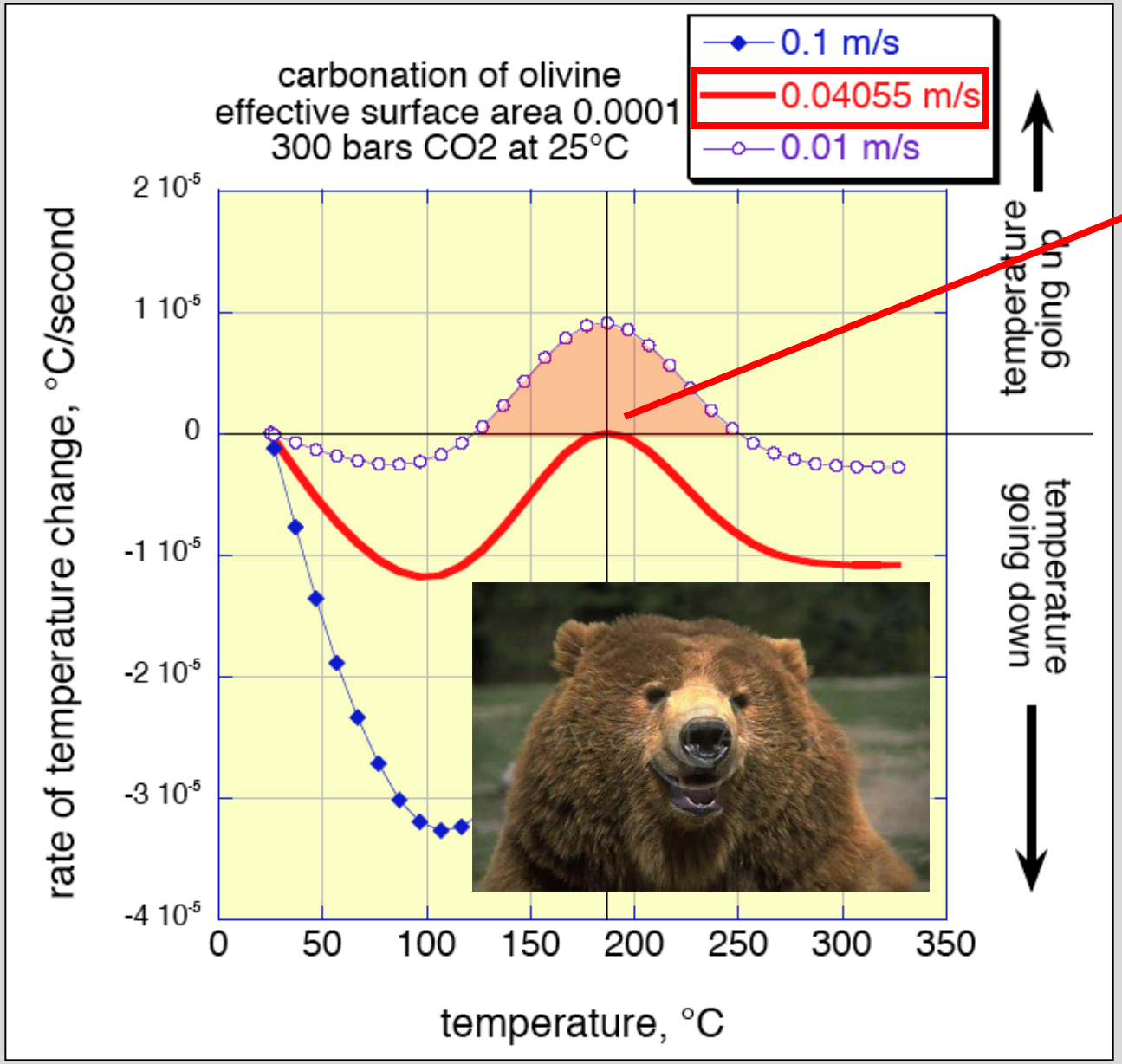
Kelemen & Matter, Proceedings of the National Academy of Sciences, 2008



self heating regime

here:
slower flow
$\Rightarrow$ heating
becomes
important

Kelemen & Matter, Proceedings of the National Academy of Sciences, 2008



no change

here:
flow rate tuned to maintain constant temperature at optimal reaction rate

Kelemen & Matter, Proceedings of the National Academy of Sciences, 2008

zero-dimensional thermal model

$$dT/dt =$$

$$(T_{in}-T)\, r_f\, C_p^f\, f\ \ w/(r_s\, C_p^s\, d)$$

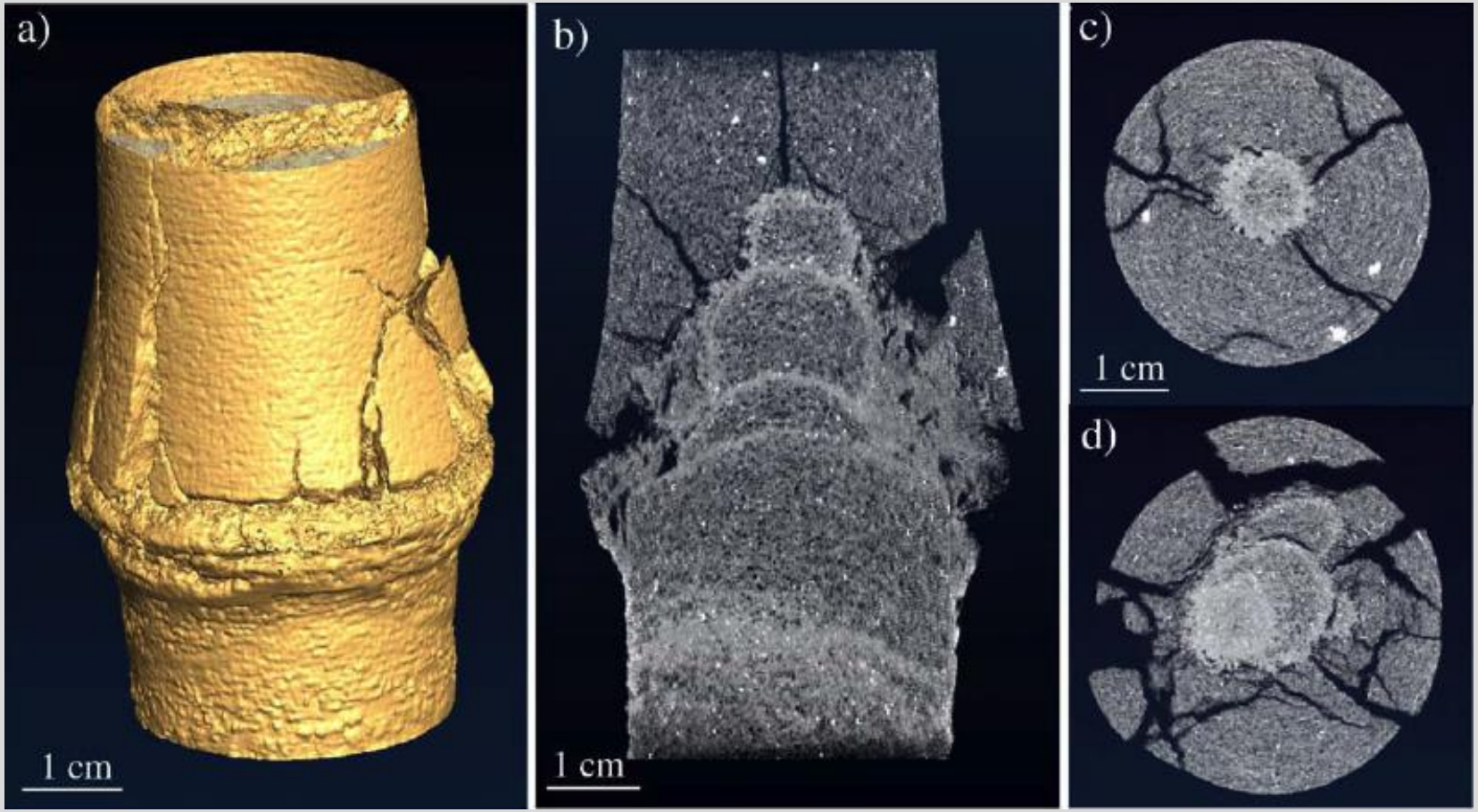
$$-\,(T-T_o)\, k/d^2$$

$$+\,G(T,P_{CO2})\,A\,DH/[C_p^s(1-f)+C_p^f(f)]$$

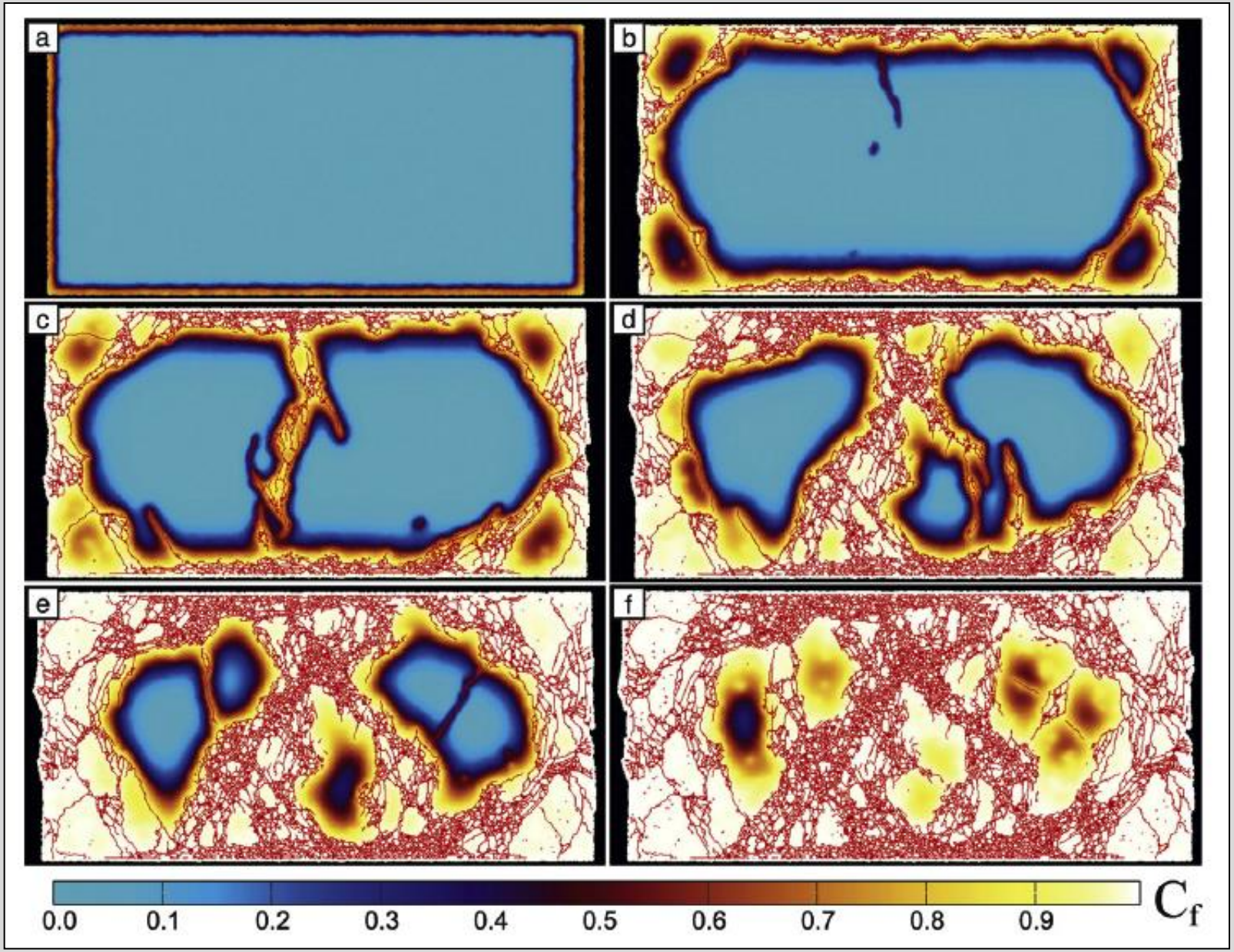
Kelemen & Matter, Proceedings of the National Academy of Sciences, 2008

reactions that condense fluid or gas to form solid usually evolve heat and increase solid volume

MacDonald & Fyfe , Tectonophysics 1985



Noirel et al., Chem. Geol. 2010



Royne et al. EPSL 2008 (Fletcher & Brantley, EPSL 2006; O'Hanley Geology 1992; MacDonald & Fyfe Tectonophys. 1985)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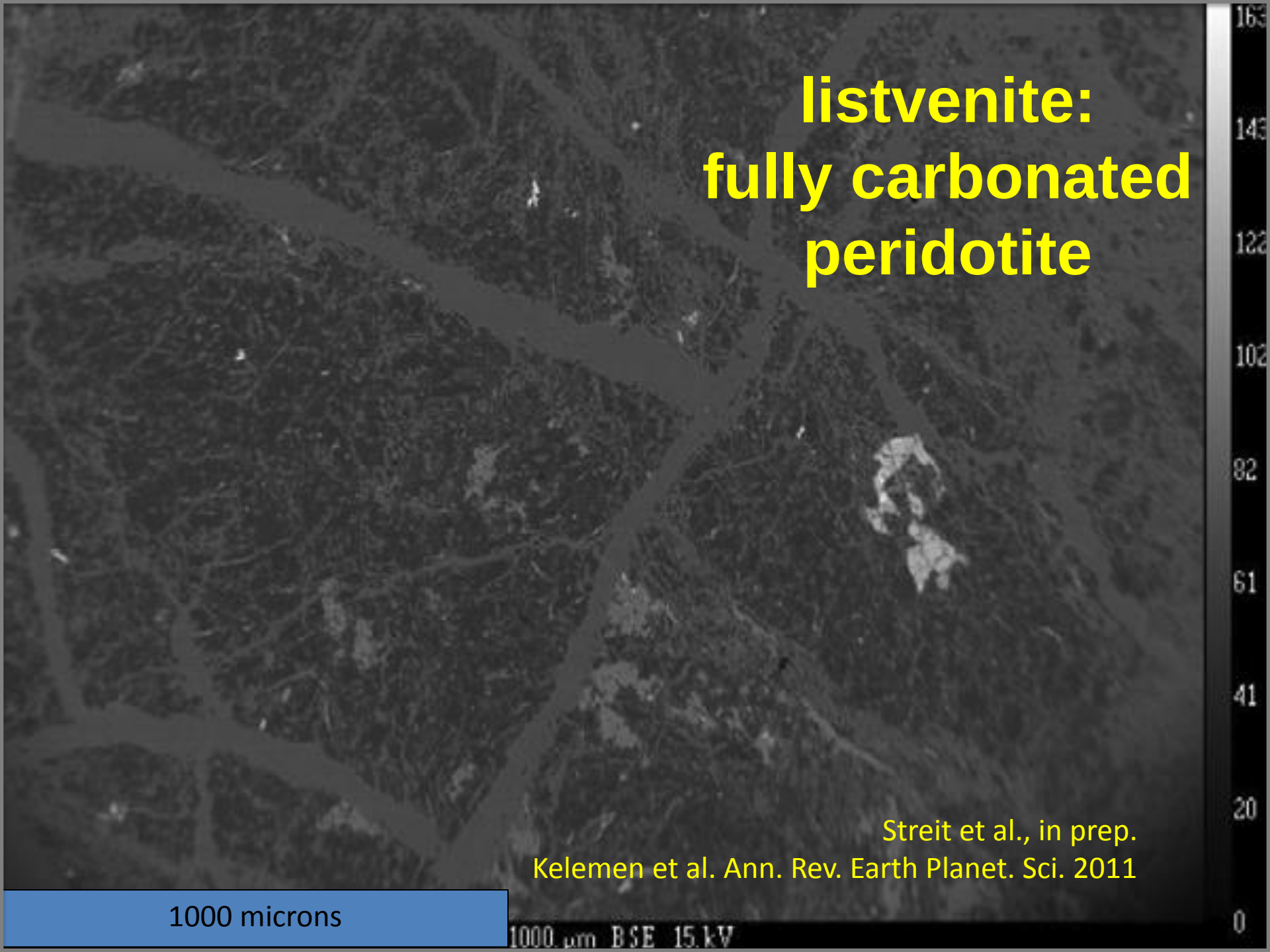
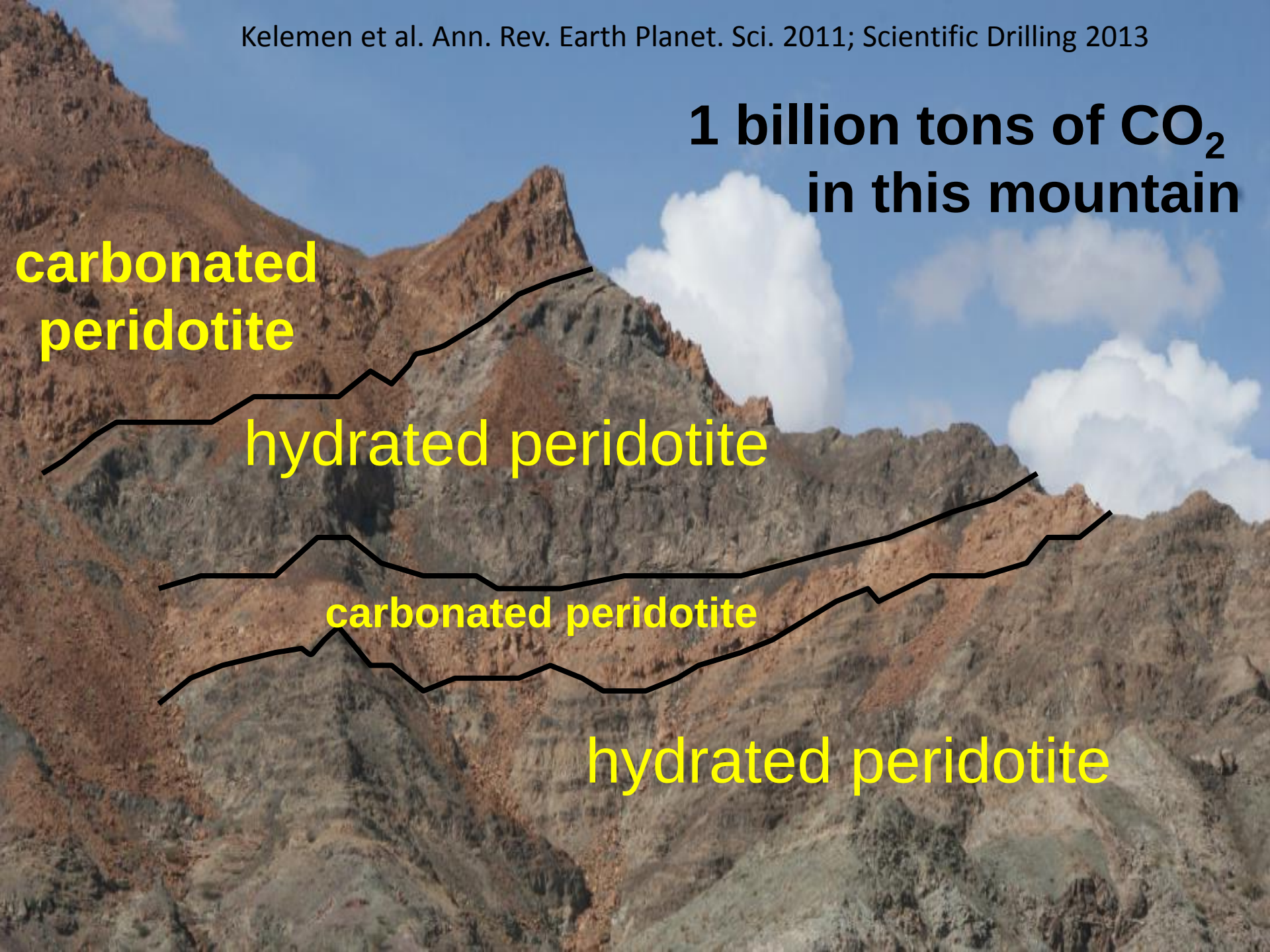
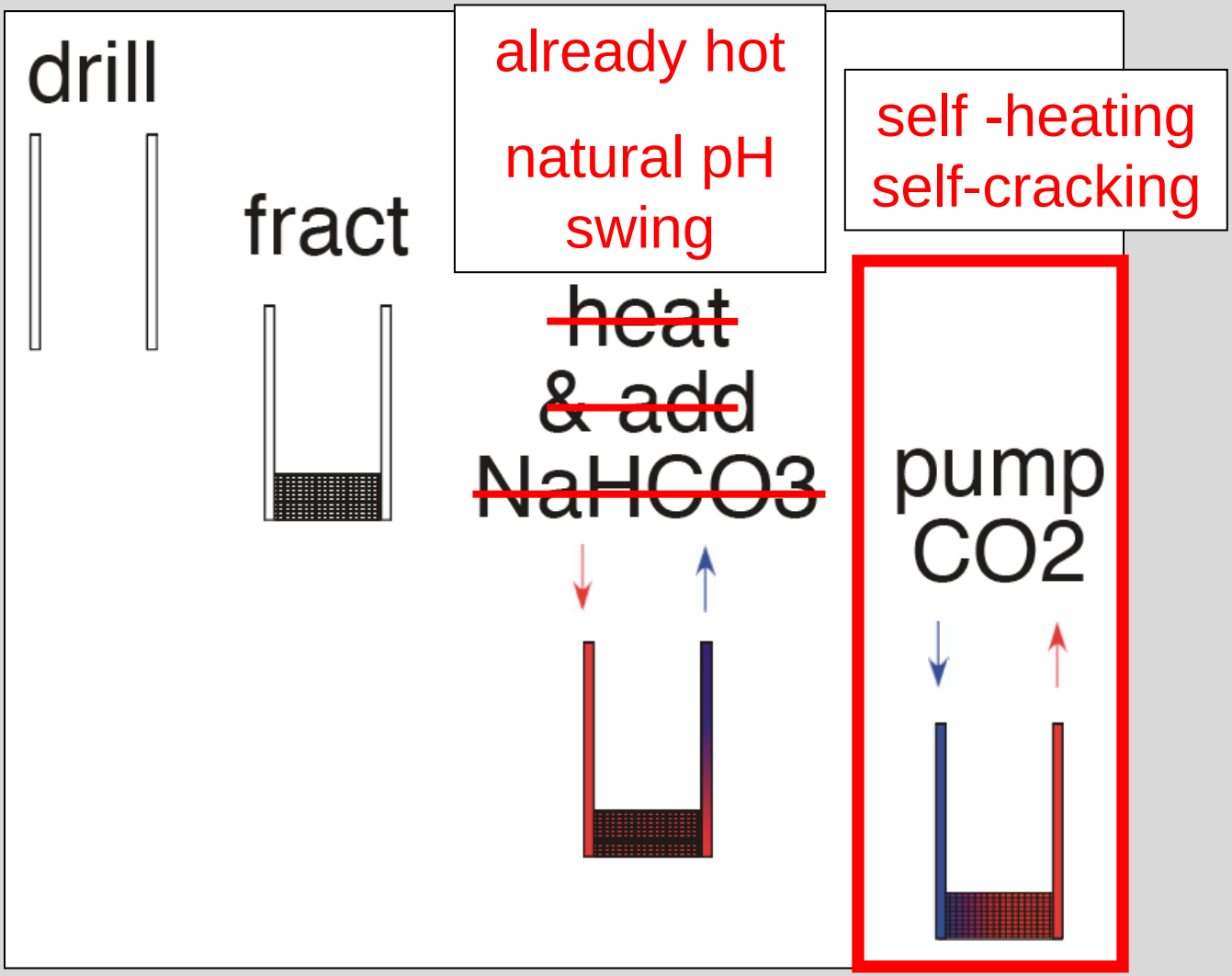

listvenite:
fully carbonated
peridotite
Streit et al., in prep.
Kelemen et al. Ann. Rev. Earth Planet. Sci. 2011
1000 microns
1000 µm BSE 15 kV
163
143
122
102
82
61
41
20
0


Kelemen et al. Ann. Rev. Earth Planet. Sci. 2011; Scientific Drilling 2013
1 billion tons of CO_2 in this mountain
carbonated peridotite
hydrated peridotite
carbonated peridotite
hydrated peridotite

in situ mineral carbonation with high P_{CO2}



individual wells ~ 1 Mt/yr

cost ~ injection into pore space

requires supply of CO_2

Kelemen & Matter, Proceedings of the National Academy of Sciences, 2008

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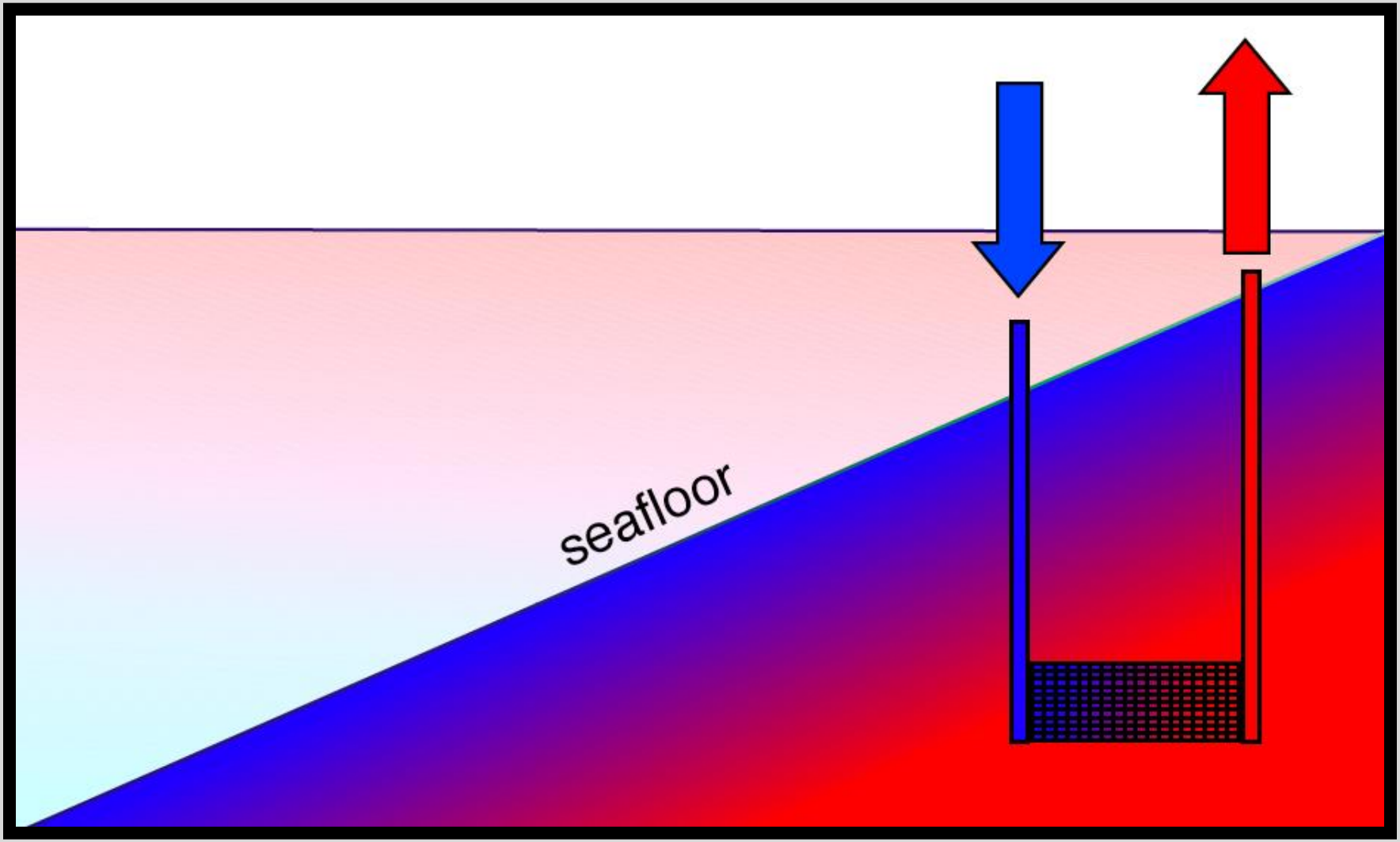
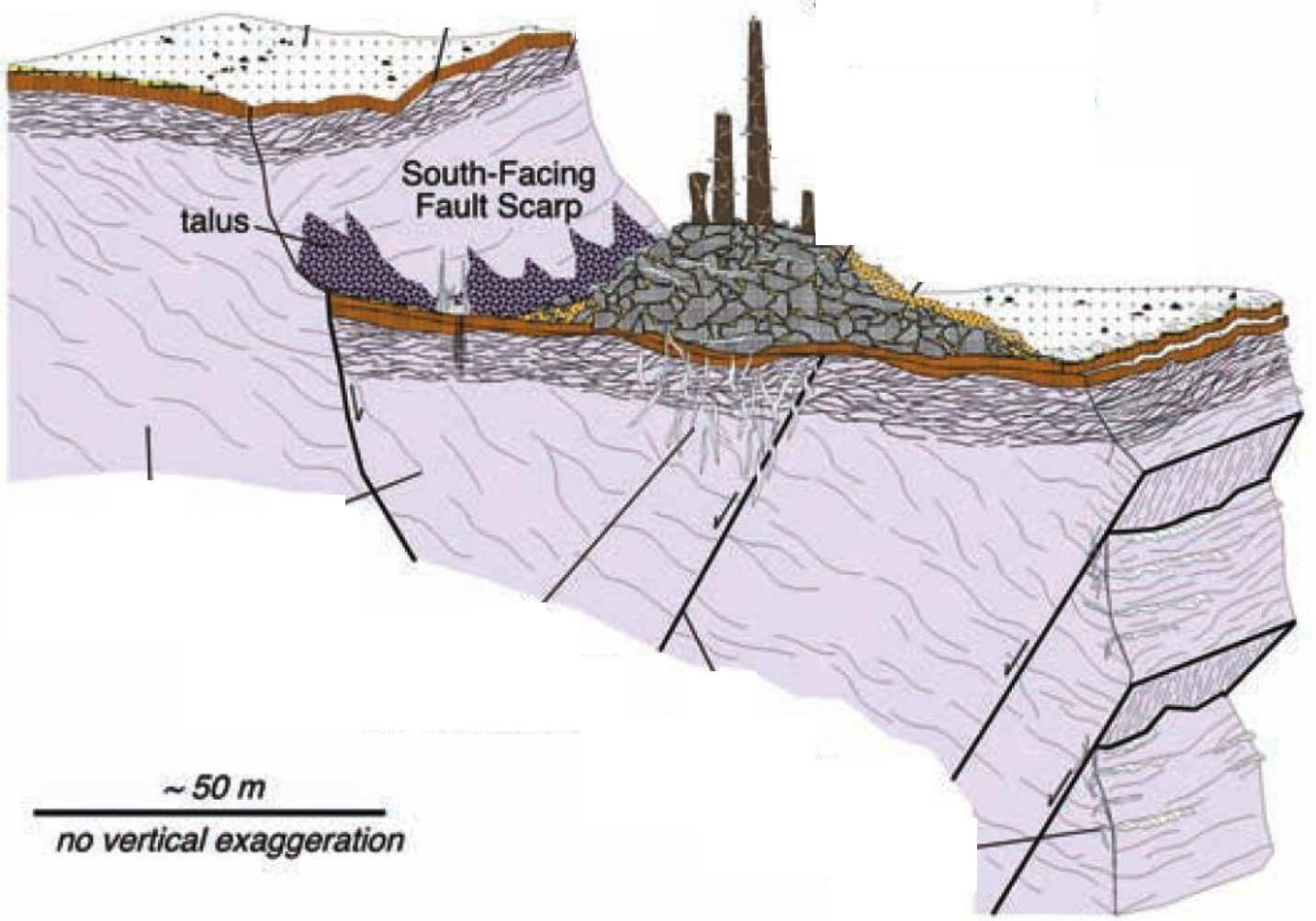
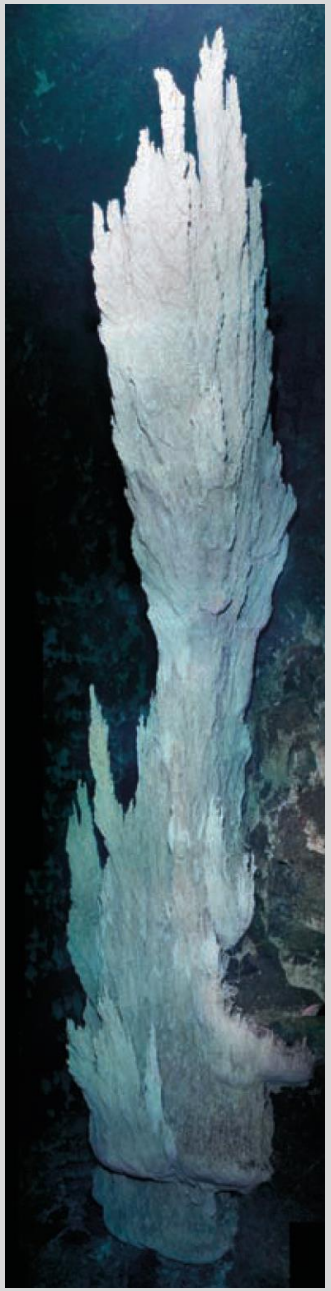
seawater as a CO2 transport fluid?



Kelemen & Matter, Proceedings of the National Academy of Sciences, 2008

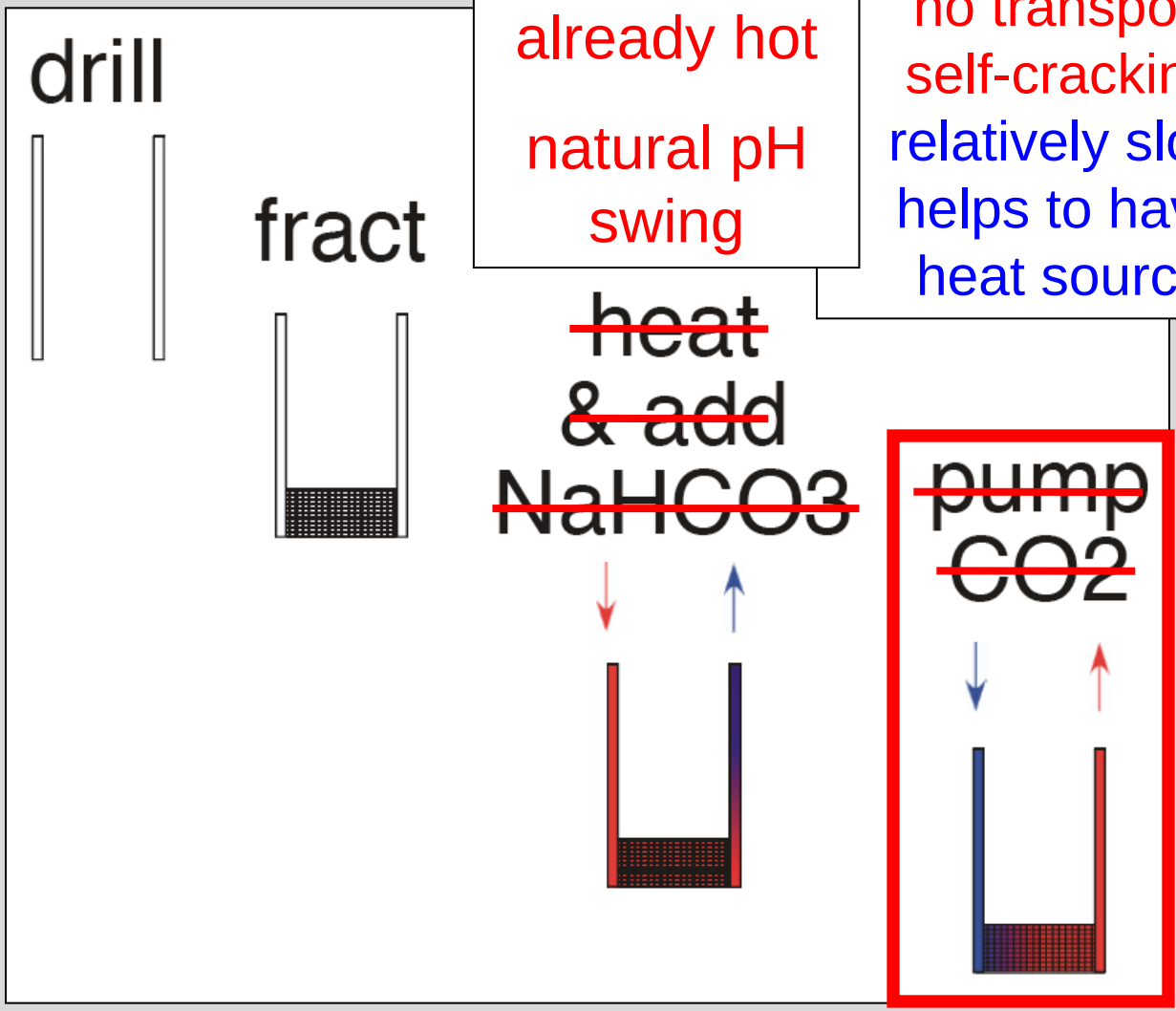
geologic CO2 **capture** & storage





Lost City hydrothermal vents, Mid-Atlantic Ridge
Kelley et al., Nature 2001, Science 2005; Früh-Green et al., Science 2003

in situ mineral carbonation using convecting seawater



already hot

natural pH swing

free CO2 capture
no transport
self-cracking
relatively slow
helps to have heat source

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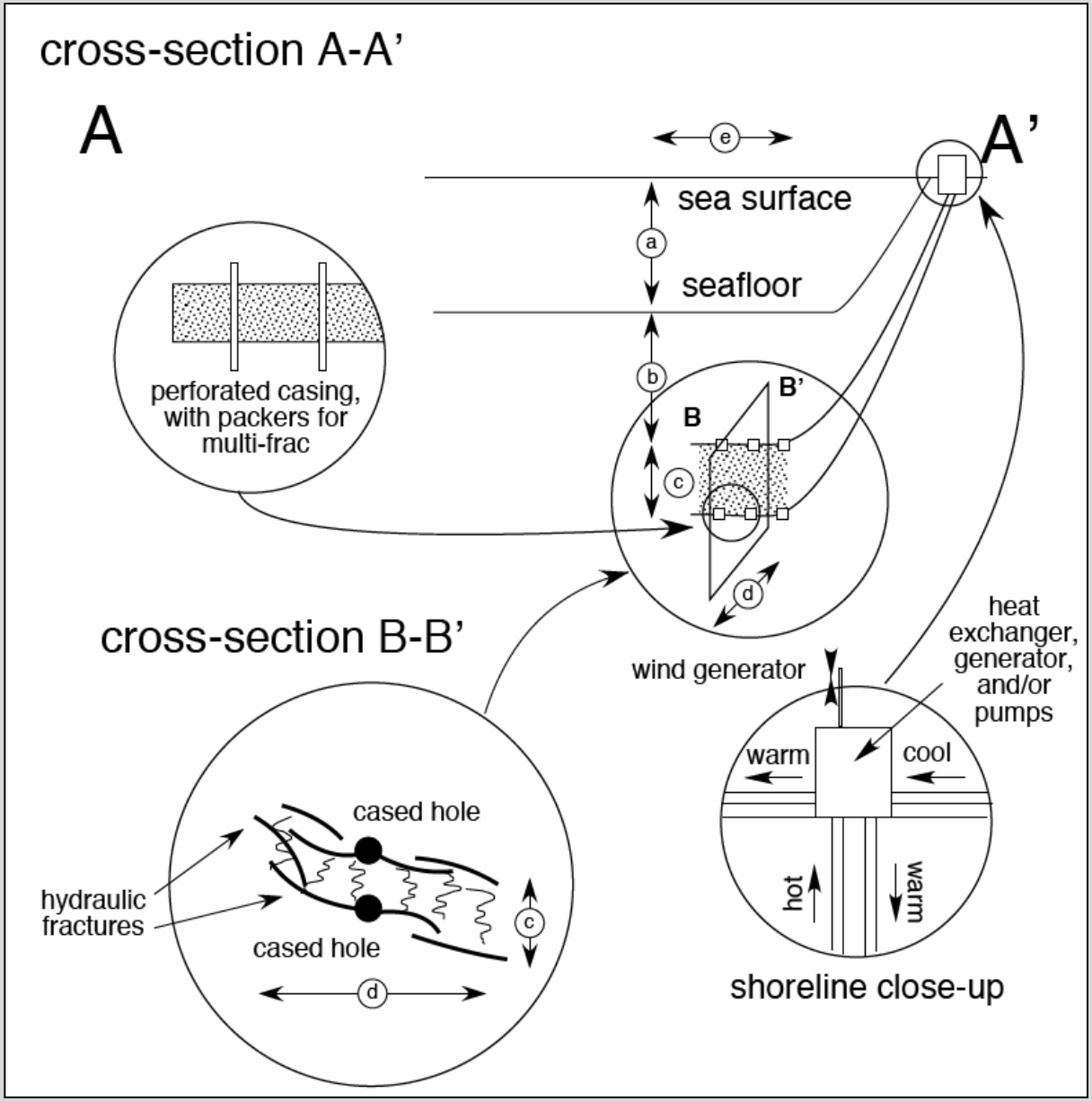
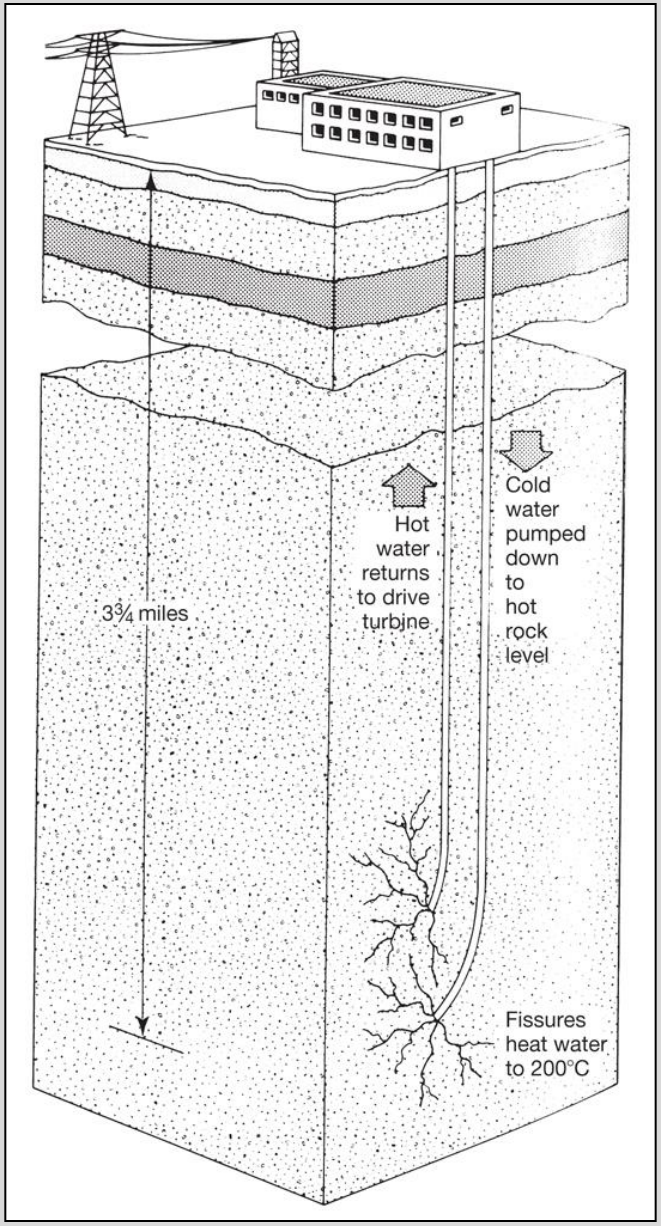
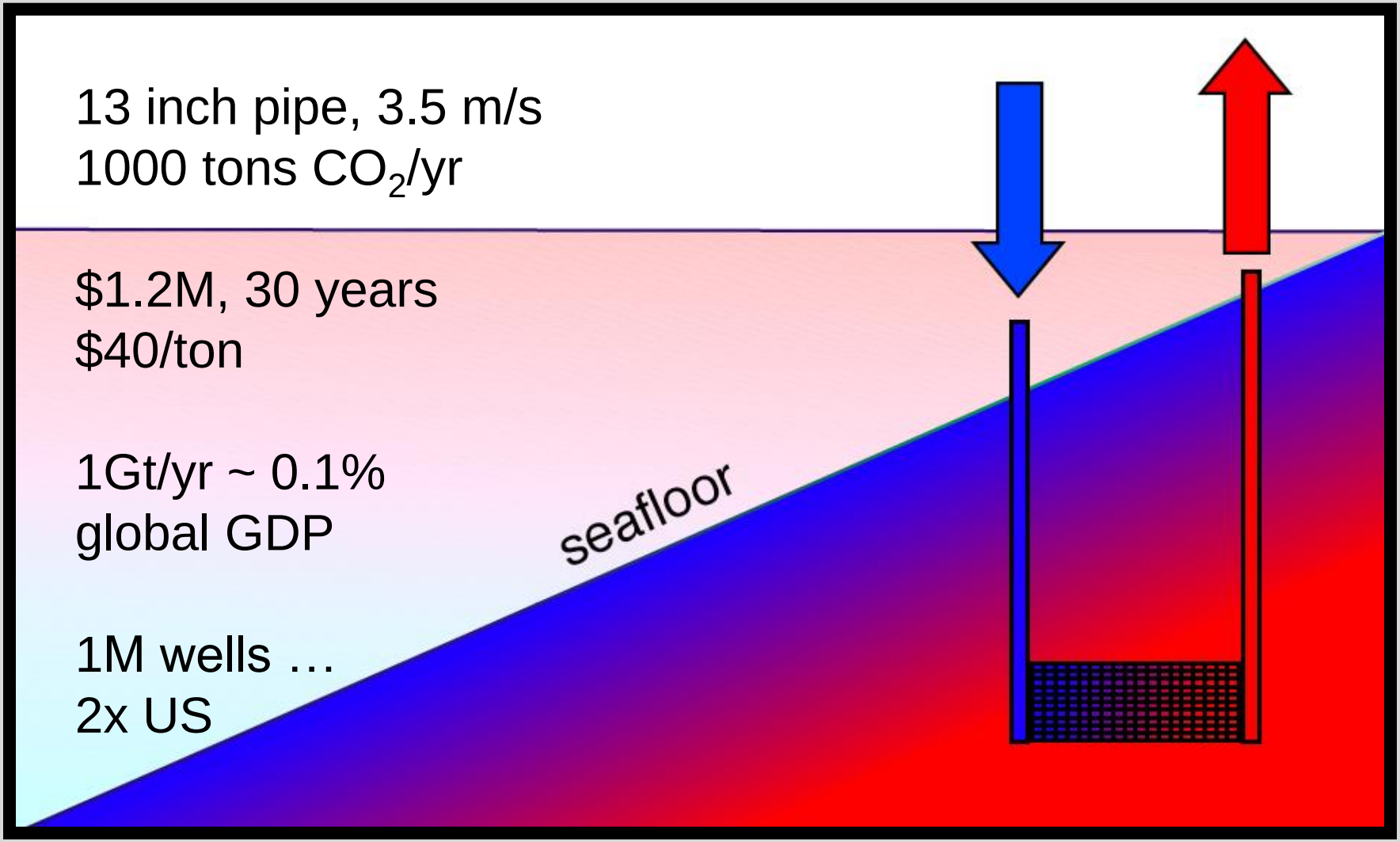
Kelemen & Matter, Proceedings of the National Academy of Sciences, 2008





Total Fantasy, 2010

seawater as a CO2 transport fluid?



Kelemen & Matter, Proceedings of the National Academy of Sciences, 2008

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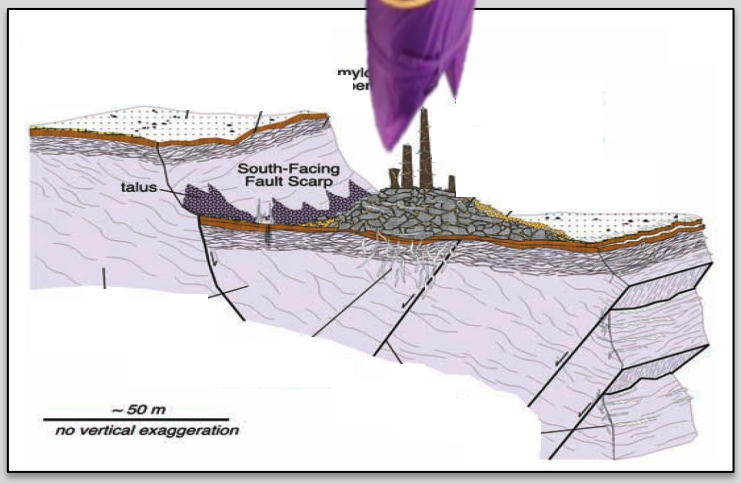
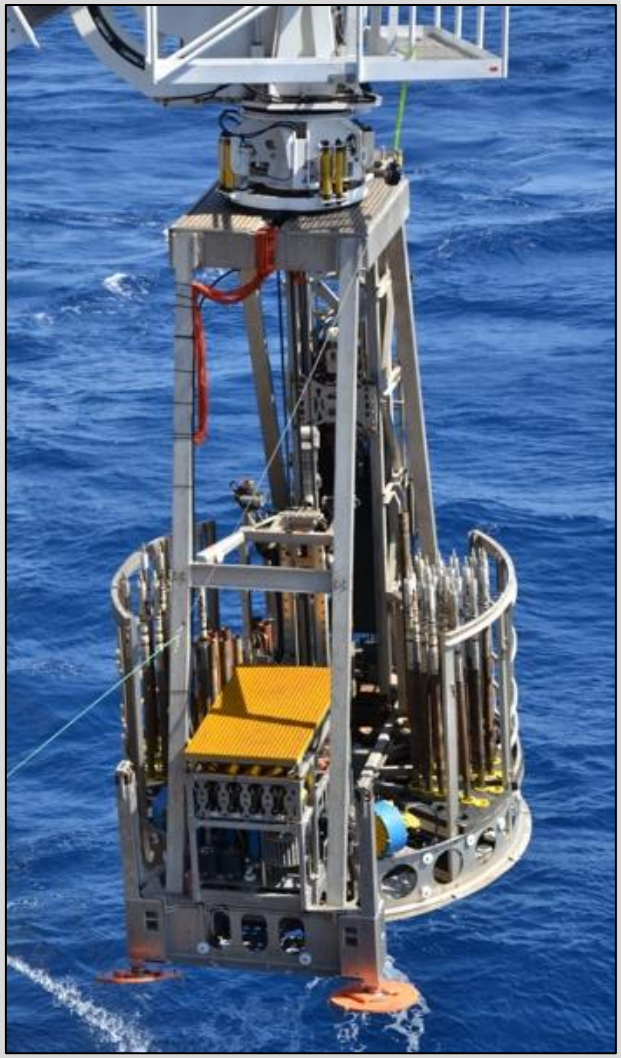
return hot carbon depleted water to sea surface
generate power,
draw down atmospheric CO_2

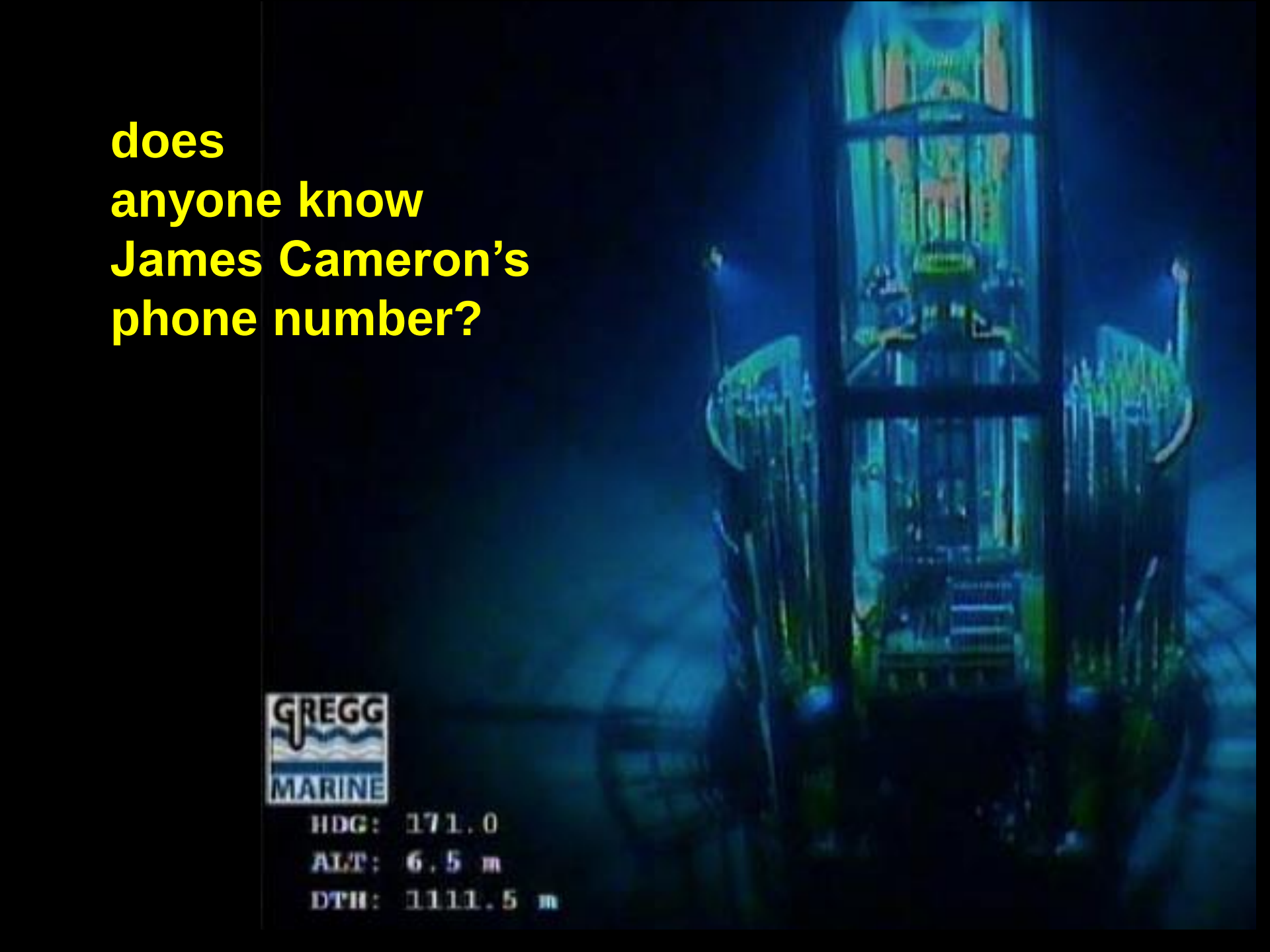
5 to 15% of slow spreading oceanic crust is peridotite

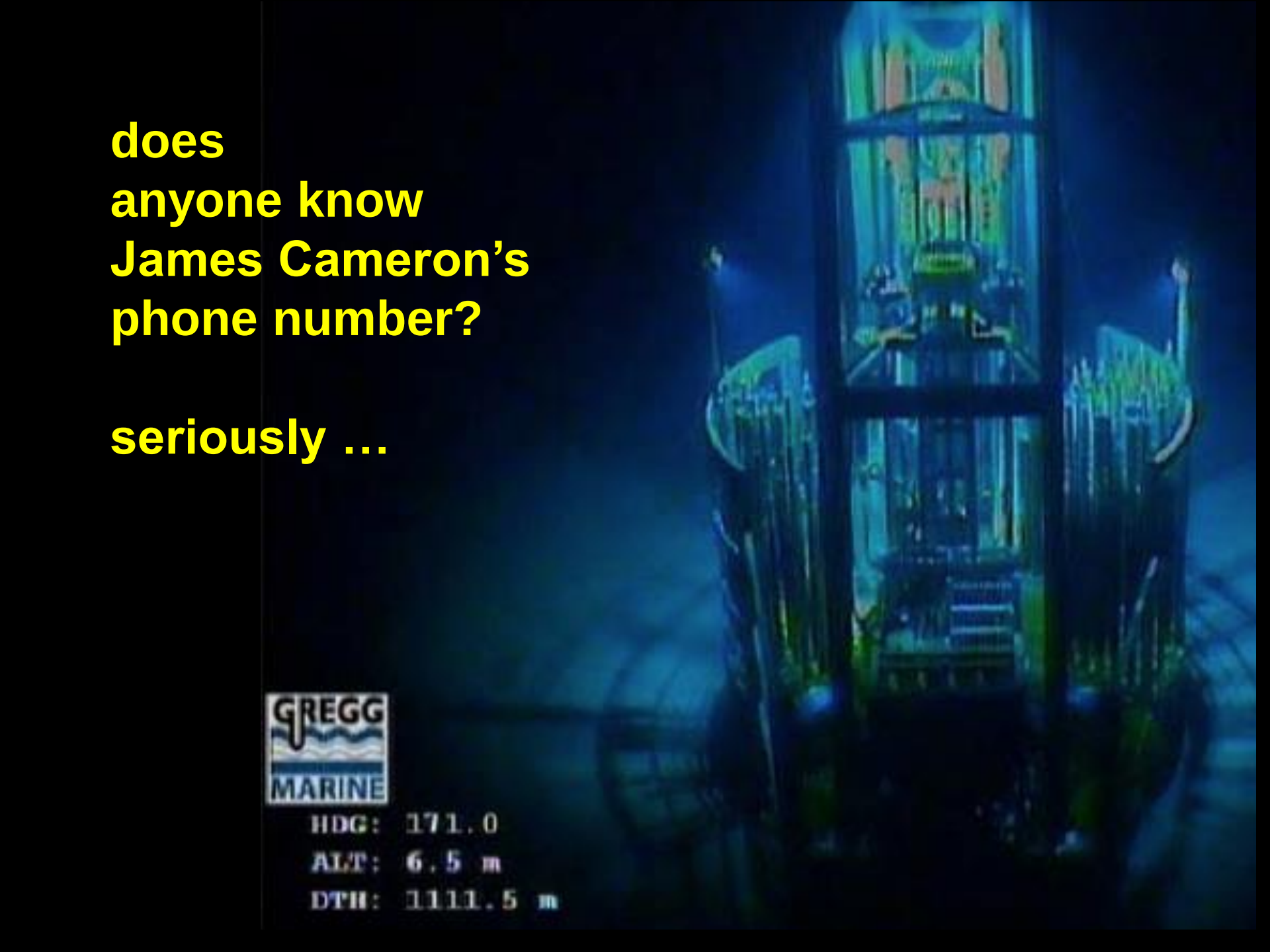
10% x 40,000km x 20km x 2km x 3Gt/km^3 = 480,000 Gt

uptake capacity, ~ 60% CO_2
~ 300,000 Gt CO_2






does
anyone know
James Cameron's
phone number?
GREGG
MARINE
HDG: 171.0
ALT: 6.5 m
DTH: 1111.5 m


does
anyone know
James Cameron's
phone number?
seriously …
GREGG
MARINE
HDG: 171.0
ALT: 6.5 m
DTH: 1111.5 m

thank you for
your attention