Use of Accelerated Olivine Weathering Against Climate Change

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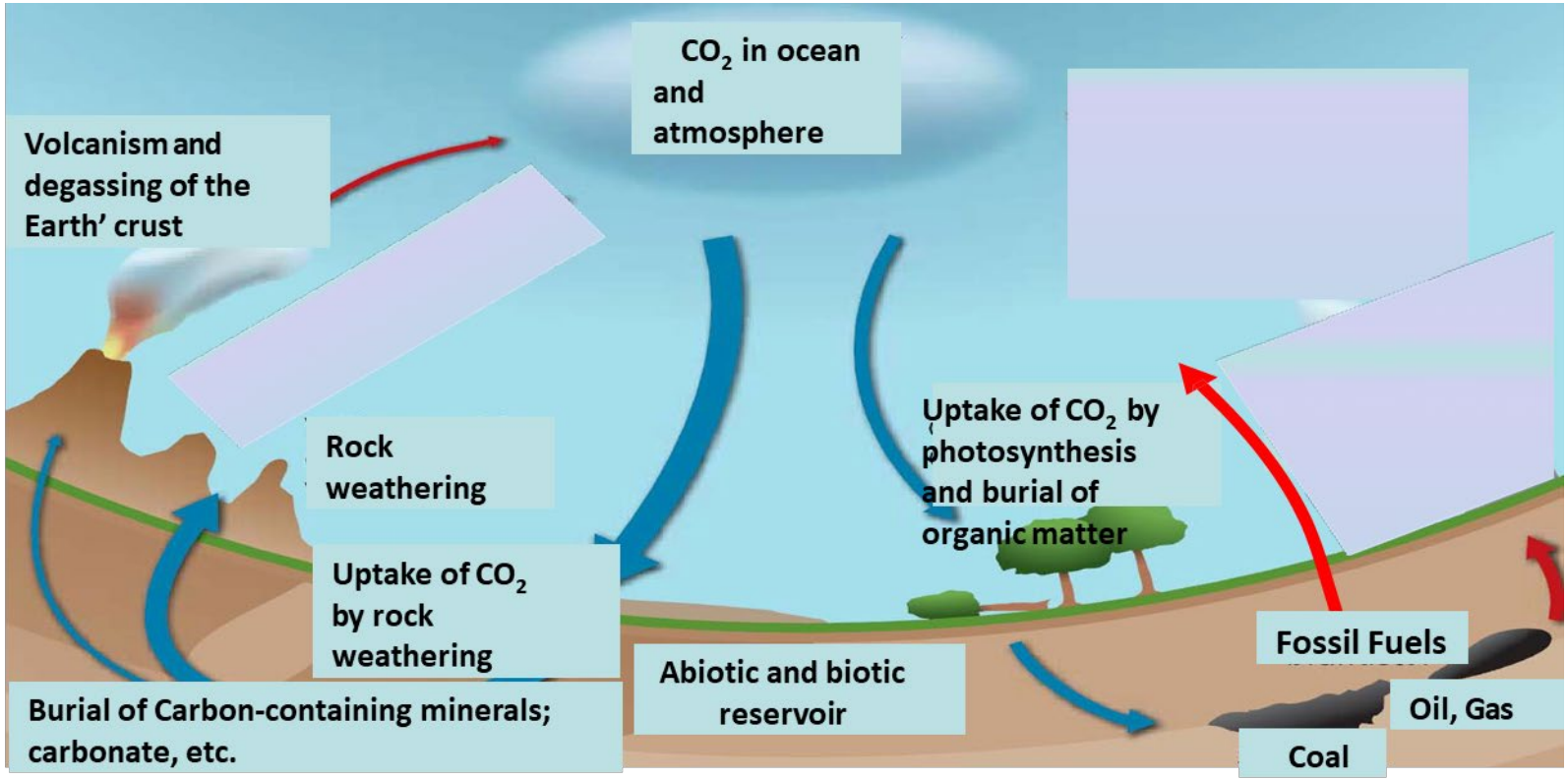
Geological past: first ~ 2 billion years: no life and thus only the left part of the diagram was active. Without CO_2 uptake by rock weathering, CO_2 pressure in the atmosphere would have been several hundred bars



Earth's CO_2 balance

Yearly natural emission:

- 2 to 2.5 billion tons
- by volcanoes and through dissociation of subducted limestones

If Earth had no effective feedback mechanism,

our atmosphere would be like the one on Venus

Feedback mechanisms

- weathering of silicate rocks converts CO_2 into bicarbonate solutions
- rivers transport solutions to the oceans
- there these are stored as carbonate rocks

- a smaller part is stored as organic carbon

Distribution of carbon on Earth

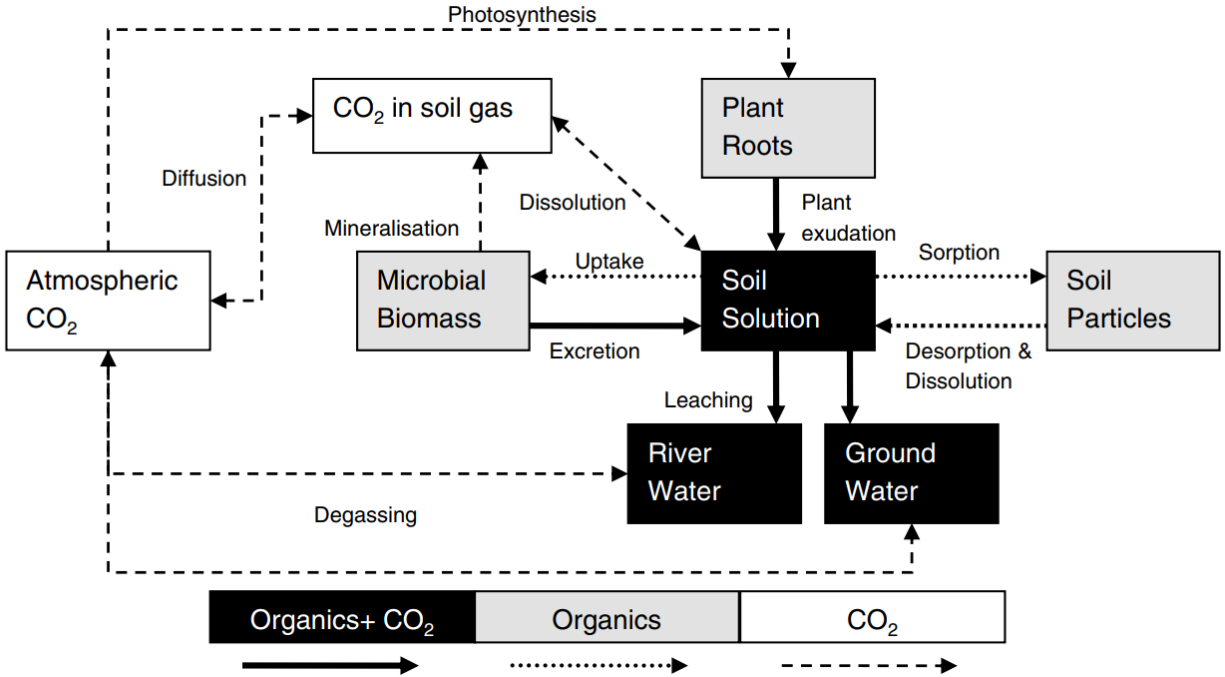
	Amount ($\times 10^{15}$ kg)	Relative (%)
Limestones ($CaCO_3$)	35,000	46.6
Dolomites ($CaCO_3.MgCO_3$)	25,000	33.3
Sedimentary carbon	15,000	20
Recoverable fossil fuels	4	0.005
Oceanic CO_2	42	0.056
Atmospheric CO_2	3	0.004
Biomass	0.56	0.0007

Anthropogenic emission	0.03 / year
Input from Earth's interior	0.0025 / year

Sedimentary rocks

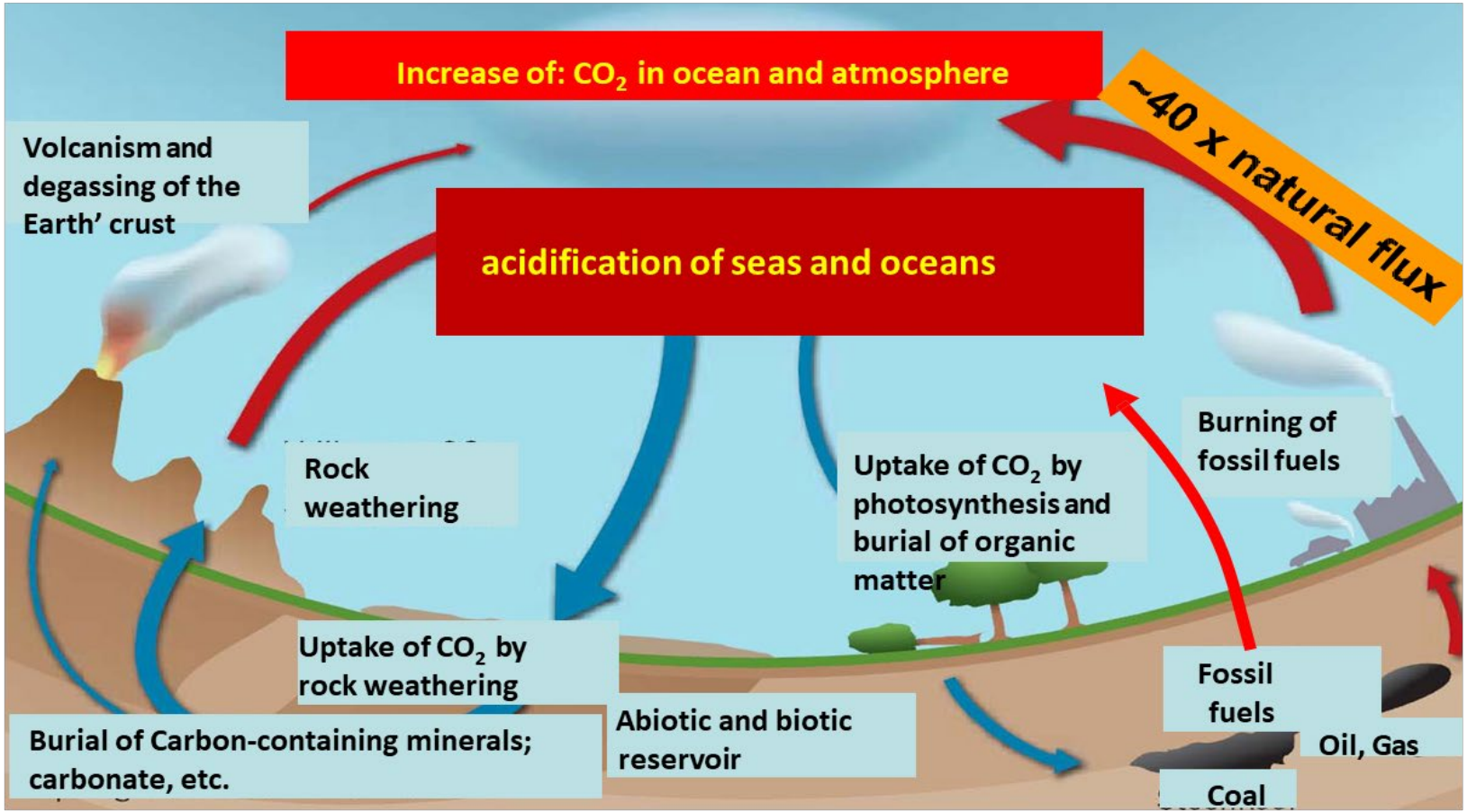
- contain 1500 times more carbon than oceans, atmosphere and biomass combined
- therefore they are the *ultimate sink* for CO_2

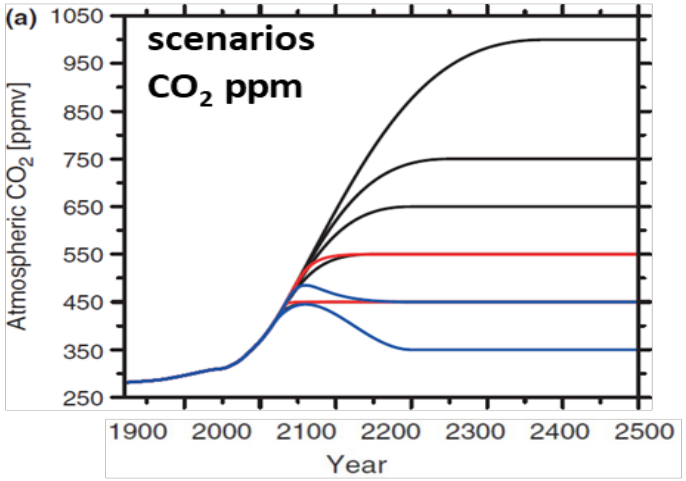
Organic Carbon And Inorganic CO_2 Dynamics In The Environment

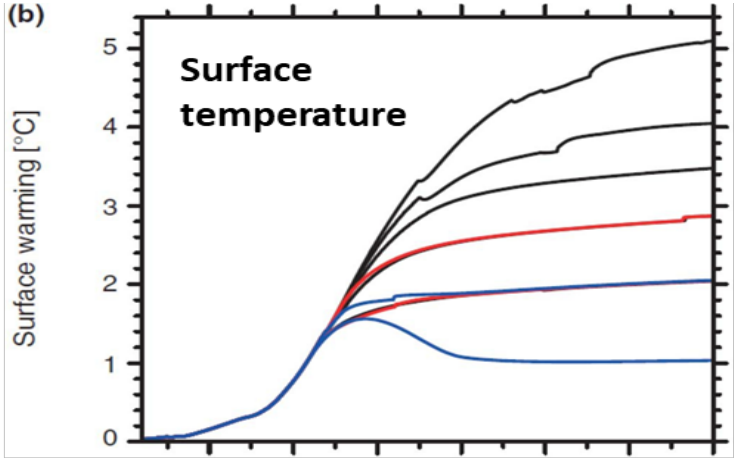


A broad conceptualization of organic carbon and inorganic CO_2 dynamics in the environment. Organic carbon in the soil solution (as low molecular weight organic acids) which is exuded by soil flora and fauna contribute substantially to weathering of soil particles. Adapted from Jones et al. [2003].

Today: burning of fossil fuels; @ 40 times as much CO_2 produced as the natural CO_2 release from the Earth' crust and volcanoes

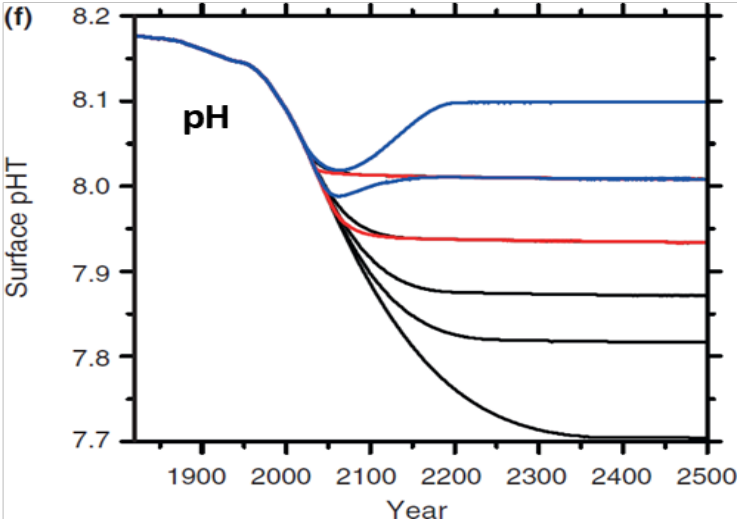






Greenhouse problem, but just as important:

pH is a logarithmic scale; so a drop of 0.3 implies a doubling of CO_2




Available online at www.sciencedirect.com
SciVerse ScienceDirect
Current Opinion in Environmental Sustainability
Future biological and ecosystem impacts of ocean acidification and their socioeconomic-policy implications
Carol Turley[1] and Jean-Pierre Gattuso[2,3]

Out of balance

- Mankind emits lot many more times more CO_2 than nature
- Earth can't compensate this

- CO_2 content of the atmosphere rises rapidly

Can the Earth fight back?

- Natural weathering is a slow process
- Enhance weathering to reach a new balance!

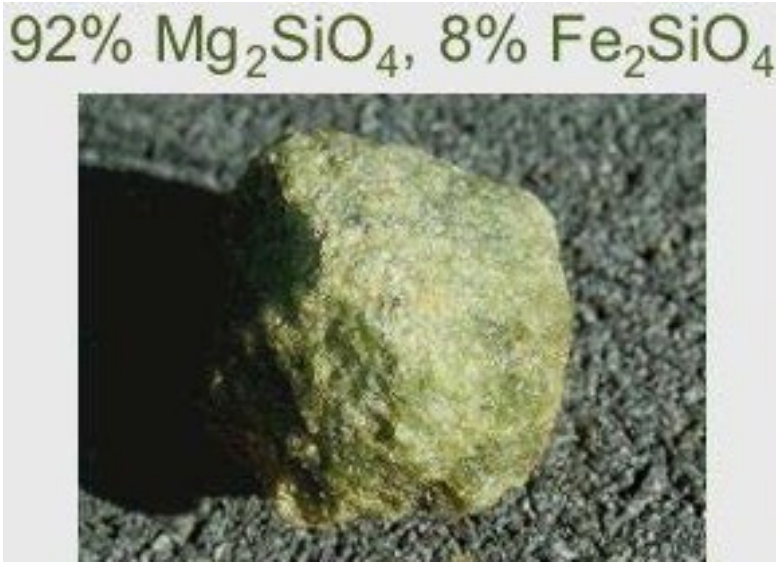
This can be achieved by:

- mining and grinding large volumes of olivine-rich rocks
- spreading the grains in the wet tropics

- let nature do the work

Why olivine?

- most abundant silicate on earth
- deposits are large and widespread
- weathers quickly and captures CO_2



Typical Mineral Reactions

(educts ⇨ ions and silica in solution, secondary minerals ⇨ precipitation reactions in the ocean)

Calcium carbonate (not a silicate)

$CaCO_3 + CO_2 + H_2O \Rightarrow Ca^{2+} + 2HCO_3^- \Rightarrow CaCO_3\downarrow + CO_2\uparrow + H_2O$

(No net-sink of 'consumed' atmospheric CO_2)

Olivine (silicate)

$Mg_2SiO_4 + 4CO_2 + 4H_2O \Rightarrow 2Mg^{2+} + 4HCO_3^- + H_4SiO_4 \Rightarrow 2MgCO_3\downarrow + SiO_2\downarrow + 2CO_2\uparrow + 4H_2O$

(Net-sink for 50% of 'consumed' atmospheric CO_2)

Albite (silicate)

$2NaAlSi_3O_8 + 2CO_2 + 11H_2O \Rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 2HCO_3^- + 4H_4SiO_4 \Rightarrow 2Na^+ + 2HCO_3^- + 4SiO_2\downarrow + 8H_2O$

(Net-sink for 100% of 'consumed' atmospheric CO_2)

Simplified equations describing reactions for the dissolution of simple carbonate and silicate minerals by different acids, illustrating the "consumption" of CO2 during weathering by carbonic acid.

Uptake of CO_2 by olivine weathering

$(Mg,Fe)_2SiO_4$ (olivine*) + 4 H_2O → 2 $(Mg, Fe)^{2+}$ + 4 OH^- + H_4SiO_4

4 OH^- + 4 CO_2 → 4 HCO_3^-

CO_2 is consumed, and Mg^{2+}, Fe^{2+}, H_4SiO_4, HCO_3^- and some Ni are produced

Reaction of serpentine is similar:

$Mg_3Si_2O_5(OH)_4$ + 5 H_2O → 3 Mg^{2+} + 6 OH^- + 2 H_4SiO_4

followed by 6 OH^- + 6 CO_2 → 6 HCO_3^-

* Minable olivine consists, with minor variations, of 0.92 Mg_2SiO_4 (forsterite) and 0.08 Fe_2SiO_4 (fayalite)

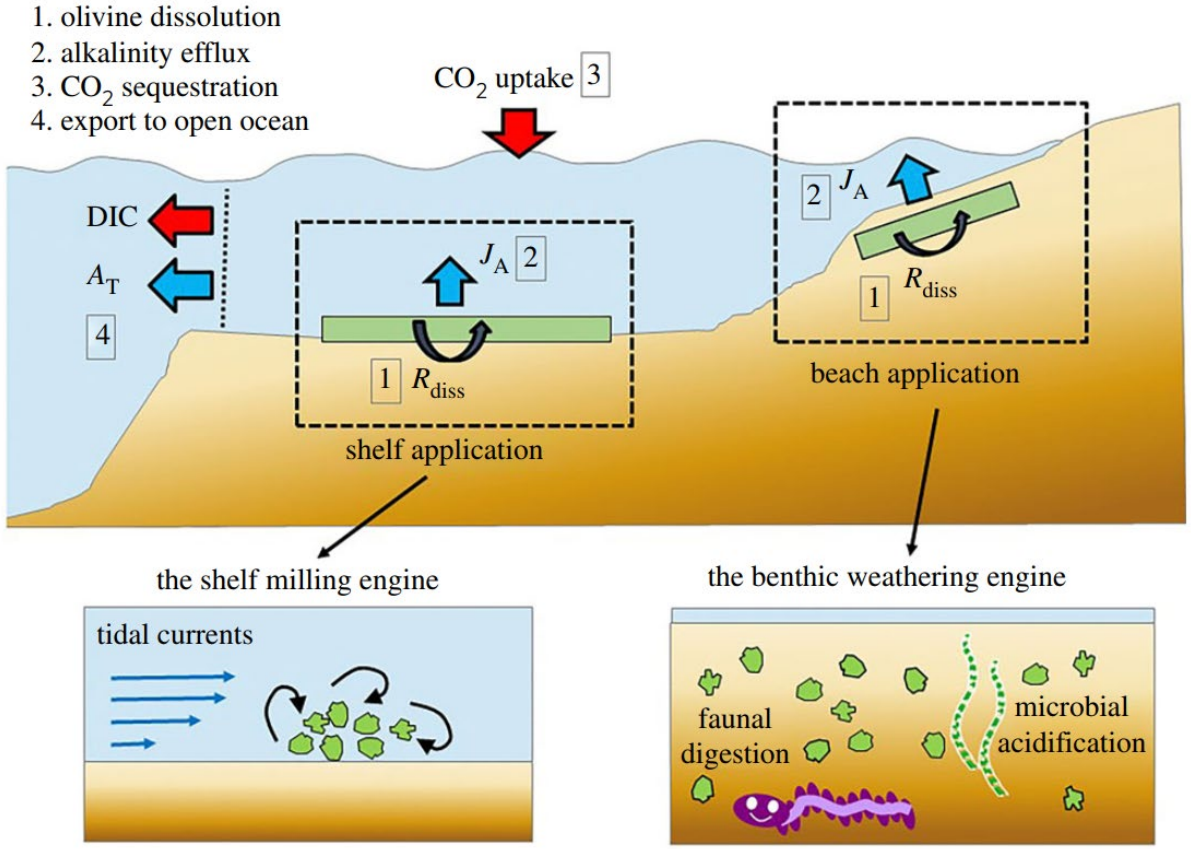
Weathering

Thus, through weathering rocks neutralise (carbonic) acid:

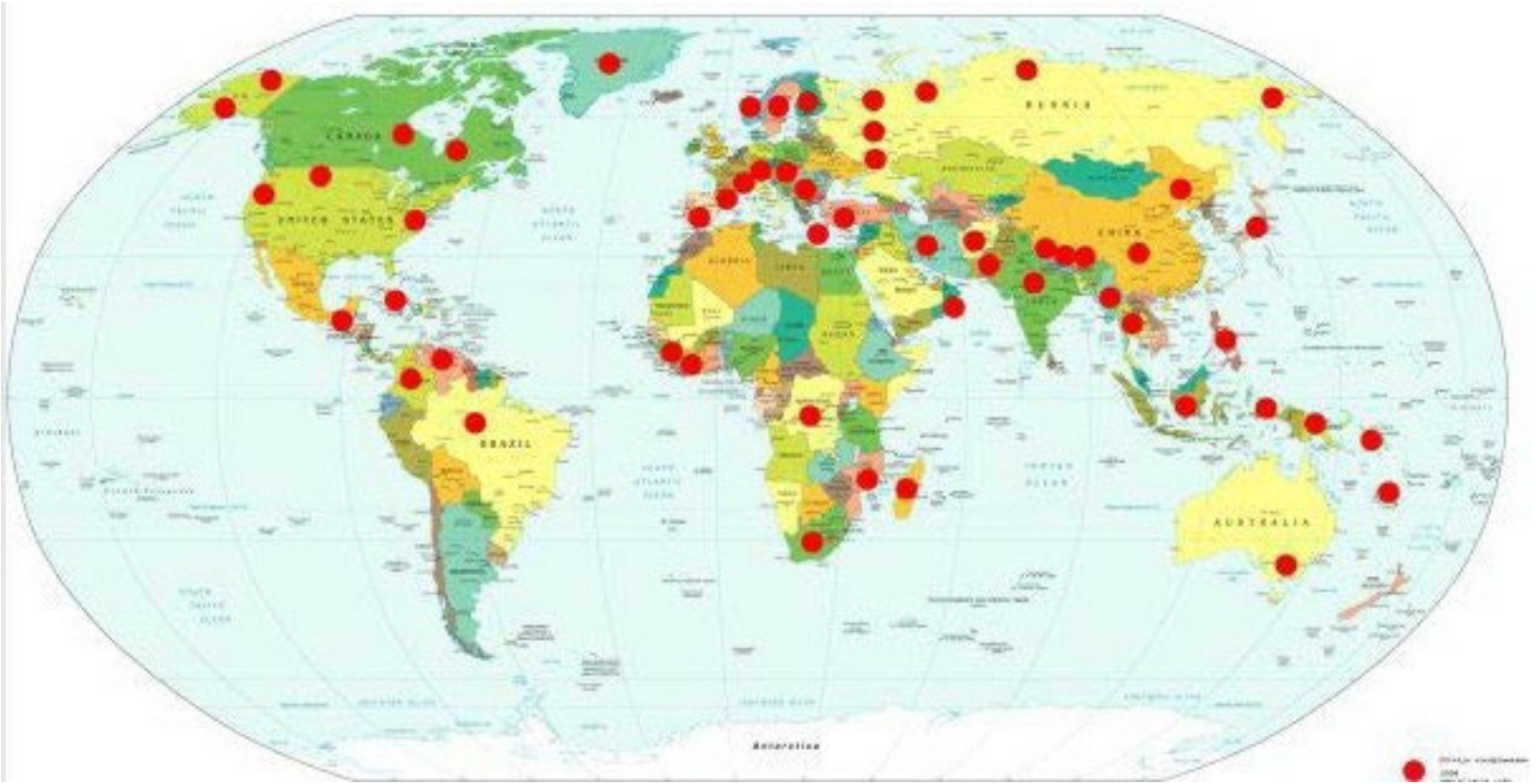
$$Mg_2SiO_4 + 4\,CO_2 + 4\,H_2O \longrightarrow 2\,Mg^{2+} + 4\,HCO_3^- + H_4SiO_4$$

greenhouse gas **innocuous bicarbonate ion**

Enhanced Silicate Weathering In The Coastal Zone



Where is it found?



Laboratory versus the real world

Laboratory: 0.2 - 0.3 micron per year

Nature : 10 - 20 microns per year

Why this discrepancy?

- symbiosis of fungi with higher plants
- fungi secrete acids
- acids dissolve minerals rapidly

Why the wet tropics?

- faster weathering
- lower wages
- usually low transport costs
- provides employment and economical growth
- large open pit mines profit: economy of scale
- mining for olivine in dunite combined with mining for ores of chromite, nickel or platinum group minerals can be economically beneficial

Objections against the stimulation of natural weathering of Olivine

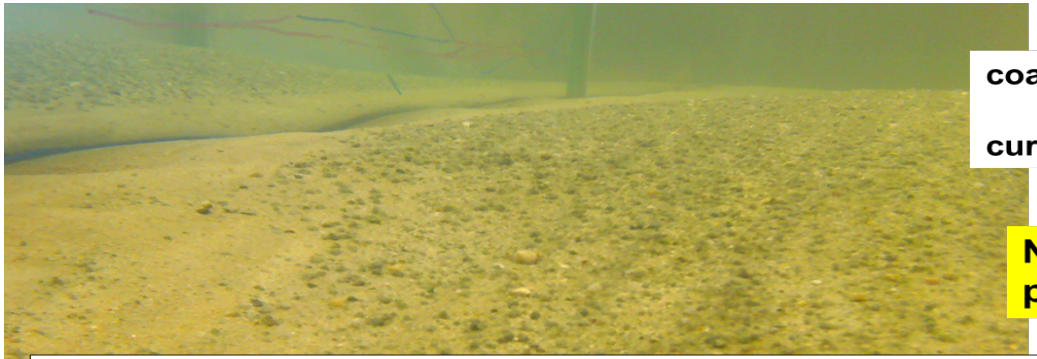
- Chemical weathering reaction would be far too slow
- The amount of olivine needed annually would be far too great
- Weathering products would deteriorate the chemical balance in seas and oceans, soils; would be poisonous, etc.

Chemical weathering reaction would be too slow

- This is often quoted from old literature without any further check.
- However this is only the case for olivine grains in the laboratory, without any physical action and without biological processes

Chemical weathering reaction would be too slow

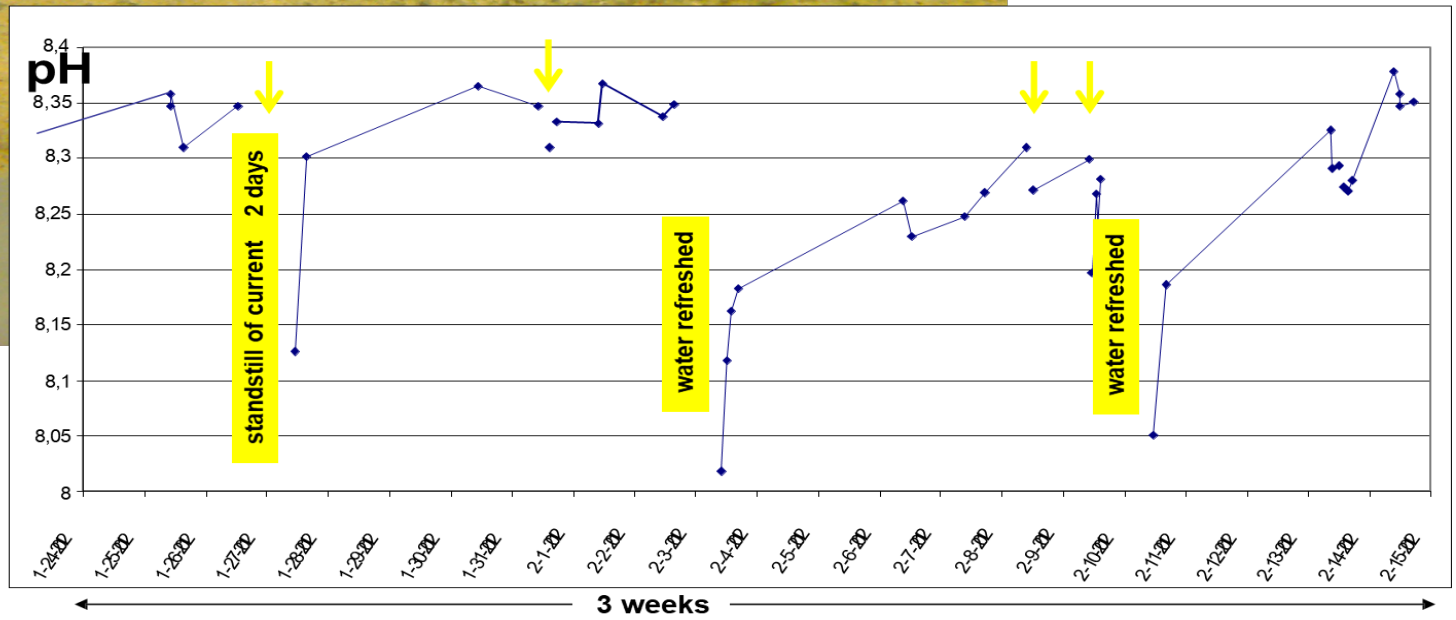
- In a flume experiment set up it was demonstrated that with an addition of 30% olivine grains to course-grained, and after all fine-grained sediment (clay and silt) had been removed, pH rises to about 8.35 when the water current transports the olivine sand.
- When the current is stopped for 2 days, grain collisions stop, and the pH of the water falls to less than 8.15, demonstrating a rapid uptake of CO2 by diffusion through the water-air interface. Also during short stops of some hours pH falls, demonstrating the uptake of CO2.
- Renewal of the water shows the same process.



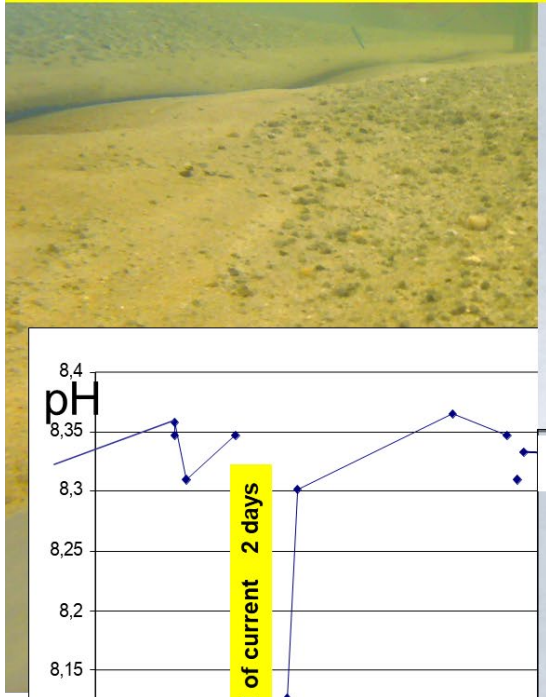
coarse sand + ~30% olivine

current velocity 40 – 60 cm/sec

Non-connected measuring points: standstill of current



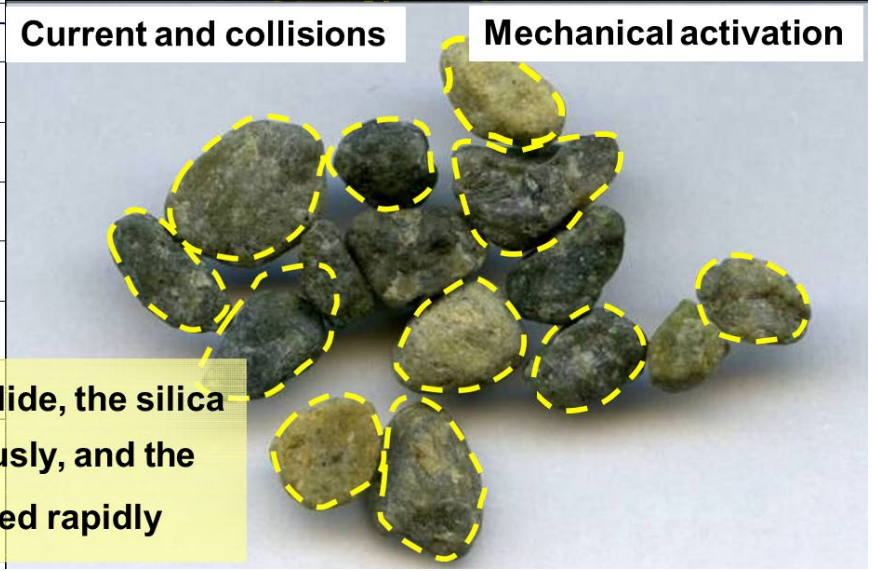
If grains do not move, a silica coating develops



Silica-coating: H_4SiO_4

Current and collisions

Mechanical activation



When the grains move and collide, the silica coating is destroyed continuously, and the weathering reaction can proceed rapidly

Olivine weathering

The H_4SiO_4 produced during the weathering process, forms a silica coating around the grains (yellow line around the grains on the previous sheet) that greatly retards the reaction.

Only when the grains are kept in motion and collide with each other, the silica coating is disrupted (interrupted line on the previous sheet), and the weathering reaction can continue rapidly.

Few Questions Answered

Question:

What if this olivine would not fully weather in one year?

Answer:

There is no problem if it would take longer, e.g. 5 or 10 years. When adding the same amount of olivine grains each year, a dynamic equilibrium will be reached in which the same amount of olivine added is weathered annually removing 1.5 GT CO_2

Few Questions Answered

Question:

This is a mega-intervention in the marine environment; are there any negative side-effects, pollution?

Answer:

Any side effects should be compared to greenhouse warming and ocean acidification as the side effects of fossil fuel burning.

Secondly a comparison should be made with the negative effects of other approaches, such as CCS, i.e. a heavy energy penalty and additional CO_2 output, potential leakage of CO_2 from filled reservoirs, catastrophes in case of masssive CO_2 escape, etc.

Few Questions Answered

Question:

Part of the olivine grains may be buried and not participate in the surface collisions anymore. They then might react at the much lower rate seen in the laboratory.

Answer:

If olivine is put in highly dynamic areas where no net sedimentation occurs, it will continue taking part in the weathering process.

If part of the grains, e.g. 50%, would nevertheless be temporarily removed from the dynamic system, that would (in the short run) double the price of a ton removed CO_2 from € 10 - € 11 to € 20 - € 22, still considerably less than the estimated costs of CCS (per ton captured CO_2 € 60 and higher).

Few Questions Answered

Question:

By dumping large amounts of olivine on the sea floor, local benthic life will suffer greatly

Answer:

Even if olivine dumping may temporarily disrupt benthic life locally, restoration of the local ecosystem will occur (gradually). Restoration time (weeks to years or longer) depends on the type of organism, the size of the disturbed area, local temperatures, etc.

But as per the current laboratory studies, the results are encouraging and there is no damage or disruption to benthic life.

Few Questions Answered

Another point brought forward is that the stimulation of natural rock weathering focuses on mitigating the effects of fossil fuel burning, while preference should be given to measures focusing on the source of the problem, i.e. fossil fuel burning itself.

Both issues are serious concerns, and have to be discussed within the framework of ecological responsibility. Only minimizing CO_2 pollution and not mitigating the effects of pollutions from the past would be comparable to an approach in which contaminated soils would not be cleaned with the argument that only the source of the pollution should be dealt with.

The immanent threat of permafrost methane release and evaporation of deep-marine methane hydrates with the risk of run-away greenhouse warming, urges to also mitigate CO_2 pollution from the last 150 years

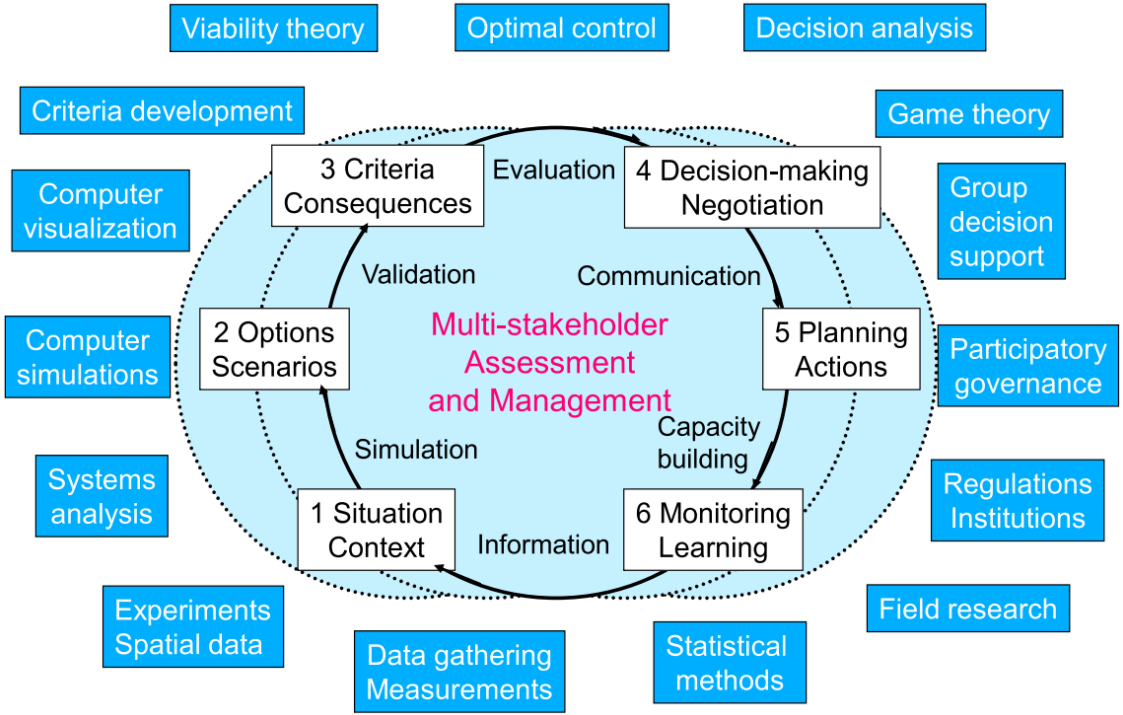
To compensate effectively

- Spread 0.7 mm of olivine on 10 million km^2 a year

Cheaper solution:

- ✓ cover 2 million km^2 with 3.5 mm
- ✓ another area of 2 million km^2 the year after
- ✓ repeat this four times
- ✓ return to the first area after 5 years

Management of Enhanced Weathering at a Geoengineering Scale



A proposed concept for multi-stakeholder assessment and management of Enhanced Weathering, adapted from Scheffran [2006]

Legal Framework on Climate Engineering With Relevance for Enhanced Weathering

- Legal instruments to regulate Enhanced Weathering can apply at different levels.
- Individual countries can promote a variety of national policies and regulations to authorize or prohibit certain Enhanced Weathering measures.
- In accordance with customary international law, countries have to ensure that activities within their own territory do not generate substantial adverse consequences for the environment beyond their own borders.
- Substantial adverse effects on the environment are not permitted in areas such as the high seas, the Antarctic etc.
- At present, there are no effective geoengineering technologies, nor binding international regulations. Hence, a consensus has to be arrived and legal framework to be created.

Enhanced weathering is the most cost-effective way to counteract climate change

References

- ✓ Mitigation of CO_2 emissions by stimulated natural rock weathering by Poppe de Boer & Olaf Schuiling, Utrecht University
- ✓ Enhanced Chemical Weathering As A Geoengineering Strategy To Reduce Atmospheric Carbon Dioxide, Supply Nutrients, And Mitigate Ocean Acidification by Jens Hartmann and others
- ✓ Negative CO_2 emissions via enhanced silicate weathering in coastal environments Filip J. R. Meysman and Francesc Montserrat
- ✓ Olivine Weathering against Climate Change by Roelof Dirk Schuiling
- ✓ Olivine Dissolution in Seawater: Implications for CO_2 Sequestration through Enhanced Weathering in Coastal Environments by Francesc Montserrat and others
- ✓ CO_2 Removal With Enhanced Weathering and Ocean Alkalinity Enhancement: Potential Risks and Co-benefits for Marine Pelagic Ecosystems by Lennart T. Bach and others
- ✓ Olivine weathering to capture CO_2 and counter climate change - by R.D. Schuiling

Thanks!

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