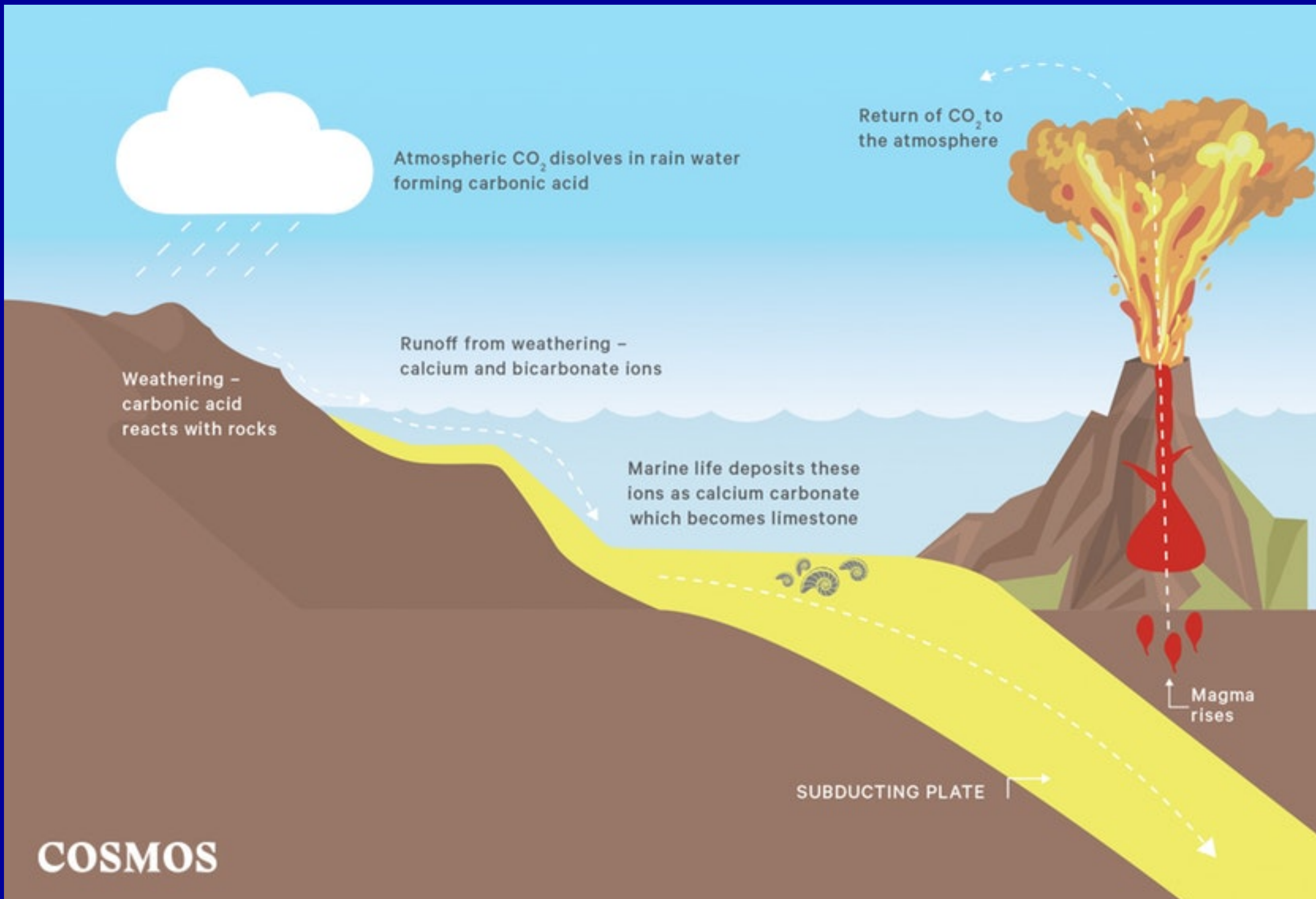
Weathering

Slow carbon cycle



Weathering

The natural process of removing CO_2 from the atmosphere

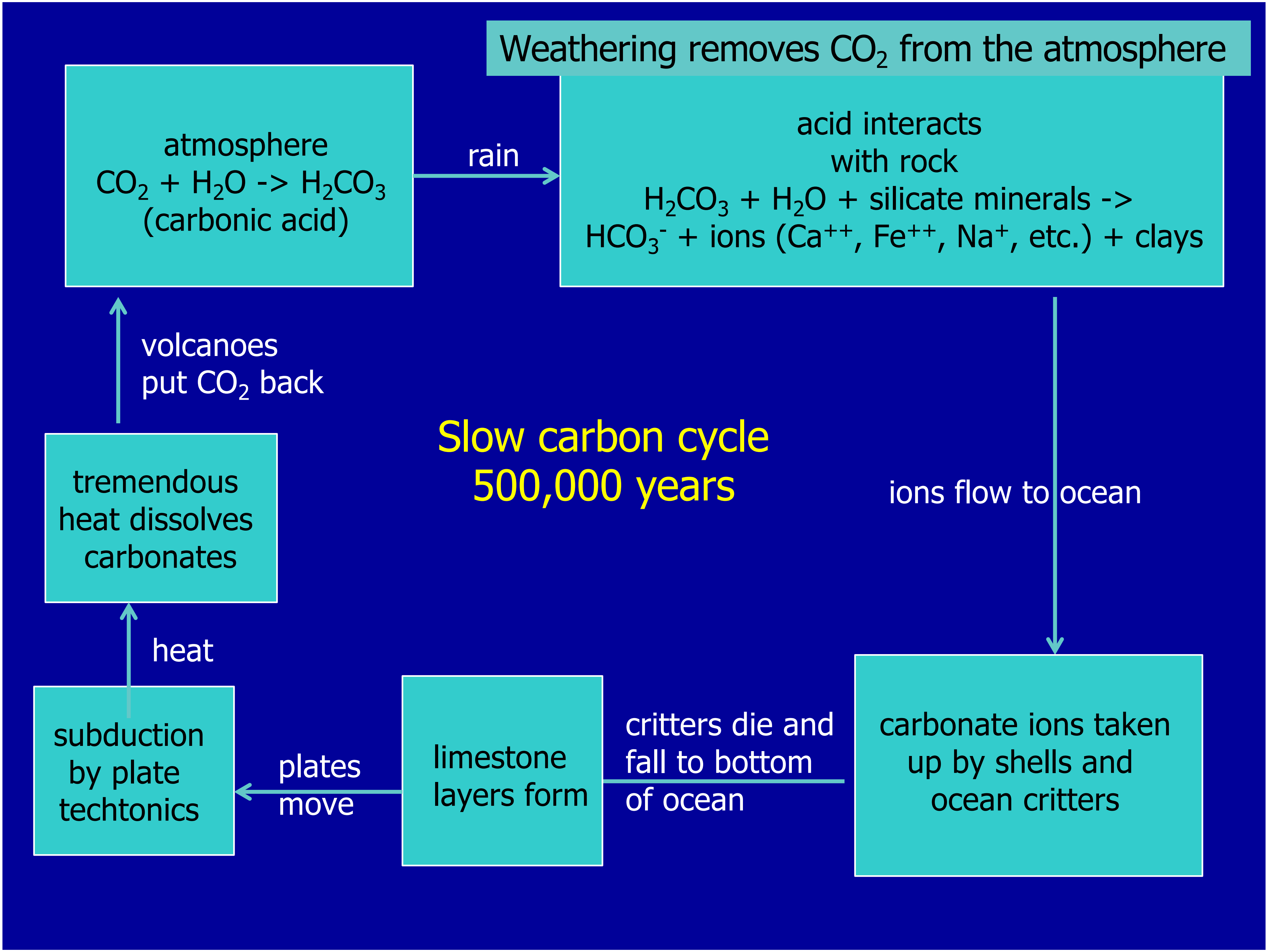
- $CO_2 + H_2O \rightarrow H_2CO_3$ which we call carbonic acid
- This mild acid falls on rock and interacts to make clays and soluble salts.
  - Reaction rates higher at higher temperature
- Salts are washed down to the ocean where they are used by coral and sea creatures (e.g. mollusks and crustaceans) to make their shells.

Weathering (cont.)

The natural process of removing CO_2 from the atmosphere

- These animals die and fall to the seafloor (limestone beds) and are carried by plate tectonics into hot magma.
- Heat dissociates the carbon and volcanos put it back into the atmosphere.
- This is known as the slow carbon cycle.
  - It takes 100s of millions of years for carbon to complete this cycle

Chemical Weathering


Weathering removes CO_2 from the atmosphere
atmosphere
$CO_2 + H_2O \rightarrow H_2CO_3$
(carbonic acid)
rain
acid interacts
with rock
$H_2CO_3 + H_2O$ + silicate minerals ->
HCO_3^- + ions (Ca^{++}, Fe^{++}, Na^+, etc.) + clays
volcanoes
put CO_2 back
Slow carbon cycle
500,000 years
ions flow to ocean
tremendous
heat dissolves
carbonates
heat
subduction
by plate
techtonics
plates
move
limestone
layers form
critters die and
fall to bottom
of ocean
carbonate ions taken
up by shells and
ocean critters

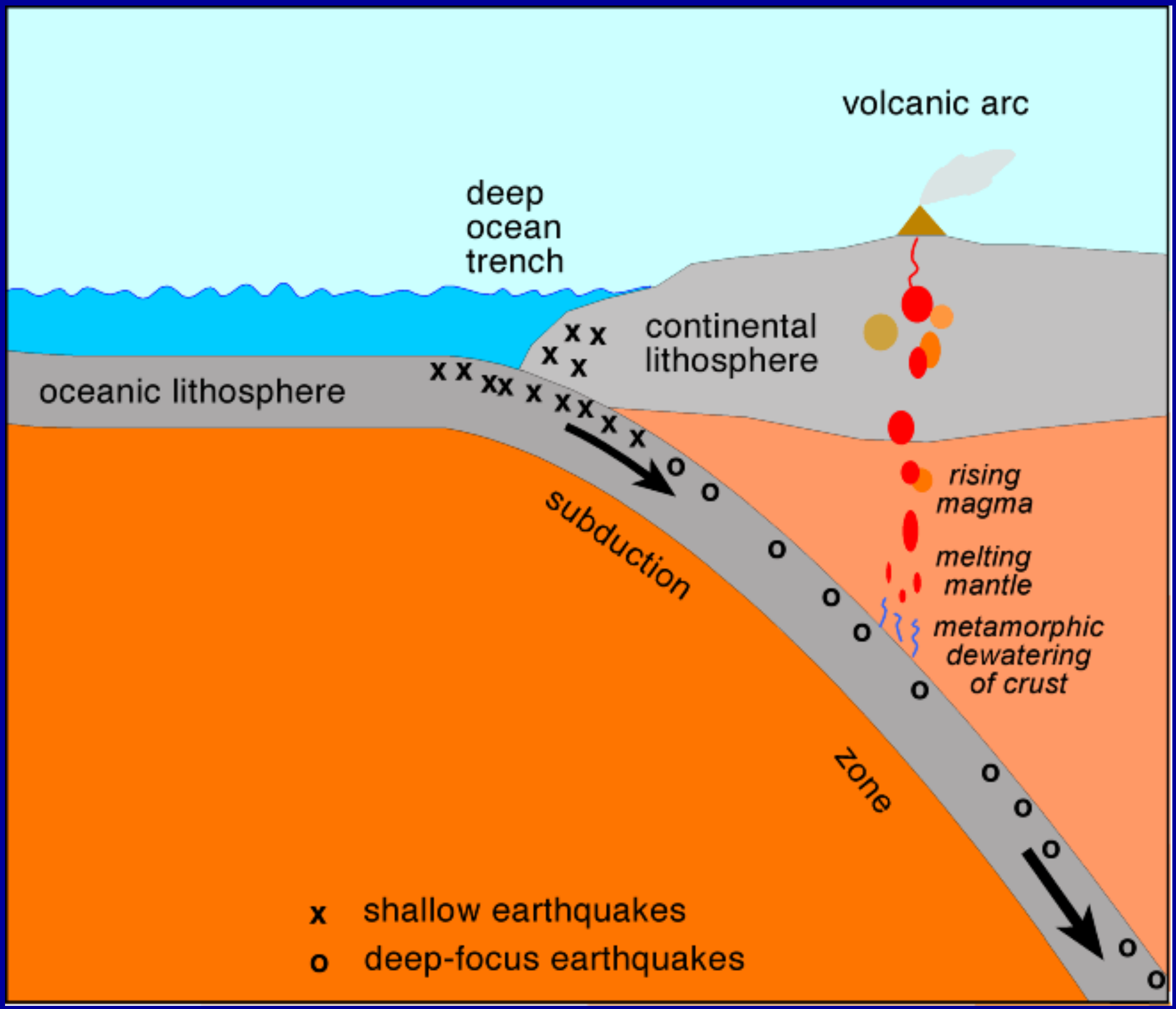
Reaction rates for weathering

- Increase with temperature (typically)
- Increase with humidity

- Most effective in the tropical latitudes
- A slow negative feedback keeping Earth's climate from getting too hot
- Cycle time 100's of thousands of years

Equatorial weathering

Subduction



volcanic arc
deep
ocean
trench
continental
lithosphere
oceanic lithosphere
subduction
zone
rising
magma
melting
mantle
metamorphic
dewatering
of crust
x shallow earthquakes
o deep-focus earthquakes

Subduction and metamorphism

Metamorphism: alteration of the composition or structure of a rock by heat, pressure, or other natural agency

- Some of this carbon is returned to the atmosphere via metamorphism of limestone at depth in subduction zones or in mountain formic (orogenic) belts
  - $CaCO_3 + SiO_2 \rightarrow CO_2 + CaSiO_3$

  followed by outgassing at the volcanic arc and mid ocean ridges.

Earth vs. Venus

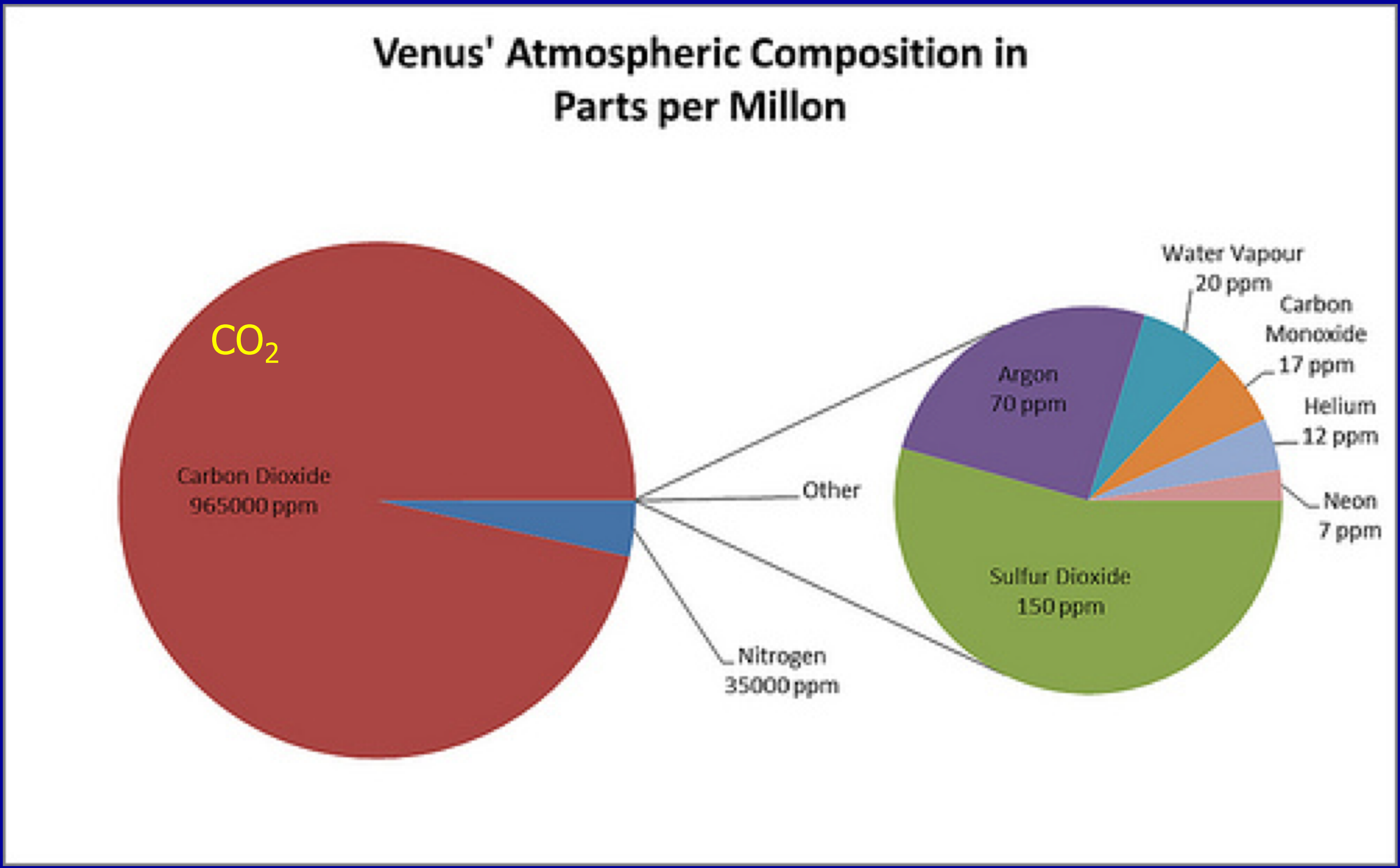
- On Earth, the C is absorbed into the oceans, where it is used by living organisms and becomes deposited as limestone (aka, the carbon cycle).
- On Venus, the oceans evaporated away, so the carbon cycle won't start. Instead C finds the O in the atmosphere, makes still more CO_2, and traps more heat. As the heat went up, this process got easier, and continued until all the C was used.

Earth vs. Venus (cont.)

- Volcanoes on both planets emit sulfur (S).
  - On Earth, S solidifies on the surface or becomes incorporated into surface minerals.
  - On Venus, temperatures have risen above the level at which S not merely melts, but evaporates to combine with from dissociated H_2O atoms to form SO_2, and clouds of H_2SO_4, sulfuric acid.
- SO_2 absorbs at different wavelengths than CO_2, further exacerbating the greenhouse effect (more on this later).

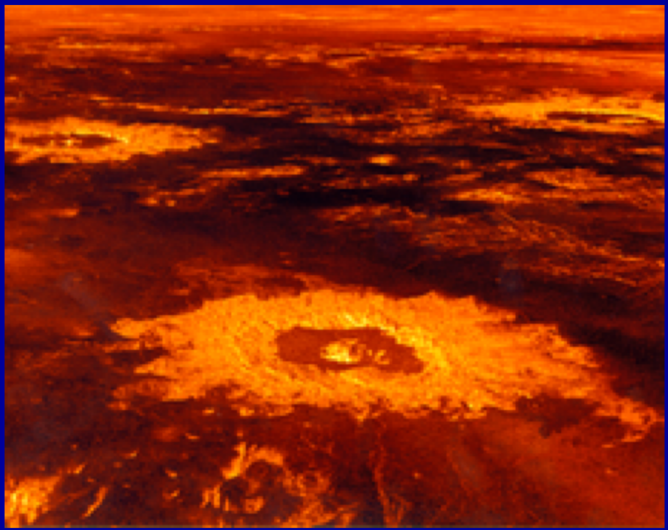
Venus has a CO_2 atmosphere

Atmospheric pressure 90 x that of Earth



Impact craters on Venus

Almost a thousand impact craters on Venus are evenly distributed across its surface.
On other cratered bodies, such as Earth and the Moon, craters show a range of states of degradation. On the Moon, degradation is caused by subsequent impacts, whereas on Earth it is caused by wind and rain erosion. On Venus, about 85% of the craters are in pristine condition.



Crust does not change continuously as does that of Earth. Instead pressure builds and there are sudden episodes of planet wide crustal overturning. The last such episode was 300-600 Mya.
Active volcanism:
In March of 2014, Venus had "hot flashes" from spots where the temperature surged 40-320^{o}C above ambient – which is already hot!

Venus conclusion

Runaway greenhouse removed the oceans.

This probably cannot happen on Earth,
but studying Venus is what got Jim Hansen
wondering what would happen on Earth.

What matters

- Atmosphere
- Rate of rotation
- Tidal disruption
- Magnetic field
- Sputtering