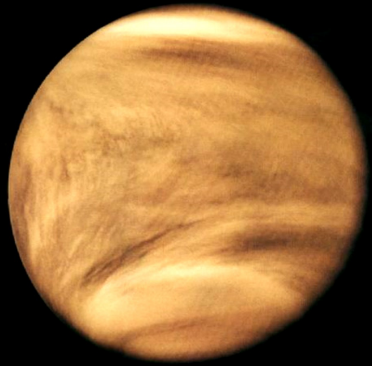
The Terrestrial Planets

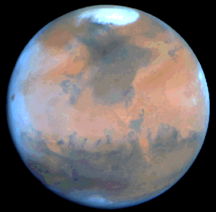
Large Bodies:

Earth (1 R_E, 1 M_E)

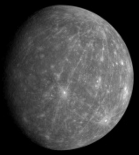


Venus (0.95 R_E, 0.82 M_E)

Small Bodies:



Mars (0.53 R_E, 0.11 M_E)

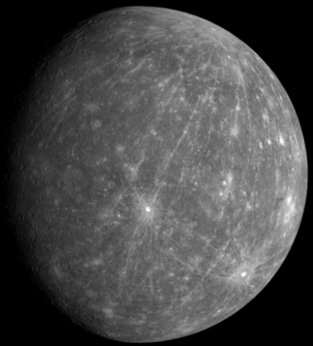


Mercury (0.38 R_E, 0.055 M_E)

Moon (0.27 R_E, 0.012 M_E)

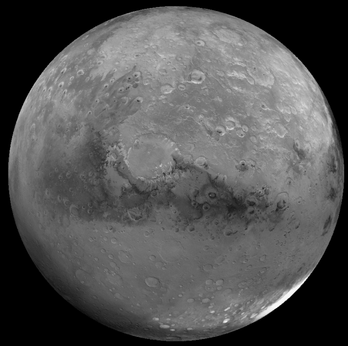
The surfaces of the small terrestrial planets were shaped primarily by impacts and early volcanism

Mars, Mercury & the Moon:
- Old, heavily cratered surfaces >3 Gyr old
- Single, continuous crust (no plates)
- Vertical Tectonism (stationary upwelling)

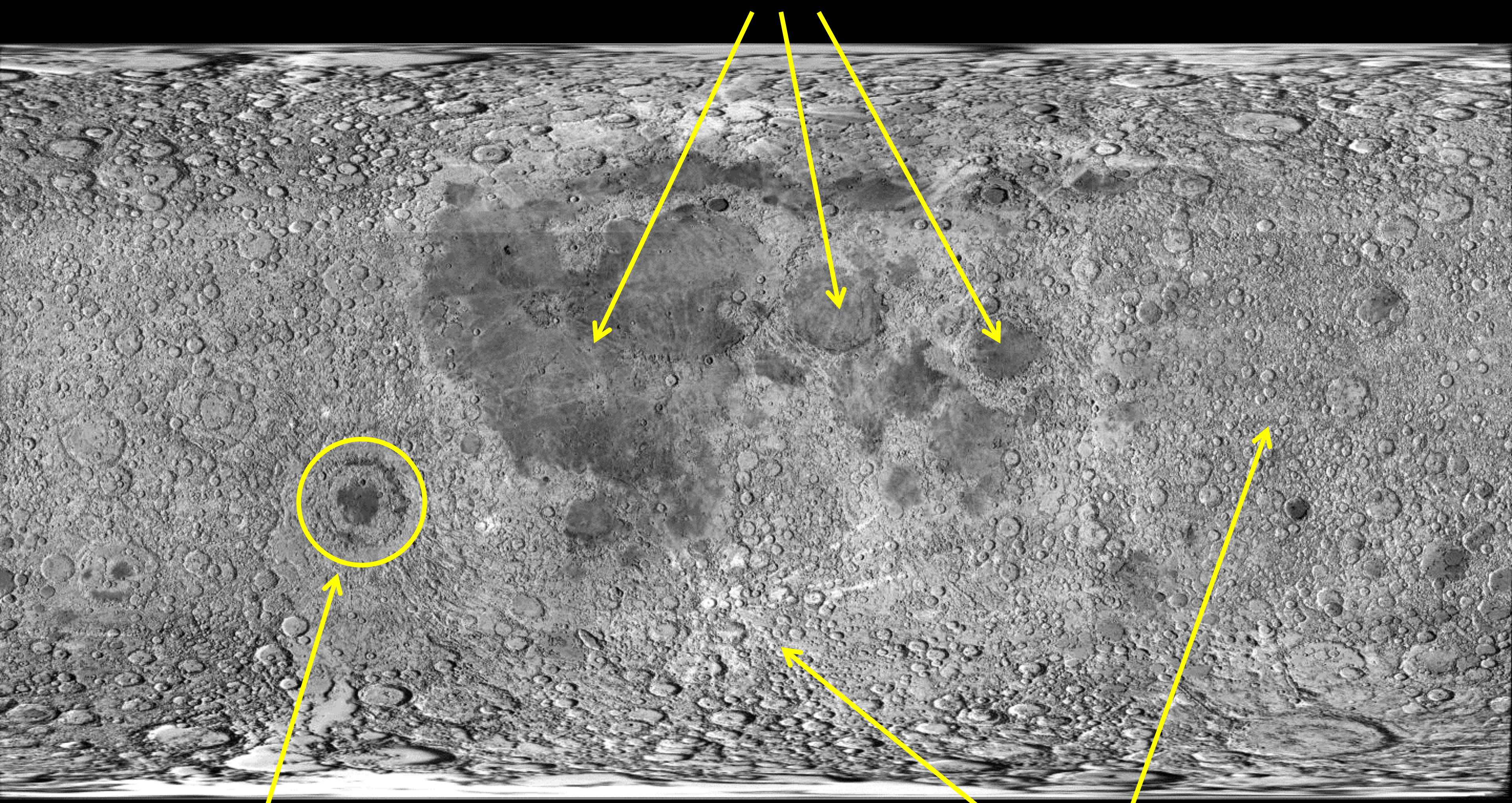


Crustal Shaping:
- Primary crust: shaped by impacts
- Secondary crust: shaped by volcanism

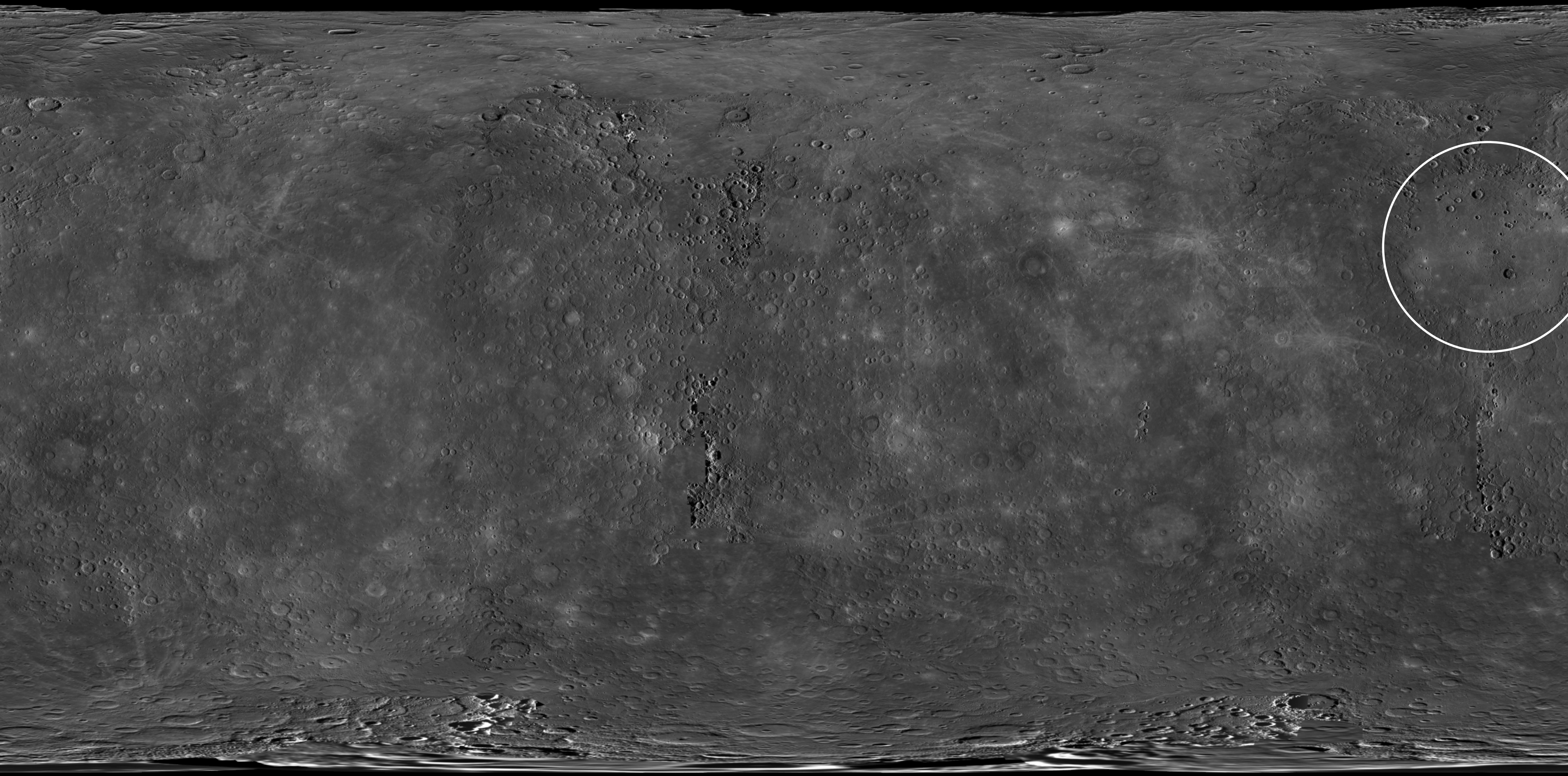
Lava plains (Maria) on the Moon
Lava plains and volcanic vents on Mercury
Hot-spot volcanoes on Mars



The Moon

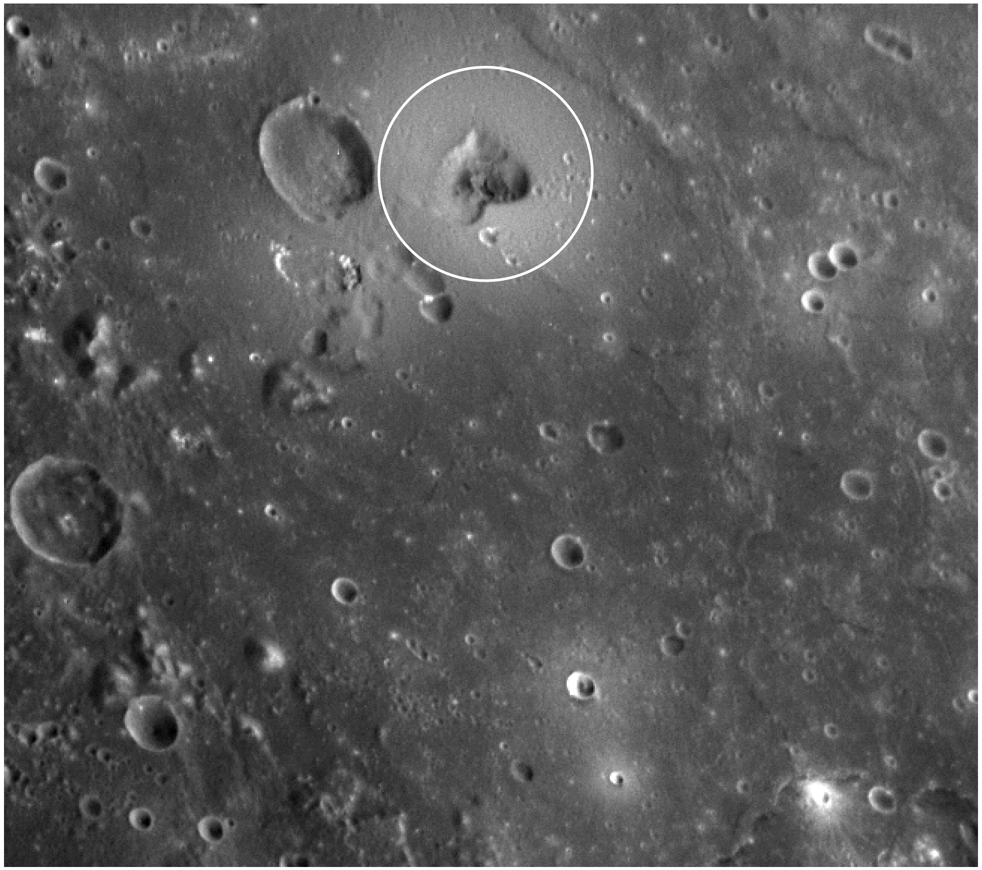


Mercury

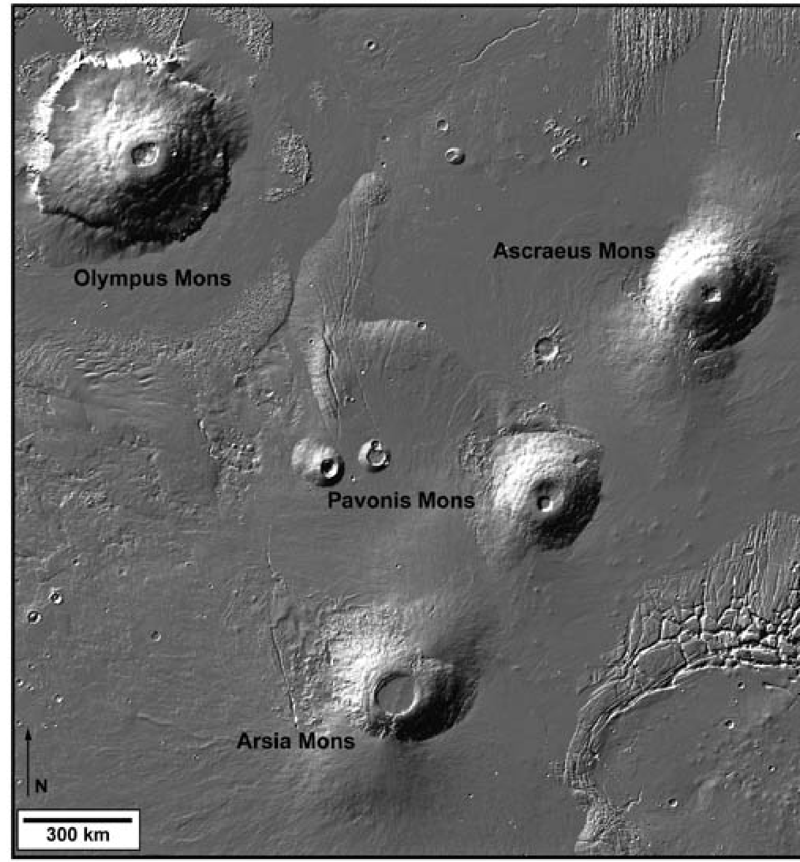


MESSENGER

Evidence of past volcanism on Mercury and Mars



Volcanic vents on Mercury
[MESSENGER]



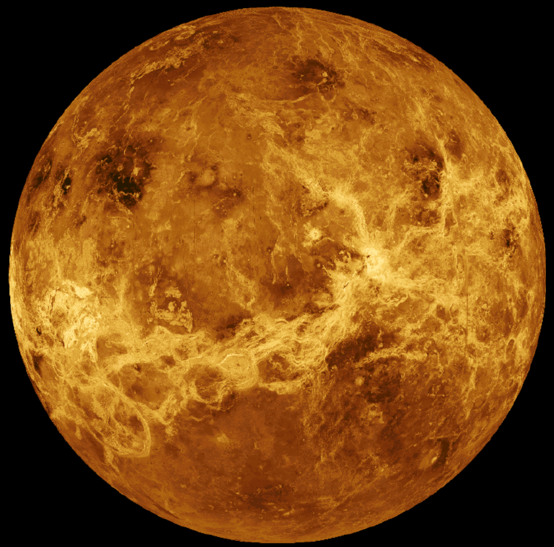
Hot Spot Shield Volcanoes on Mars
[NASA MGS]

The surfaces of the large terrestrial planets are young, with active tertiary crusts.

Earth's surface is ~100 Myr old

Venus' surface is ~500 Myr old

Earth: plate tectonics & lateral recycling:
subduction, sea-floor spreading &
Up-thrust constantly rebuild the crust.

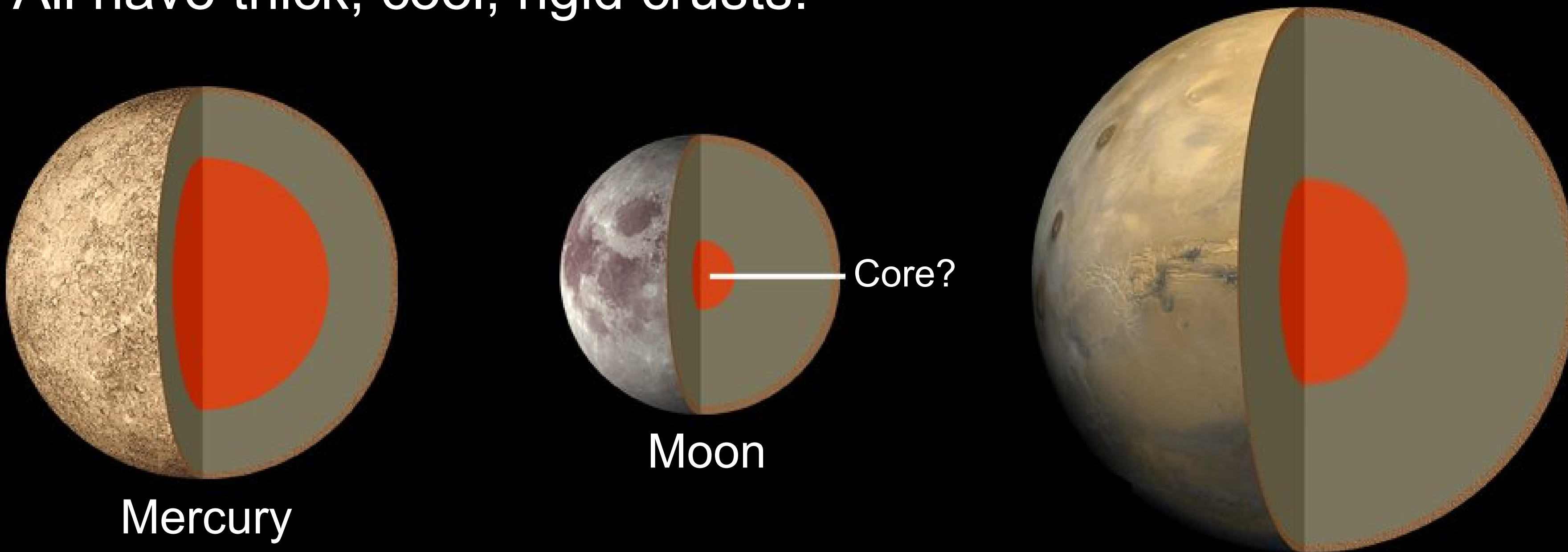


Venus: one-plate crust & vertical recycling:
volcanoes over mantle upwelling,
compression over mantle down-welling.

The interiors of the small terrestrial planets cooled rapidly and have mostly solidified.

A solid mantle ends tectonic activity.

All have thick, cool, rigid crusts.

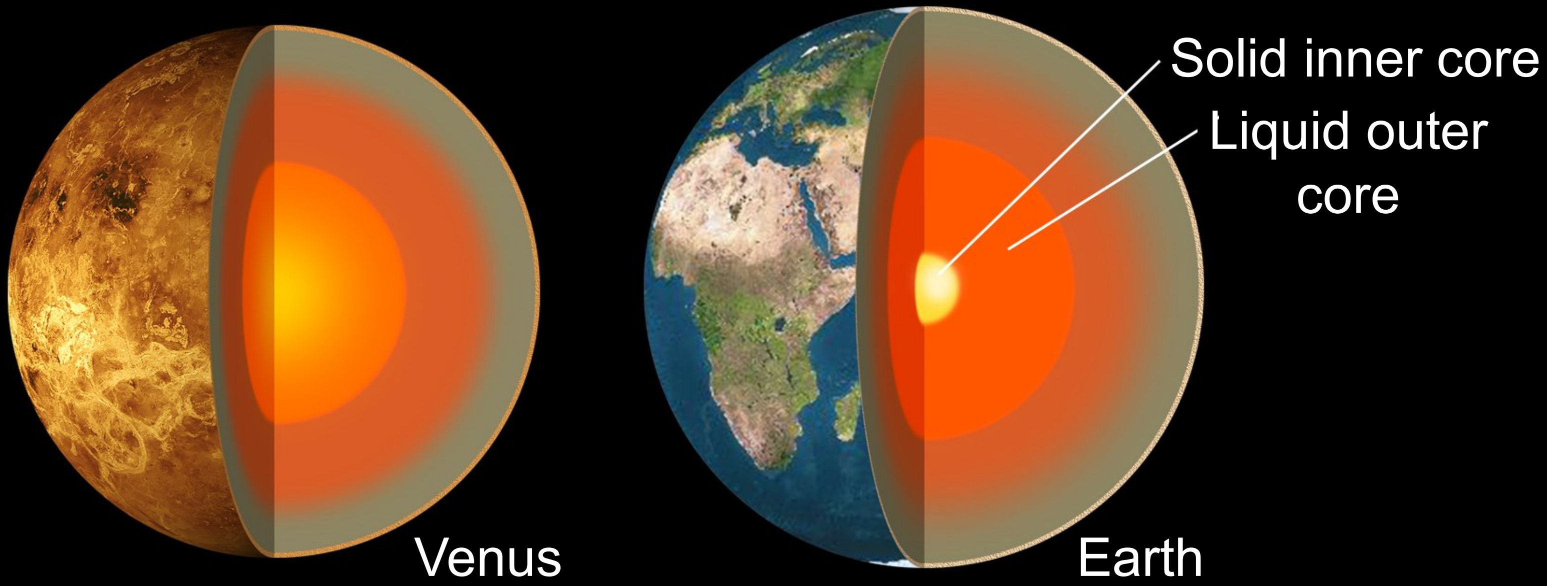


Mercury has signs of ancient volcanic vents.

Mars has large, extinct shield volcanoes.

The large terrestrial planets cool more slowly and are still hot.

Kept hotter longer by energy released from the decay of radioactive elements.



Convective motions in molten mantles drives tectonism and gives them active tertiary crusts.

The evolution of Terrestrial Planet atmospheres is driven by three primary effects:

Greenhouse Effect:

- Solar heating & atmospheric cooling balance
- Helps determine if H_2O is liquid, ice, or vapor

Planetary Gravity:

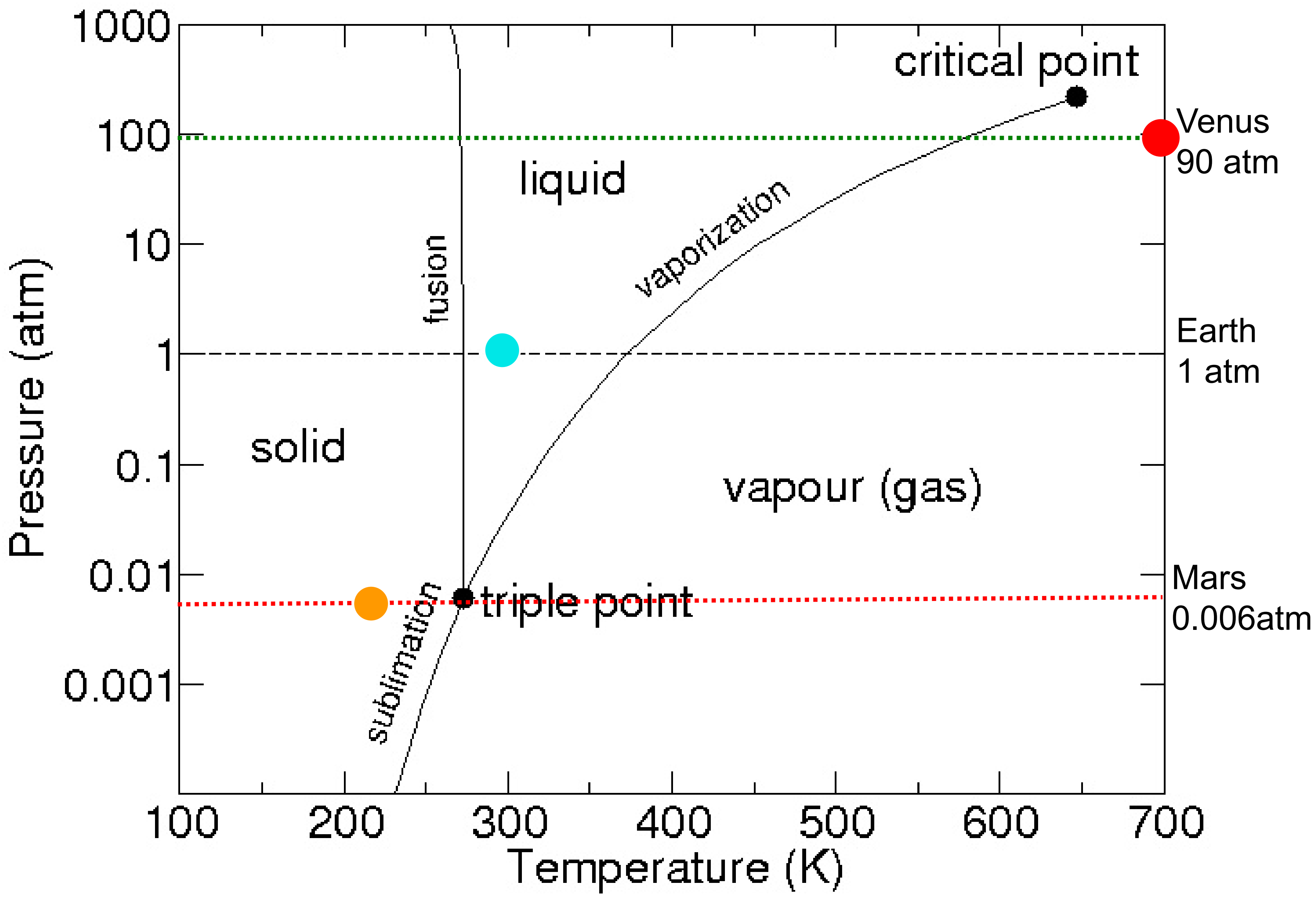
- Determines a planet's ability to retain hot atoms & molecules.

Chemistry of CO_2 and H_2O:

- CO_2 is easily dissolved in liquid H_2O
- Help determine the atmospheric CO_2 content, and its contribution to the Greenhouse Effect.

The Greenhouse Effect makes a planet's temperature warmer than if it had no atmosphere.

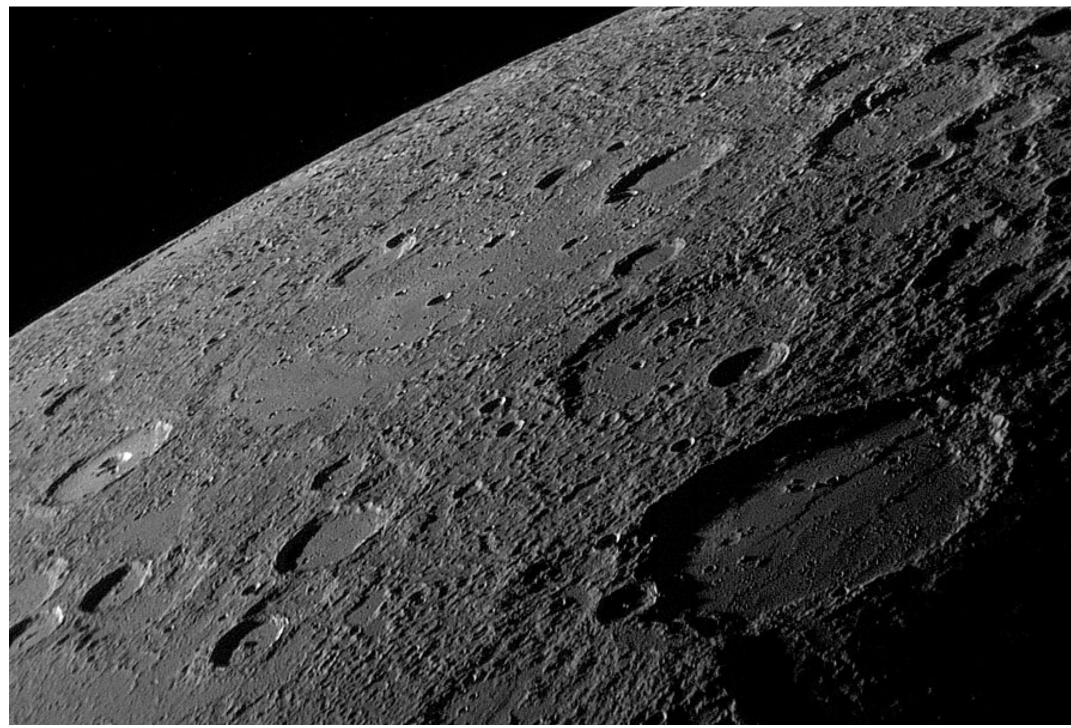
	Without Atmosphere	With Atmosphere	ΔT	Water Phase
Earth	255K	290K	+35 K	Liquid
Venus	280 K	750 K	+470 K	Vapor
Mars	214 K	220 K	+6 K	Ice


1000
100
10
1
0.1
0.01
0.001
Pressure (atm)
100
200
300
400
500
600
700
Temperature (K)
critical point
liquid
vaporization
fusion
solid
vapour (gas)
triple point
sublimation
Venus
90 atm
Earth
1 atm
Mars
0.006atm

Mercury is too hot for liquid water, and its gravity too weak to retain an atmosphere.

Lack of liquid water shutdown CO_2 and H_2O chemistry resulting in a *Runaway Greenhouse Effect*

Surface gravity was too weak to hold onto its hot atmosphere, so it lost all of its volatiles after ~1 Gyr



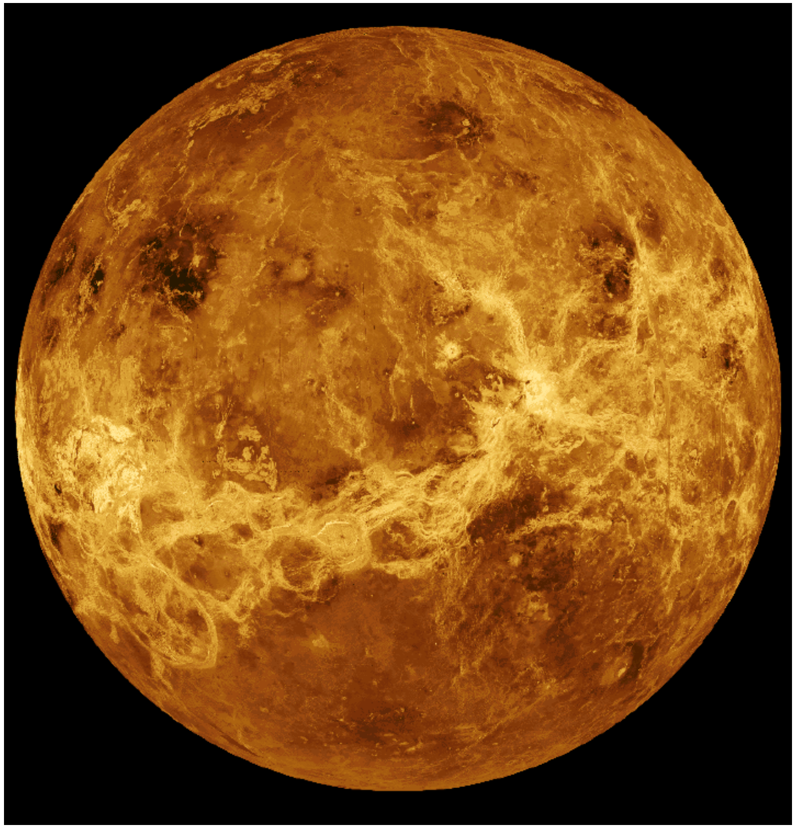
Result: *Mercury has no atmosphere today*

Venus' Atmosphere was also too hot for liquid water, but large enough to retain its atmosphere.

May have had early oceans that evaporated resulting in a *Runaway Greenhouse Effect.*

Gravity strong enough to retain its atmosphere, so ended up with a hot, heavy CO_2 and N_2 atmosphere.

All H_2O lost to UV photolysis
H_2 escaped and the O reacted with other gasses.



Result: *Venus has a bone dry, hot, heavy CO_2 atmosphere*

Earth's Atmosphere was warm enough for abundant liquid water, and large enough to keep it.

The H_2O condensed into massive, deep oceans and setup a water cycle of evaporation and precipitation.

CO_2 chemistry in liquid water results in most of the CO_2 locked up in the oceans & carbonaceous rocks.

Plants thrive in liquid water, converting CO_2 into O_2

A mild Greenhouse Effect keeps Earth warm enough for liquid water

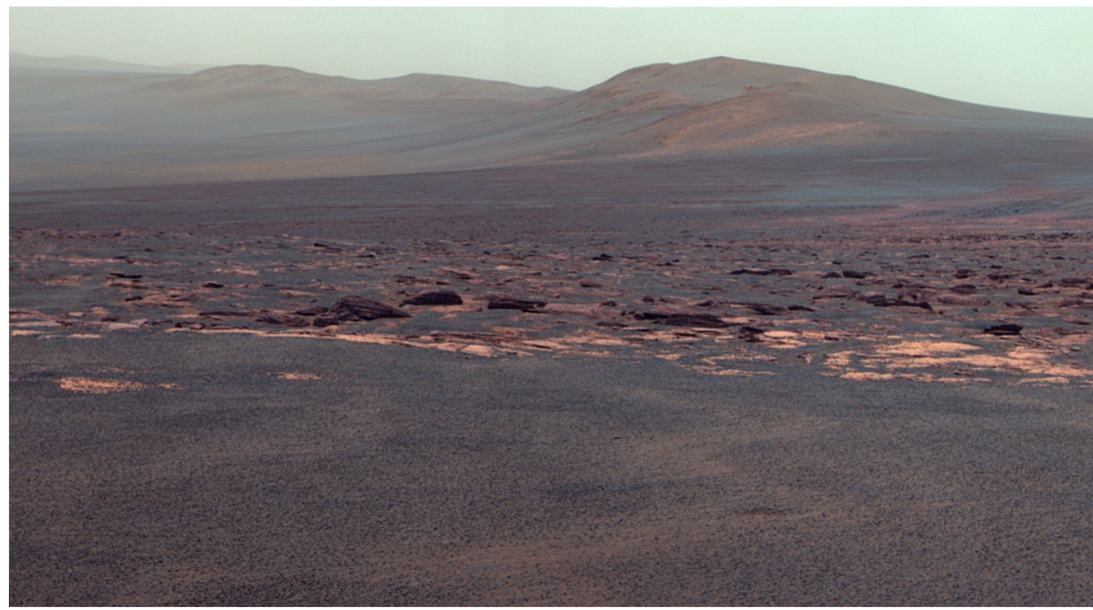
Result: *Earth has a warm, moist N_2 & O_2 atmosphere*

Mars' Atmosphere may have been warm enough for liquid water during first Gyr, but could not keep it.

Some CO_2 locked into carbonaceous rocks??
Evidence of past water from the Mars Rovers.

As Mars cooled, H_2O froze out (most may already have frozen into saturated rocks).

CO_2 and N_2 escapes Mars' weak gravity, aided by the solar wind.



Result: *Mars has a cold, dry, thin CO_2 atmosphere today, but might have been hospitable in the past.*

The *present-day* terrestrial planet atmospheres are different outcomes of atmosphere evolution from similar starting points.

	Earth	Venus	Mars
CO_2	0.035%	96%	95%
N_2	77%	3.5%	2.7%
H_2O	1%	0.01%	0.007%
Ar	0.93%	0.007%	1.6%
O_2	21%	trace	trace
Temp	290K	750K	220K

Habitable (Earth)

Inhospitable Today (Venus, Mars)