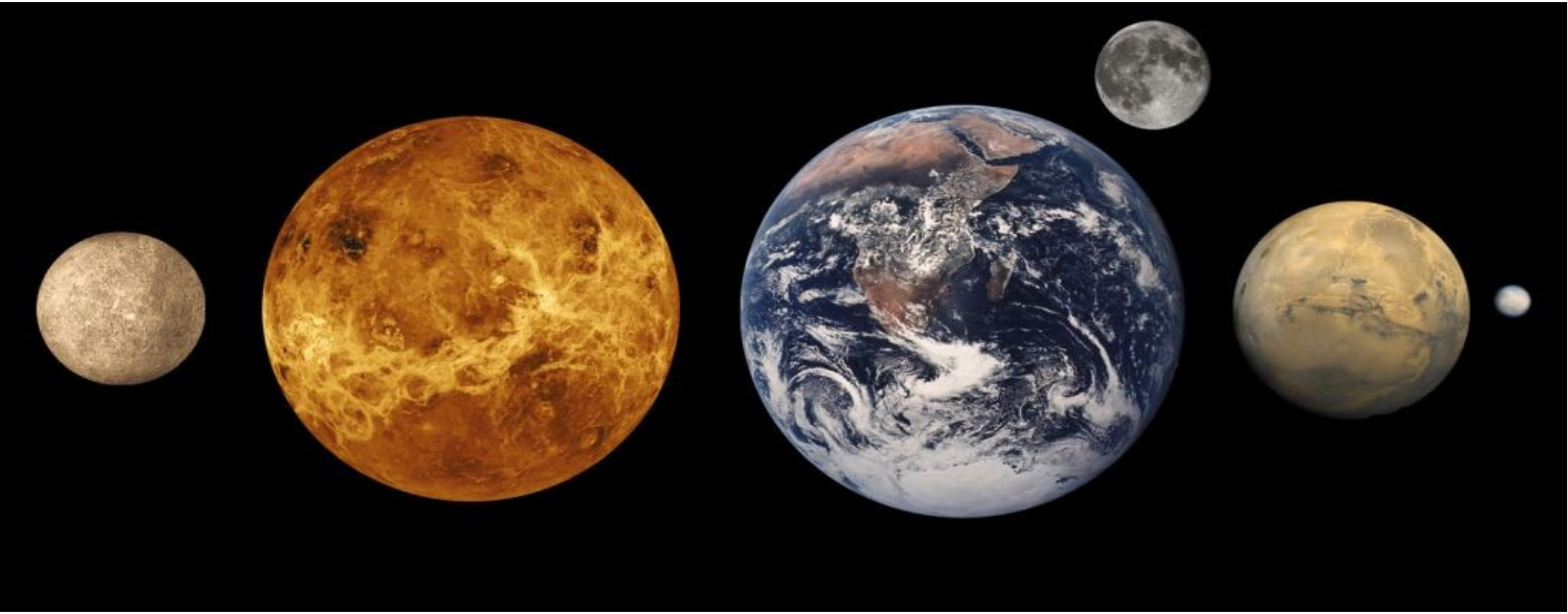
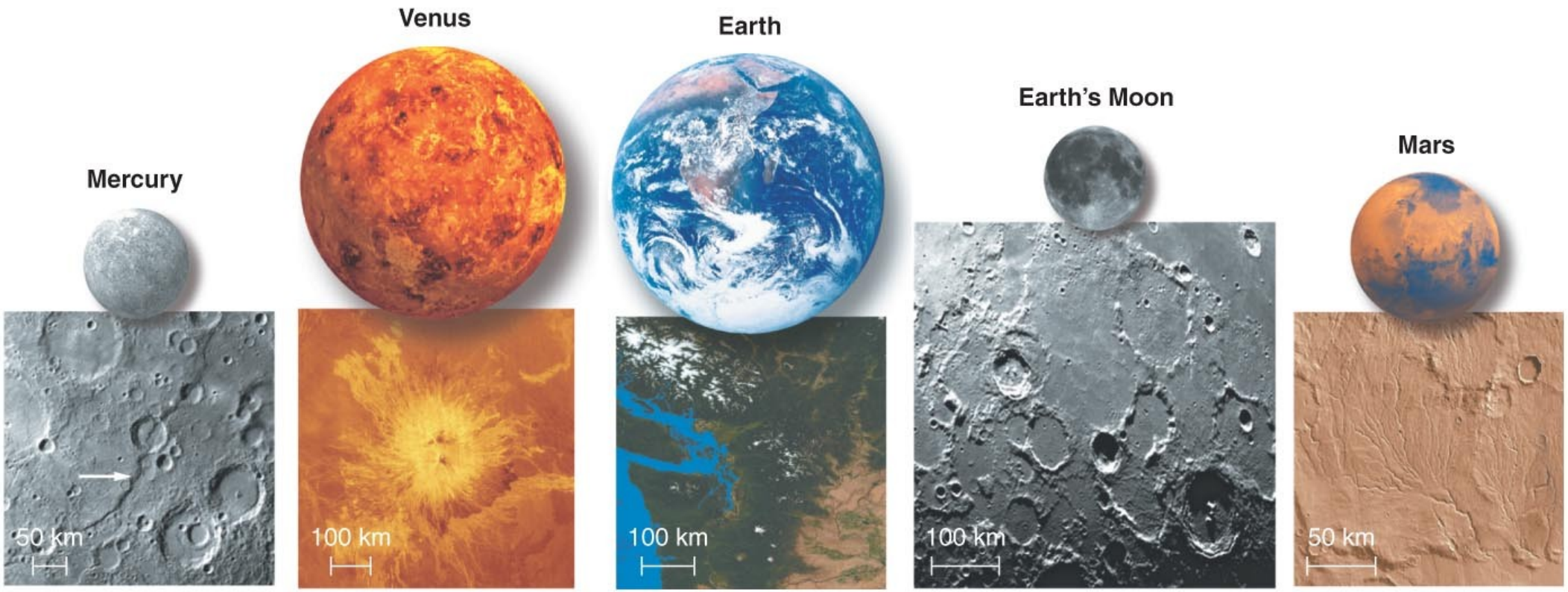
The Terrestrial planets



Geological Destiny



Heavily cratered Mercury has long steep cliffs (arrow).

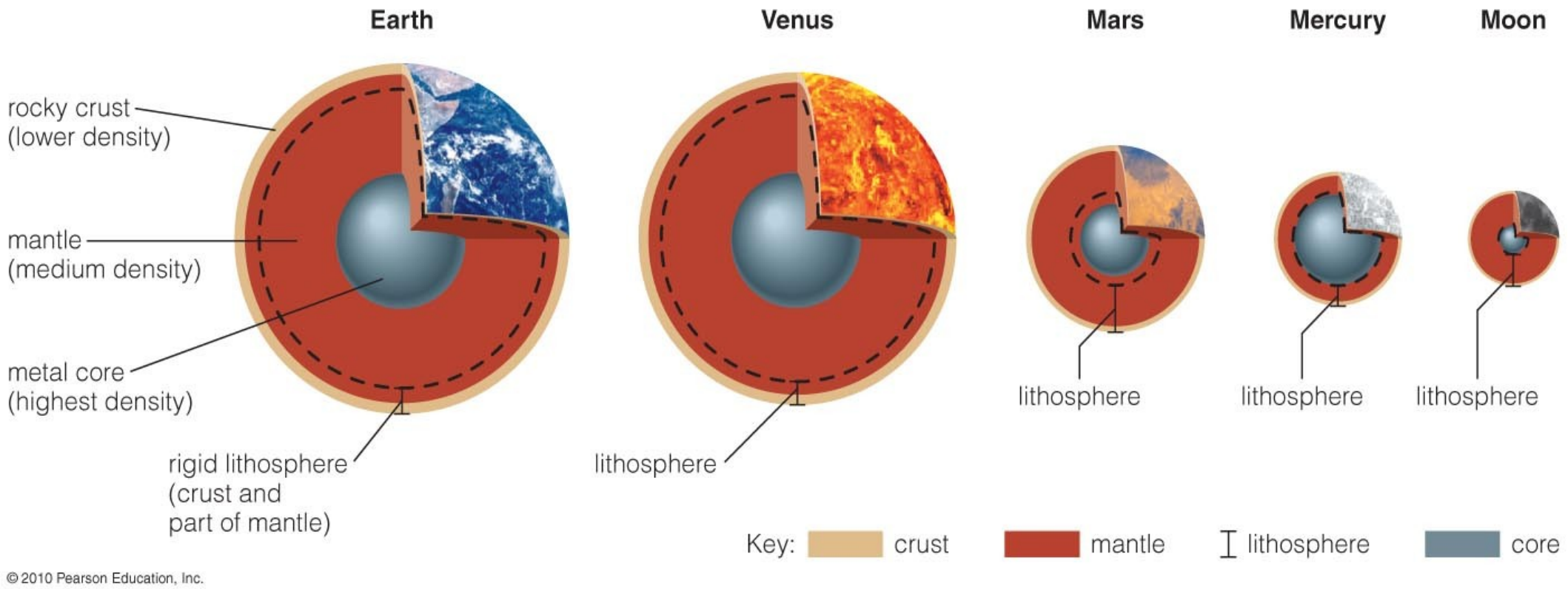
Cloud-penetrating radar revealed this twin-peaked volcano on Venus.

A portion of Earth's surface as it appears without clouds.

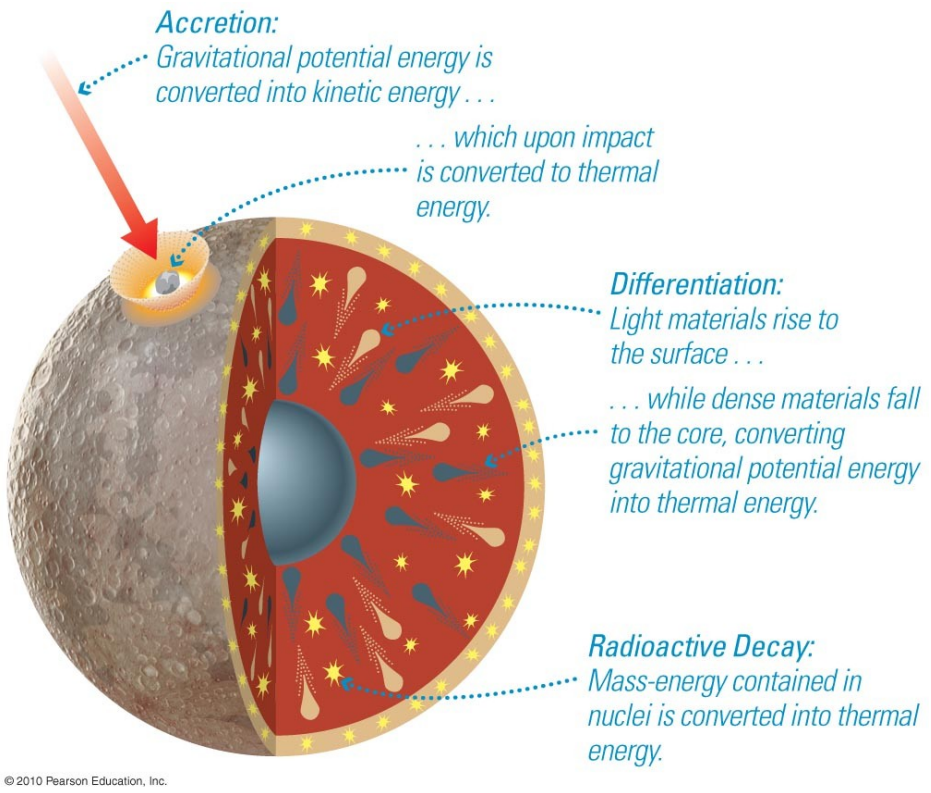
The Moon's surface is heavily cratered in most places.

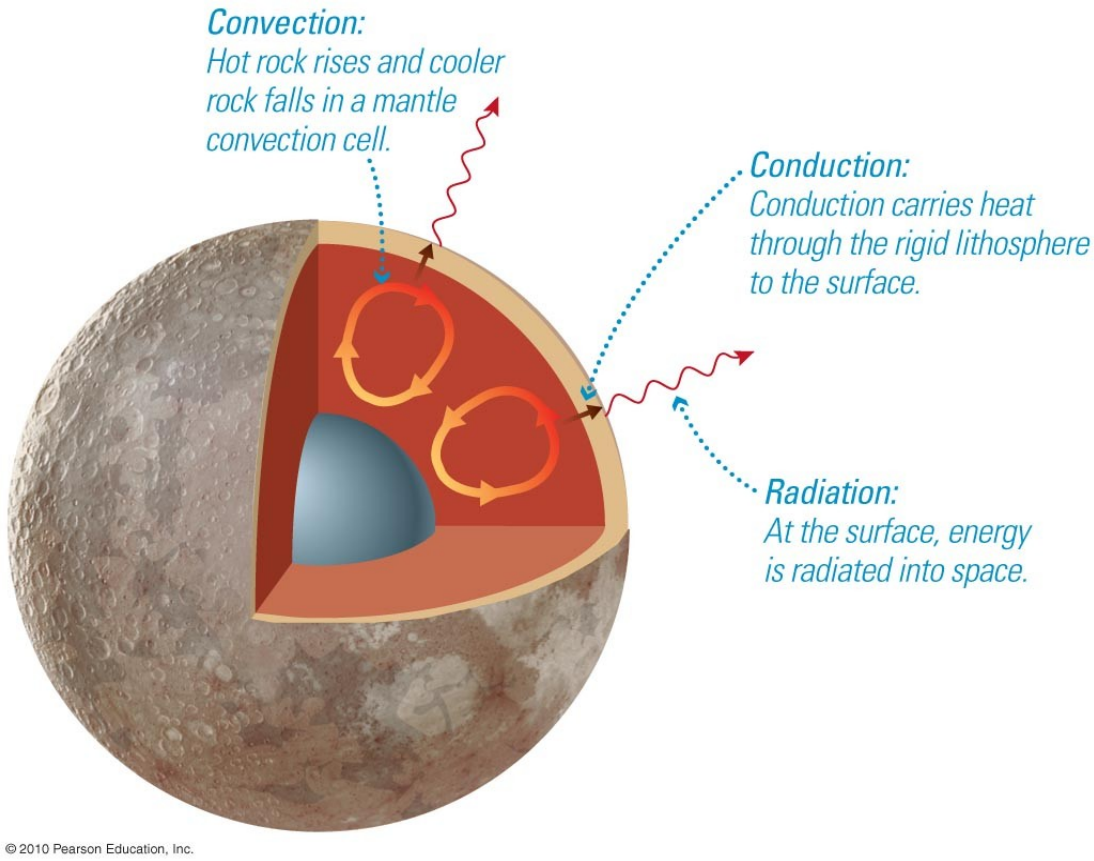
Mars has features that look like dry riverbeds; note the impact craters.

Geological Destiny

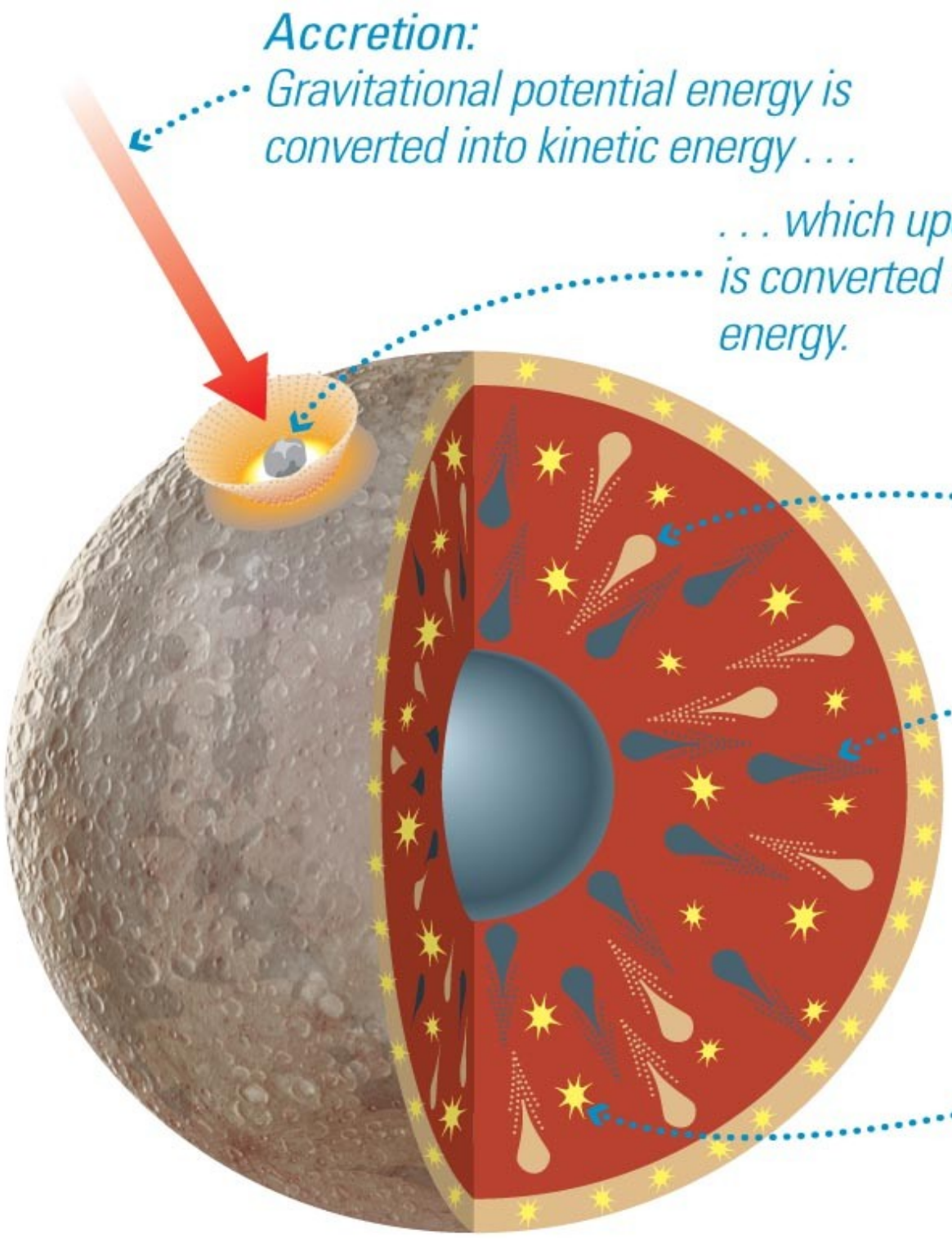


Heating vs Cooling

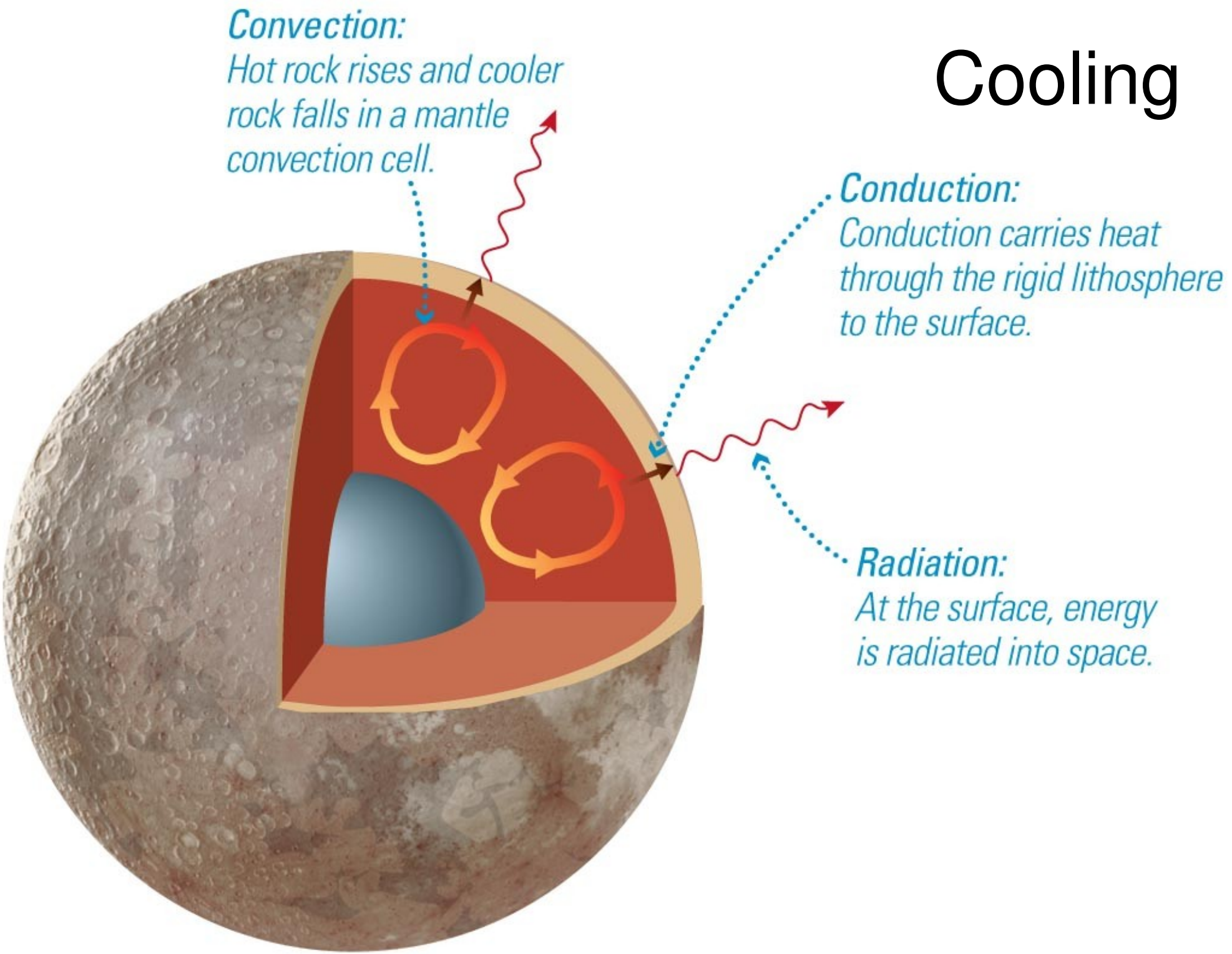




Heating



Cooling



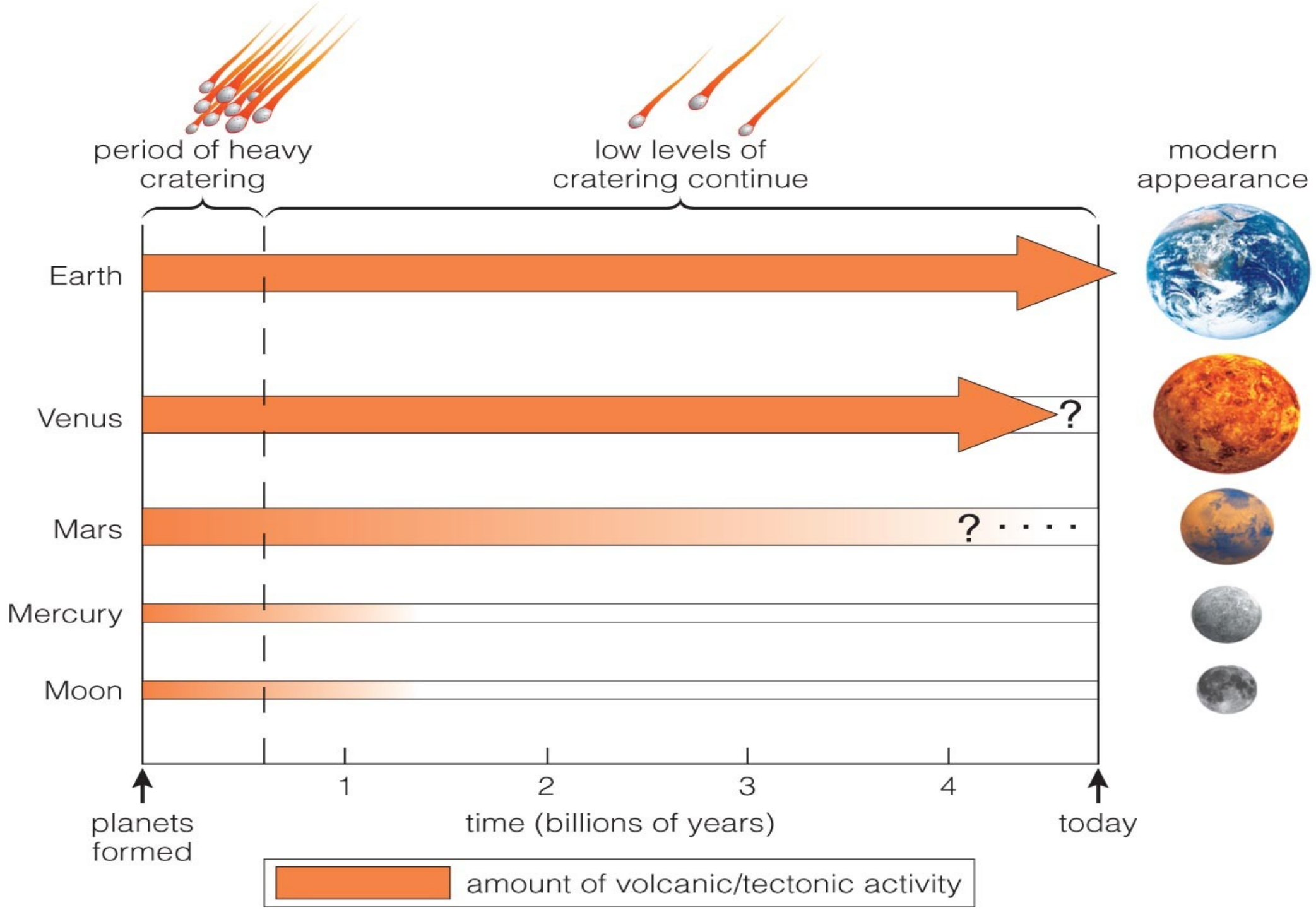
How is it small objects cool quicker?

The critical concept is that the main sources of initial heat depend on the VOLUME of the body

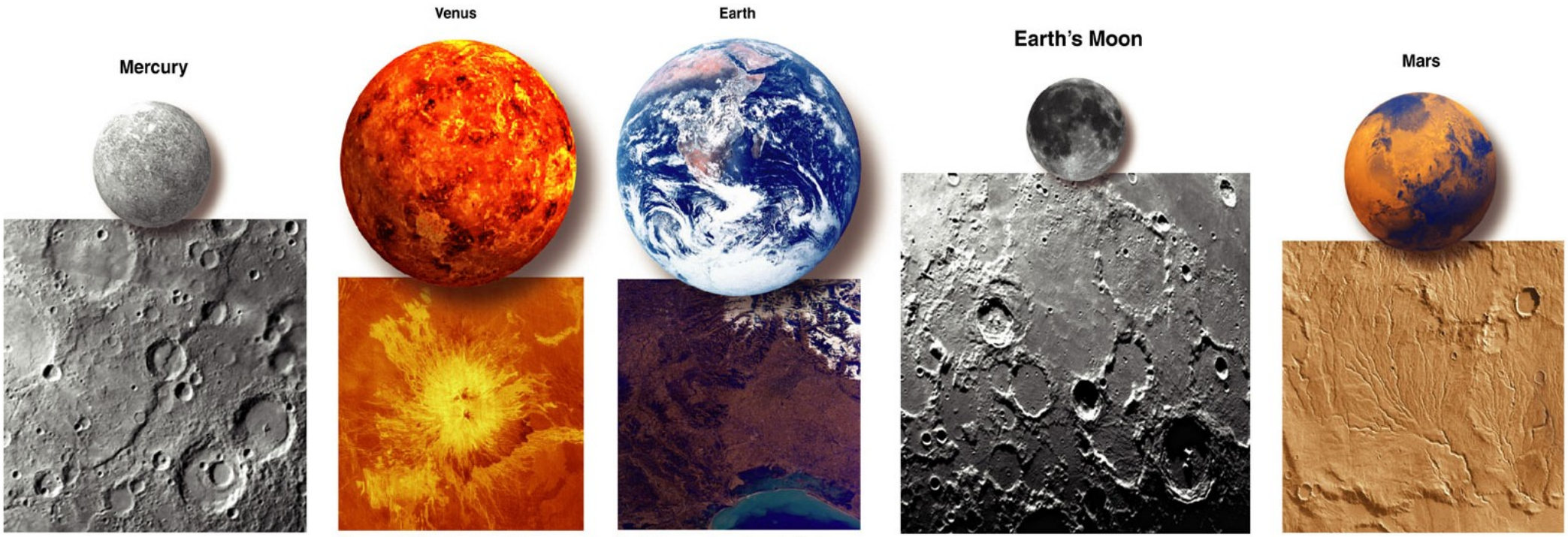
But the heat has to pass out the SURFACE of the object to cool to space

So the “rate you can get rid of heat, divided by total amount you started with” goes as:

(surface area)/volume *proportional to* $(r^2)/(r^3) = 1/r$
so the largest objects take longer



Terrestrial Planet Surfaces



Mercury is heavily cratered, but also has long, steep cliffs—one is visible here as the long curve that passes through the center of the image.

The central structure is a tall, twin-peaked volcano on Venus.

Earth has a variety of geological features visible in this photo from orbit.

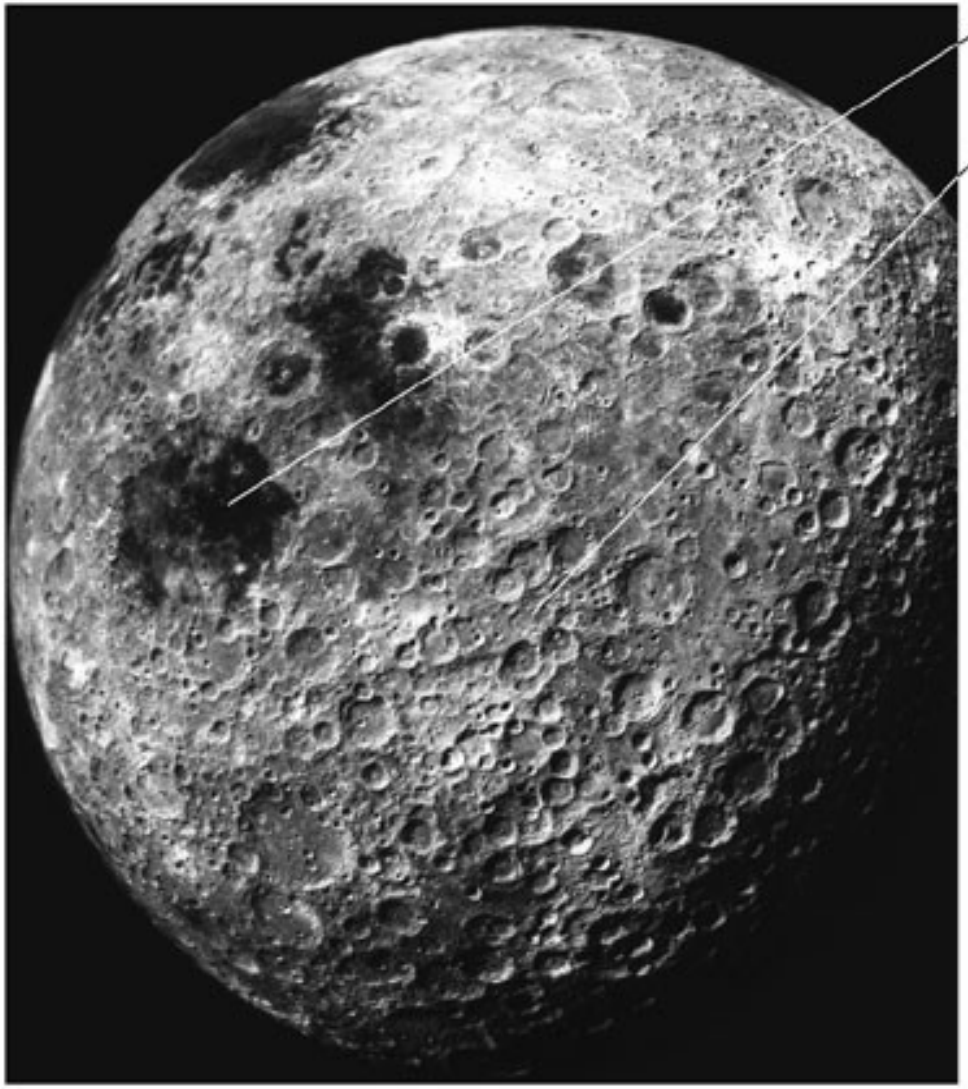
The Moon's surface is heavily cratered in most places.

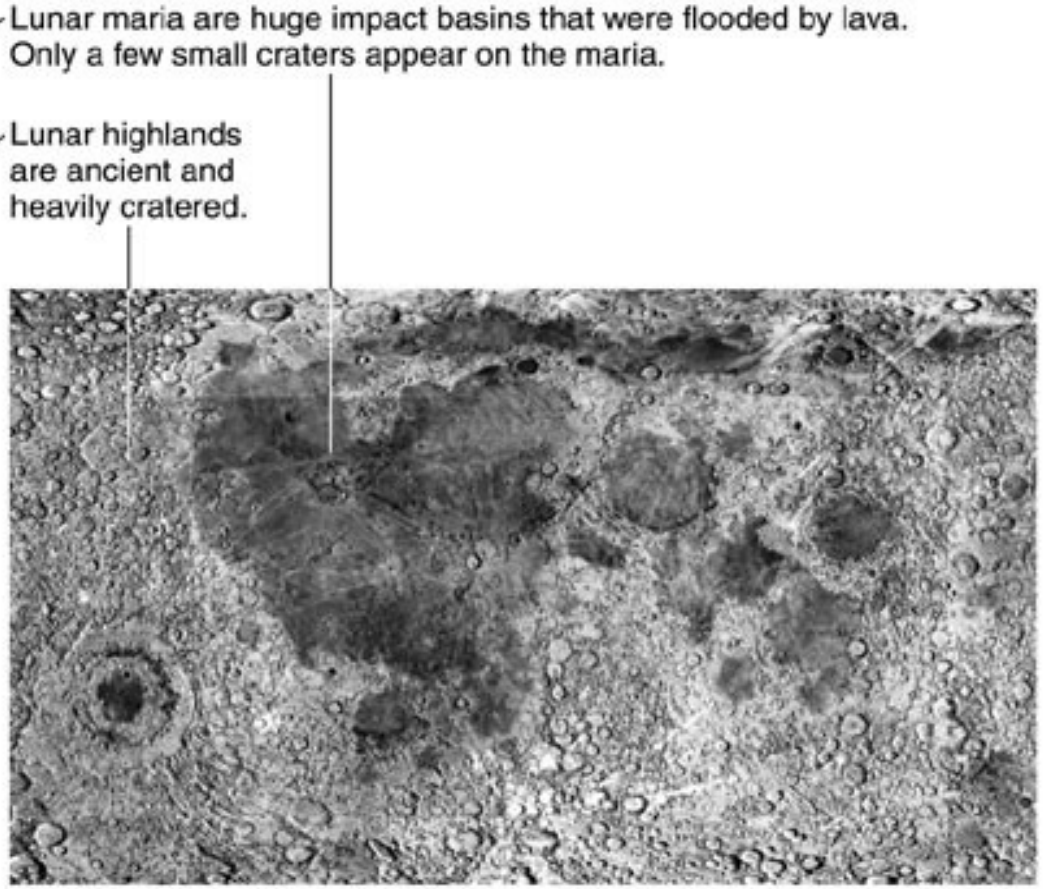
Mars has impact craters like the one near the upper right, but it also has features that look much like dried up riverbeds.

How do they compare to one another?

The Moon : A wealth of data

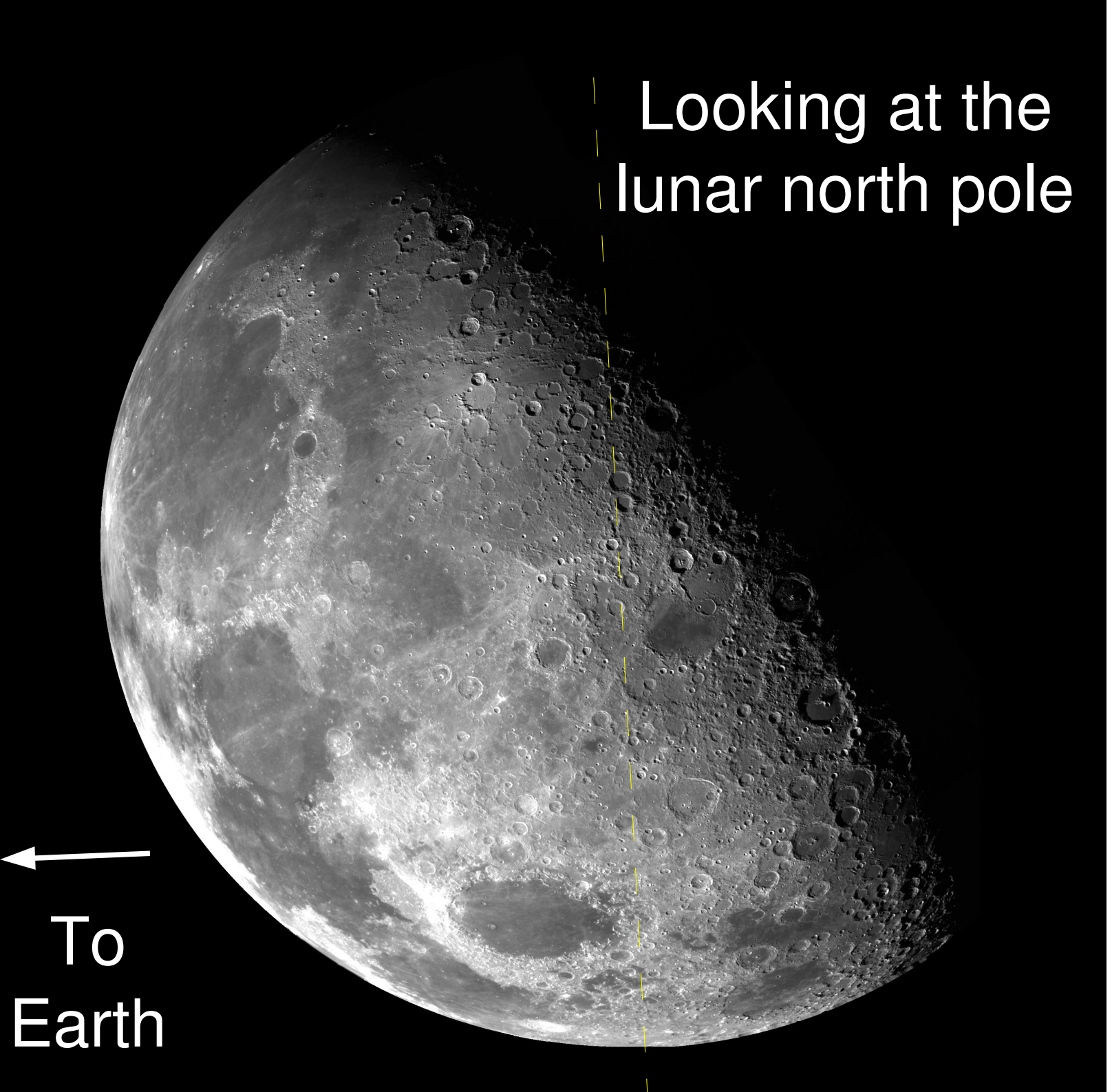
Our Moon intensely studied by orbiters and sample returns, giving surface geology.





The lunar surface dichotomy

Low-lying mare vs. highlands



Observe :

-Mare

-Highlands

-craters

Download this image from the lecture website and zoom around!

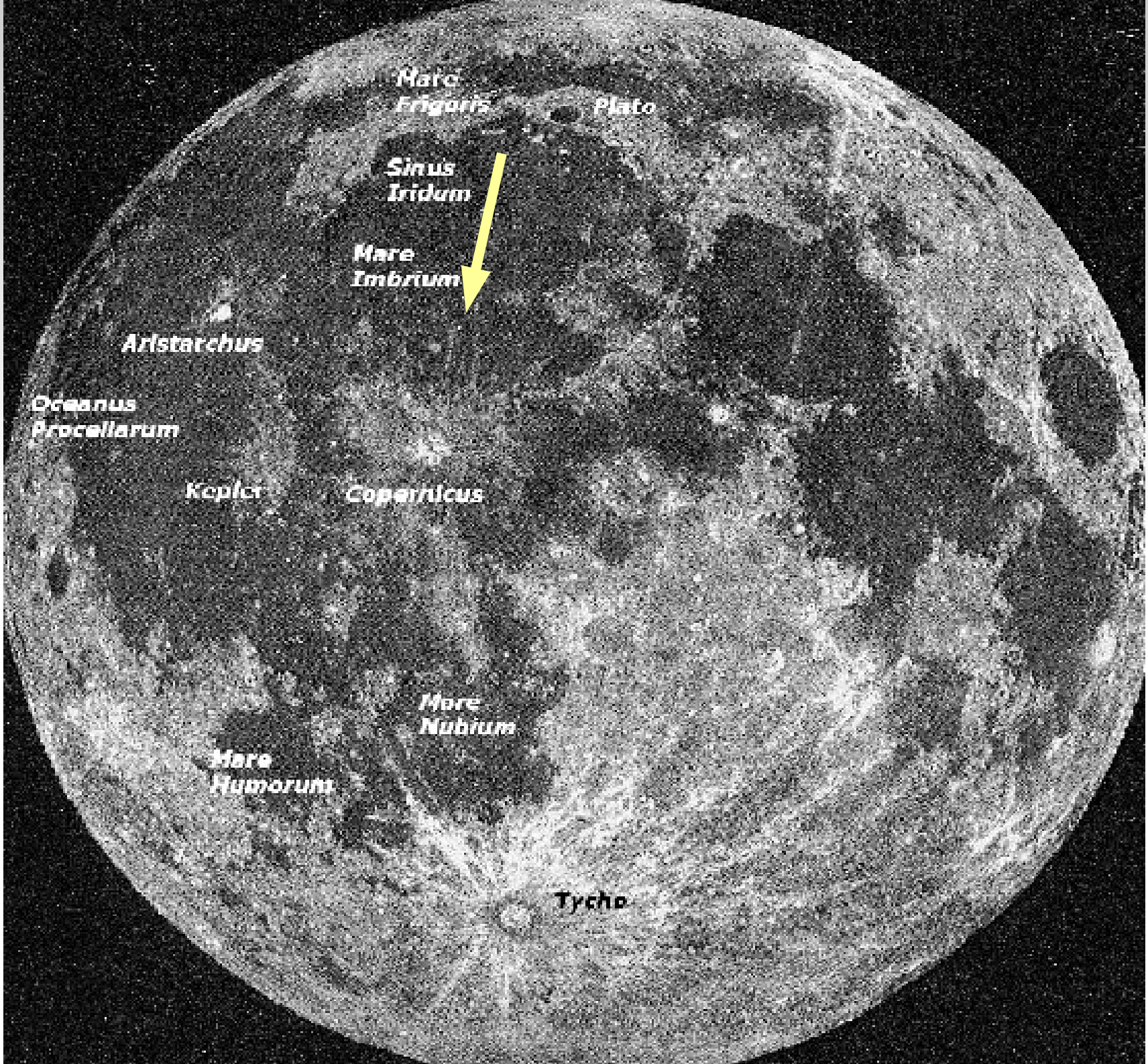
Over Mare Imbrium, looking towards Copernicus

Note how smooth the Mare region is

The ring of mountains is the nearly-buried rim of the Imbrium basin

Observe rays and chains of secondary craters from Copernicus – stratigraphic information.

(Apollo 17 orbiter photo)


Mare
Frigoris
Plato
Sinus
Iridum
Mare
Imbrium
Aristarchus
Oceanus
Procellarum
Kepler
Copernicus
Mare
Nubium
Mare
Humorum
Tycho

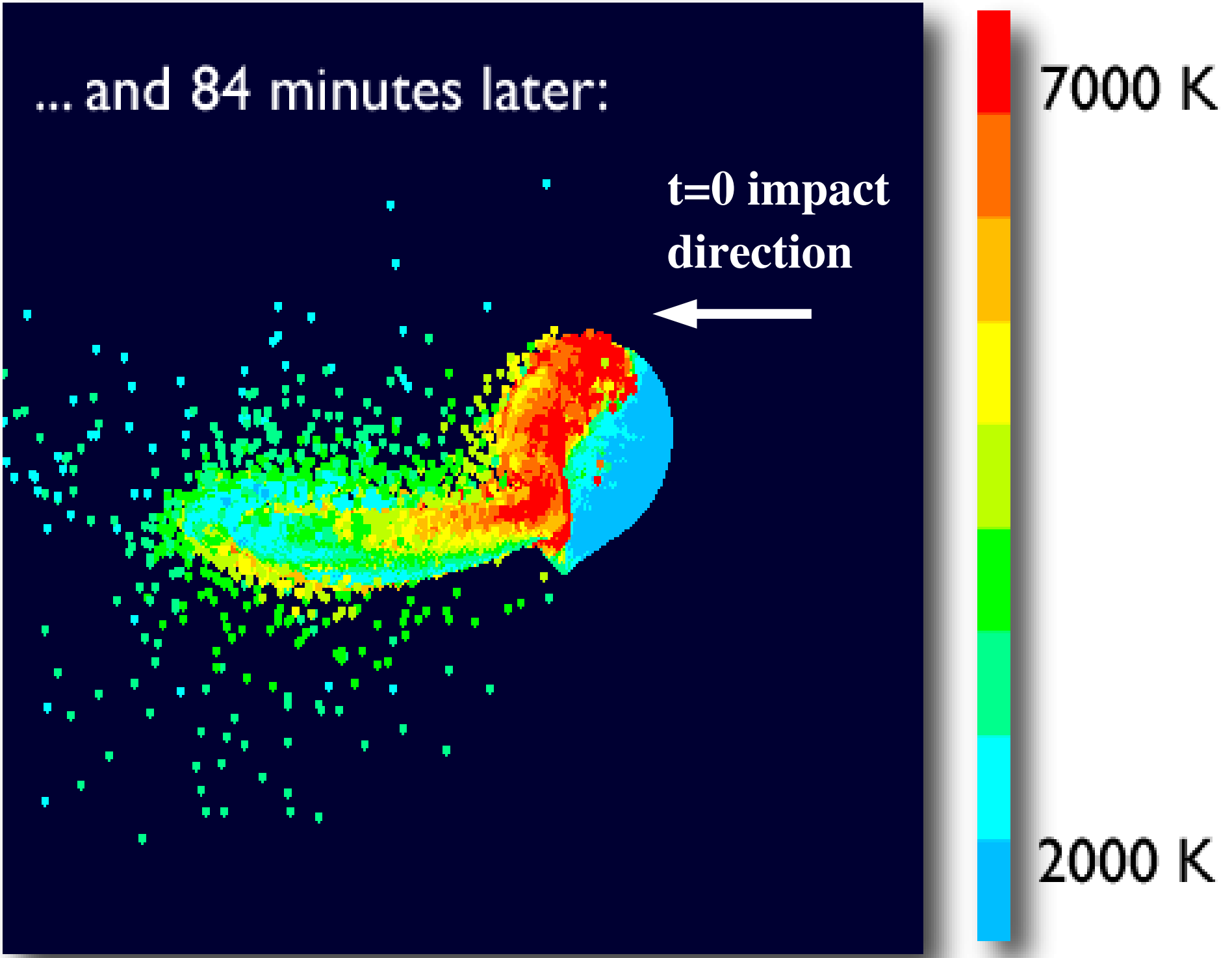

2441
ASA

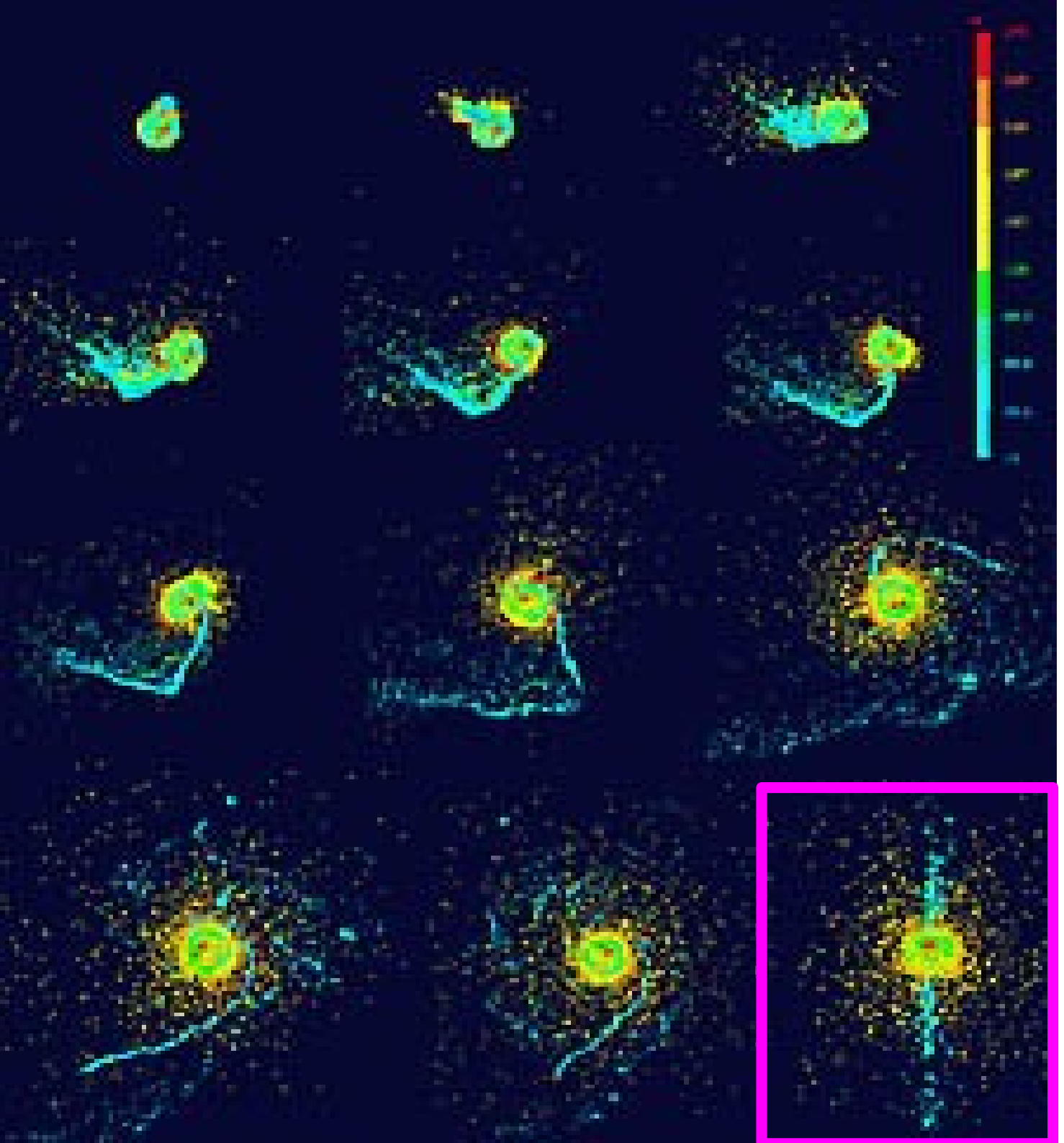
Lunar Formation

Our Moon formed 4.4-4.5 billion years ago

- Giant impact of Mars-sized object into Earth
  - nicknamed 'Theia'
- Earth surrounded by an accretion disk, out of which the moon accretes

"By far the biggest Boom the Earth has ever been involved in!"


... and 84 minutes later:
t=0 impact direction
7000 K
2000 K



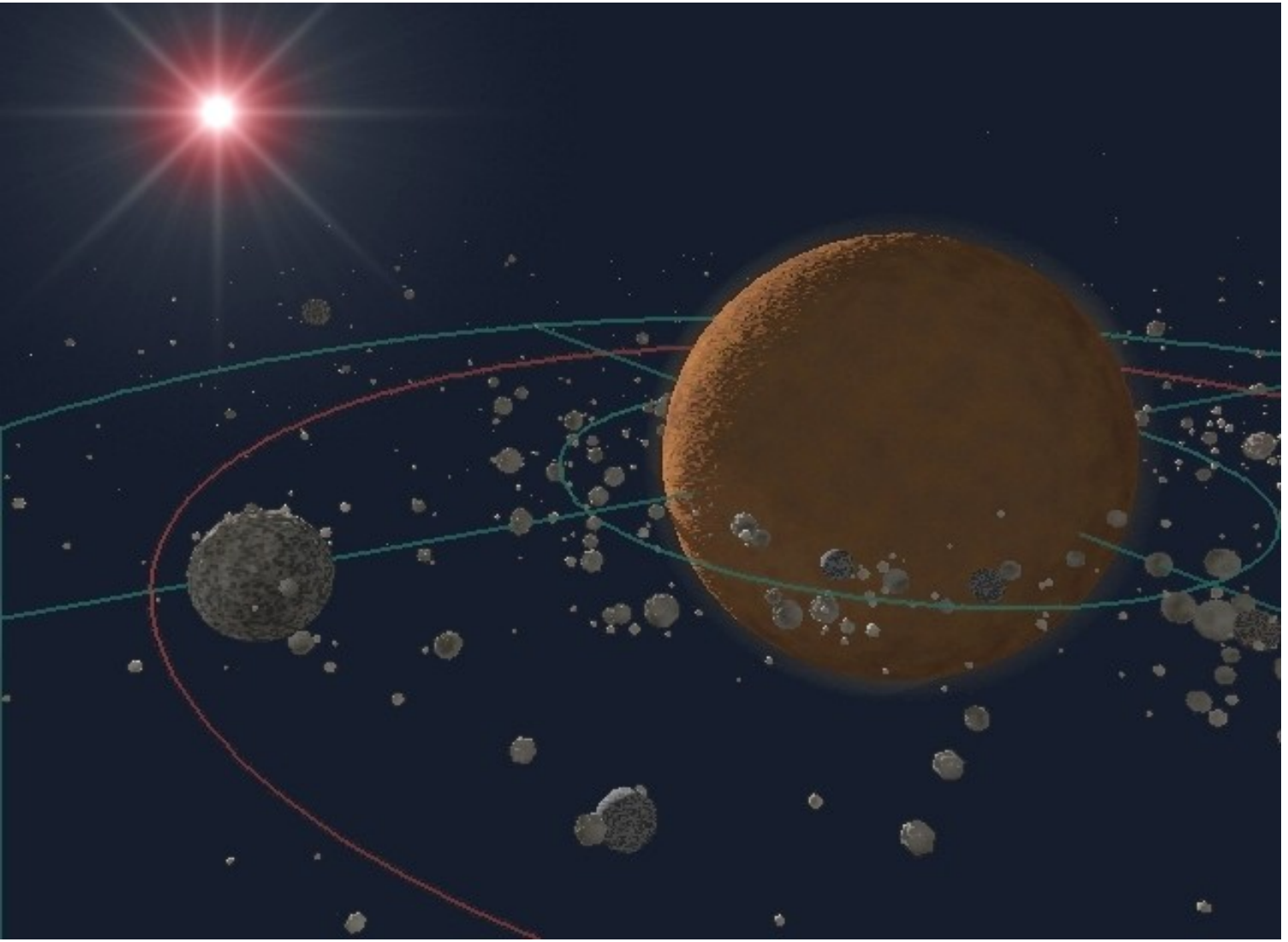
Time snapshots of the production of the disk

(see text figs 15.14 and 15.15)

Generation of the post- impact accretion disk

Edge-on view; other panels are 'face on' views

Moon accretes out of impact-generated disk, near the Earth...



This scenario explains many things:

- proximity of Moon to Earth ~Gyr ago
- low iron abundance of the Moon
- volatile depletion of the Moon
- the high angular momentum of E/M system

The Moon

Rapid initial evolution

The Moon evolved rapidly outward due to tides

The Moon cooled quickly (by about 4.3 Gyr)

During this initial phase the heavily-cratered lunar highlands formed (late heavy bombardment)

Subsequent Lunar history

Lunar Highlands : Ancient crust of anorthosite
Lunar Mare : Volcanic floodplains in craters/basins

1. Young Moon cratered during *late heavy bombardment* (4.4-3.9 Gyr ago)

2. Reheated (by radioactivity?) and mare created by basalt flooding (3.9-3.2 Gyr ago)

3. Volcanism stops. Moon cratered *gradually* over last 3 billion years.

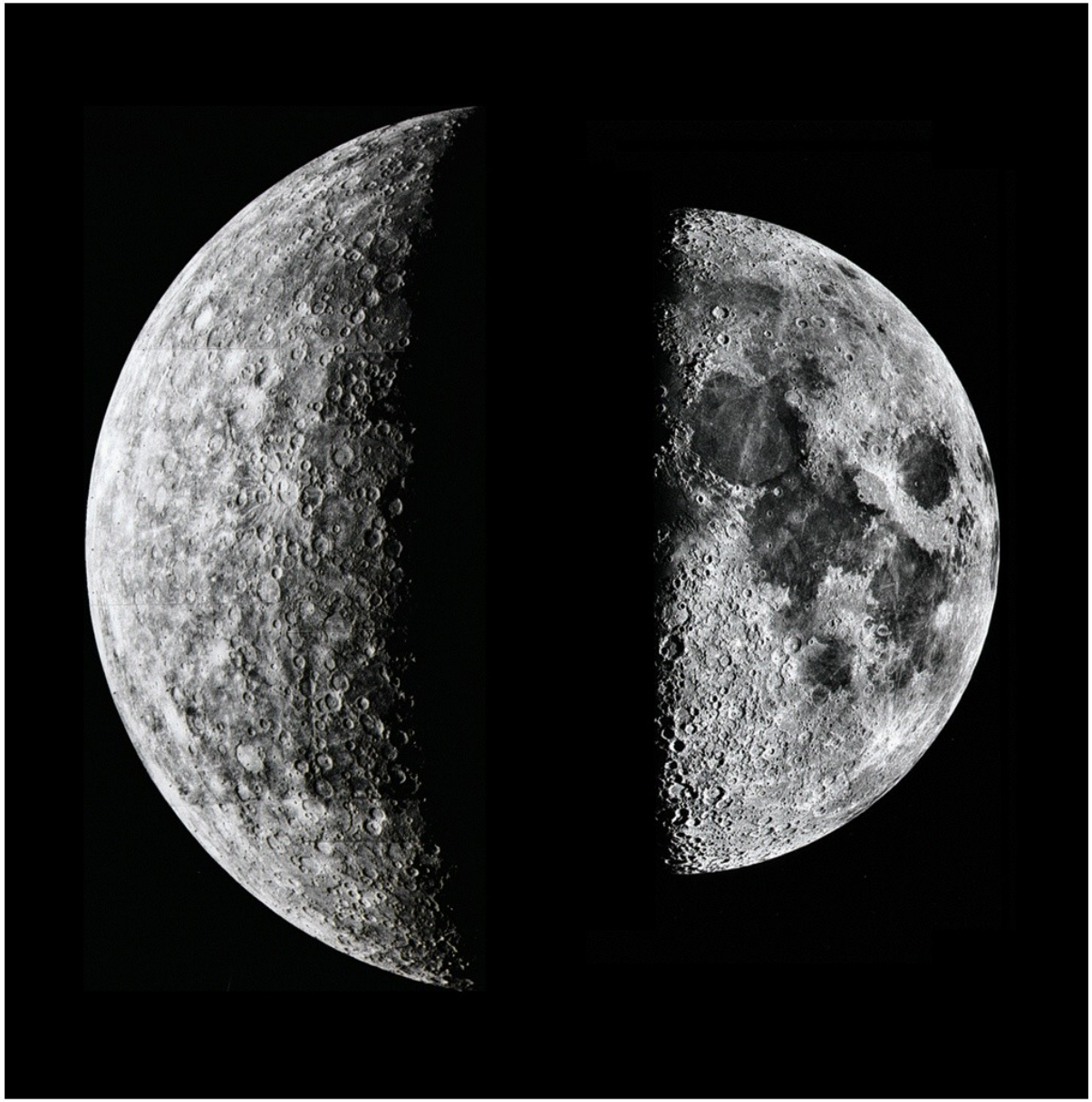
Lunar cooling

The mare show signs of crustal compression (raised ridges forced up as crust cooled)

Here: a portion of lunar mare showing ridges

Last 3 Gyr: The only erosional process on the Moon is *impact cratering*

Mercury and the Moon: Barren worlds

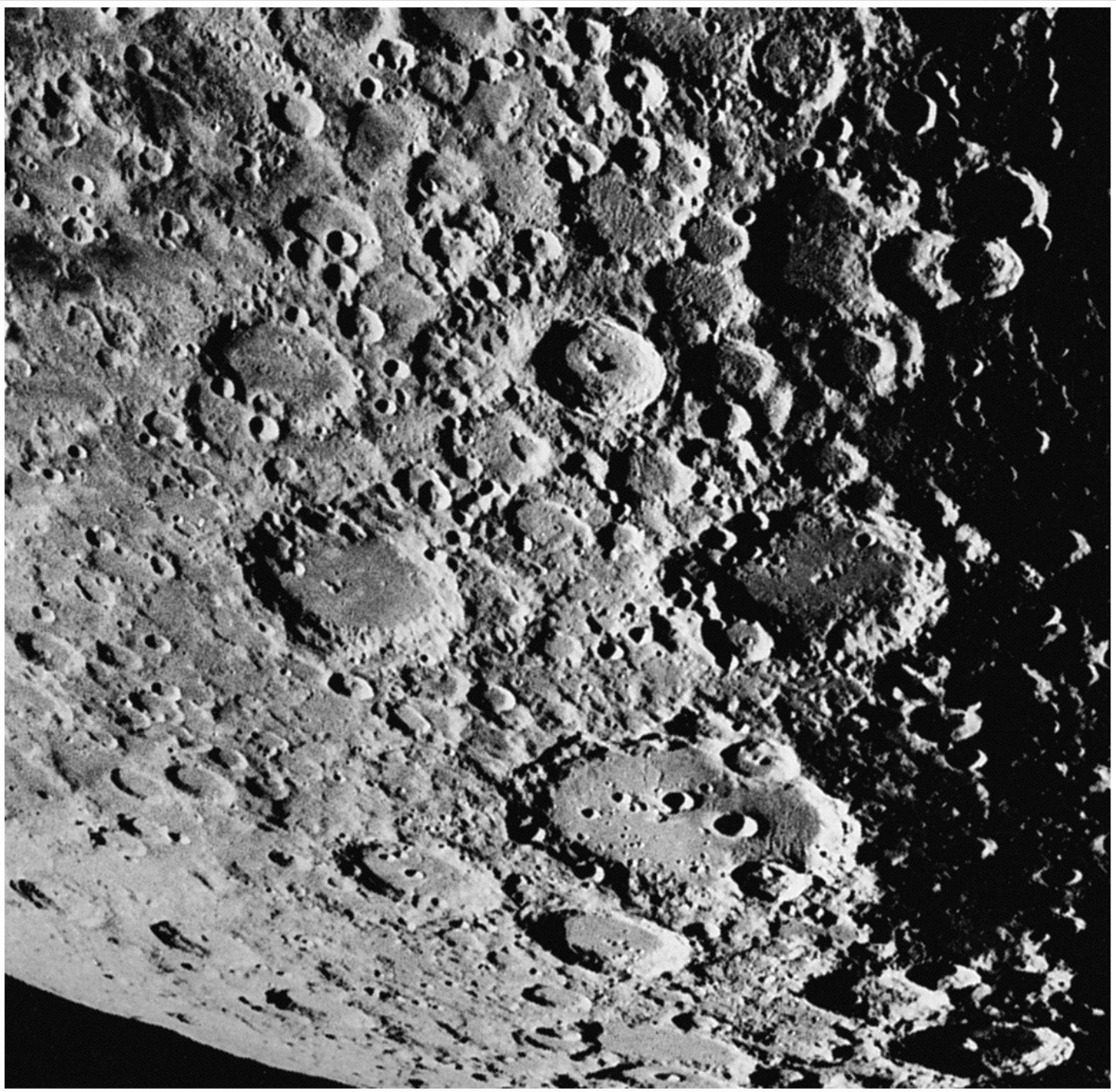


Mercury and Moon appear similar photographically

Mercury lacks the evident dark mare (which are iron-rich basalts on our Moon)

<-- to scale

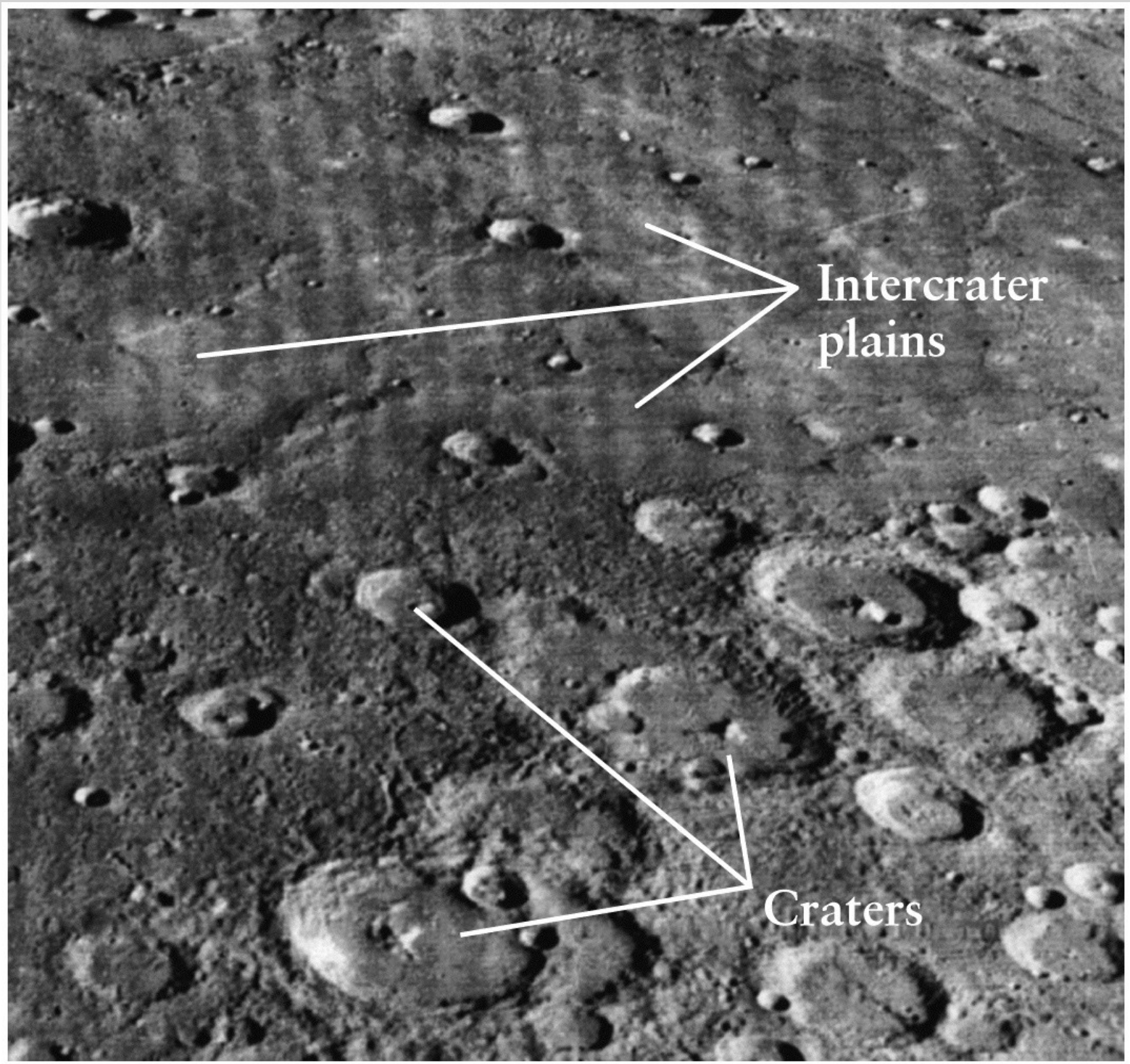
Mercury's surface cratered *sorta* like our Moon



<--Note the extensive crater overlap (called *saturation*) and inter-crater plains

Is it the Moon, or is it Mercury?

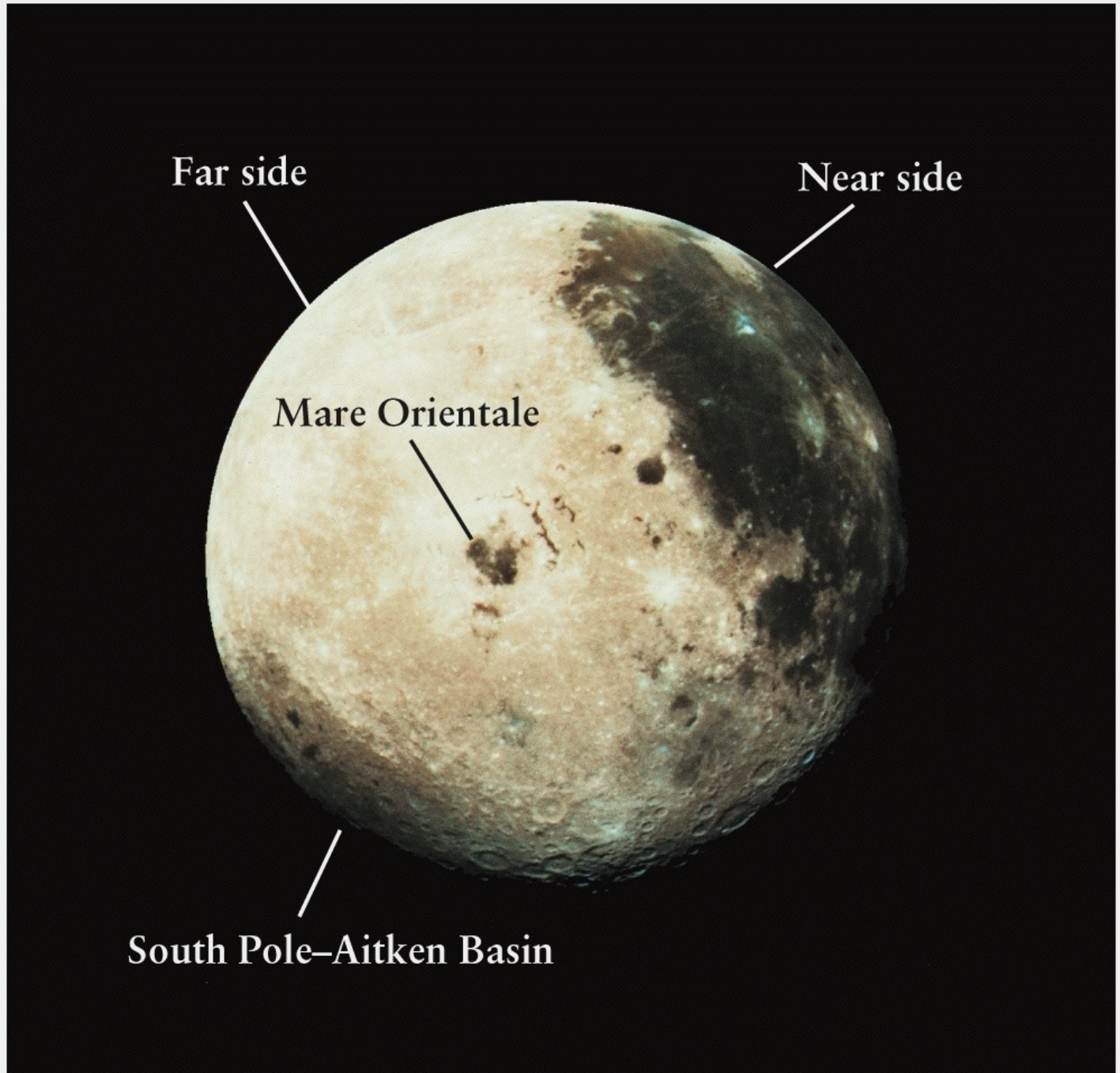
Mercury's surface sorta like our Moon



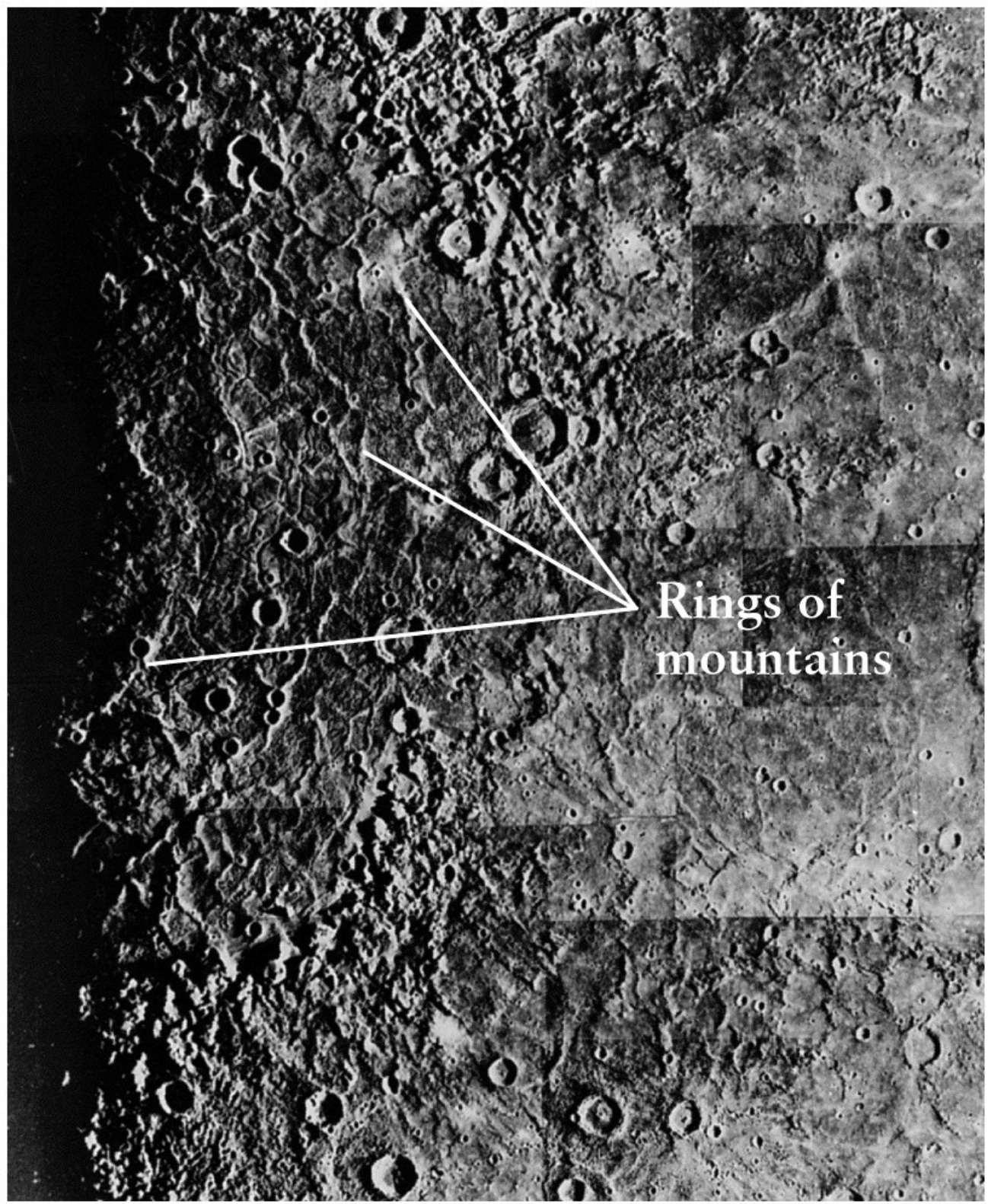
Mercury has inter-crater 'plains', which are lower than the craters.

Near-global flooding, late in history; but lava more viscous than lunar lavas => more localized

Mercury has large 'impact basins' like our Moon



Orientale basin on the Moon; at the 'leading point'. Earth is to the right.

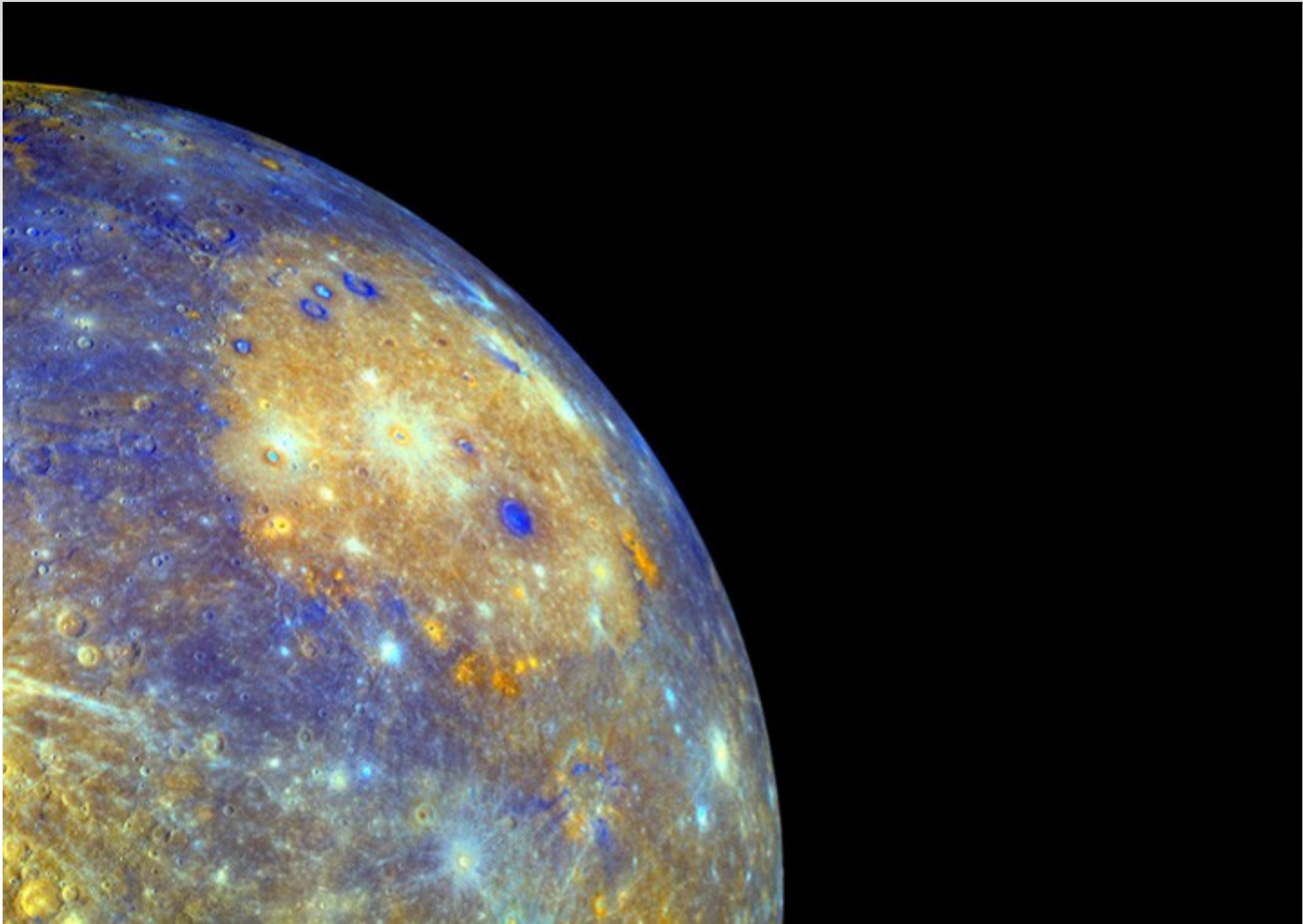


Mercury has one known impact basin. Caloris 1300 km diameter!

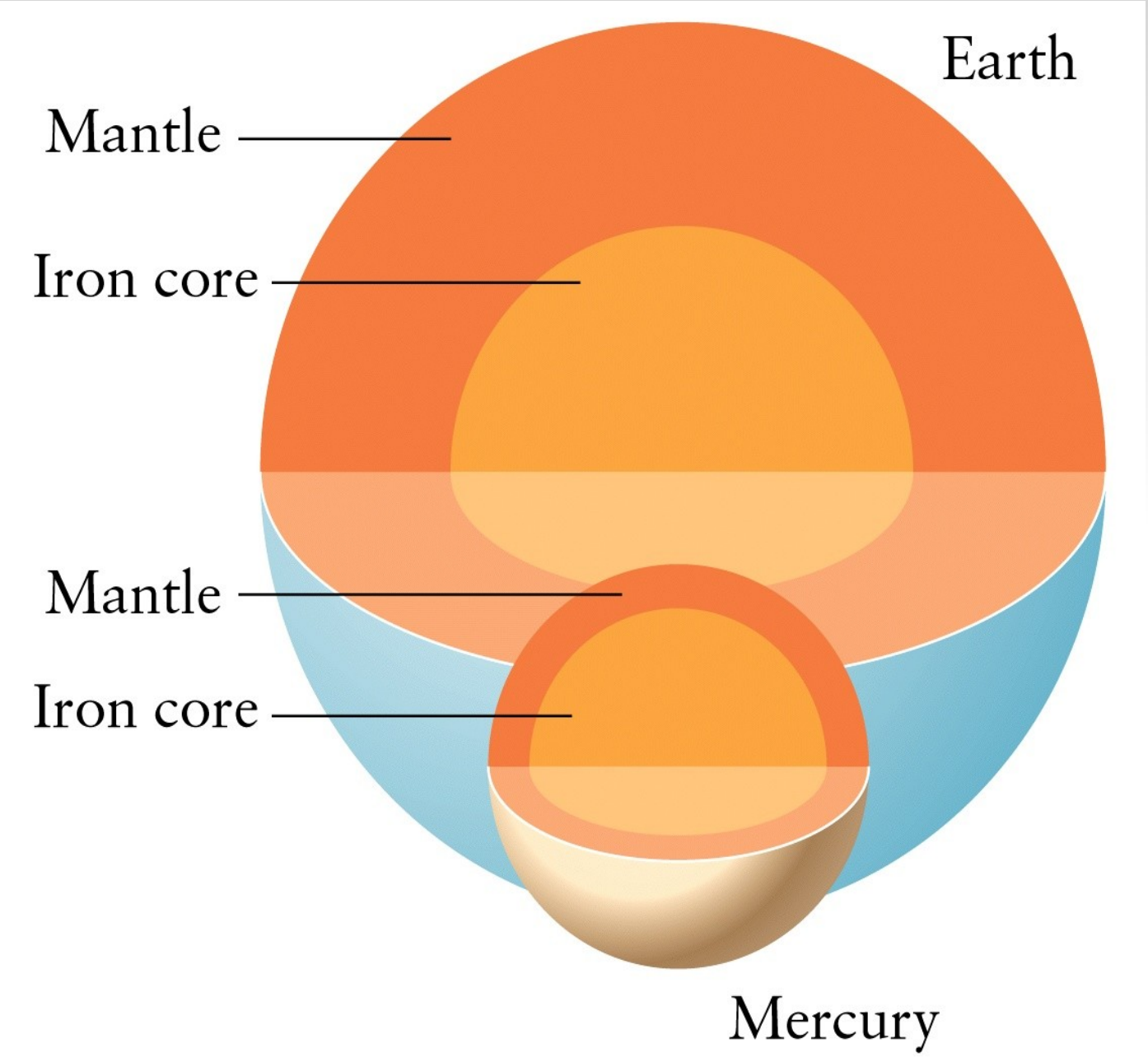
Seen on the 'terminator' (line separating day from night)

Q: Is it old or young?

Caloris in false colour



Mercury must have a high metal content

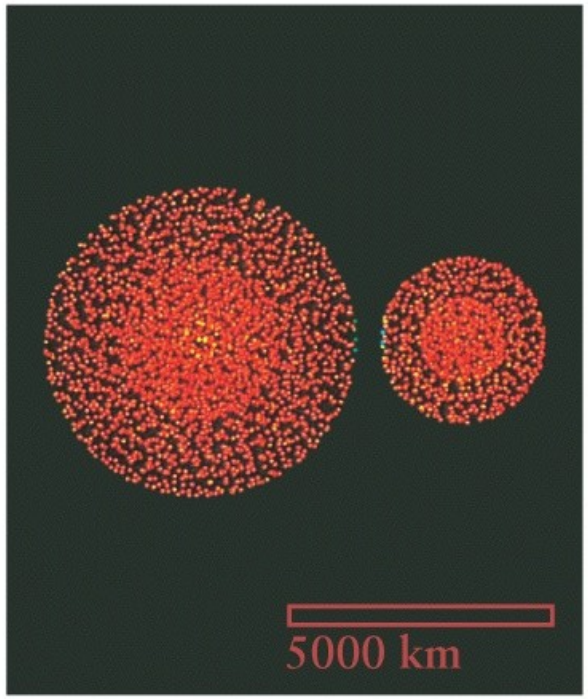


Why?

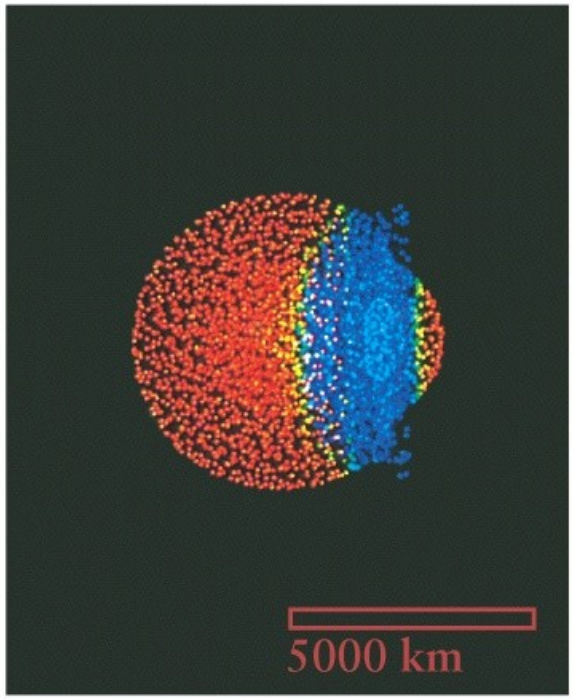
High mean density:5.43 g/cc

Must have a large iron core (~75% radius)

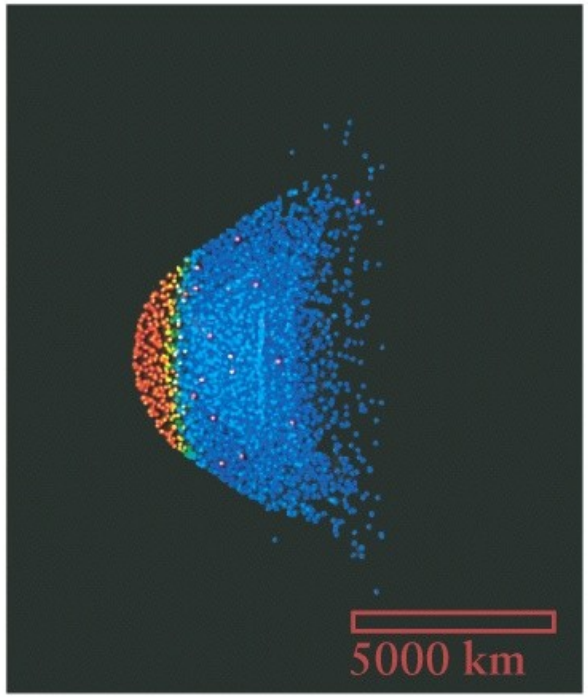
Why is the metal content so high???



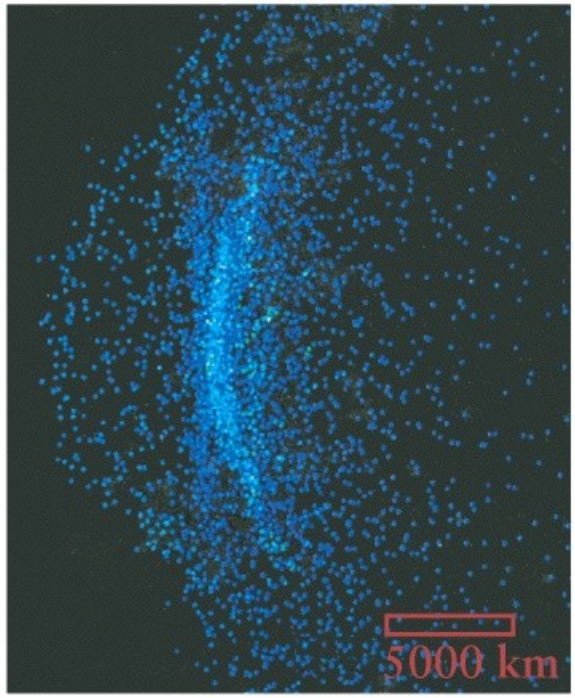
$t = 0$



$t = 3$ min



$t = 6$ min



$t = 30$ min

Why so metal rich?

Possibilities:

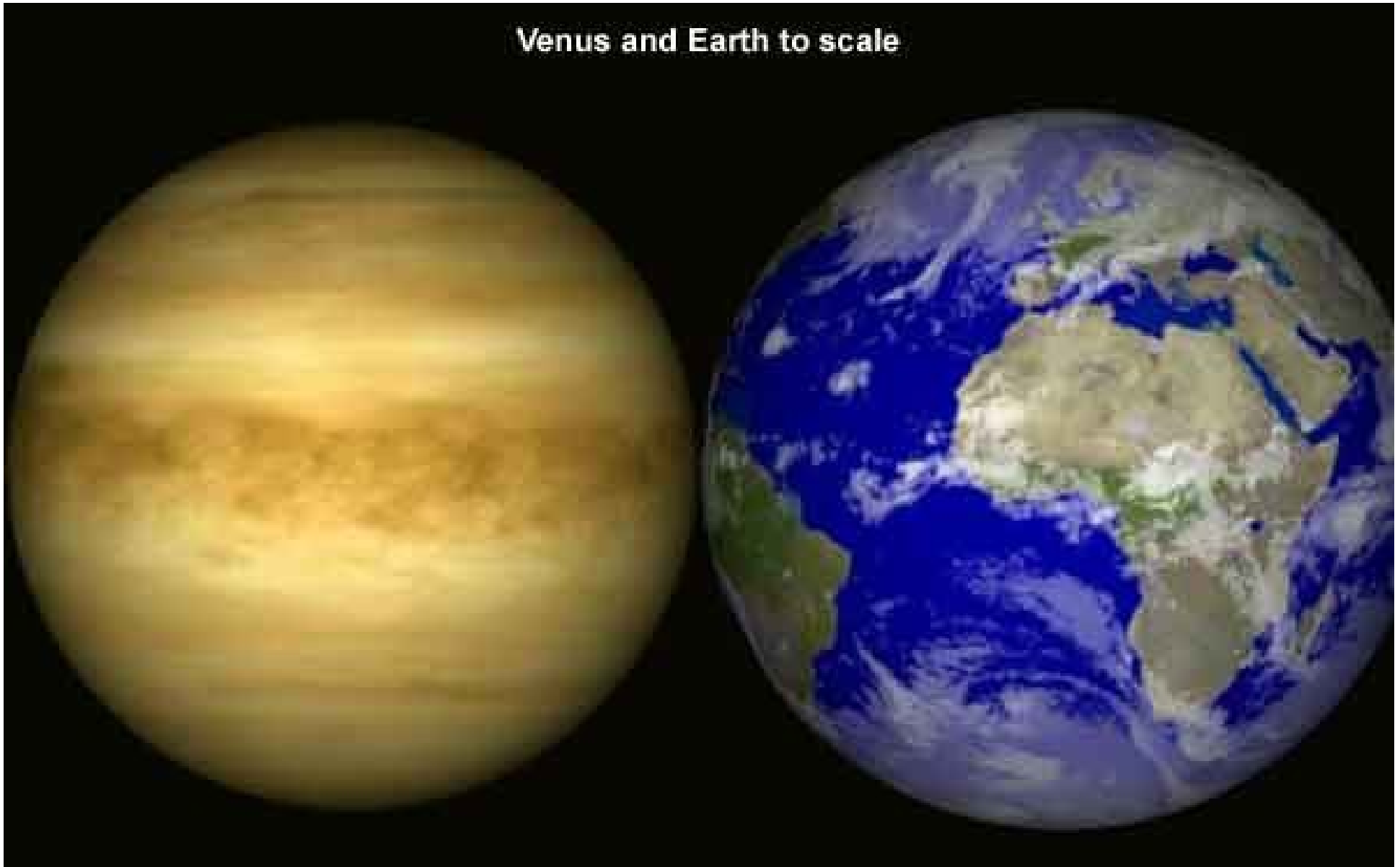
1. Did an impact strip off the mantle?

<--Similar to Moon-forming event

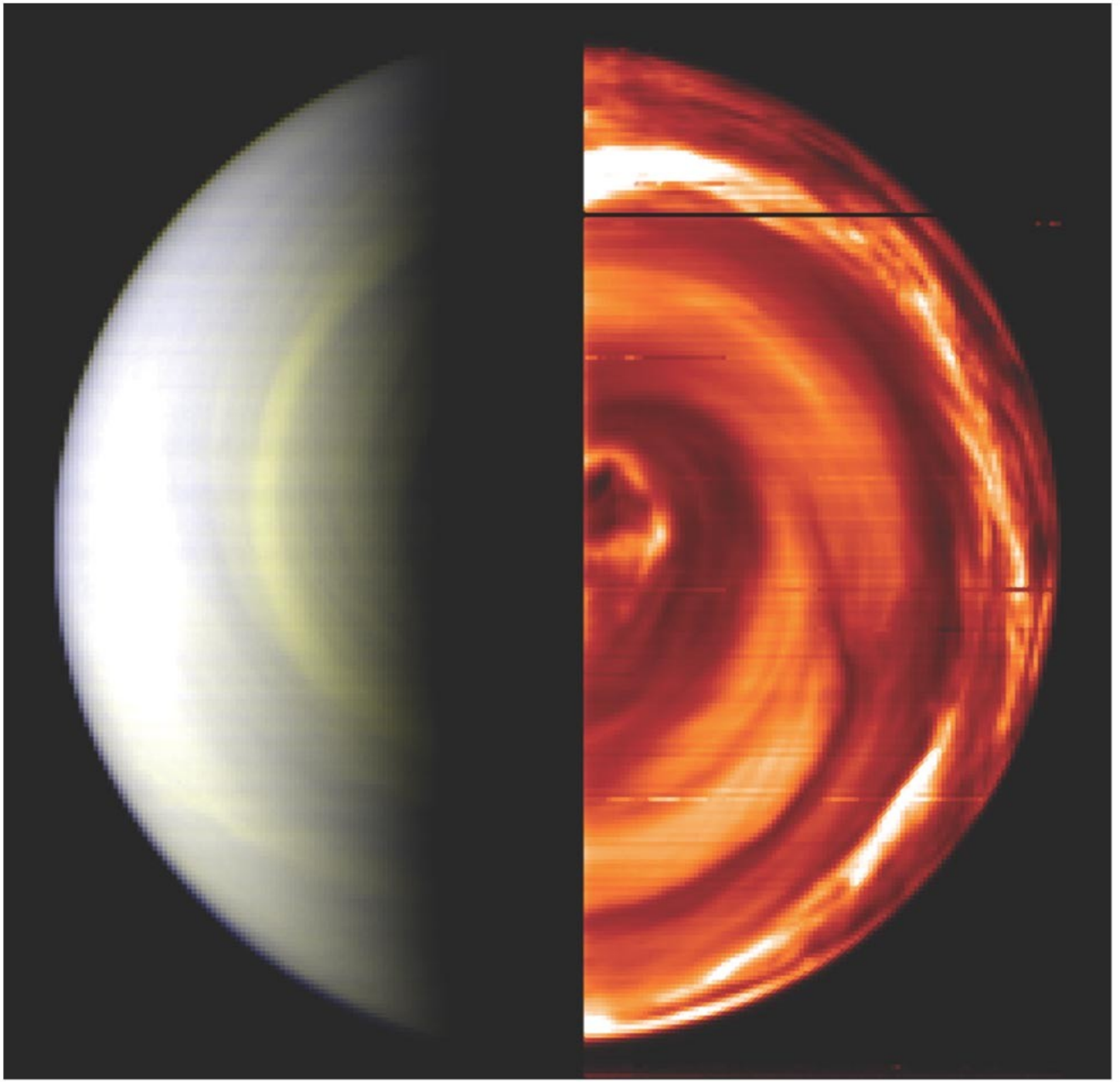
OR

2. Did Mercury just form with little rock??? (Lewis model)

The active terrestrial planets



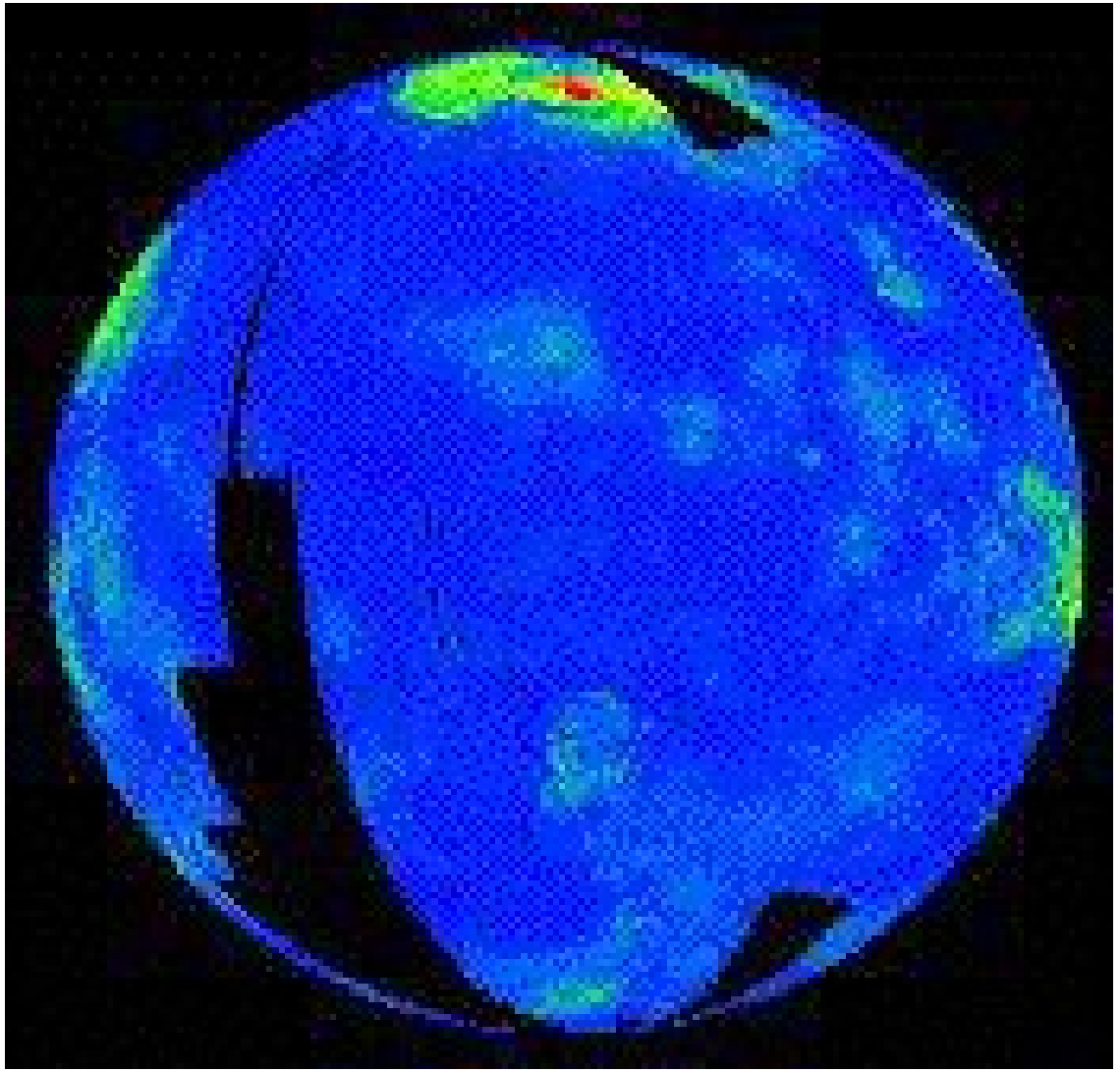
Venusian surface hidden by clouds



-Cannot see to surface using light of visible or IR wavelengths

-Atmosphere is 90 bar pressure at surface.

Surface of Venus is 'relatively' uniform



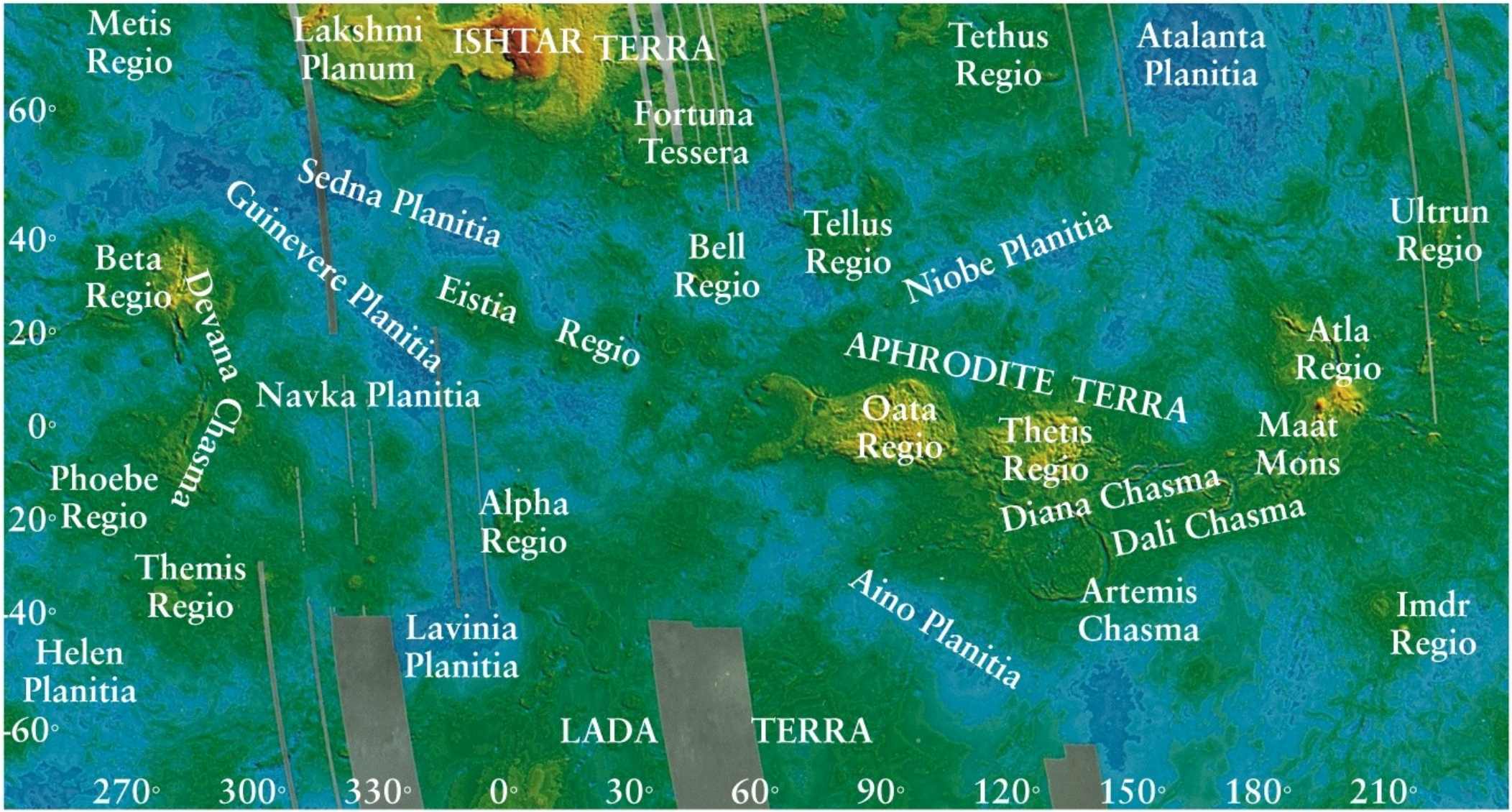
Arecibo telescope's radar map
(1960s, color is topography)

Maps of surface made by reflecting radar(radio wavelengths) off of surface.

**60% of surface lies within 500 m of the average elevation.
(compare Earth)**

A few highlands (called 'regio' or 'terra') exist which are comparable in size to continents

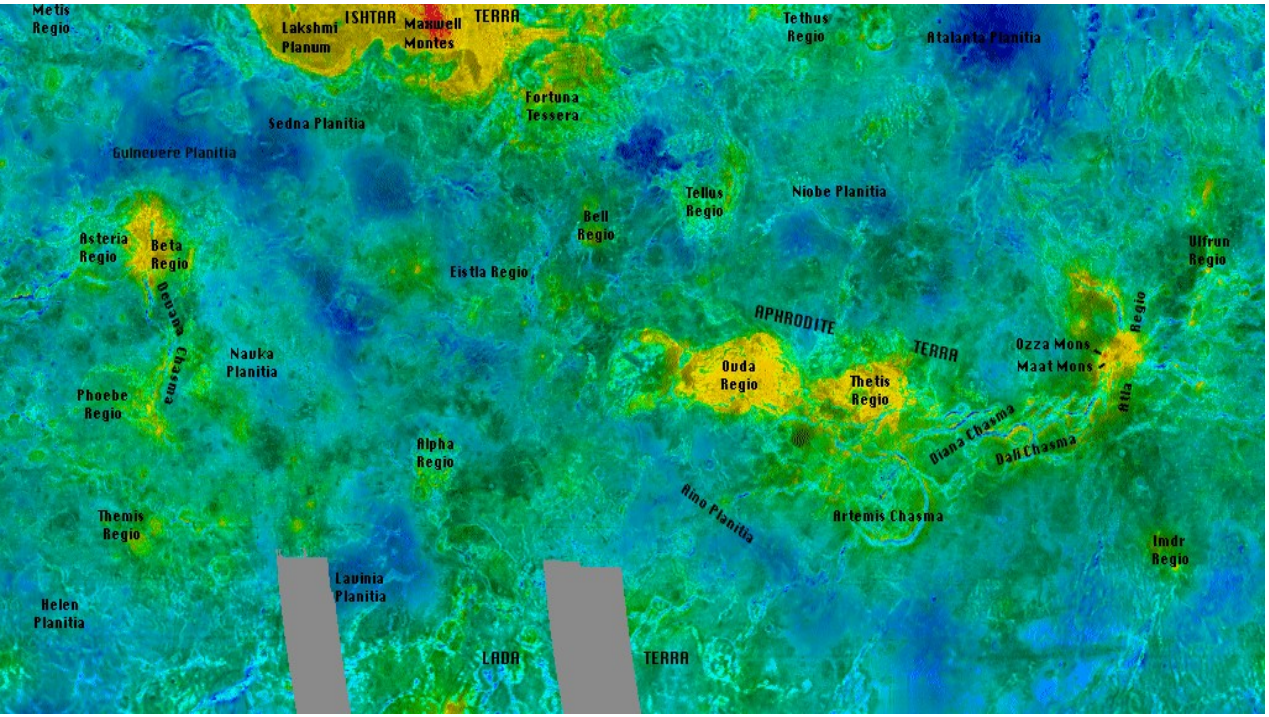
Smooth, relatively crater-free surface
with lots of volcanism present.
-Colour table here is altitude; note low-lying regions
-Hardly any impact features → surface relatively fresh/young

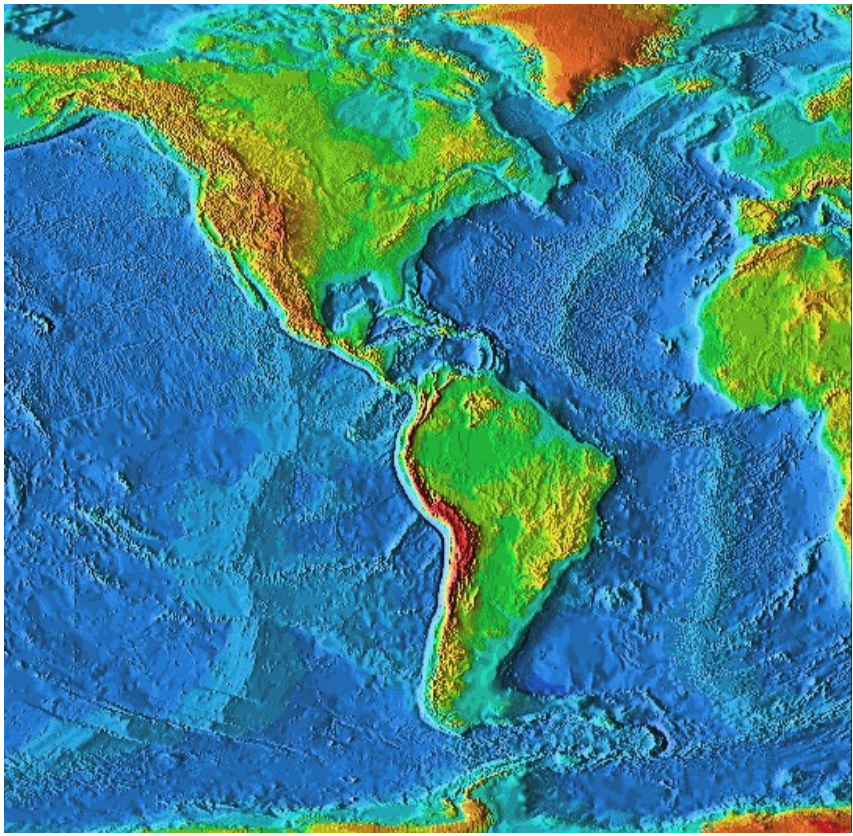


Venus vs. Earth

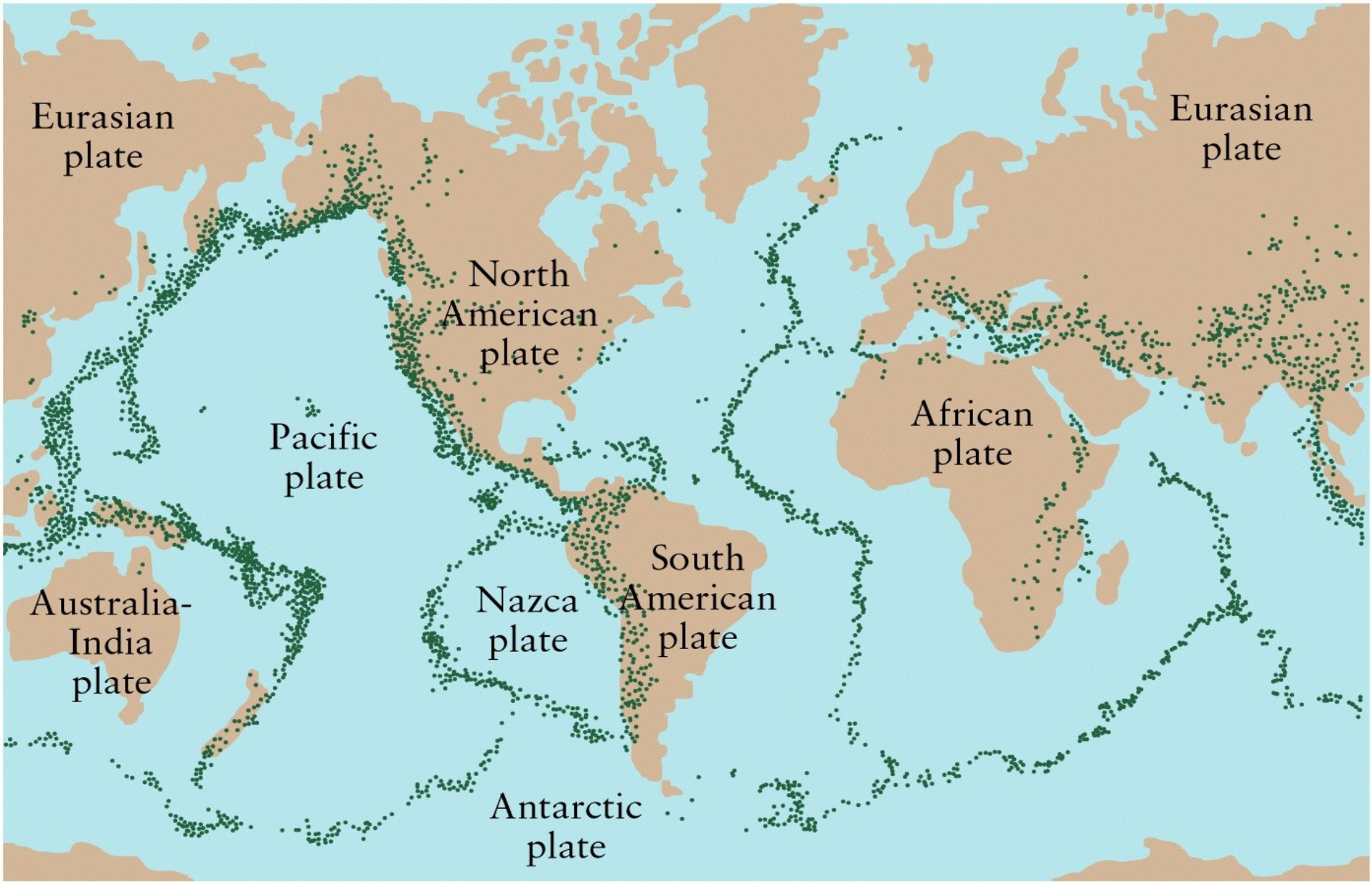
Venus and Earth both have surfaces shaped by volcanic activity

But on Earth, most of this activity is related to *plate tectonics*, whereas on Venus most appear to be *hot spot volcanism*



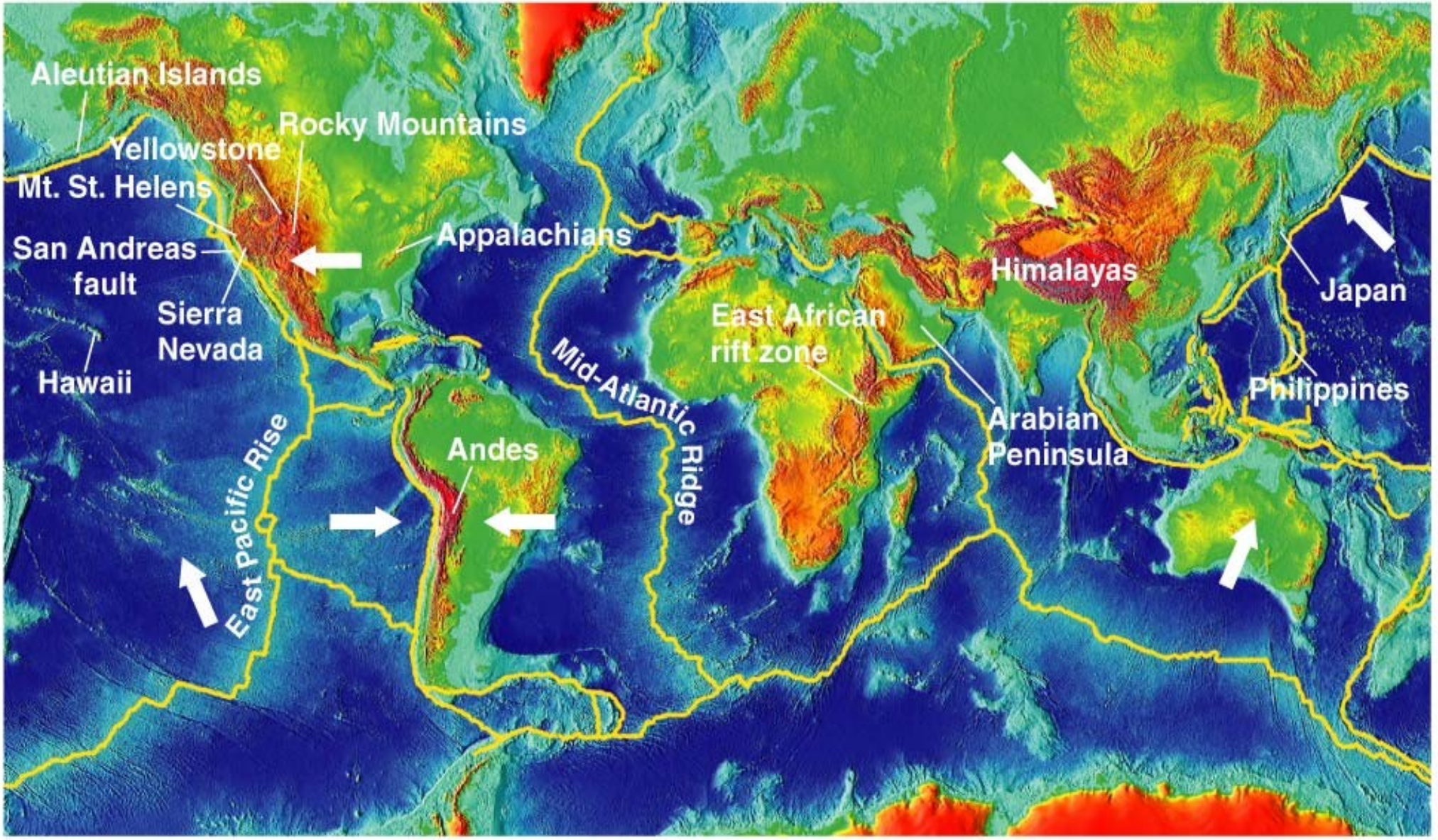


2 kinds of volcanism: boundary & hot spot



Map of volcanic activity on Earth

The plates move, colliding in places

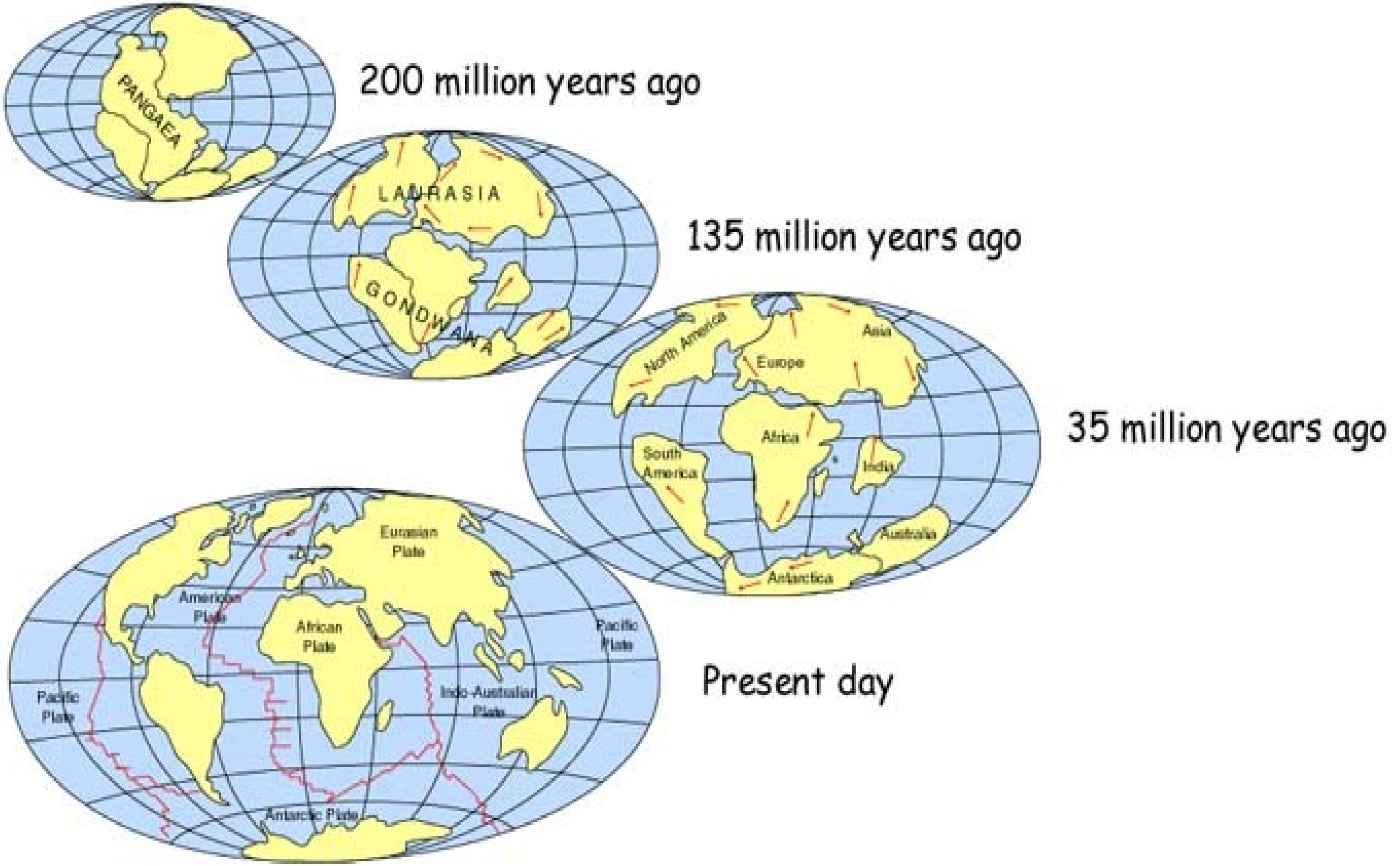


Earth's crust broken into many moving plates

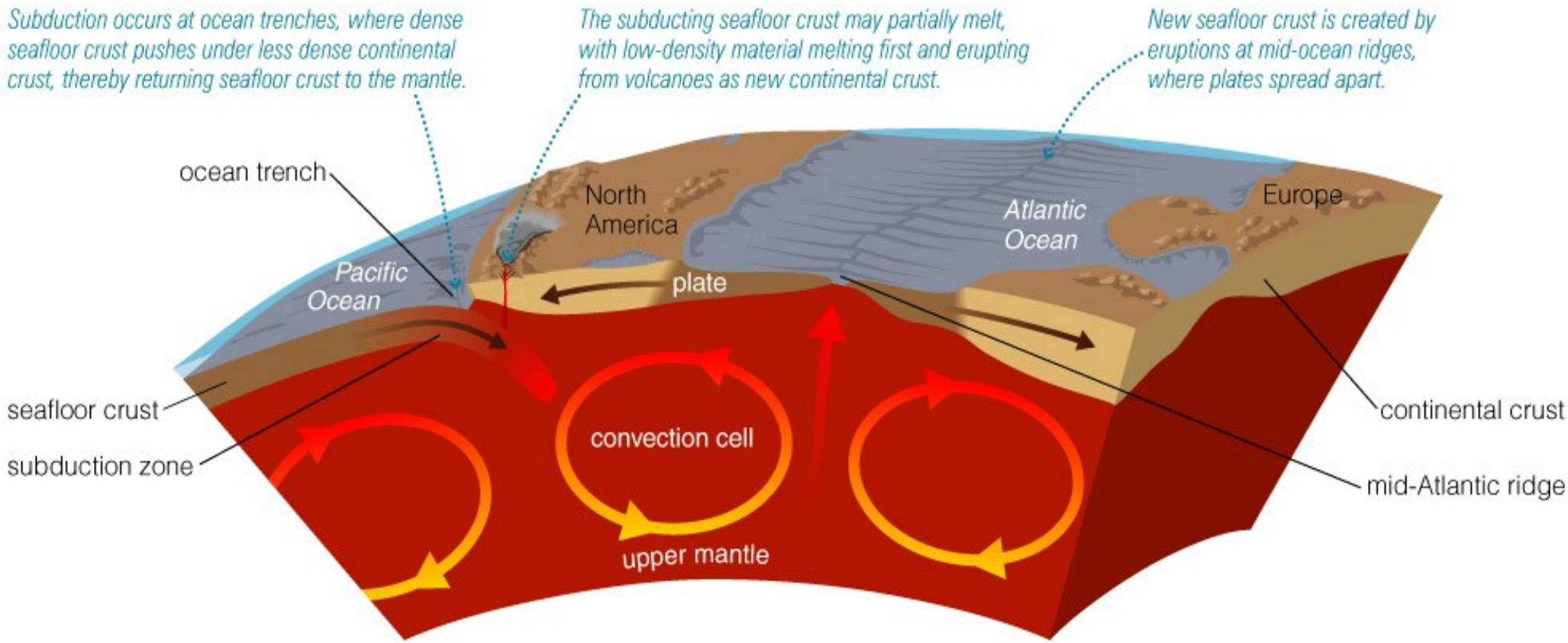
Example of crustal compression

Indian plate is moving north fast and ramming into Asia, pushing up the huge Himilayan mountain range

Separation of the continents is well understood

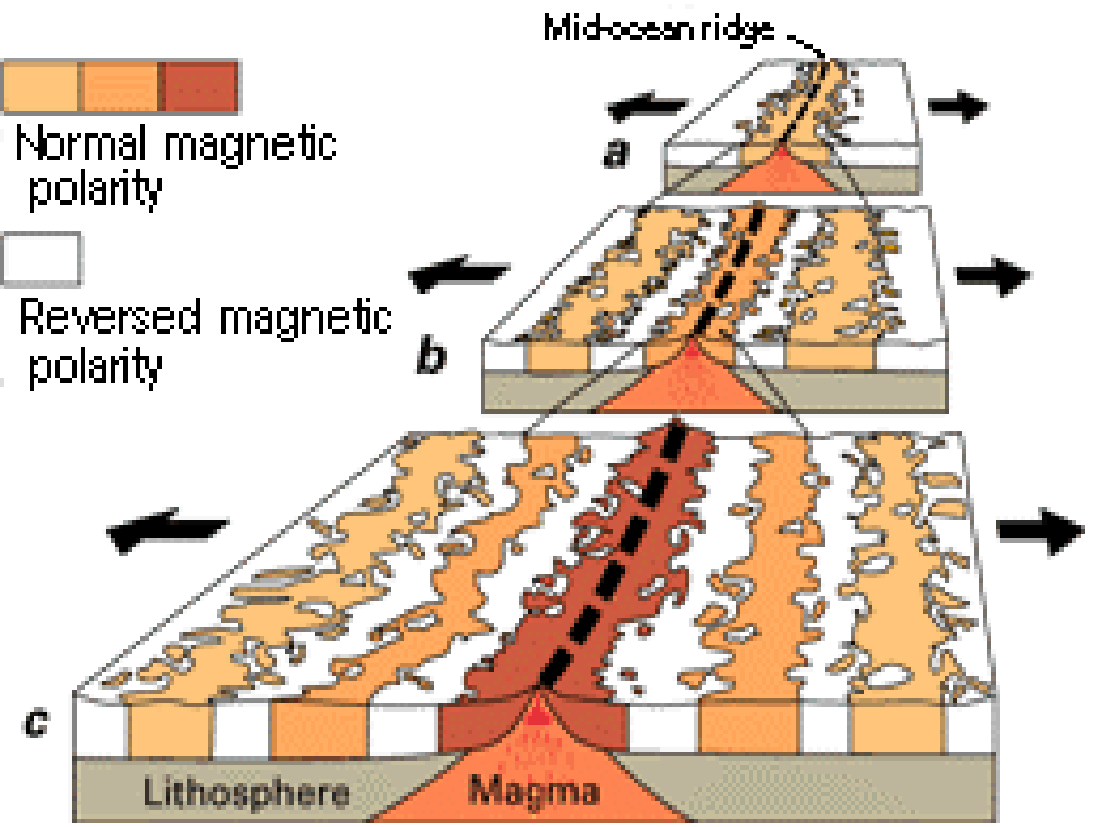


Earth's plate tectonics are driven by convection cells in the mantle

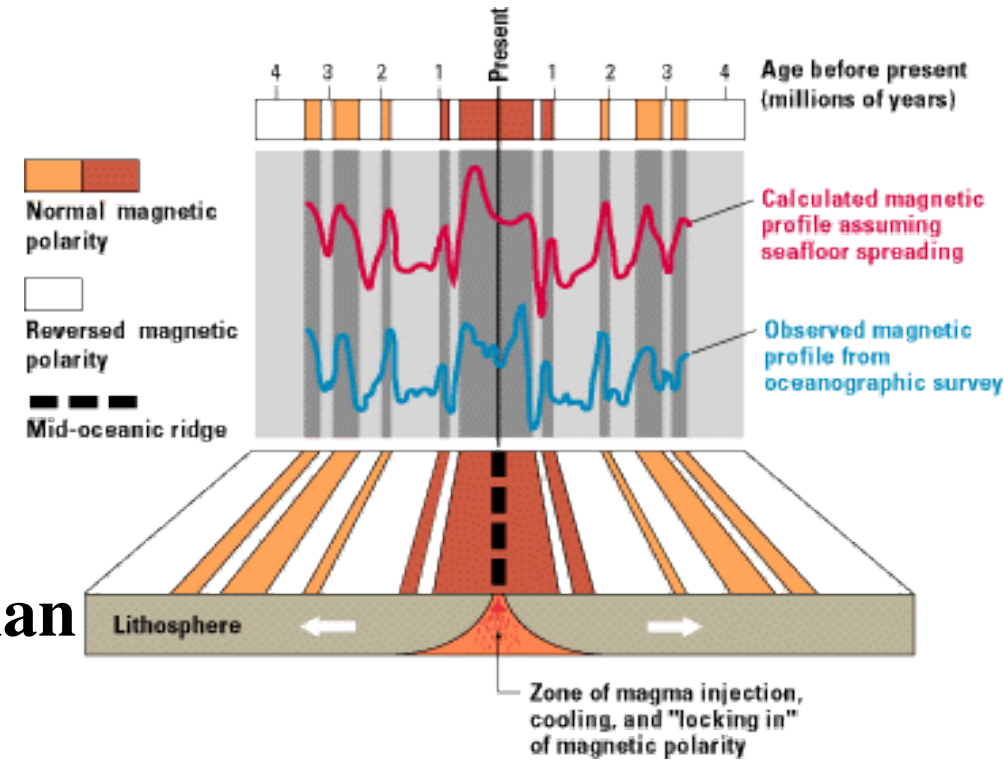


Movie shown in class

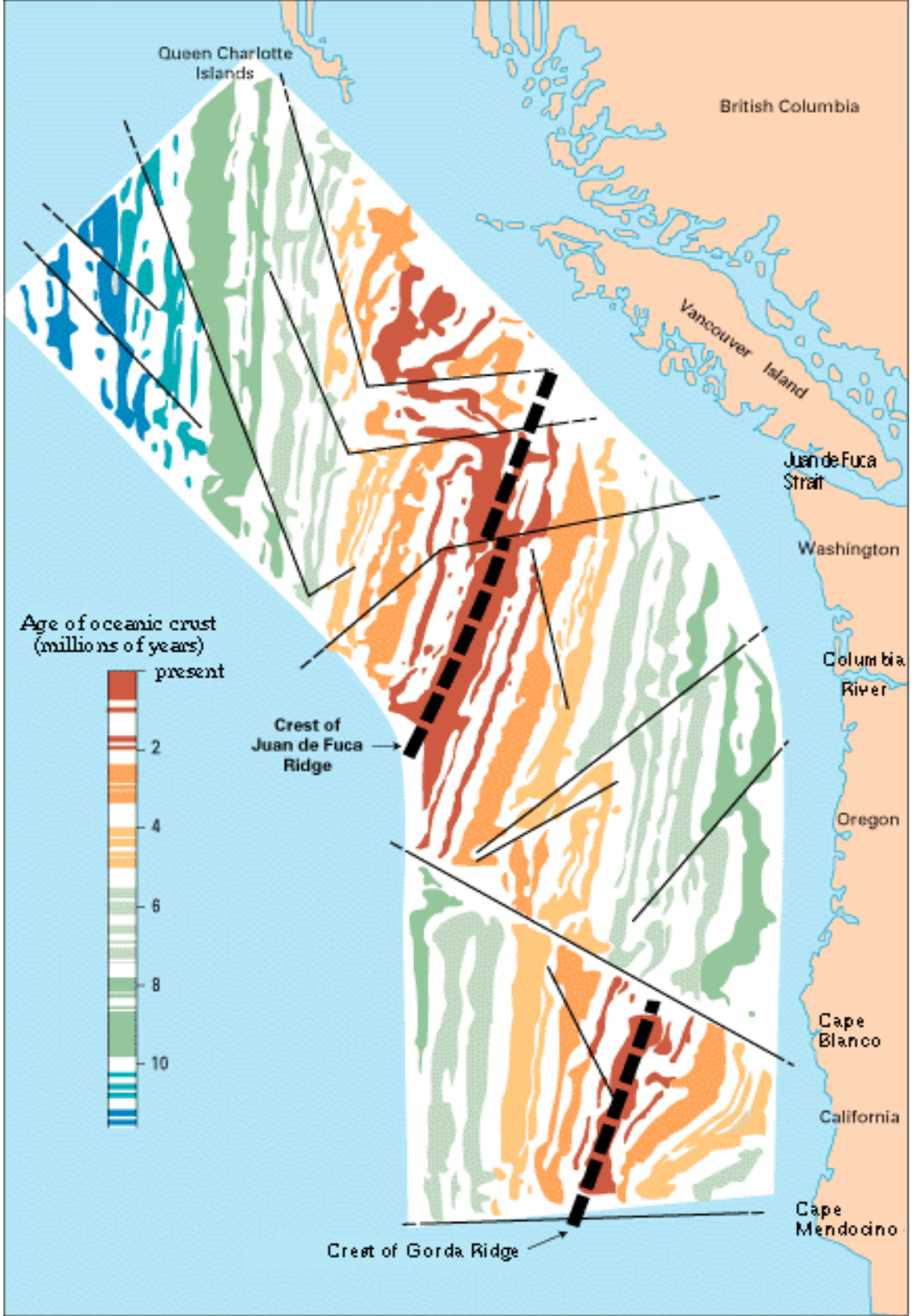
At the oceanic ridges, new crust is created, and the magnetic field at the time is 'frozen' into the rocks



- **This can be measured.**
- **Surprise: The Earth's magnetic field has reversed many times**
- **Magnetic north and south flip (relative to spin pole)**



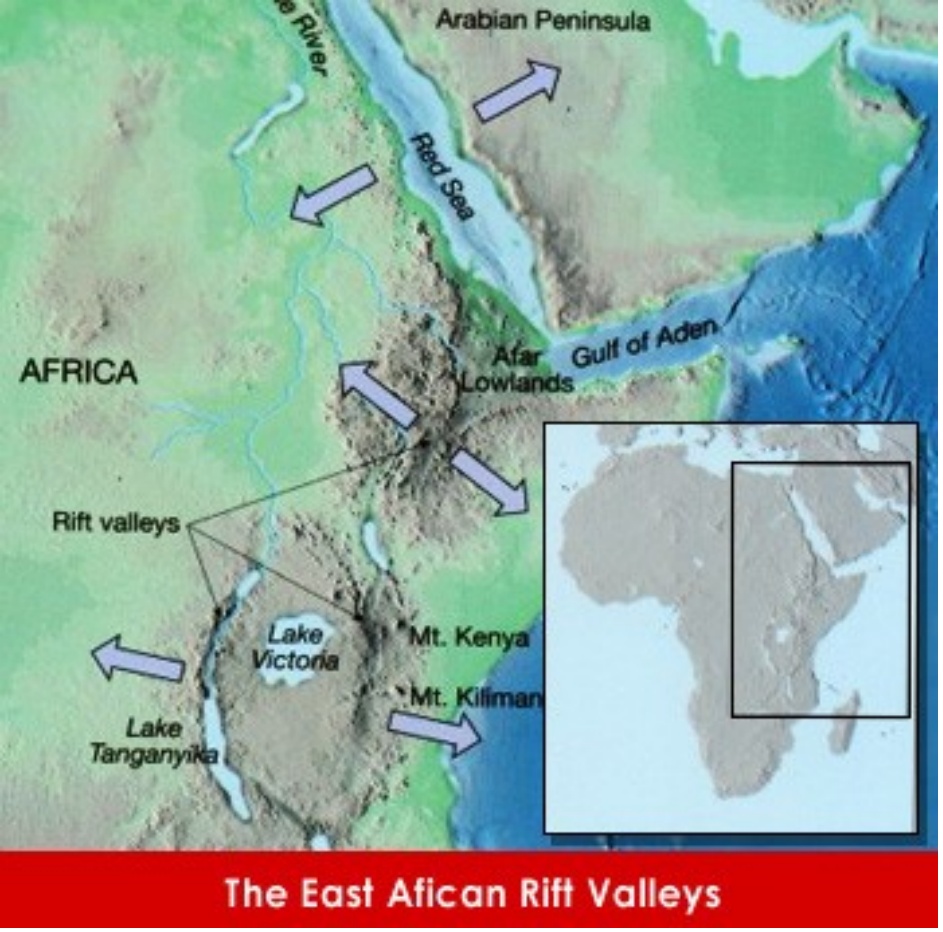
- **Thought to be because of large-scale changes in the deep mantle currents..**
- **Similar signature in ancient martian crust**

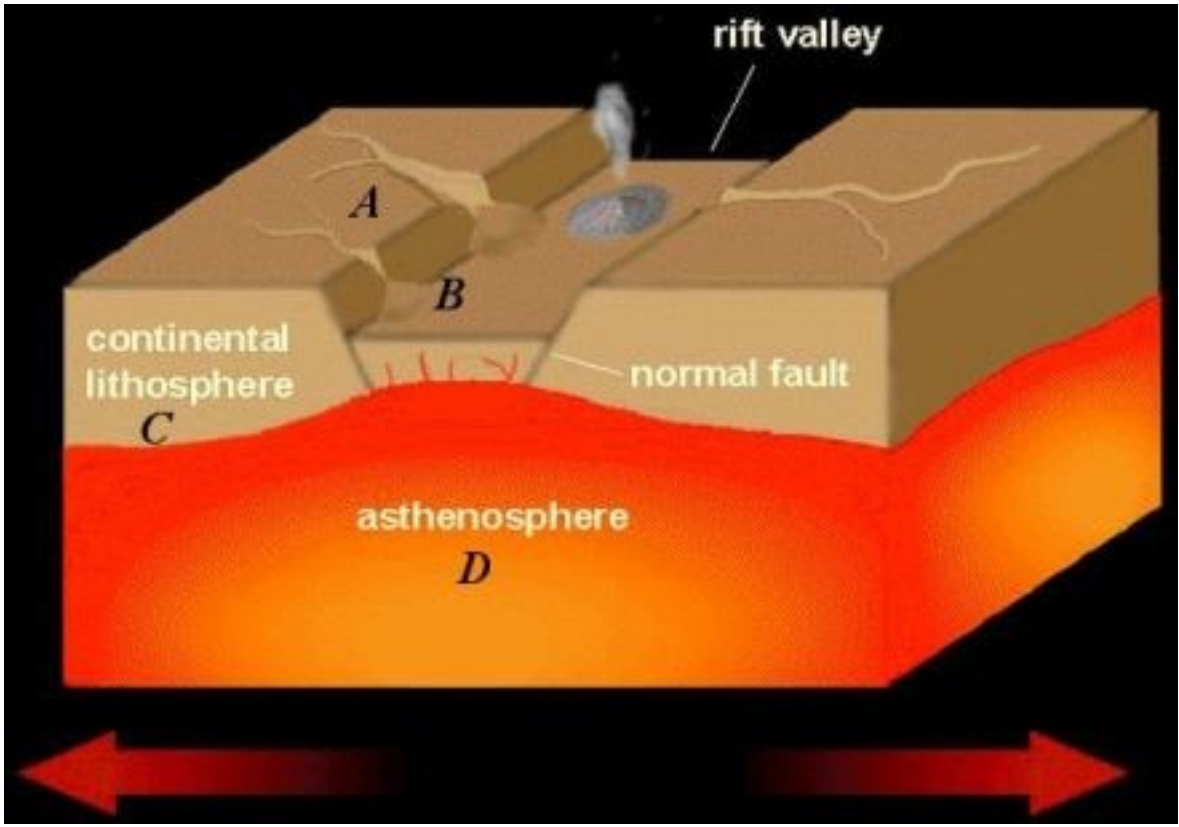


Closer to home : Seafloor spreading and polarity off the Juan de Fuca ridge

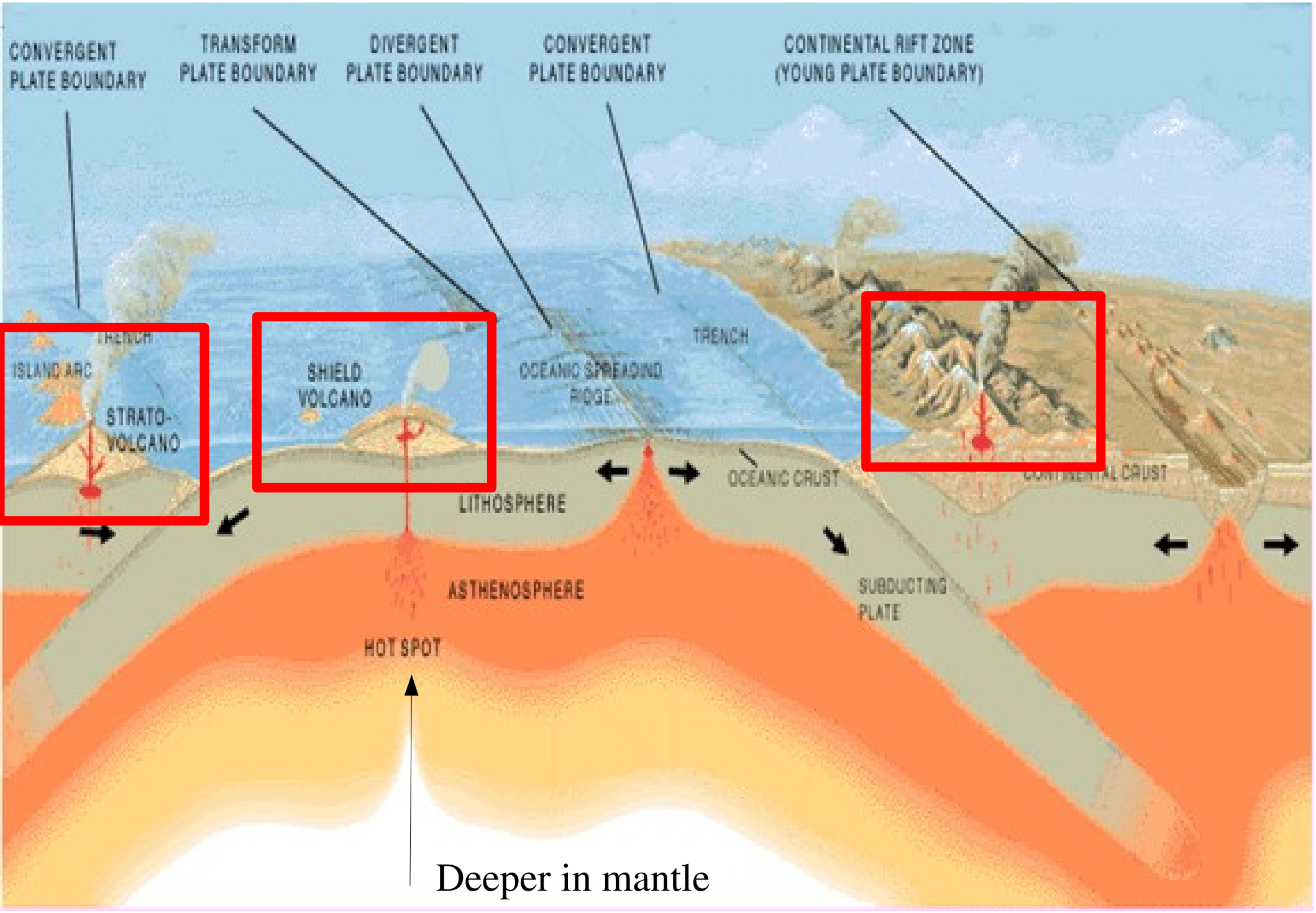
Over the last ~10 Million years

East African Rift Valley

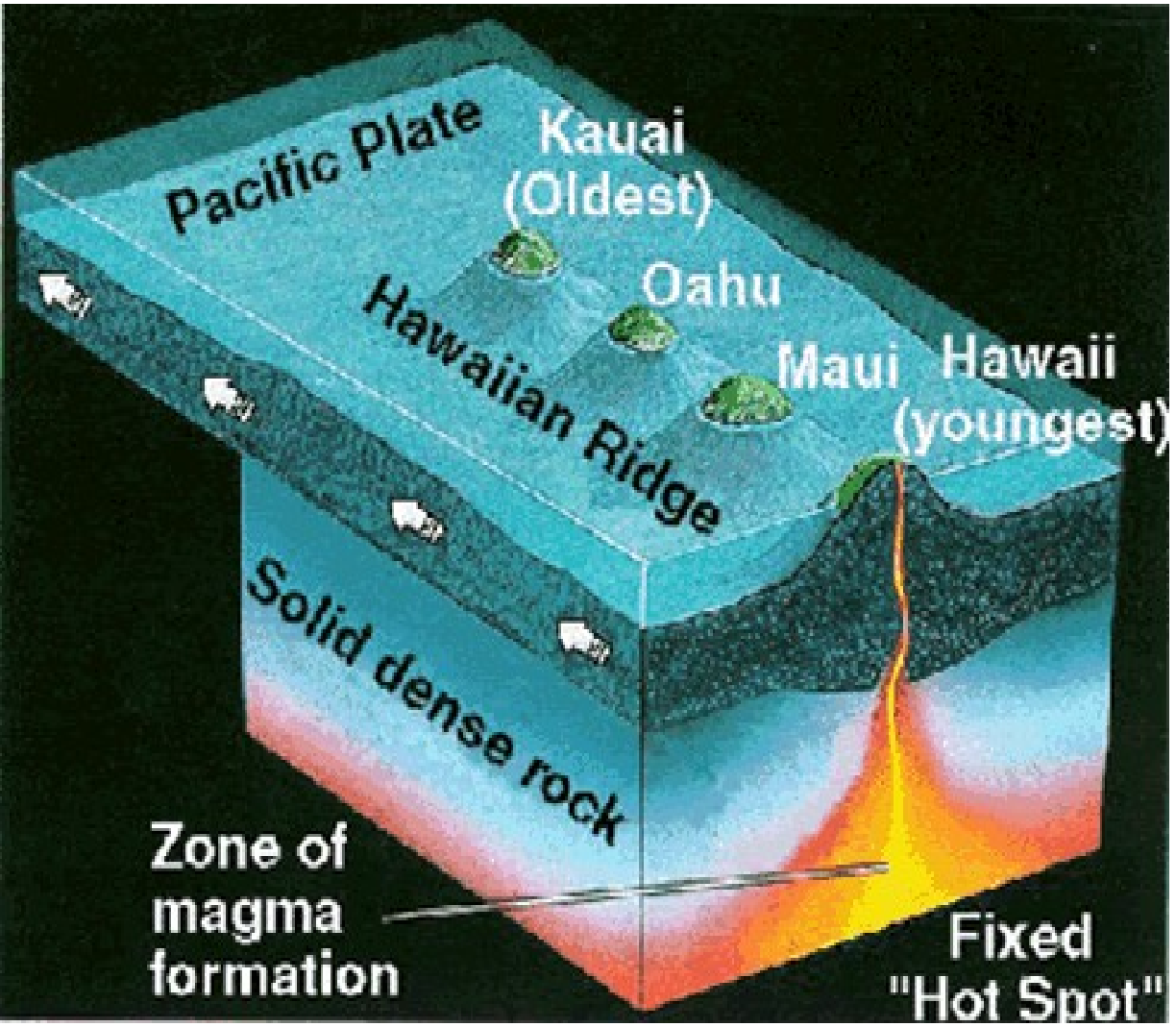




Volcanism: at BOTH *plate boundaries* and *hot spots*

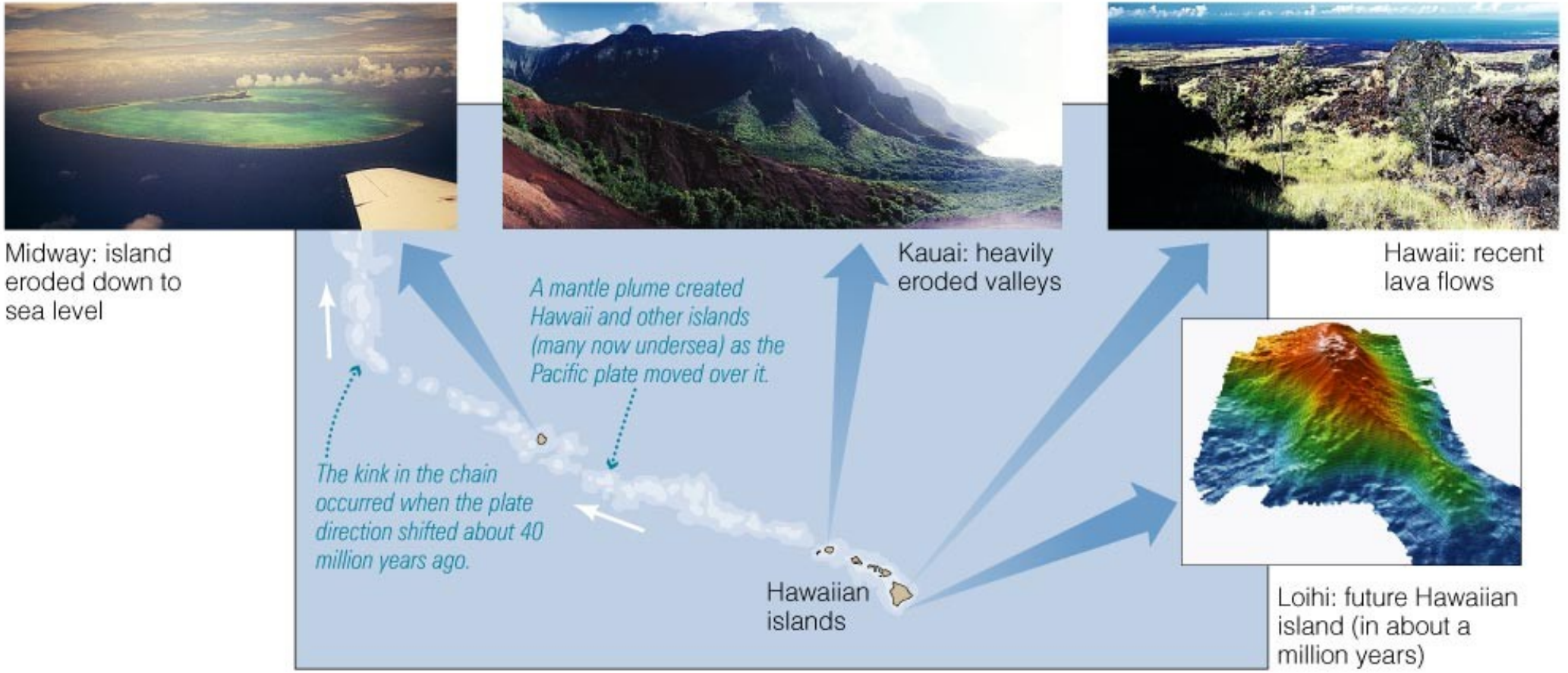


Volcanism: Hot spot volcanoes on Earth created the Hawaiian island chain

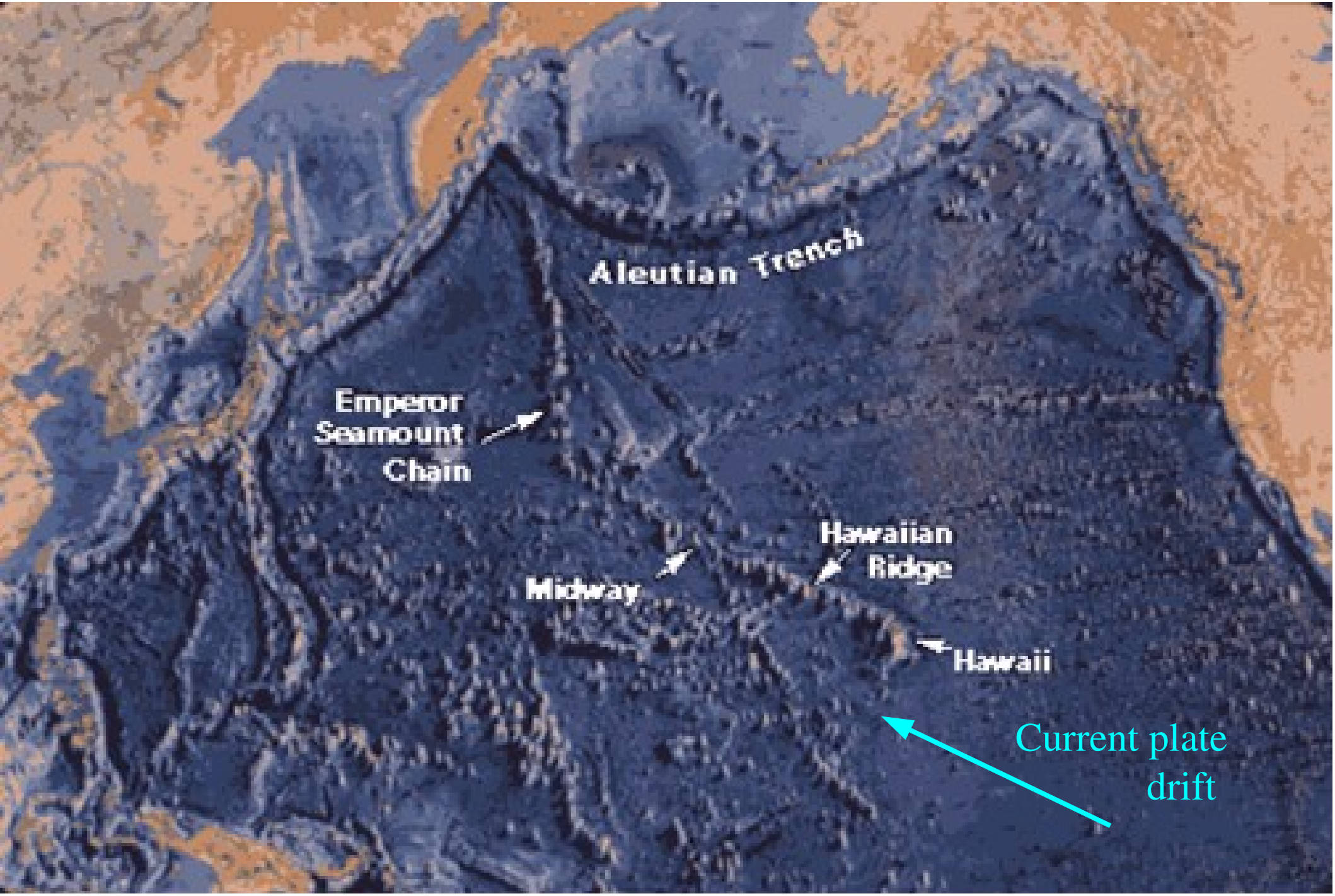


A fixed hot spot in the mantle pumps lava up and creates a chain of shield volcanoes as the plate moves over it.

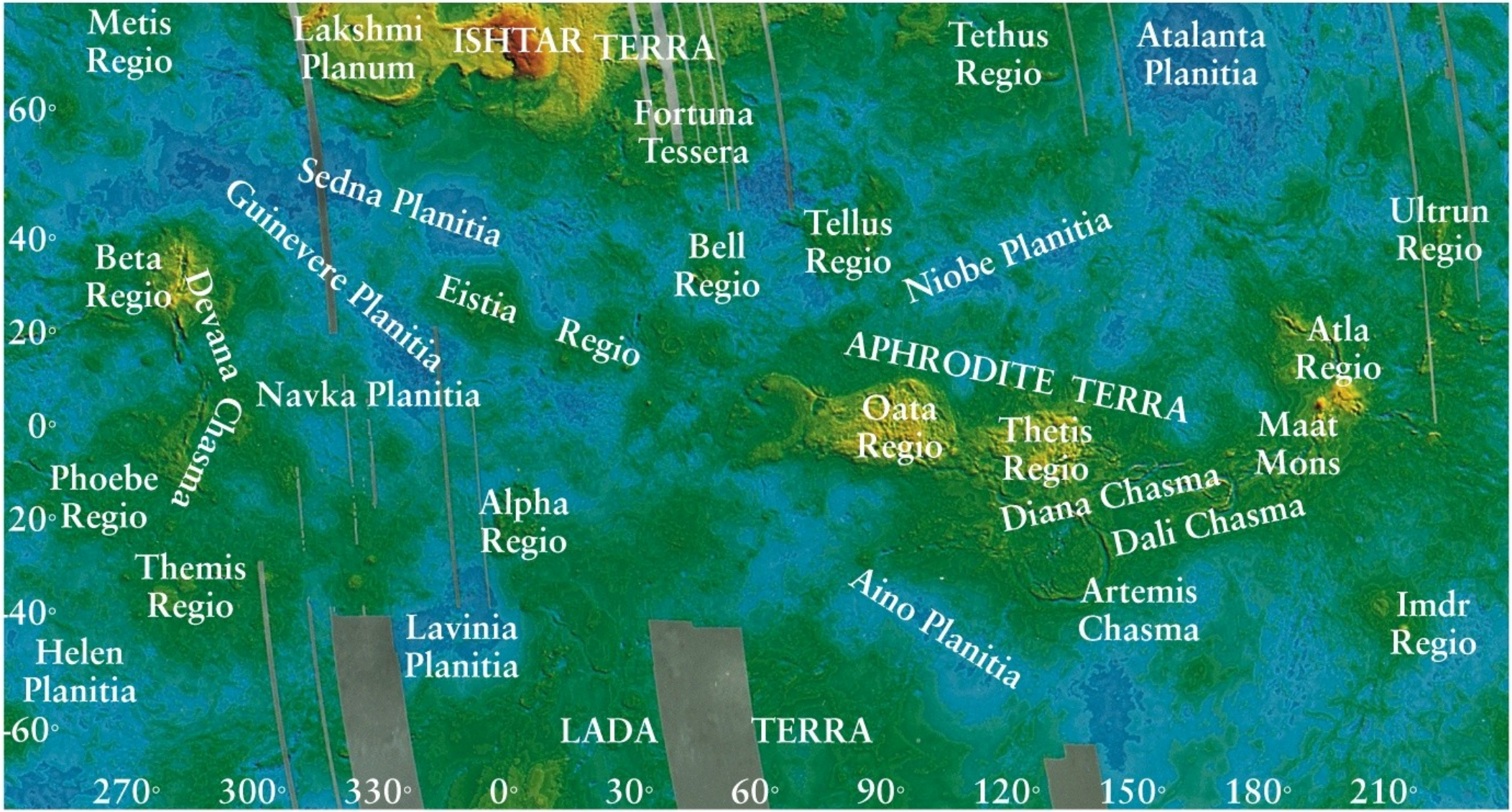
Another island (already named! Loihi) will be created in the future, and many other (now submerged) islands are part of the chain.



These island chains can run thousands of km.

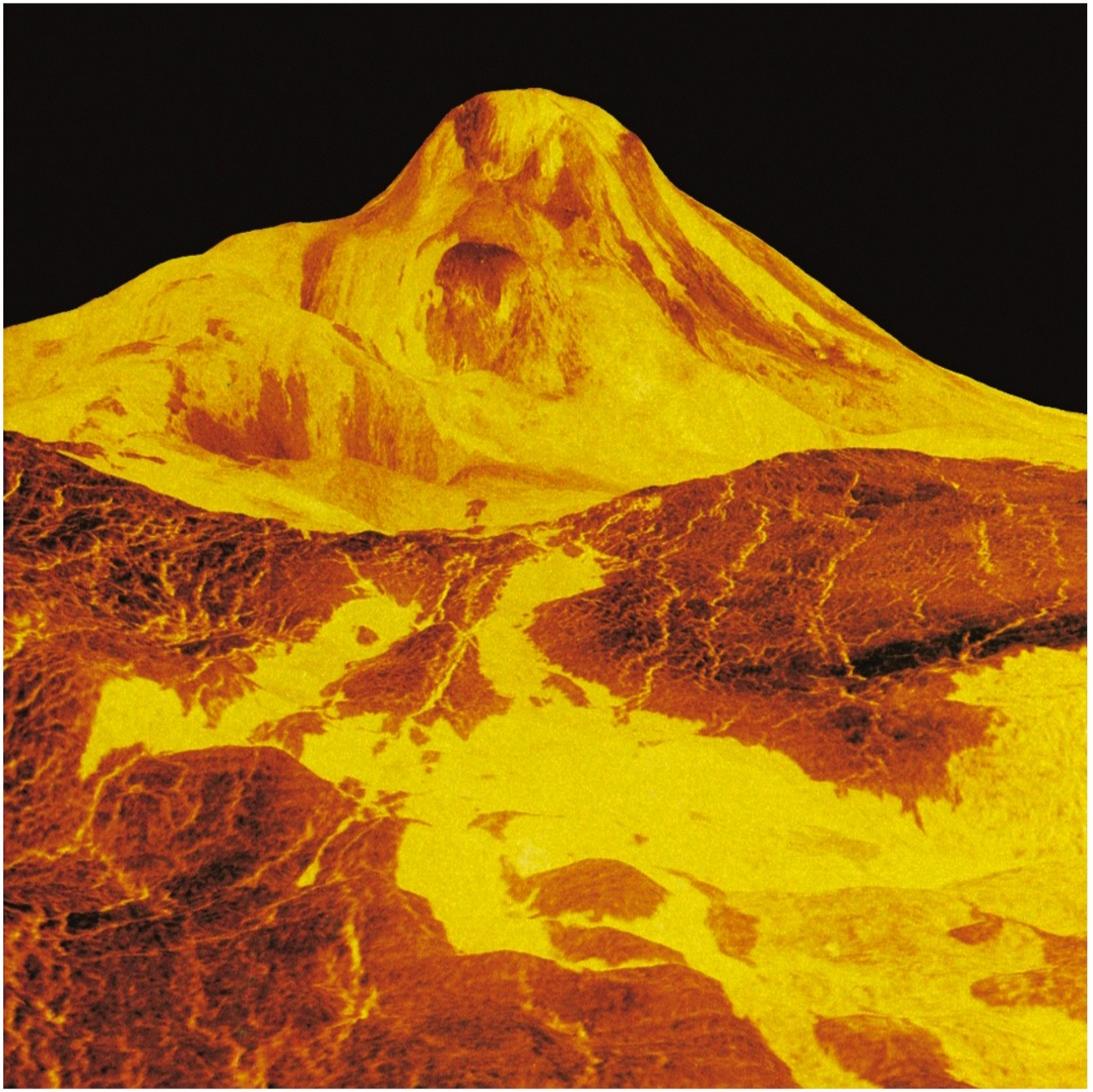


Venus has many volcanic mountains and chasms but no plate structure



Very large fraction is volcanic

Many volcanoes have 'fresh' lava flows

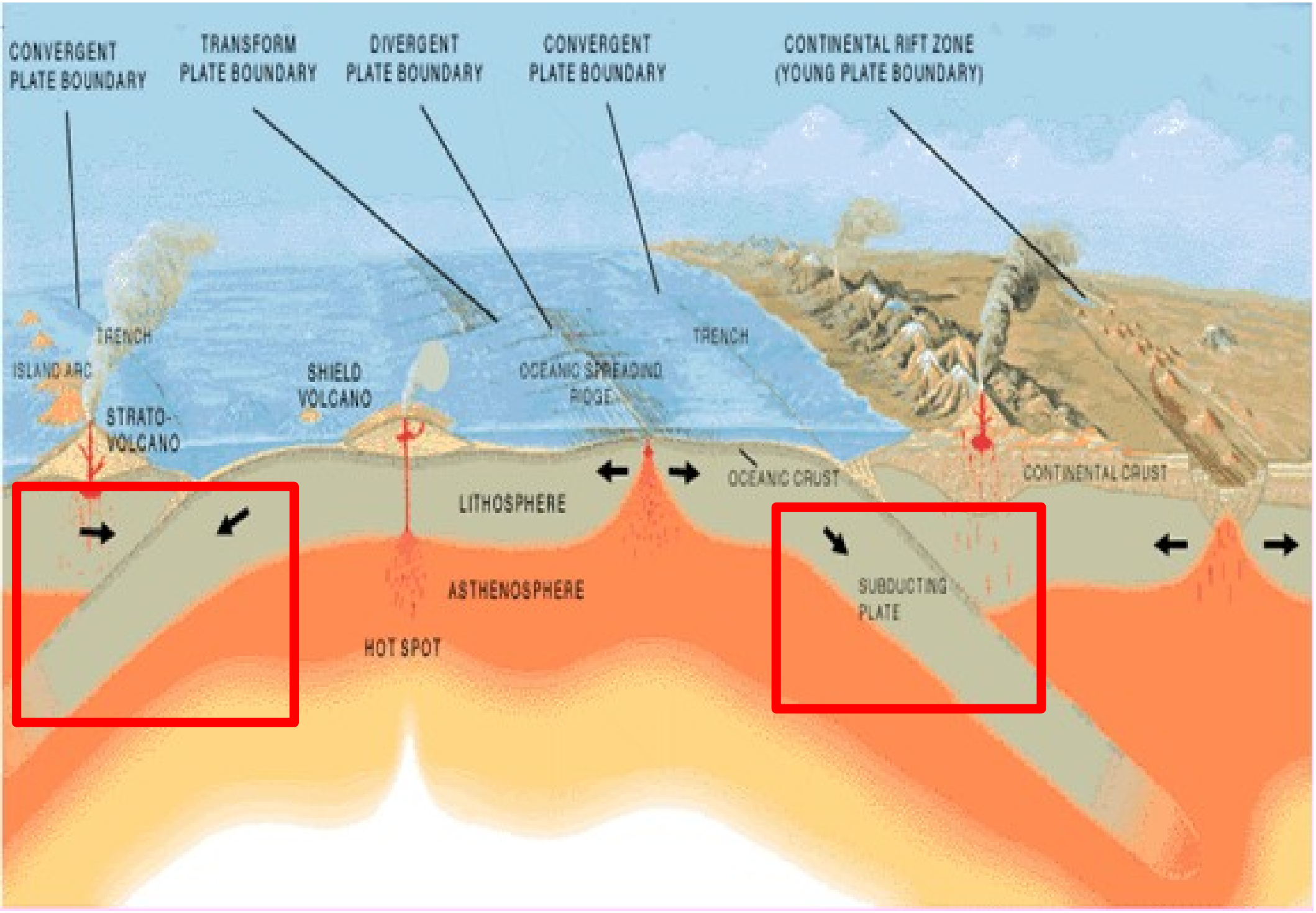


Radar image of
Maat Mons
(in Aphrodite Terra)
Shield volcano
8 km tall !
(Everest: 9 km)

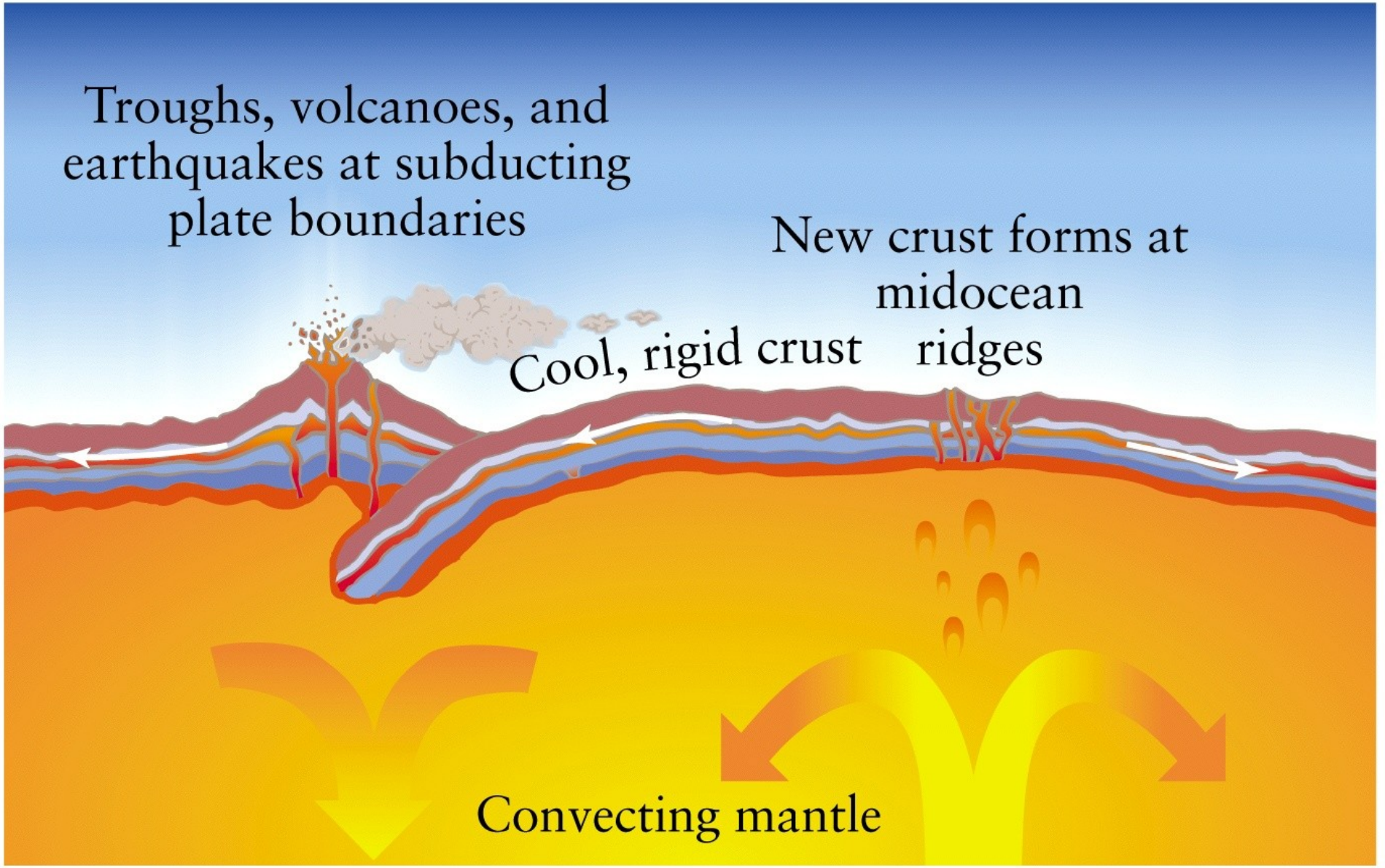
Lava flows
< 10 Myr old (?)

So: New crust is being created...it must be destroyed somewhere...

Crustal subduction, on Earth @ plate boundaries

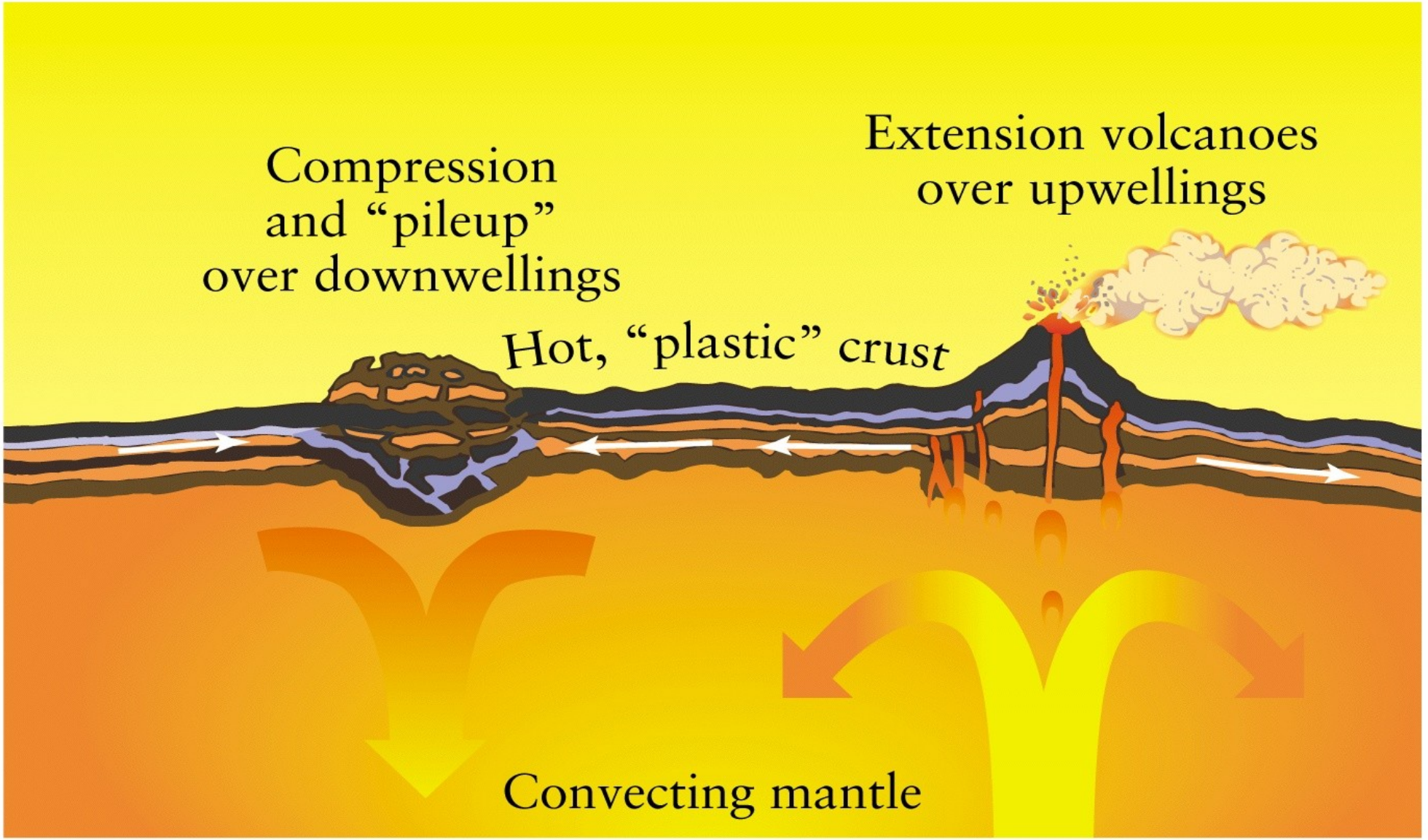


Earth: new crust at ridges, lose crust at boundaries (subduction)

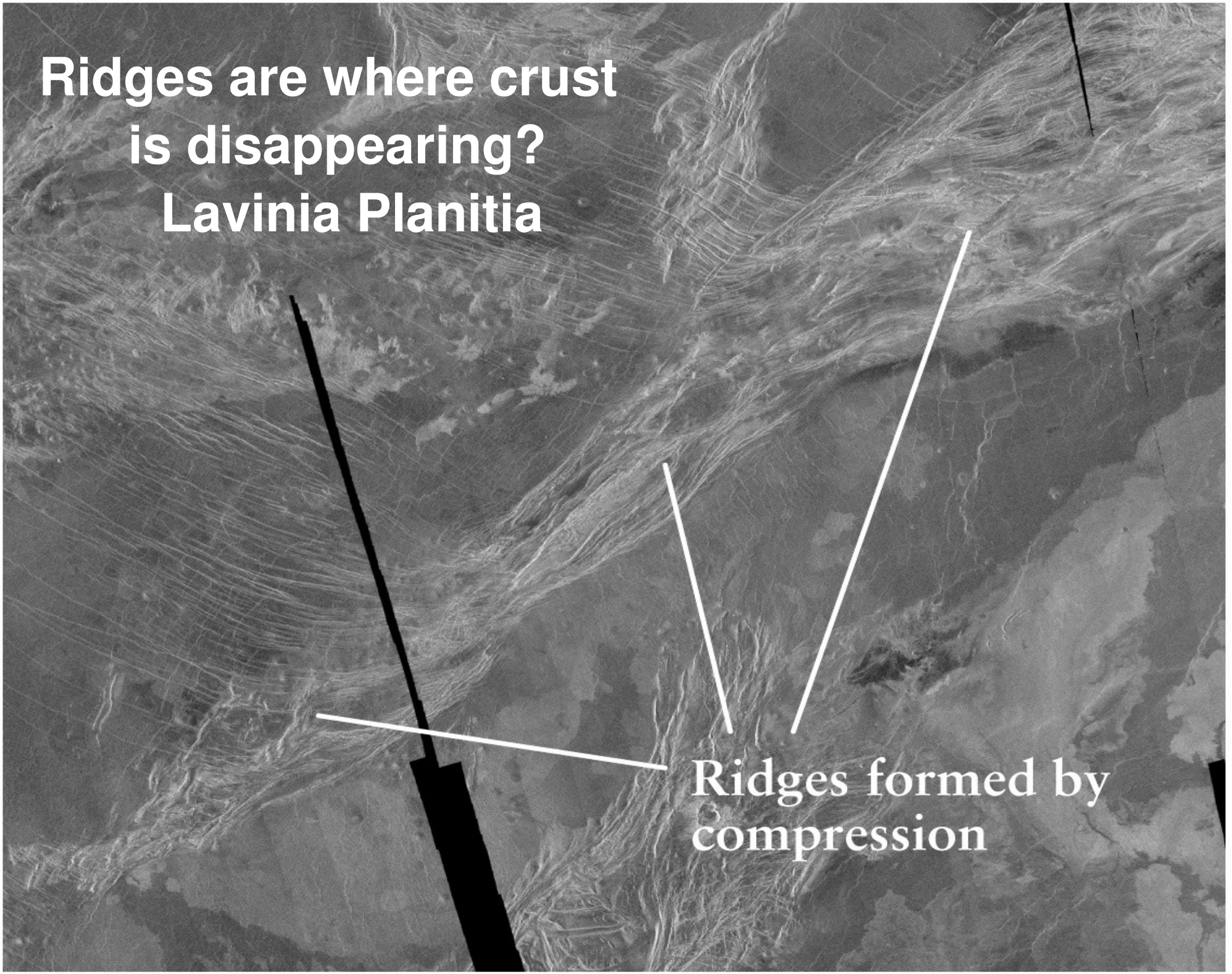


a Earth

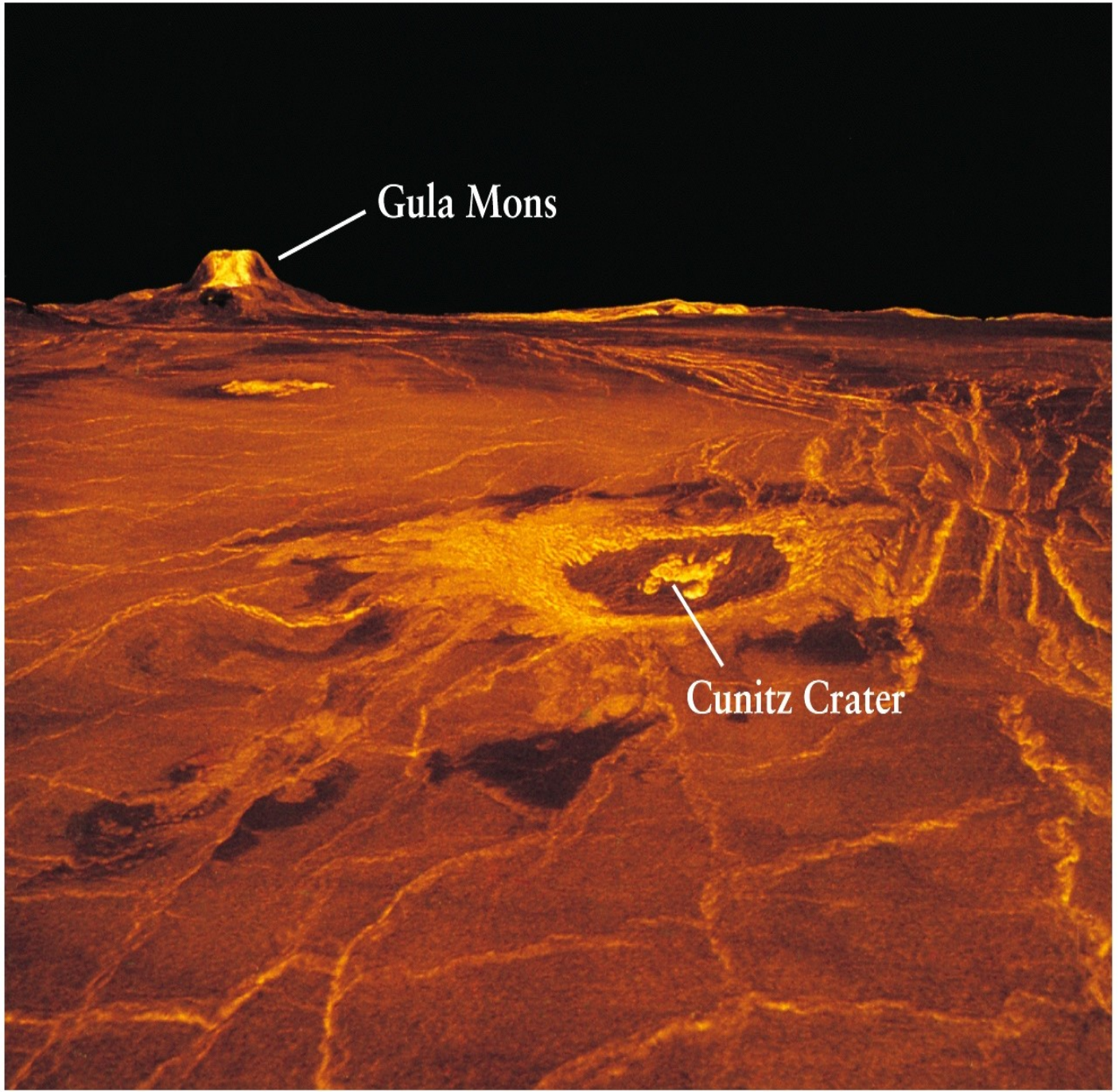
Venus: add crust at volcanoes, lose crust at compressed valleys and ridges (chasms)



b Venus


Ridges are where crust
is disappearing?
Lavinia Planitia
Ridges formed by
compression

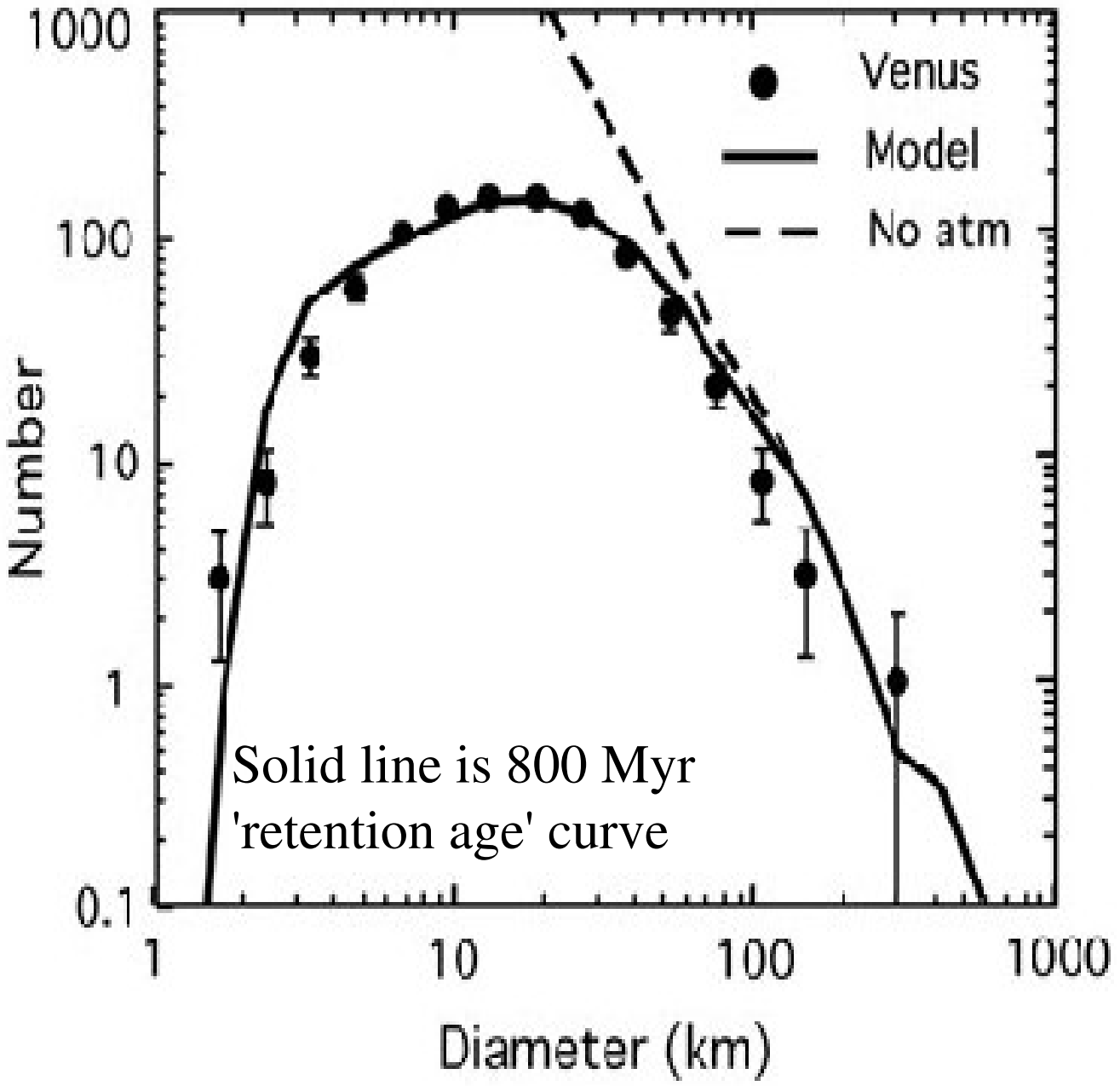
What about the AGE of the venusian surface?



There are impact craters found on the surface of Venus, but...

There are NO large impact basins on Venus (why not?)

What about the AGE of the venusian surface?



Atmosphere now shields out impactors that would create impact craters smaller than about D=3 km

But big old ones would have gotten through... so surface must be younger than ~1 Gyr

Explanation for Venus' young age. Currently a big debate.

- Equilibrium resurfacing?

Constant lava flow simply gradually erases all old craters and keeps surface young.

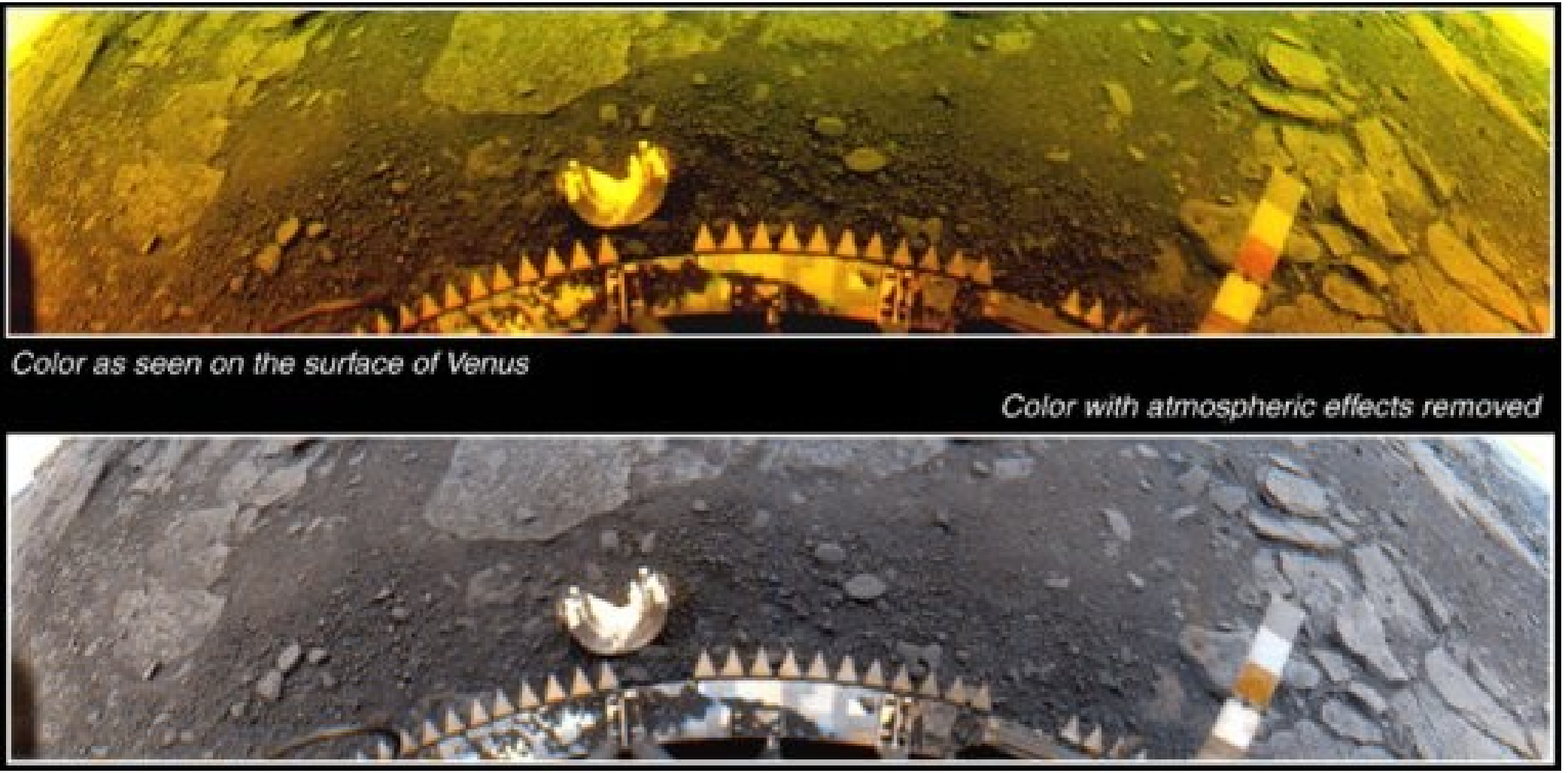
-global catastrophe hypothesis?

Flooding over entire venusian surface at same time as mantle 'breaks through' crust. Currently favoured, but poor understanding of the mechanism how this could have happened

Venusian surface is inhospitable

Only landed on by Russian landers

Surface temperature is VERY hot (460 C)



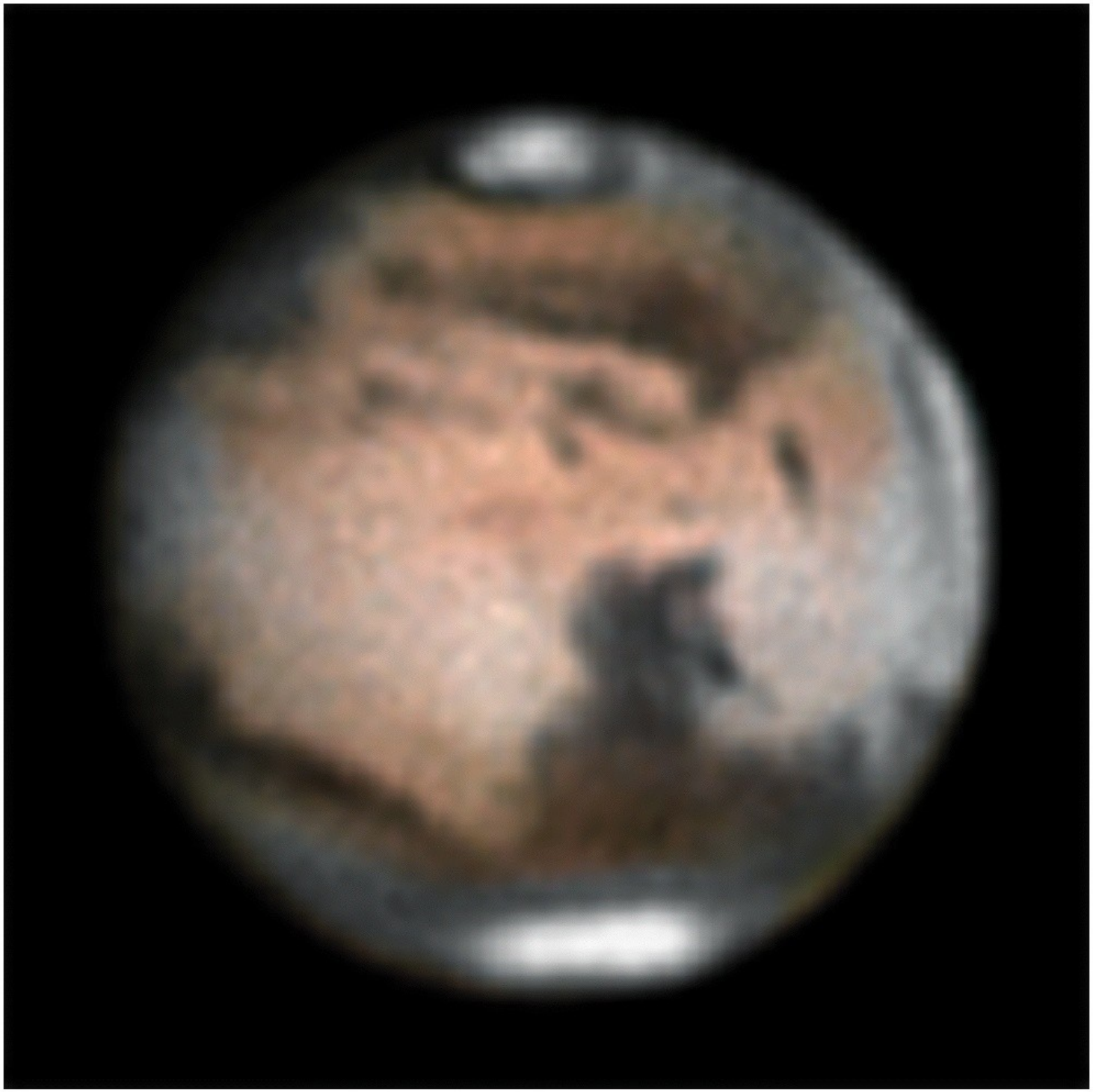
Color as seen on the surface of Venus

Color with atmospheric effects removed

Even THIS only lasted <2 hr!

Venusian surface, as seen by Russian Venera landers

Baked rock under a hazy uniform sky.



MARS:
The red planet

~1/2 R of Earth

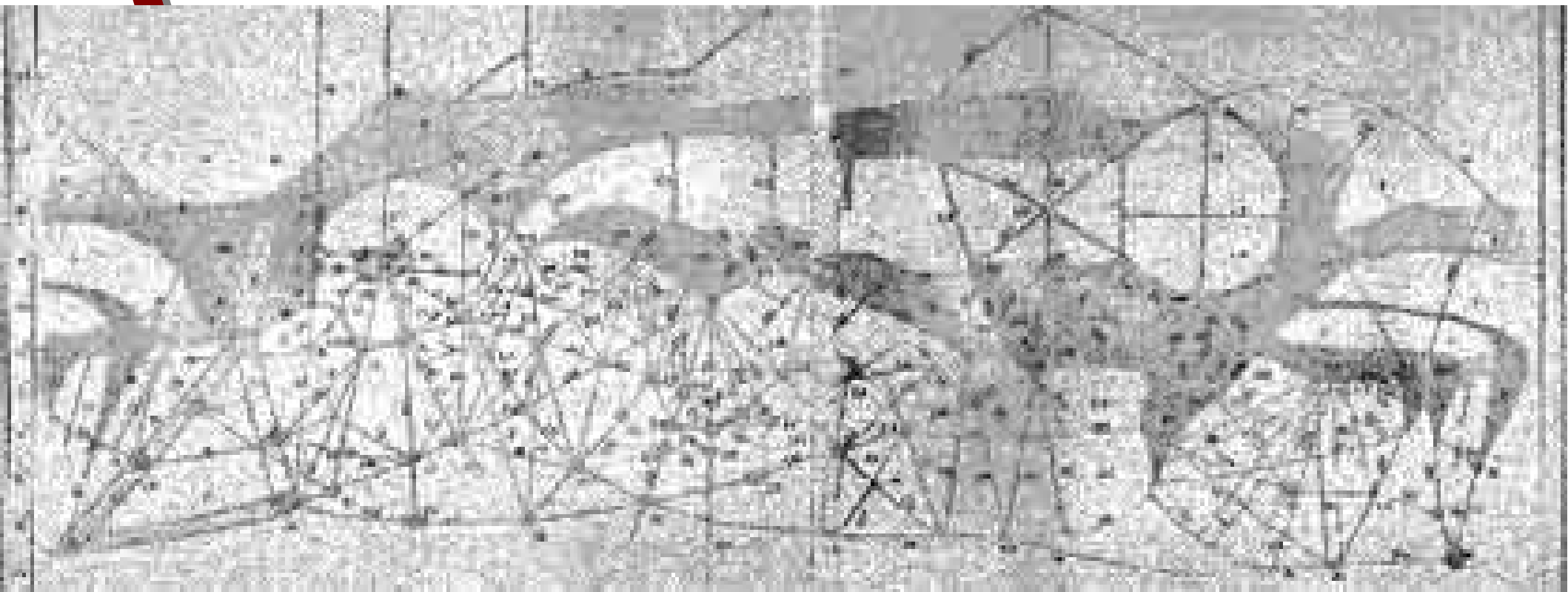
Mars :Lots of wonderful history

Vegetation?

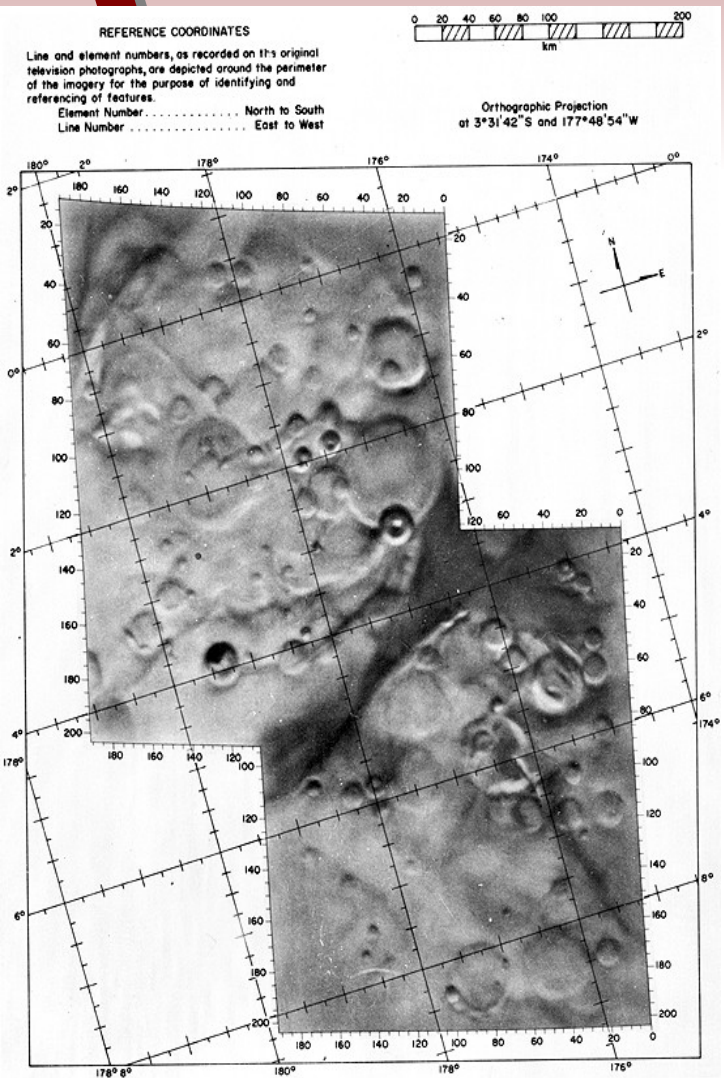
Nope, brown. Brown looks green next to red...

Canals?

Nope....overactive imaginations.



First close-up views: Mariner 4,6,7 (1964-1969)



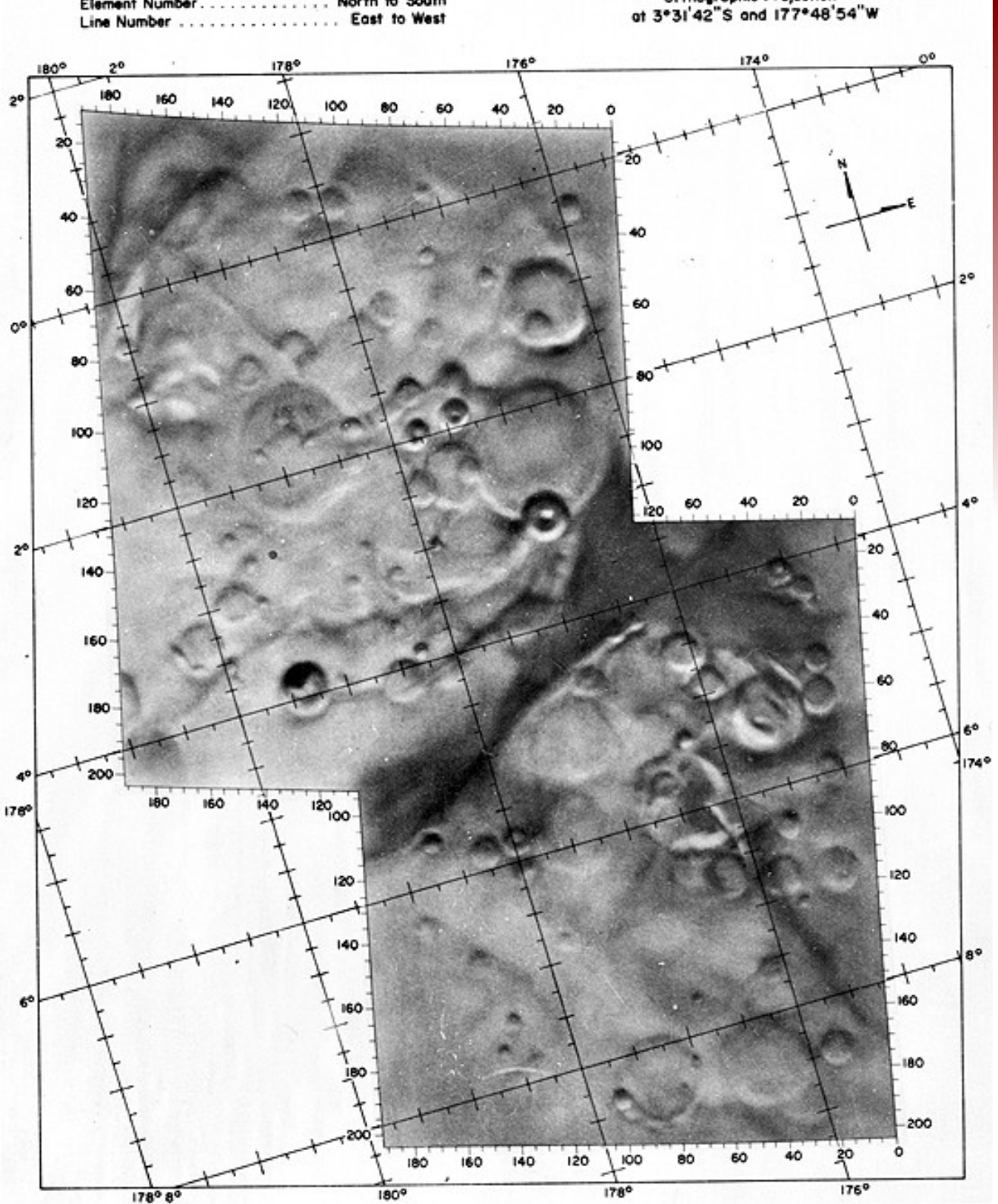
Dark areas not vegetation: just grey

No canals...no martians.....rats!

Many craters! Including some impact basins. Much of surface ancient.

But only 10% of surface imaged by these *fly-by* spacecraft missions.

NEED AN ORBITER.



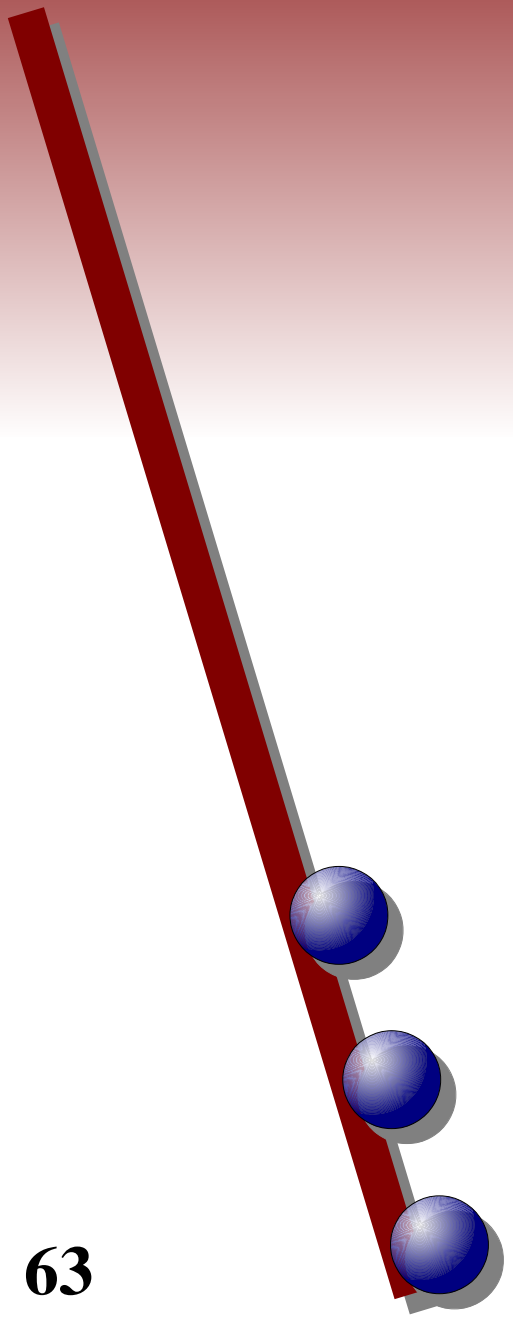
Mariner 4 imaging

An interesting surface

Many more craters than Earth's surface, but can see partial erosion

NOT a dead world

Surface of Mars is varied



Has earthlike spin and obliquity

Has YOUNG *and* ANCIENT surface regions.

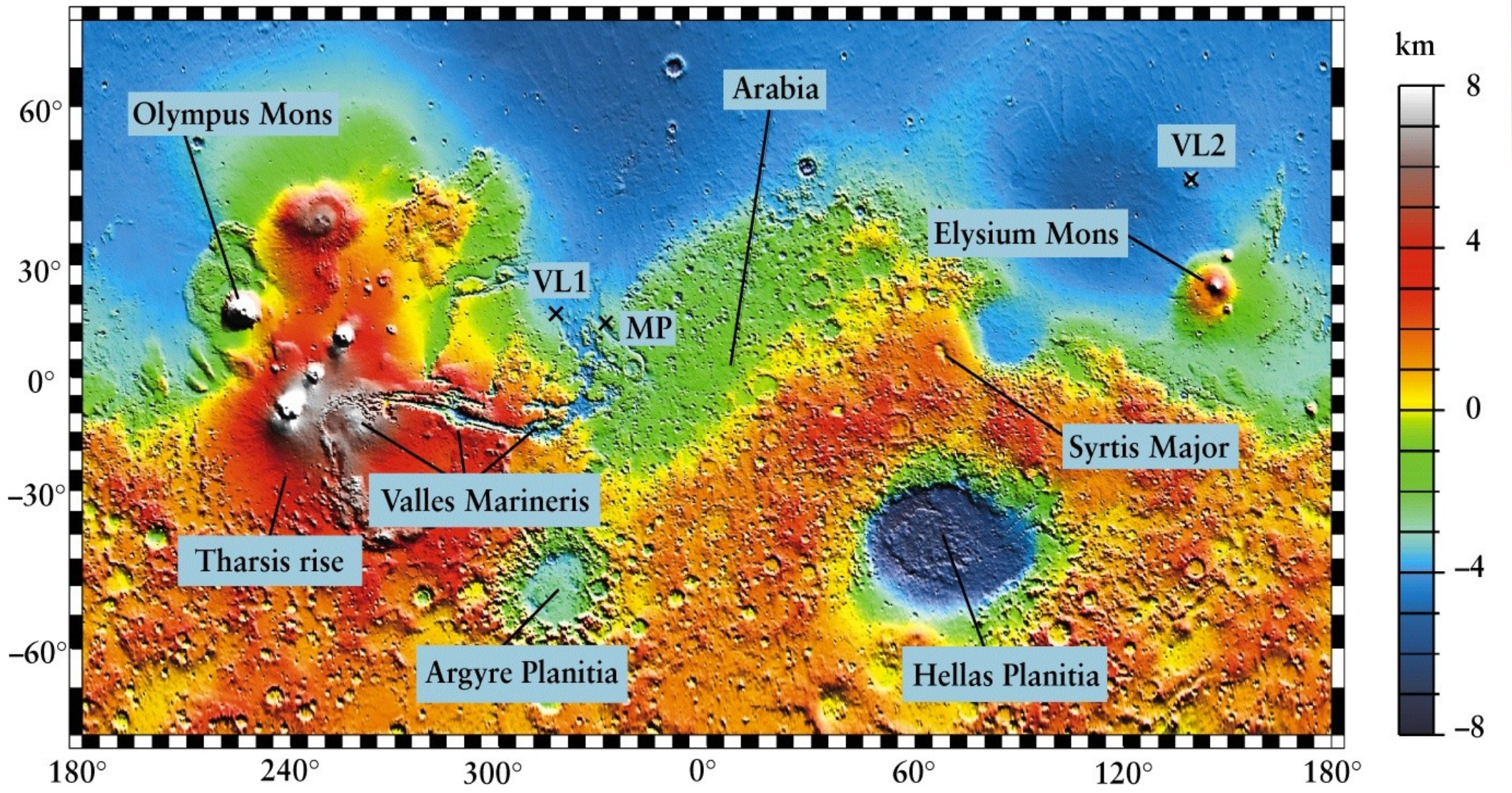
Has active atmosphere (but thin).

Has 'recent' geologic activity.

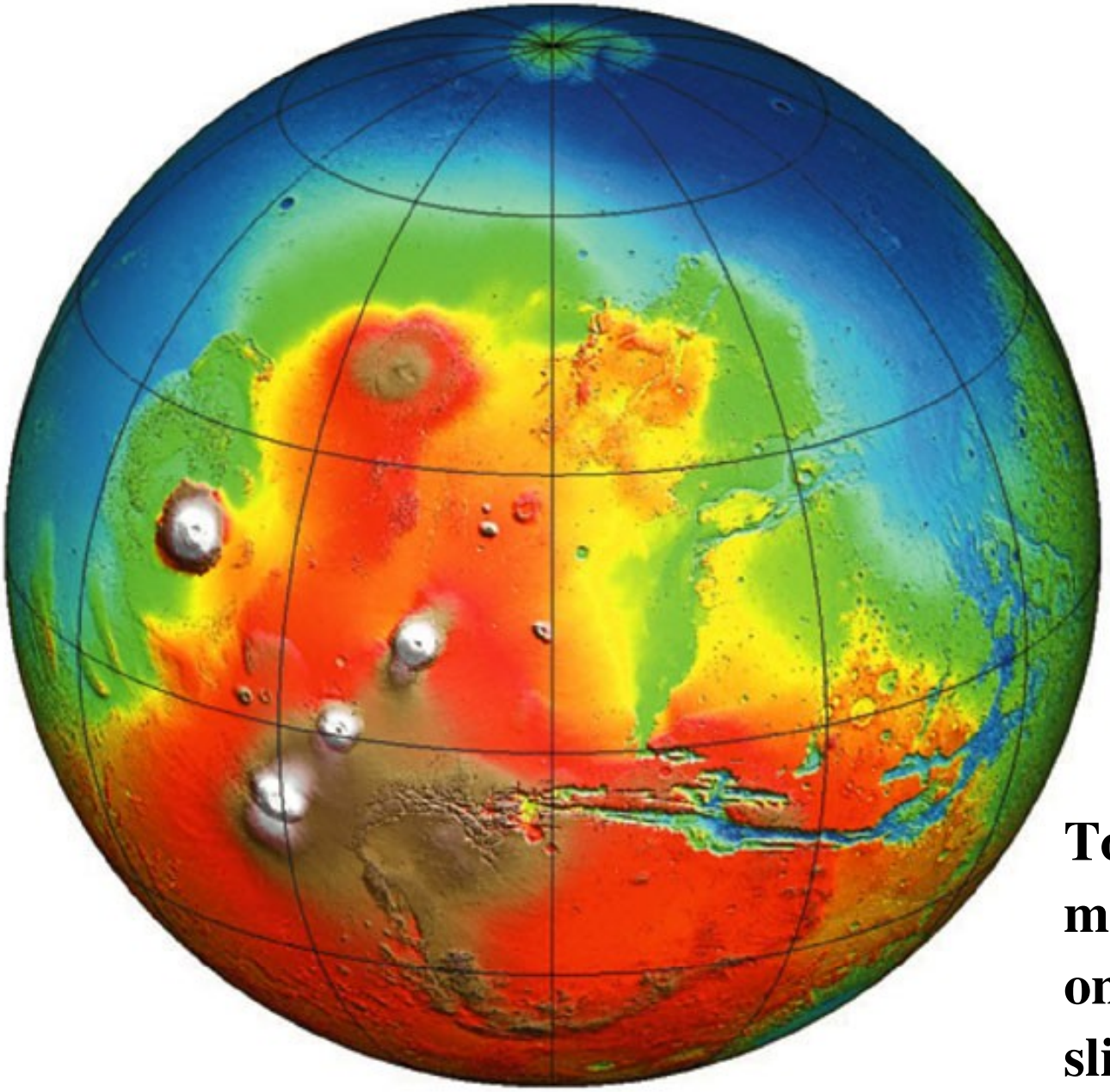
Has evidence of liquid water in the past (but how much? when?)

The crustal dichotomy of Mars
Northern Lowlands/Southern Highlands

You can see a great zoomable map at : mars.google.com

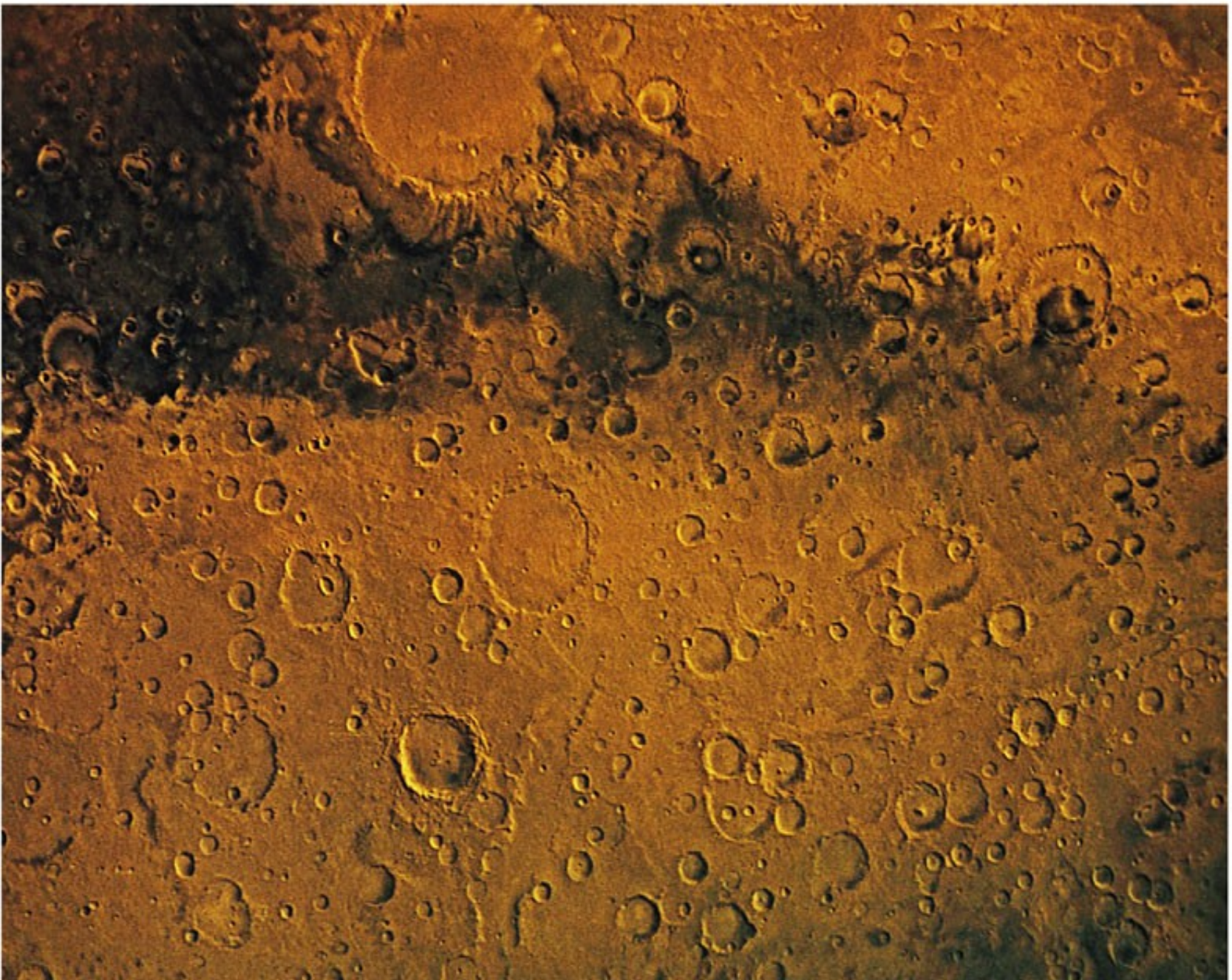


The crustal dichotomy of Mars
Northern Lowlands/Southern Highlands



Topographic map; scale on previous slide

The crustal dichotomy of Mars
Southern Highlands heavily cratered



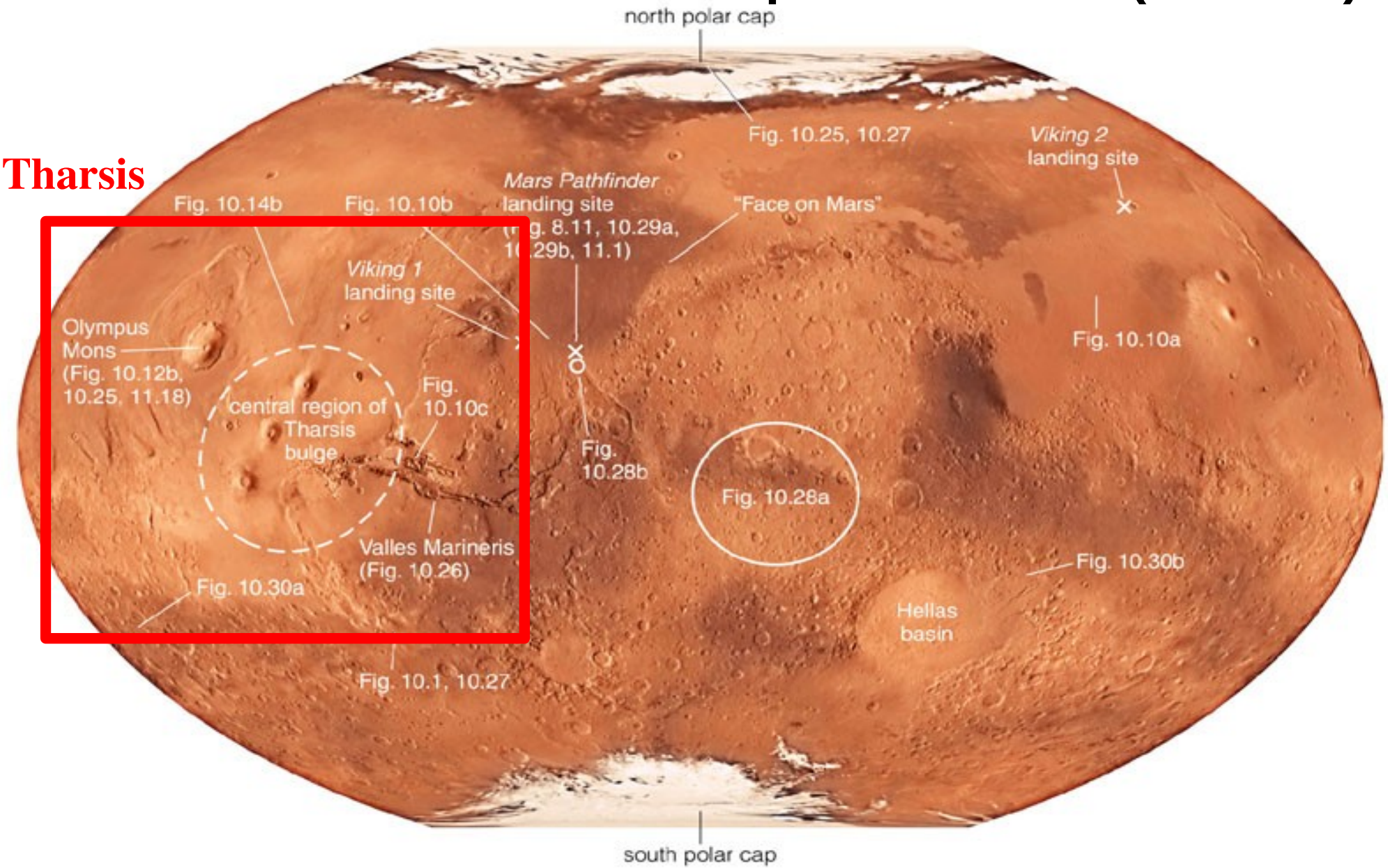
Note older craters appear *eroded*.

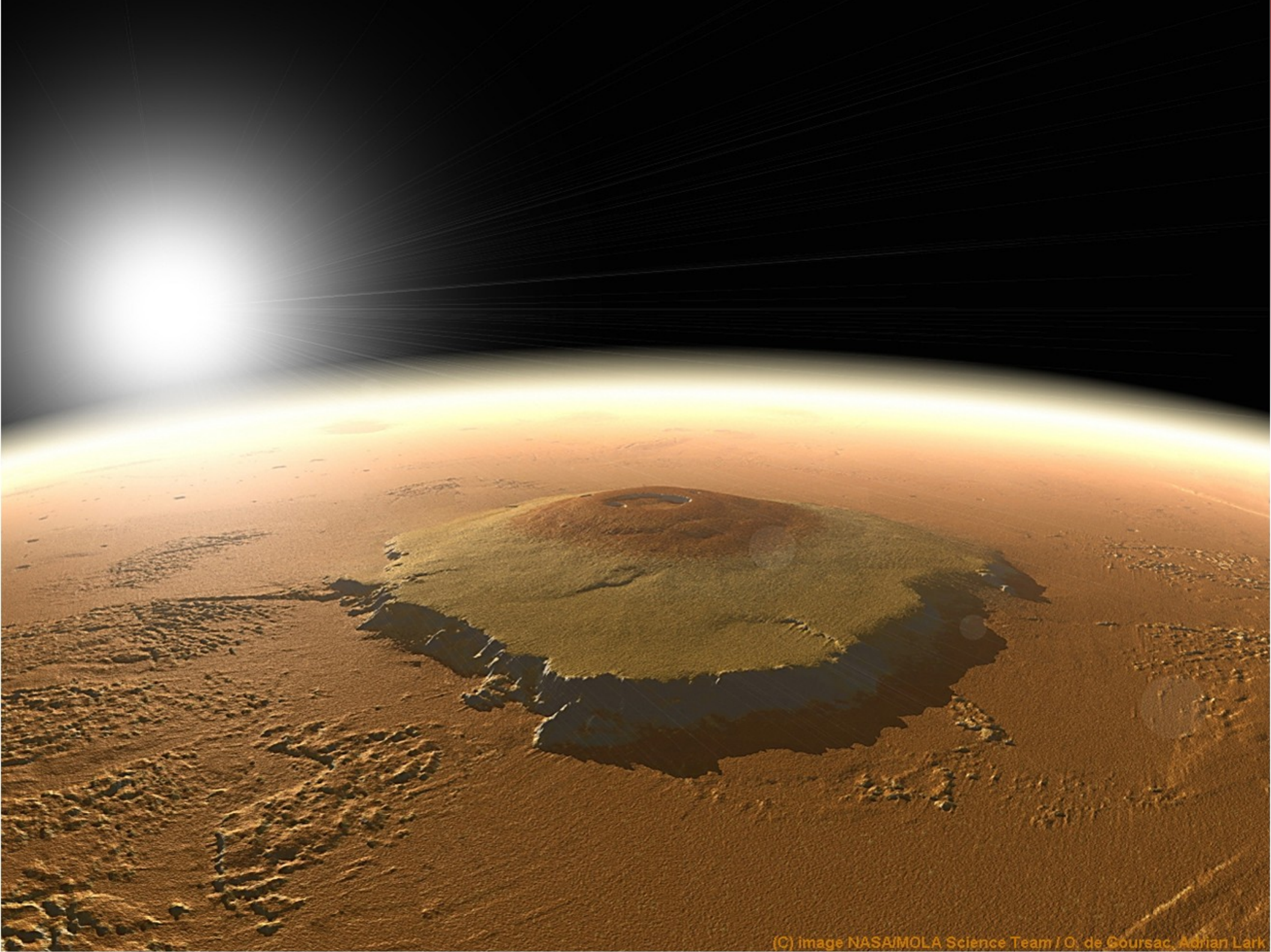
What geologic process eroded them?

The Tharsis rise/plateau

-3 shield volcanoes here + Olympus Mons

Hot-spot volcanism (isolated)

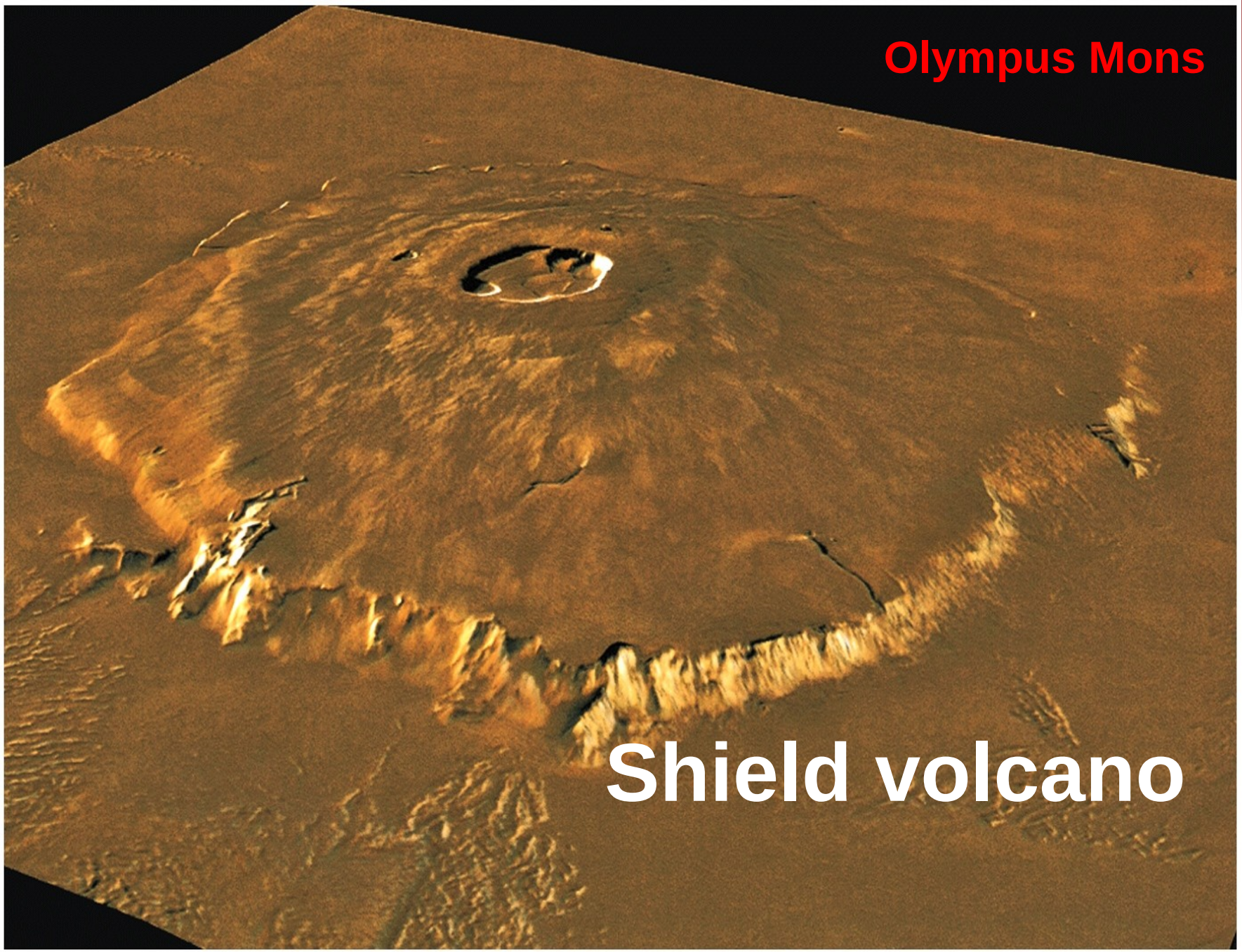



(C) image NASA/MOLA Science Team / O. de Goursac, Adrian Lark

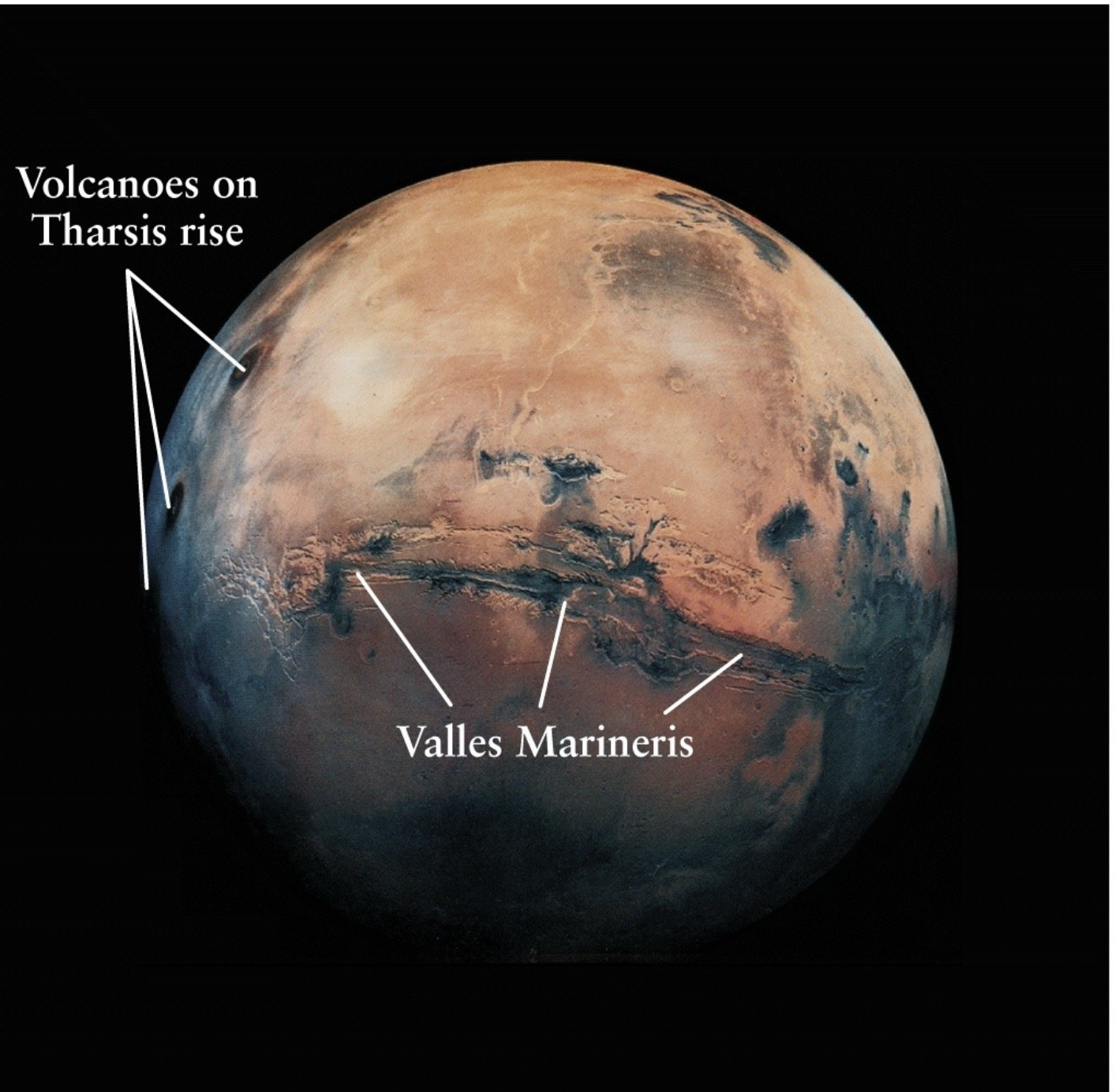
Mars has heeeuugge volcanoes

24 km high!

Dwarfs Mauna Kea



Mars has some deep chasms

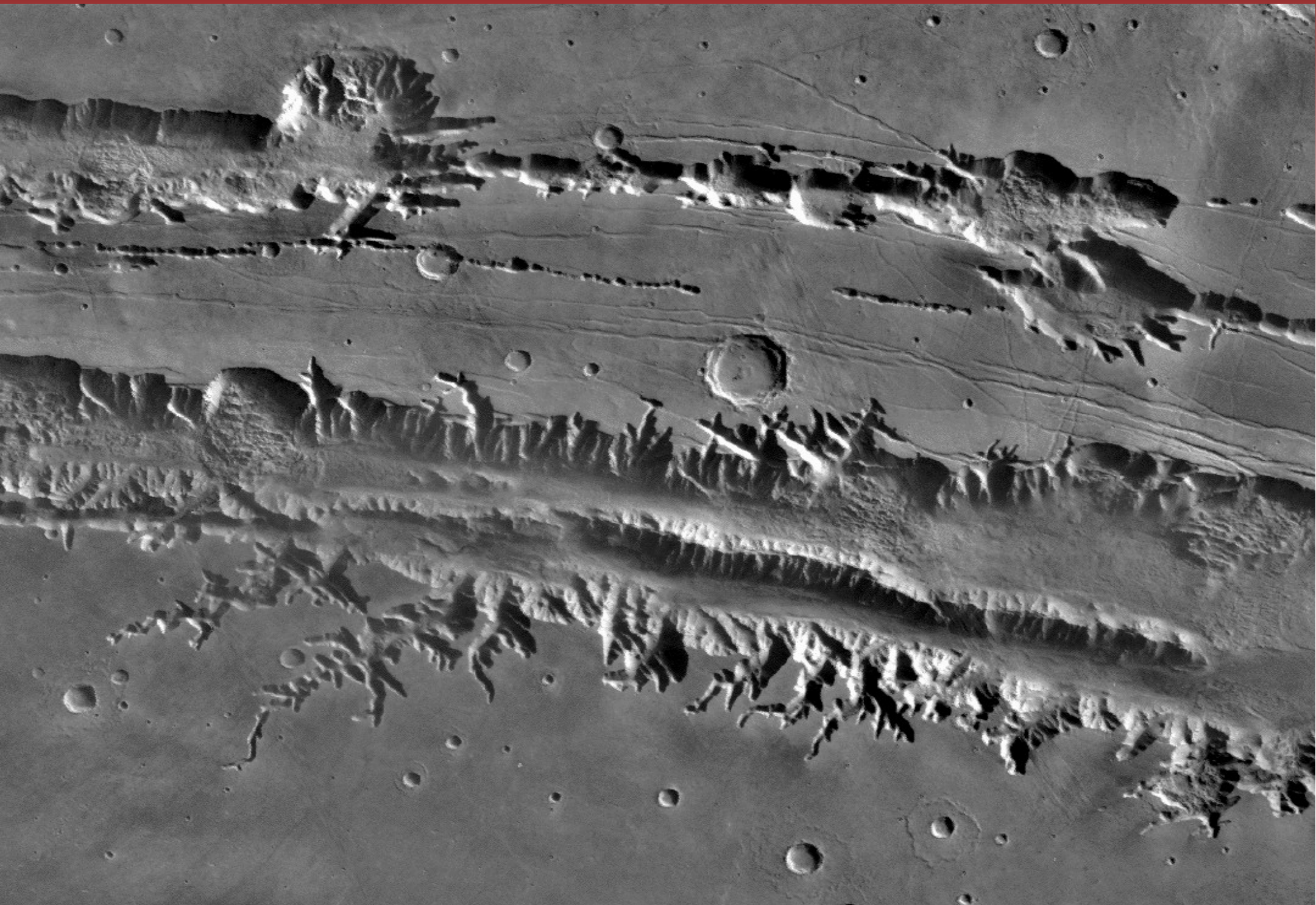


Valles Marineris

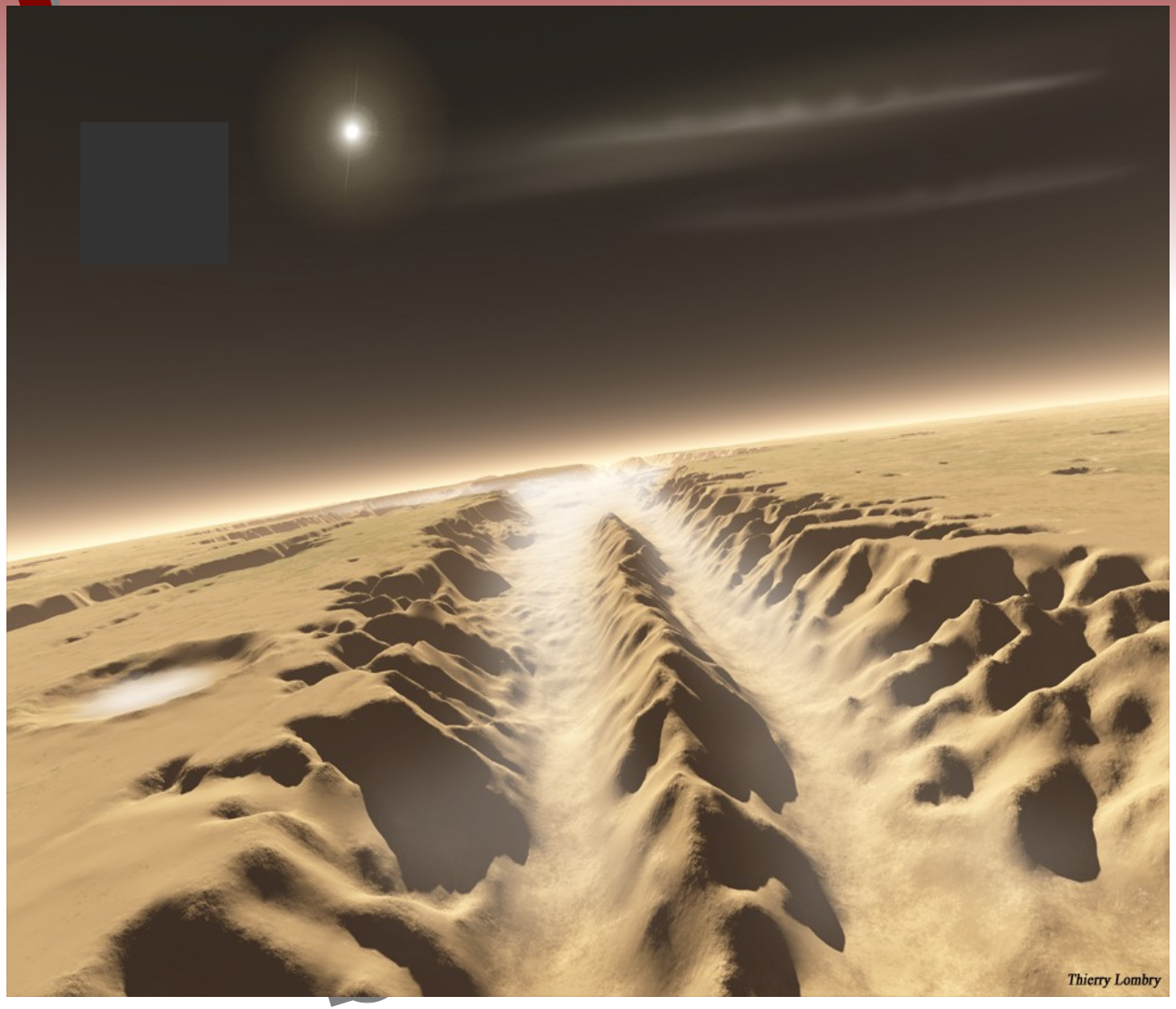
Rift valley
4000 km long
600 km wide
8 km deep

Dwarfs the Grand Canyon

Valles Marineris up close



Mars has some deep chasms



Valles Marineris

Rift valley

Evidence for crustal expansion when the Tharsis region rose

The timing of the Thrasis uplift -- Clearly very young

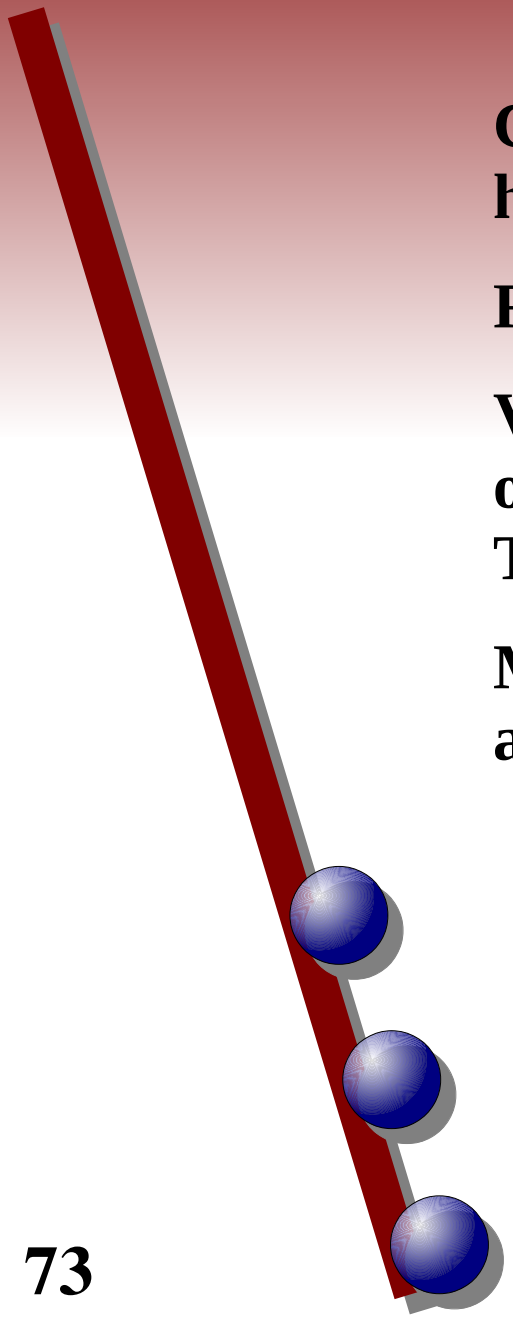
Crater density < young northern lowlands < old southern highlands

Flanks of some of the volcanoes almost crater free.

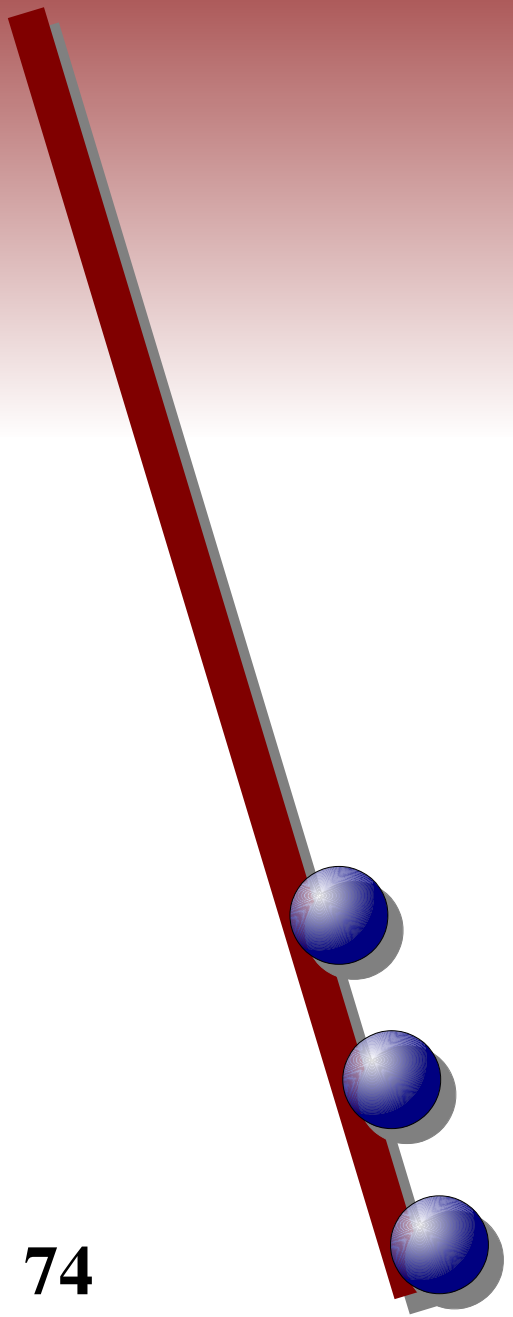
Valles Marineris must have formed nearly the same time or after most uplift because this deep valley 'cuts through' Tharsis.

Most scientists believe most of the main uplift occurred about 1.3 Gyr ago

- **This is boundary of Amazonian geologic epoch**
- **Age of 1.3 Gyr is combination of crater density models and cosmochemistry**



The martian core



Martian density 3930 kg/m^3 < Earth

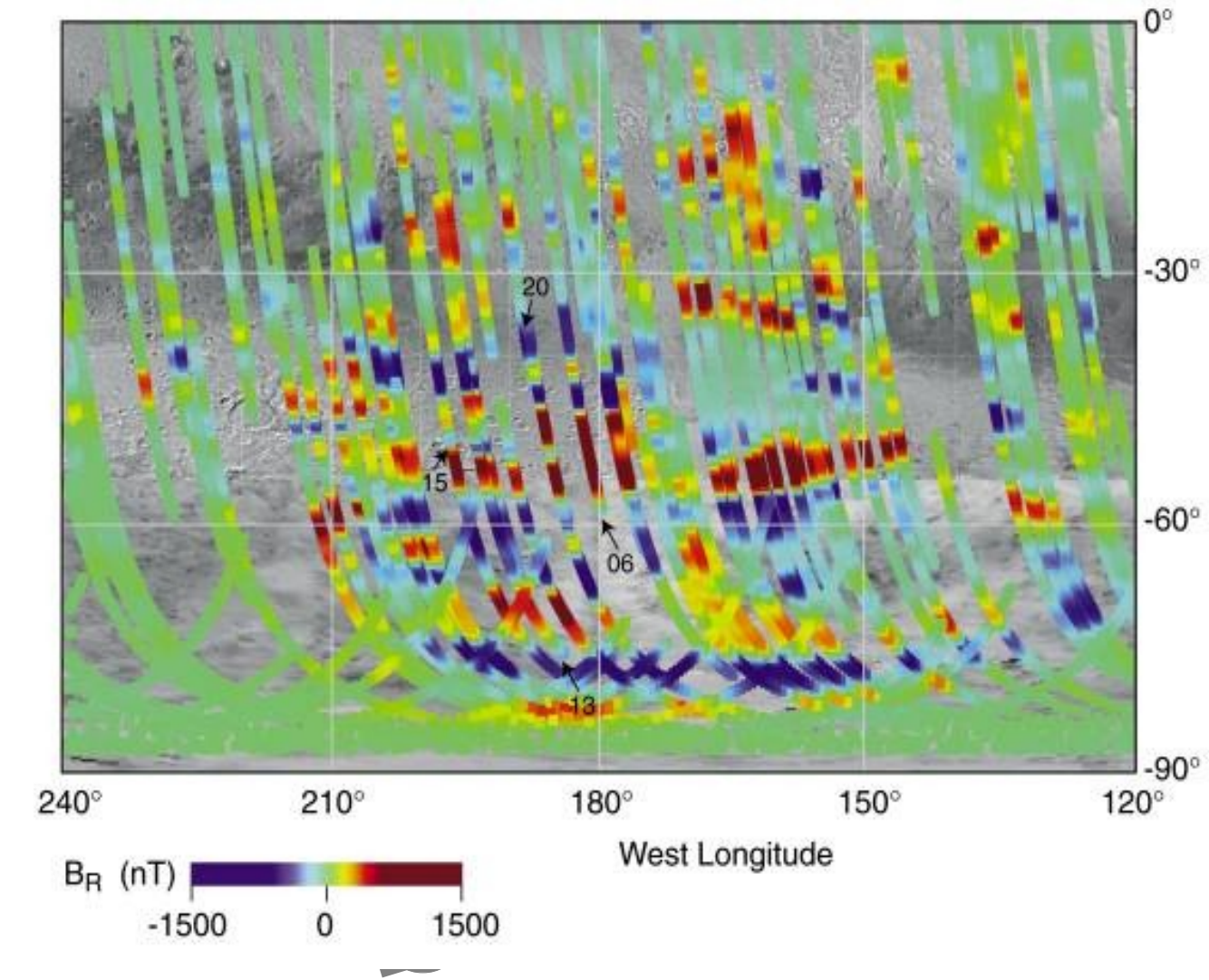
Mars does not currently have a magnetic field

Probably the planet has cooled and the core solidified, but it appears that there is a small 'recent' volcanism from the upper mantle.

Martian core thought to contain sulfur, which interferes with the conductive properties of iron.

There IS evidence of a magnetic field in the past in the highlands! It even reverses!

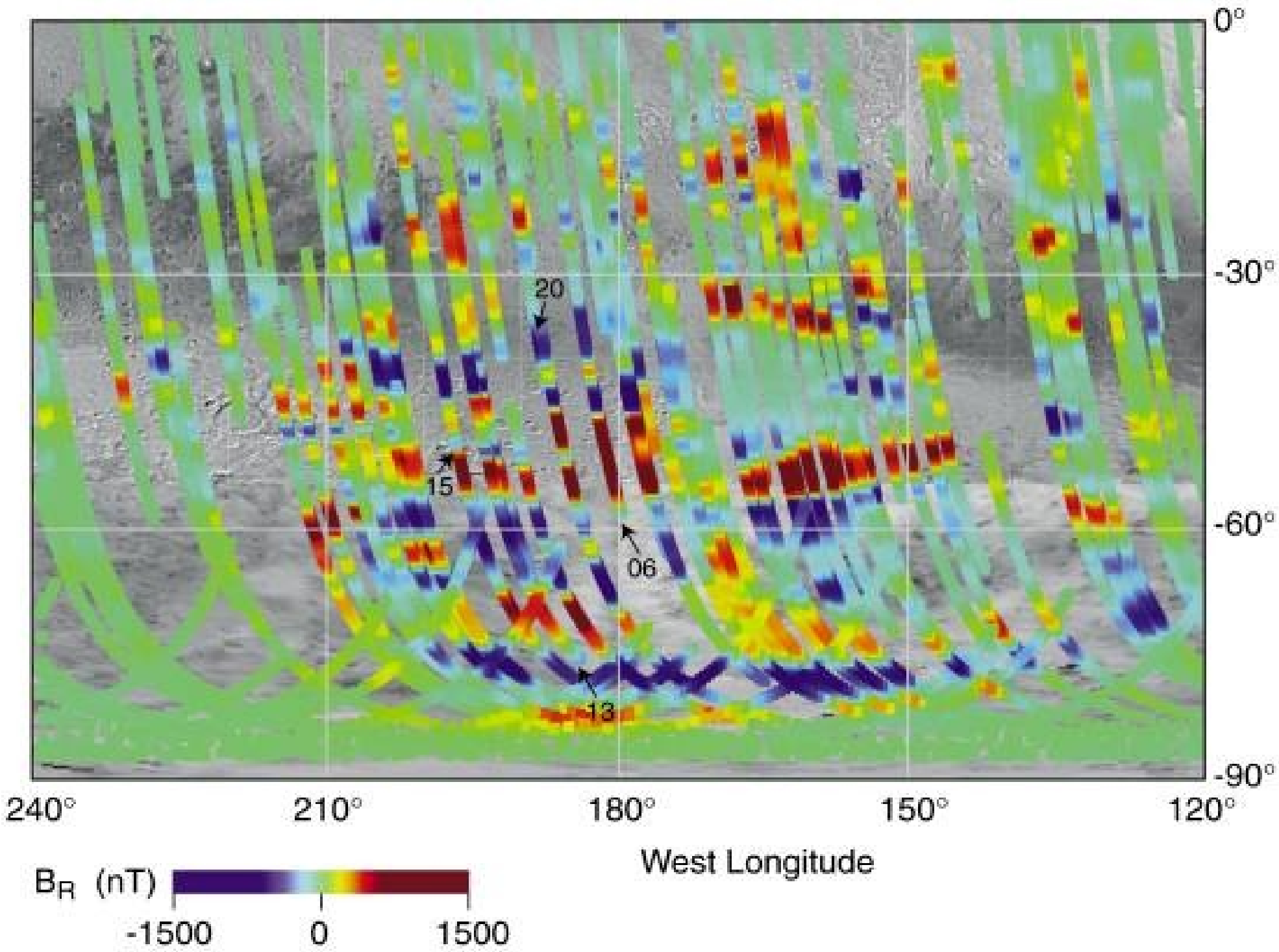
Evidence of plate tectonics?



Spacecraft detect preserved evidence of an ancient (reversing) magnetic field.

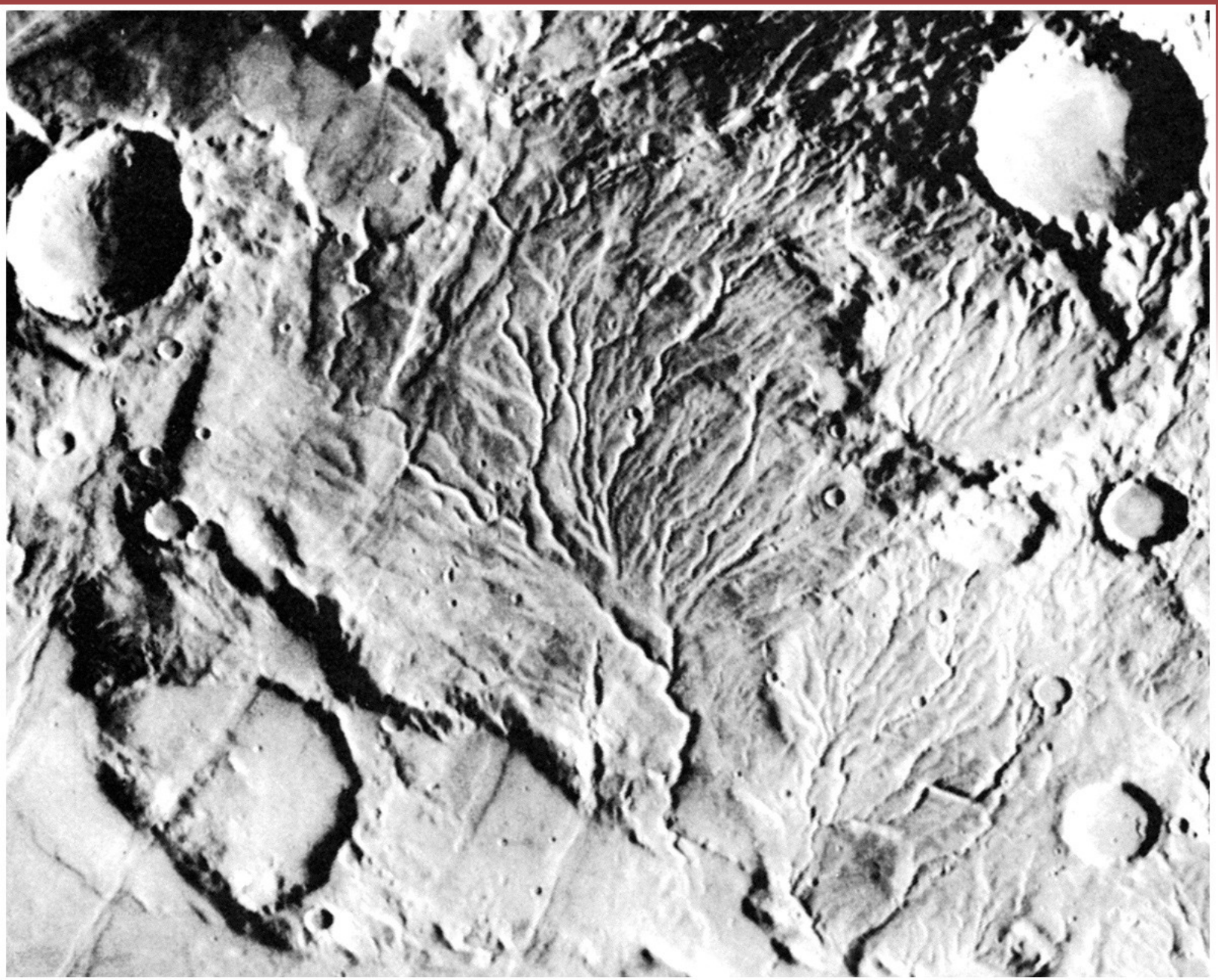
Similar to geomagnetic reversals on Earth

Implies Mars had plate tectonics in past? Controversial.


0°
-30°
-60°
-90°
20
15
06
13
240°
210°
180°
150°
120°
West Longitude
B_R (nT)
-1500
0
1500

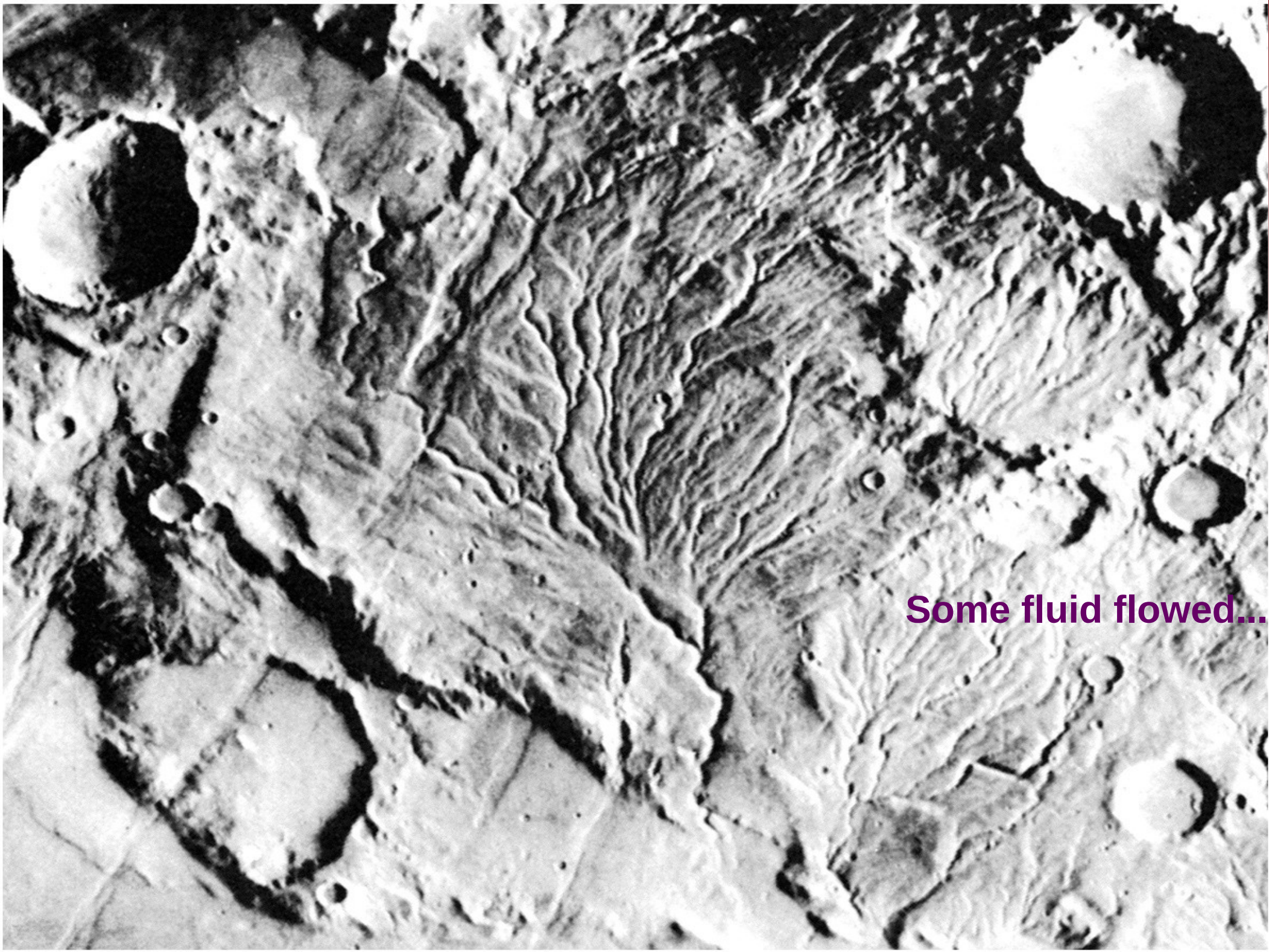
The big question: Wet Mars?

Mars likely had flowing H20 long ago

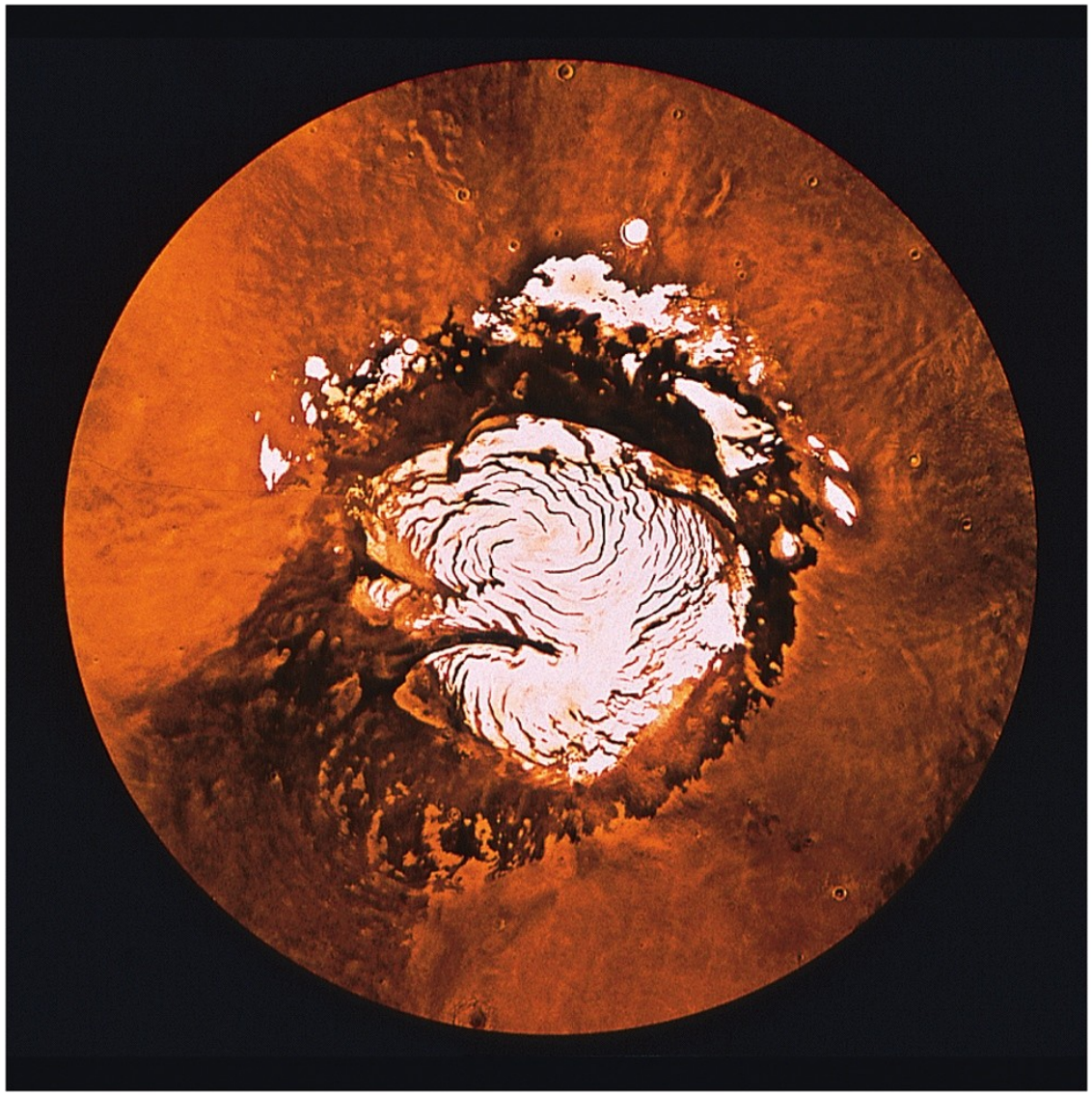


Dendritic river channels as seen on Earth

Some cut through craters


Some fluid flowed...

Mars has polar caps



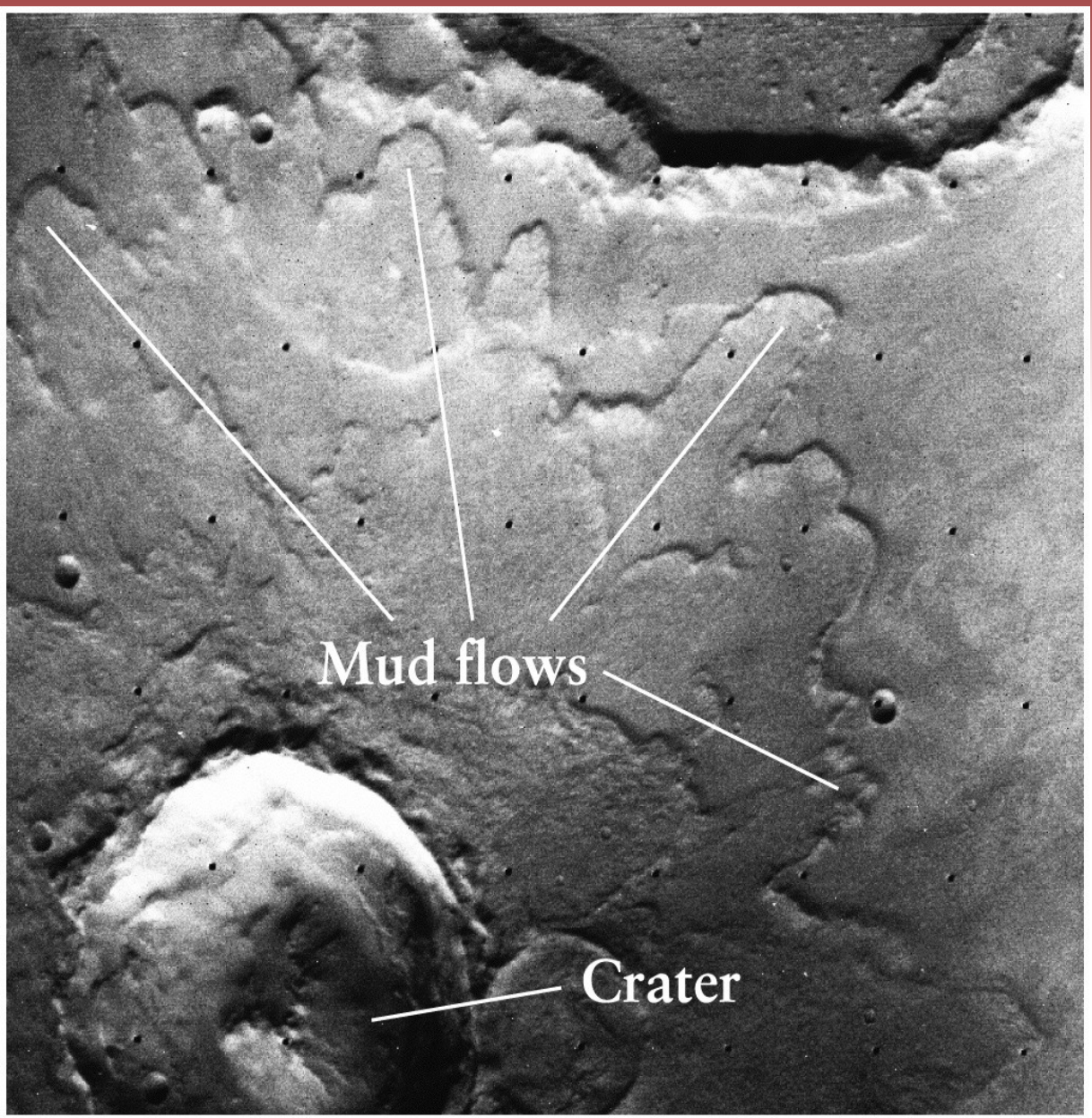
They show a seasonal cycle of melting and then deposition.

Although made of ice, it's CO_2...

Winter temperature is -140°C, cold enough to freeze CO2.

Northern cap has a largish reservoir of H_20 (how big?)

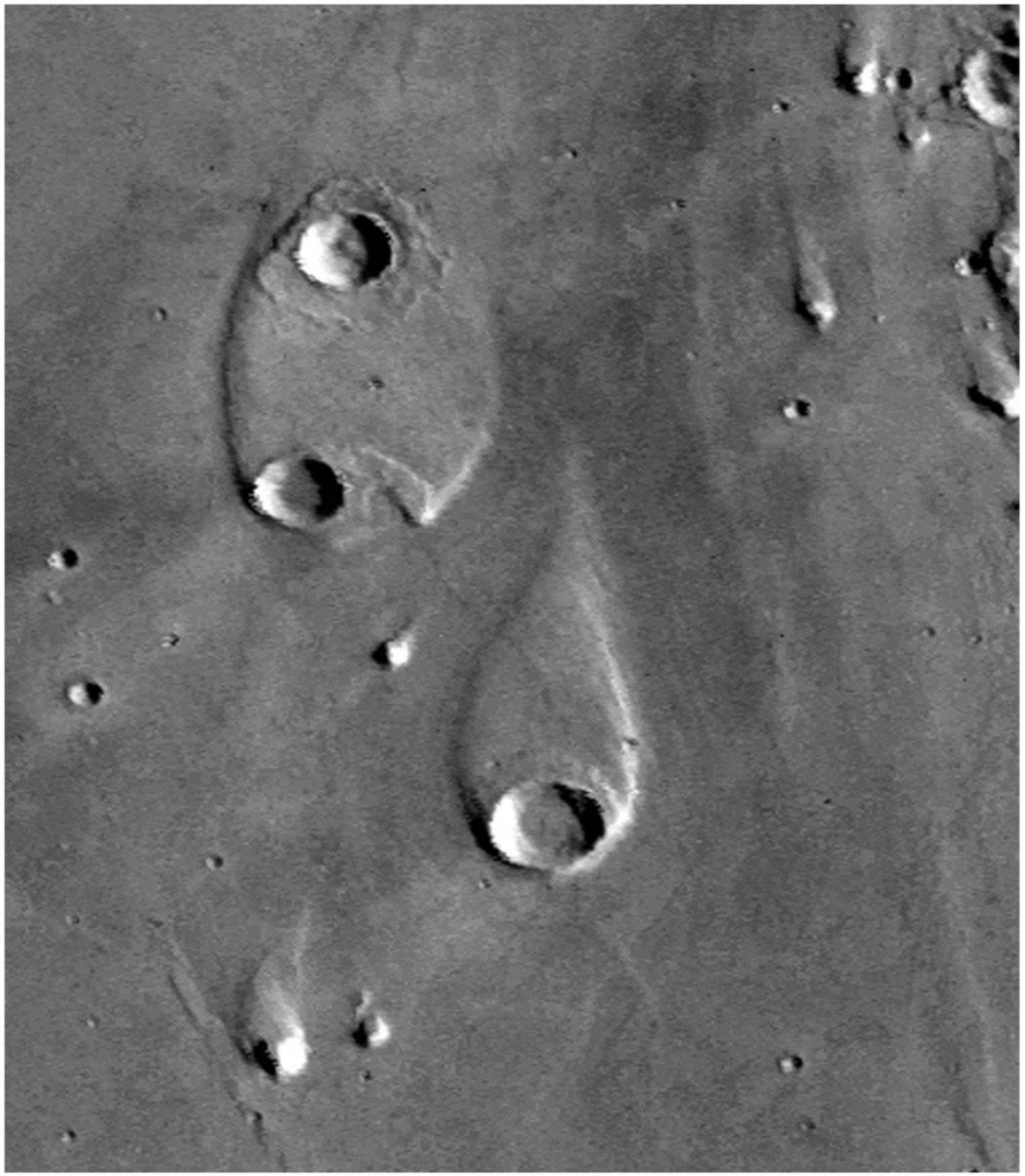
The case for H20: subsurface



Some martian craters are surrounded by 'petal-shaped' ejecta blankets.

Believe to be sub-surface water melted by the impact which then flowed away from the crater.

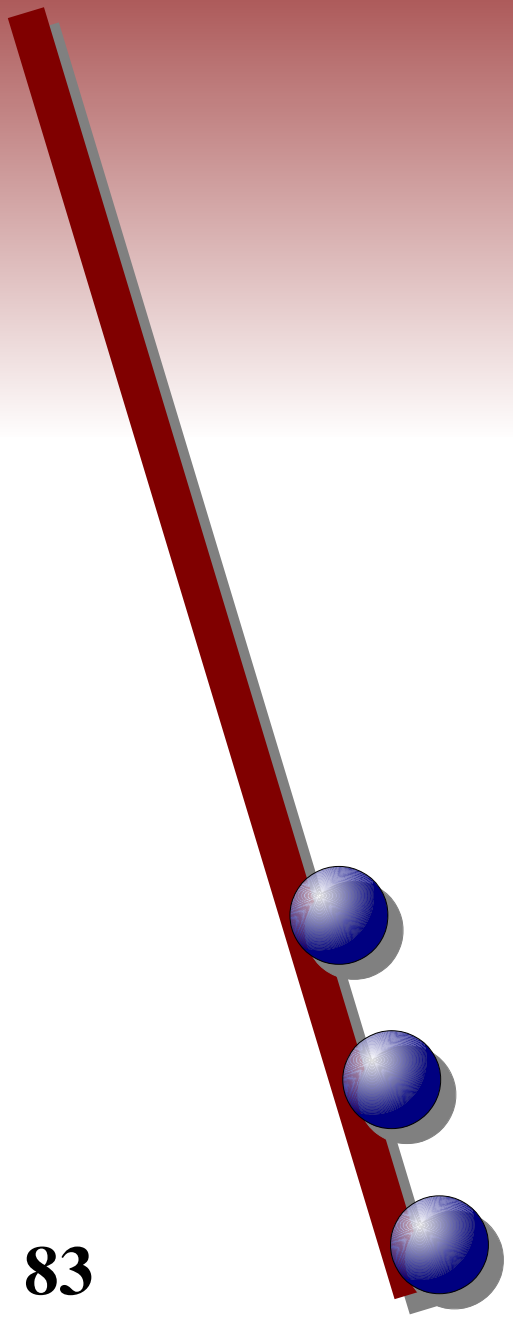
The case for H20: Flow features



There are many features seen on the surface which look like they have been produced by water flowing freely, in large quantities, on the surface.

To left: teardrop-shaped flow features

But water is not flowing NOW.

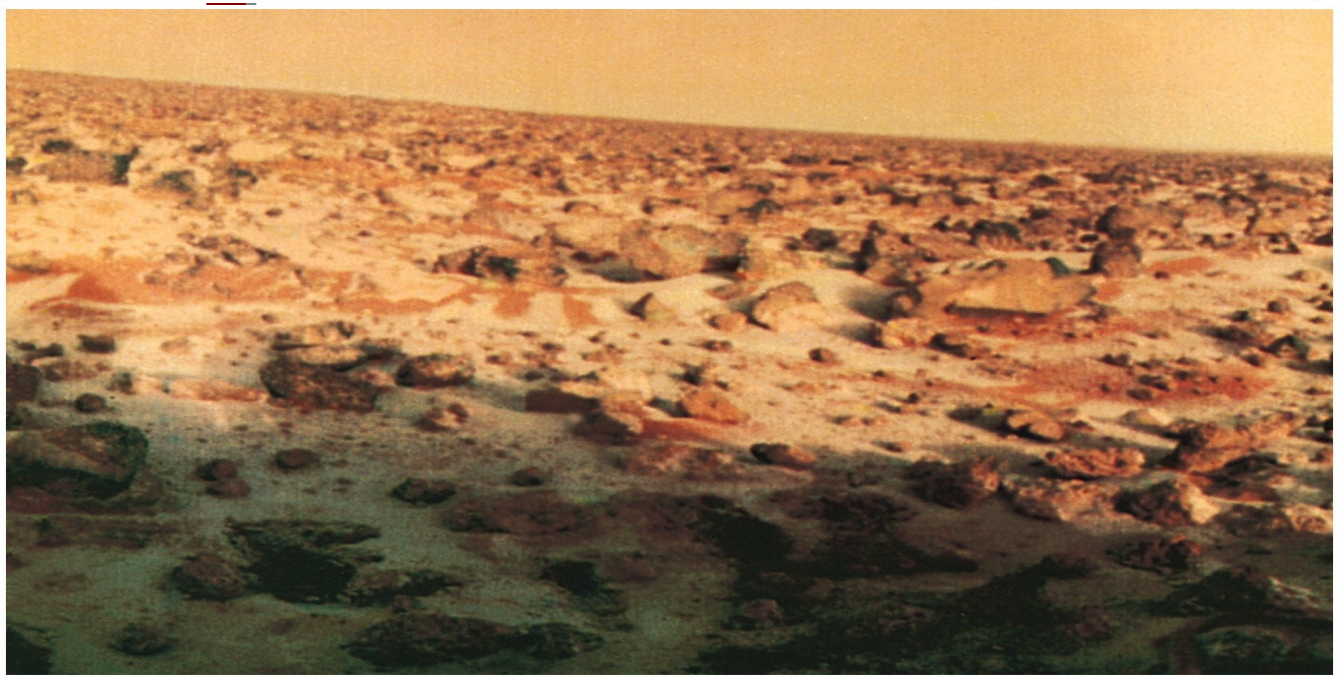


Why not?

Because although Mars has an atmosphere, it is too thin to have a surface pressure high enough for water to sit on the surface!

Refer to the phase diagram of water... current martian atmospheric pressure always drops below the triple point of 6 mbar during the season.

Seasonal migration of volatiles



Summer: CO_2 in atmo, note reddish iron-bearing rocks.

Winter: CO_2 frost forms and the martian atmospheric pressure drops.

Atmosphere migrates!

CO_2 ices goes into atmosphere, then circulates and freezes out on winter pole