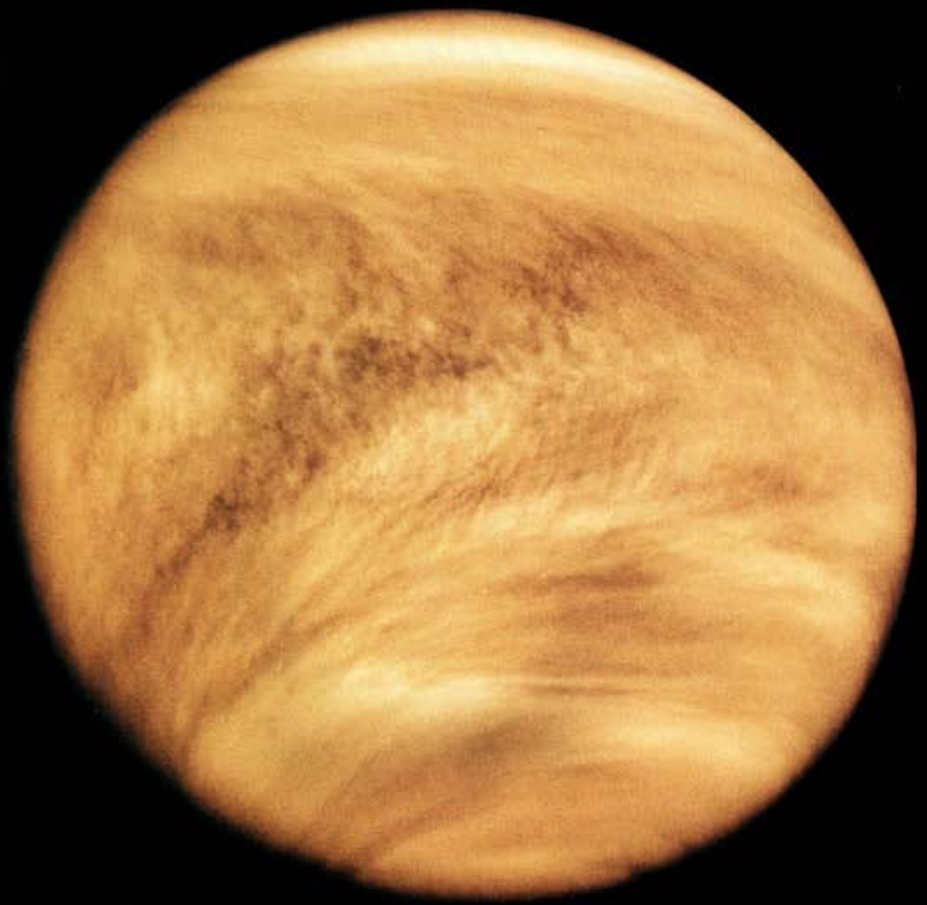
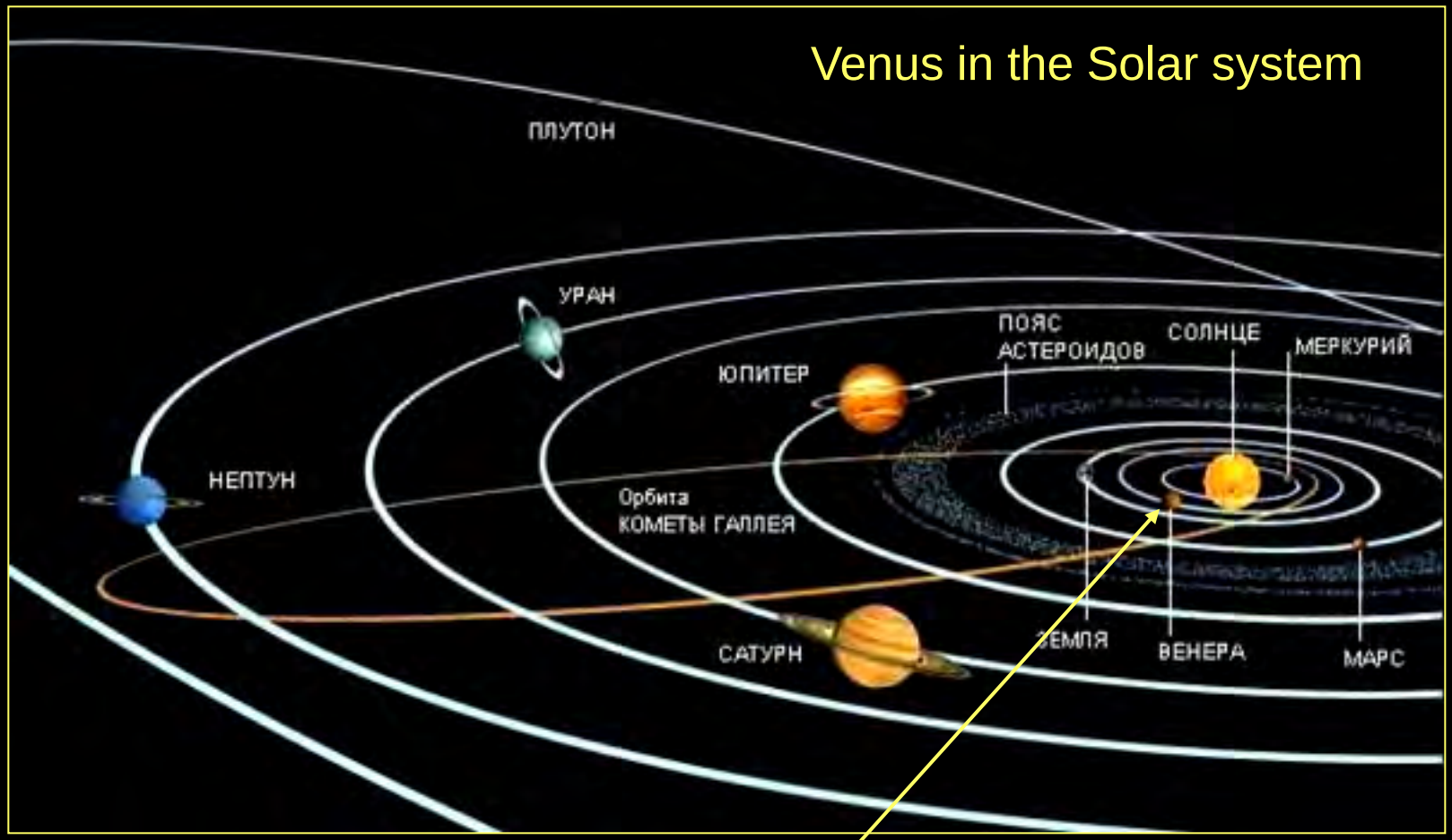
Venus



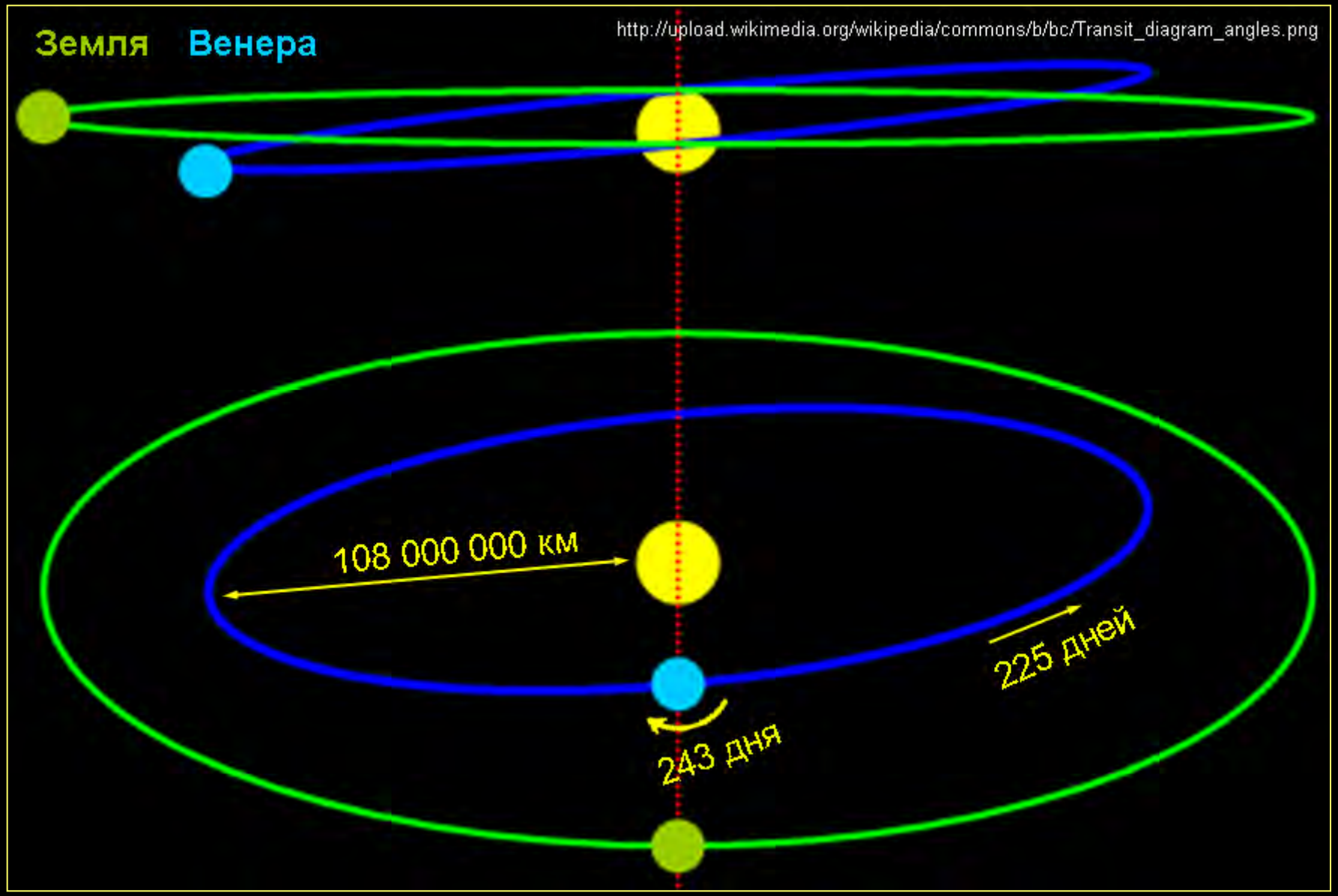
Venus imaged in UV,
Pioneer Venus,
clouds are seen

Venus, mosaic of the
Magellan radar images,
planet surface is seen

Venus in the Solar system



Orbit of Venus



What we knew about Venusbefore space flights to this planet

Distance to the Sun	0.72 of Earth's
Mean radius	0.95 of Earth's
Mass	0.81 of Earth's
Bulk density	0.95 of Earth's
Surface gravity	0.91 of Earth's
Atmosphere	CO_2

Expectations were that Venus is very similar to Earth:

- Generally similar geology
- Understandably warmer climate
- Maybe hospitable to life

A.& B. Strugatsky
Strana bagrovykh tuch.
Moscow, 1959

Successful missions to Venus: 23 missions

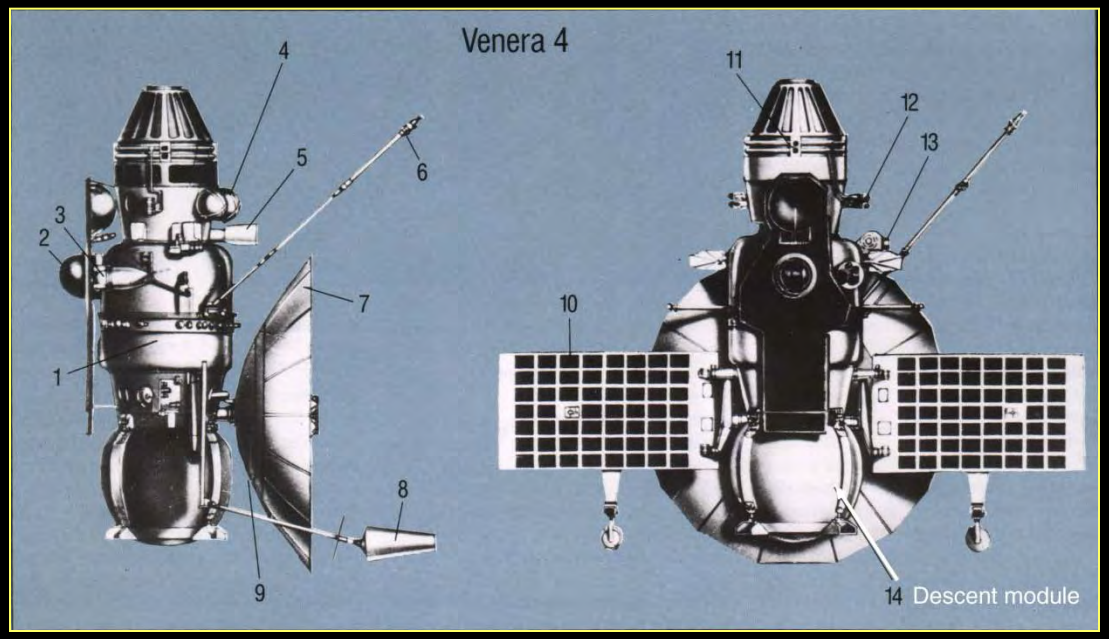
Mariner 2, US	1962	Flyby
Venera 4, USSR	1967	Entry probe
Mariner 5, US	1967	Flyby
Venera 5	1969	Entry probe
Venera 6	1969	Entry probe
Venera 7	1970	Soft landing
Venera 8	1972	Soft landing, K, U, Th
Mariner 10	1974	Flyby
Venera 9	1975	Soft landing, TV panorama, K, U, Th
Venera 10	1975	Soft landing, TV panorama, K, U, Th
Pioneer Venus Orbiter	1978	Radar mapping
Pioneer Venus Entry	1978	Entry probes
Venera 11	1978	Entry probe, soft landing
Venera 12	1978	Entry probe, soft landing
Venera 13	1982	Entry probe, soft landing, geochemistry
Venera 14	1982	Entry probe, soft landing, geochemistry
Venbera 15	1983	Orbiter, radar mapping
Venera 16	1983	Orbiter, radar mapping
Vega 1	1985	Baloon, soft landing, geochemistry
Vega 2	1985	Baloon, soft landing, geoghemistry
Galileo	1990	Flyby on the route to Jupiter
Magellan	1990	Radar orbiter

Venus Express 2005 -2015. Orbiter, mostly atmosphere and plasma studies, surface is seen on the night side only.

Mariner 2 – first successful mission to Venus

!962, Flyby, Confirmed very hot surface environment

Venera 4, First successful entry to atmosphere 1967



Cruise spacecraft

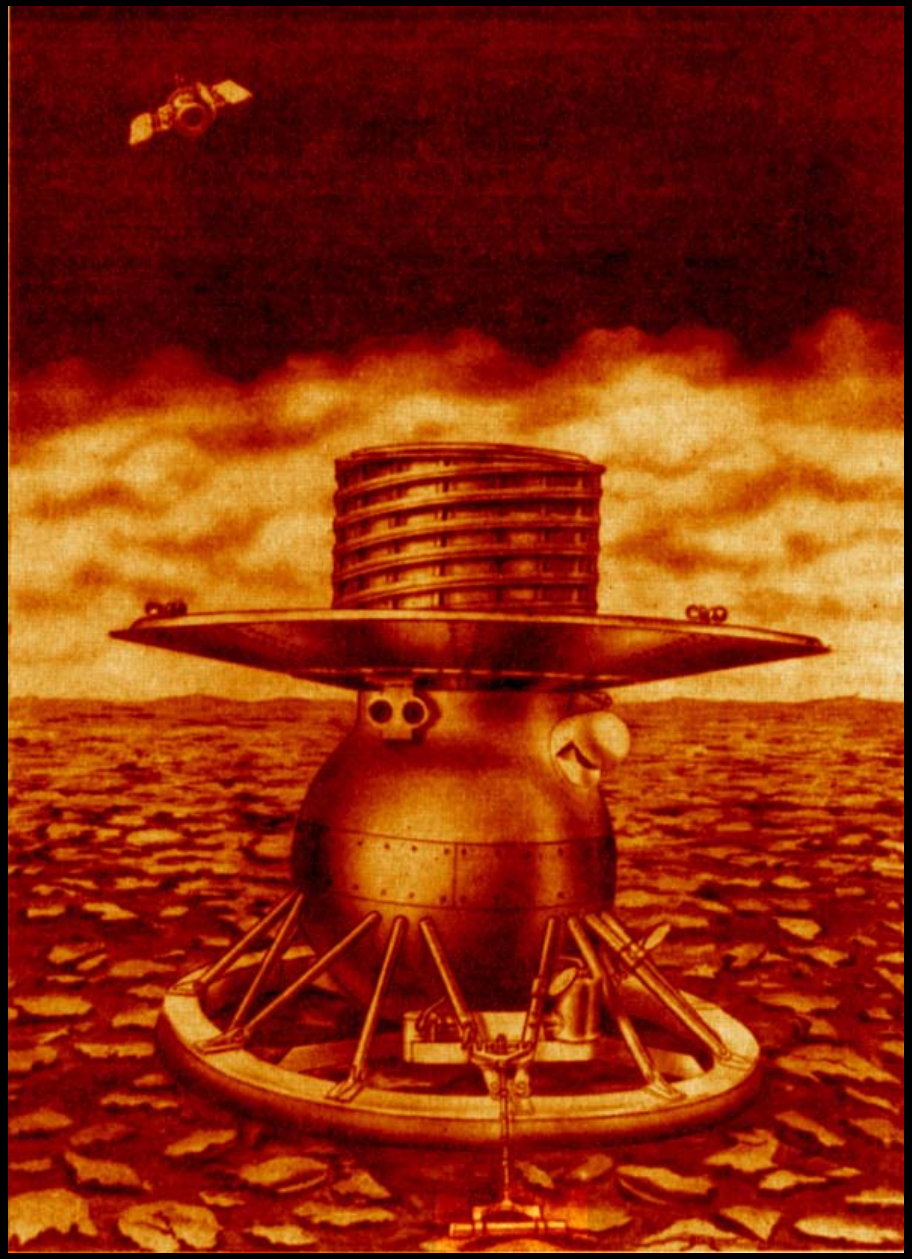
CO_2 (with admixture of N_2) atmosphere, Measurements down to 20 bar level, where it was crashed by the atmosphere pressure

Atmosphere probe

Venera 9, 1975

First TV panoramas from the surface

=> Soil and rocks



First geochemical analysis of the sutface material

=> K, U, Th by gamma spectrometry

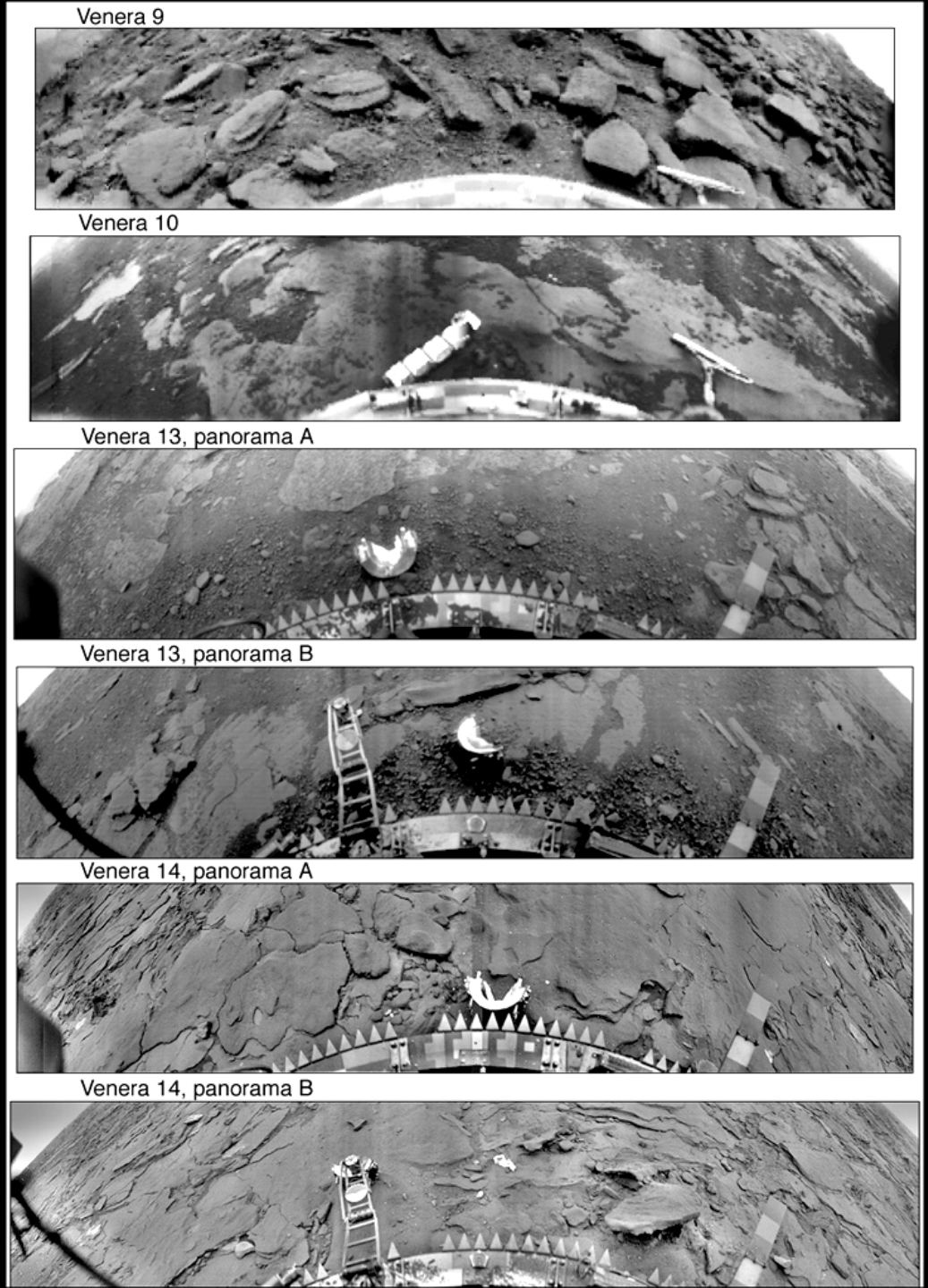
TV panoramas taken by Venera 9, 10, 13 and 14.

Geochemical analyses:

K, U, Th

and

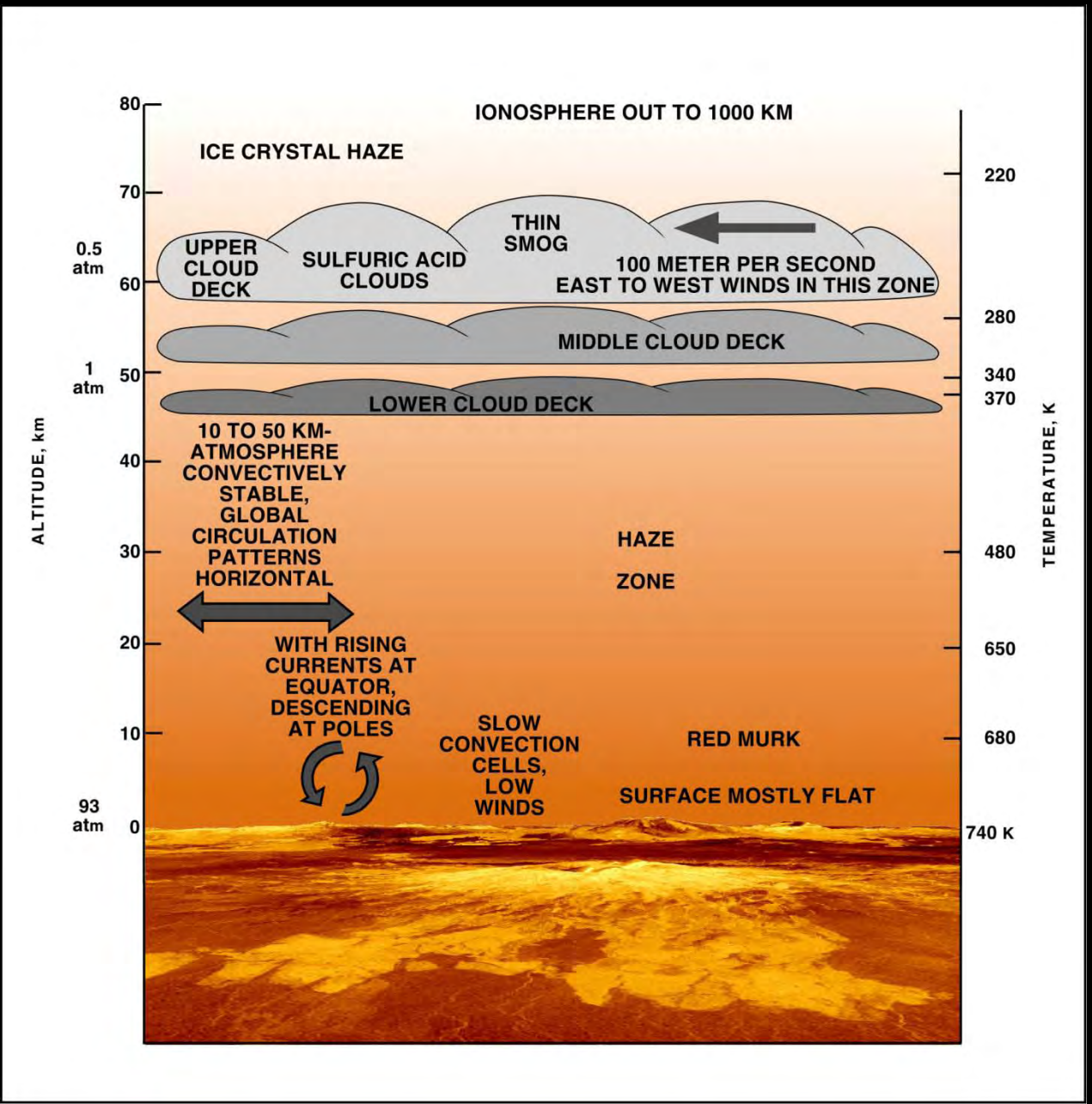
Petrogenic elements
Si, Fe, Al, Ca,…



Venera 13 mosaicing and art by Don Mitchel

Surface is very dark (reflectivity 3-5%) and reddish, sky - orange

Venus atmosphere



P surface = 93 bar
T = 470 C
at 6052 km radius.

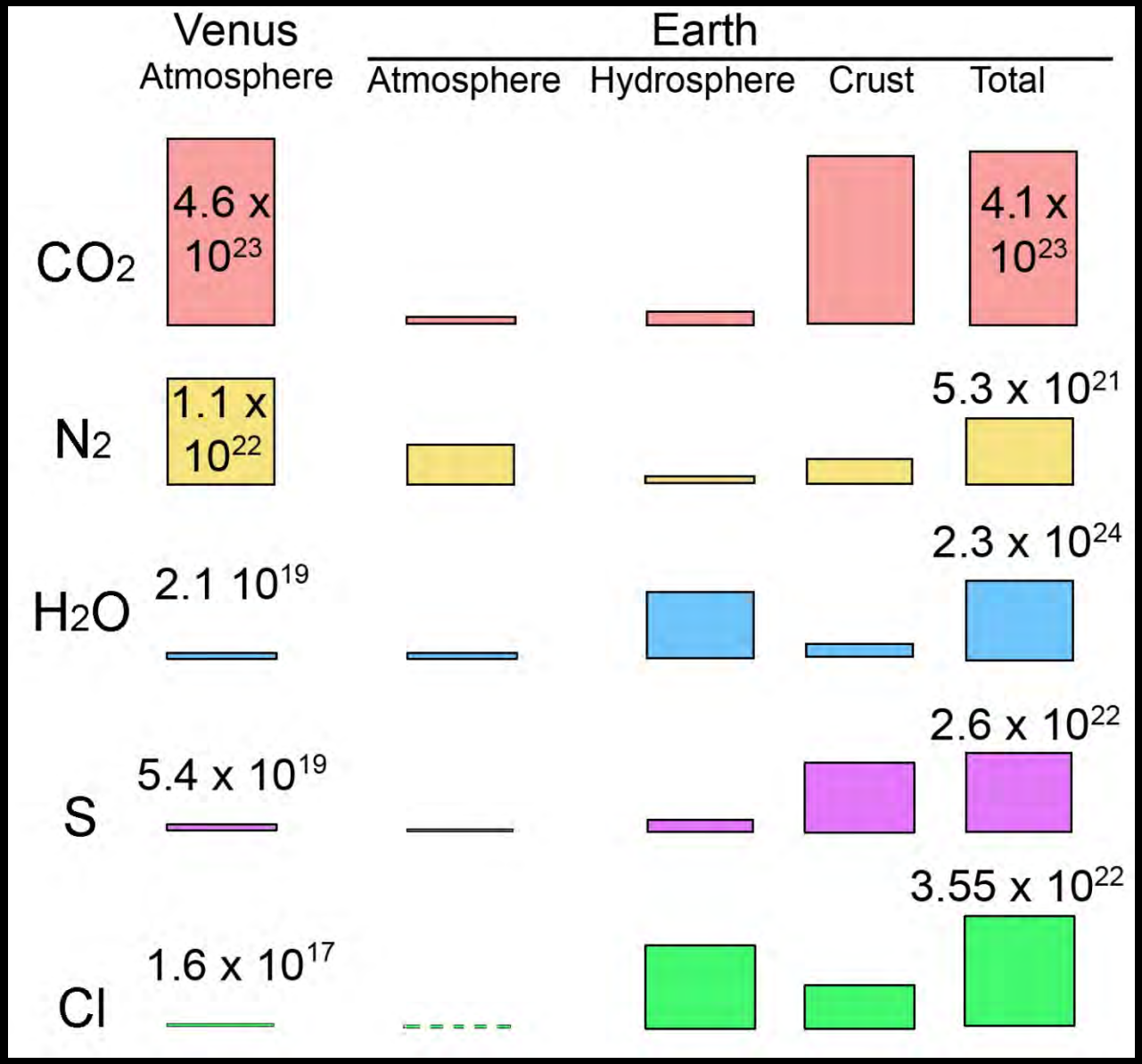
CO_2 major component
N_2 admixture
O_2 and H_2O traces.

Three cloud decks
at 45 – 70 km altitude
Concentraded H_2SO_4.

Strong zonal winds
from E to W ~100 m/s
at the clouds level.

Light from the sky is
orange

Venus atmosphere: Venus v.s. Earth volatile inventories



V ≈ E

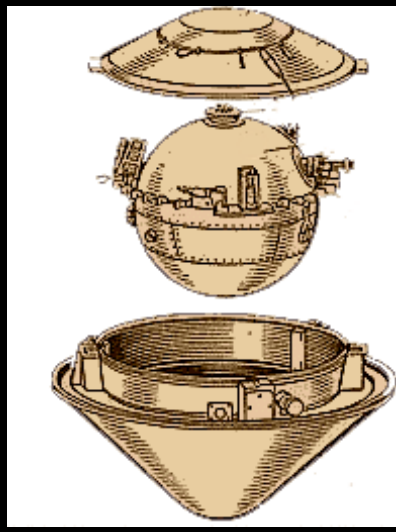
V ≈ E

V << E

V ≈ E?

V ?? E

Venus atmosphere: D/H ratio



Pioneer Venus large probe measurements:

D/H ratio on Venus = 150 x terrestrial ocean.

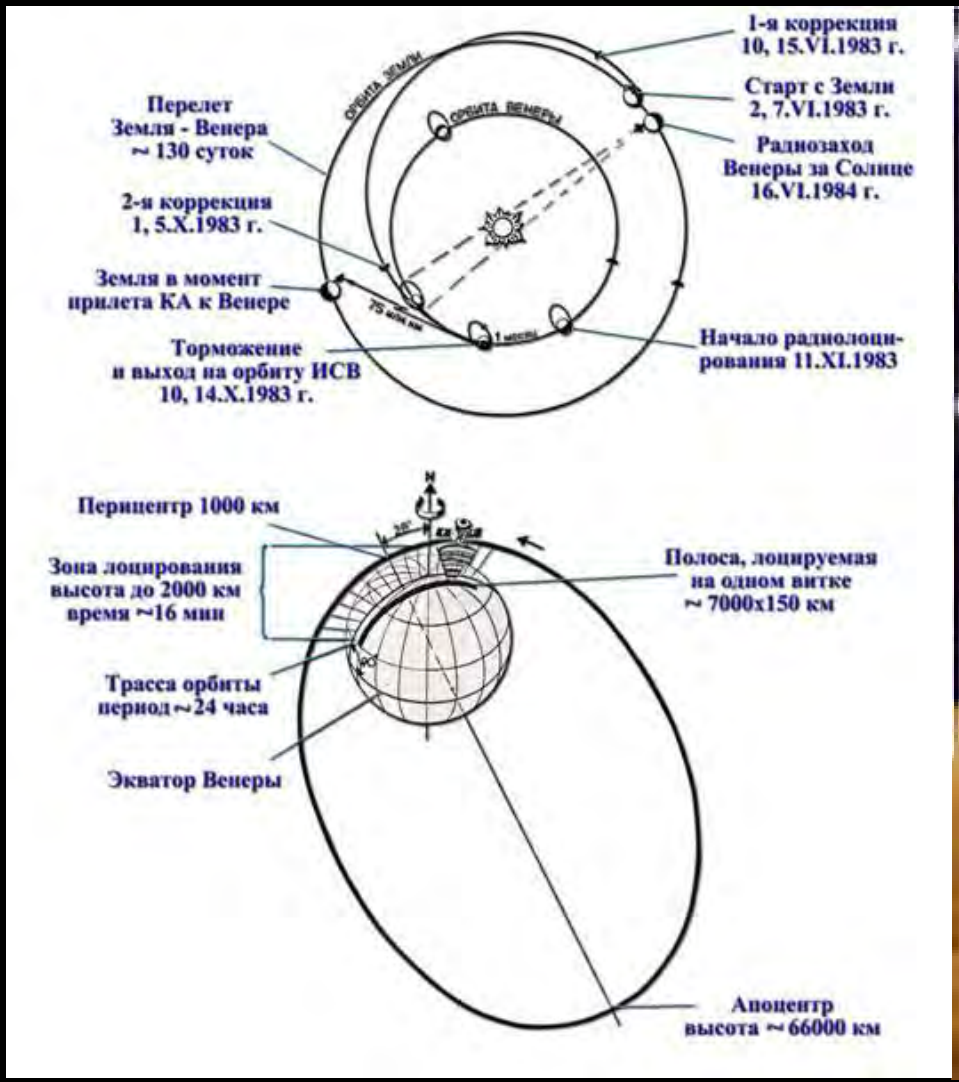
Obviously this is due to ***hydrogen escape*** from atmosphere of Venus.

Model estimates show that original amount of water on Venus was 260 to 7700 times the amount present today.

This is enough to cover the planet with 4 to 115 m of H_2O

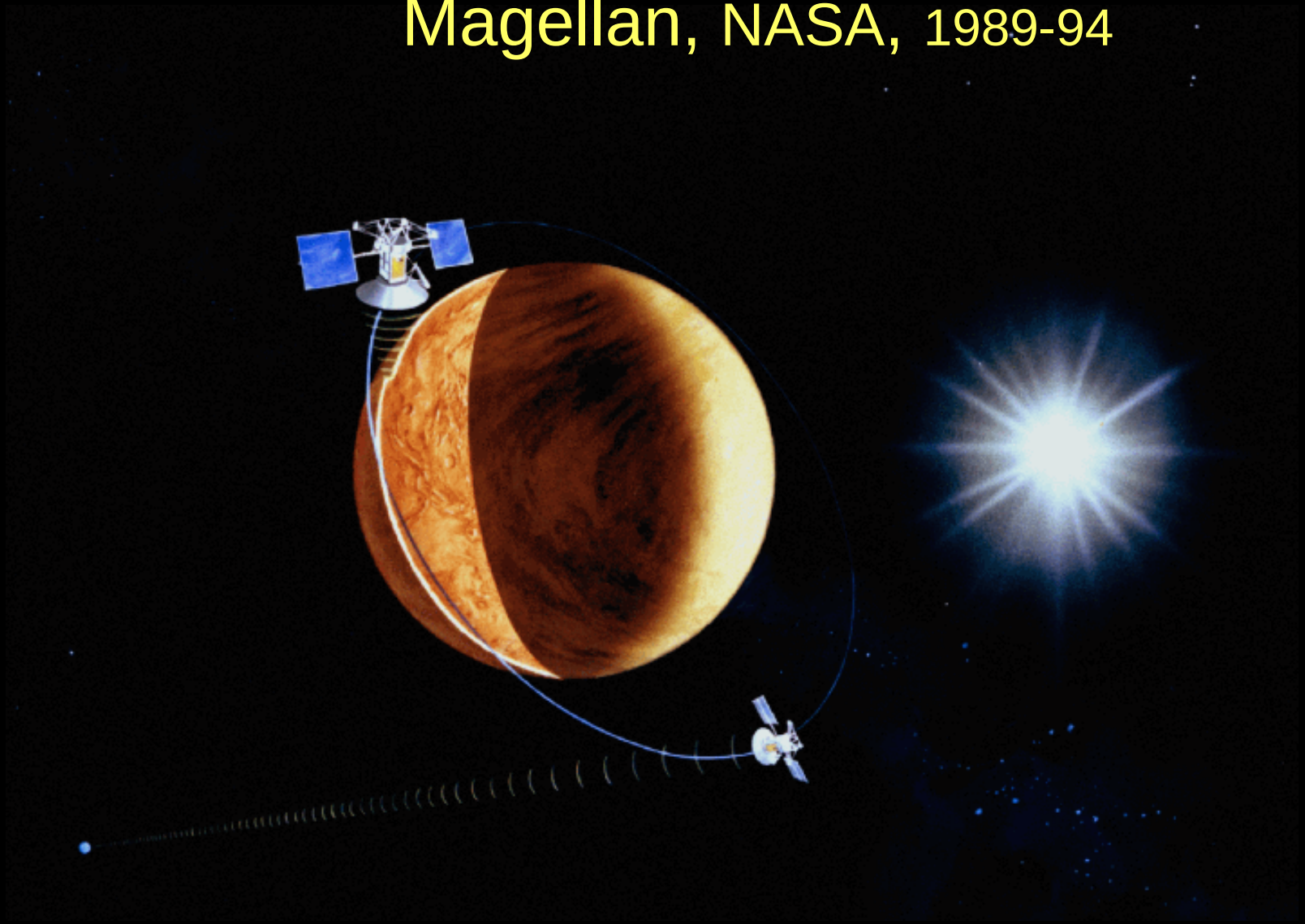
Donahue & Russell, Venus II, 1997

Venera15-16, 1983-84



Side-looking radar imaging of the surface with 1-2 km resolution.
Radar altimetry.

Magellan, NASA, 1989-94



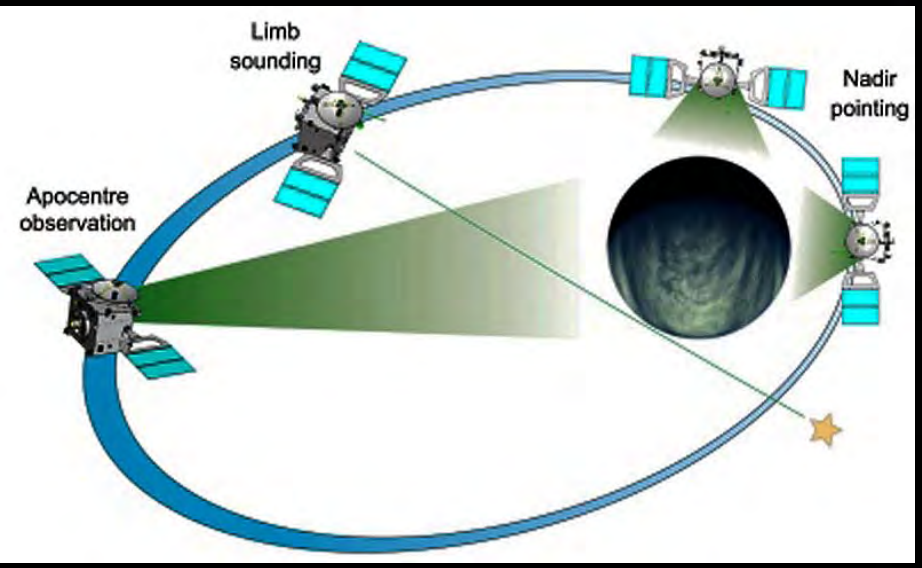
Side-looking radar imaging of the surface from the polar orbit with 100-200 m resolution. Radar altimetry

Venus Express

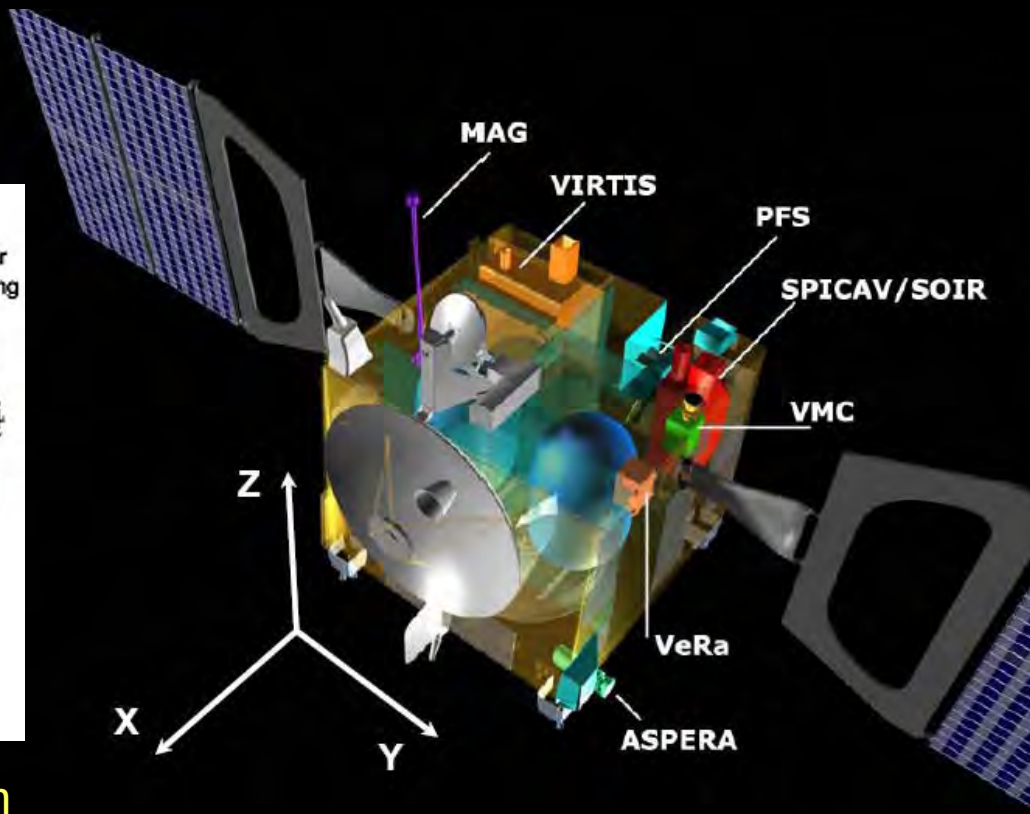
ESA mission to Venus, 2005 - 2014

Venus Express is a satellite optimized for studying the atmosphere of Venus, from the surface right up to the ionosphere.

Two IR spectrometers can observe the planet surface



24-h orbit elliptical, 250 km x 66 000 km



Venus Express payload

- **VIRTIS** (P. Drossart, G. Piccioni) - UV-vis-near IR imaging and high resolution spectrometer **(IPF/ DLR, MPS)**
- **SPICAV / SOIR** (J.-L. Bertaux, O. Korablev, P. Simon) -UV & IR spectrometer for solar/stellar occultations and nadir observations
- **PFS** (V. Formisano) - high resolution IR Fourier spectrometer **(IPF/ DLR)**
- **VMC** (W.J. Markiewicz) - Venus Monitoring Camera **(MPS, IPF/ DLR, IDA/ TU-BS)**
- **VeRa** (B. Häusler, M.Pätzold) - radio science experiment (Uni Bundeswehr, Uni Koeln)
- **ASPERA** (S. Barabash) - Analyzer of Space Plasmas and Energetic Atoms (IRF, MPS)
- **MAG** (T. Zhang) – Magnetometer (TU-BS)

Проект ВЕНЕРА Д –Федеральная Космическая Программа России

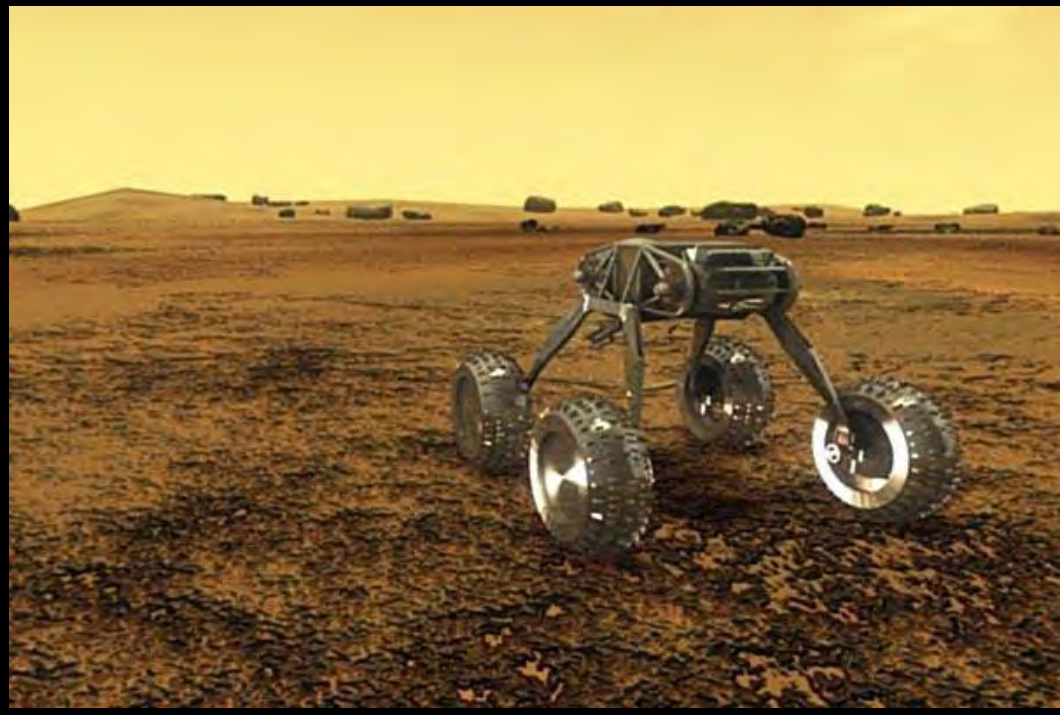
Venera D

Orbiter
Landers
Balloon(s)

Launch in 2020s' ???

Other proposals

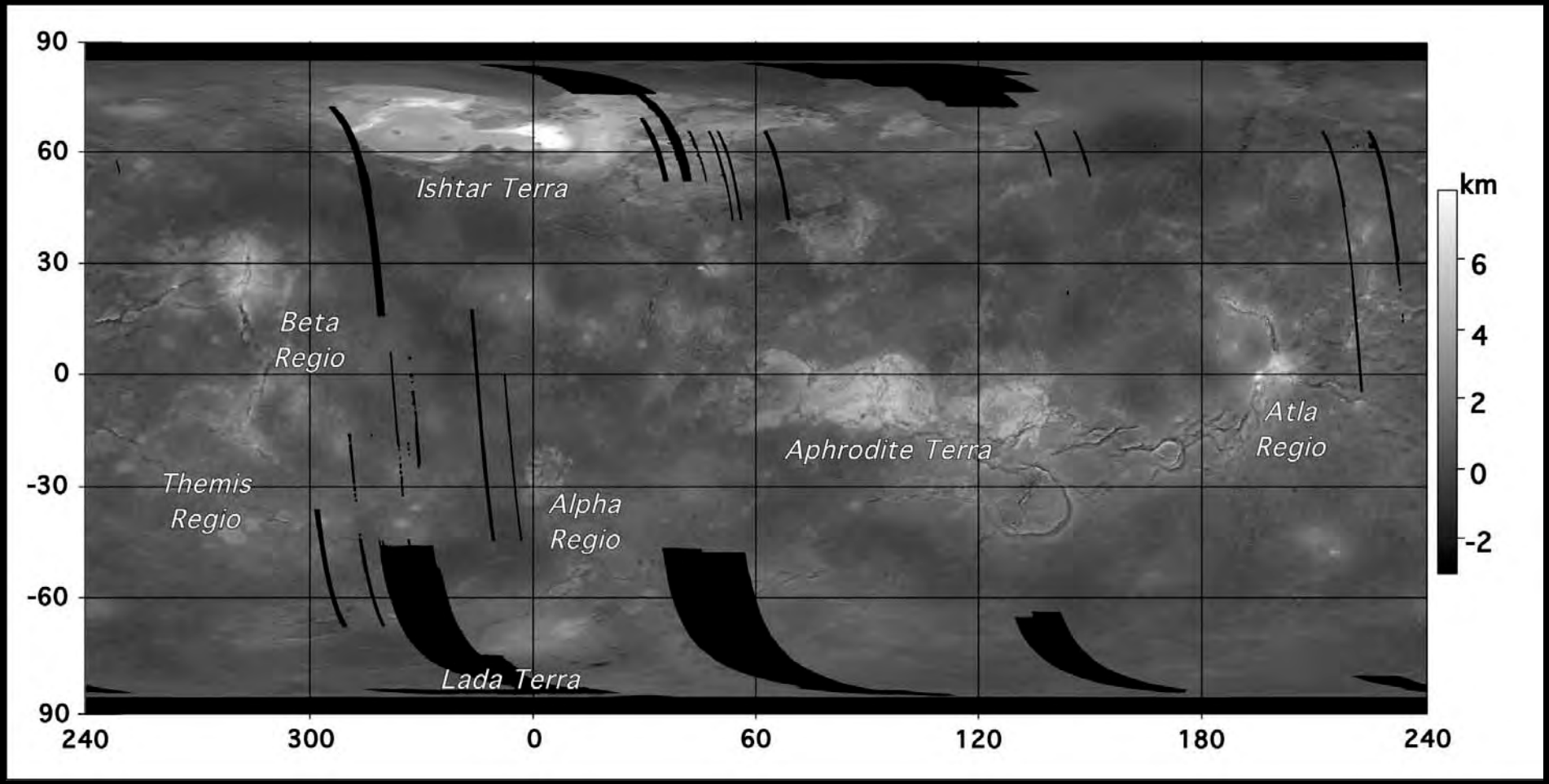
Venus In-Situ Explorer (VISE)
NASA's New Frontiers program.
Balloon, which from time to time comes to the surface. Makes observations and goes up
For cooling



Geoffrey Landis and Kenneth Mellott
NASA's Glenn Research Center.
Electronics wirks at 200ºC.
Permanently being cooled using energy of small nuclear reactor.

Magellan SAR map

Simple cylindrical projection



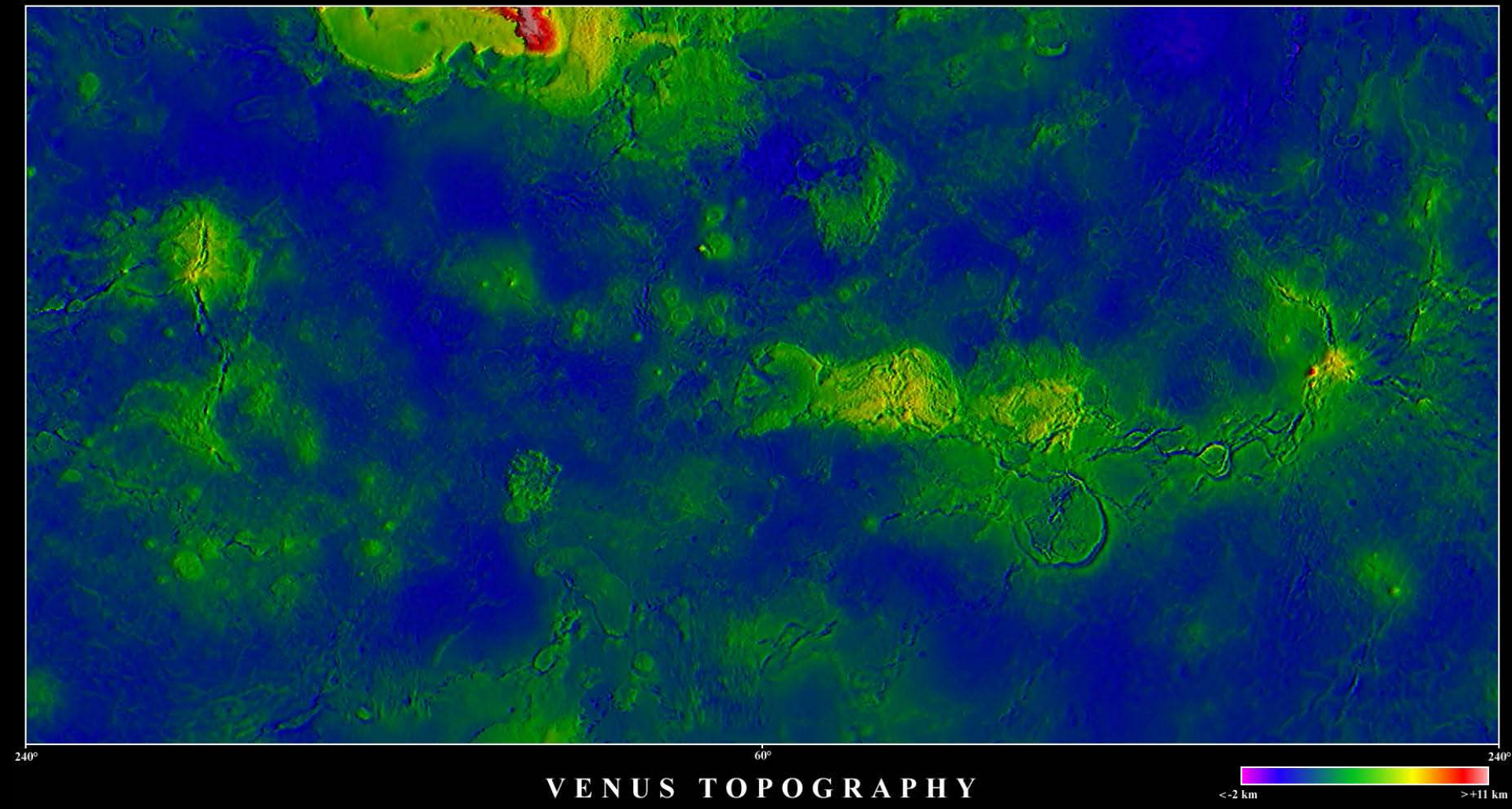
Dark – relatively smooth surface

Bright – rough surface

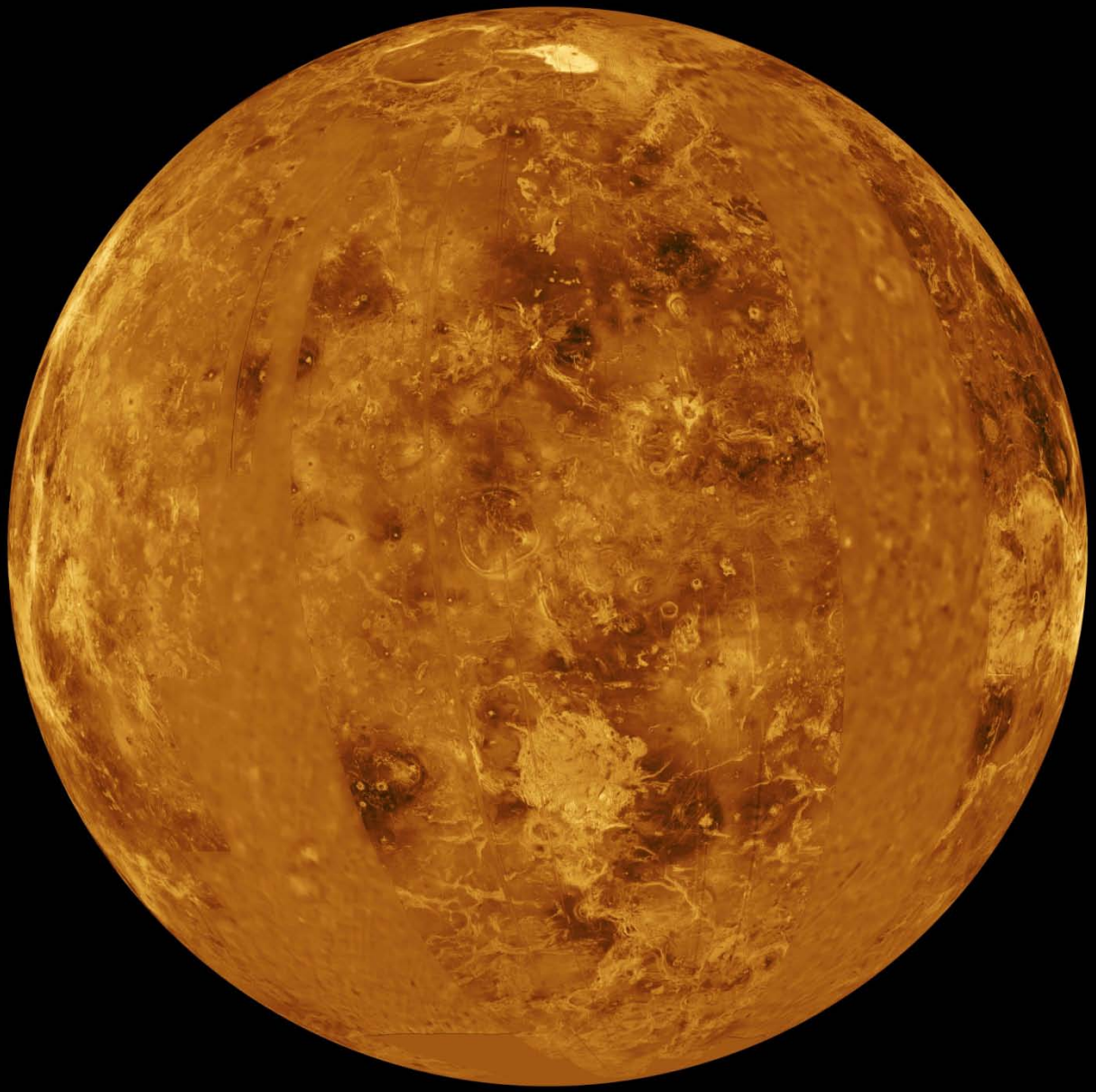
Very bright – rough and very reflective surface

Magellan topography map

Mercator projection

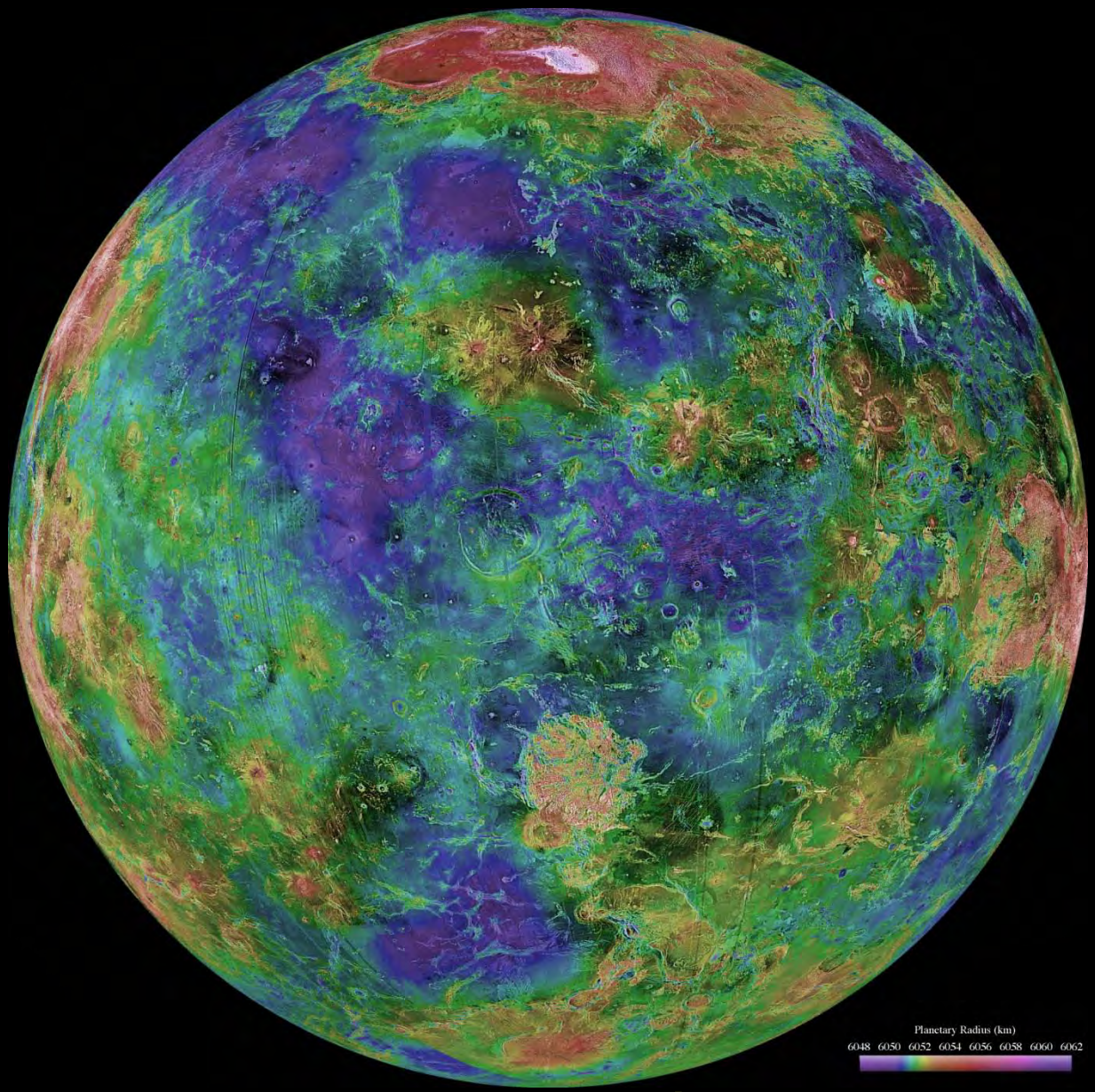


Venus hemisphere centered at 0 deg longitude



Radar backscatter

Venus hemisphere centered at 0 deg longitude

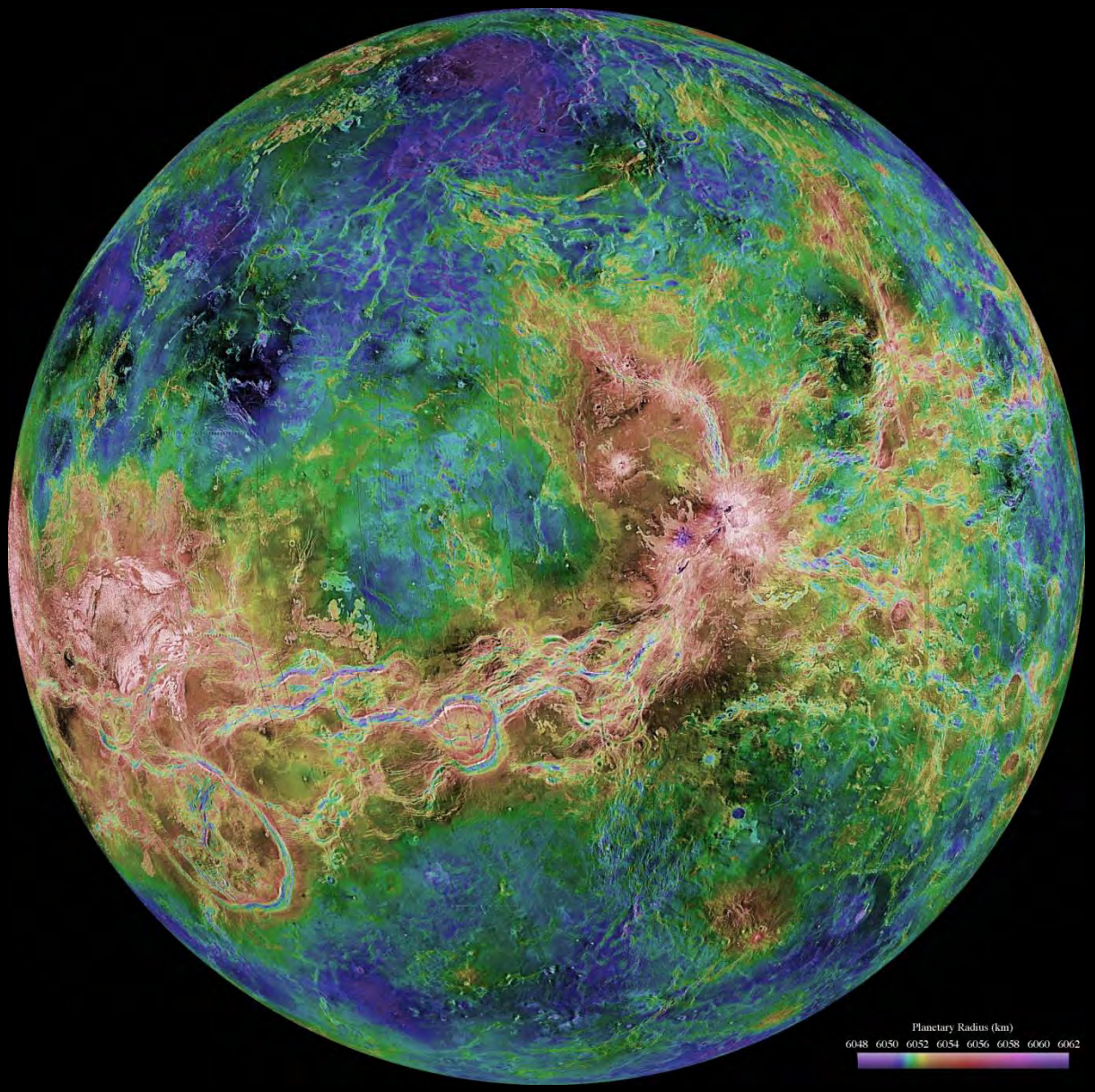


Topography

Venus hemisphere centered at 270 deg longitude

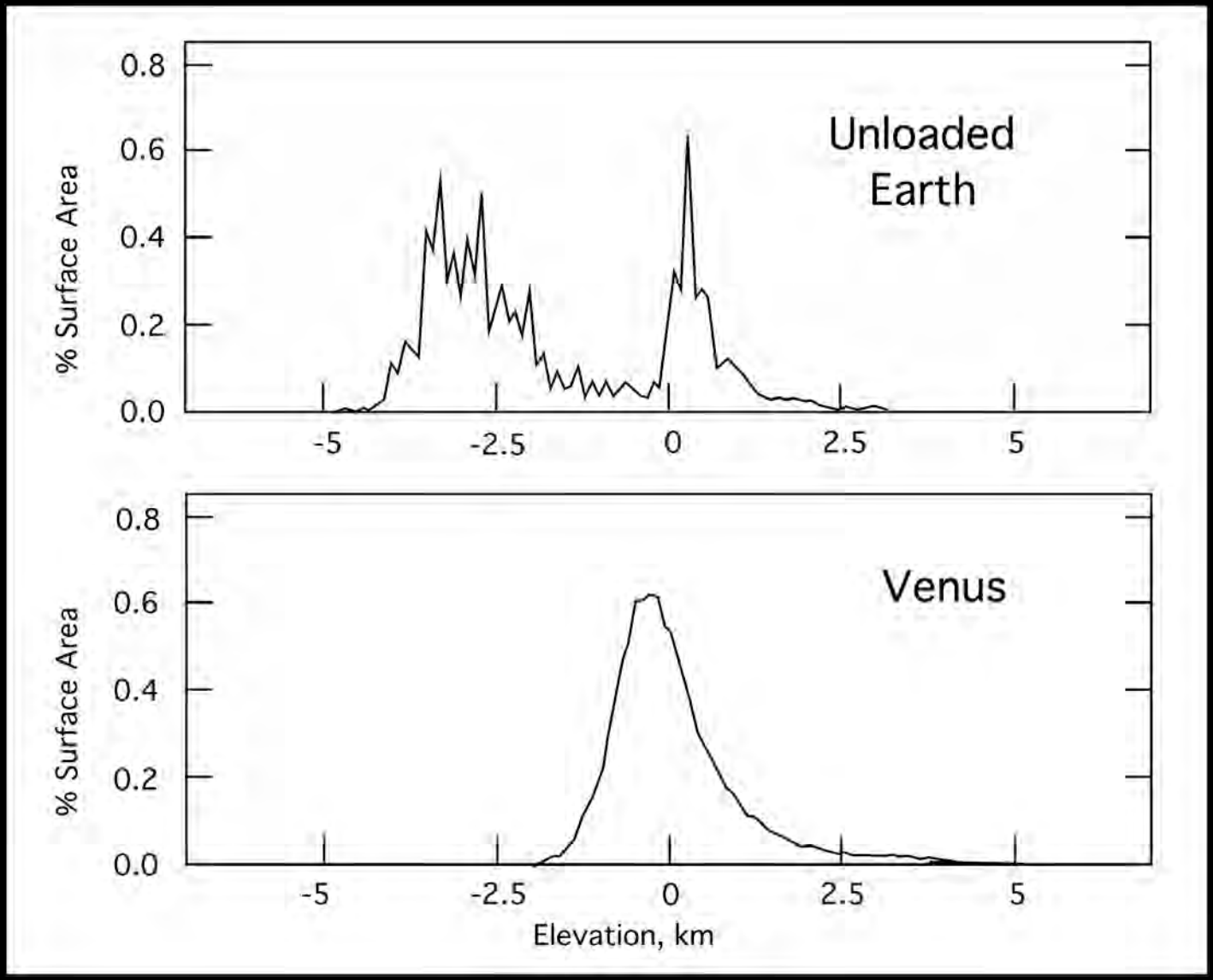
Radar backscatter

Venus hemisphere centered at 270 deg longitude



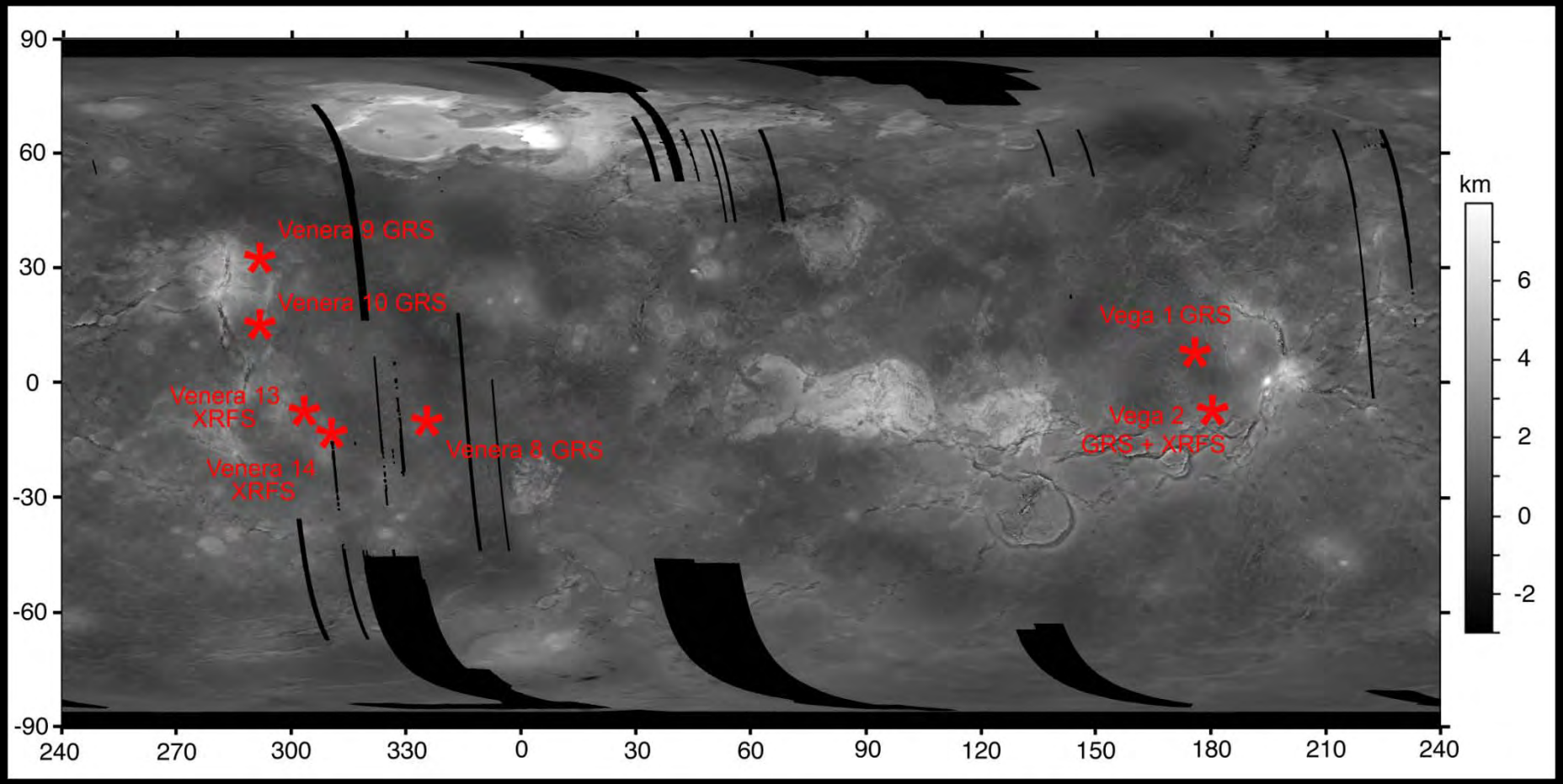
Topography

Hypsometric curves for Earth and Venus



Two types of crust on Earth, one type on Venus?

Venera - Vega *in situ* measurements:



In situ measurements in 7 sites:

Venera 8, 9, 10, Vega 1 => GRS => K, U, Th

Venera 13, 14 => XRFS => Major elements

Vega 2 => GRS + XRFS => K, U, Th + Major elements

Venera - Vega *in situ* measurements:

Venera 13, 14, Vega 2 X-ray fluorescence spectrometry

Oxide	Venera 13	Venera 14	Vega 2
SiO_2	45.1 ± 3.0	48.7 ± 3.6	45.6 ± 3.2
TiO_2	1.59 ± 0.45	1.25 ± 0.41	0.2 ± 0.1
Al_2O_3	15.8 ± 3.0	17.9 ± 2.6	16.0 ± 1.8
FeO	9.3 ± 2.2	8.8 ± 1.8	7.74 ± 1.1
MnO	0.2 ± 0.1	0.16 ± 0.08	0.14 ± 0.12
MgO	11.4 ± 3.0	8.1 ± 3.3	11.5 ± 3.7
CaO	7.1 ± 0.96	10.3 ± 1.2	7.5 ± 0.7
K_2O	4.0 ± 0.63	0.2 ± 0.07	0.1 ± 0.08
S	0.65 ± 0.4	0.35 ± 0.31	1.9 ± 0.6
Cl	<0.3	<0.4	<0.3

Mafic (basaltic) compositions

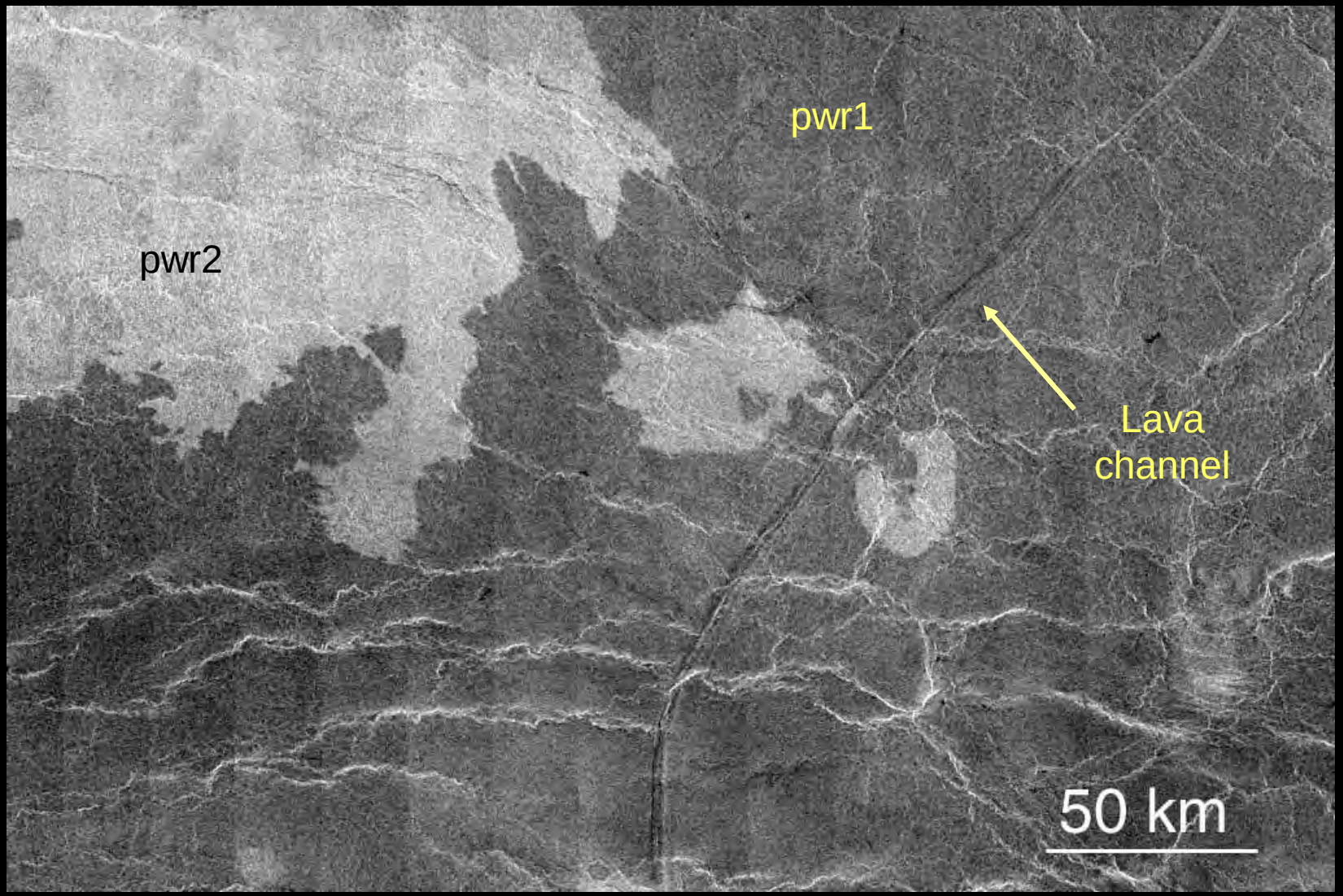
Venera - Vega *in situ* measurements:

Venera 8, 9, 10, Vega 1, 2 gamma-ray spectrometry

Element	Venera 8	Venera 9	Venera 10	Vega 1	Vega 2
K %	4.0 ± 1.2	0.5 ± 0.1	0.3 ± 0.2	0.45 ± 0.22	0.40 ± 0.20
U ppm	2.2 ± 0.7	0.6 ± 0.2	0.5 ± 0.3	0.64 ± 0.47	0.68 ± 0.38
Th ppm	6.5 ± 0.2	3.7 ± 0.4	0.7 ± 0.3	1.5 ± 1.2	2.0 ± 1.0

“Basaltic” range of K, U, Th contents

Plains with wrinkle ridges (pwr)

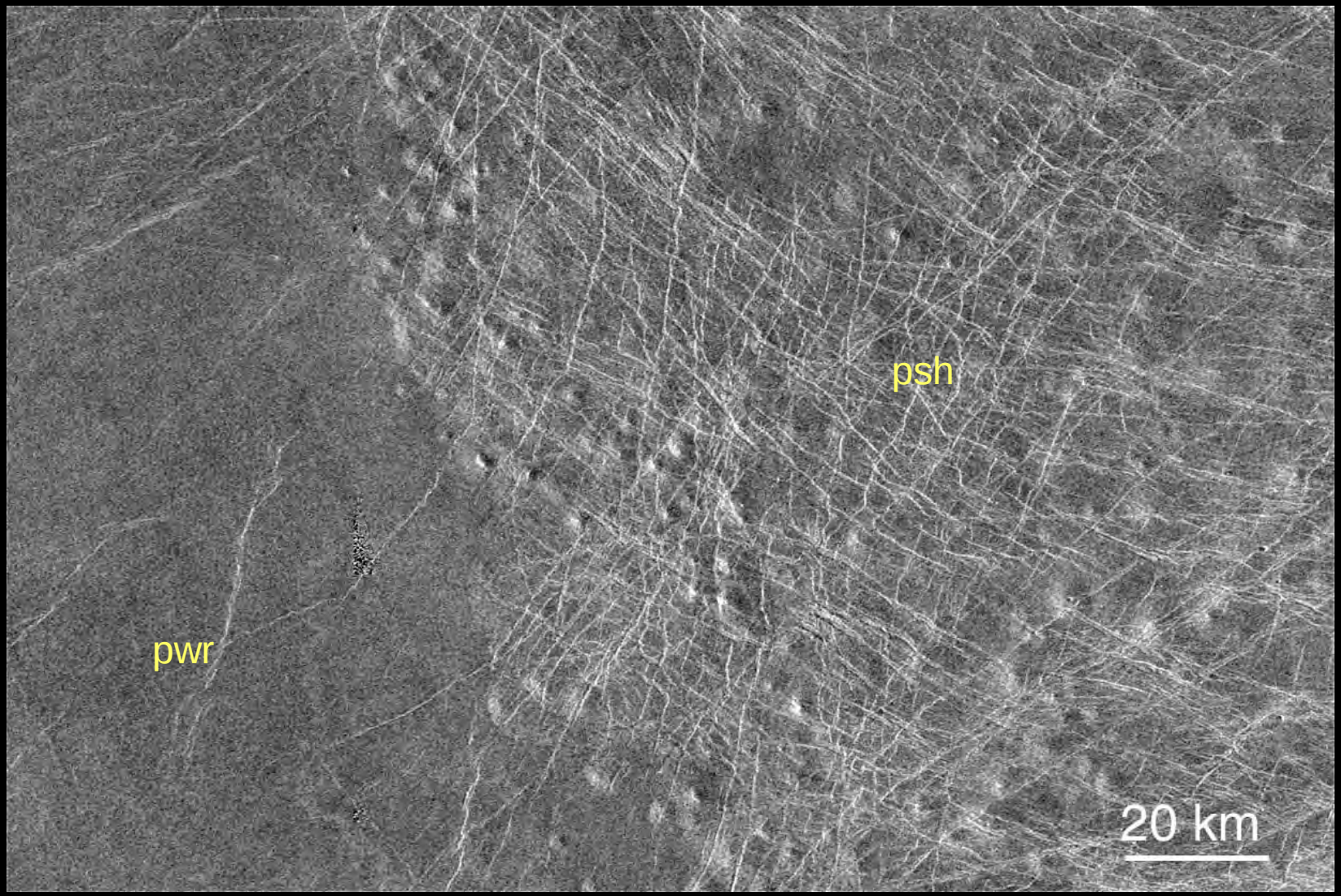


Volcanic lava flows, younger are radar bright = more rough (aa).
All deformed by wrinkle ridges (compressional structures).

Hawaii, aa and pahoehoe lavas

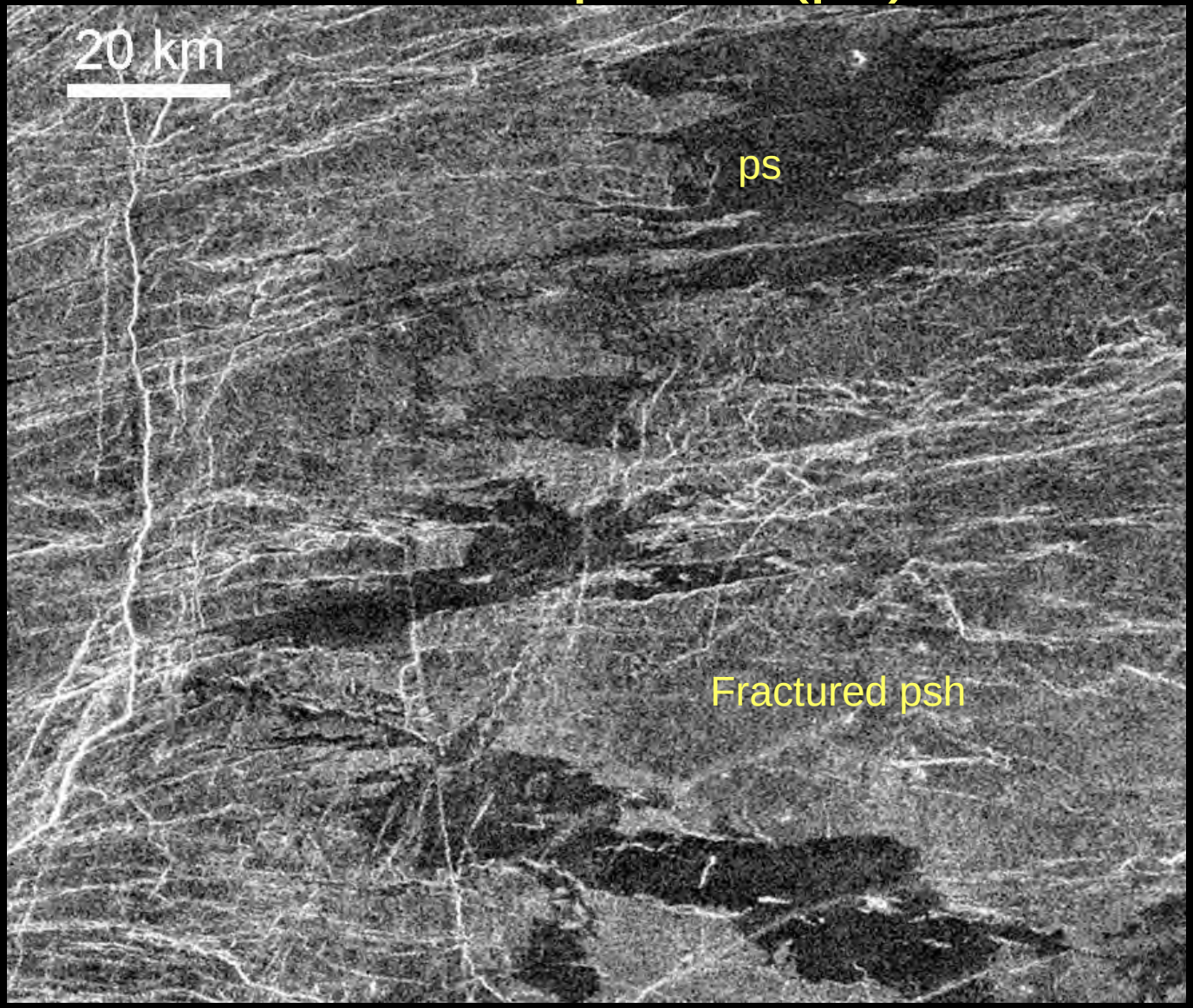
Aa lava is bright in side-looking radar, pahoehoe is darker

Shield plains (psh)



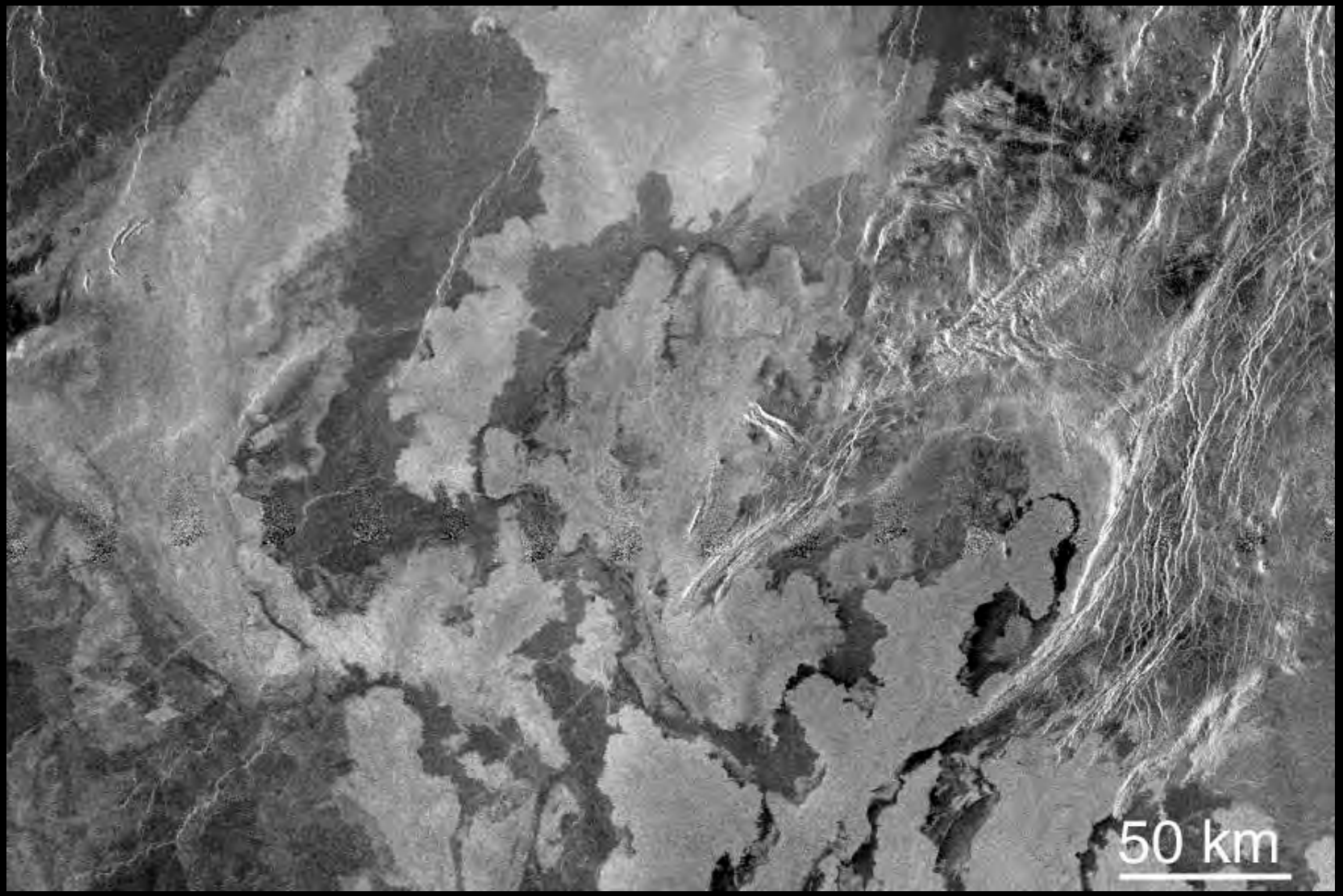
Volcanic shields with gentle (3-5 deg) slopes
embayed by plains with wrinkle ridges

Smooth plains (ps)



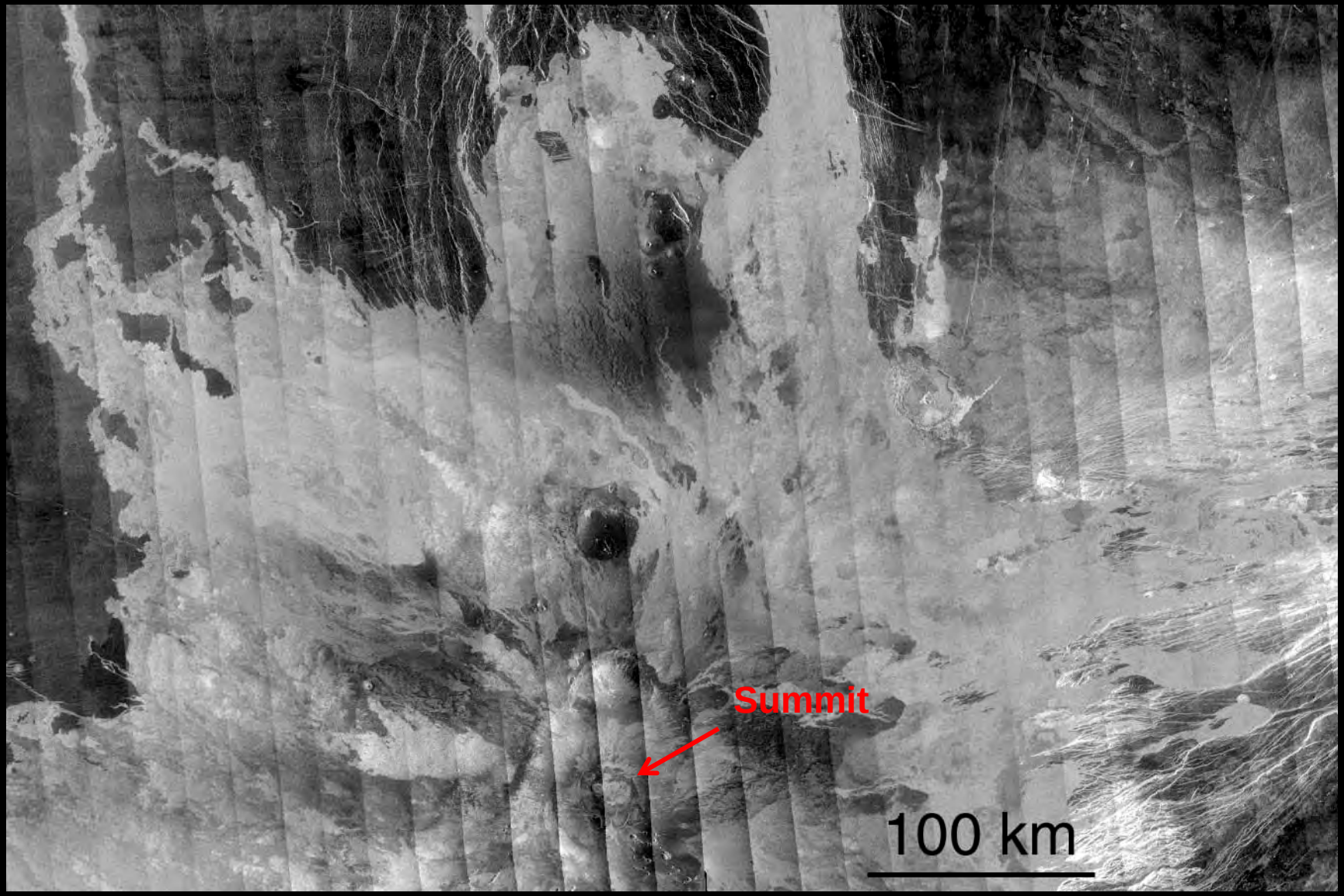
Ps plains are typically radar dark = smooth surface
Intrude in narrow depressions = very non-viscous

Lobate plains (pl)



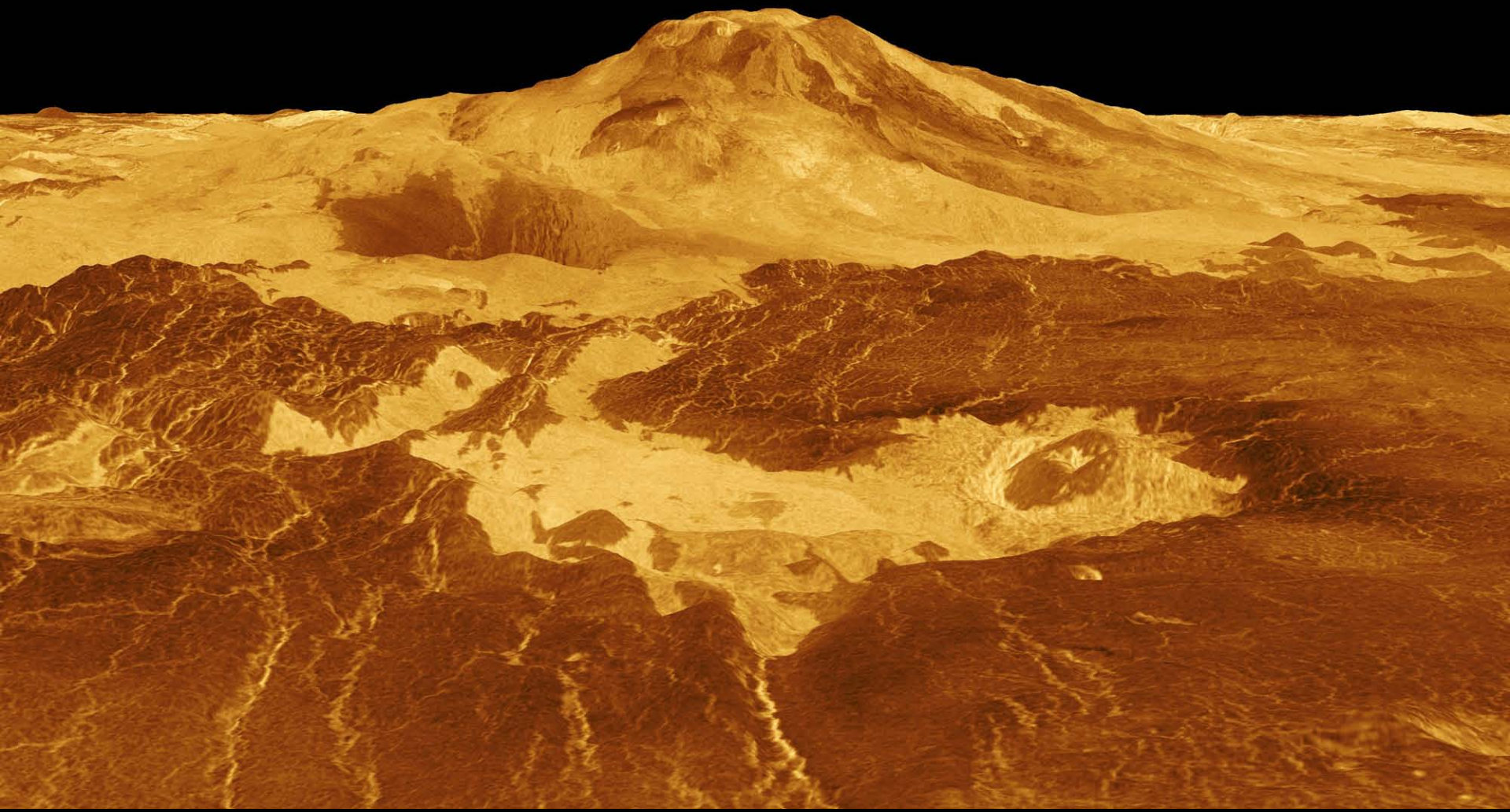
Volcanic flows with rather rough (aa) surface,
Superposed on plains with wrinkle ridges and shield plains

Maat Mons volcano – highest on Venus (+9 km)



Maat slopes are covered by radar bright lobate flows superposed on surrounding plains with wrinkle ridges

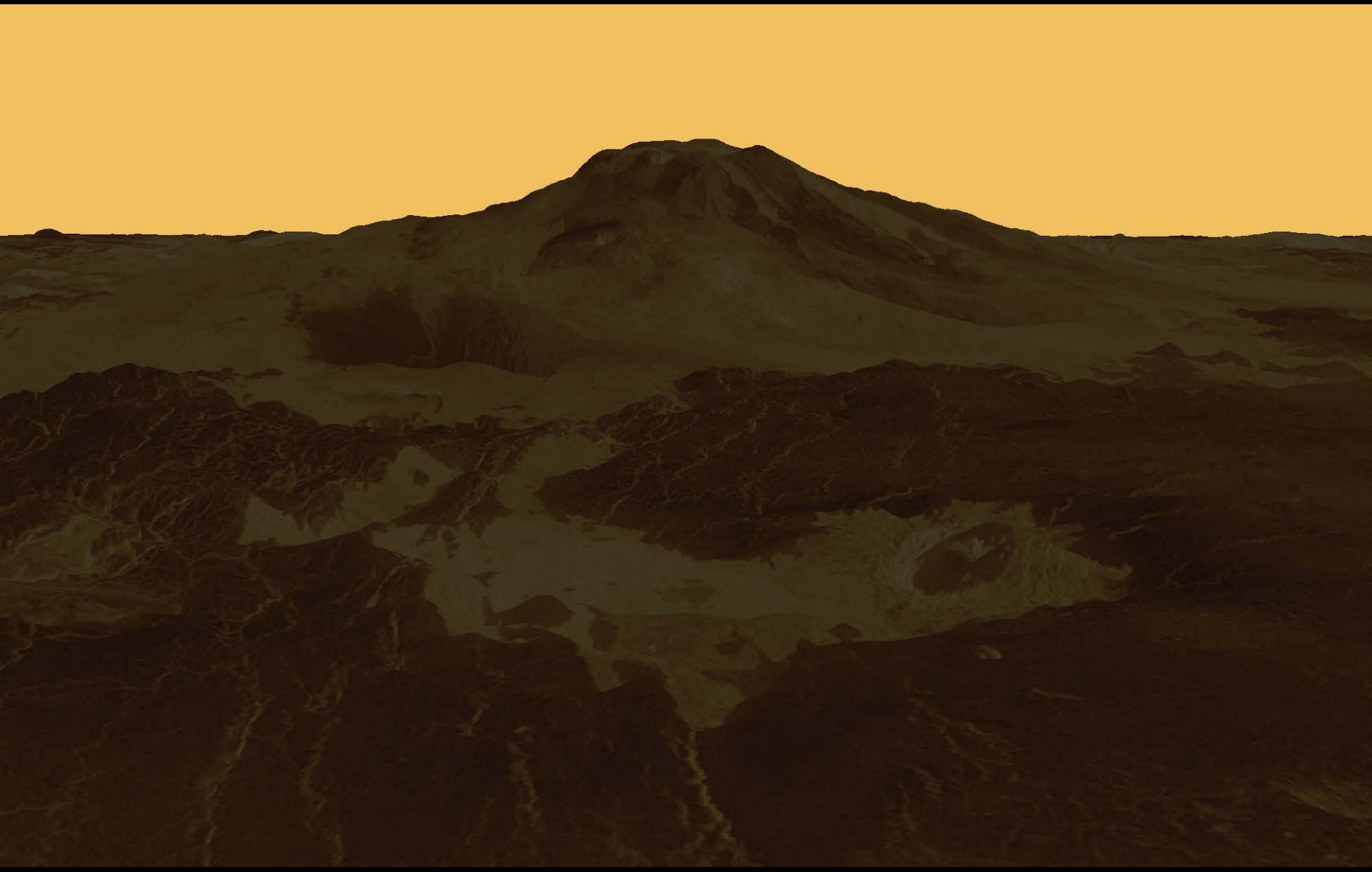
Maat Mons volcano – perspective view



Three unrealistic things:

Surface brighter than sky
Radar bright is not visually bright
About 20 : 1 vertical exaggeration

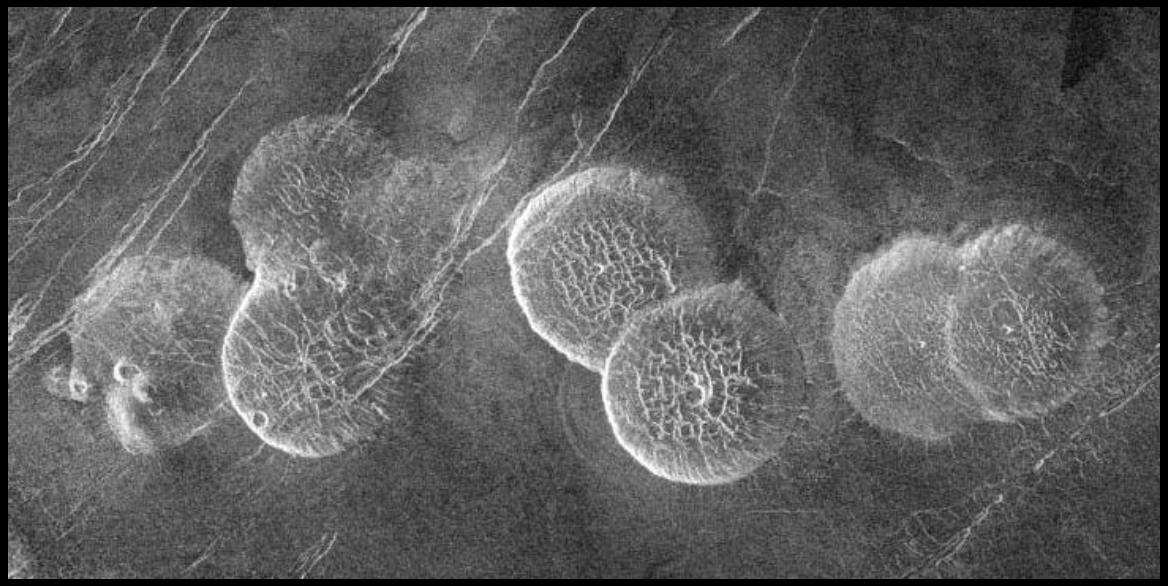
Maat Mons volcano – “real” illumination



Maat Mons volcano – “real” illumination
No vertical exaggaration

Mauna Loa basaltic shield volcano, Hawaii

Rare type of volcanic constructs: steep-sided domes



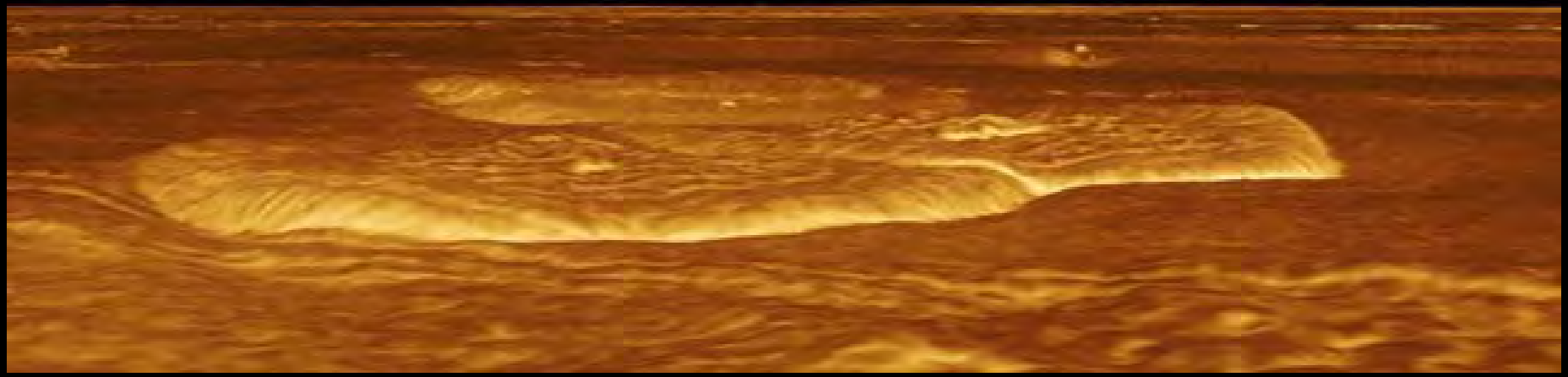
Tens km in diameter,
Hundreds meters high,
Steep-sided:

=> Viscous lavas

=> **Evolved composition e.g. dacites?**

or

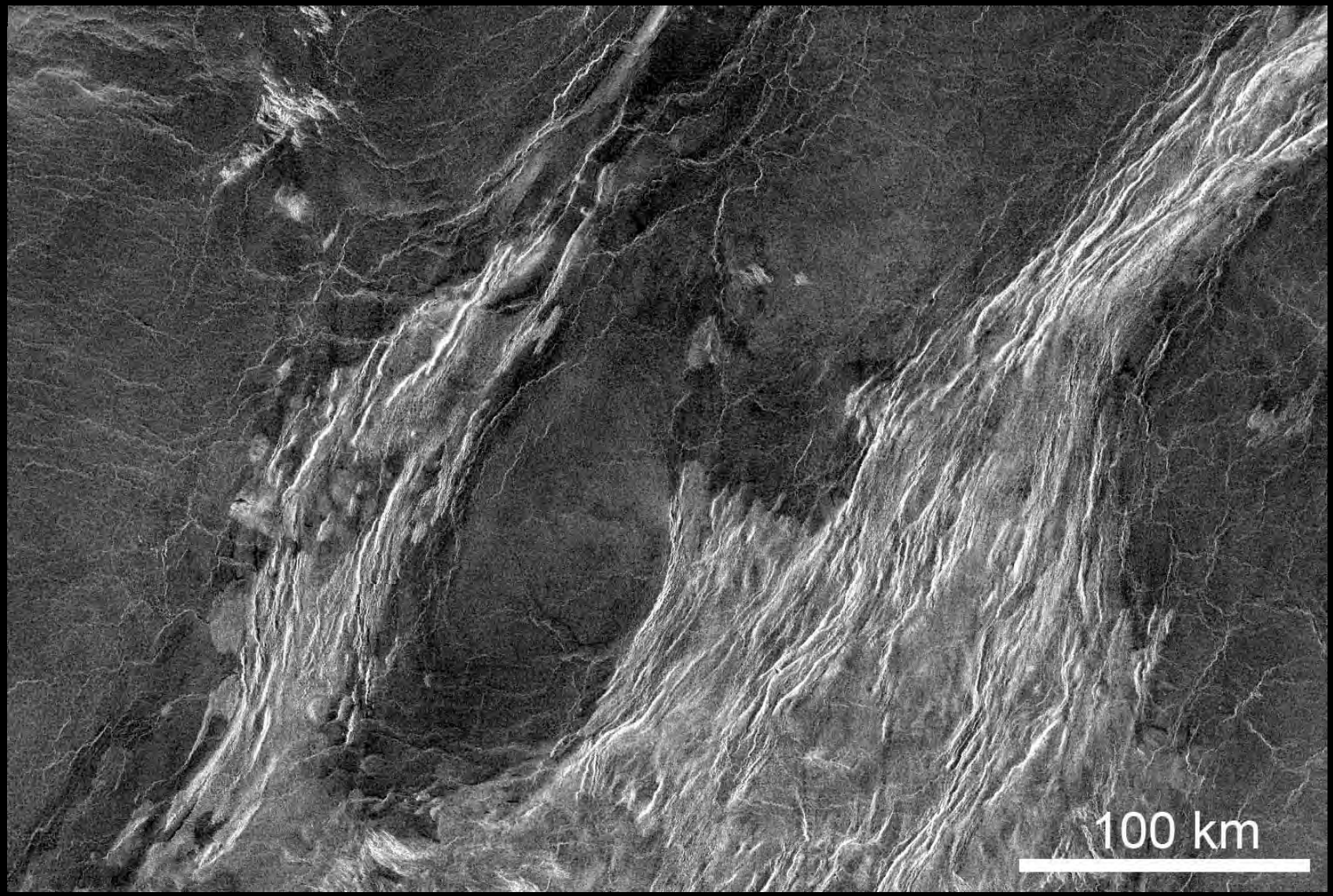
=> **Basalt with gas bubbles?**



Lava dome of Novarupta, Katmai, Alaska

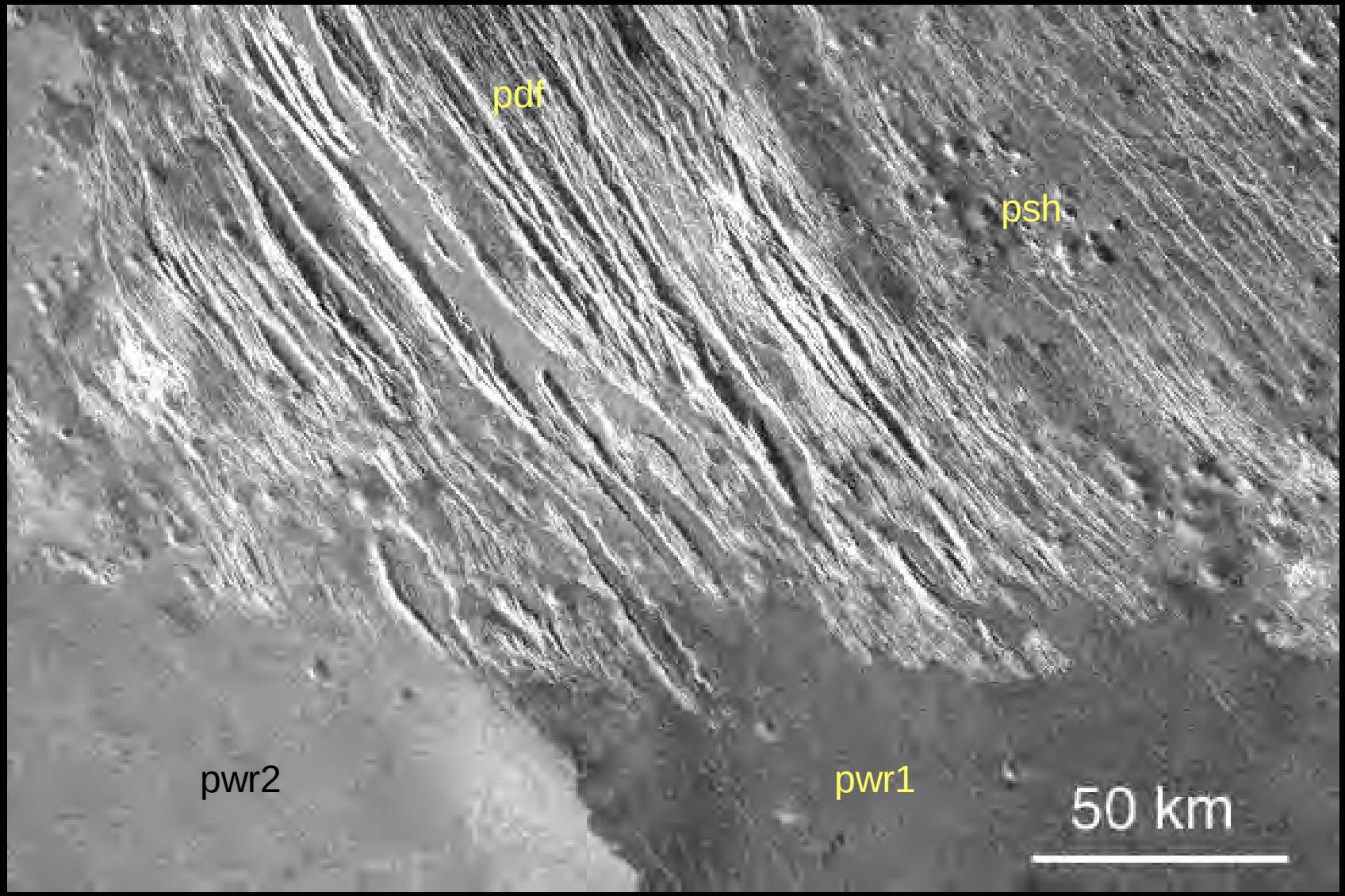
Viscous (siliceous) lavas form steep-sided domes

Ridge belts (RB, pfr)



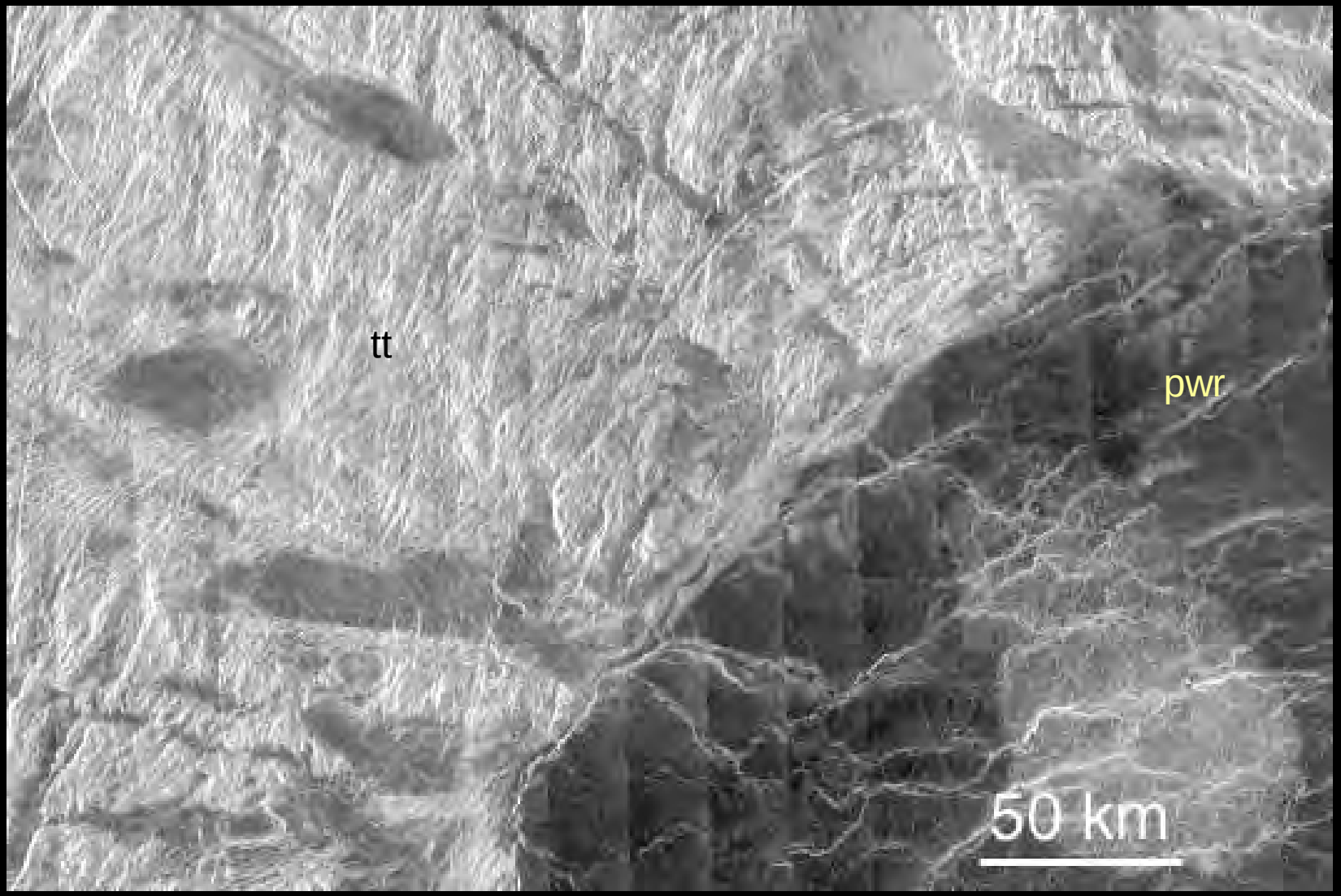
Volcanic (?) plains material deformed into relatively broad ridges thus forming Ridge Belts, embayed by plains with wrinkle ridges

Densely fractured plains (pdf)



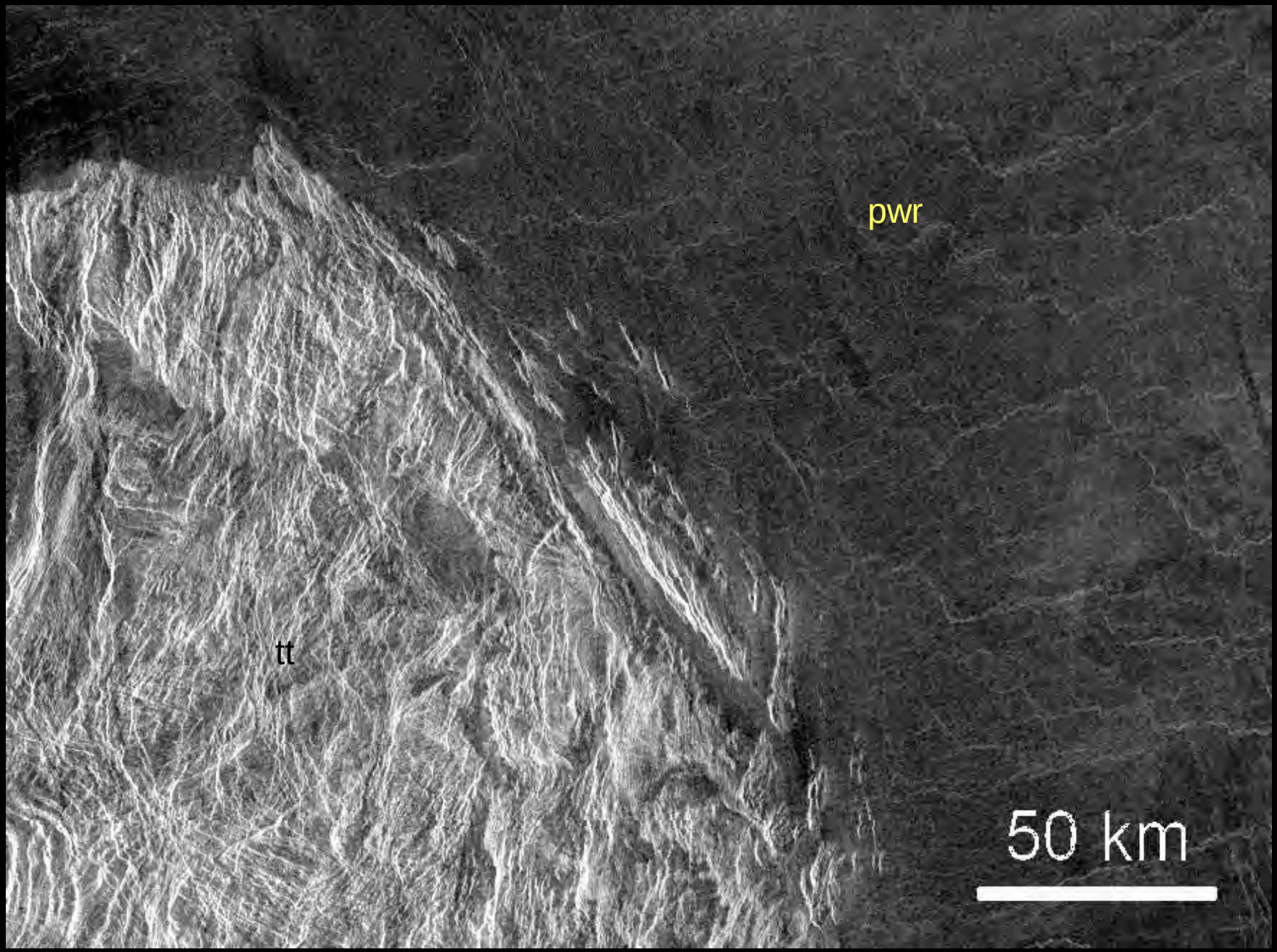
Volcanic (?) plains material densely fractured and embayed by shield plains (psh) and plains with wrinkle ridges (pwr)

Tessera terrain (tt)

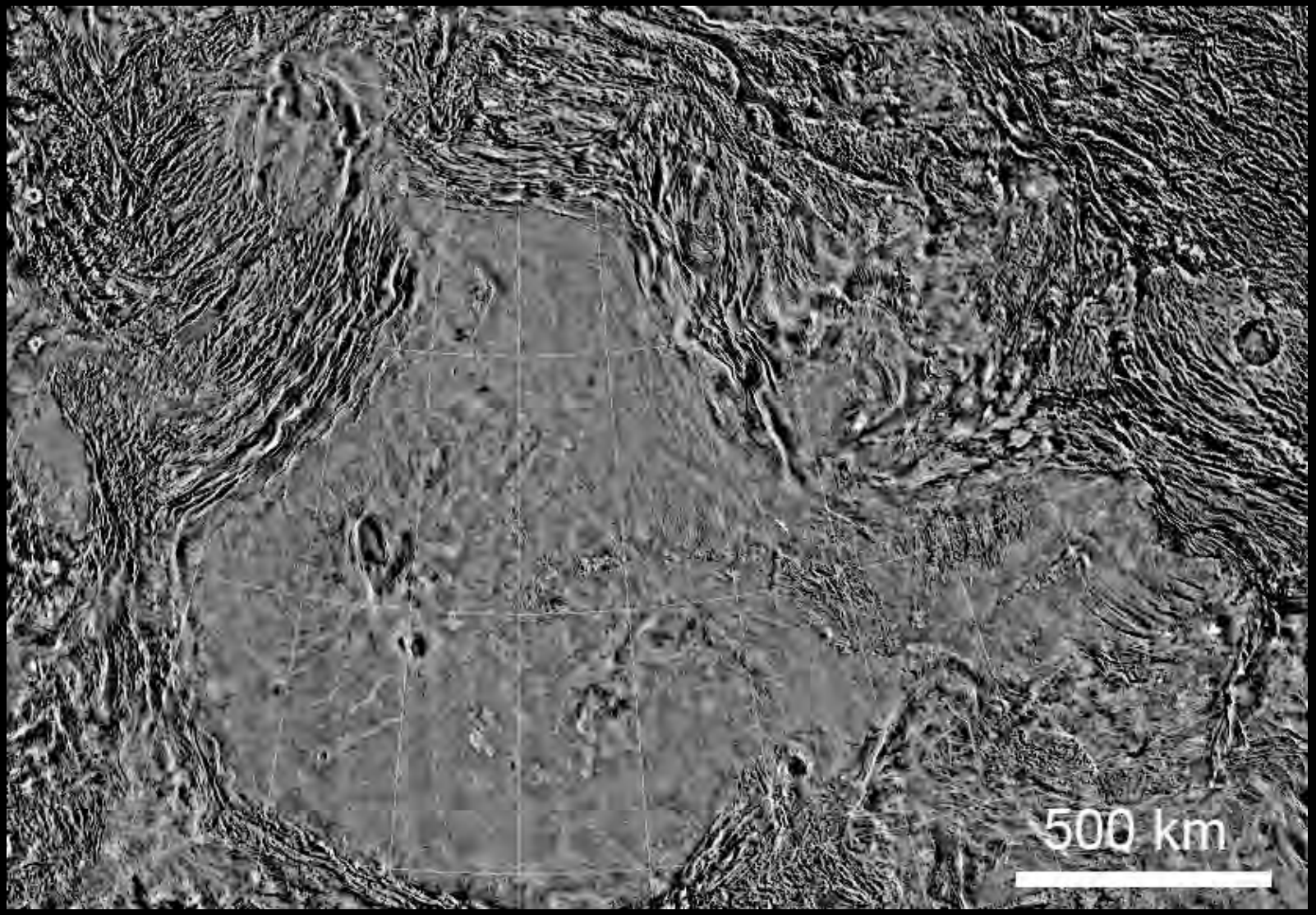


Highly deformed (compressional ridges + extensional grooves) material of unknown origin with radar bright = rough surface

Another example of tessera terrain (tt)

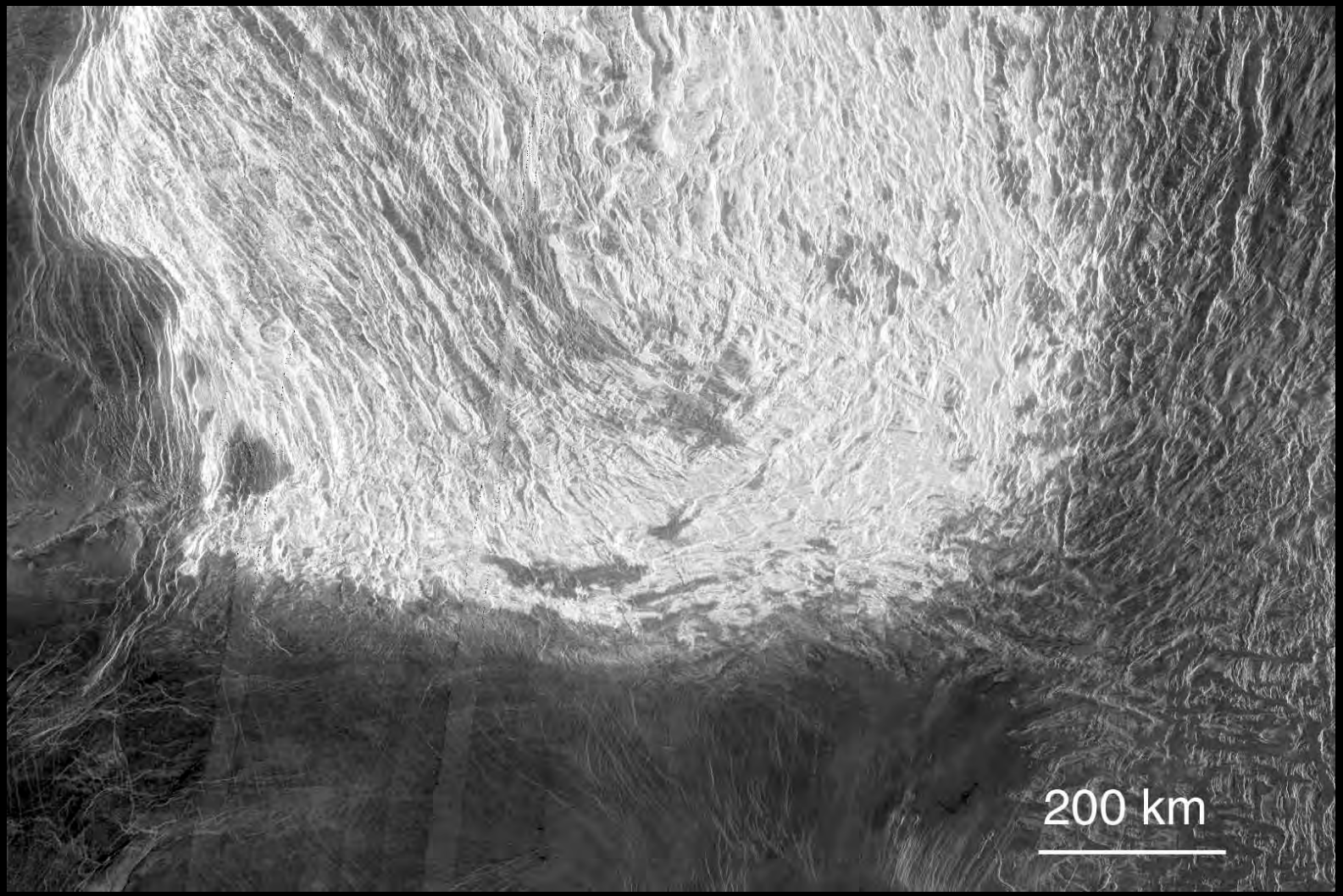


Plateau Lakshmi and mountain belts around



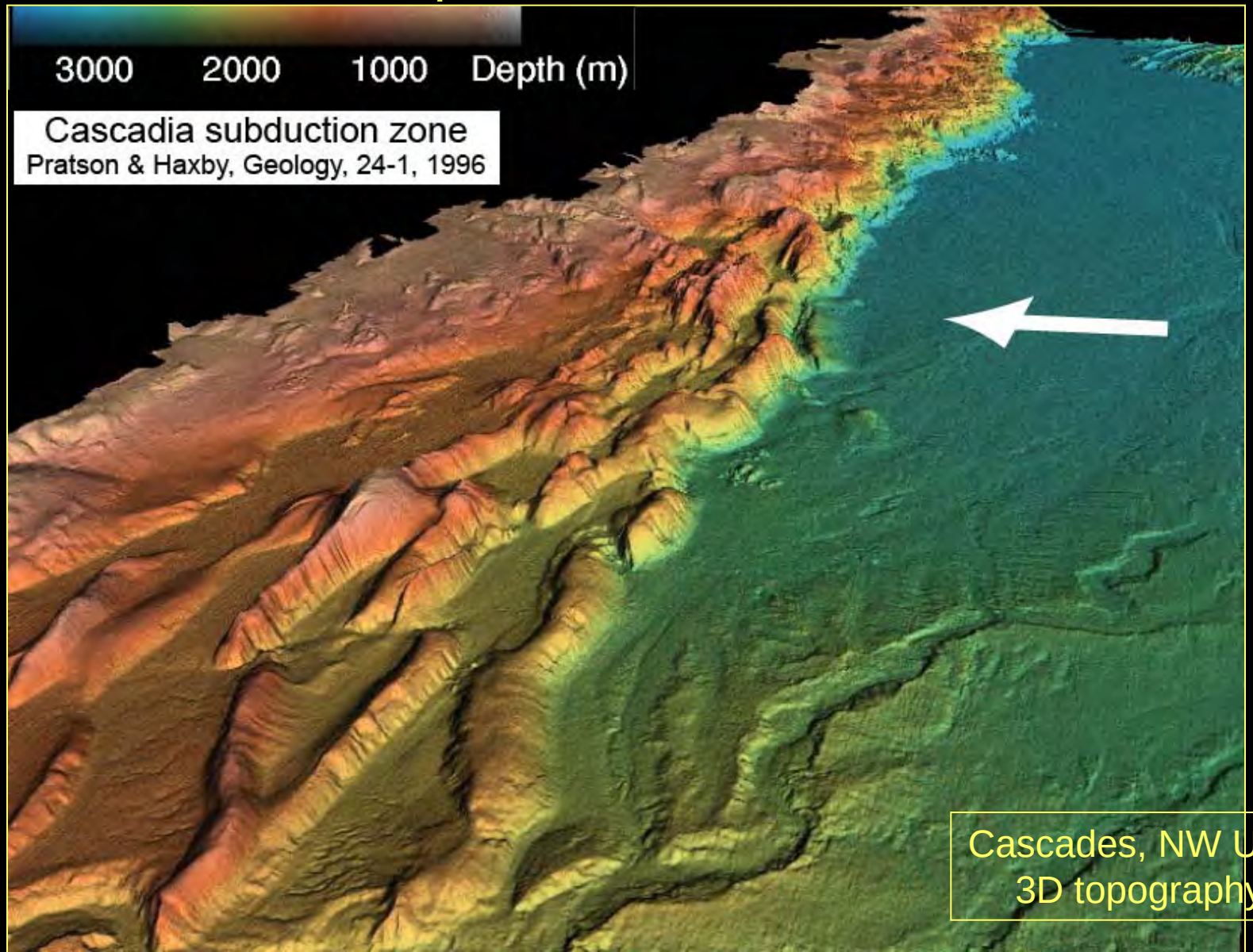
High standing (+5 km) volcanic plateau with two calderas surrounded by high (up to +11 km) mountain belts

Maxwell Montes

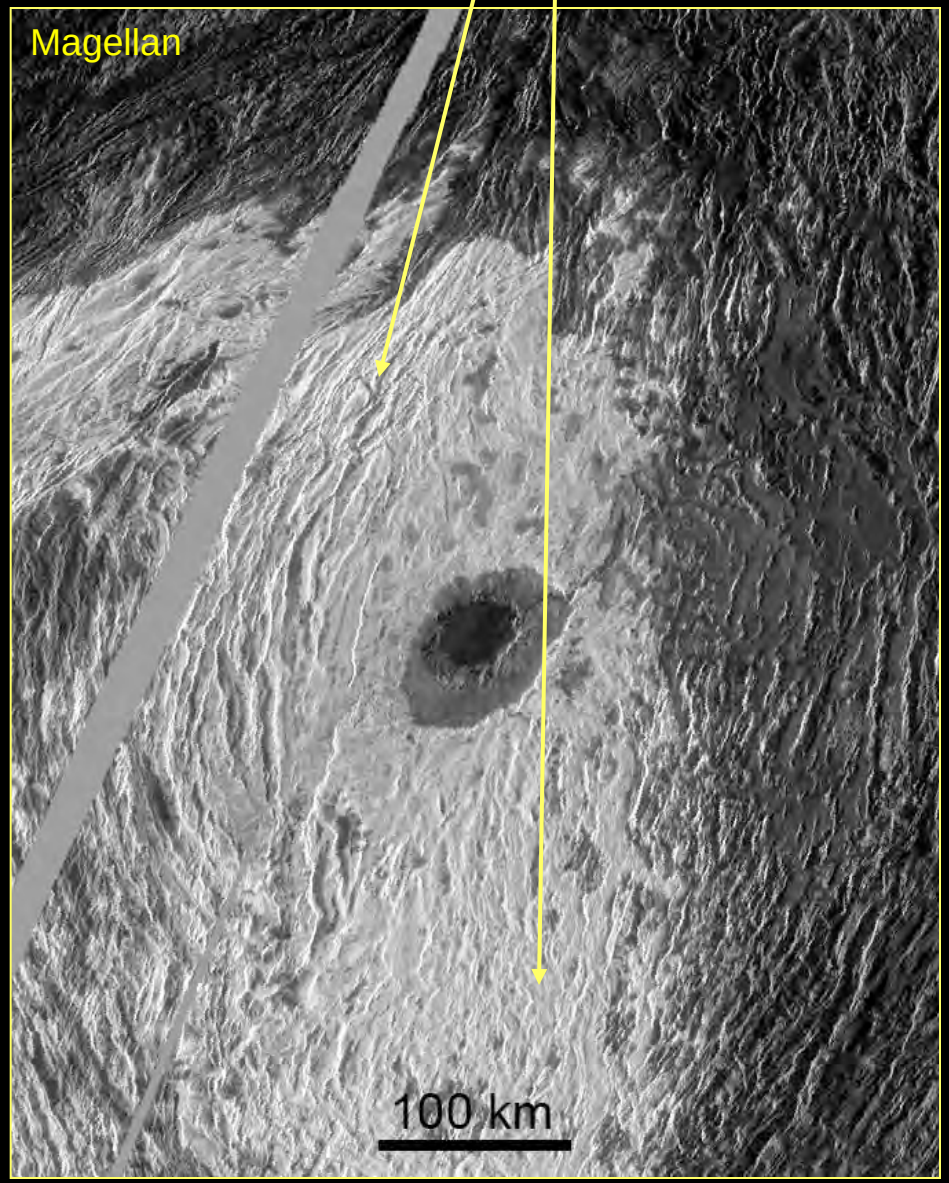


Very high mountain ridge massif, above some altitude (“snow line”) its surface is very bright (chemical weathering or metal cover).

Mountain ridge belts around Lakshmi resemble mountain belts in the zones of subduction and collision on Earth – compressional environment



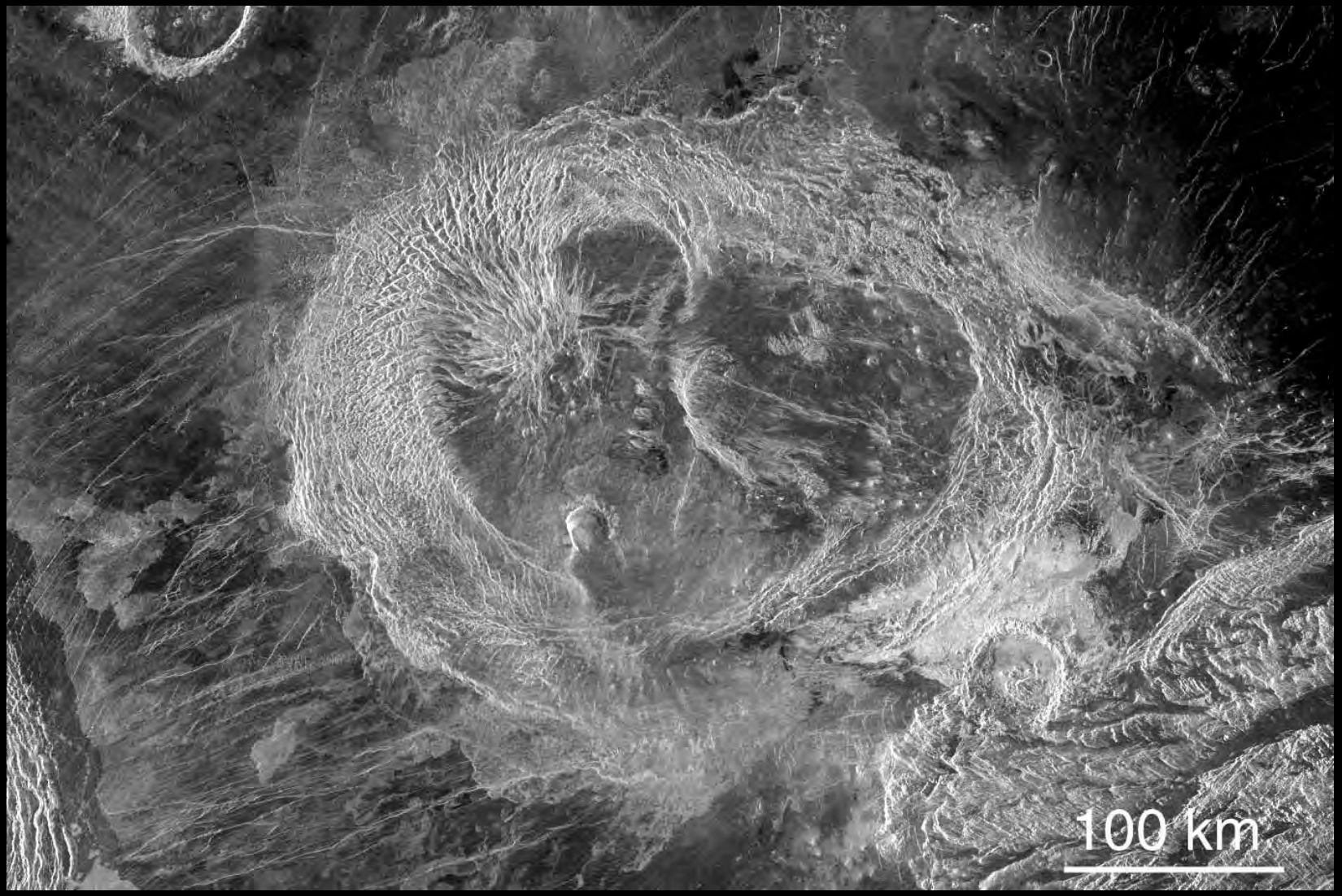
Maxwell Montes – the highest on Venus



Above +5 km surface looks very bright (“snow line”) – material like metal or semimetal

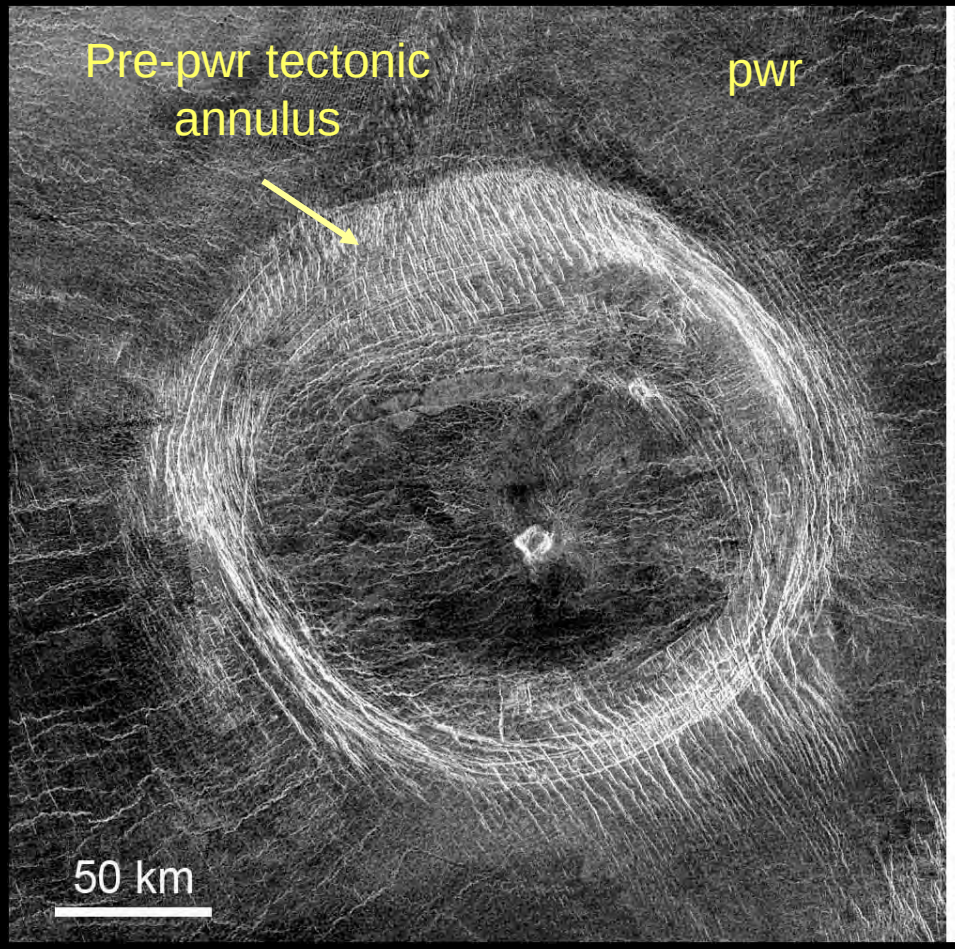
Himalaya with the highest mountain on Earth – Everest Mons

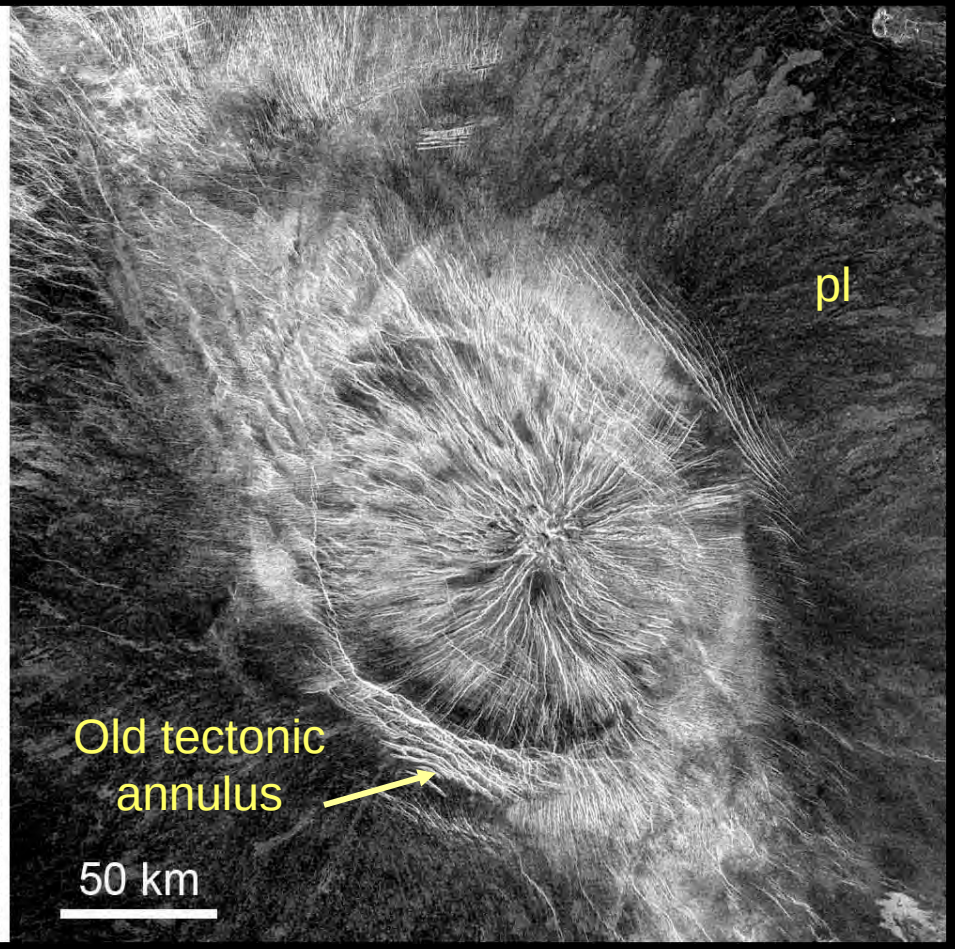
Coronae – circular / ovoidal volcanic-tectonic structures



Several hundred coronae are observed on Venus surface

Coronae Thourus (left) and Dhorani (right)

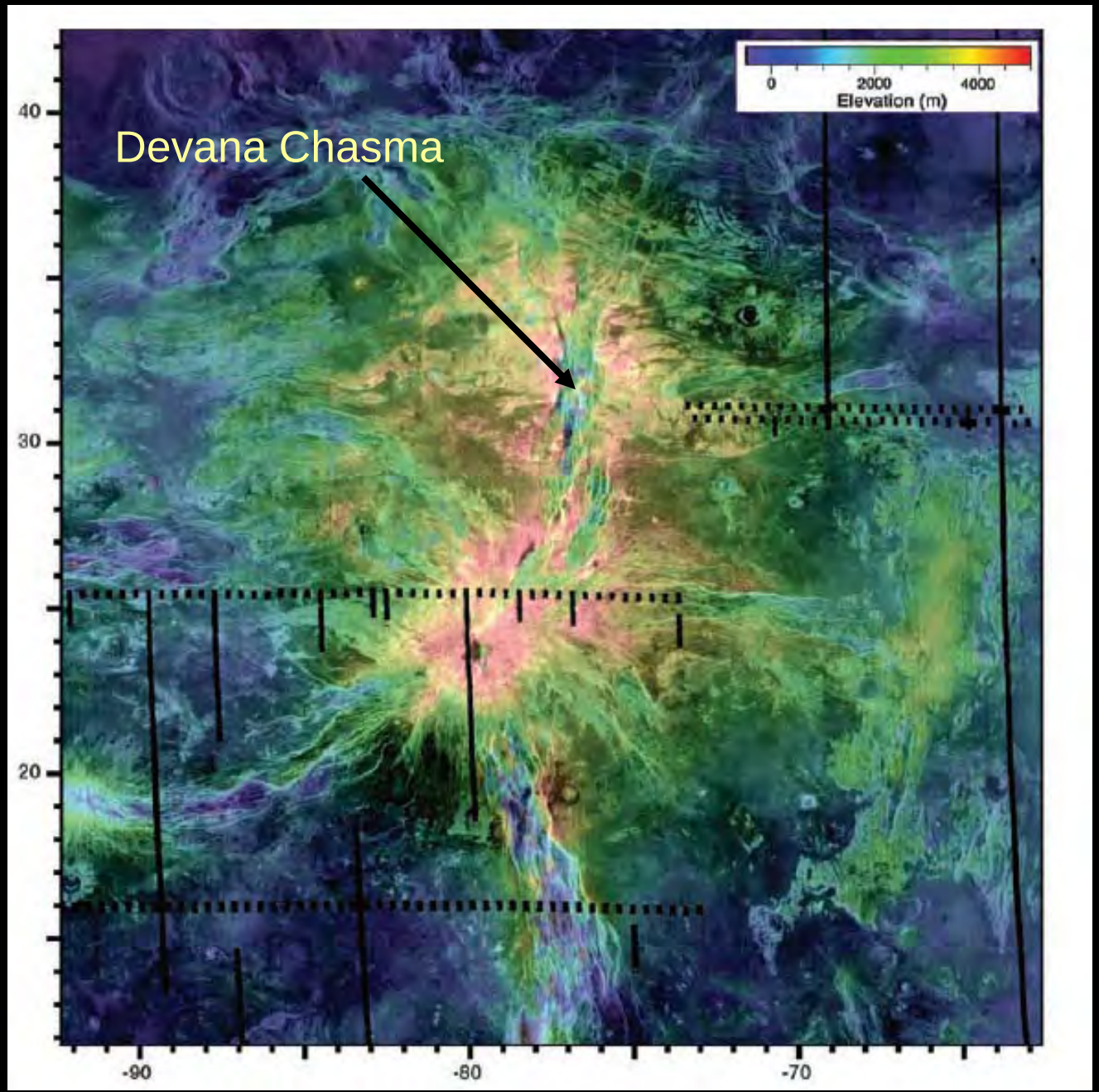




Thourus activity predated emplacement of plains with wrinkle ridges (pwr), no young volcanic activity is associated

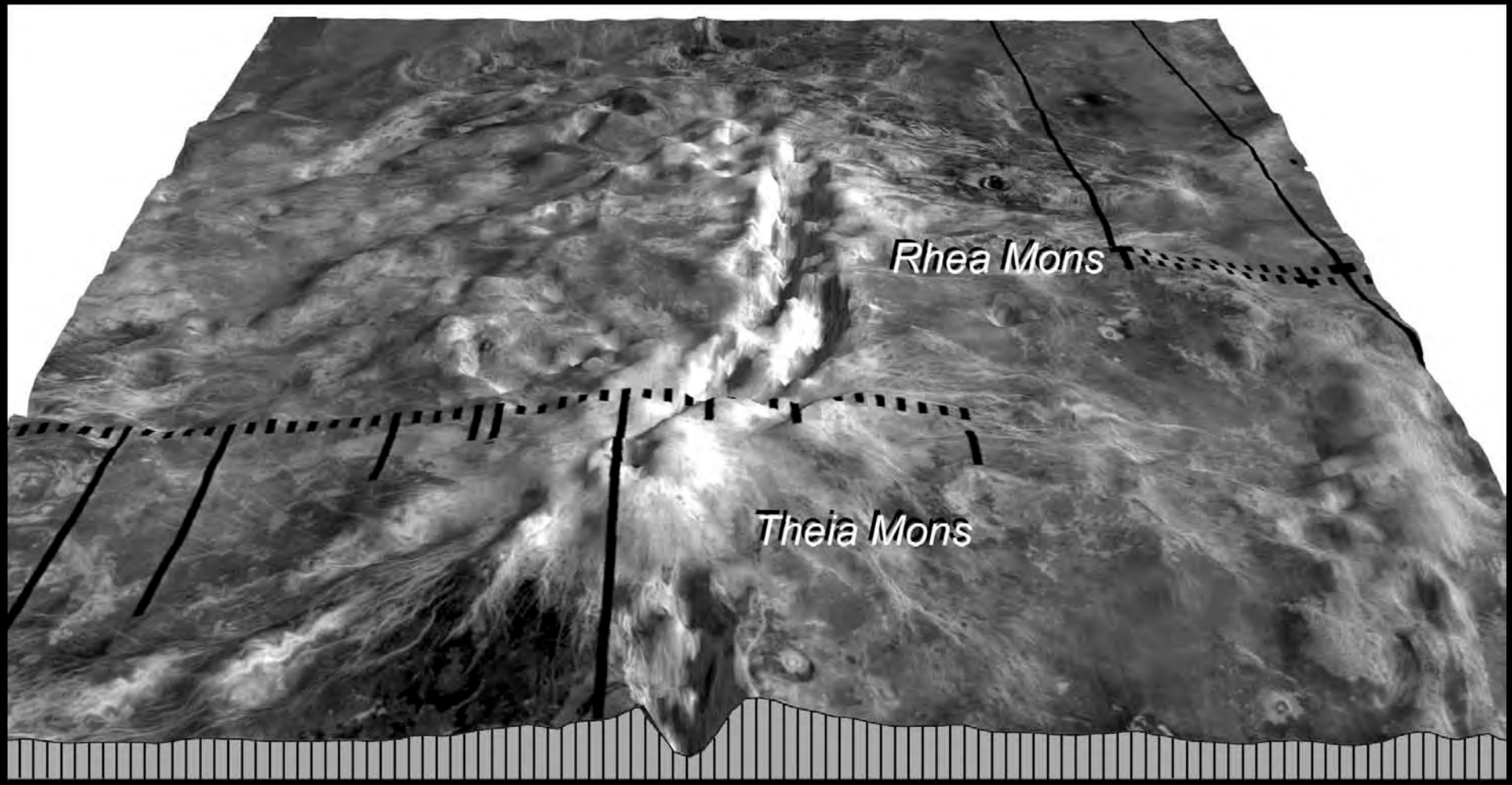
Dhorani activity both predated (part of tectonic annulus) and postdated (pl) the emplacement of plains with wrinkle ridges

Beta Regio – tectonic rise cut by Devana rift zone

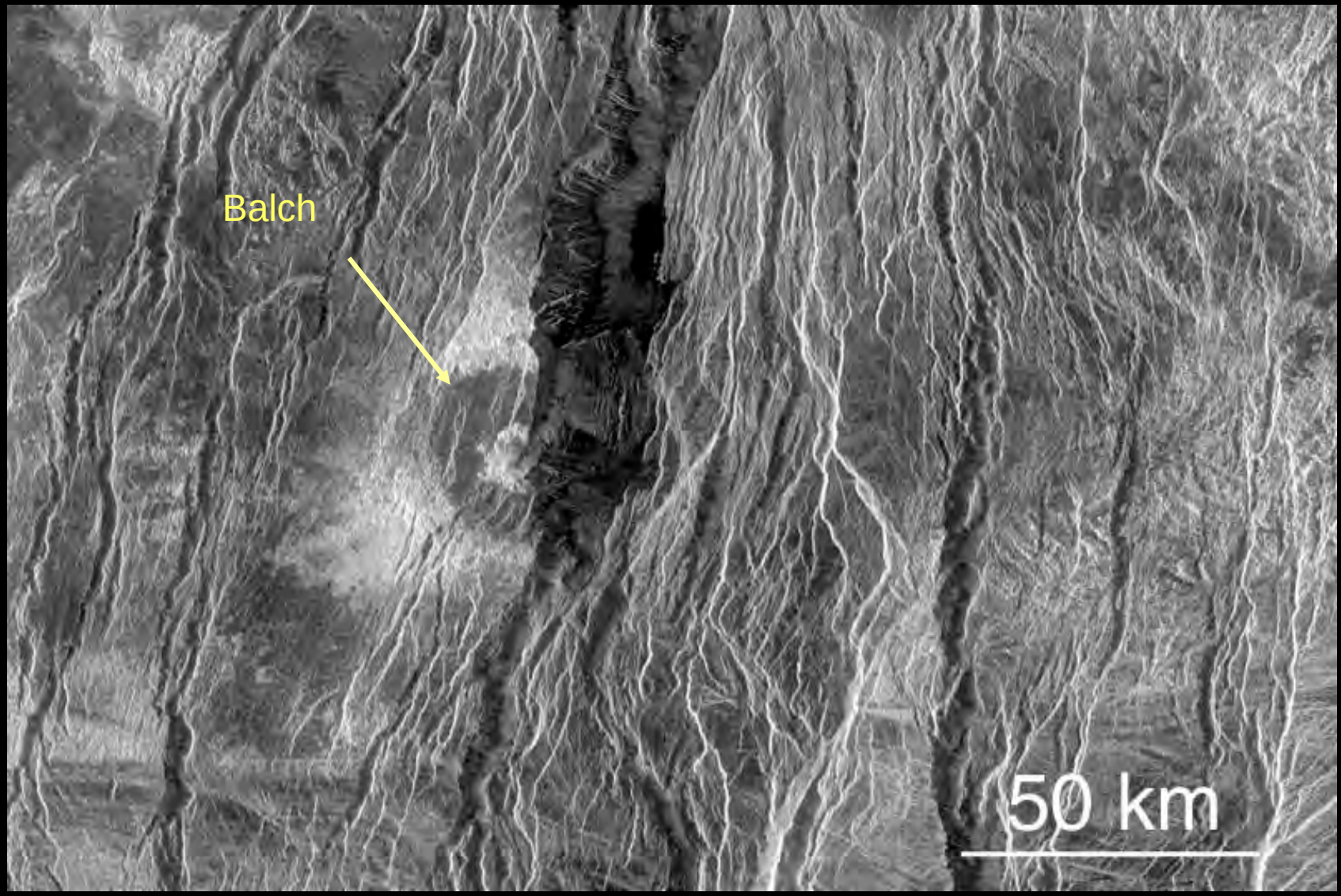


Beta Regio cut by Devana rift zone

Perspective view

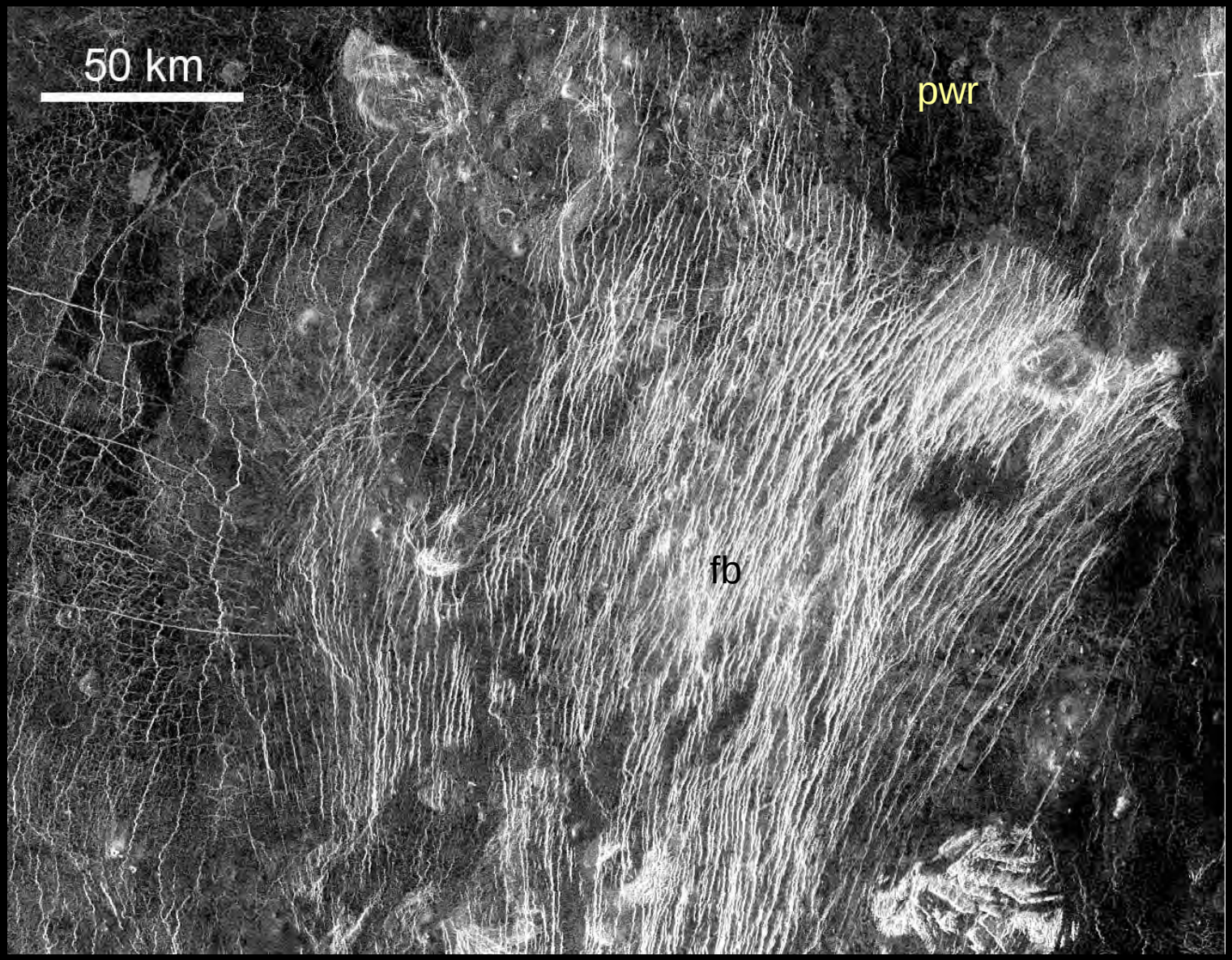


Devana Chasma rift and impact crater Balch



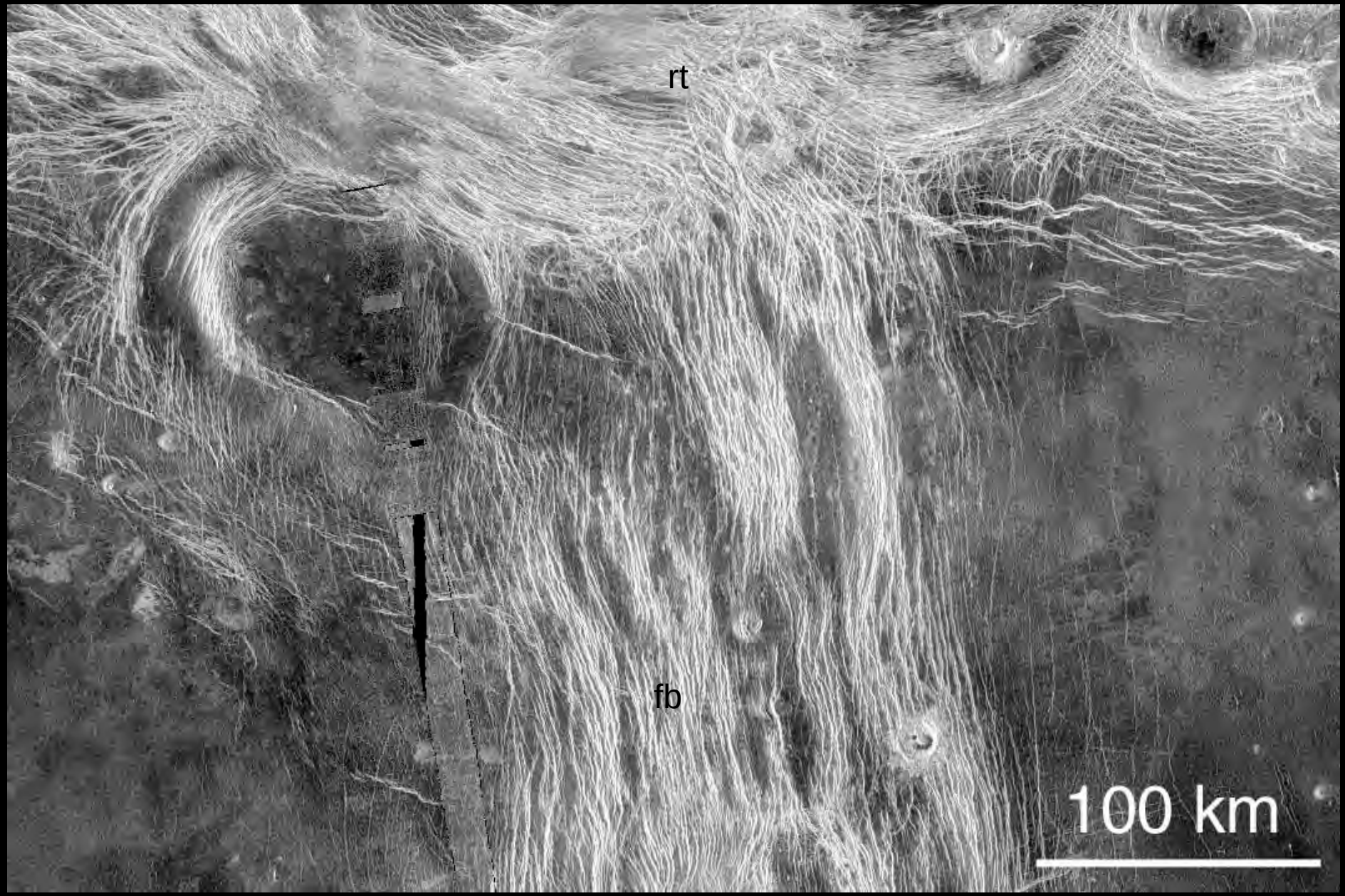
If to assume that crater Balch was originally circular,
the tectonic stretch here is 10 km

Fracture belt: Ancient rift zone

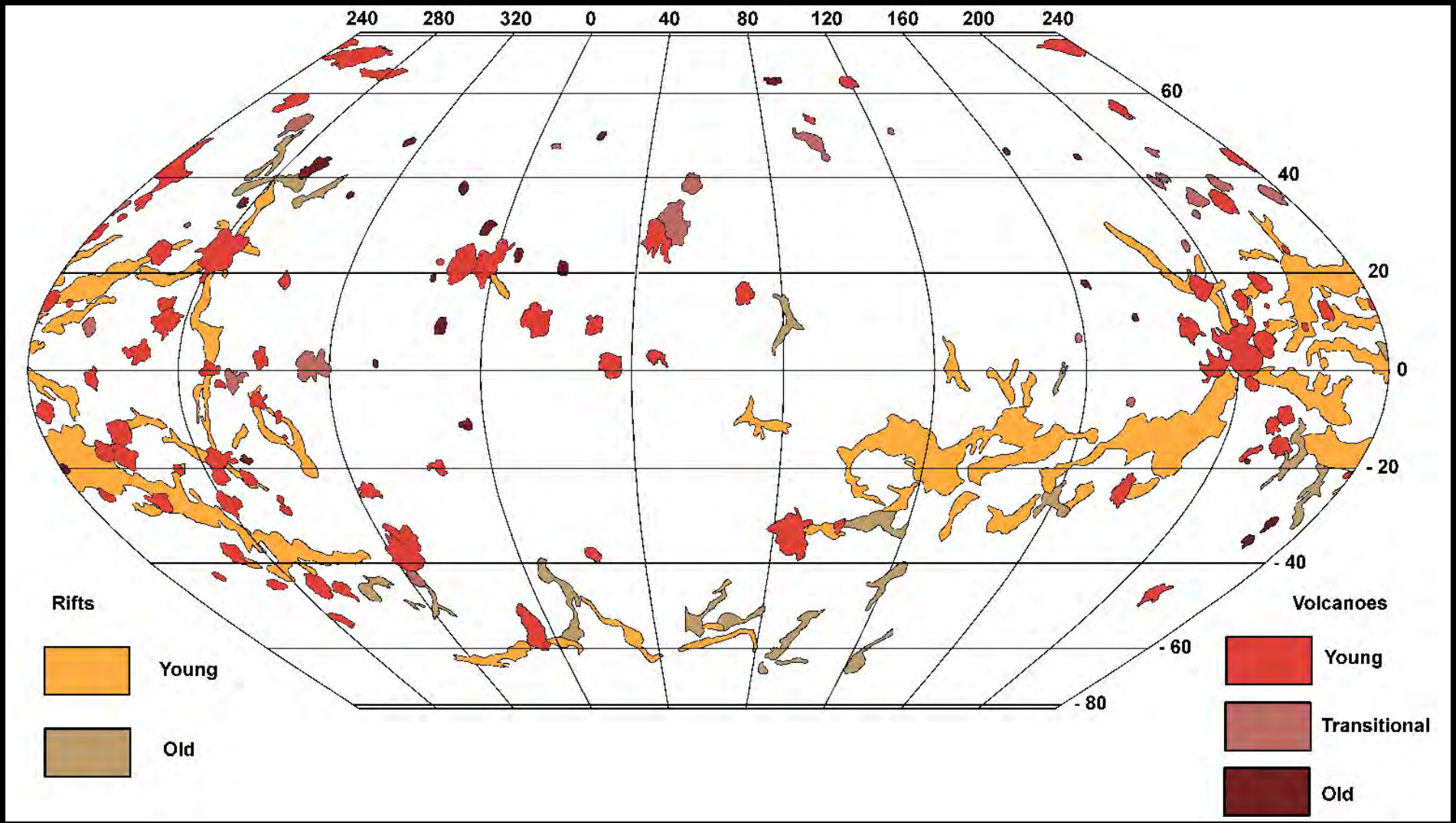


Fracture belt faults mostly predated plains with wrinkle ridges and are embayed by them

Fracture belt (fb) and younger rift (rt)

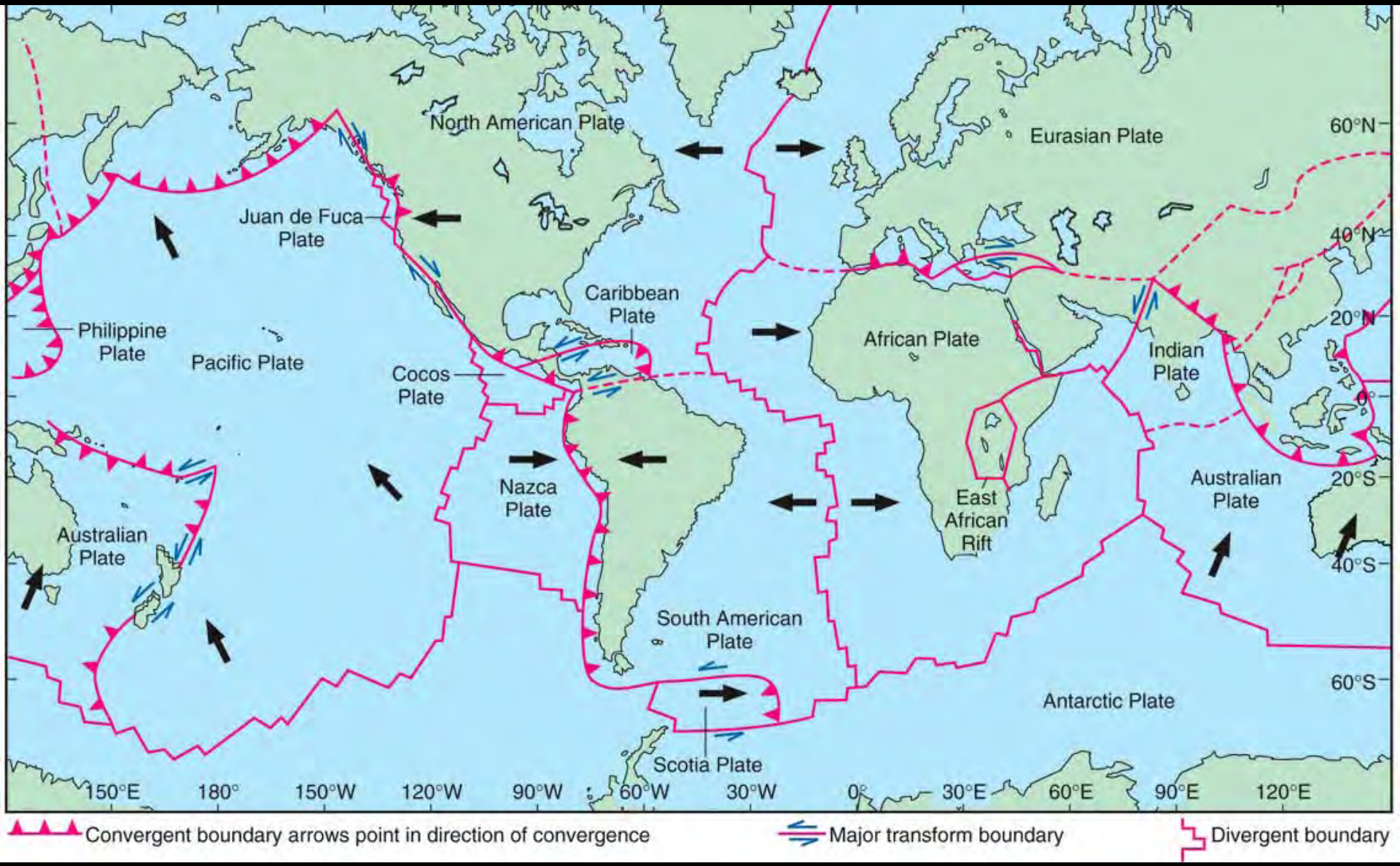


Young and old rifts and large volcanoes

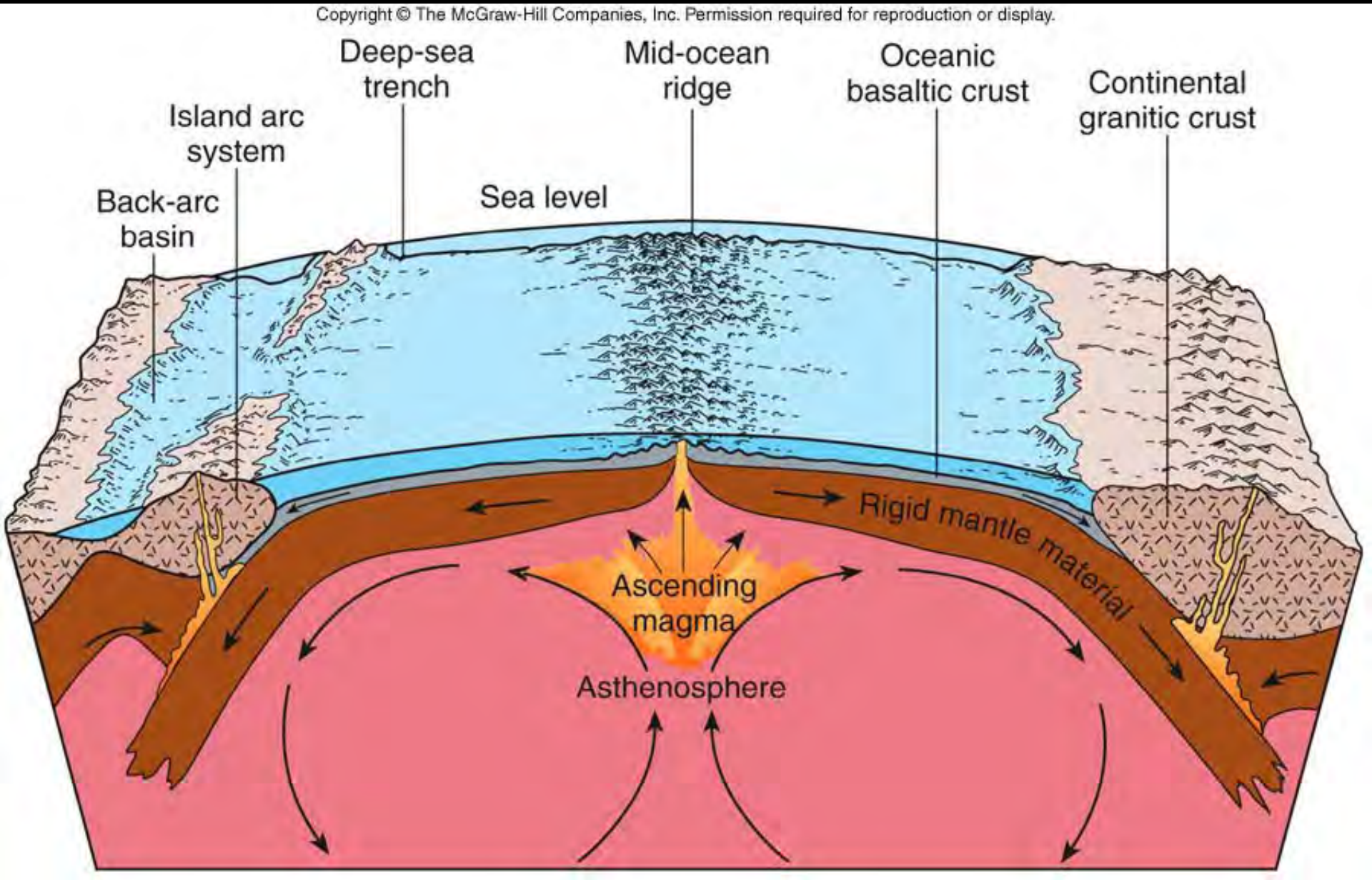


Volcanoes often associate with rifts but their presence outside rift zones is also common

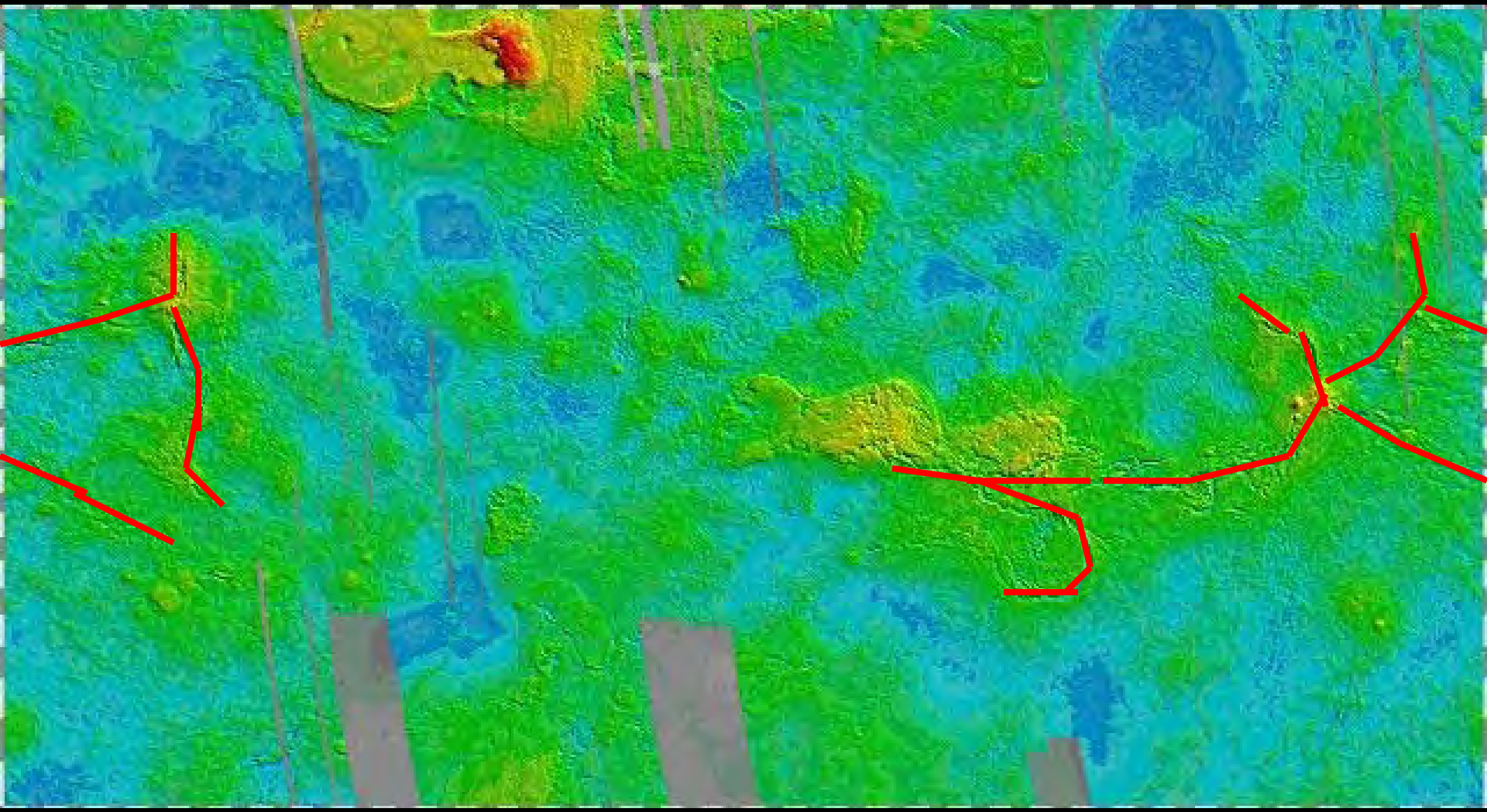
Lithosphere plates of Earth



Divergent and convergent plate boundaries

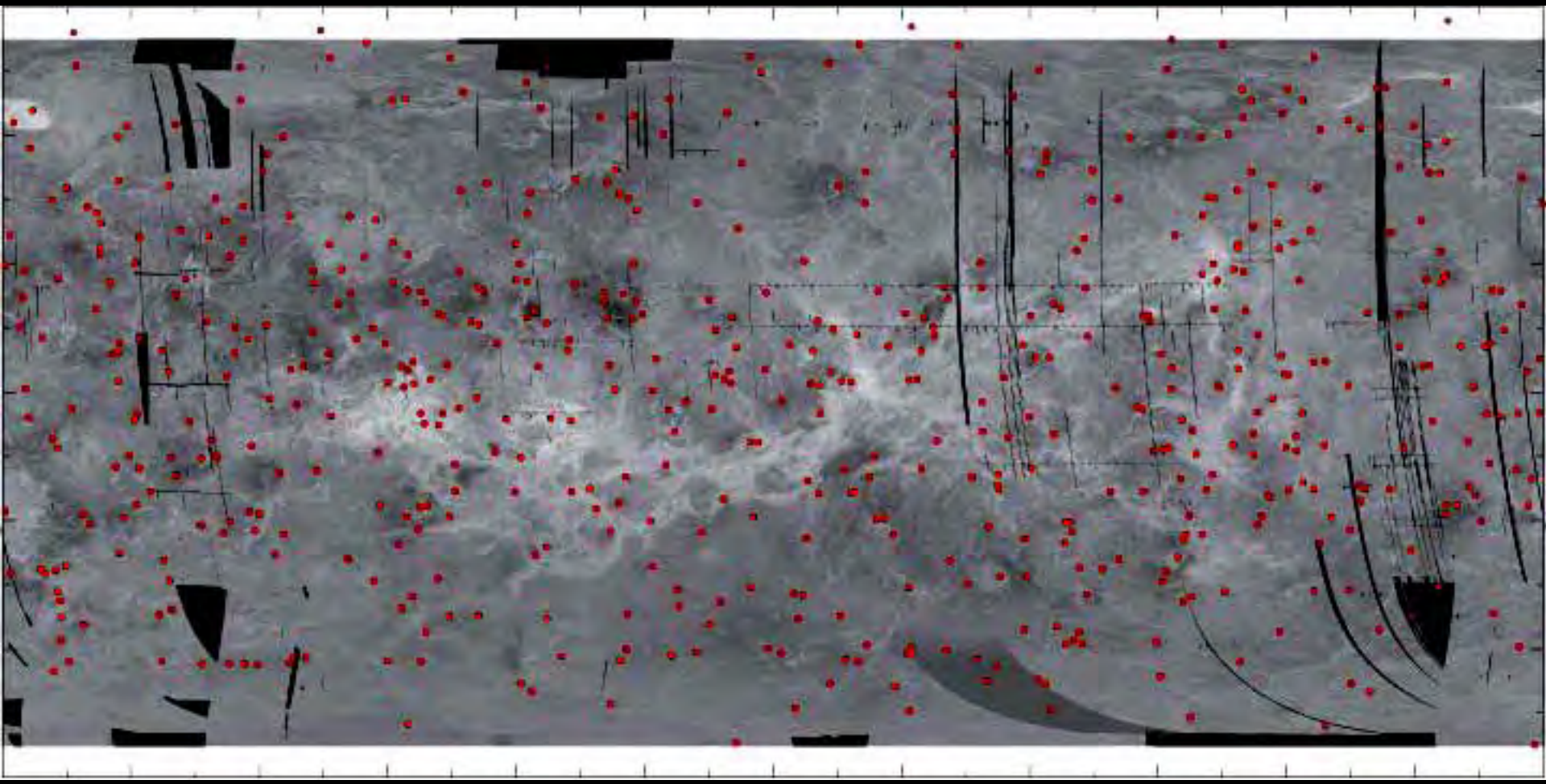


Topography of Venus



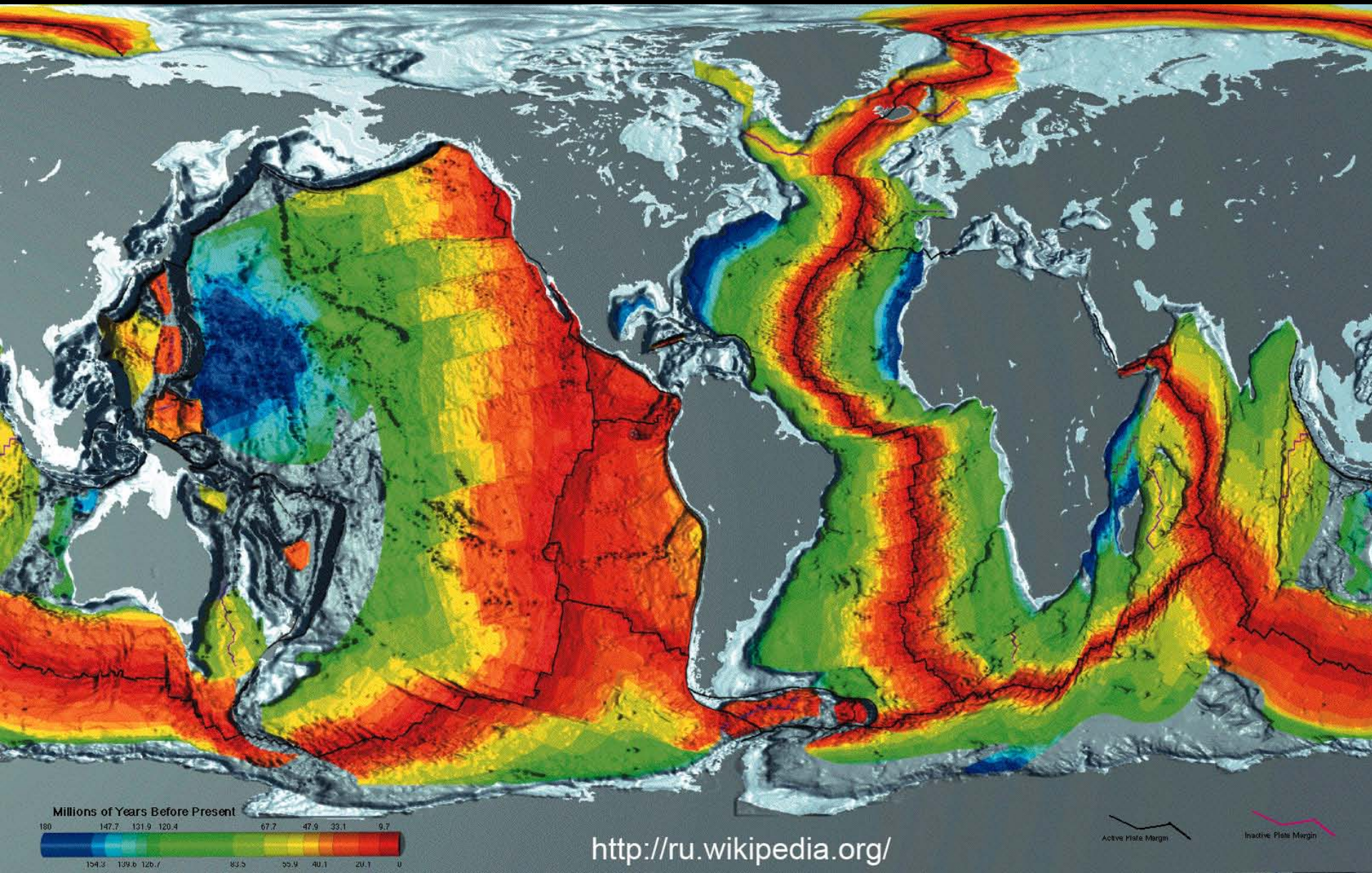
Rift zones do not have subductional and collisional counterparts expected if plate tectonics would work

Impact craters of Venus

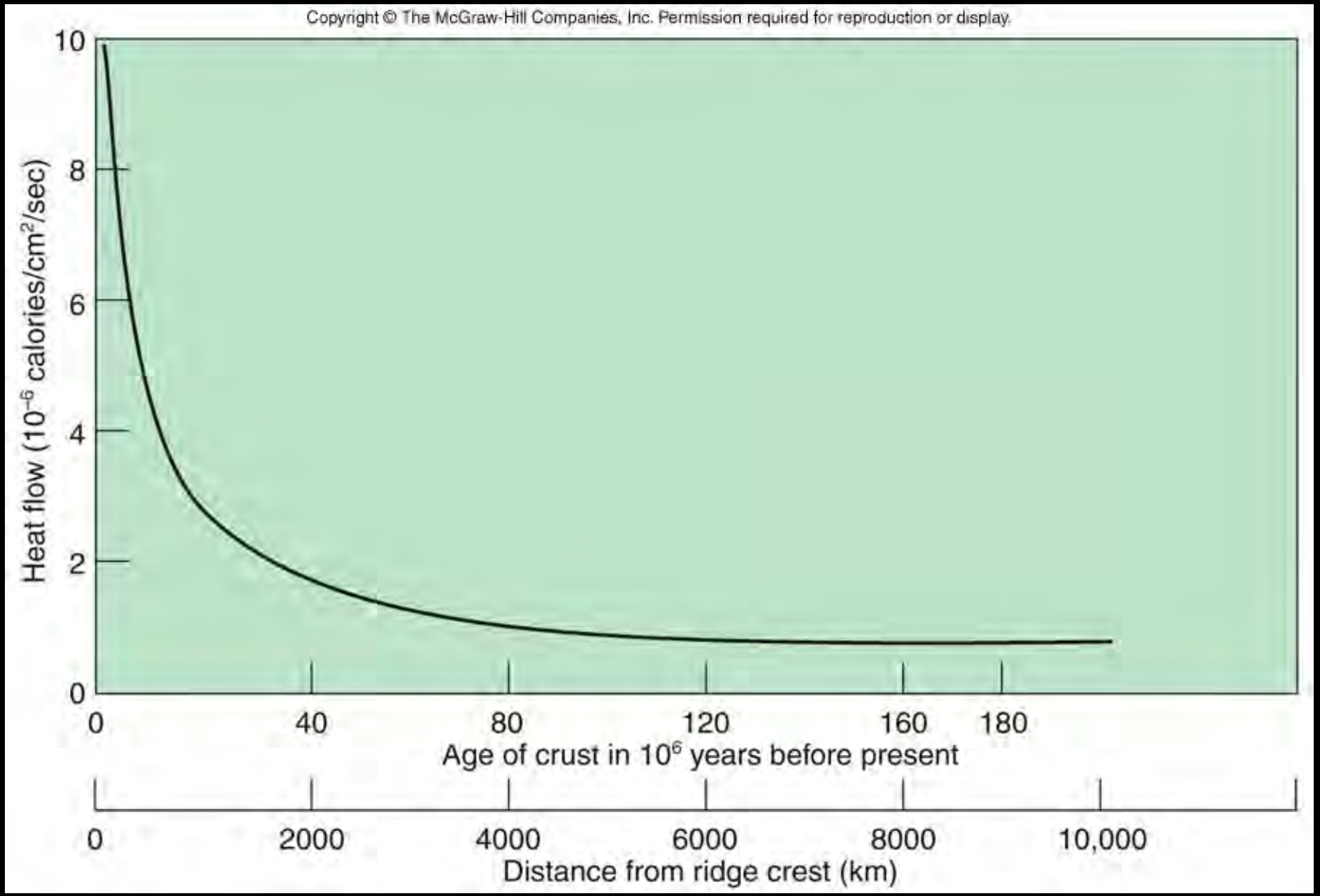


Spatial distribution is very close to random one that contradicts suggestion on possible plate tectonics

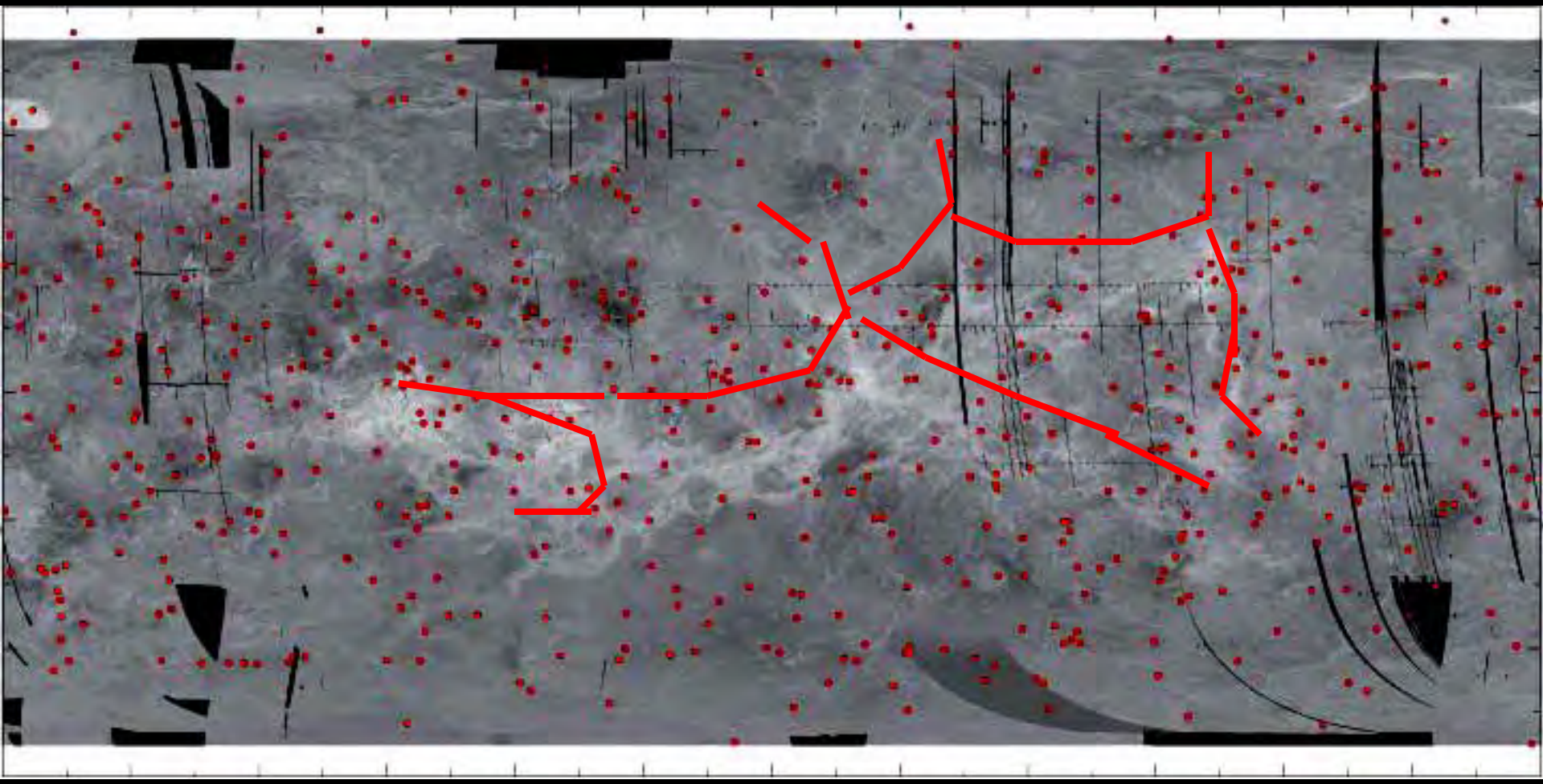
Earth: Age of rocks of the oceanic floor increases with distance from the rift of the mid-oceanic ridge



Age of crust increases with distance from ridge

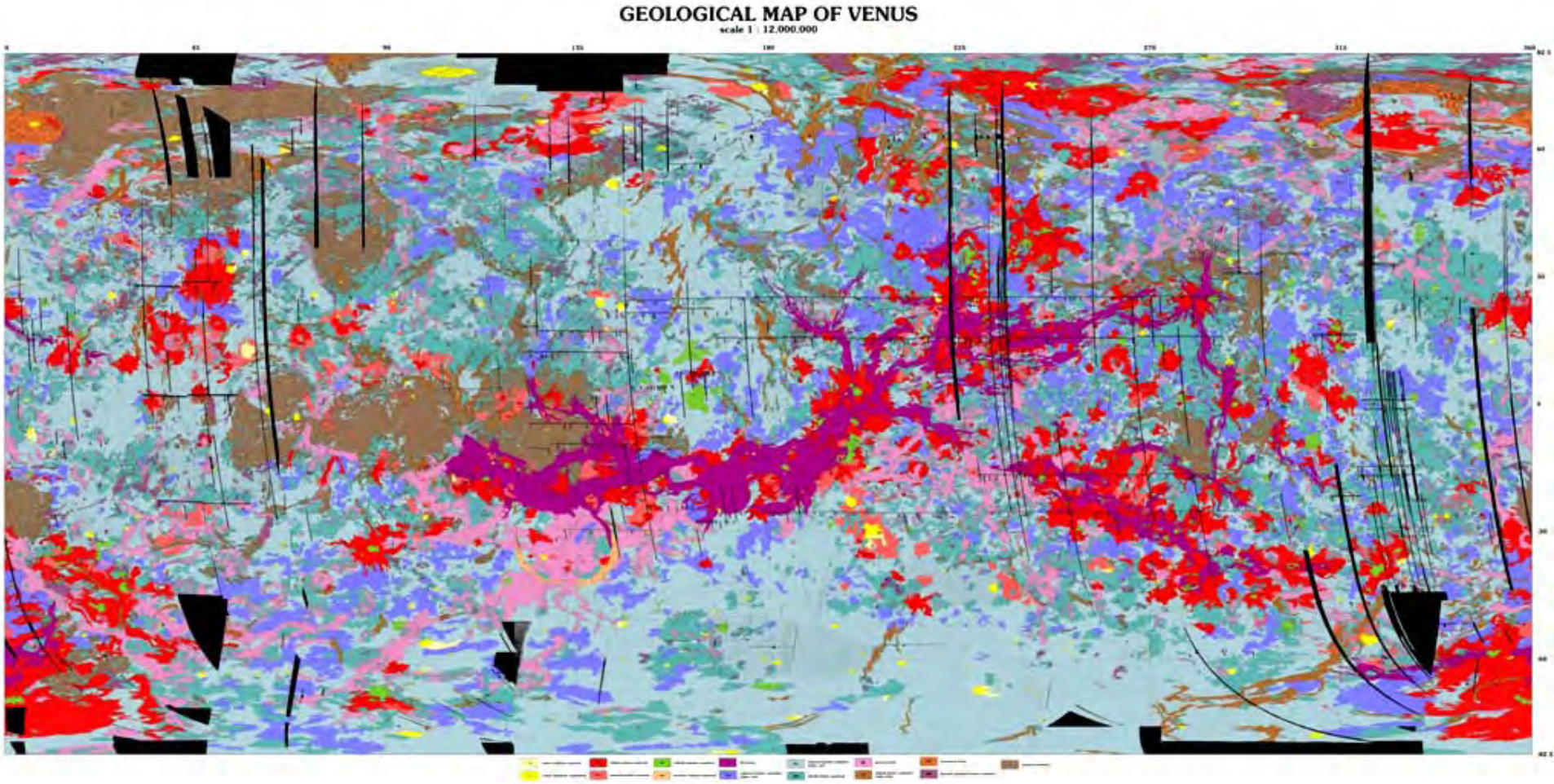


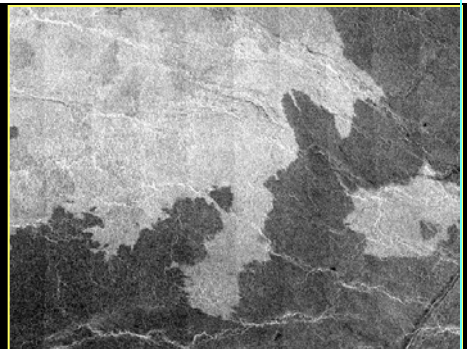
Impact craters and rift zones on Venus



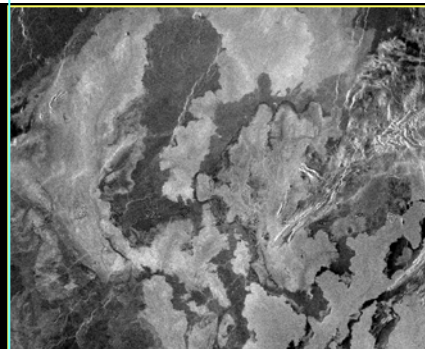
No regular increase of crater density with distance from rift zones

Geologic map of Venus, Ivanov & Head, 2011

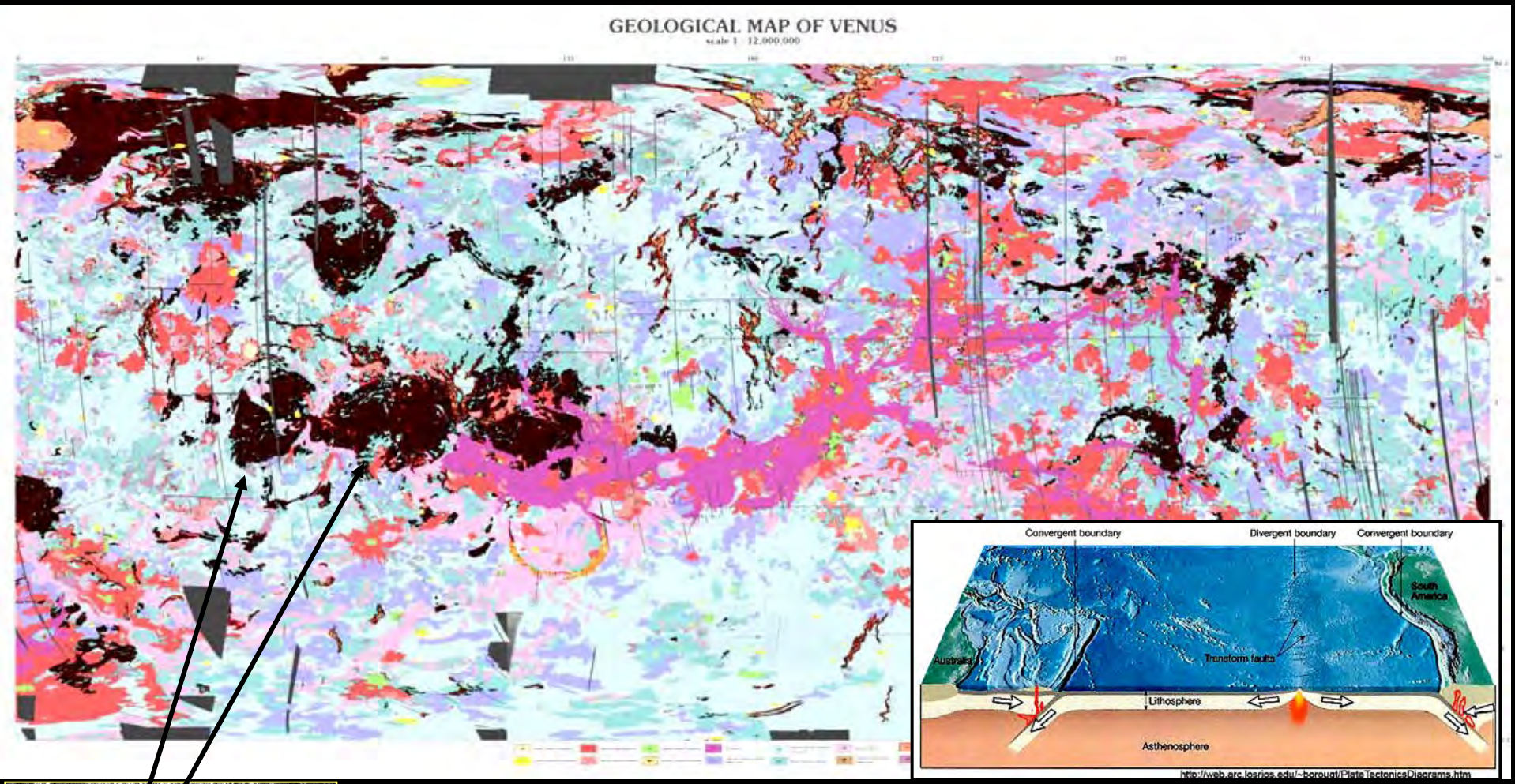


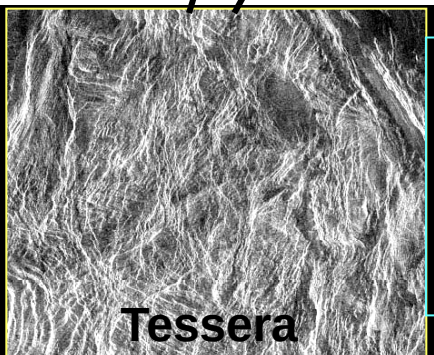


Most part of the surface are volcanic plains – analog of secondary crust: oceanic crust of Earth и crust in lunar maria. Is there on venus tertiary crust like granitic crust of Earth continents Земли?



Geologic map of Venus, Ivanov & Head, 2011





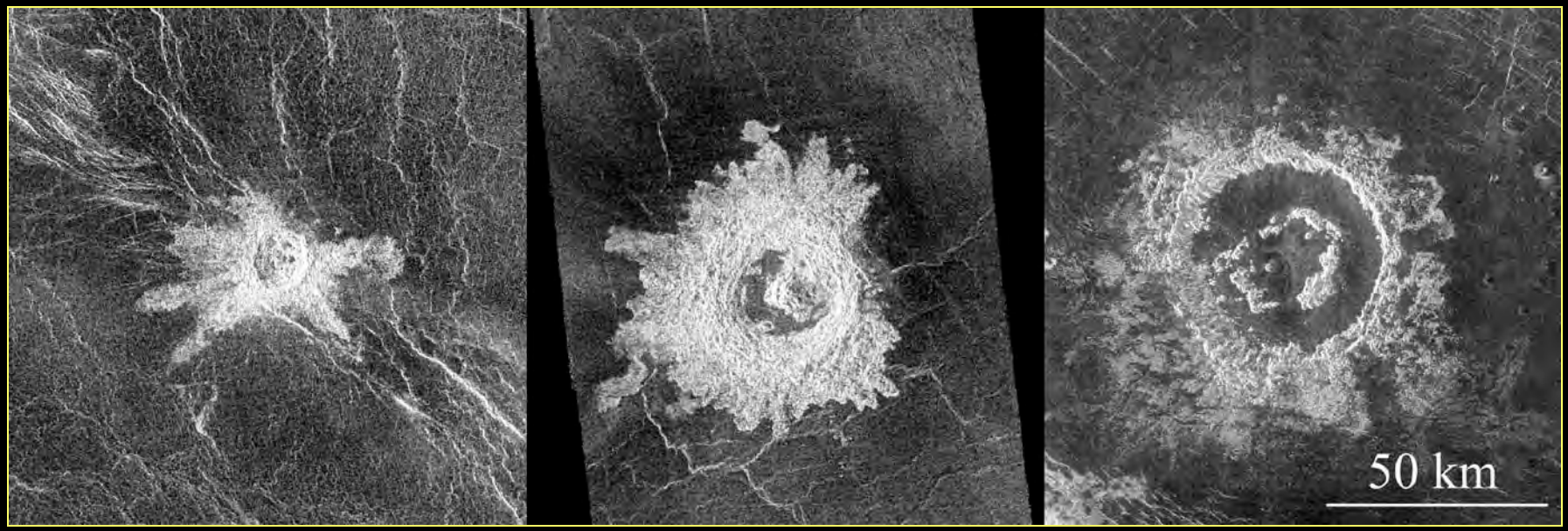
Comparing to basaltic plains tesserae have the lower radar emissivity: Non-basaltic.
May be they represent pieces of the tertiary crust on Venus
May be on Venus were oceans and plate tectonics?

May be long time ago Venus was looking like this:

But may be then at the absence of magnetic field hydrogen formed due to dissociation of water was escaping from Venus. The released oxygen was spent for oxydizing the crust material

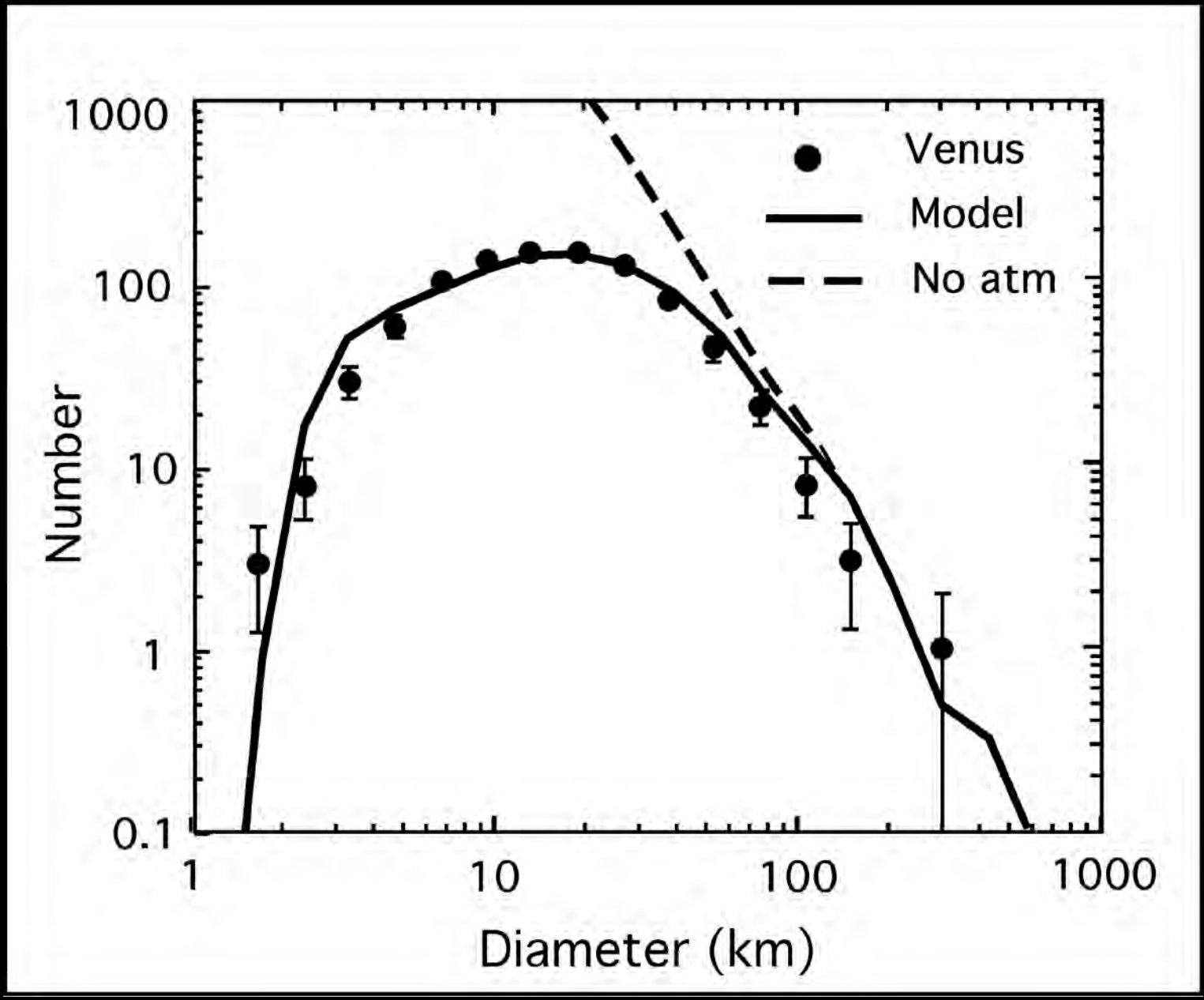
and Venus dried up?

Impact craters of Venus



Crater with associated radar-dark parabola

Craters on Venus: Age of population 0.5-1 b.y.



Wind streaks

10 km

Not necessarily “normal” winds, could also be “impact” winds

Yardangs on Venus

Yardangs of Iran

5 km

Yardangs are ridges carved by wind erosion

Dune field on Venus

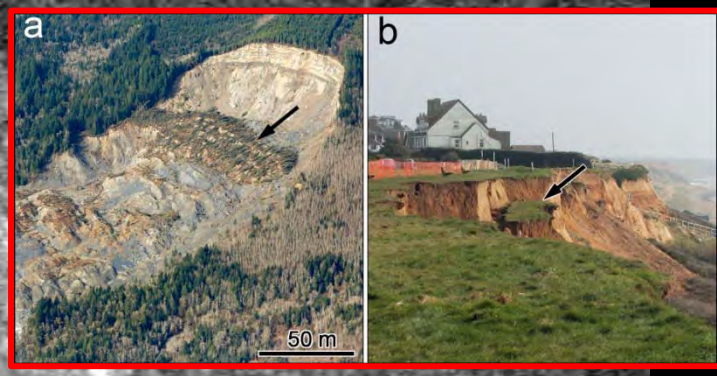
Dunes of Namibia

5 km

Only two dune field are observed on Venus. Not enough resolution?

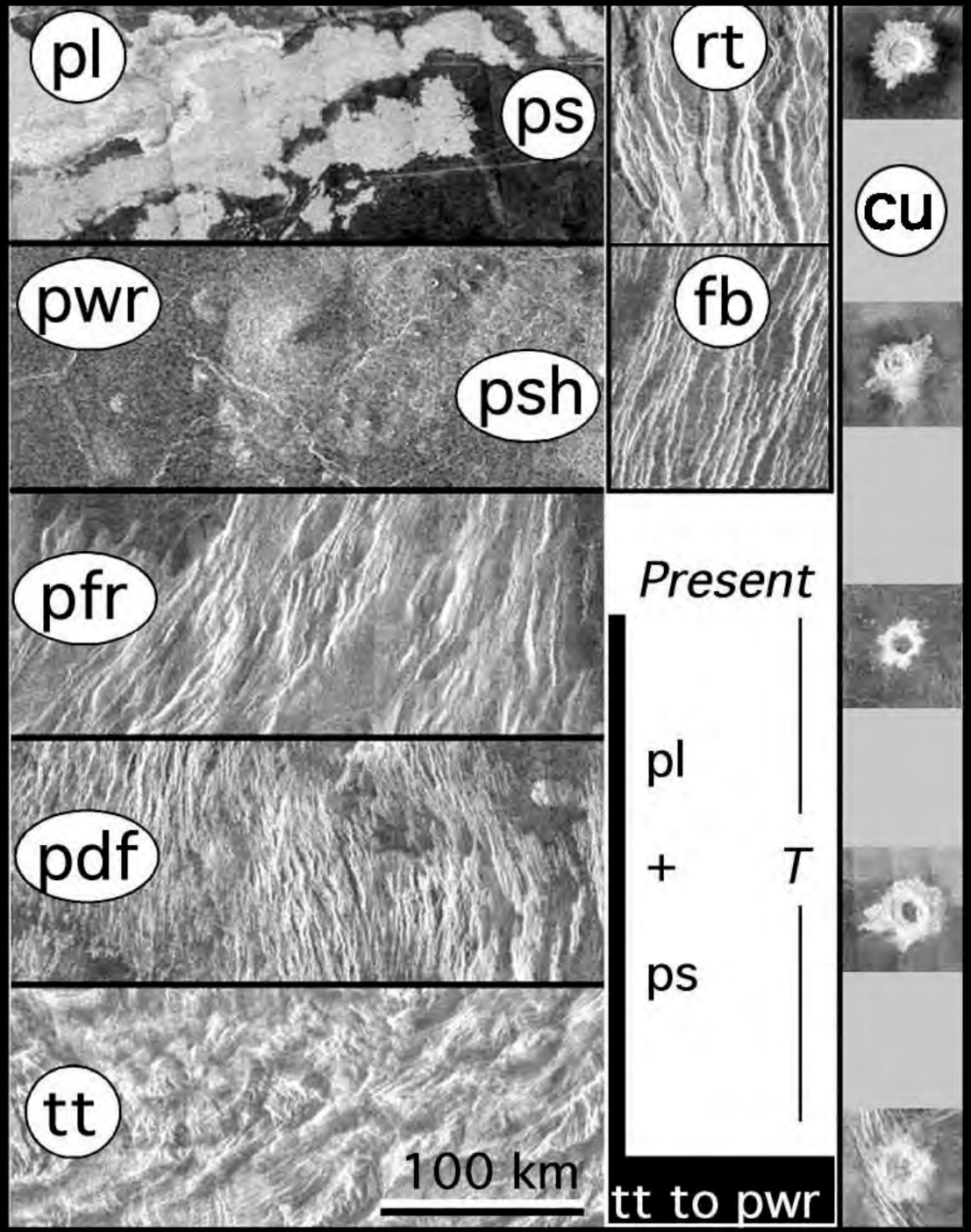
Down-slope movement processes

Landslides on Earth



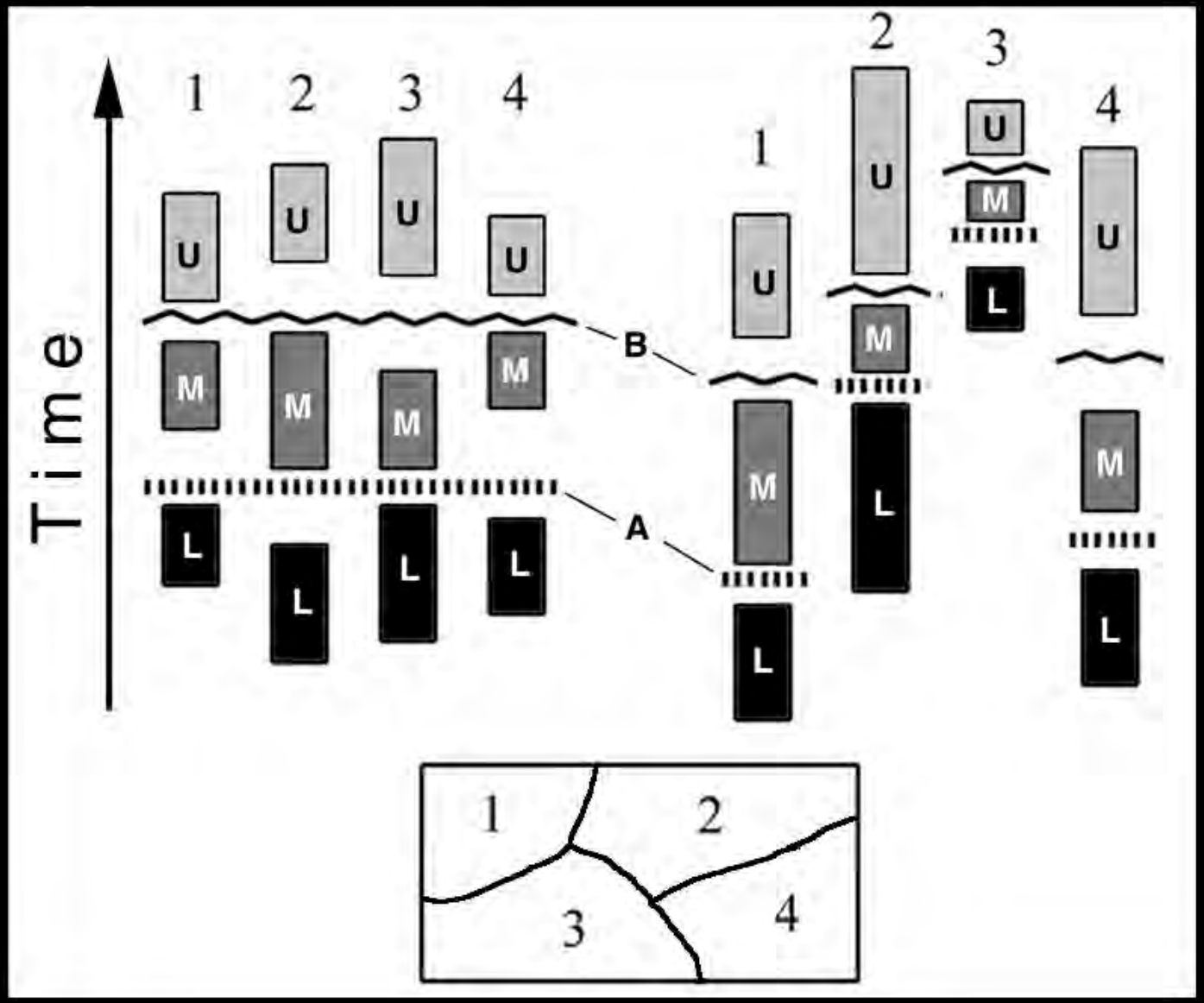
10 km

Collapse of the steep-sided dome slope



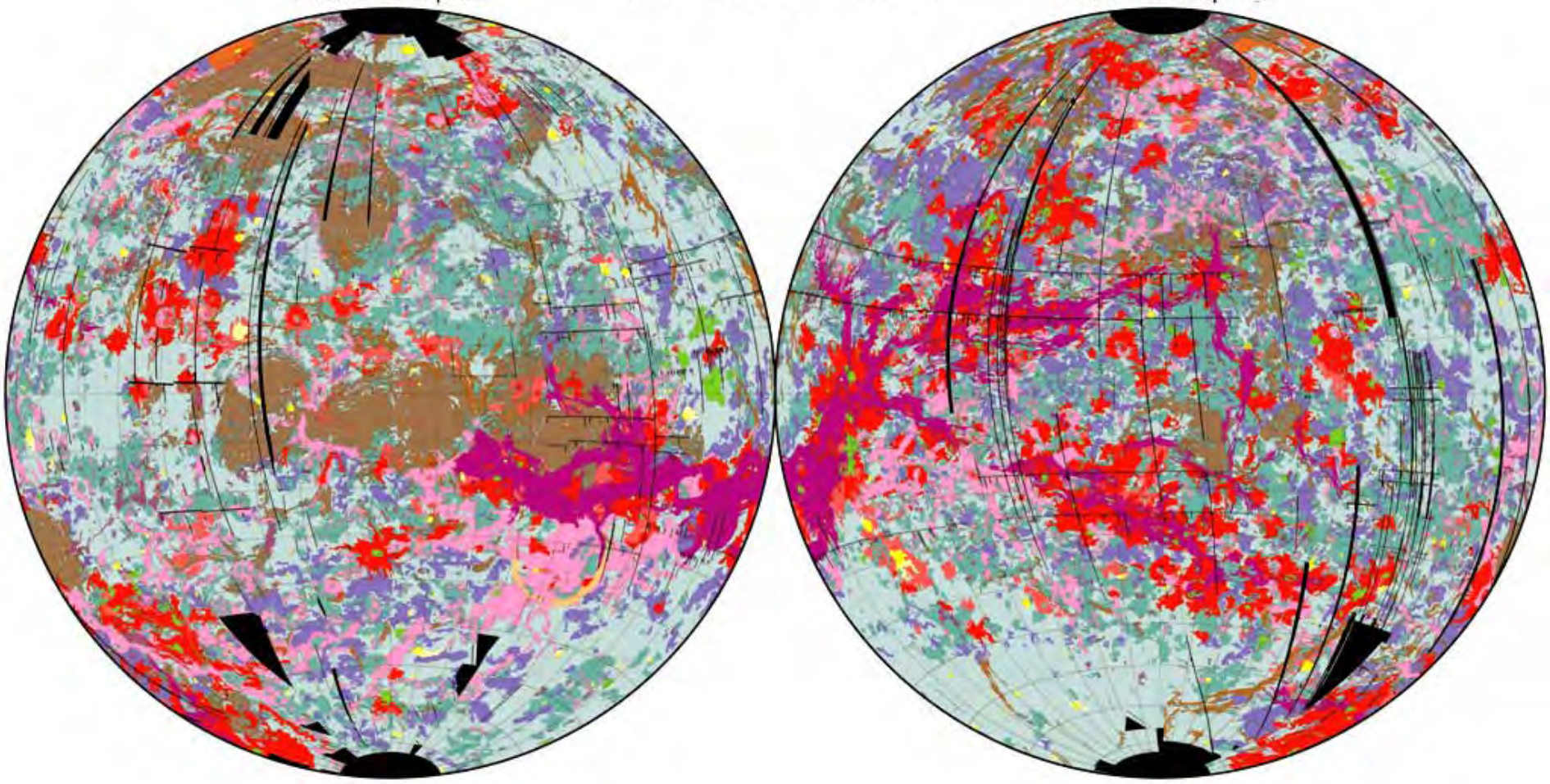
Global stratigraphy by Basilevsky & Head, 2000

Synchronous v.s. nonsynchronous options of correlation of geologic units on Venus



Geologic map of Venus

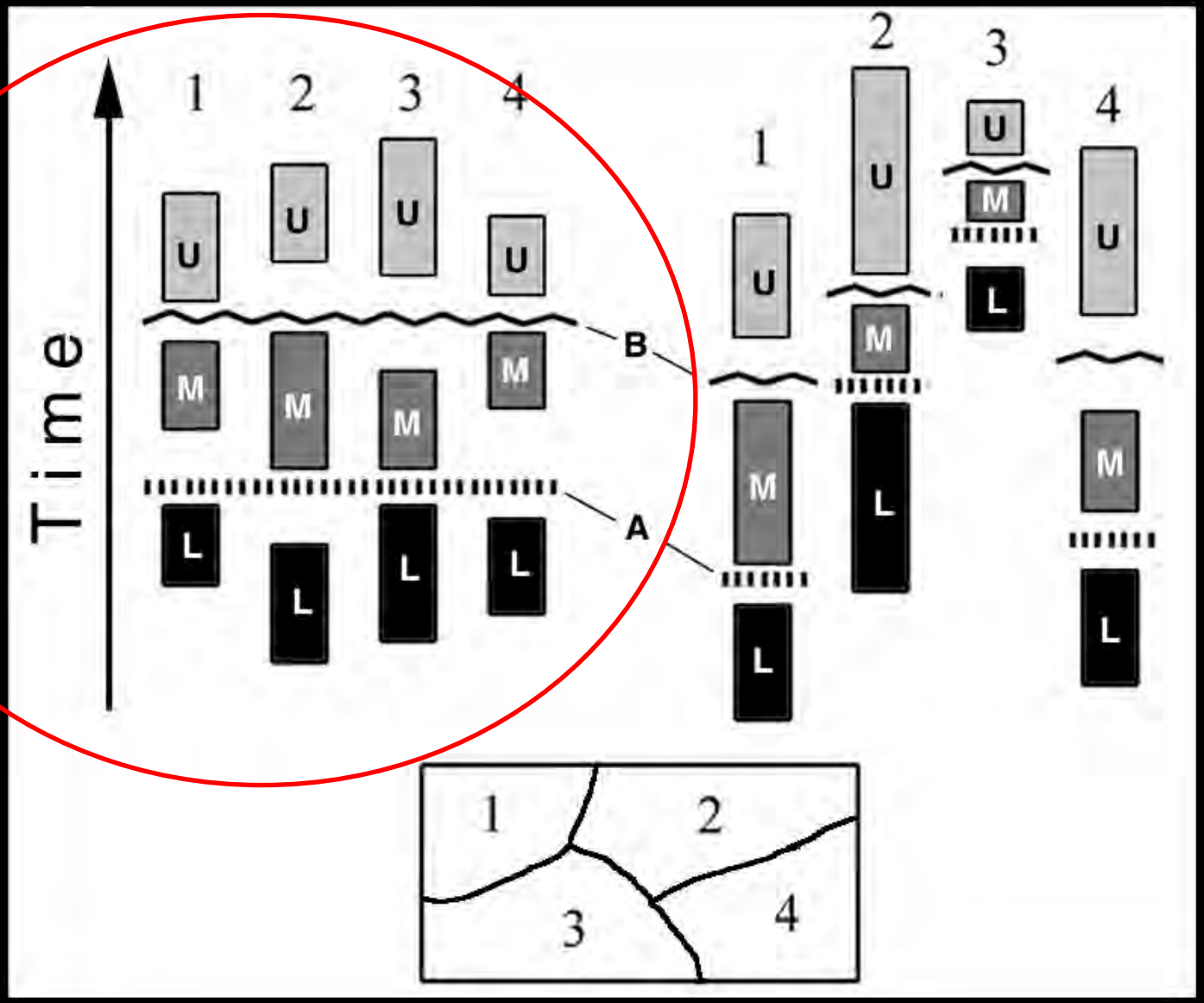
Ivanov and Head, 2011



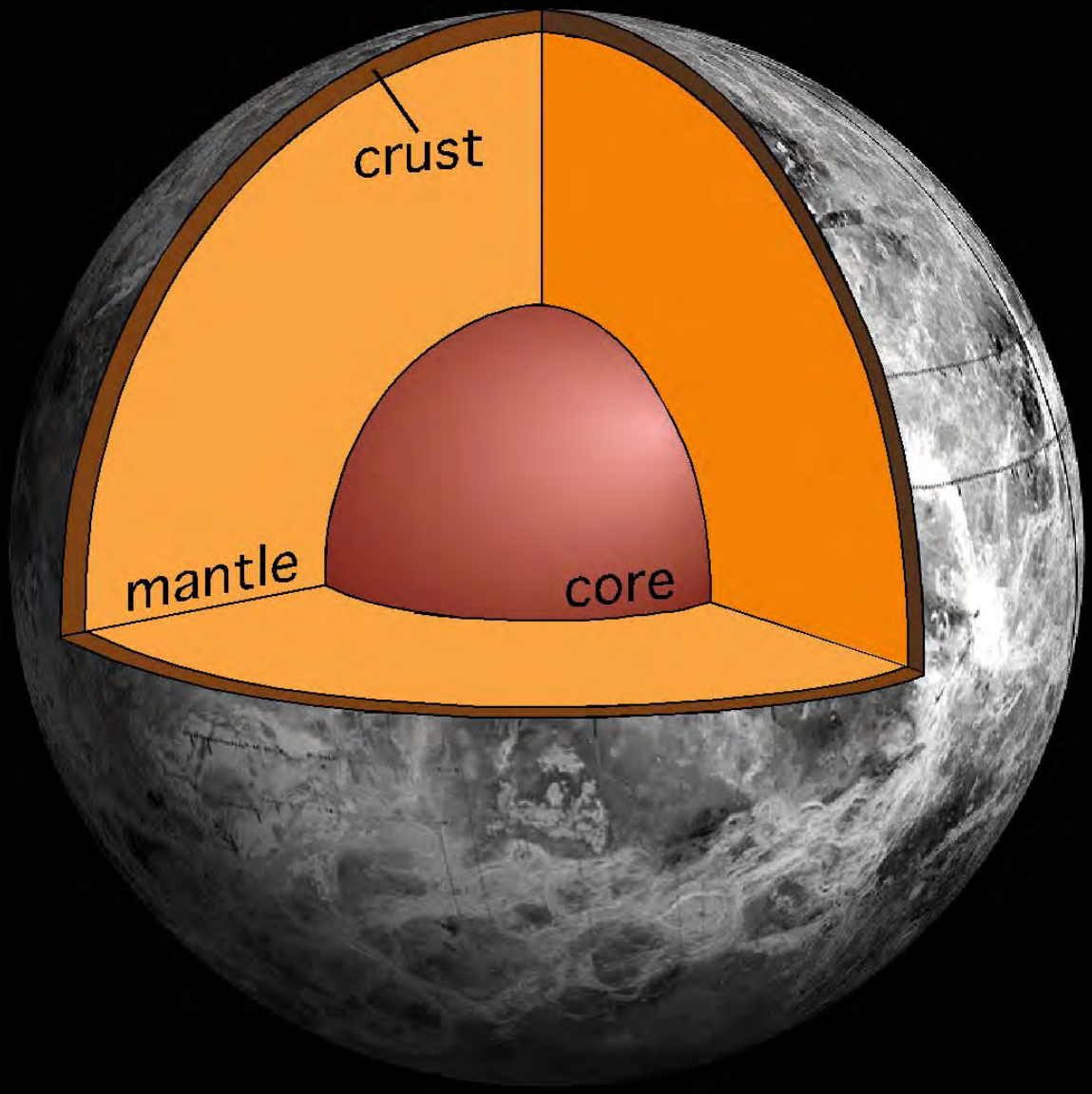
cf	crater outflow material	sc	shield clusters material	rp_1	regional plains material, lower unit	mt	mountain belts
c	crater material, undivided	ac	artemis chasma material	psh	shield plains material	pdl	densely lineated plains material
pl	lobate plains material	rz	rift zones	gb	groove belts	t	tessera material
ps	smooth plains material	rp_2	regional plains material, upper unit	pr	ridged plains material / ridge belts		

Synchronous v.s. nonsynchronous options of correlation of geologic units on Venus

Correct



Venus internal structure



Presented based on analogy with that of Earth. May be not real.

Geologic history of Venus

T ~ 0.5 – 1 млрд. лет.

~1T ago to NOW – Sparse volcanic plains (pl) and volcanic constructs+ rifting. No plate tectonics.

~1.1T to 1T – vast lava eruptions (pwr + psh) + moderate tectonic deformations. No plate tectonics.

~1.1 T ago – Formation of tesserae – Volcanism + intensive tectonics. Possibly sporadic plate tectonics.

- ? - ? - ? - ? - ?

? b.y ago - Lost of water through hydrogen escape

?? b.y ago - early evolution, planet could be more similar to Earth; Could be plate tectonics and ocean

4.5 b.y ago - Accretion of the planet

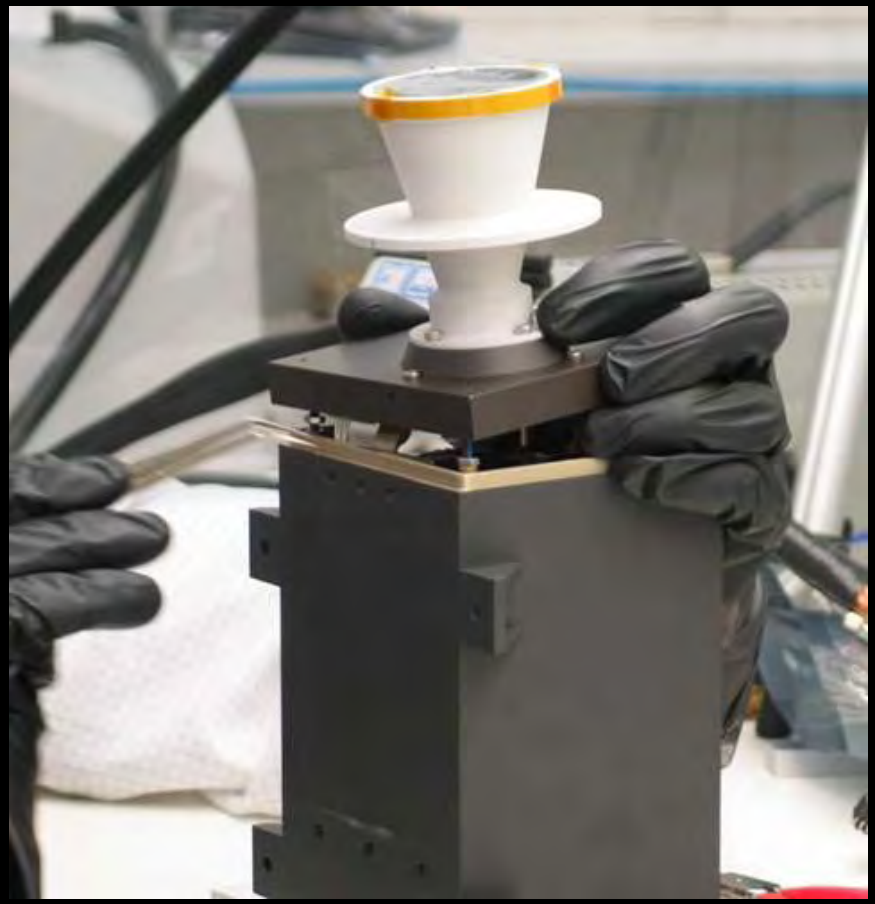
Unresolved problems:

- What was happening on Venus between its accretion and the formation of tessera terrain?
- Did Venus once have an ocean?
- Did plate tectonics ever occur on Venus?
- Is geological history "directional" or "non-directional" or some combination of these models?
- Is tessera terrain composed of thickened basaltic crust or of a different low-density material?
- Is Venus still volcanically and tectonically active?

Answering the last of the mentioned problems:

Is Venus still volcanically and tectonically active?

Answer: YES – given by the analysis of observations taken by Venus Monitoring Camera (VMC) onboard of ESA Venus Express.



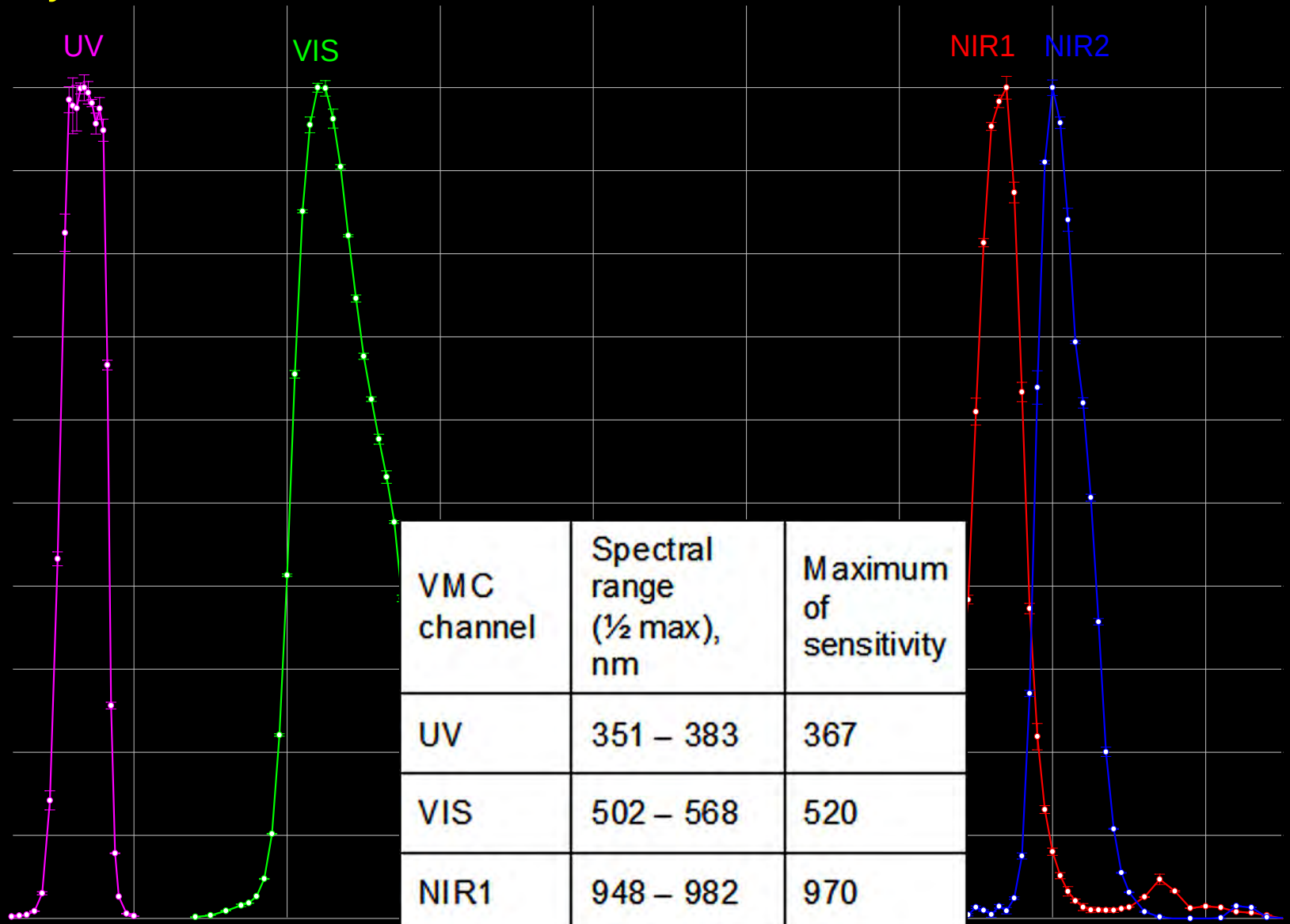
Science Goals

Dynamics

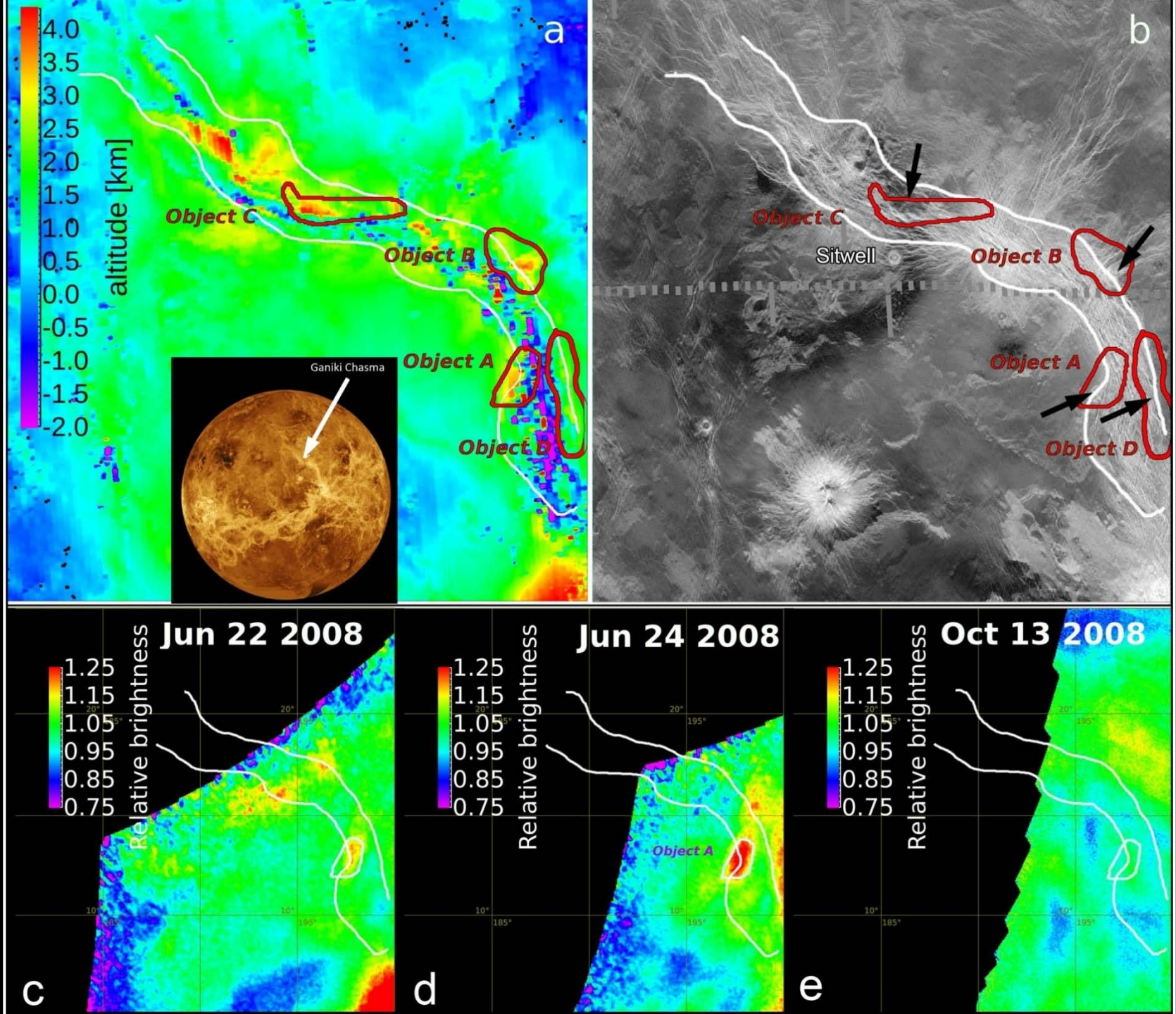
Airglow

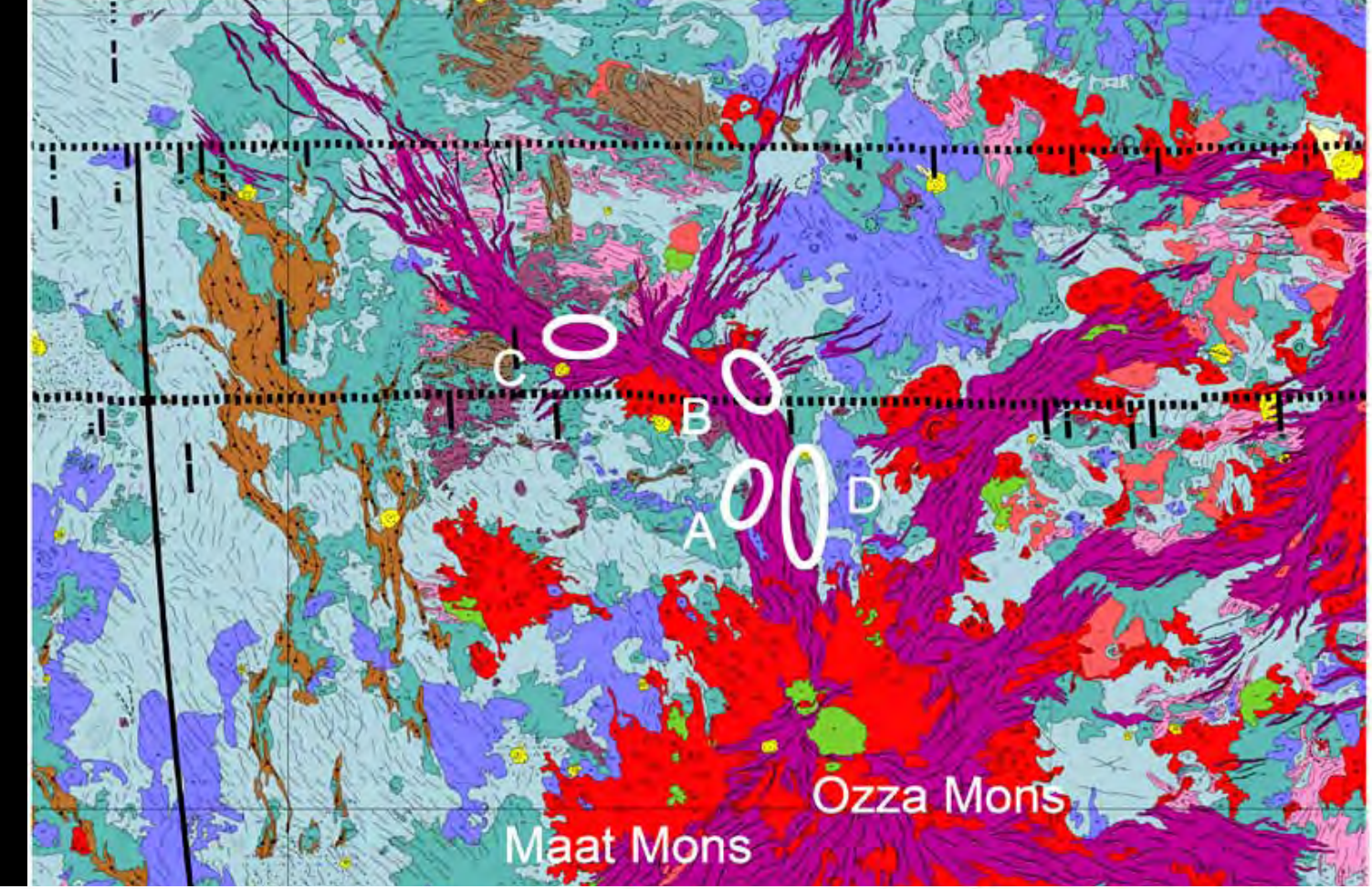
Water

Surface



VMC channel	Spectral range (½ max), nm	Maximum of sensitivity
UV	351 – 383	367
VIS	502 – 568	520
NIR1	948 – 982	970
NIR2	988 – 1025	1000


a
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
altitude [km]
Object C
Object B
Object A
Object D
Ganiki Chasma
b
Object C
Sitwell
Object B
Object A
Object D
c
Jun 22 2008
1.25
1.15
1.05
0.95
0.85
0.75
Relative brightness
d
Jun 24 2008
Object A
e
Oct 13 2008

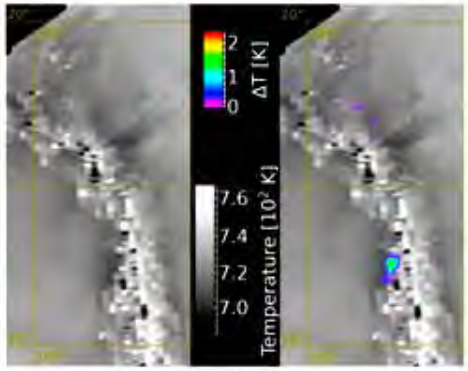


Geologic map of the study area

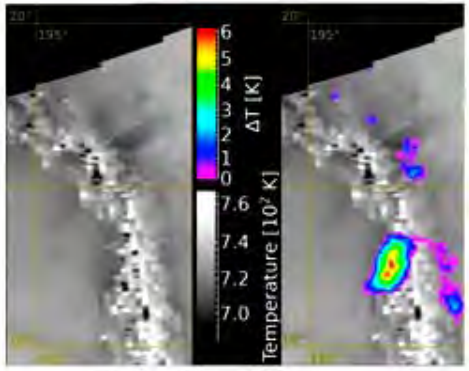
Legend for rift-associated units

- rz — rift zones
- pl — lobate plains material
- sc — shield clusters material

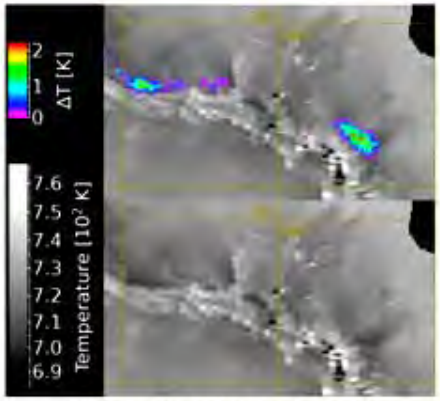
From: Ivanov and Head (2011) Planeary and Space Science, 59, 1559-1600.



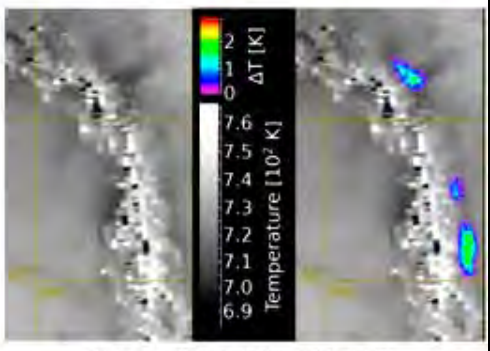
Object "A", orbit 793



Object "A", orbit 795



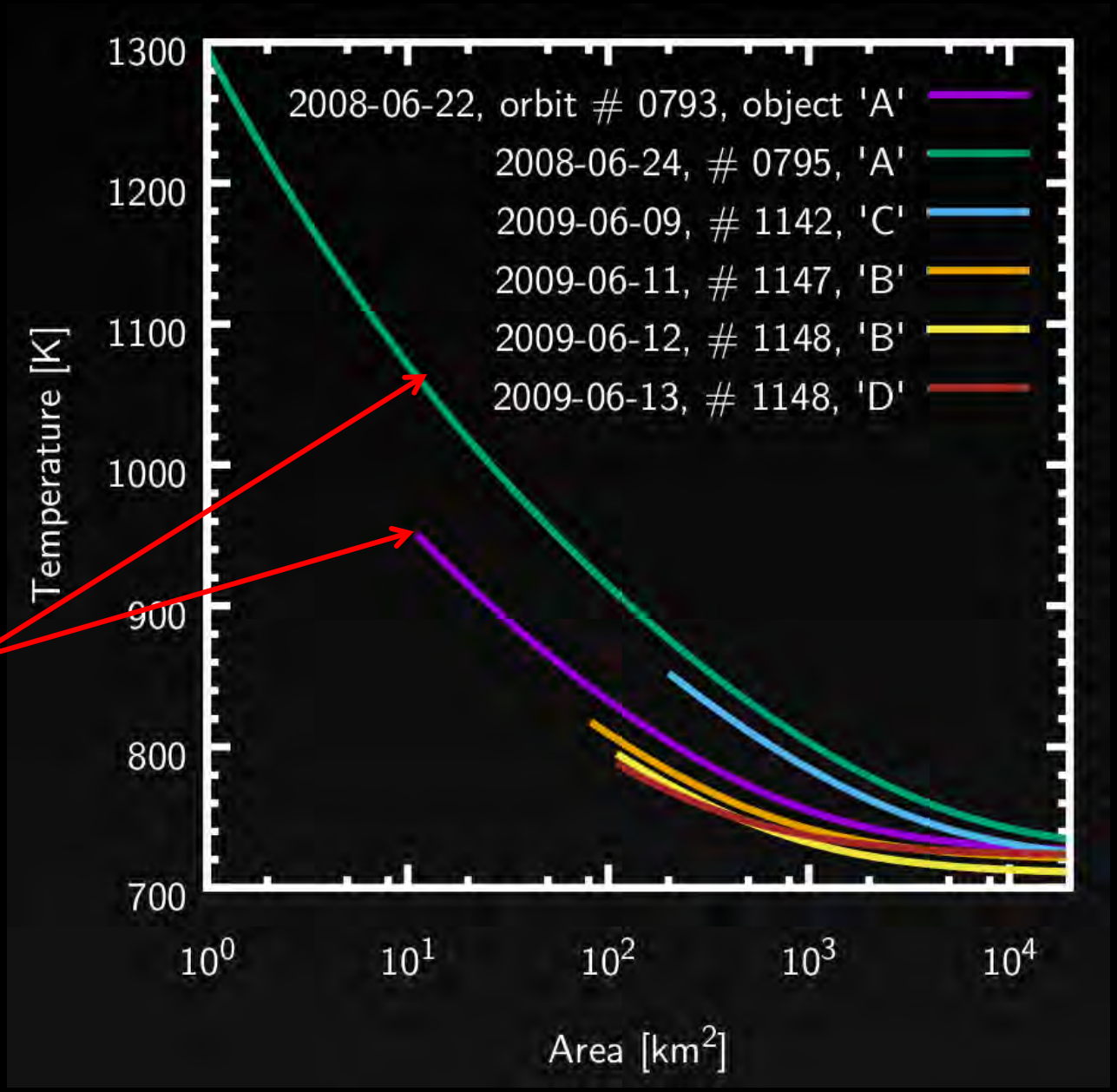
Objects "B" and "C", orbit 1147



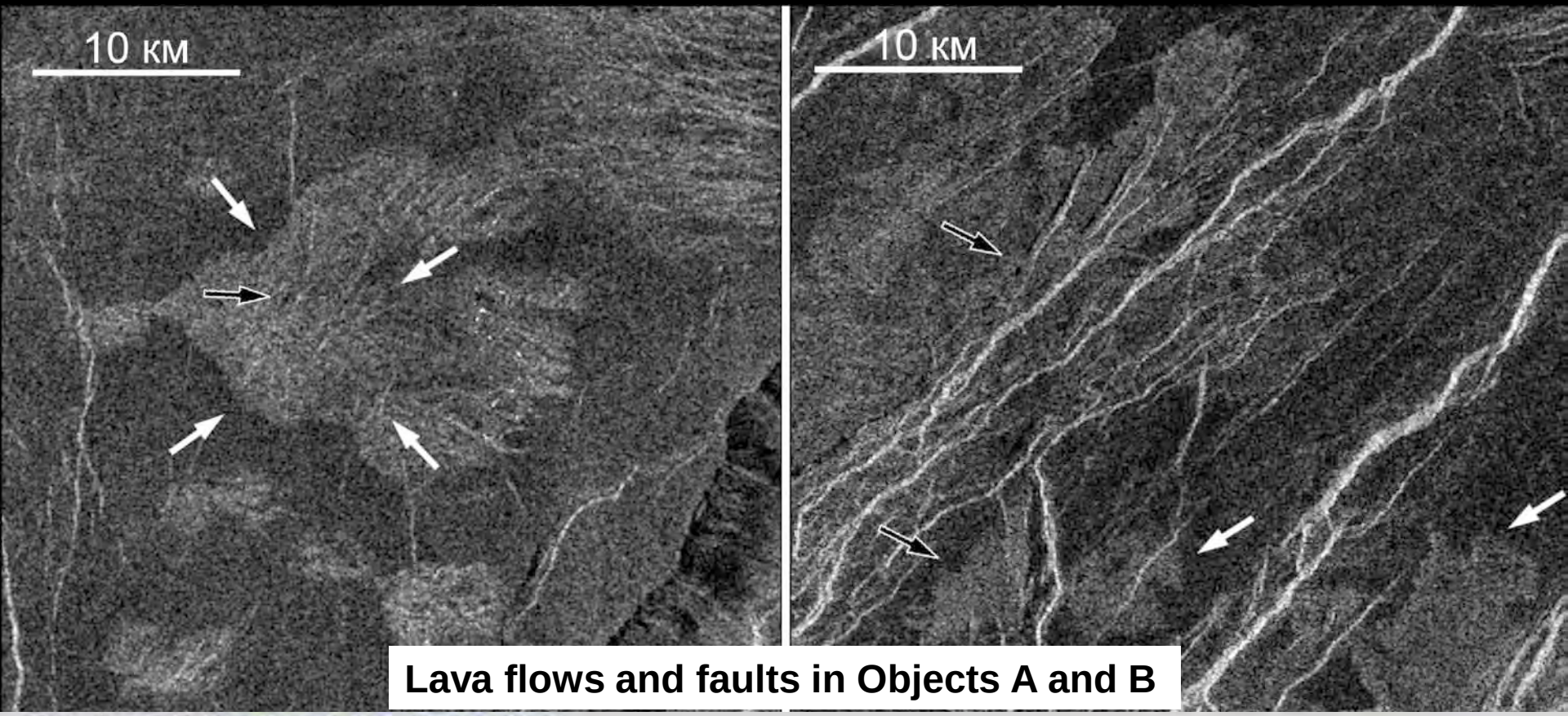
Objects "B" and "D", orbit 1148

Nyigagongo lava lake, East-African rift zone

1 km



Combinations of temperature and size of the hot spots that produce observed excess of the brightness



Lava flows and faults in Objects A and B

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Active volcanism on Venus in the Ganiki Chasma rift zone

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Thank you for your attention

Venus transit through the Sun disk 2004