PIECES OF PLANETARY GEOLOGY

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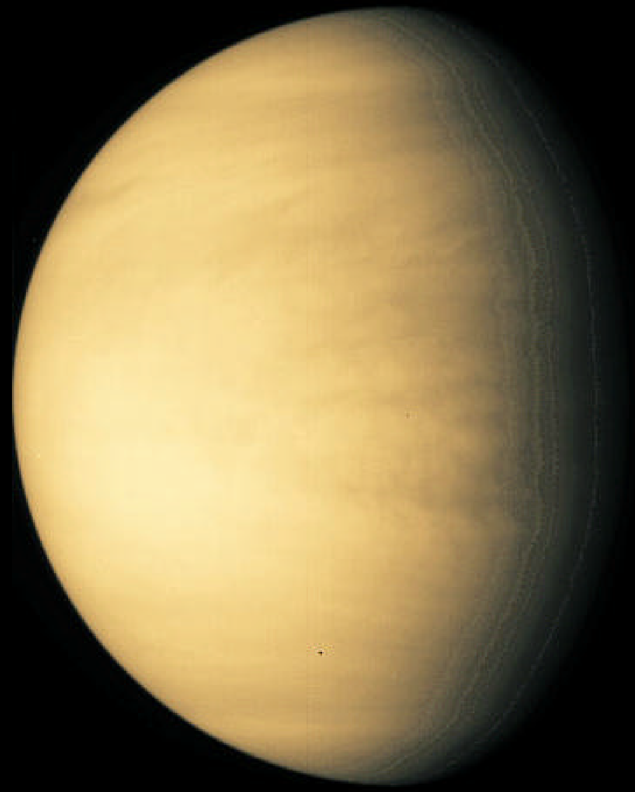
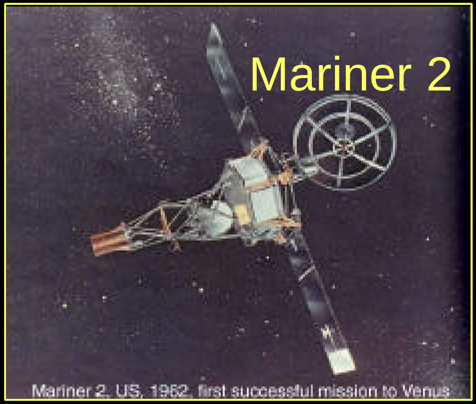
Venus exploration history

Distance to Sun 108,000,000 km (0.72 of Earth's)
Mean radius 6051 km (0.95 of Earth's)
Mass 4.87 x 10^{24} kg (0.81 of Earth's)
Bulk density 5.24 g/cm^3 (0.95 of Earth's)
Surface gravity 8.87 m/s^2 (0.91 of Earth's)



Expectations that Venus is very similar to Earth, somewhat warmer, and even hospitable for life

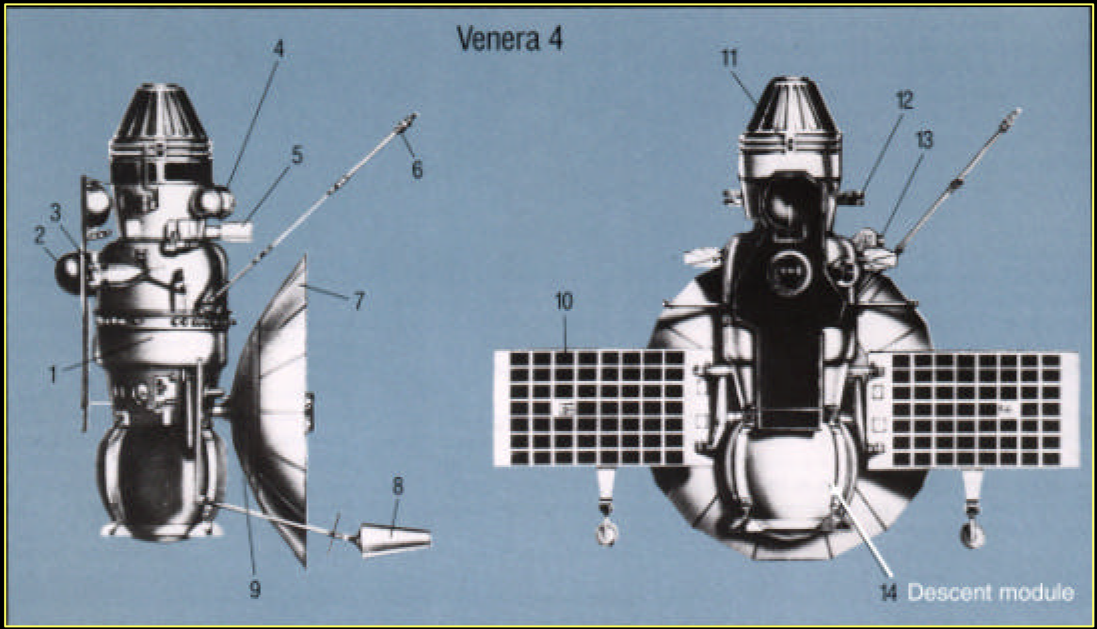
Successful missions to Venus



Mariner 2, US, 1962, first successful mission to Venus

Mariner 2, USA	1962	Flyby
Venera 4, USSR	1967	Entry probe
Mariner 5, US	1967	Flyby
Venera 5, USSR	1969	Entry probe
Venera 6, USSR	1969	Entry probe
Venera 7, USSR	1970	Soft landing, T, P
Venera 8, USSR	1972	Soft landing, K, U, Th
Mariner 10, USA	1974	Flyby on the way to Mercury
Venera 9, USSR	1975	Soft landing, TV panorama, K, U, Th
Venera 10, USSR	1975	Soft landing, TV panorama, K, U, Th
Pioneer 12 Orbiter, USA	1978	Global radar mapping, gravity
Pioneer 13 Entry, USA	1978	Entry probes
Venera 11, USSR	1978	Entry probe, soft landing, TV failure
Venera 12, USSR	1978	Entry probe, soft landing, TV failure
Venera 13, USSR	1982	Entry probe, soft land., TV, surface chemistry
Venera 14, USSR	1982	Entry probe, soft land., TV, surface chemistry
Venera 15, USSR	1983	Orbiter, radar mapping
Venera 16, USSR	1983	Orbiter, radar mapping
Vega 1, USSR	1985	Atm. baloon, soft landing, surface chemistry
Vega 2, USSR	1985	Atm. baloon, soft landing, surface chemistry
Galileo, USA	1990	Flyby on the way to Jupiter
Magellan, USA	1990	Global radar mapping, gravity

Venera 4, First successful entry to atmosphere



Cruise spacecraft

Entry probe

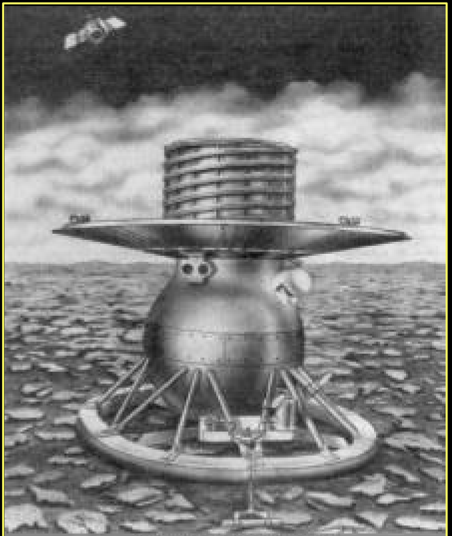
CO_2 (with admixture of N_2) atmosphere,
Composition and physics of clouds
Measurements down to 20 bar level

Expected to reach the surface: land or sea?

Venera 9 and 10 landers

Venera 9/10, USSR, 1975, first TV panoramas of Venus surface

First TV panoramas of Venus surface, Geochemical measurements: K, U, Th contents like in terrestrial basalts


Venera 9/10 lander

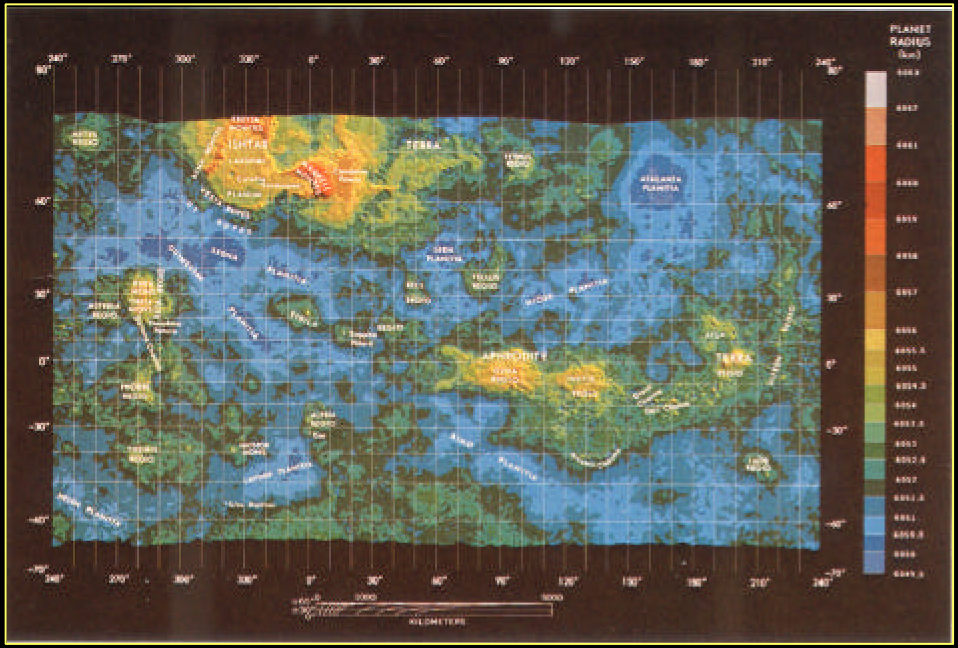

Venera 9


Venera 10

Pioneer Venus

Orbiter

Entry probes



Orbiter:
Global topography,
Radiophysical properties, Gravity

Entry probes:
Composition of atmosphere,
Enrichment in deuterium

Venera 13 and 14

TV panoramas

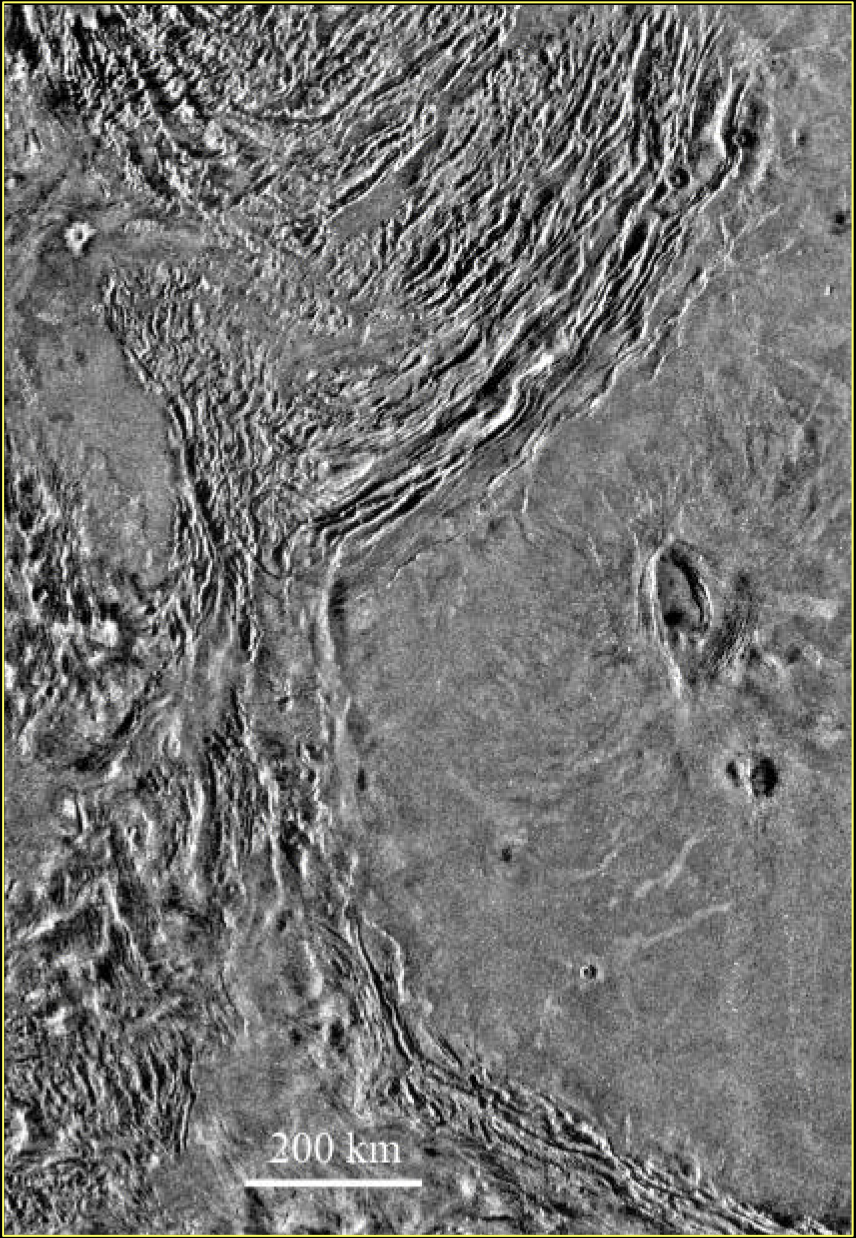
Geochemistry of surface material:
Alkaline V13 and tholeitic V14 basalts

Atmosphere probing

Venera 13

Venera 14, Lucky strike

Venera 15 and 16



Photogeology of Venus:

Vast basaltic volcanism

Intensive "horizontal" tectonics

Low abundancy of impact craters => 500 m.y. old surface

Magellan

Magellan, US, 1990, SAR images (100-200 m), radioph. properties, gravity

Future mission(s):

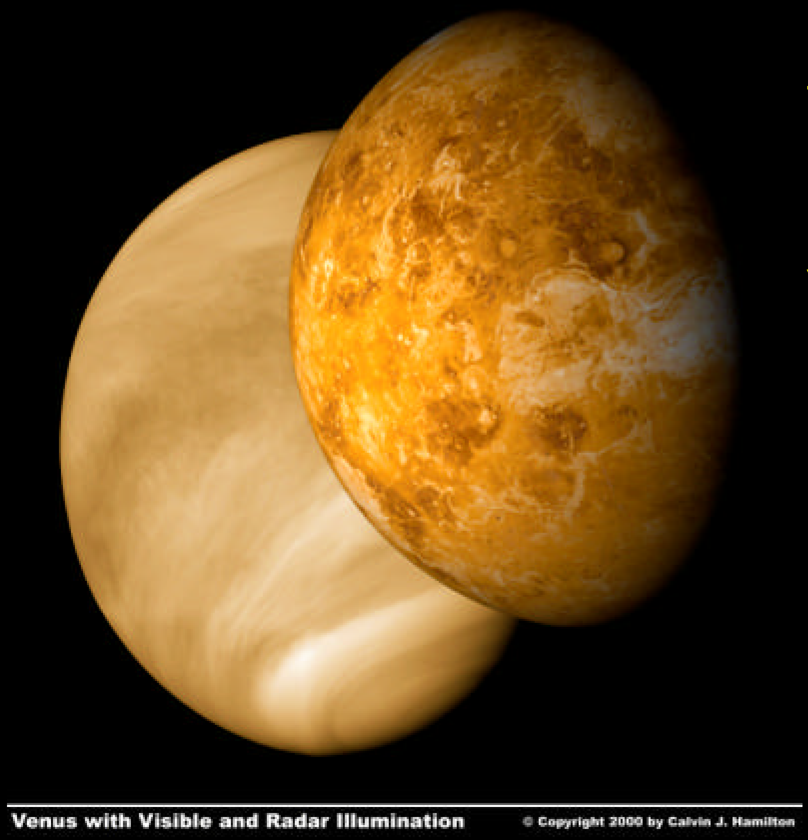
European Venus Express

Atmosphere studies
and
Long-wave radar
for subsurface sounding.

Will it fly?

What's next?

Venus geology and stratigraphy



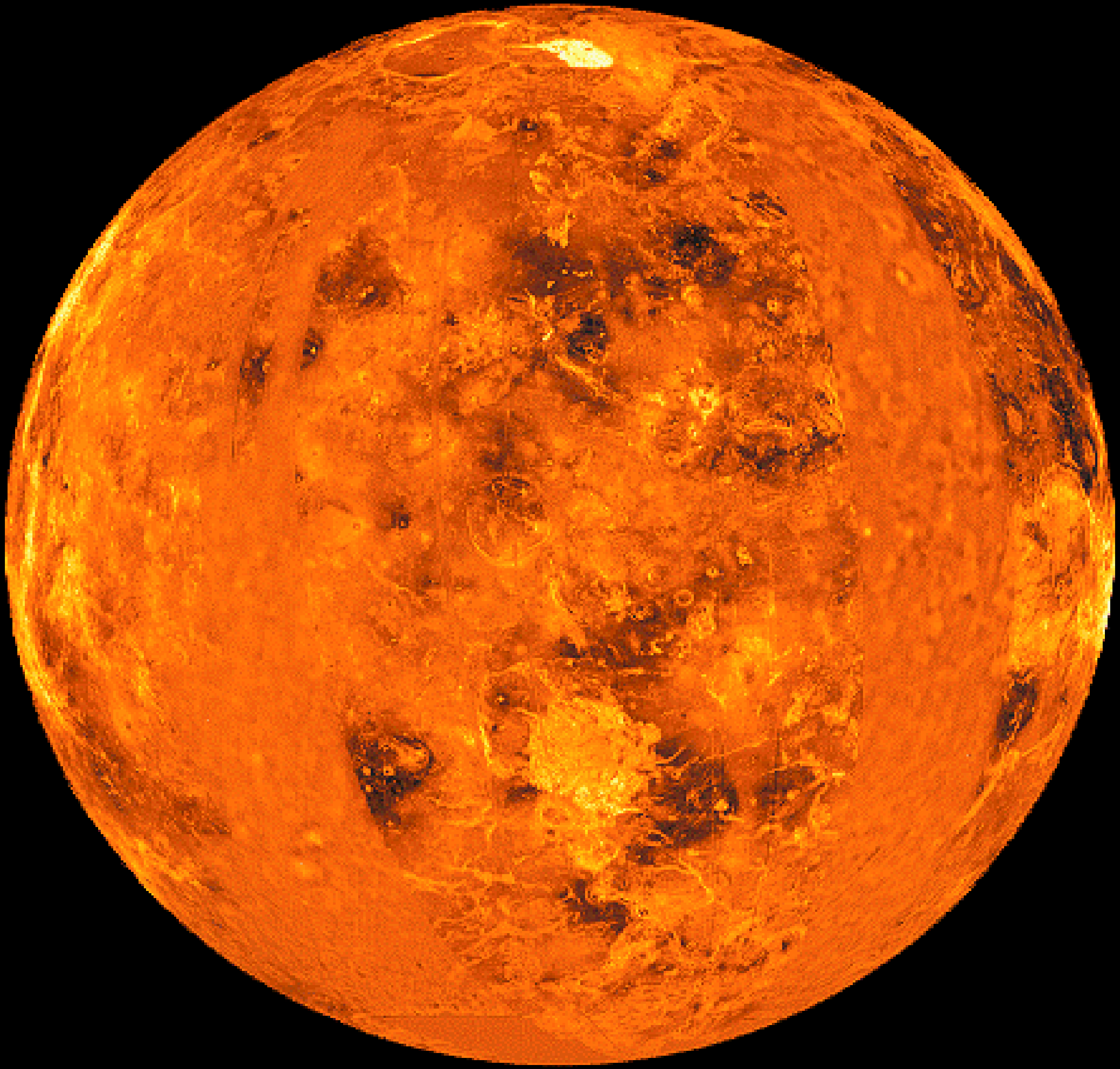
Venus is a planet very similar to Earth in size (R_V=0.95R_E) and mass (M_V=0.8M_E) that implies similarity in bulk composition and surface gravity.

Venusian atmosphere is CO_2 with minor N_2.
Surface pressure is ~90 bar, density 65 kg/m3.
Surface temperature +460^{o}C

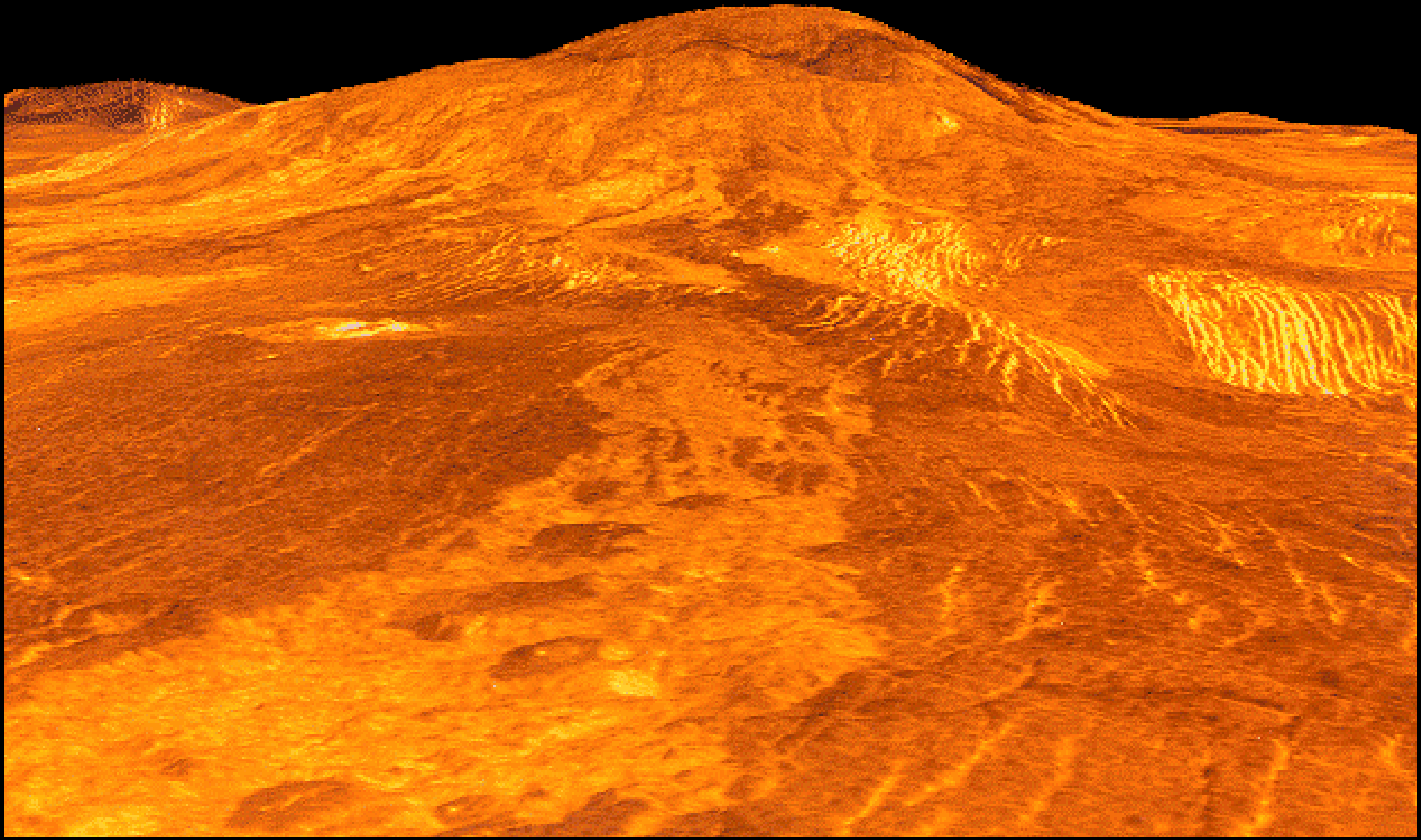
Cloud layers are at the heights of 50 to 70 km.
Clouds are droplets of concentrated H_2SO_4.
Strong zonal E=>W winds at high altitudes so clouds rotate around planet for 4 Earth's days

No liquid water on the surface, H_2O vapor in atmosphere ~100 ppm

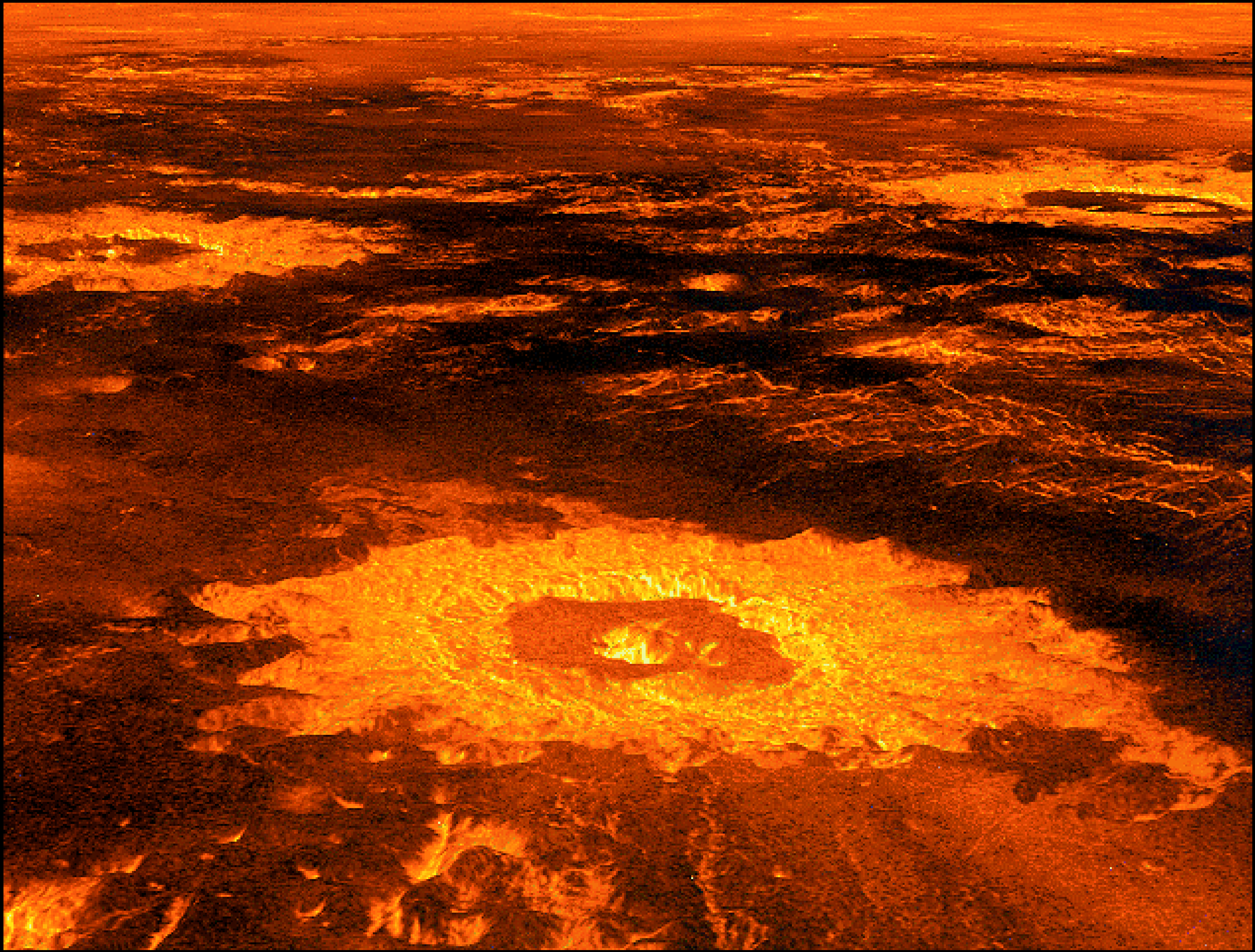
Global radar (Magellan) mosaics of Venus



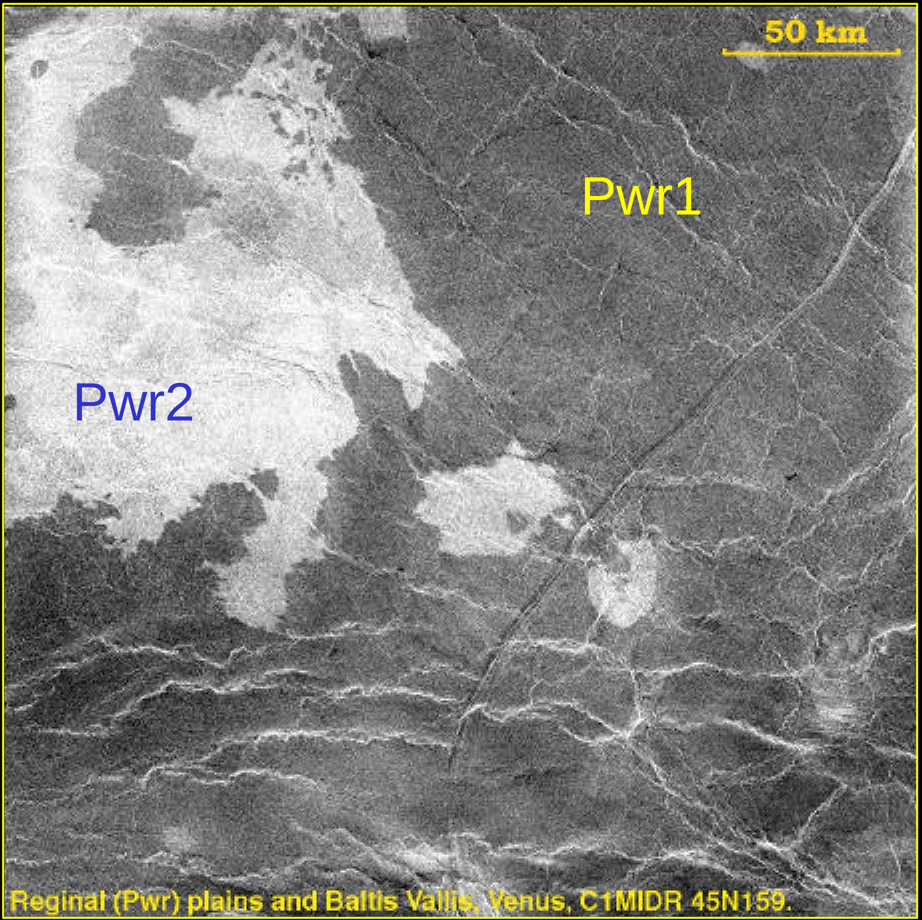
Sif volcano siiting on Guor Linea rift zone

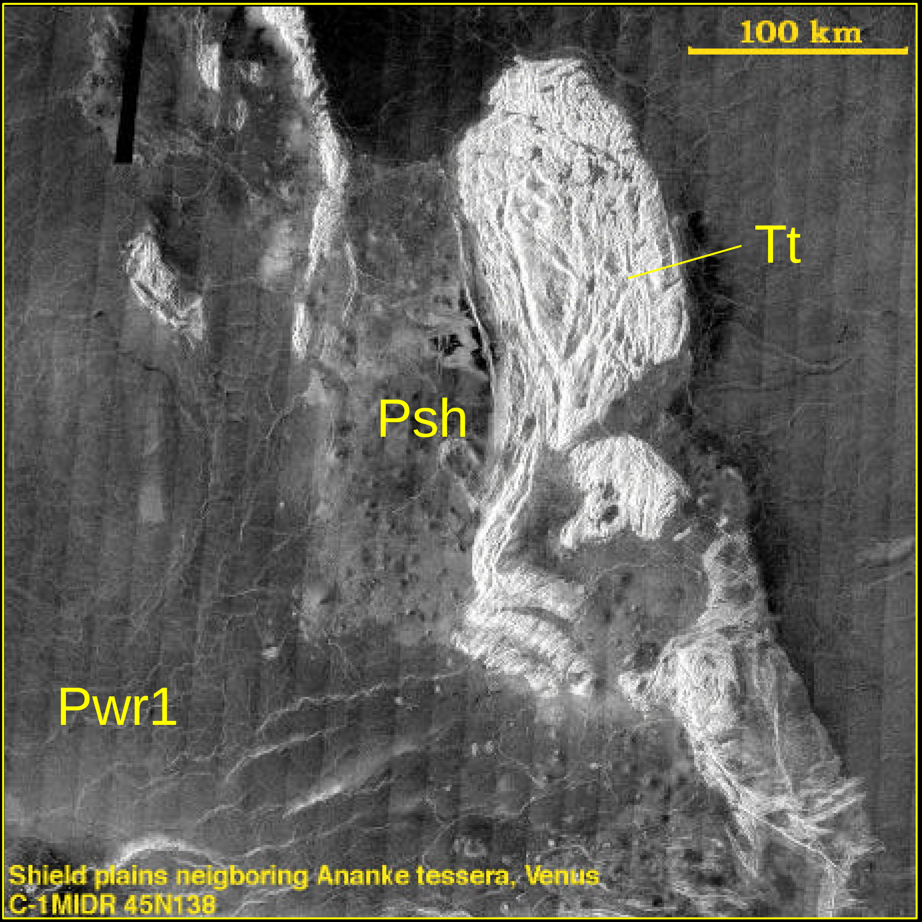


Crater farm – rare case of closely spaced impact craters



Regional plains





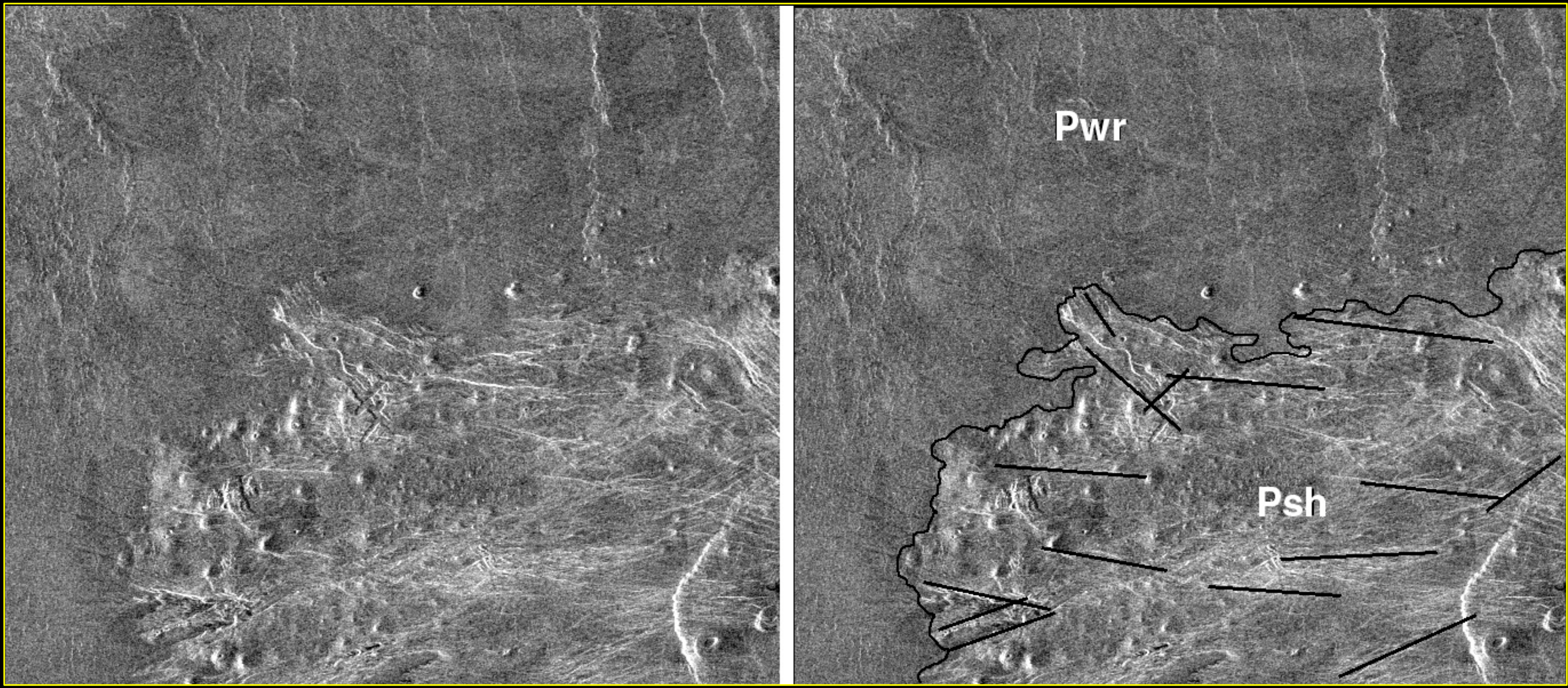
Occupy 70-75% of Venus surface. Present in two varieties:

Plains with wrinkle ridges Pwr (Venera 9, 10, 13, 14, Vega 1 and 2) and Plains with shields Psh (Venera 8). All made of basaltic lavas.

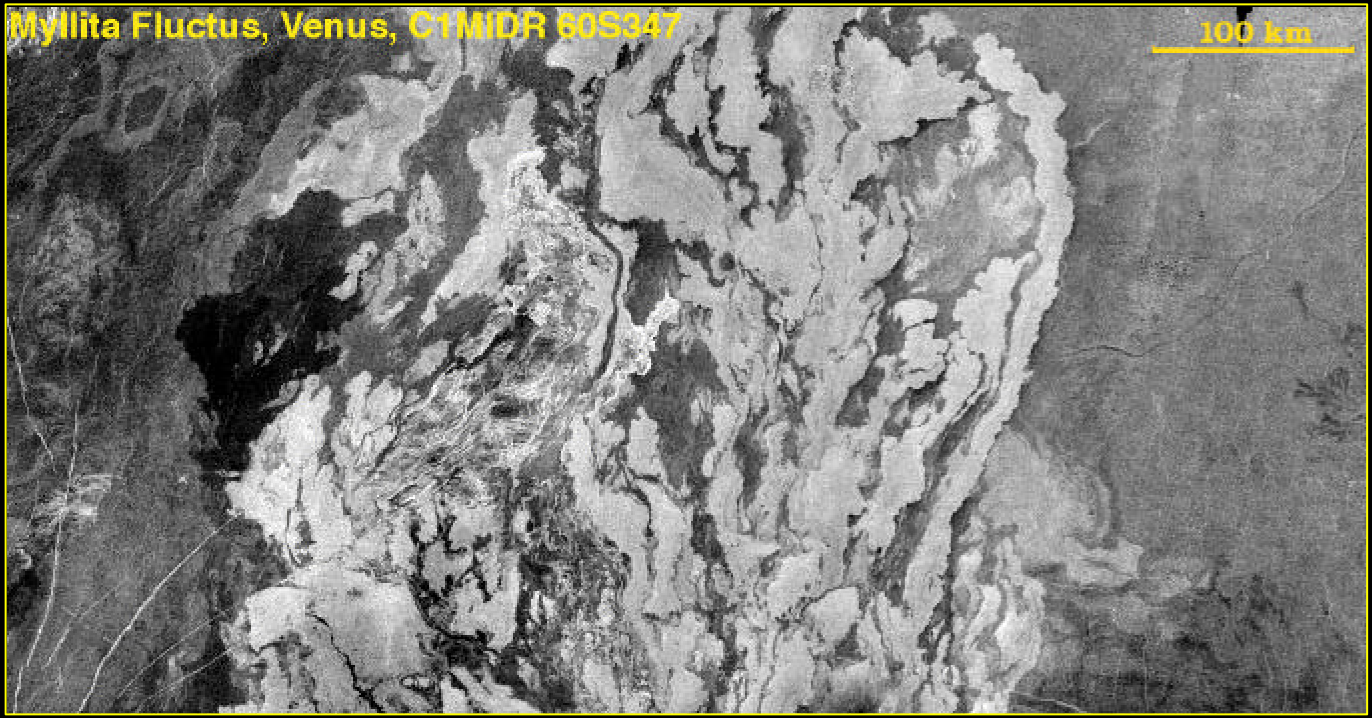
Widely deformed by wrinkle ridges (compression).

Their mean age is close to the mean surface age of the planet (0.5- 1 b.y.).

Plains with wrinkle ridges Pwr often embay Plains with shields Psh, so typically Psh is older than Pwr although opposite relations are also observed



Post-regional-plains volcanism

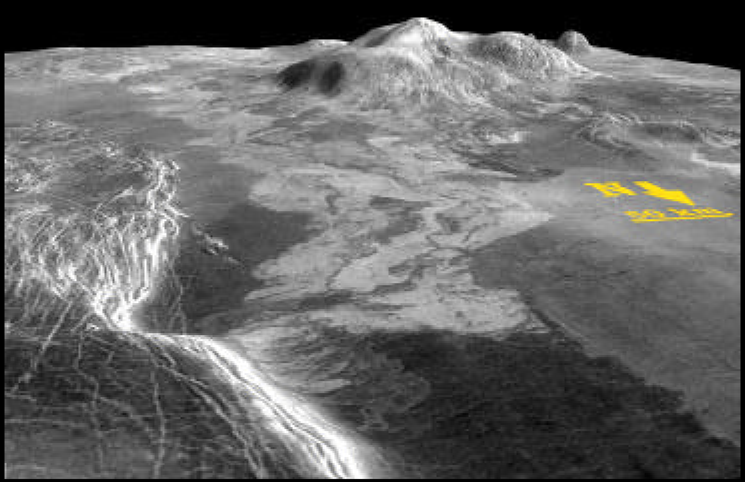


Two major types:
1) Plains-forming flows and
2) Volcanic constructs

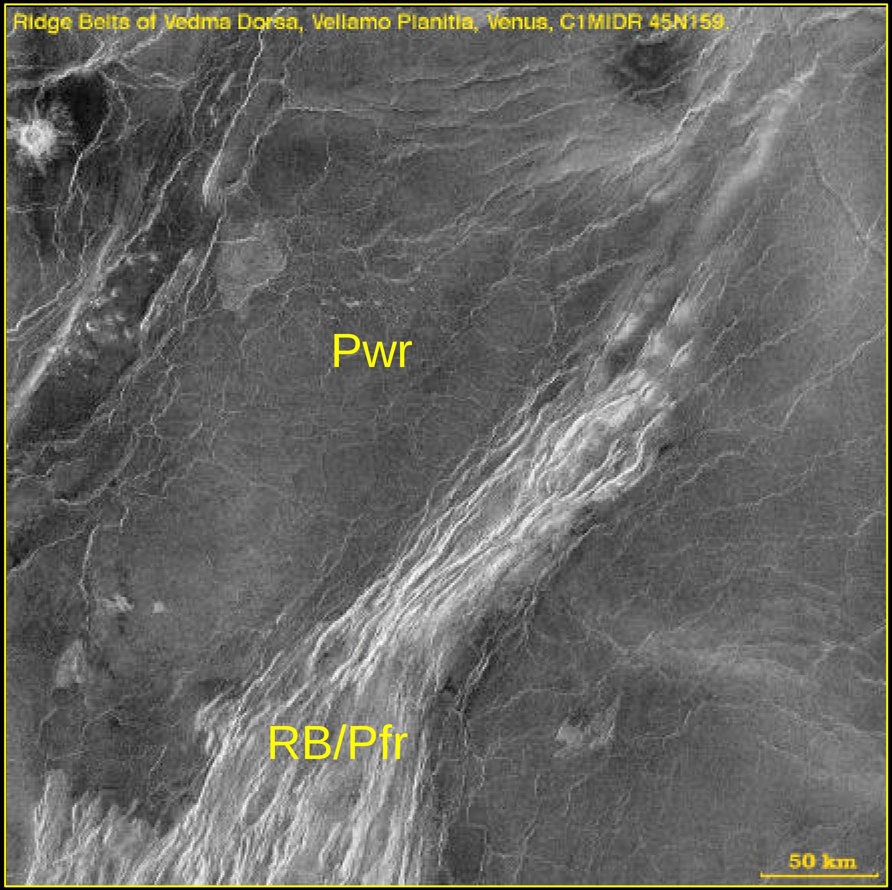
Plains-forming flows, some up to hundreds km long, typically associate with rifts and coronae.

Volcanic constructs, small, intermediate and large (>100 km in diameter), typically they are gentle sloped - basalts. Many of them are associated with rifts

Sekmet Mons volcano

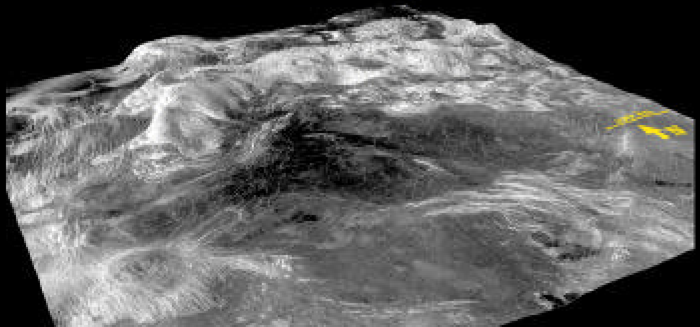


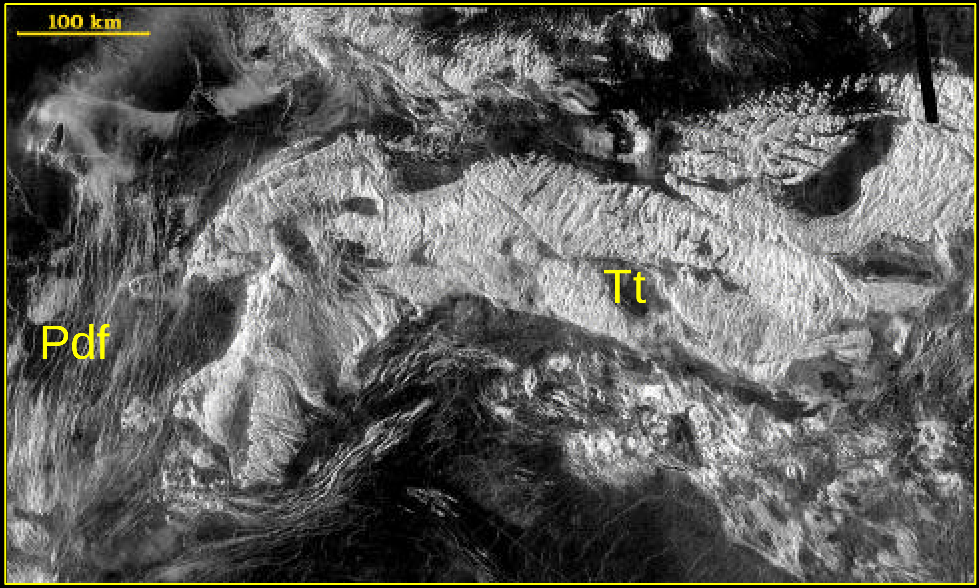
Pre-regional-plains formations



Three major types:
1) Ridge belts (RB/Pfr),
2) Densely fractured plains (Pdf),
3) Tessera terran (Tt)

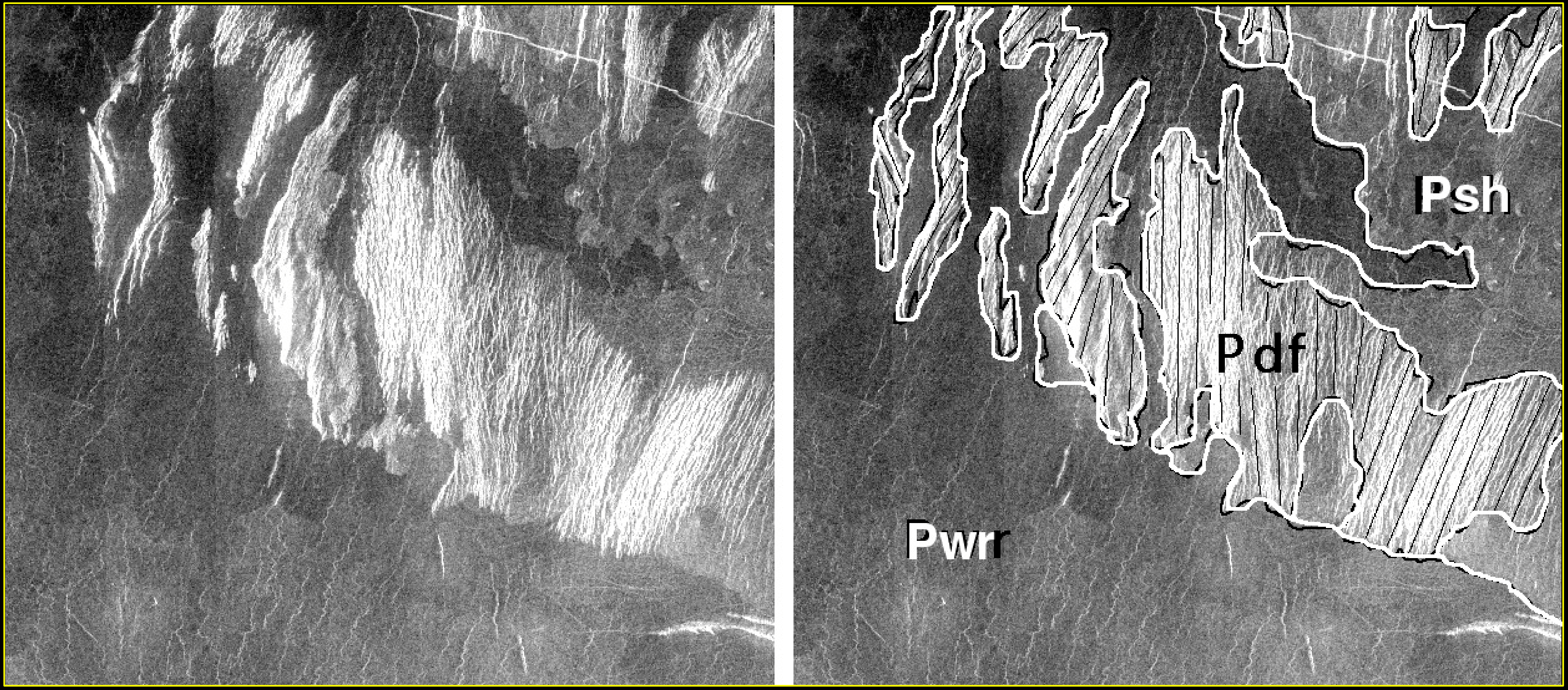
Tessera Meshkenet



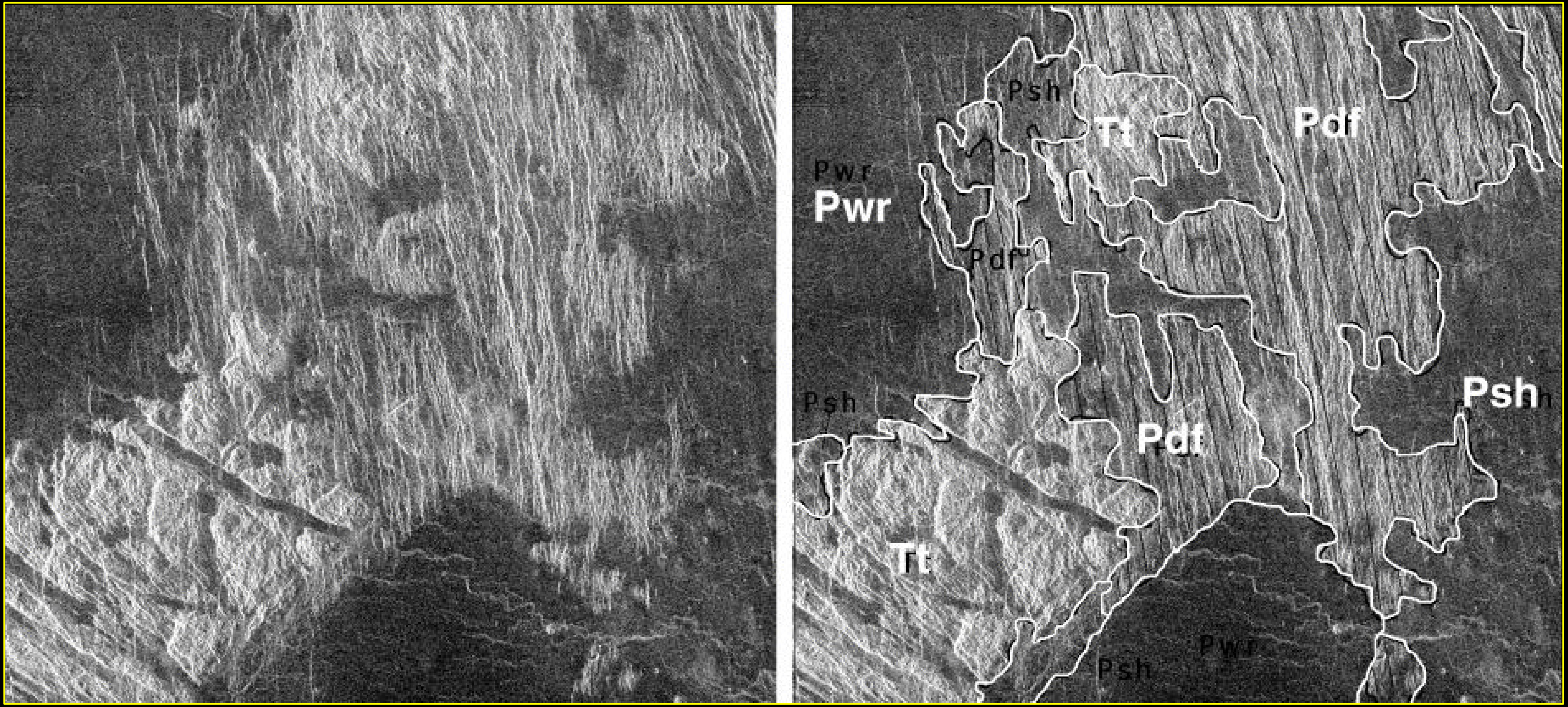


Tessera (Tt) and Densely fractured plains (Pdf)

Densely fractured plains Pdf are embayed by both Plains with wrinkle ridges Pwr and Plains with shields Psh

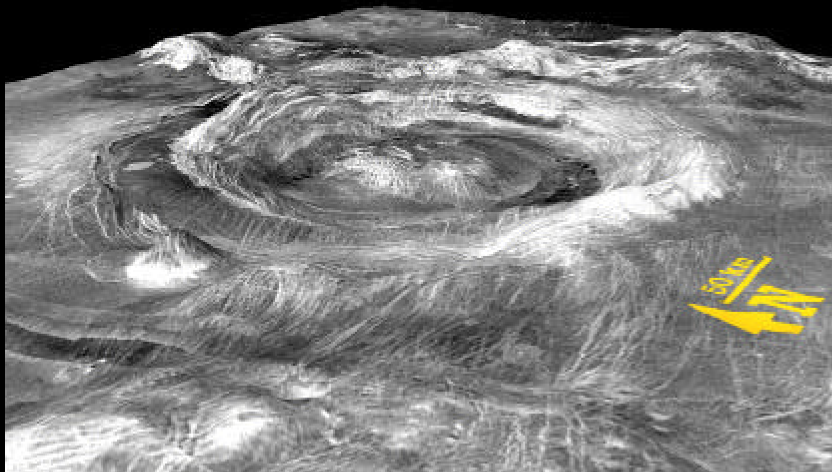


Tessera terrain Tt is embayed by Densely fractured plains Pdf, Plains with wrinkle ridges Pwr and Plains with shields Psh



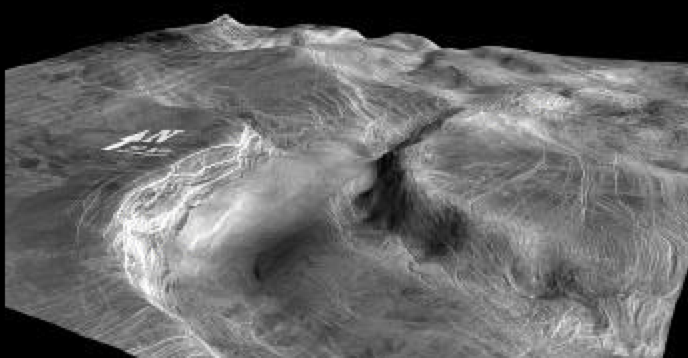
Tectonic structures

Corona Aramaiti

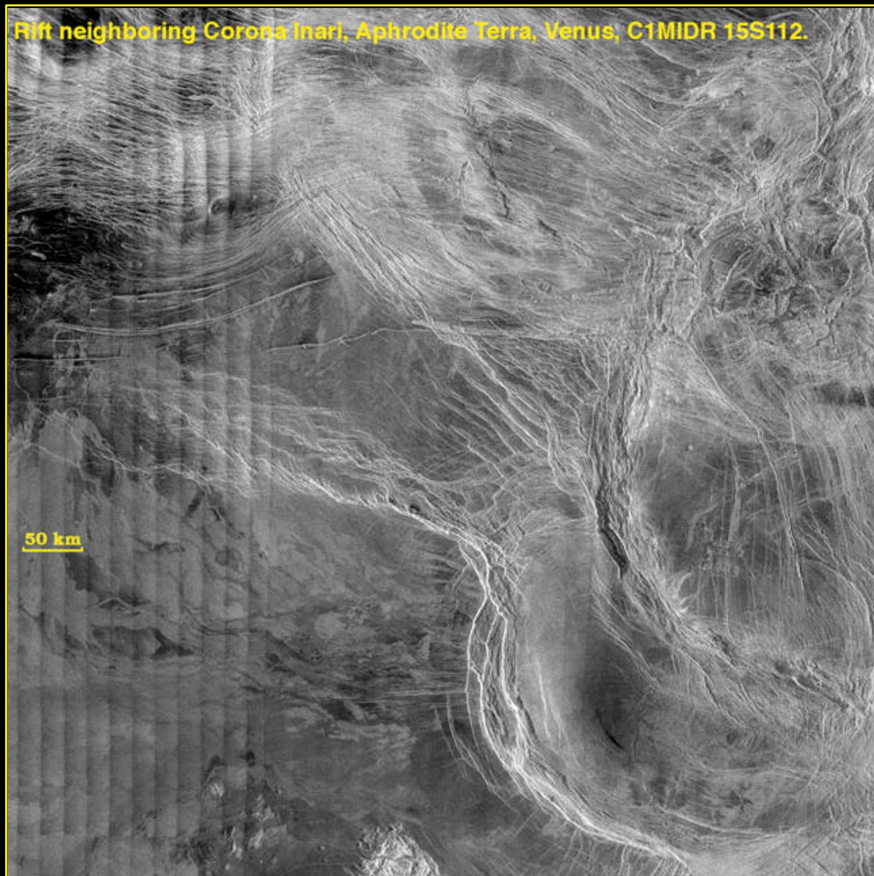


Coronae are circular features typically formed by several stages of tectonism and volcanism

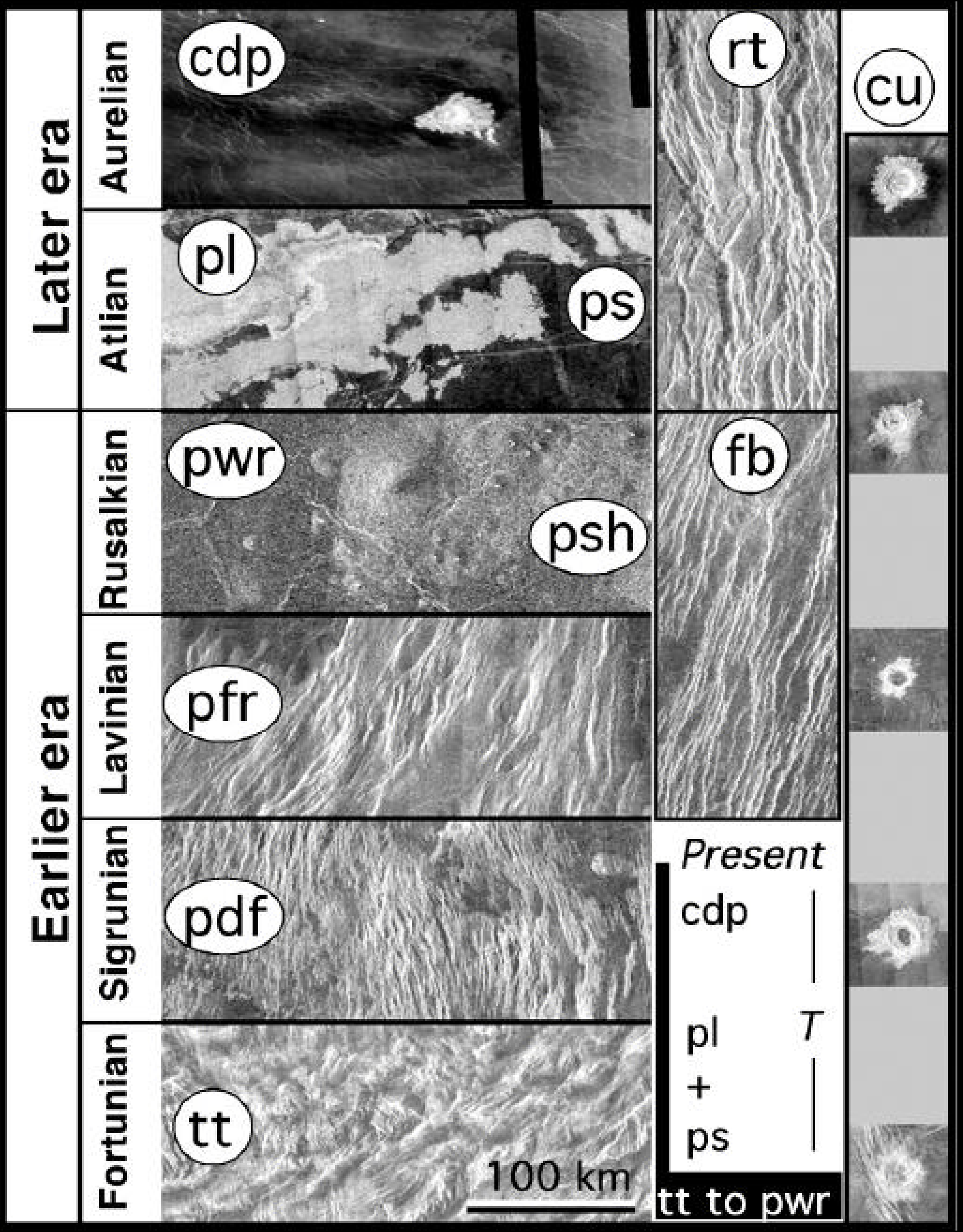
Rift neighboring Corona Inari, Aphrodite Terra



Rifts consist of swarms of grabens and fractures, young rifts form topo-graphic troughs, resemble continental rifts of Earth.



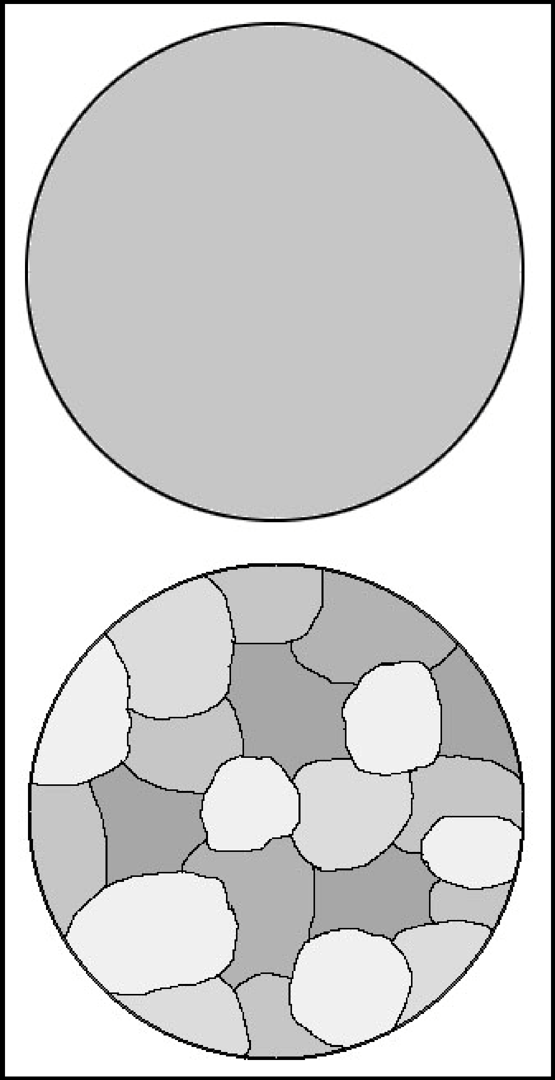
Rift neighboring Corona Inari, Aphrodite Terra, Venus, C1MIDR 15S112.

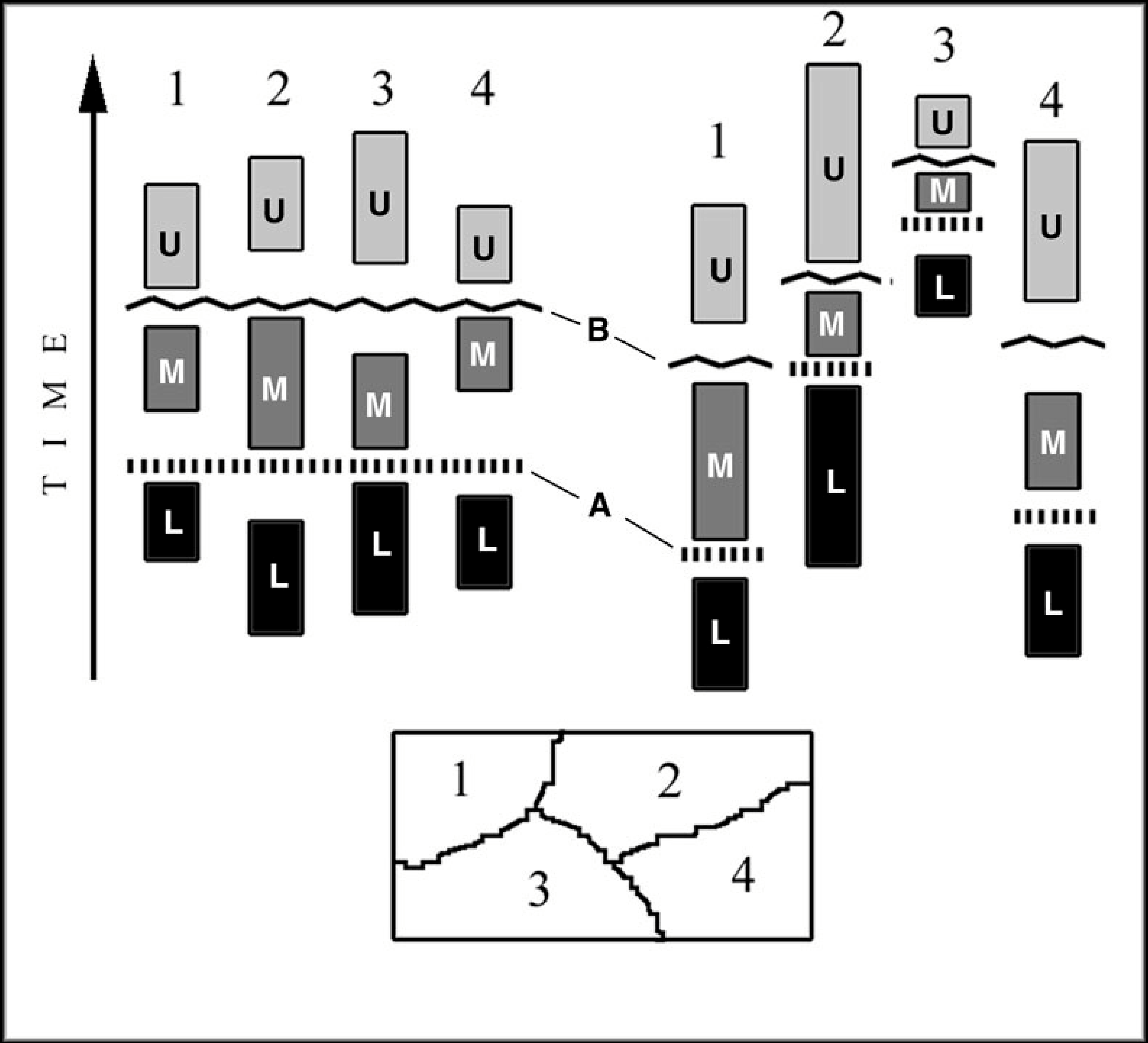


Venus stratigraphy as inferred from the observed age relations of the geologic units

Basilevsky and Head, 1995, 1998, 2000; *Head and Basilevsky*, 1998

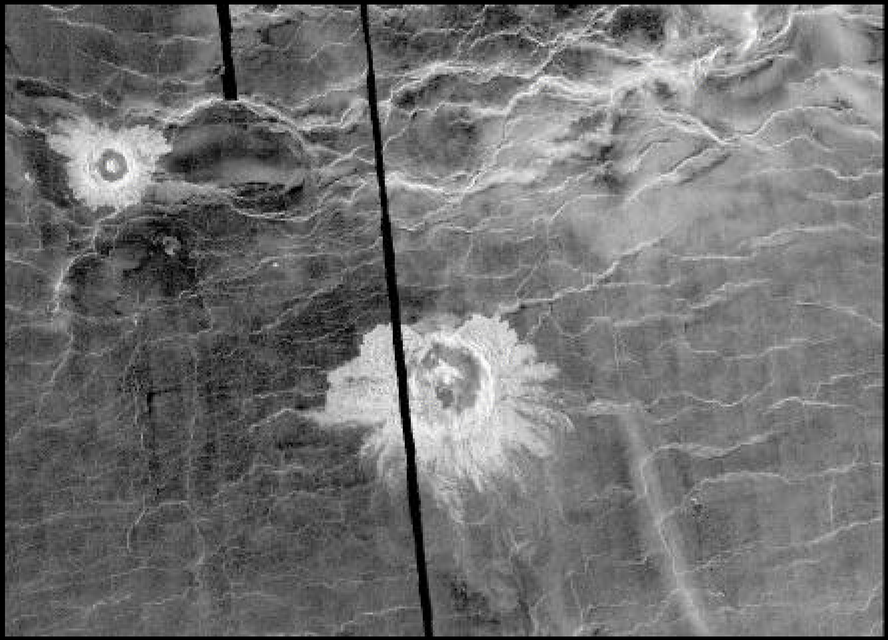
Synchronous v.s. Diachronous controversy





In diachronous case numerous violations of consistency of the established sstratigraphic relations should be observed

Estimation of time interval between the emplacement of Pwr and Psh lavas and their wrinkle ridging



Central-peaked craters Barto (48 km) and Valentina (26 km) both superposed on Pwr plains and wrinkle ridges

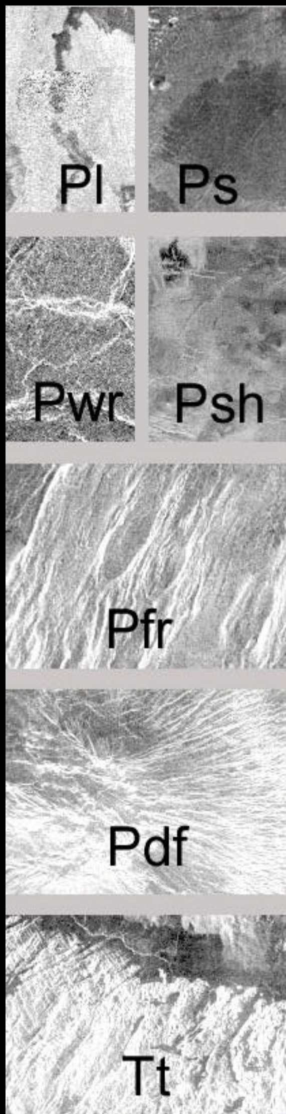
Craters superposed on Pwr+Psh regional plains may postdate wrinkle ridges (Barto) and may predate them (Barrymore).

Double-ring crater Barrymore (57 km) superposed on Pwr plains but cut by wrinkle ridges

Total number of craters superposed on Pwr+Psh regional plains ~650 Among them only 7 craters are cut by wrinkle ridges, the rest postdate both plains material and wr. ridges

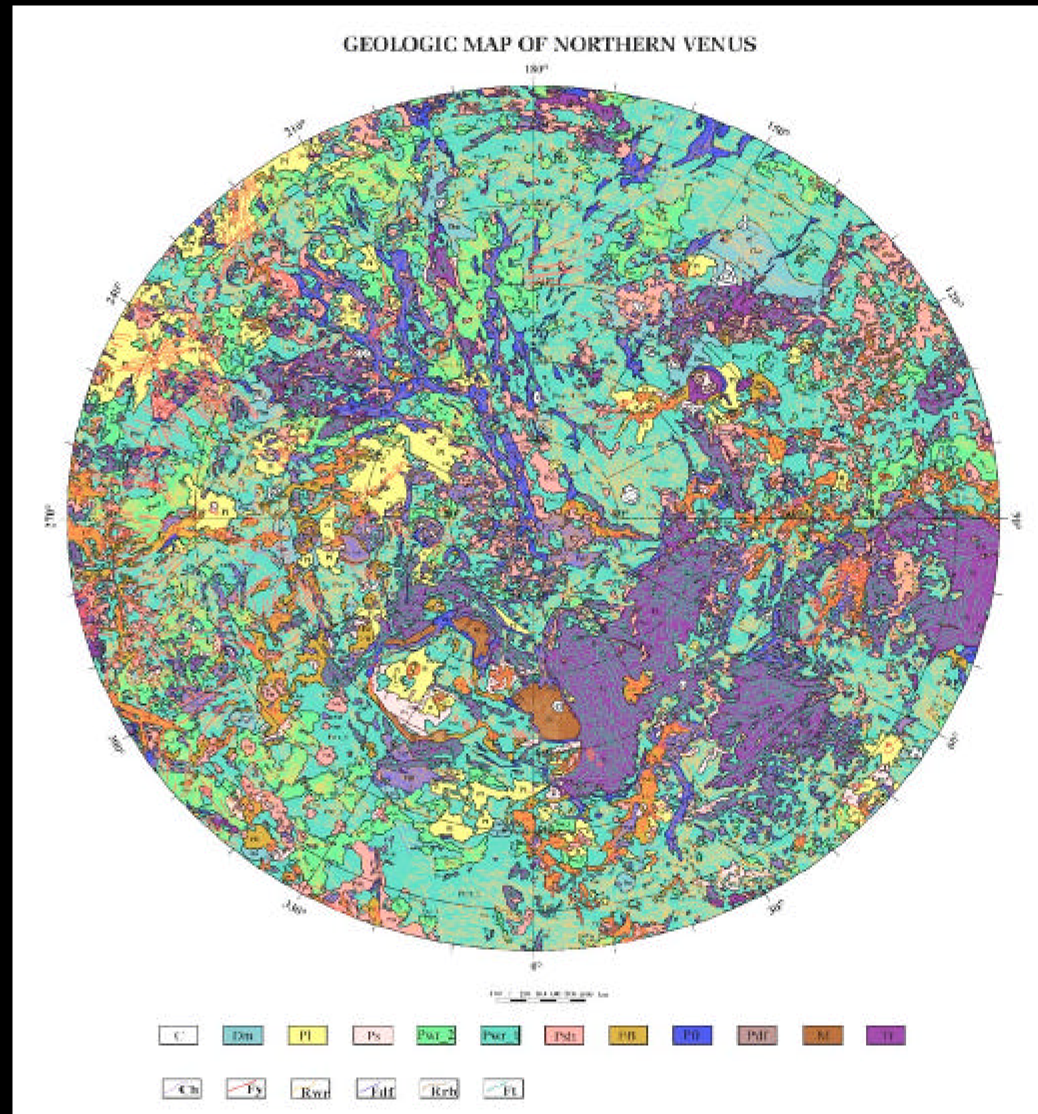
If age of regional plains is T, time interval between emplacement of regional plains lavas and their wrinkle ridging is ~1% of T.

If age of regional plains is T how large or small is time interval of formation of pre-regional-plains units?

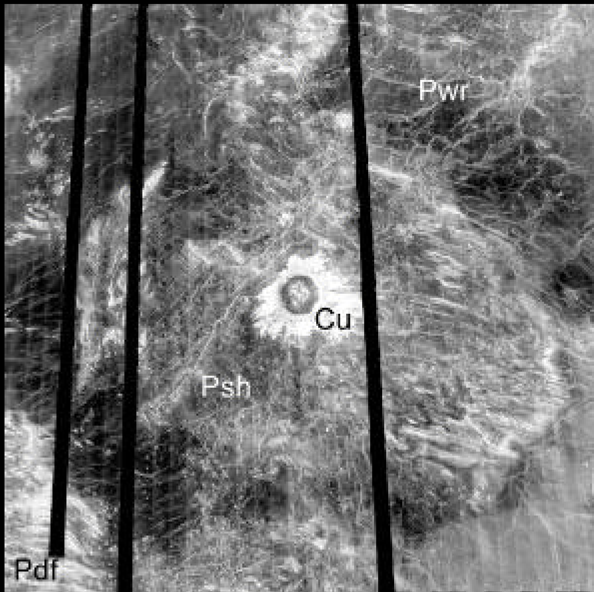


T

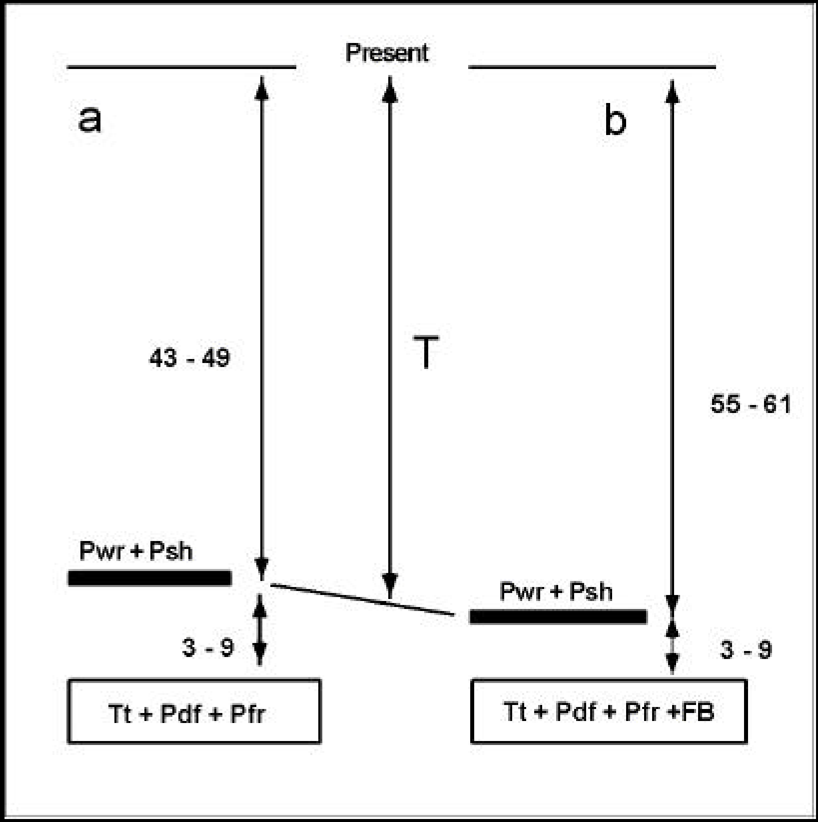
How long?



Craters on geologic units of Northern Venus



Unit	Craters on the unit	Including on younger ones
DM/Pl/Ps	18	0
Pwr/Psh	106	17
FB/Pfr/Pdf	43	41
Tt	21	16



New data:

Craters sup. on Pdf+Pfr = 146
Among them superposed on Pwr+Psh = 127
Predate Pwr and Psh £ 19
DT £ **19/127**

The time interval between the formation of Tt+Pdf+Pfr±FB and the end of emplacement of regional plains D**T** should be geologically short, from a few % to about 20% of T, (*Basilevsky et al*., 1999)

New study extends this conclusion for all Venus,
Pivchenkova & Kryuchkov, 2001

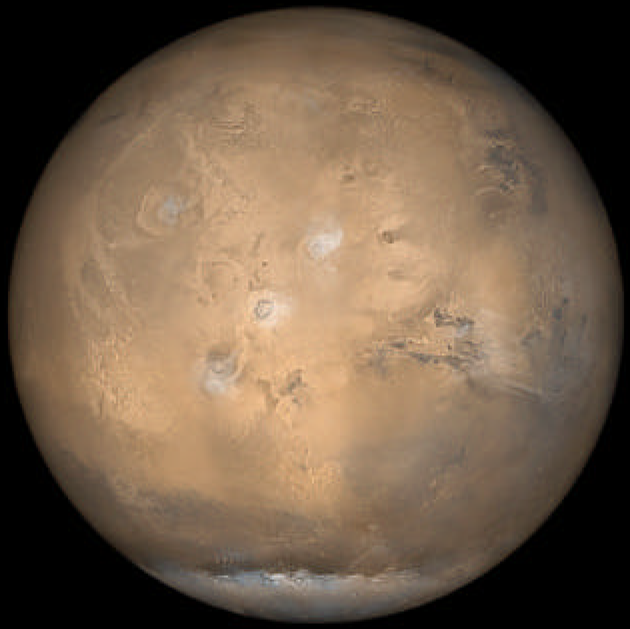
Venus geologic history

We see in morphology only the last 20% of the planet history: 0.5-1 b.y from 4.5 b.y. of the planet life

In the beginning of it, there was intensive mean tectonic and volcanic activity (Tt + Pdf + Pfr + Psh + Pwr + FB) then changed by long period of the activity (Pl + Ps + RT) with much smaller mean rates.

The activituy called “intensive” was as intensive as globally averaged volcanic and tectonic activity of Earth in modern geologic epoch.

Mars mineralogy



Late northern summer on Mars,
Wide angle MOC MGS

Igneous mineralogy

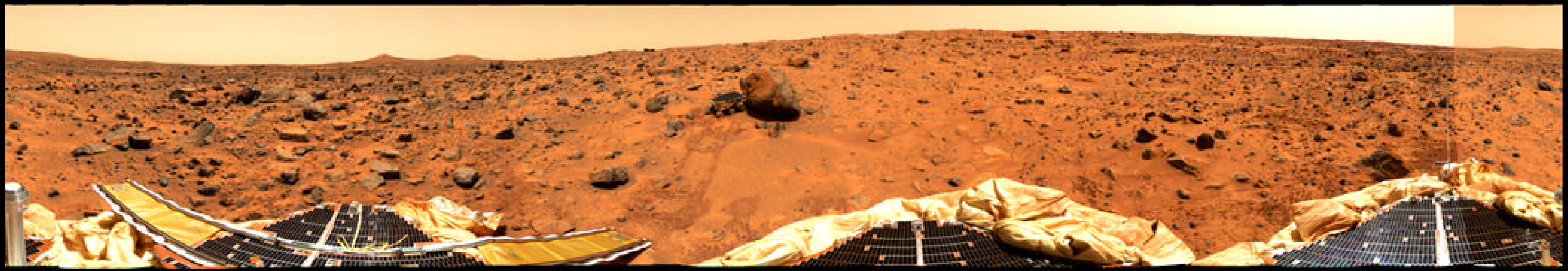
Minerals of igneous rocks of Mars

Surface mineralogy

Sediments and soils

Seasonal and perennial mineralogy

Ices and frosts



Pathfinder Gallery panorama

Igneous mineralogy

Shergotty-Nakhla-Chassigny (SNC) meteorites

Diabase Clinopyroxenite Dunite

= mafic/ultramafic association

Shergotty, Zagami, EETA 79001, ALHA 77005

- Pyroxene pigeonite $En_{60}Fs_{28}Wo_{12}$ - $En_{21}Fs_{61}Wo_{28}$
- Pyroxene augite $En_{48}Fs_{20}Wo_{32}$ - $En_{25}Fs_{47}Wo_{28}$
- Maskelenite (plagioclase glass) $An_{57}Ab_{42}Or_{1}$ - $An_{43}Ab_{53}Or_{4}$
- Olivine
- Chromite

Nakhla, Lafayette, Governador Valadares

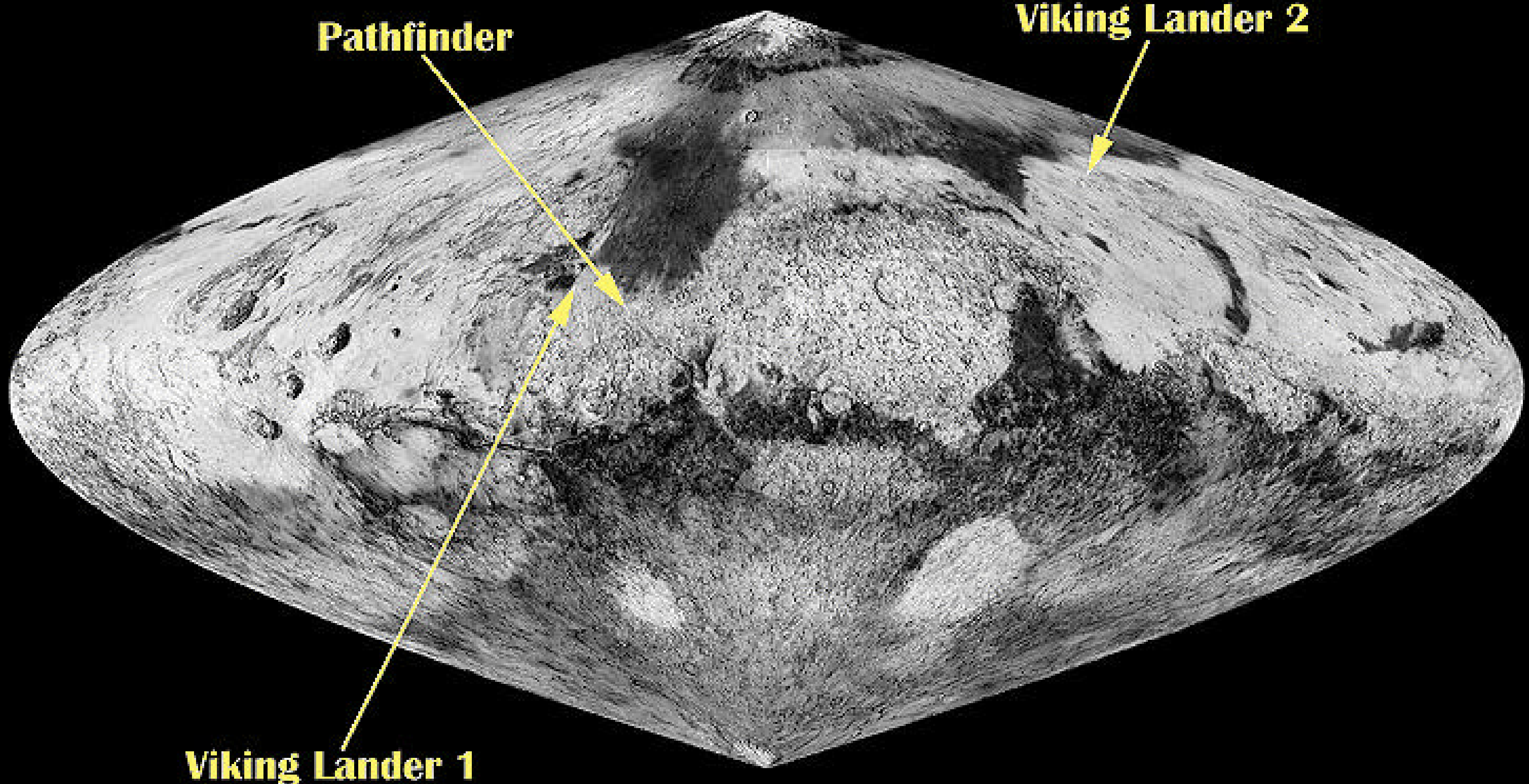
- Pyroxene augite $En_{38}Fs_{23}Wo_{39}$ dominant phase
- Olivine Fa_{65-67}

Chassigny

- Olivine Fa_{32} dominant phase
- Augite, Orthopyroxene, Silica glass

If andesites are on Mars, low-Ca plagioclases may present

Landing sites on Mars



Surface mineralogy

Soil: Viking results, % by weight: X-Ray Fluorescence Analysis

Gas Chr/ Mass Sp: H_2O up to 1%

Const,	Chryse fines	Chryse clod	Utopia fines
SiO_2	43	42	43
Al_2O_3	7.3	7	43
Fe_2O_3	18.5	17.6	17.8
MgO	6	7	6*
CaO	5.9	5.5	5.7
K_2O	<0.15	<0.15	<0.15
TiO_2	0.66	0.59	0.56
SO_3	6.6	9.2	8.1
Cl	0.7	0.8	0.5

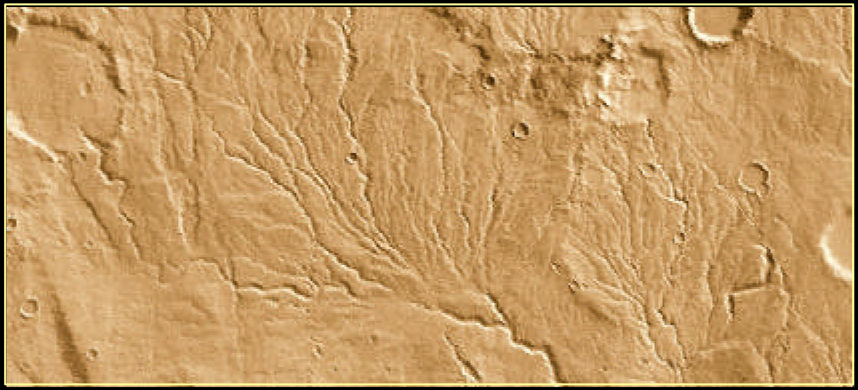
Multicomponent mixture of weathered and unweathered minerals:

Unweathered:	Mafic minerals
Weathered:	Smectite clays, palagonite and/or scapolite
Iron	Amorphous and crystalline oxyhydrates
Accessories	Sulfate and chloride salts
Carbonates	Very low, if any
Organic material	No

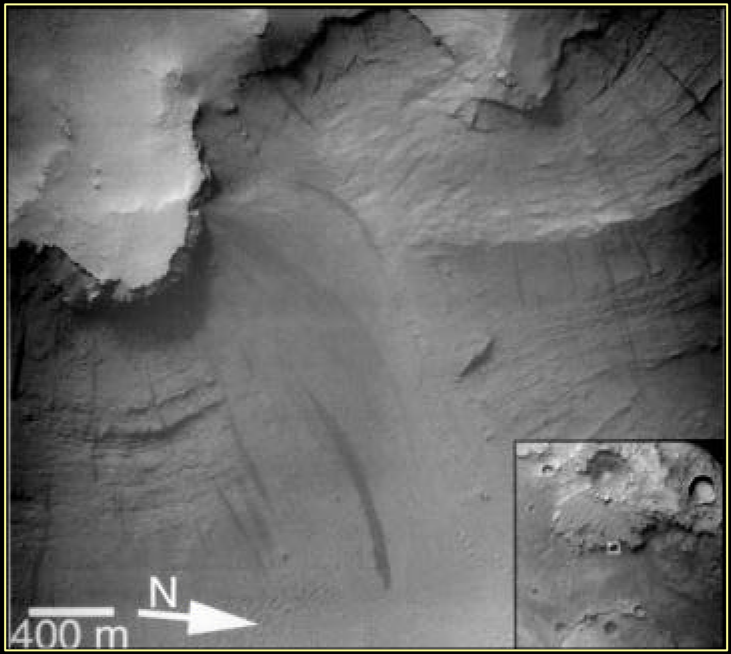
Banin et al., 1992

Surface mineralogy, cont.

Surface water => sediments



Valley networks, Southern highlands



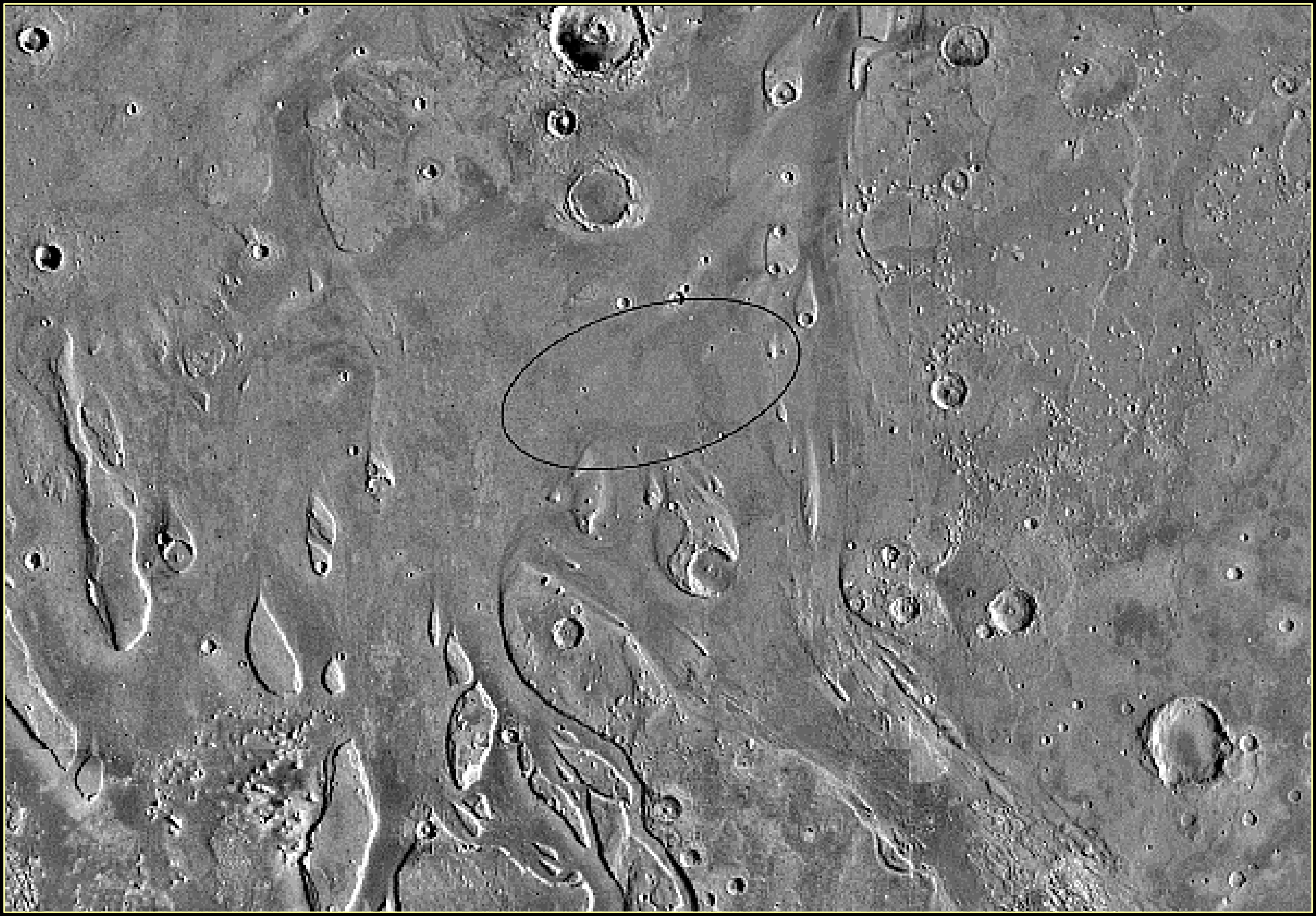
Layered sediments, Arabia

Crater Yuty with mud-flow ejecta

Morphological evidence of surface water and sediments implies H_2O-involved chemical weathering, water-laid deposition and formation of evaporites:

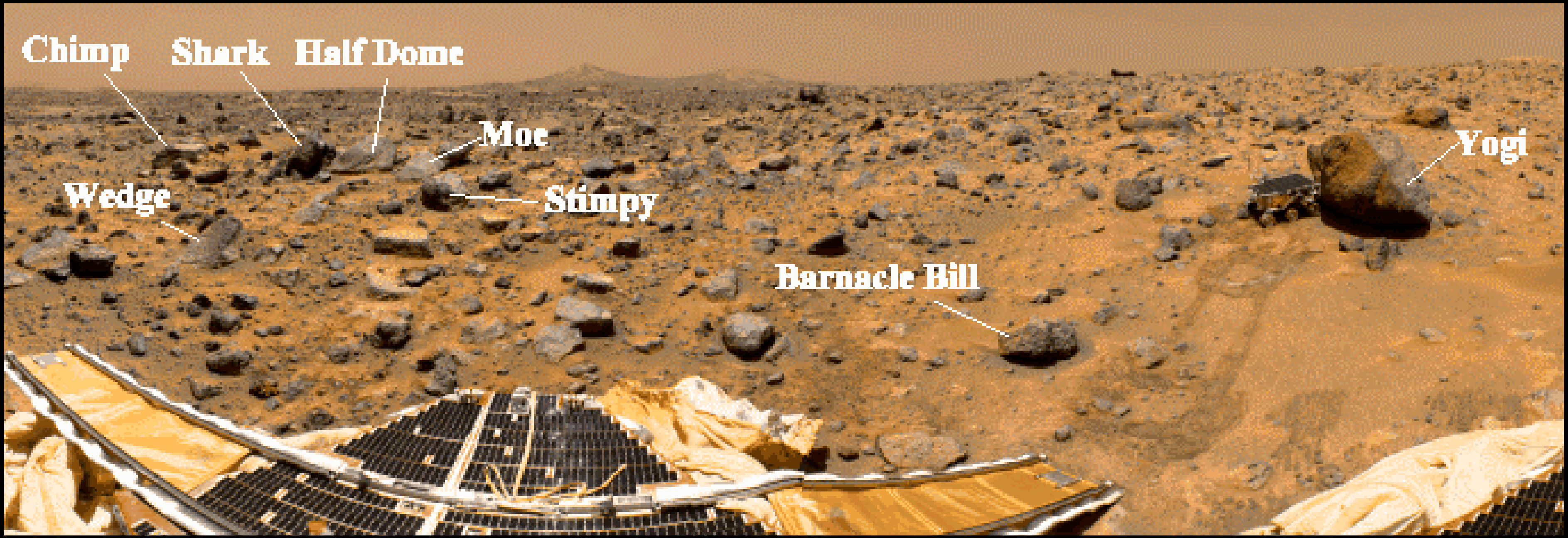
Clays
Carbonates
Sulfates, chlorides

Mars Pathfinder landing site



Intentionally selected in boulder-abundant area in the mouth of Ares Valley: Garbage bag of rock lithologies the valley upstream was expected.

Rocks studied by APXS

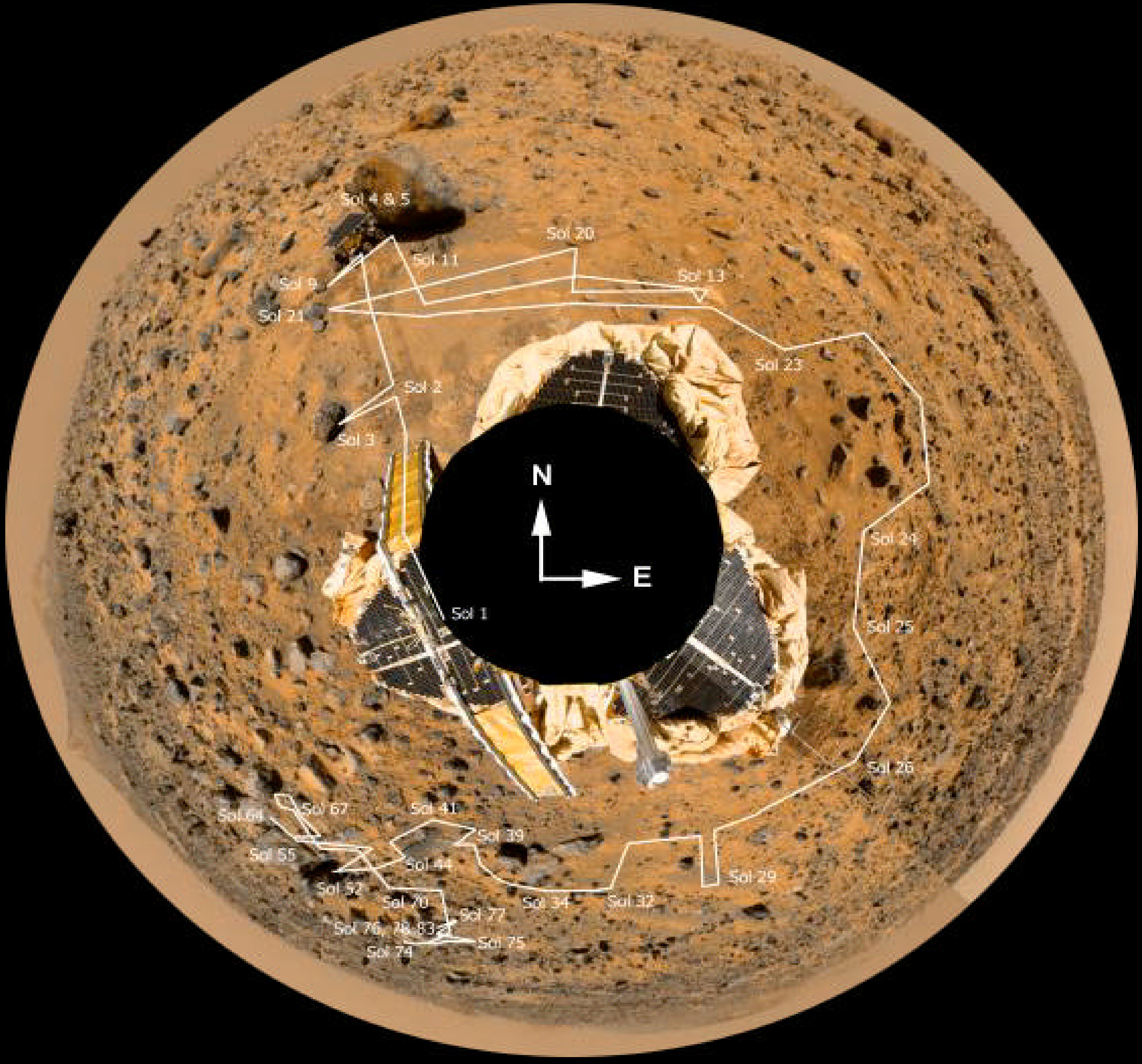


Geology
Catastrophic floods deposits
Moderate eolian modification
5-7 cm net eolian deflation
Ejecta from Big Crater
may present
(Golombek e a., 1997)

Geochemistry
Andesitic dust-free rocks
Soils similar to Viking soils:
mixture of weathered local rocks
and more mafic compositions
(Martian meteorites)
(Rieder e a. 1997; Dreibus e a.,1998)

Geology & Geochemistry
APX analyzed rocks represent
local extensive unit composed
of late stage differentiate of
basaltic magma
(Britt e a., 1998)

Mars Pathfinder site map

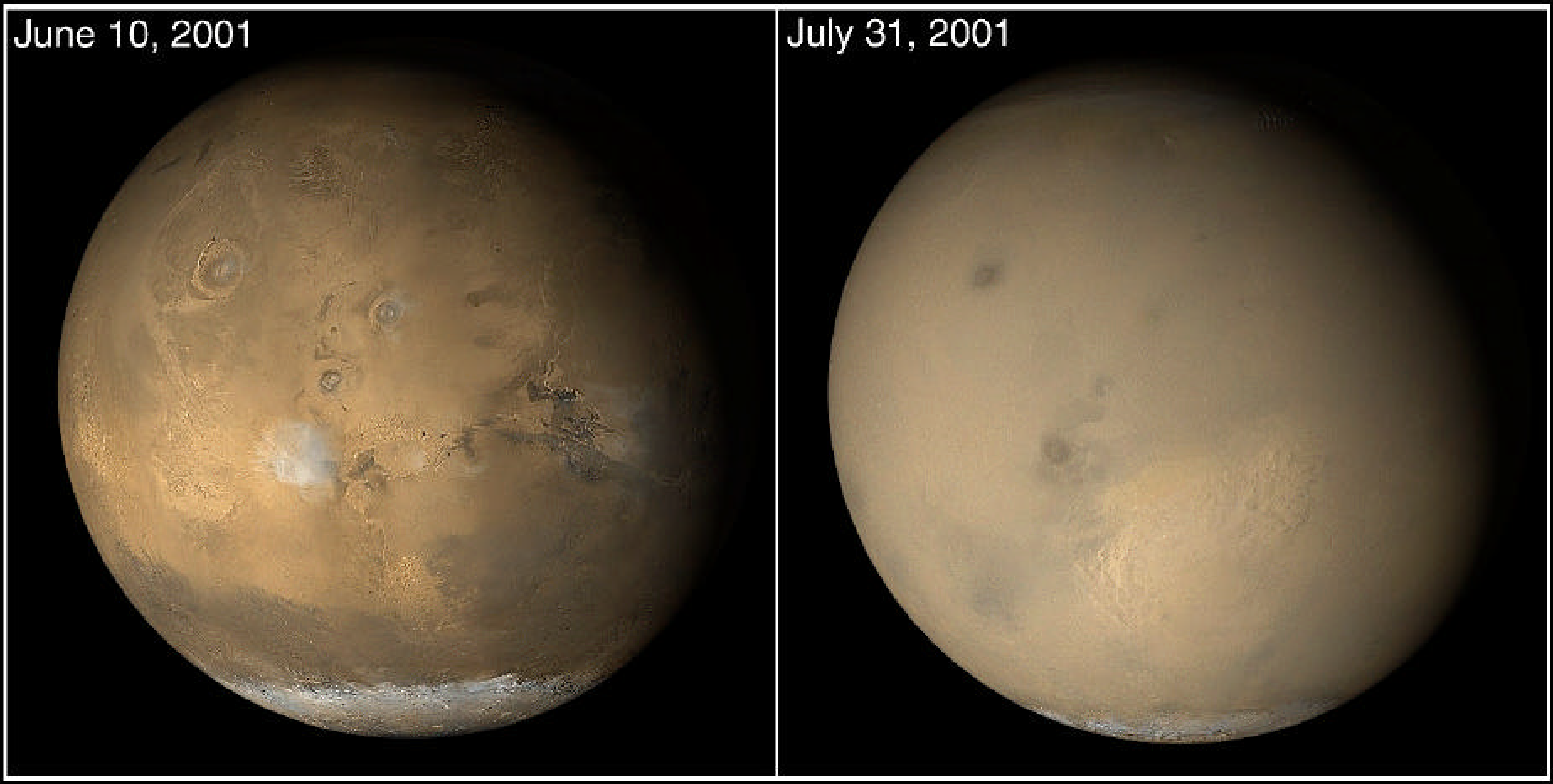


Mars Pathfinder - APXS Preliminary Results

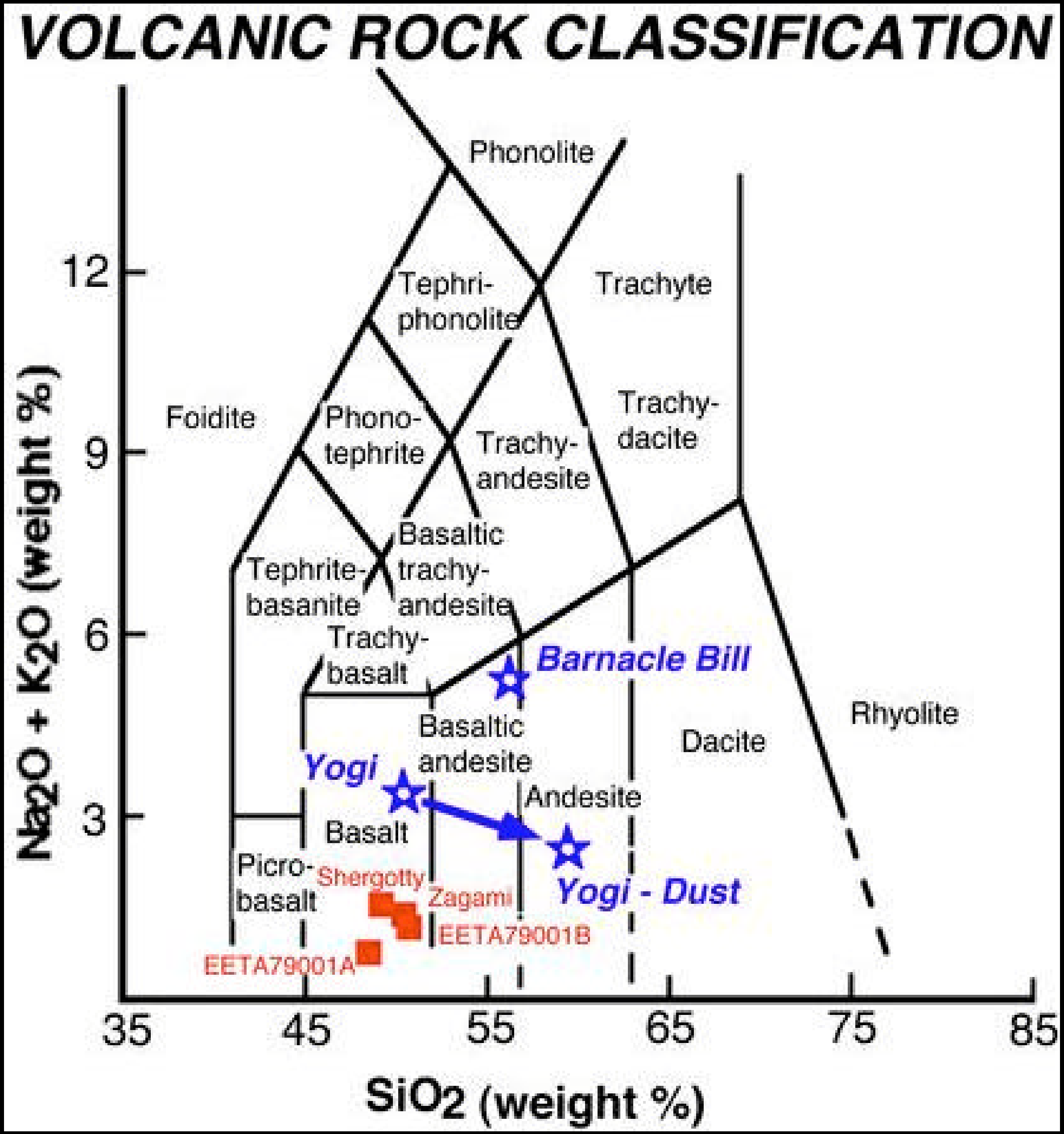
Oxide	A-2, Soil	A-4, Soil	A-5, Soil	A-3, Rock BB	A-7, Rock Yogi
SiO_2	46.1	43.3	43.8	55.0	50.9
Al_2O_3	8.0	10.4	10.1	12.4	11.4
FeO	19.5	14.5	17.5	12.7	13.8
MgO	8.7	9.0	8.6	3.1	6.3
CaO	6.3	4.8	5.3	4.6	5.8
Na_2O	4.3	5.1	3.6	4.2	2.5
K_2O	0.6	0.7	0.7	1.4	1.1
MnO	0.5	0.5	0.6	0.9	0.5
TiO_2	1.1	1.1	0.7	0.7	0.8
SO_3	4.3	6.2	5.4	2.2	4.2

Notes:
Values for potassium and manganese are upper limits
Minor elements such as phosphorus, chlorine and chromium are omitted from this table.

Global dust storms as effective mechanism of global averaging of composition of dusty soil

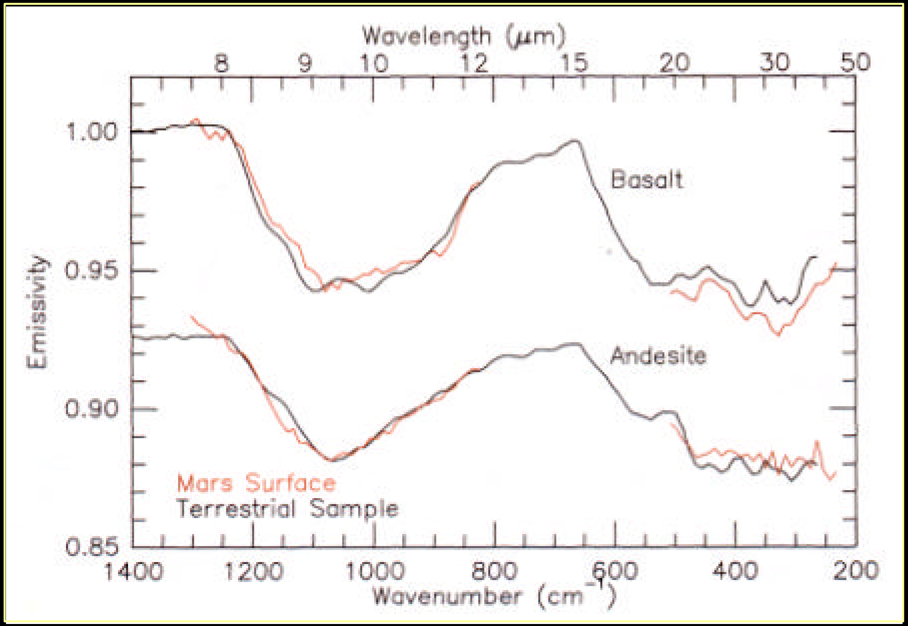


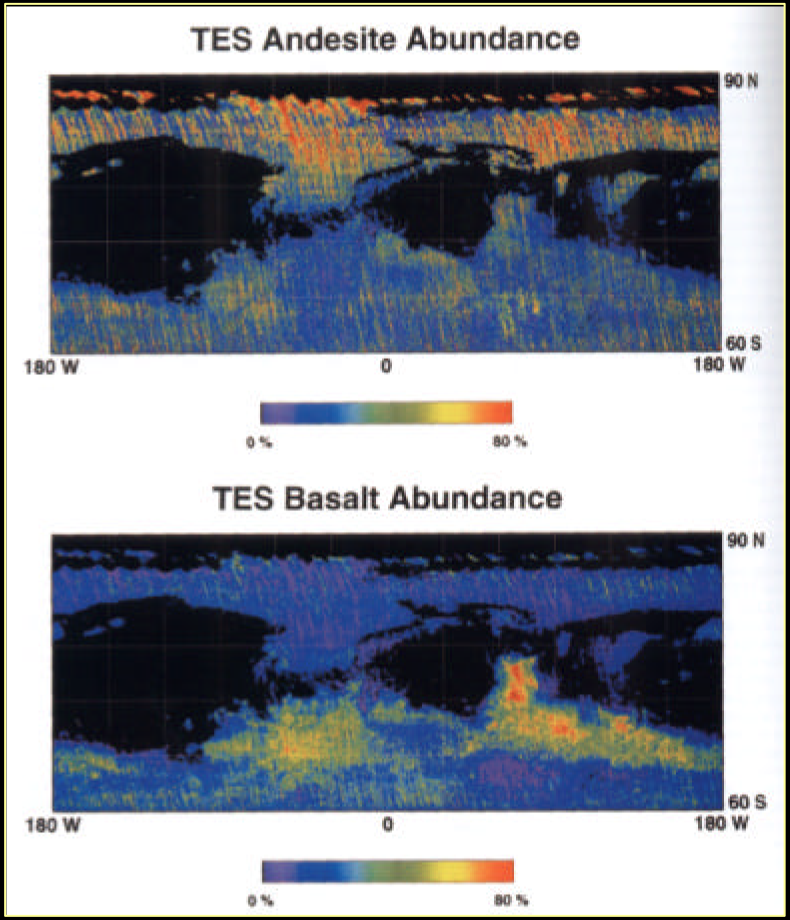
Mars Pathfinder - APXS Preliminary Results



TES: Surface/igneous mineralogy

Basalt-andesite areal distribution, *3 km spatial resolution*



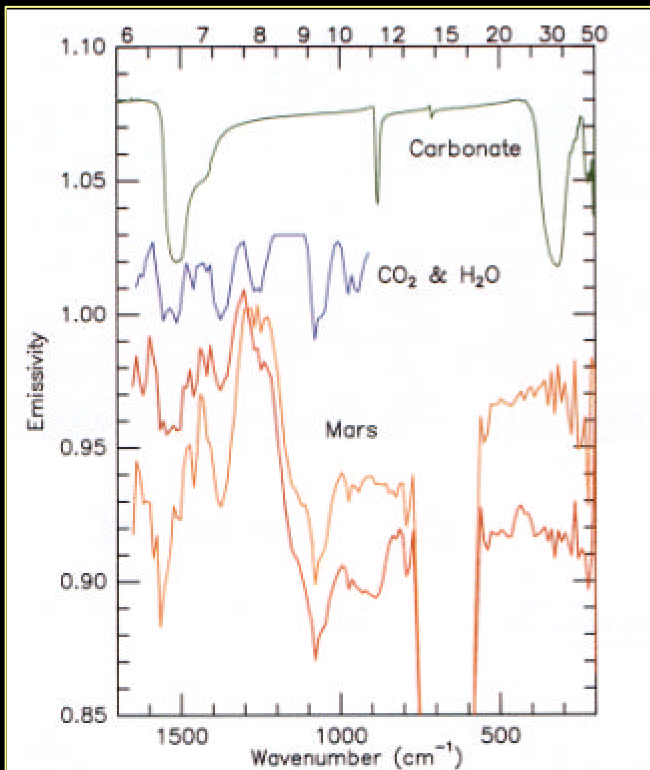


In dark regiones spectral signatures of basalts and andesites are seen. The surface can be separated into two geographically distinct units with boundary along the planetary dichotomy:

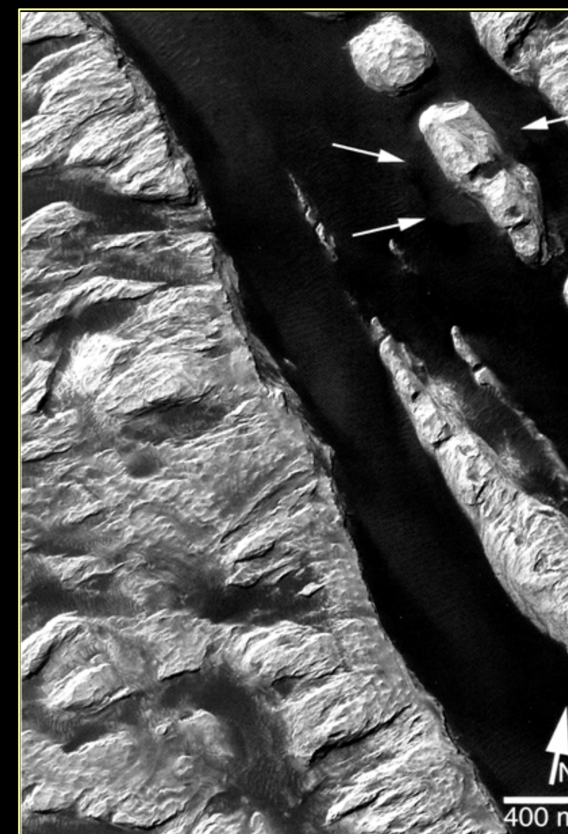
The “basaltic” composition is confined to older surfaces and “more silicic” surface type concentrates in the younger northern plains.

Bandfield et al., 2000; *Christensen et al.*, 2001.

TES: Surface mineralogy
Carbonates and weathering products



Carbonates, quartz and sulfates have not been identified at detection limit of 5, 5, and 10% respectively and 3 km spatial resolution.

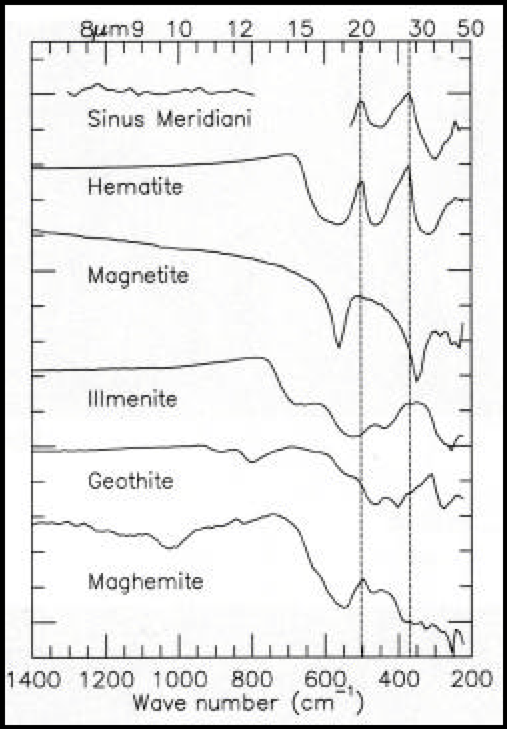


White Rock feature (8ºS, 335ºW), a place of expected evaporites was found to be not anomalously bright ands with no signatures of sulfates and carbonates; spectrally flat halite can not be excluded

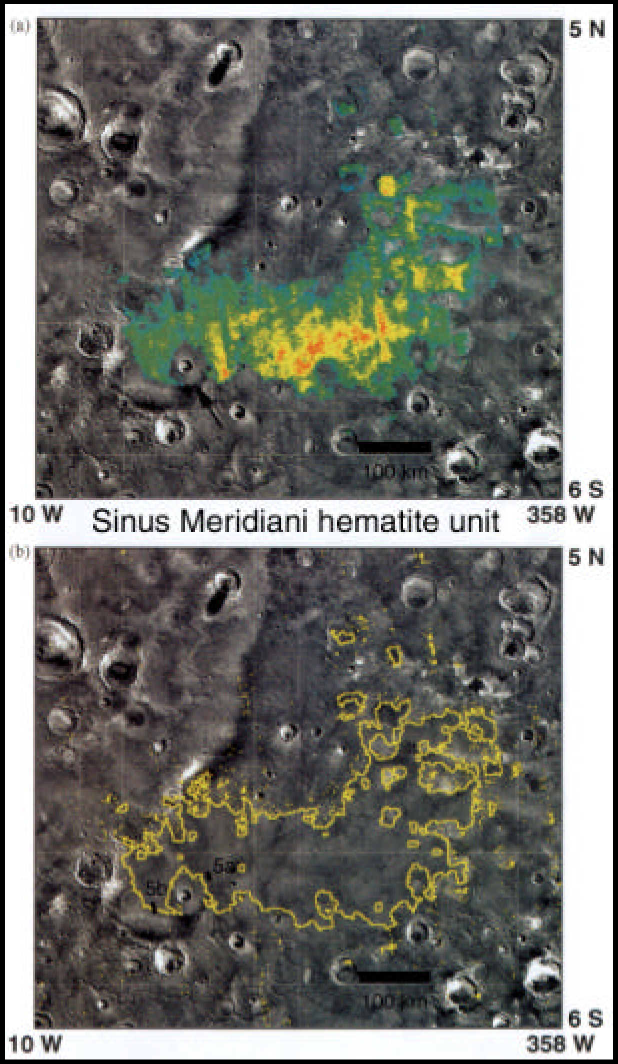
Christiansen et al., 2000, 2001

TES: Surface mineralogy

Hematite



Crystalline gray hematite has been uniquely identified from TES data and its occurrence has been mapped globally.
It is distinct from the fine-grained, 5-10 mkm, red, crystalline hematite considered to be a minor spectral component in Martian bright regions



Three localities of crystalline gray hematite: Sinus Meridiani, Aram Chaos, Ophir/Candor small deposits.

Most likely formed by chemical precipitation from aqueous liquids under ambient or hydrothermal conditions. *Christensen et al*., 2000

Seasonal and perennial mineralogy
Ices and frosts

Late winter at south pole,
MGS Wide angle MOC

H_2O ice

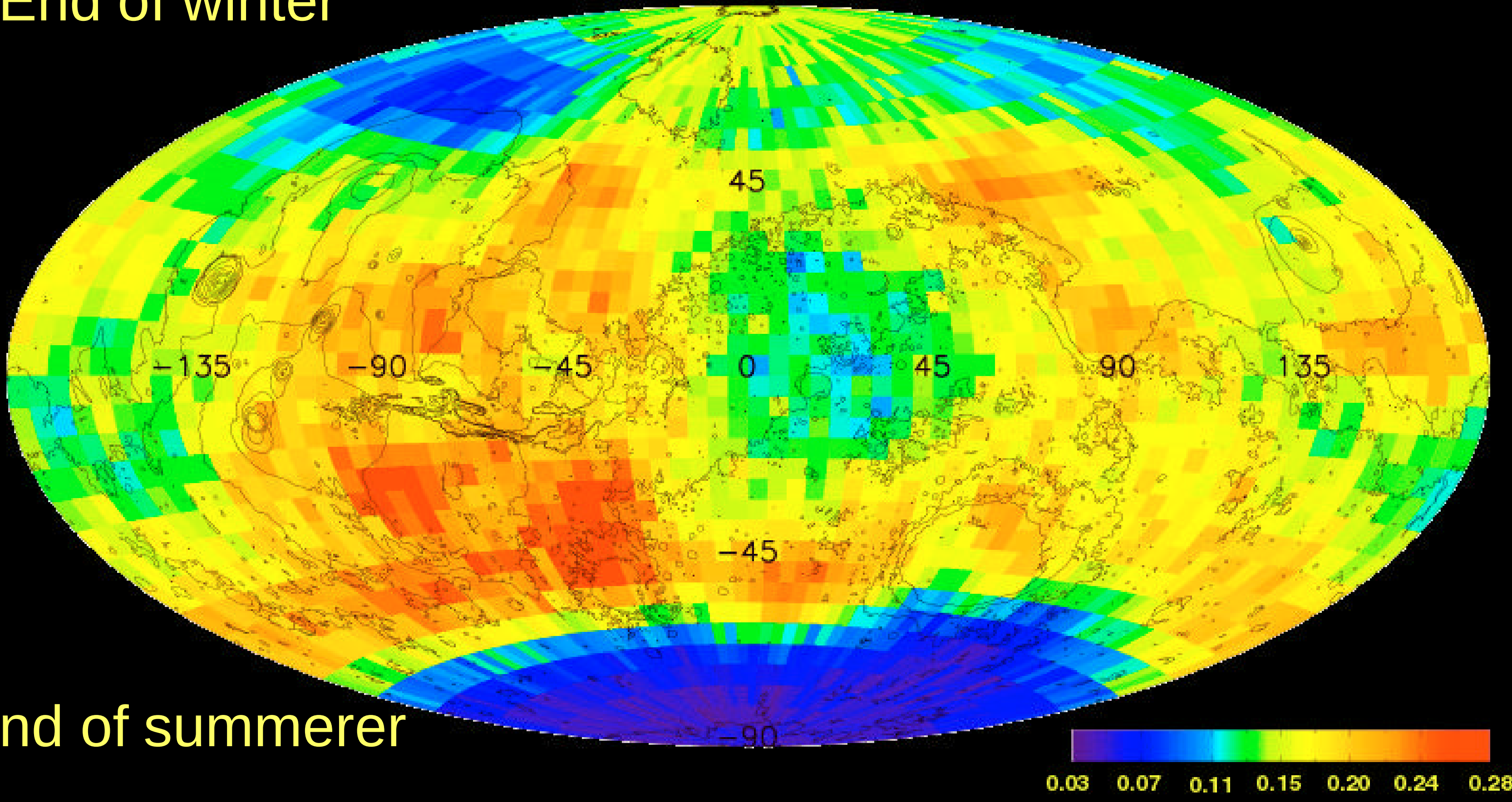
CO_2 ice
- white CO_2 ice
- “black” CO_2 ice (slabs)

Clathrate CO_2 $6H_2O$
- expected,
- no signature found

MARS ODYSSEY HEND data: **(0.4 eV-100 keV)**

Mitrofanov et al., Science, 2002

End of winter



End of summerer

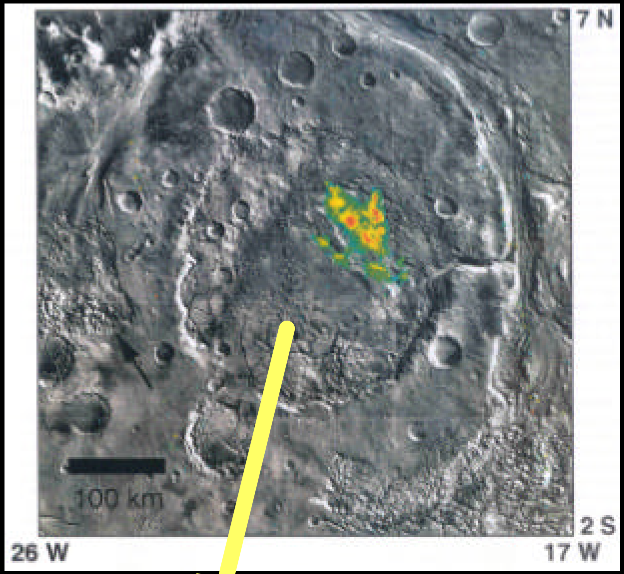
Surface and ground ice (low neutron flux) at high latitudes

Higher flux at north pole due to CO_2 ice mantle

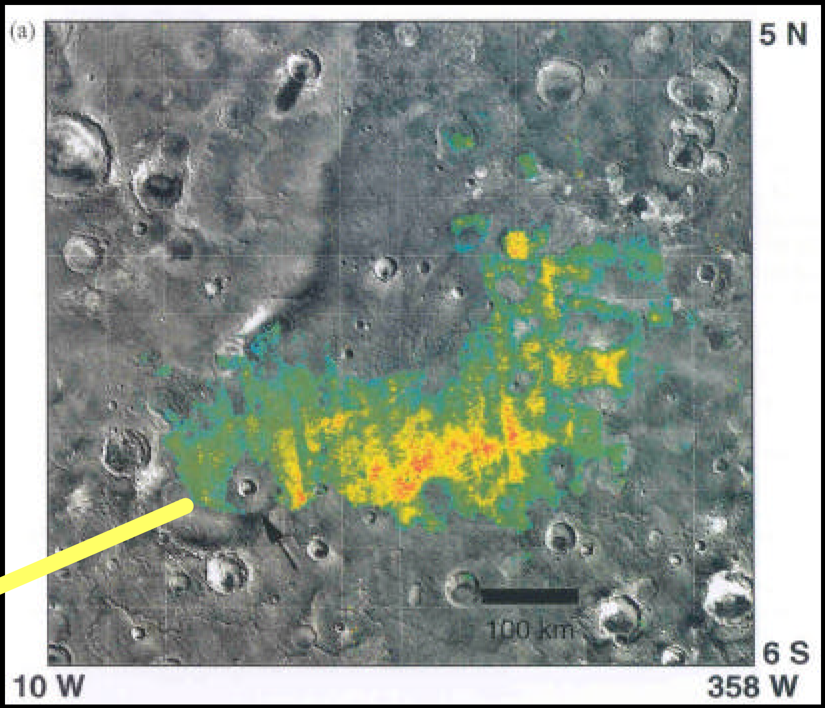
Low-flux (high-water) antipodal regions in equatorial part

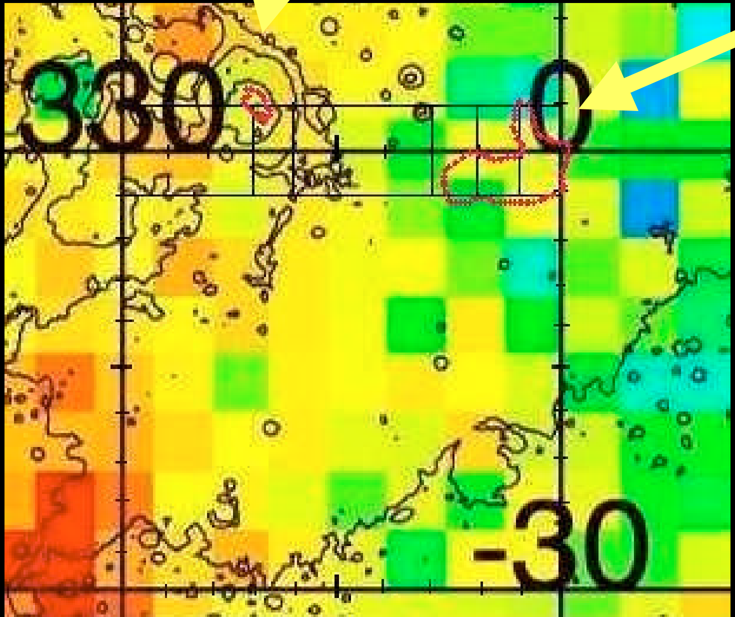
TES observed hematite deposits as seen in HEND

Aram Chaos



Sinus Meridiani





Hematite deposits which are consudered to be water-precipitated show no positive signature of bound water

Christensen et al., 2002 for TES
Mitrofanov et al., 2002 for HEND

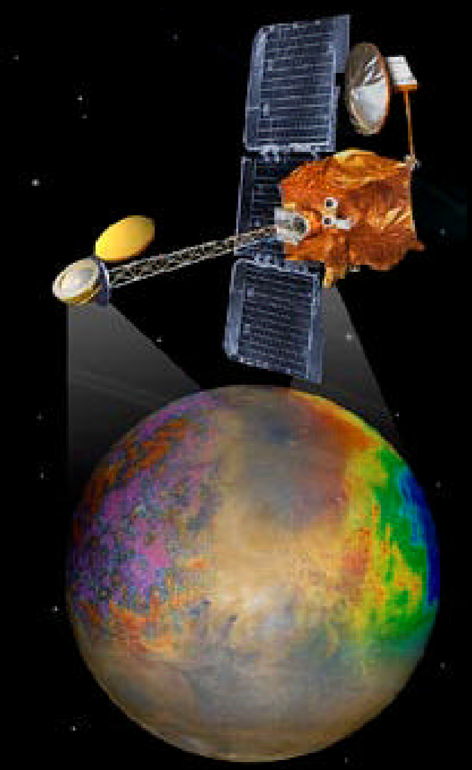
Conclusion: Mars mineralogy is still largely enigmatic!

Igneous mineralogy: No geochemically evolved rocks among Martian meteorites : Truth or sampling effect?

Surface mineralogy: Morphologic evidence of humid environment on early and (locally) more recent Mars and absence of signatures of water deposited minerals. If gray hematite was deposited from aqueous solutions why don't we see signatures of other expected water-deposited phases?

Seasonal mineralogy: Does clathrate CO_2 $6H_2O$ play significant role in Martian ice deposits?

Expected progress in near future



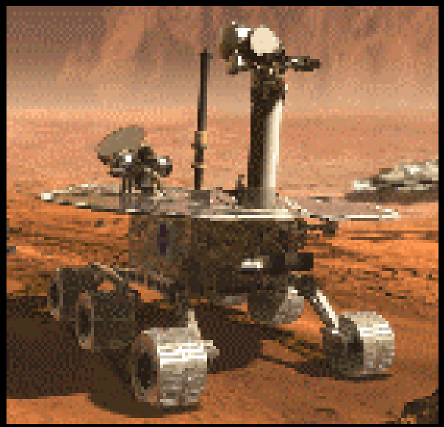
Mars Odyssey -now working

Gamma-spectrometer

Si, O, Fe, Mg, K, Al, Ca, S, C, U, Th … => 20 elements detected with spatial resolution of 400 km (height of orbit)

IR spectrometer Themis

IR mode: 9 spectral bands indicative for carbonates, silicates, hydroxides, sulfates, hydrothermal silica, oxides and phosphates with 100 m spatial resolution



2003 Mars Exploration Rovers

Two rovers arriving to Mars in January-February 2004

Panoramic camera
Miniature thermal emission spectrometer
Mossbauer spectrometer
Alpha proton X-ray spectrometer
Microscopic imager
The rock abrasion tool!

Geology and volcanism of Triton

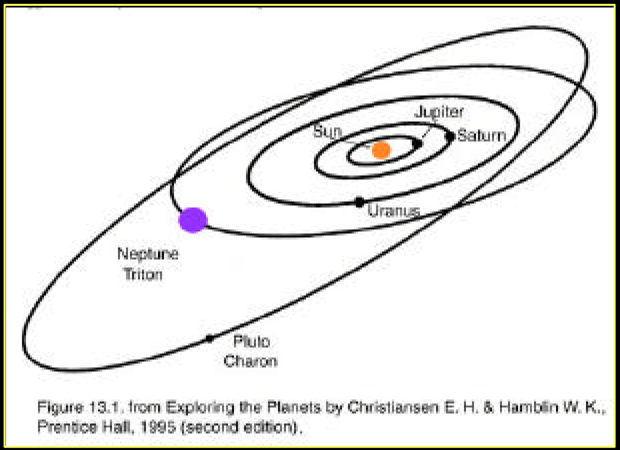
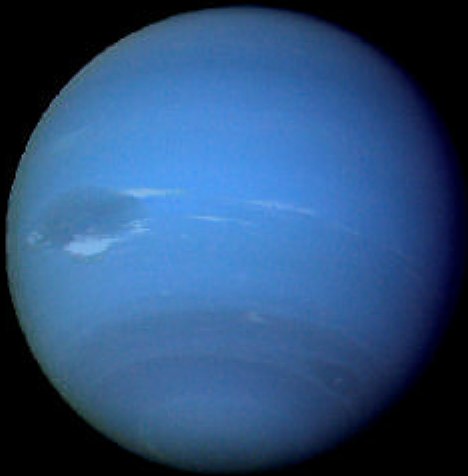
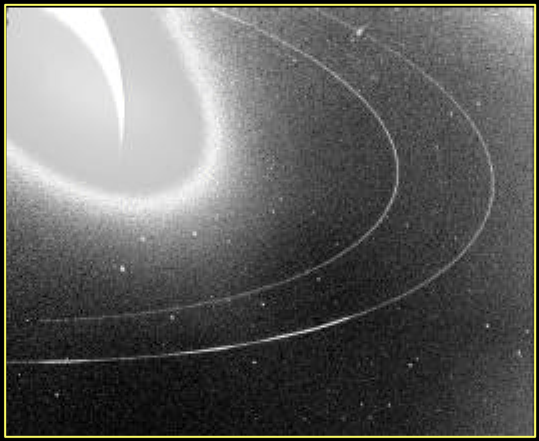


Figure 13.1. from Exploring the Planets by Christiansen E. H. & Hamblin W. K., Prentice Hall, 1995 (second edition).

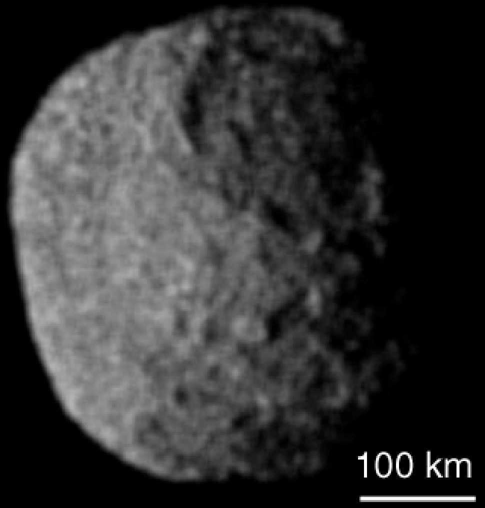
Neptune/Triton in Solar system



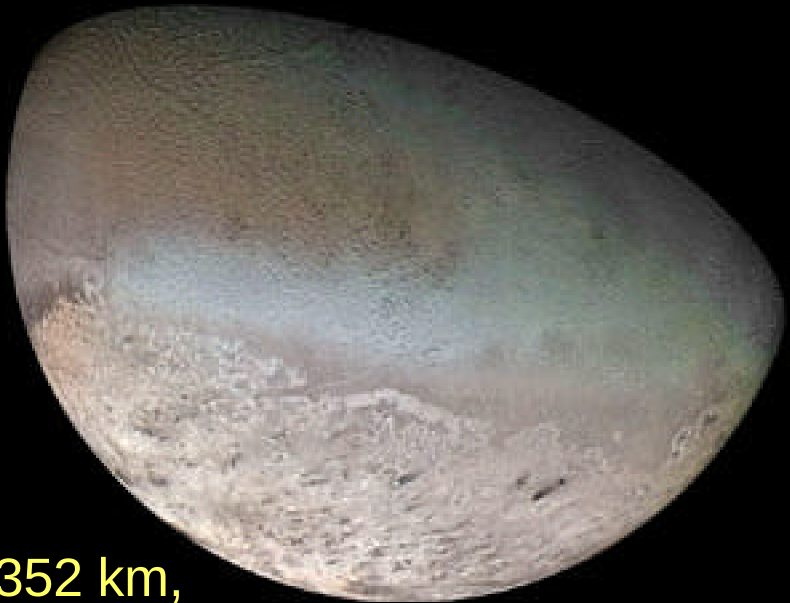
Neptune,
30 a.e, from Sun



Neptune rings



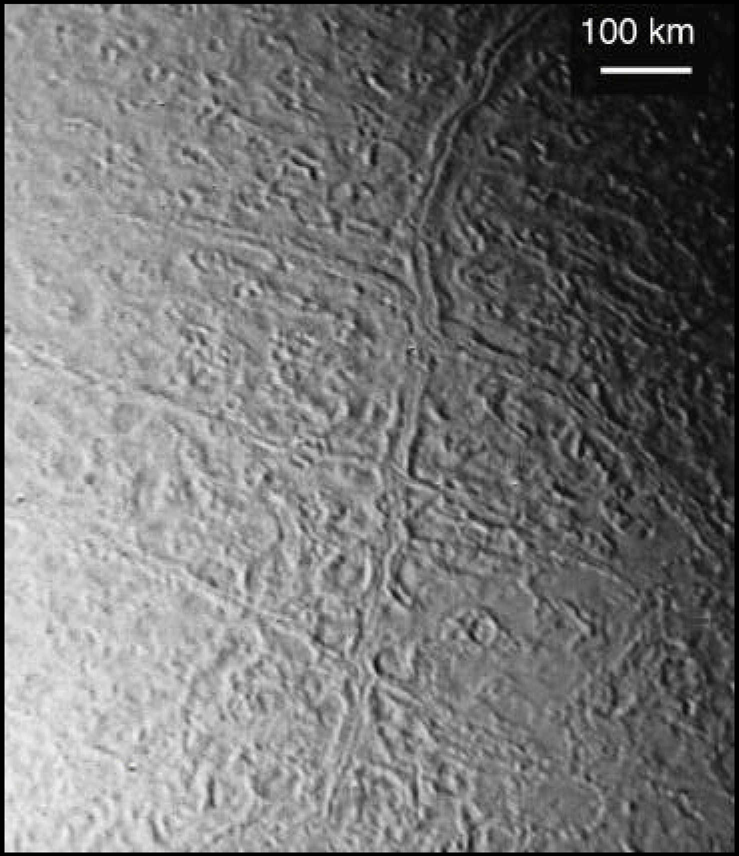
Proteus



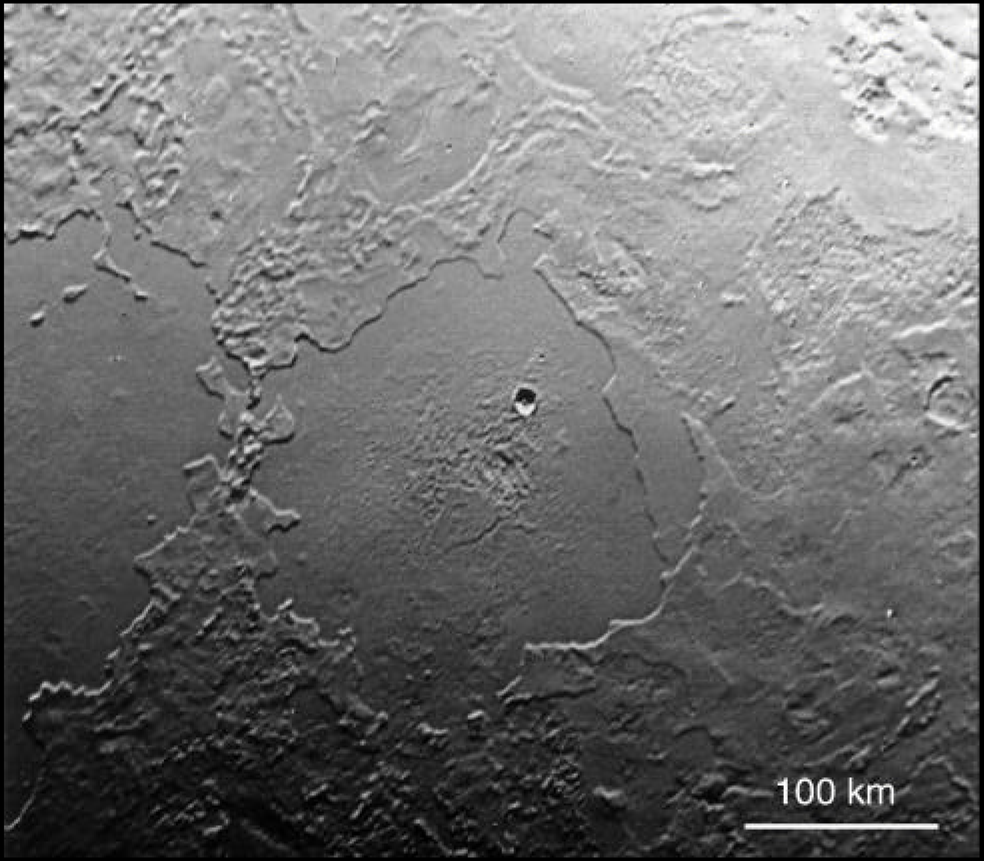
Triton, R = 1352 km,
? = 2065 kg/m^{-3}, surf gravity = 1/12 g, T surf. = 38 K

Tectonics and volcanism

Cantelupe terrain



Cantelupe terrain is a signatiure of relatively early tectonism on Triton

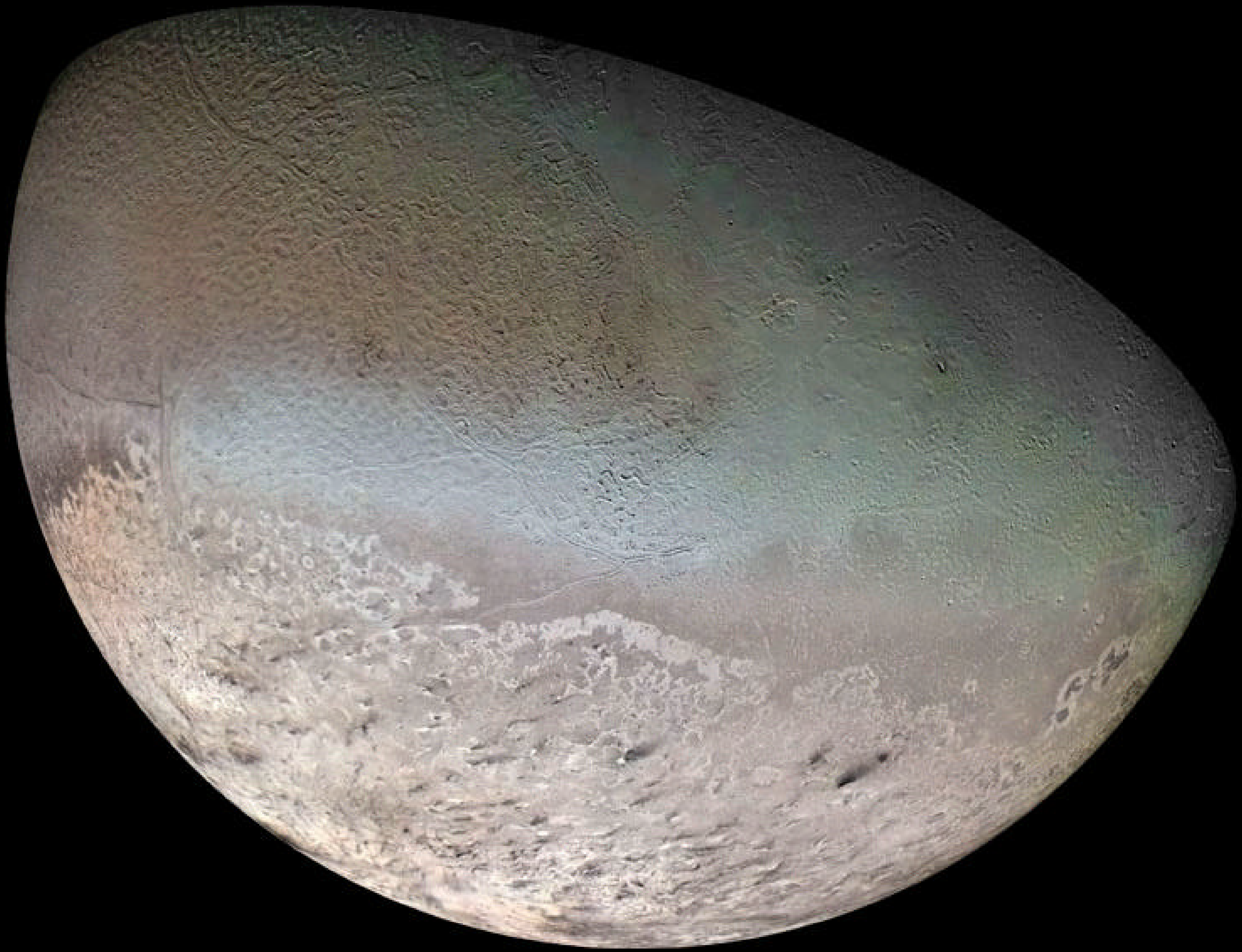


Volcanic plains

Plains on Triton are resulted from cryovolcanism (melted ices of H_2O…)

Ices of H_2O, CO_2 play role of rocks:
Form «lithosphere», ice topography withstand for geologic time

South polar cap

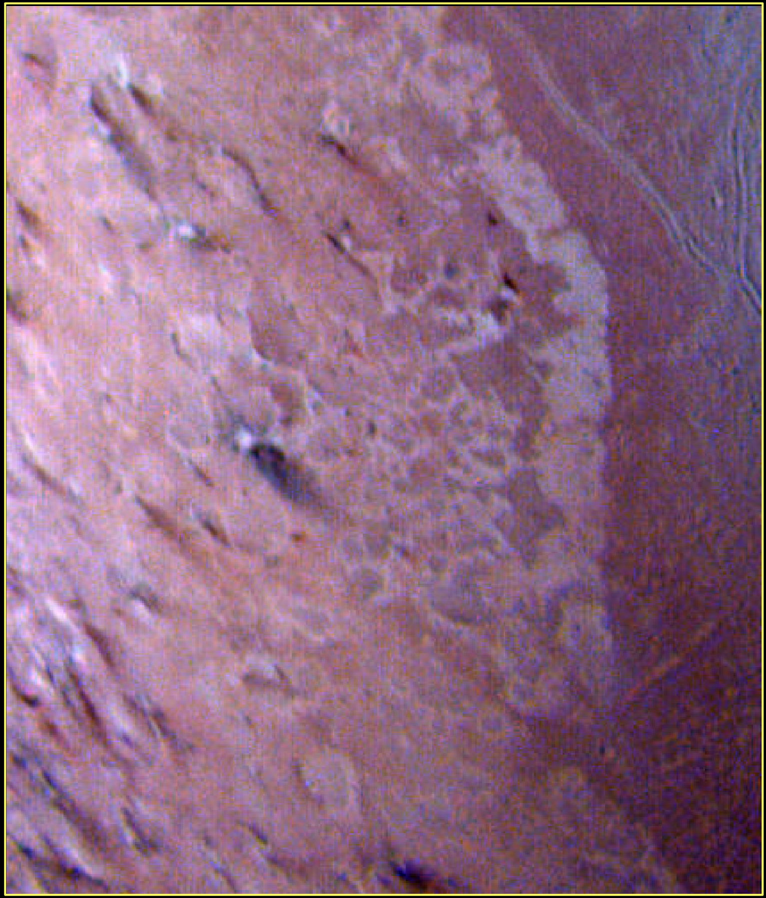


Ices of N_2 and CH_4 play role of water ice on Earth:
Seasonal caps, frosts, clouds

Polar phenomena

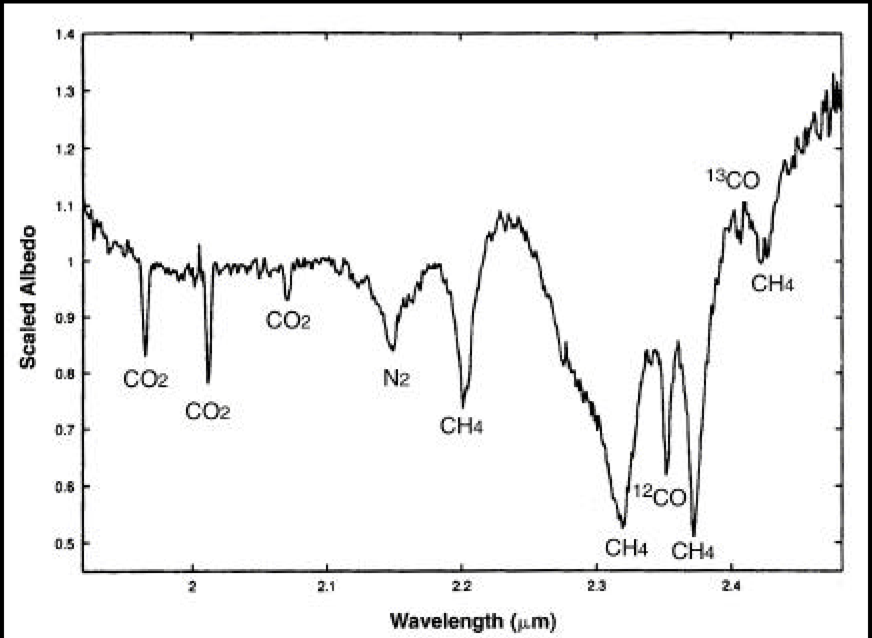
Enigmatic white collars

Polar caps, permanent (down to 45 deg latitude) and seasonal (one Tritonian year = 165 years of Earth).



Plumes of nitrogen gas with dark fine particles on the south polar cap background (N_2 ice with CH_4 admixture (pinkish color)

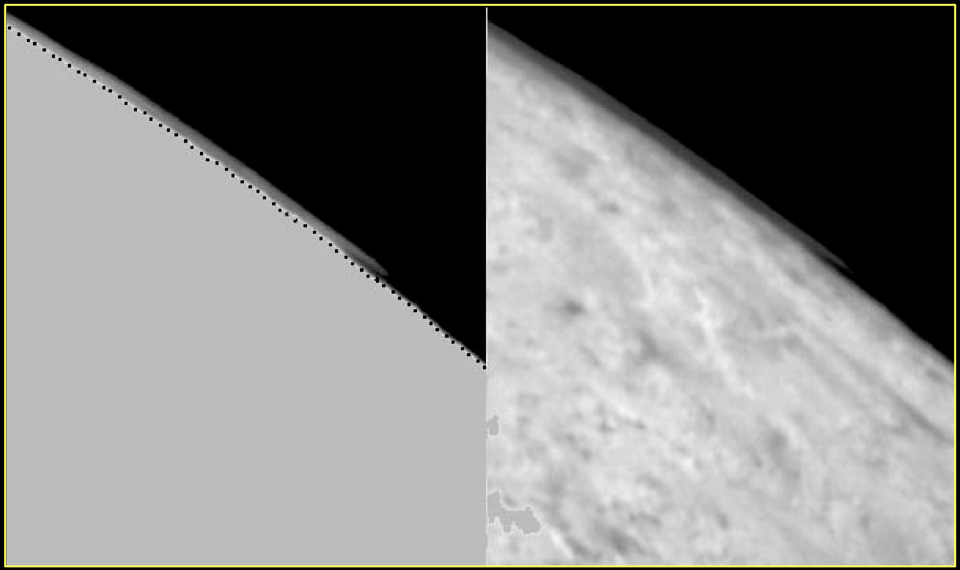
Triton atmosphere



Major component N_2.
Minor component CH_4.
Too thin and cold for radiative processes.
Heat is transported by conduction

Haze: photochemically transformed hydrocarbons

Clouds seen on the limb: Condensed nitrogen?

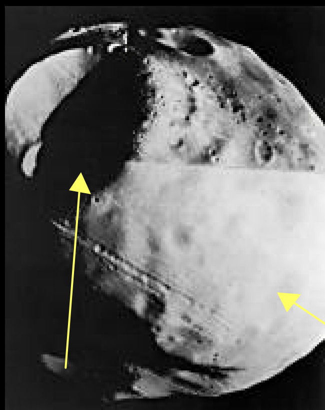


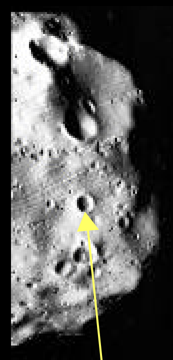
Clouds

Small planetary satellites and asteroids

Phobos and Deimos satellites of Mars

Viking images





Deimos

Phobos – 27 x 22 x 18 km
6,000 km above Mars surface
Deimos 15 x 12 x 11 km
20,000 km above mars surface
Discovered by Asaf Hall, 1877

Crater Stickney, Phobos

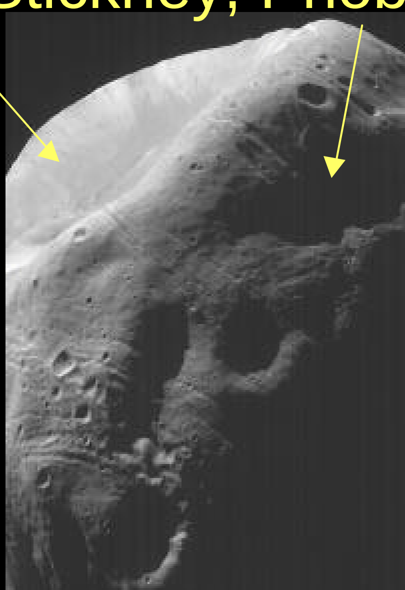
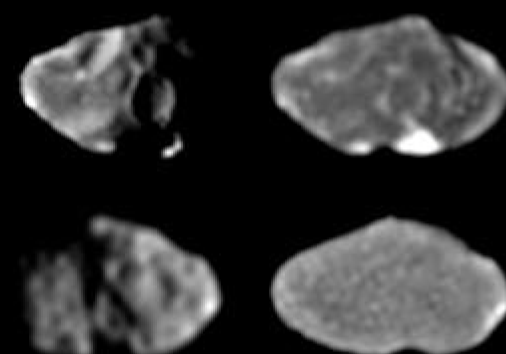


Image of MGS MOC



Images taken by Galileo

Amalthea – satellite of Jupiter
181, 000 from Jupiter
270 x 170 x 150 km
Discovered by E. Barnold, 1892

Impact cratering is leading geological process

Three asteroids recently imaged

Gaspra, 19 x 12 x 11 km
Spectral type S

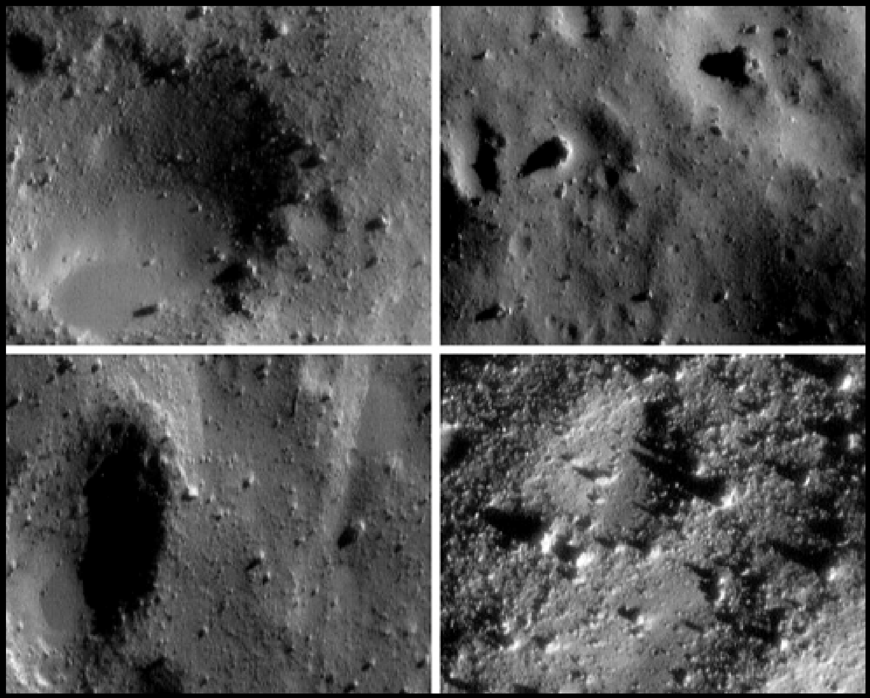
Ida (56 km long) and its
1.5 km satellite Dactile
Both spestral type S

Mathilda, 59 x 47 km
Several large impact
craters are seen

Leading geologic process is impact craters. Why so large craters formed on Mathlda not dstroying the Asteroid?

Near Earth asteroid Eros

33 x 13 13 km,
90 kg person would weigh 60 g
Spectral type S, which is a possible source of ordinary chondtrites
Orbit perihelion 1.13 ae
Orbit aphelion 1.78 ae



Leading geological process – impact cratering.
Enigmatic phenomenon -- accumulation of fine material at the floors of depressions.

How to sort out fine material from coarse one?