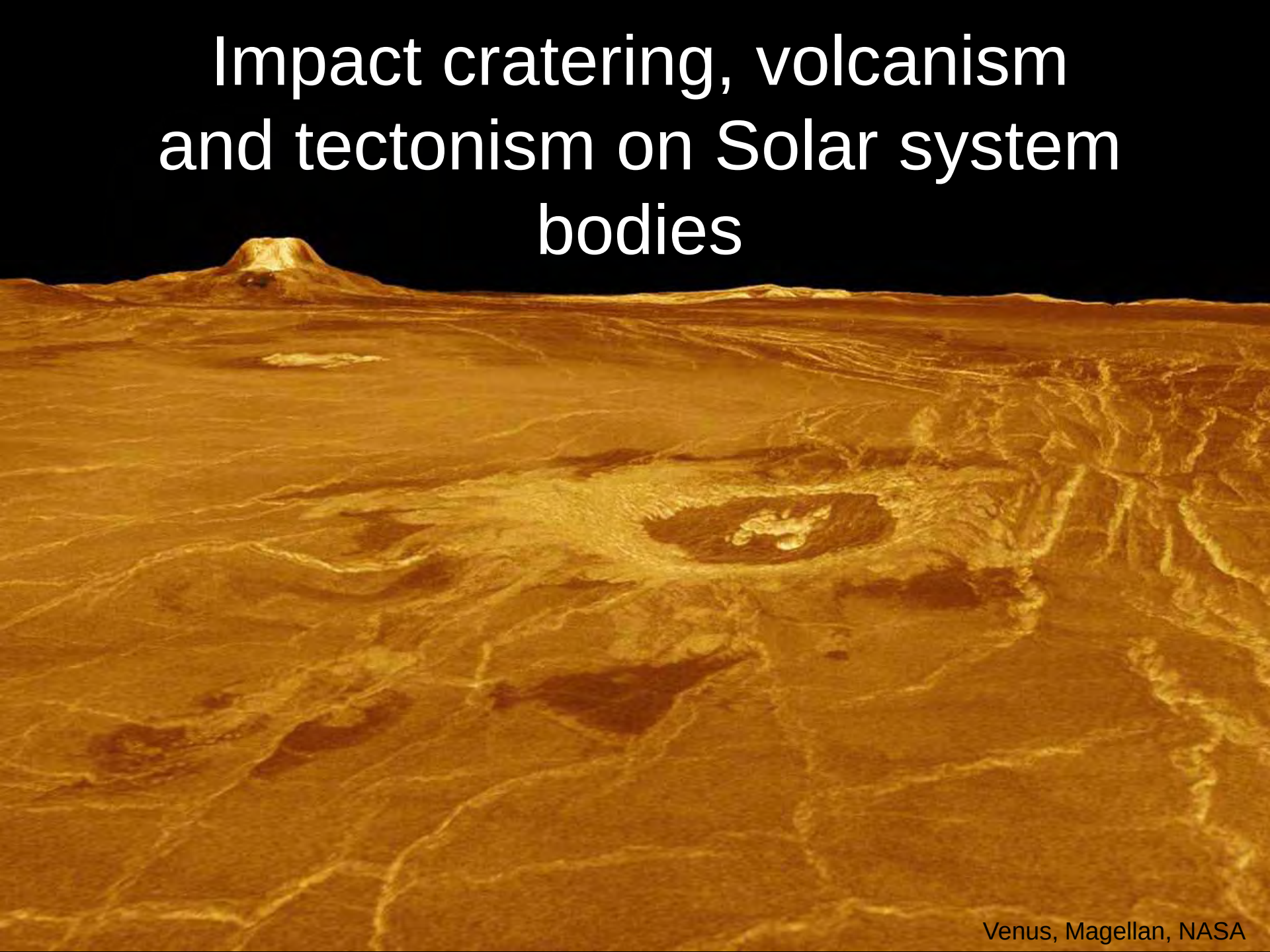
Impact cratering, volcanism and tectonism on Solar system bodies



Venus, Magellan, NASA

Impact cratering

Bolide: Photo of Hiroyuki-Iida, Japan

Sterlitamak impact crater, Russia

Meteor crater, panorama of crater interior

Meteor crater rim seen from the road

Roter Kamm crater, Namibia, D = 2.5 km

New Quebec crater, Canada, D = 3.4 km

Elgygytgyn crater, Chukotka, Russia, D = 18 km

Elgygytgyn crater, Dr. Feldman is exploring it

Impact crater Nordlingen Ries, Germany

D = 23 km

Bunte (pied) breccia, crater Ries, Germany

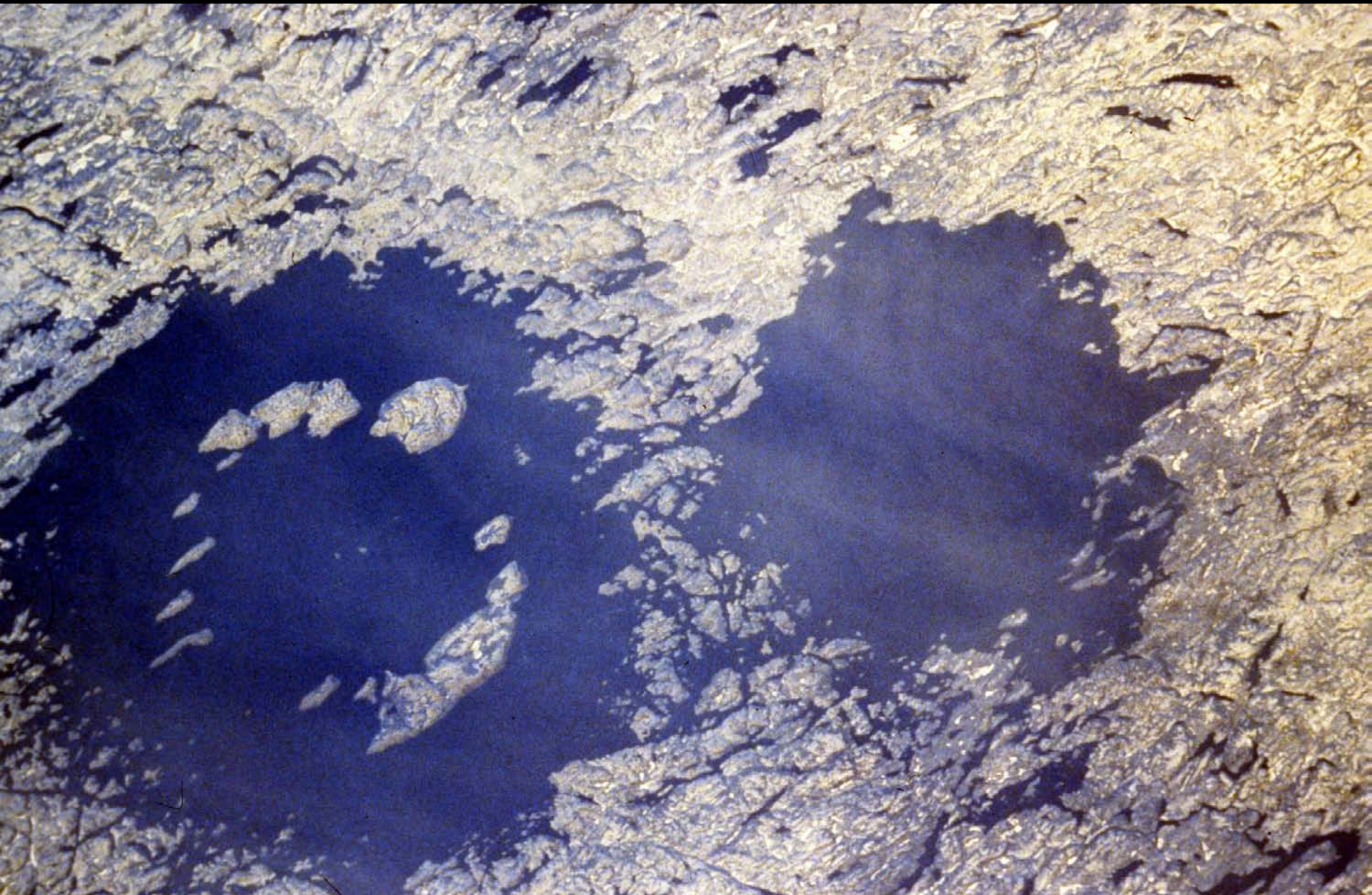
Фото А.Т. Базилевского

Suevute, crater Ries, Germany

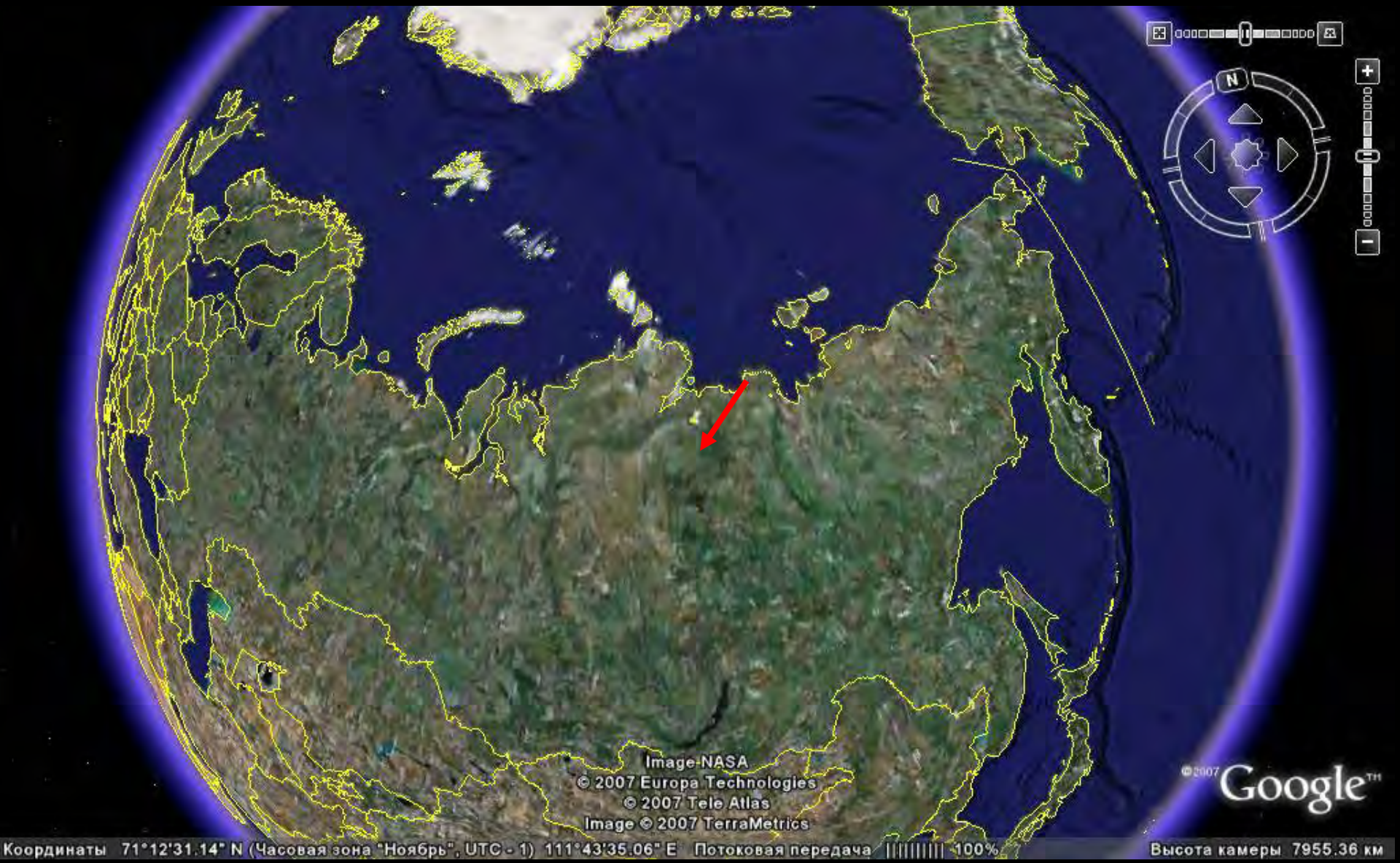
Фото А.Т. Базилевского

Moldavite: splash of impact melt from crater Ries

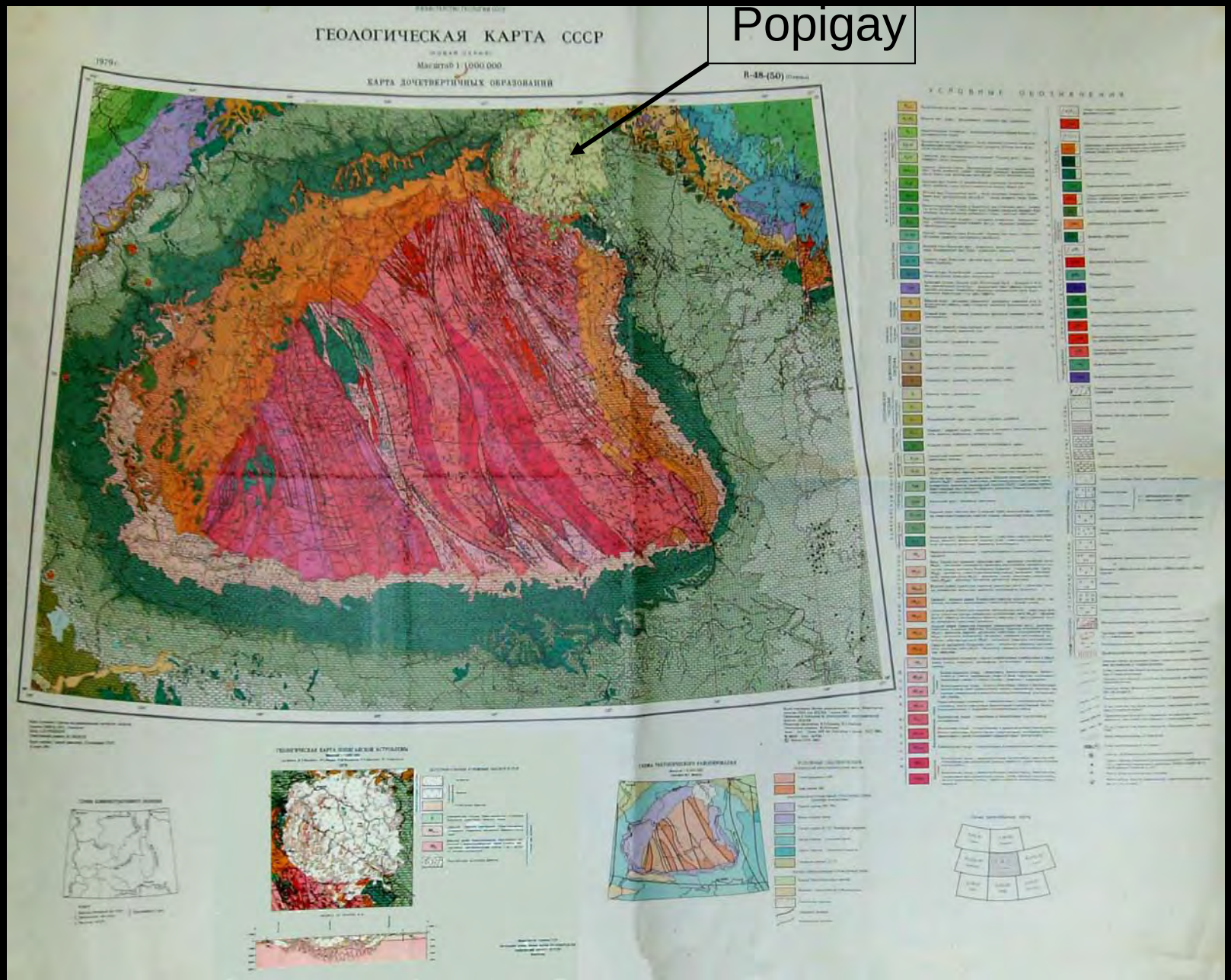
Craters Clear Water West (36 km) & East (26 km) Quebec, Canada



Popigai crater, Siberia, Russia, D = 100 km



Popigai crater, geologic map of the region



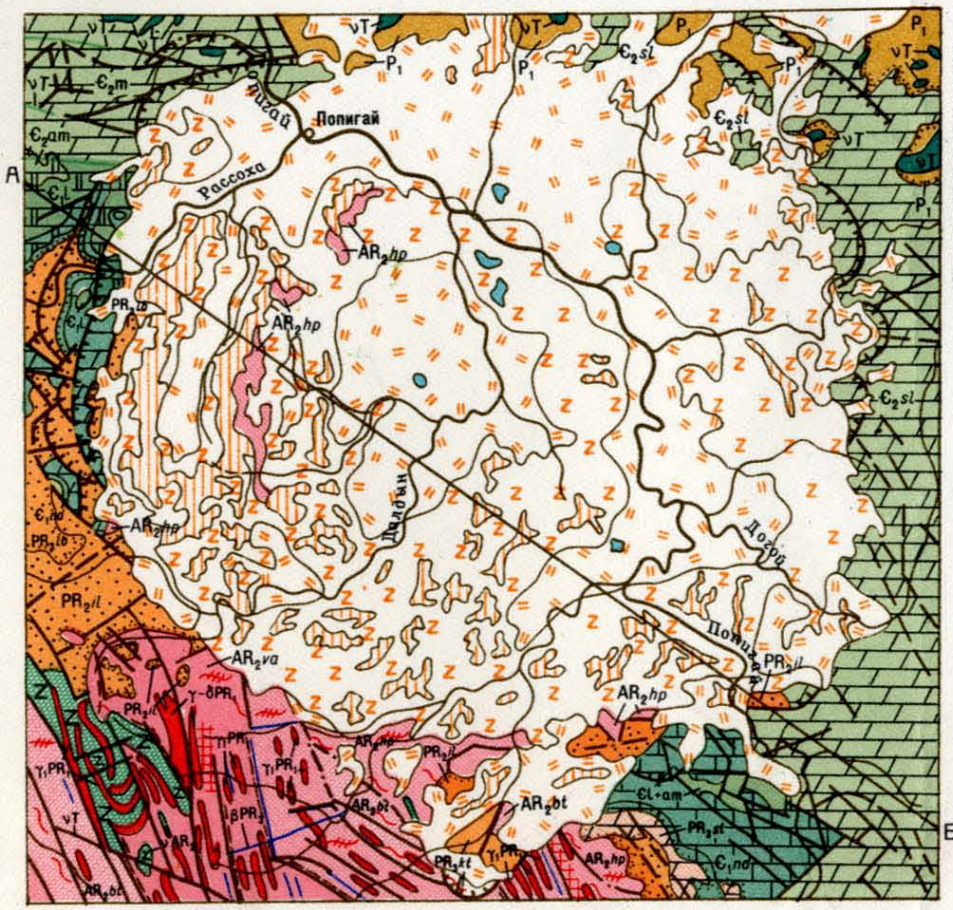
Popigai geologic map by Masaitis et al., 1978

ГЕОЛОГИЧЕСКАЯ КАРТА ПОПИГАЙСКОЙ АСТРОБЛЕМЫ

Масштаб 1:1 000 000

Составили: В.Л.Масайтис, М.С.Мащак, М.В.Михайлов, А.Н.Данилин, В.Т.Кириченко

1978



ДОПОЛНИТЕЛЬНЫЕ УСЛОВНЫЕ ОБОЗНАЧЕНИЯ

ПАЛЕОГЕНОВАЯ СИСТЕМА

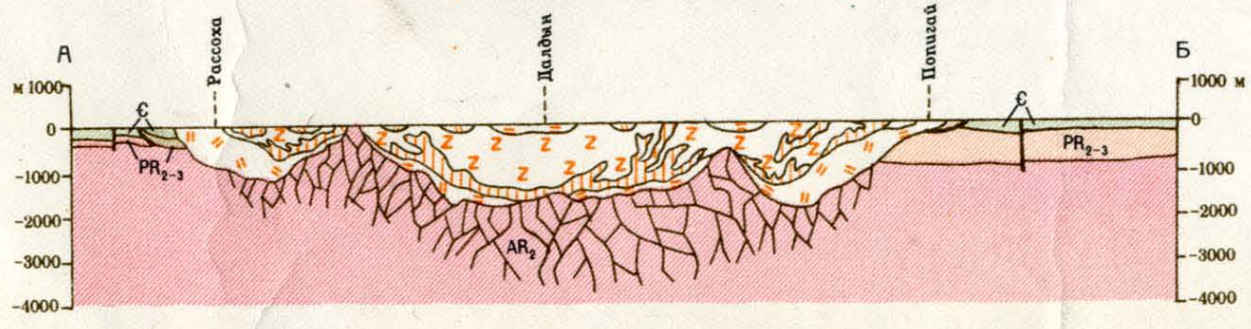
Коптогенные образования

- Тагамиты
- Зювиты
- Аллогенная брекчия

Только для разреза

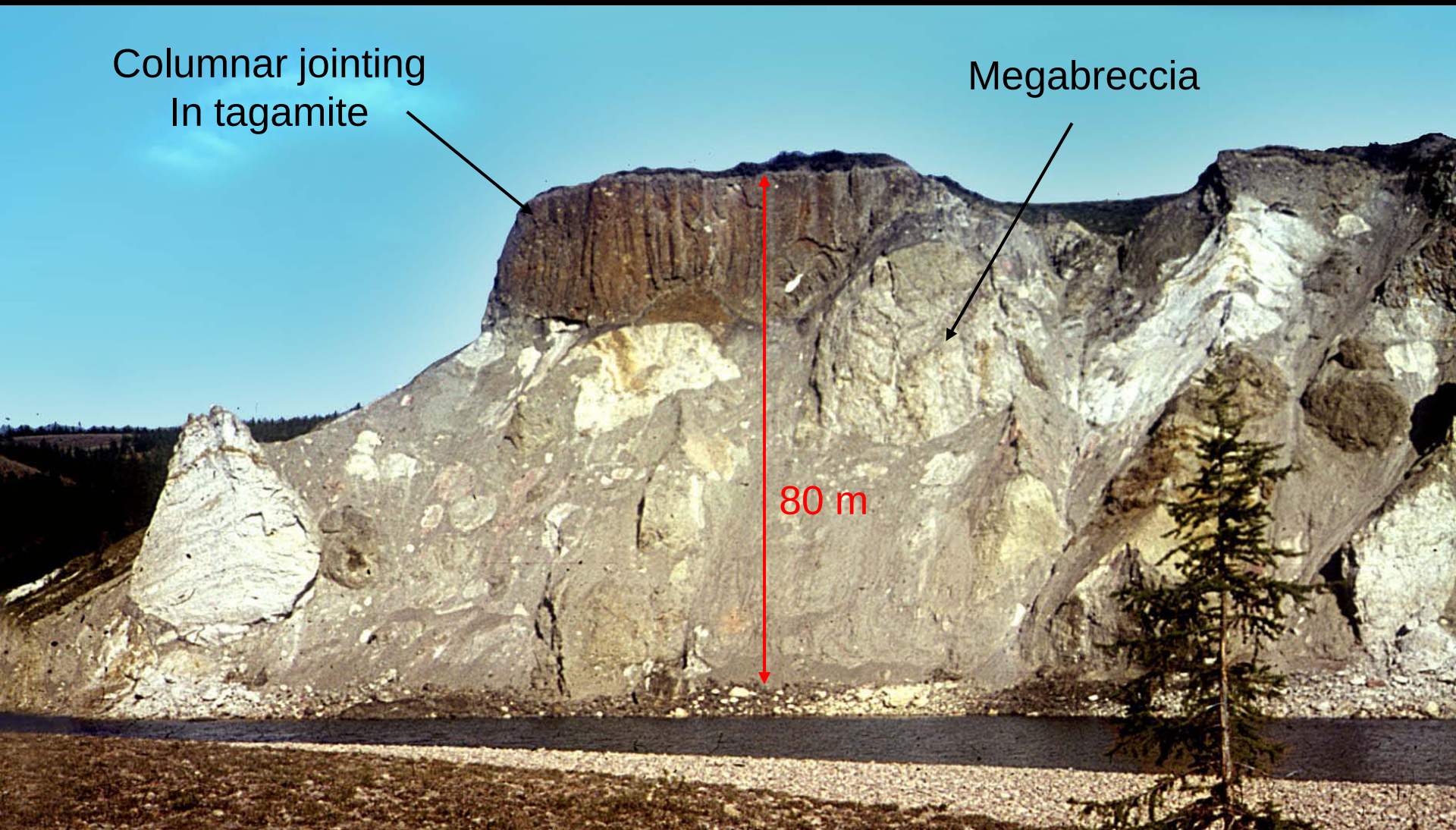
- ϵ — Кембрийская система. Нерасчлененные отложения. Доломиты, известняки, мергели, глины
- PR_{2-3} — Средний – верхний протерозой. Нерасчлененные отложения. Гравелиты, песчаники, кварцито-песчаники
- AR_2 — Верхний архей. Нерасчлененные образования хапчанской и верхнеанабарской серий (гнейсы, плагиогнейсы, кристаллические сланцы и др.), частично мигматизированные
- Апогнейсовая аутигенная брекчия

РАЗРЕЗ ПО ЛИНИИ А-Б



Министерство
Всесоюзный ордена Ленина
геологический и
Лени

Popigai crater (astrobleme)
Megabreccia and tagamites at Rassokha river

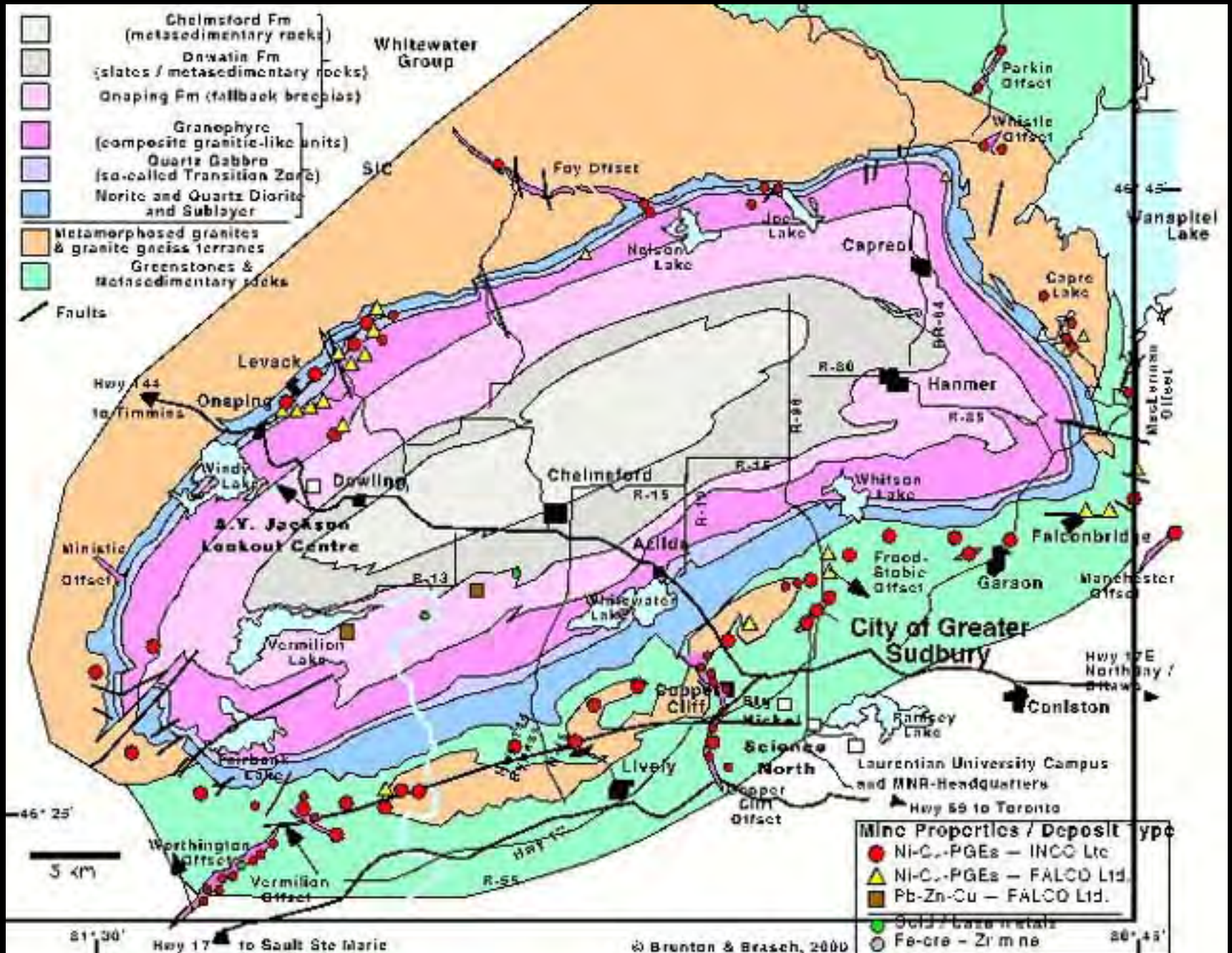


Tagamite = solidified impact melt, crater Janisjarvi, Russia

Photo B.A. Ivanov

Sudbury crater (astrobleme)
Has very rich nickel deposit inside

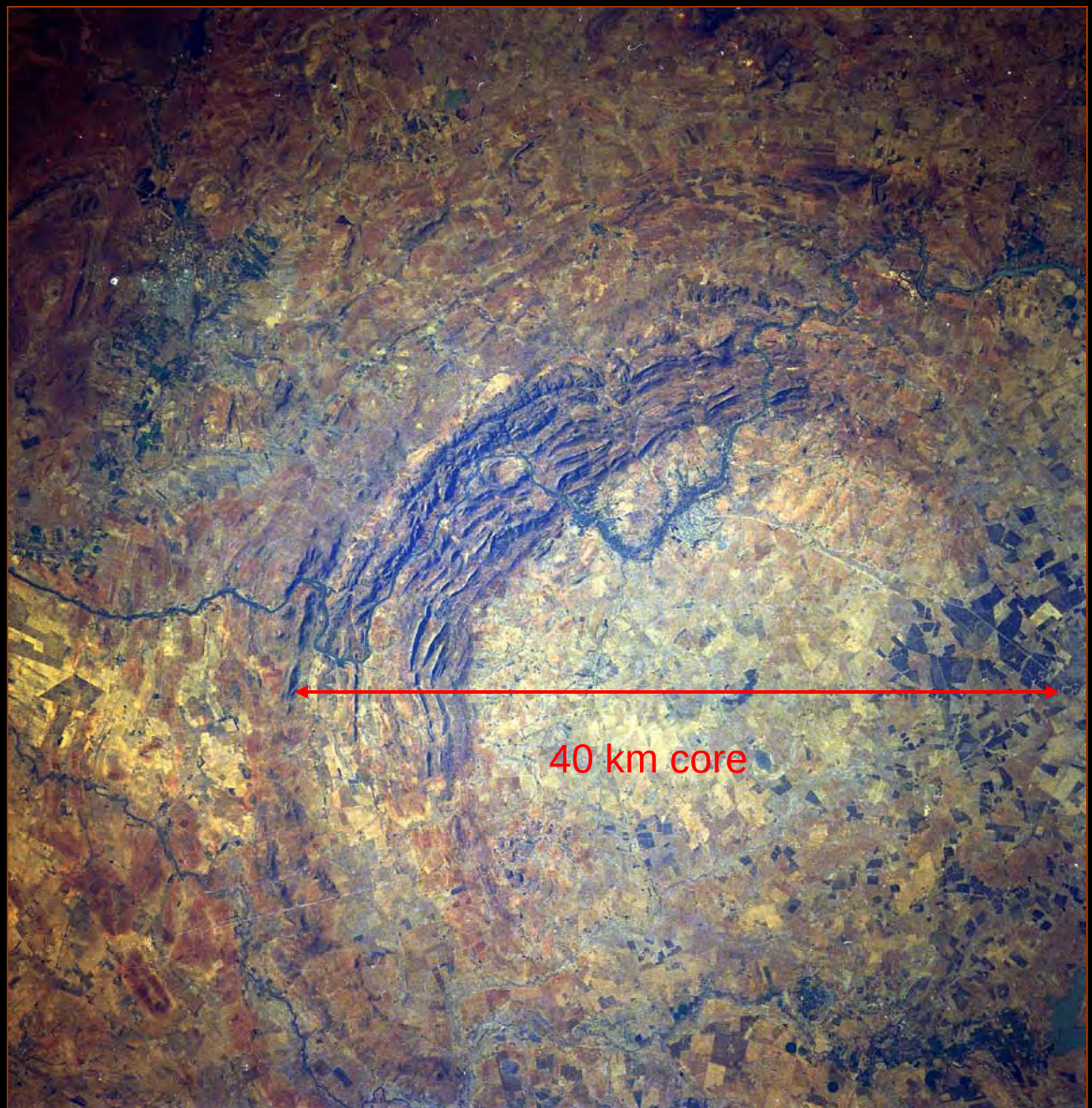
Sudbury crater geologic map



Sudbury shutter cones

Vredefort crater, South Africa, initially D ~ 300 km

Formed 2 b.y. ago

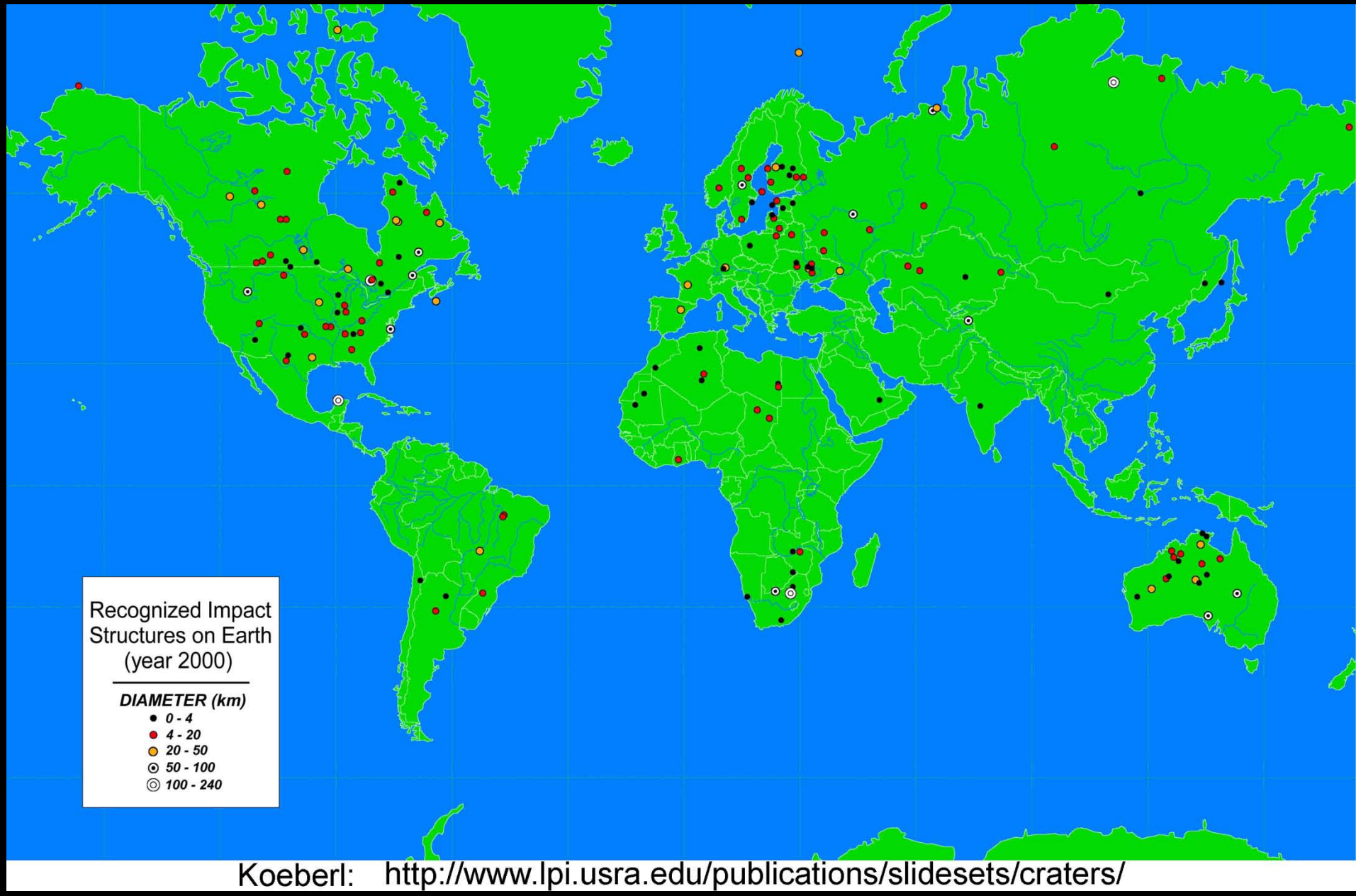


Has gold deposits within

Tunguska event

Tunguska event: radially fallen forest

World map of impact structures

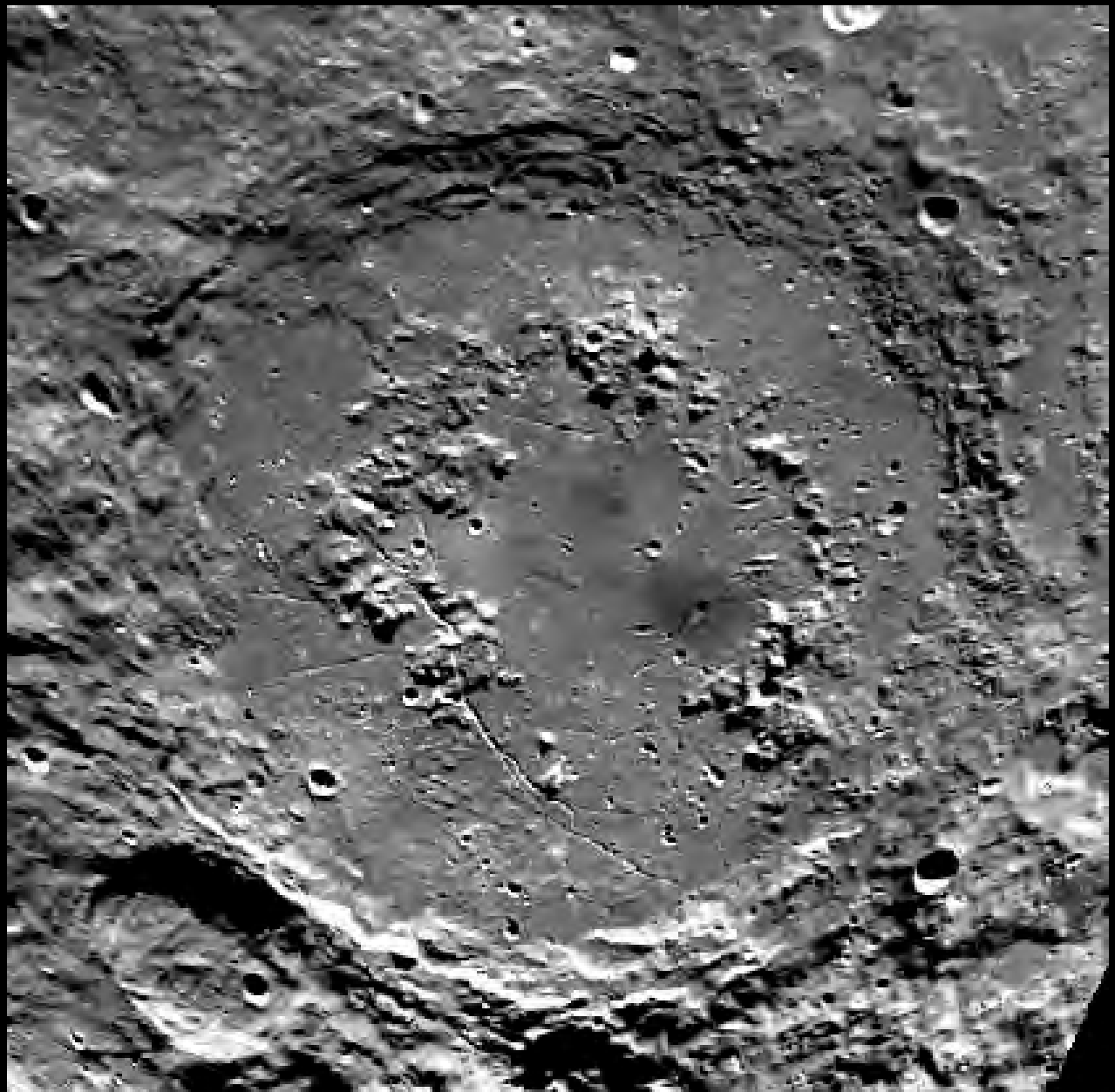


Koeberl: http://www.lpi.usra.edu/publications/slidesets/craters/

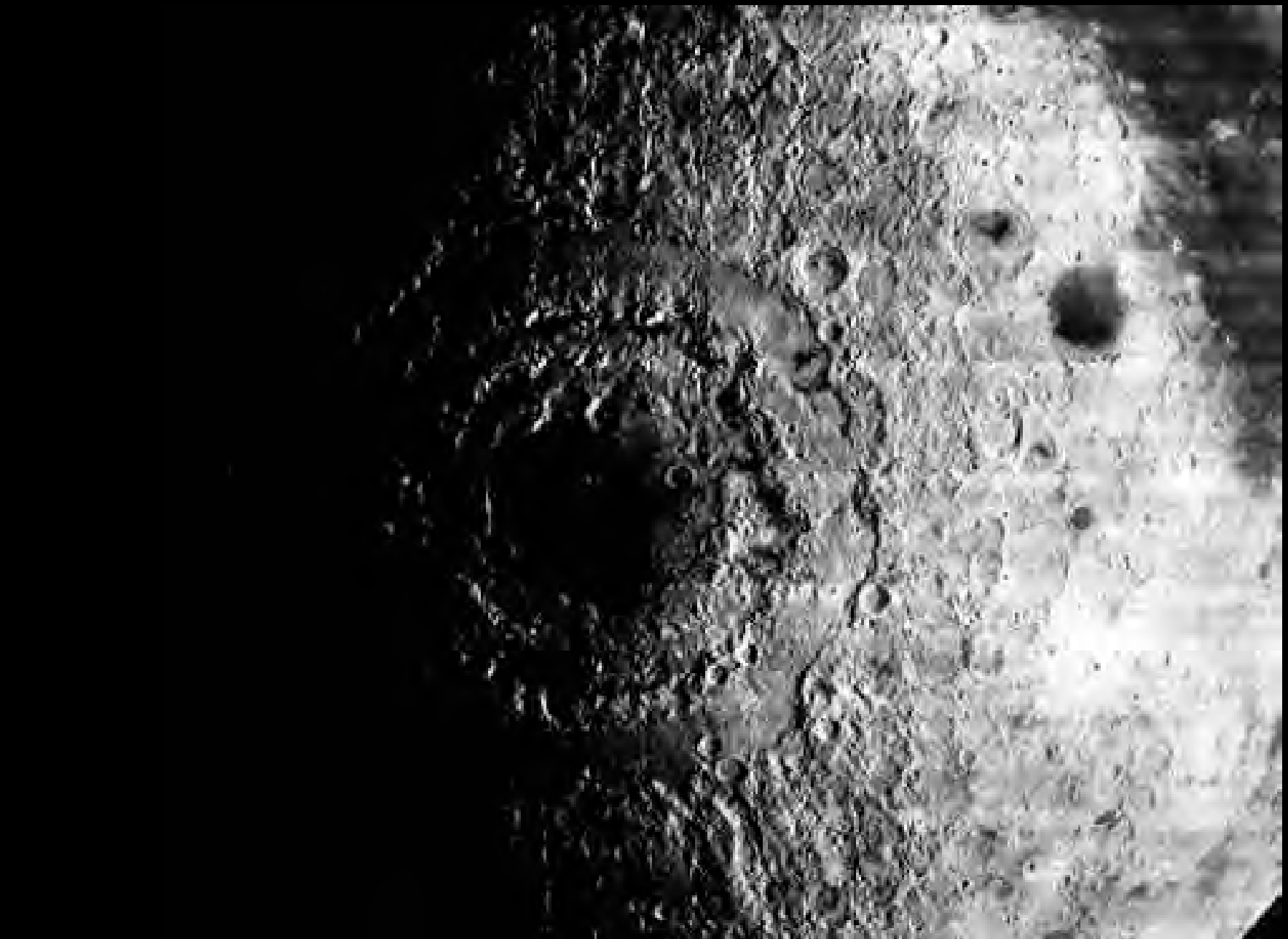
Lunar simple crater

Lunar complex crater: central-peaked

Lunar complex crater: double-ringed

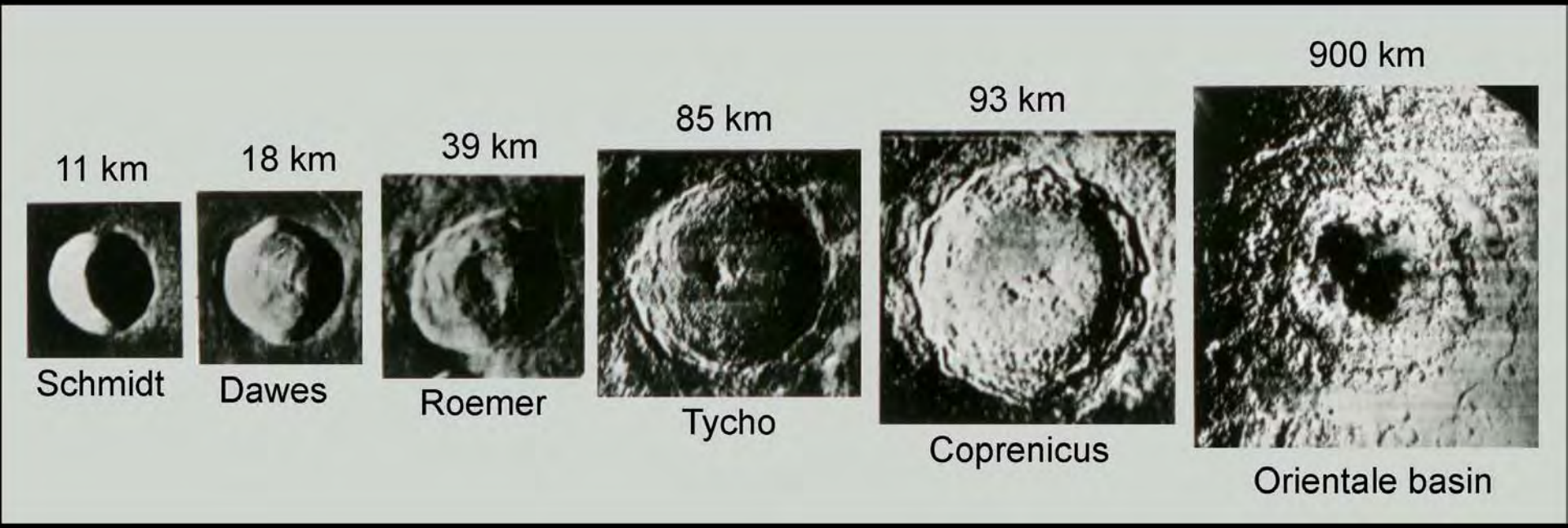


Lunar Orientale basin: multi-ringed

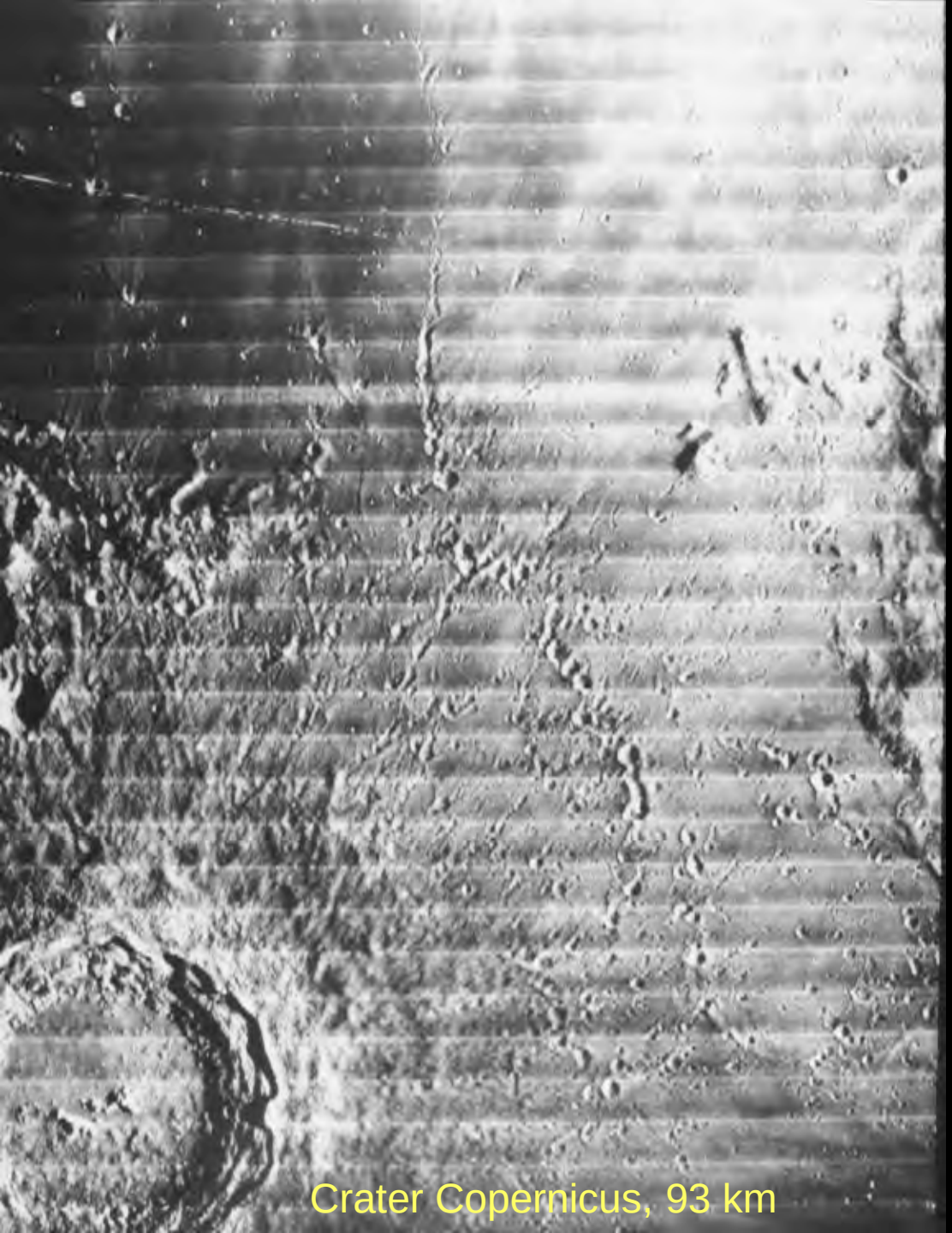


Morphology of impact craters depends on their size
от их диаметра

On the Moon
<10 km – bowl-shaped
15-20 km – transition to craters with central peak
20-90 km – craters with central peak
> 90 km – ringed basins



Basilevsky & Grebennik, 1980



Lunar crater Copernicus with secondary crater around

Mercury

Small craters – bowl-shaped
Large – with central peak
Very large – ringed basins

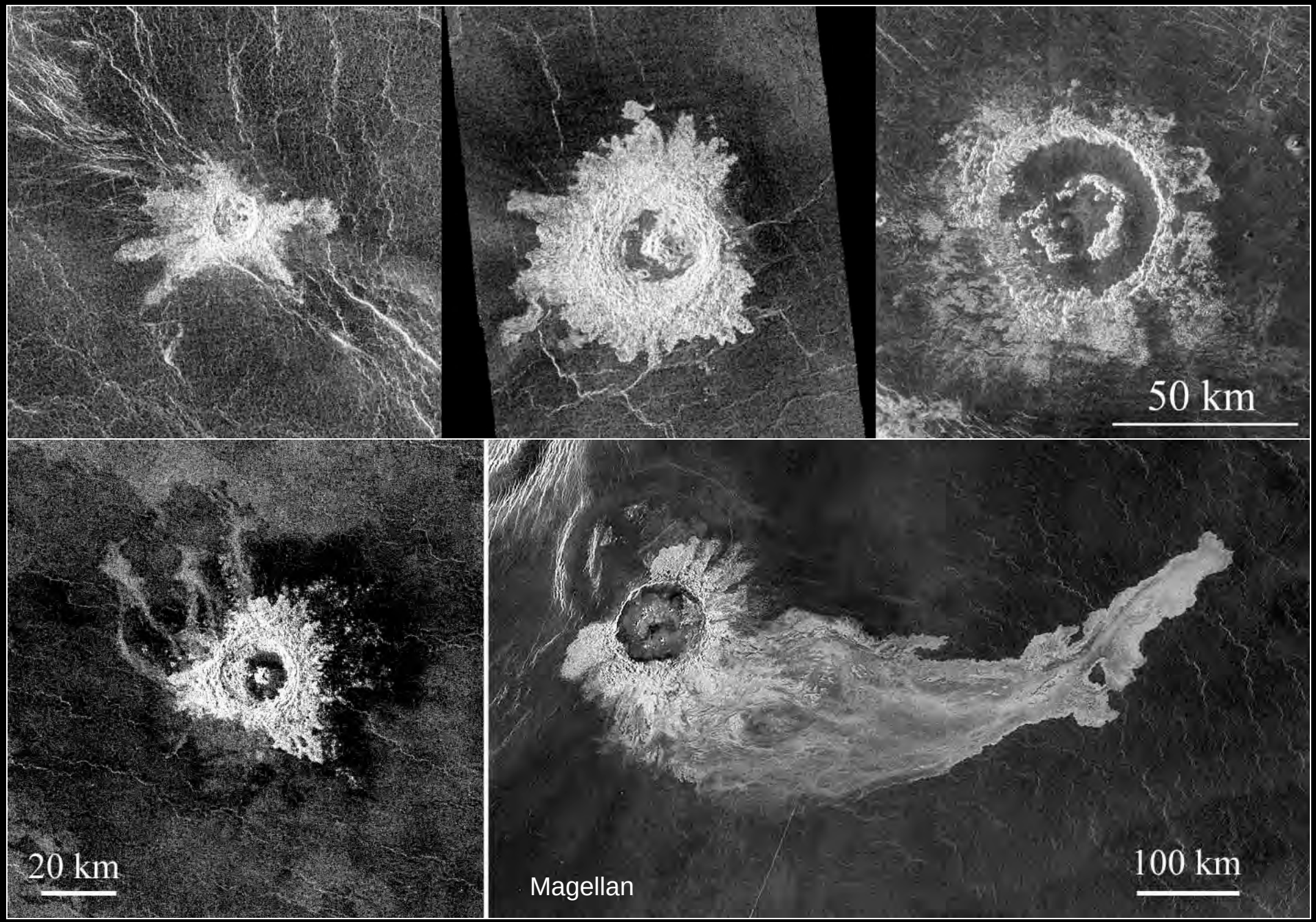
Messenger, NASA

Caloris Basin

1600 км

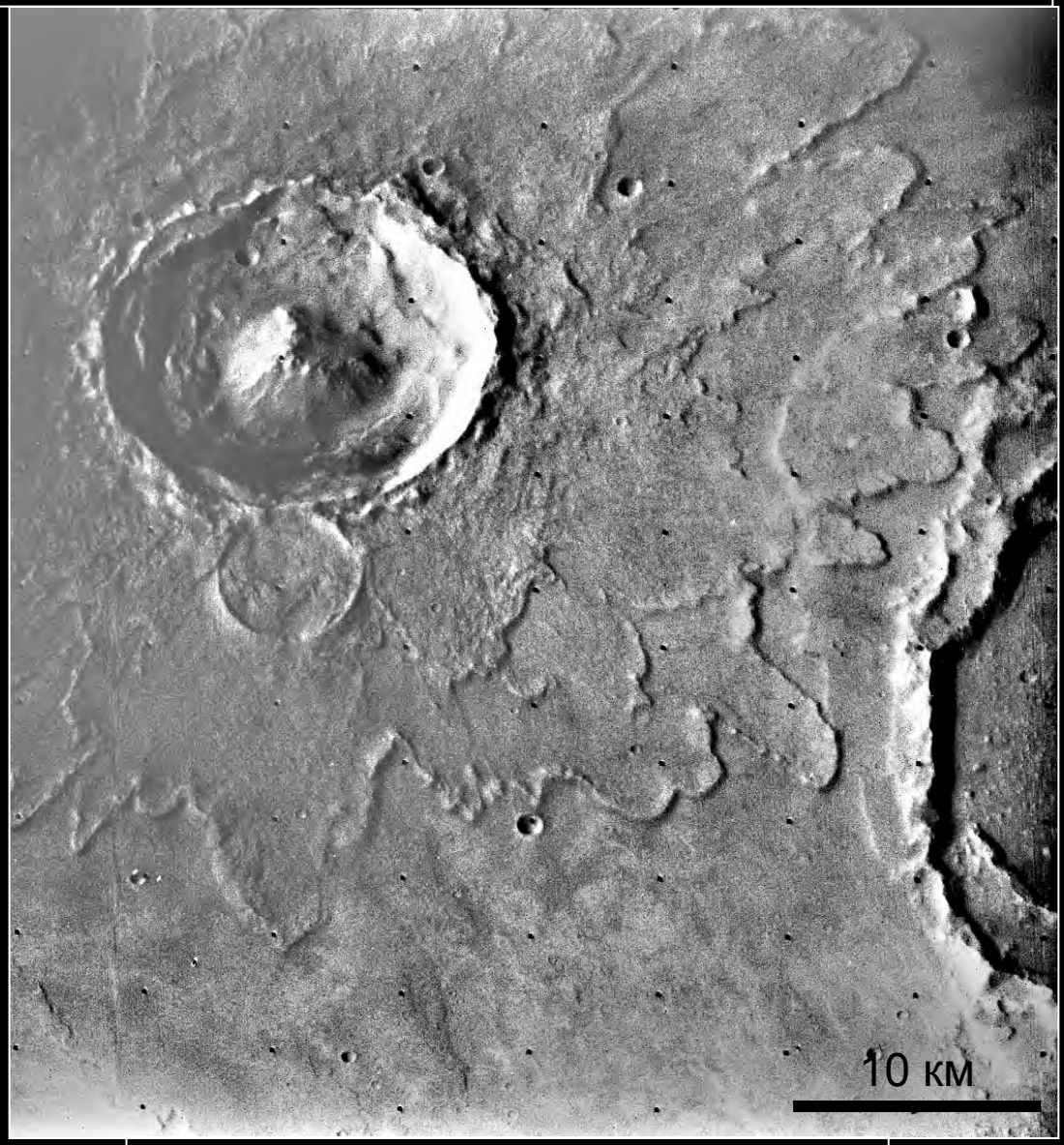
Mariner 10 images

Impact craters of Venus



Impact craters of Mars: Small crater bowl-shaped, large - with central peak and excavate material, containing water ice

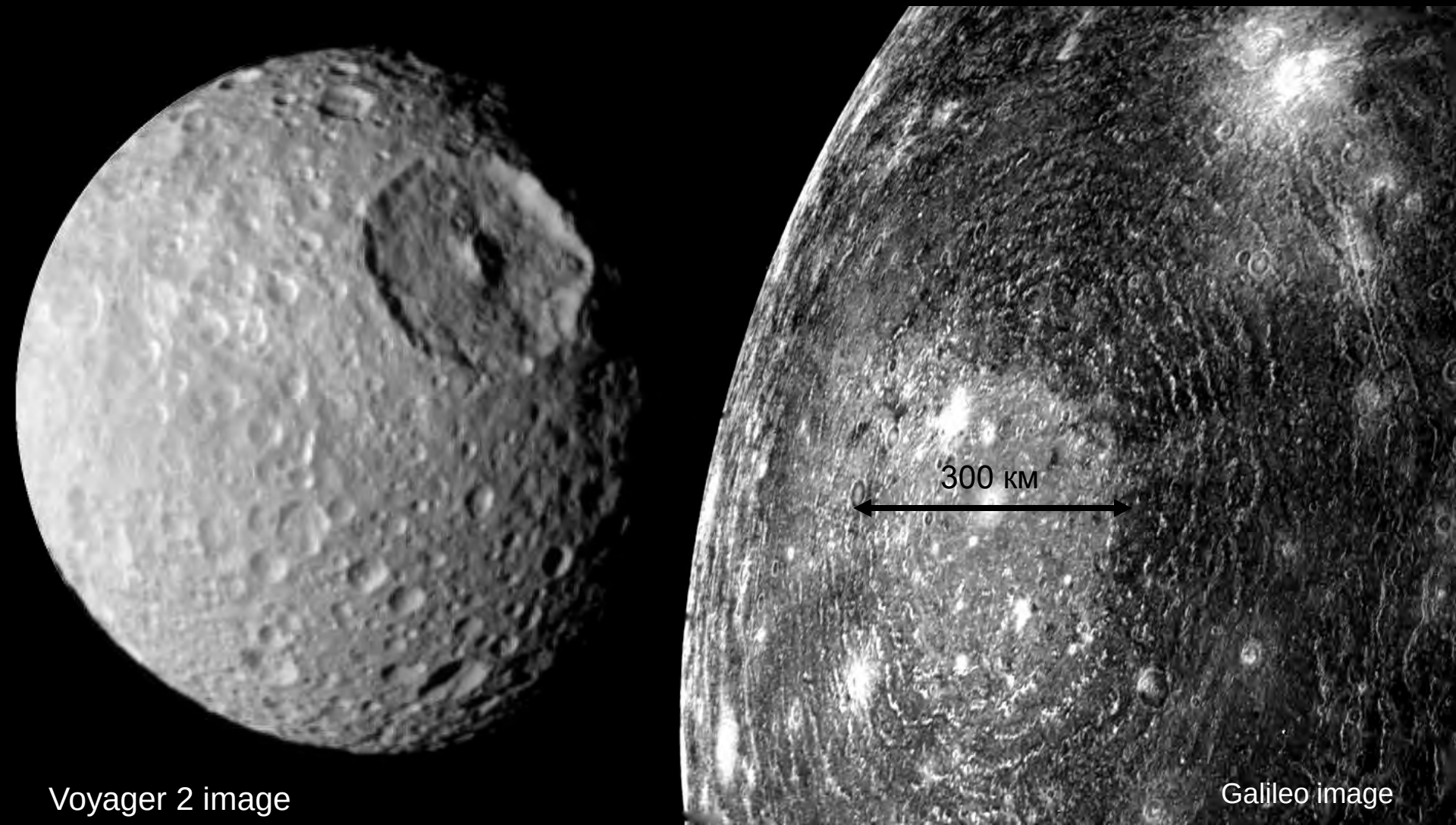
Unnamed bowl-shaped crater with «normal» ejecta



Crater Yuti with central peak, ejecta are fluidized (mud flows)

100-km crater
with central peak
on Mimas (D = 400 km)

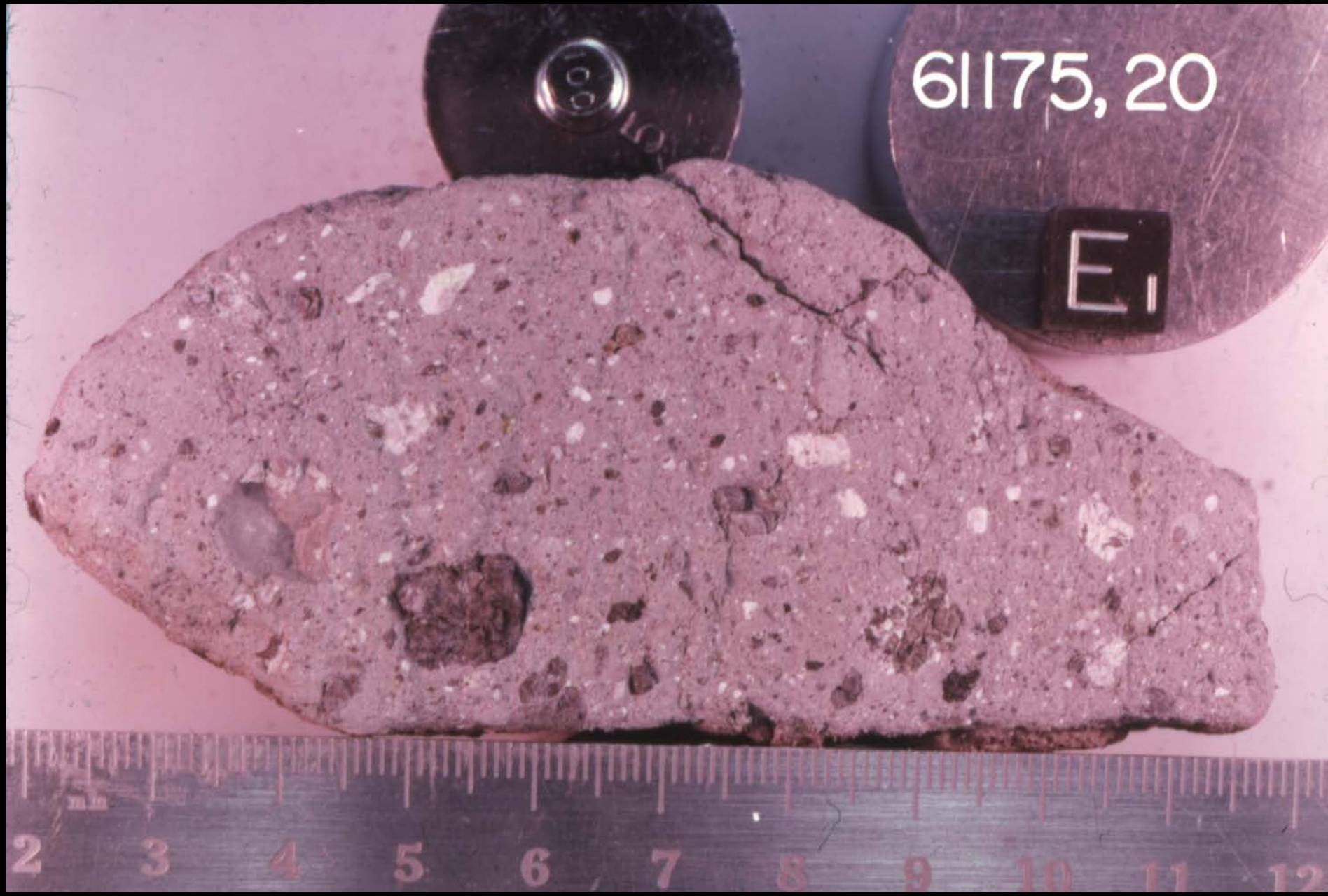
Impact basin
on Callisto (D = 4680 km)



Voyager 2 image

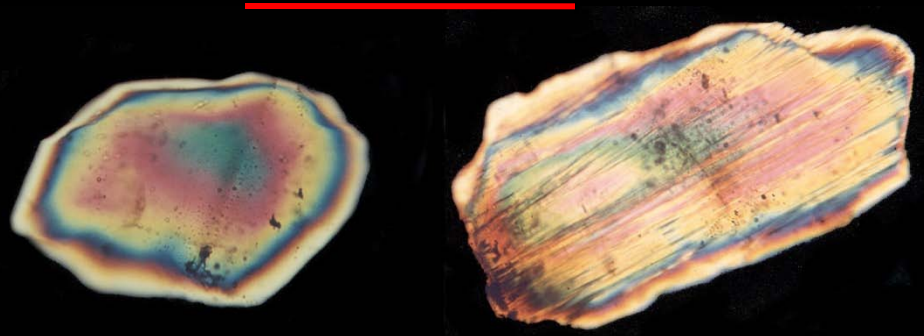
Galileo image

Highland breccia Apollo 16, Fragments are well seen



Grains of quartz affected and not affected by impact

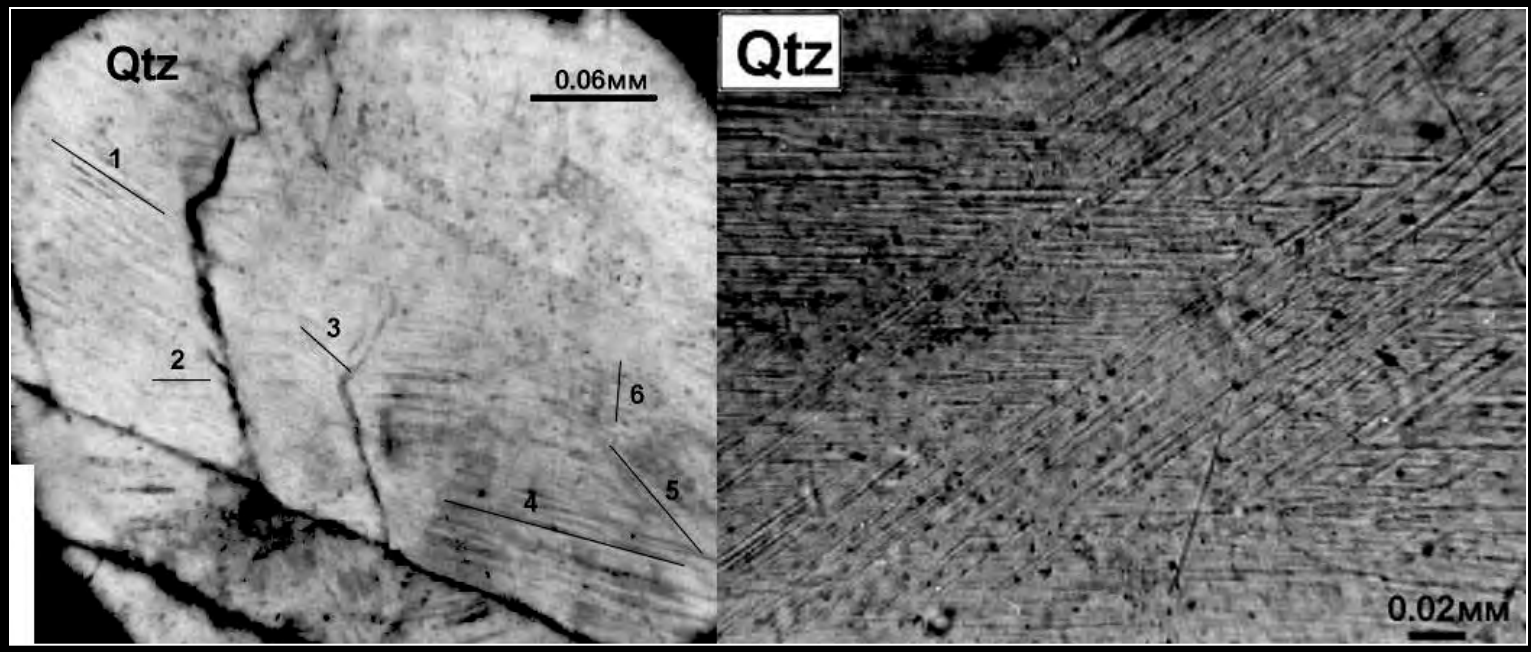
20 micron



No impact effects

Planar structures
in impacted quartz

http://www.lpi.usra.edu/publications/slidesets/craters/



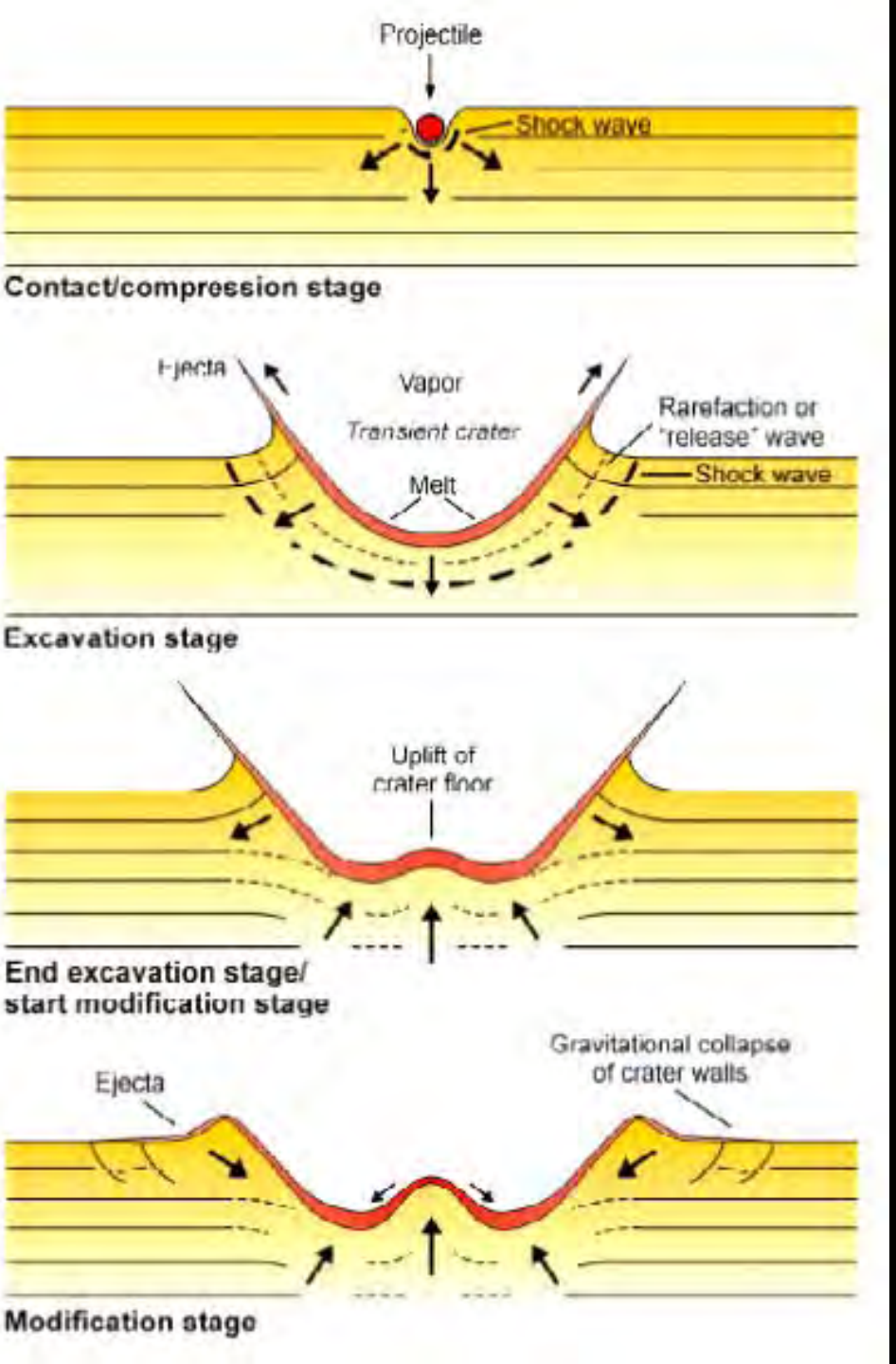
Planar structures in impacted quartz
Crater Janisjarvi, Karelia, photo of L.V. Sazonova

Impact diamonds from Australia and Brazil

Impact diamond.
Quinsland, Australia

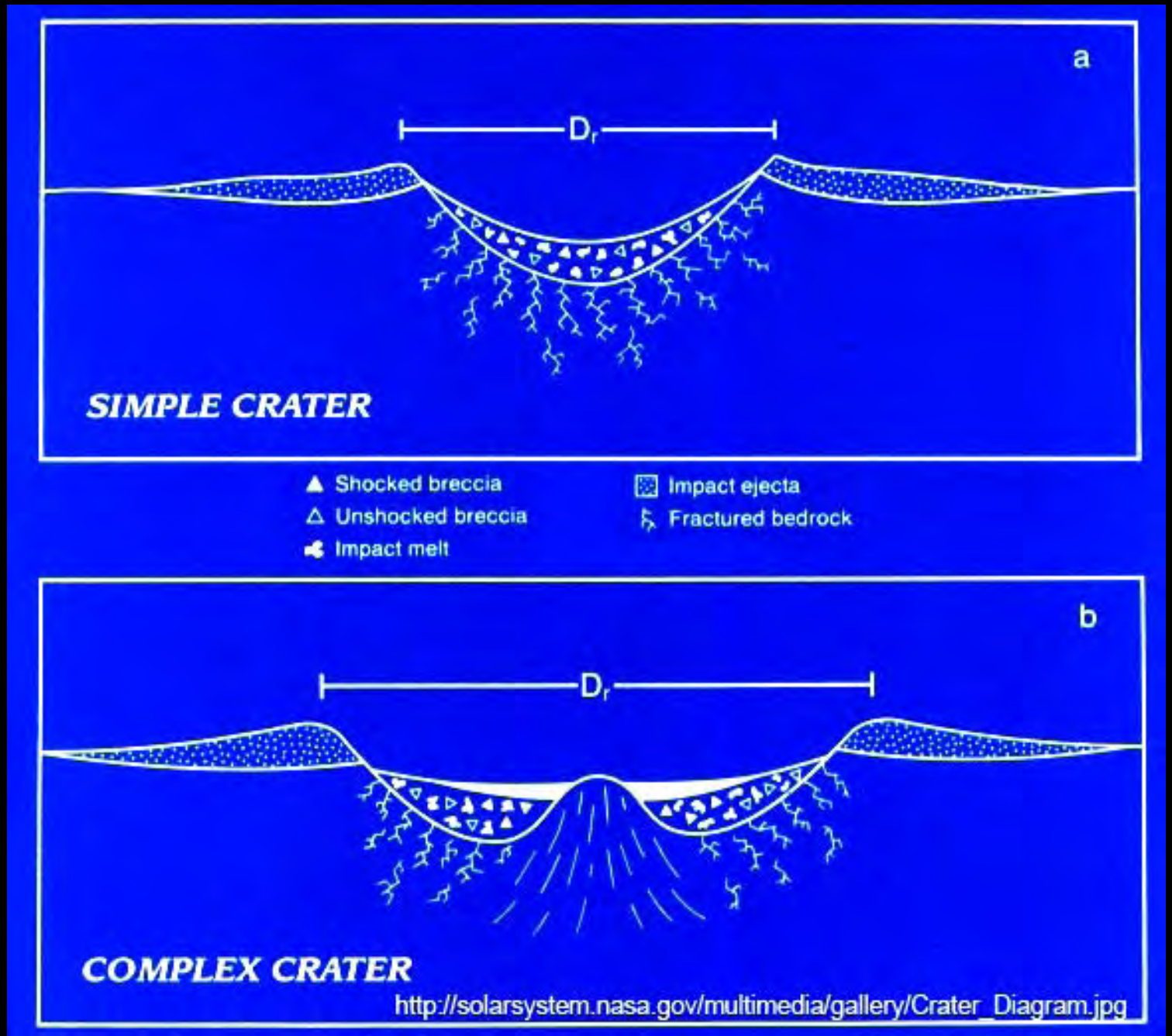
Impact diamond (carbonado)
Brazil

Stages of impact



http://www.psi.edu/explorecraters/intro_pics/impact_stages_16.jpg

Structure of impact craters: Synthesis of terrestrial and lunar data



Mean speed of collision (km/s) of meteoroids with planetary bodies

Planetary body	Escape velocity	Early planatesimals	Asteroids	Comets
Mercury	4.3	4.7	20	62
Venus	10.3	11.5	18	47
Earth	11.2	12.5	18	40
The Moon	2.37	6.1	14	38
Mars	5.03	5.6	10	31

Specific kinetic energy of projectile (erg/g) in comparioson with specific energy of explosion

TNT	Nuclear	V = 5 km/s	V = 15 km/s	V = 30 km/s	V = 45 km/s
4×10^{10}	1×10^{16}	1.2×10^{11}	1.1×10^{12}	4.5×10^{12}	1×10^{13}

Impact induced transformations of materials

1 bar = 1 km/cm2, 1 kbar = 103 bar, 1 Mbar = 106 bar

Mechanical crushing	Several kbar
Modification of crystal structure	
Planar elements	100-200 kbar
Isotropization of minerals SiO2	260-300 kbar
Transformation into glass with preservation of rock structure	
High pressure phases	50-250 kbar
Quartz => coesite, stishovite	
Graphite => diamond, lonsdeleite	
Impact melting	
Grain-to-grain friction	200-300 kbar
Release after impact compression	
Quartz, feldspars	400-600 kbar
Pyroxenes	800-1,000 kbar
Impact vaporization (silicates)	> 1-2 Mbar

M impact vapor ≈ M projectile
M impact melt ≈ 10 M projectile

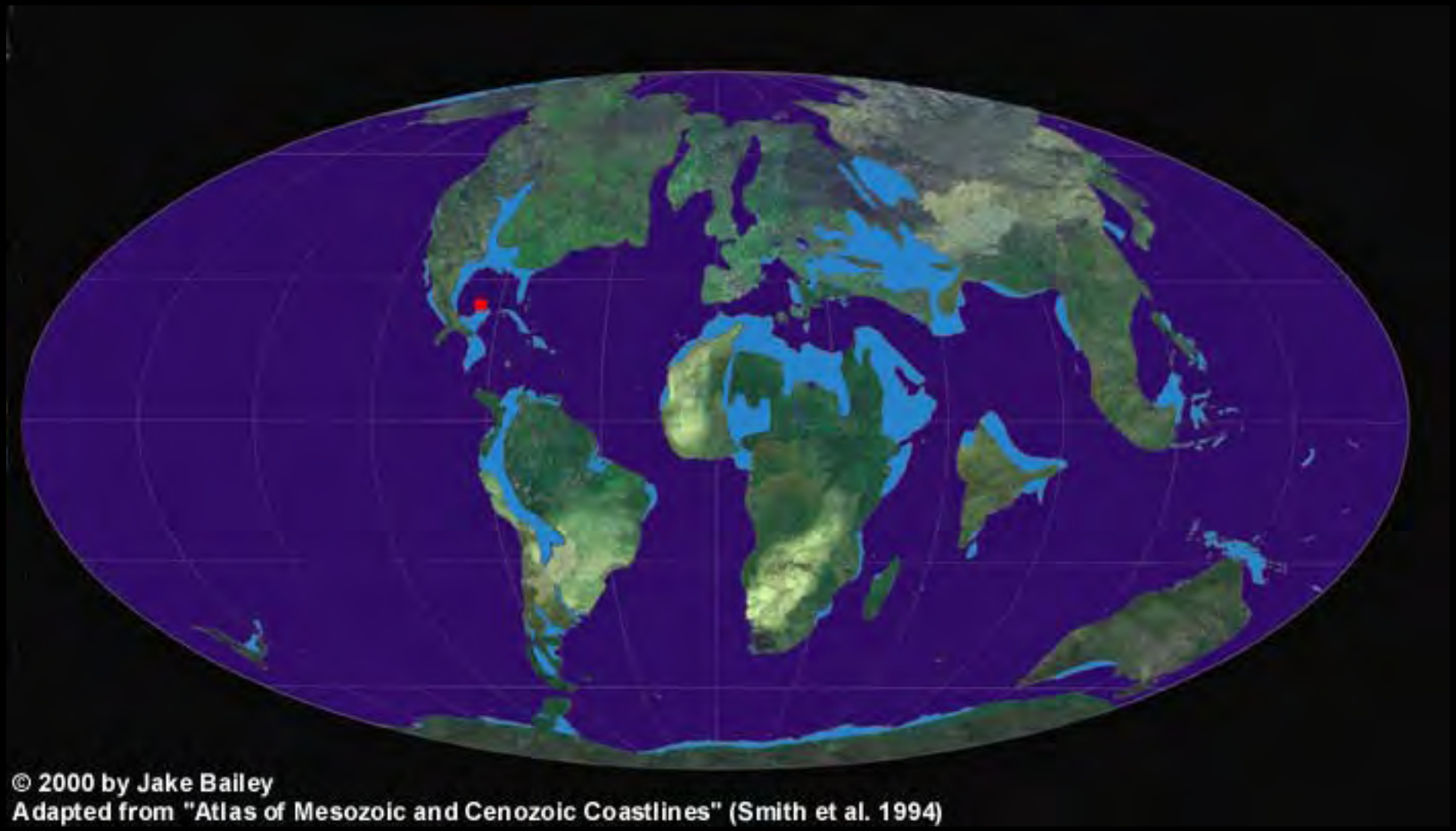
Experimental data on energy distribution (%) in impacts

	Target – sand	Target - basalt
Heating		
Projectile	~6	4-12
Target	~25	19-23
Compaction	~20	1
Crushing	~8	10-24
Ejection	~53	42-53

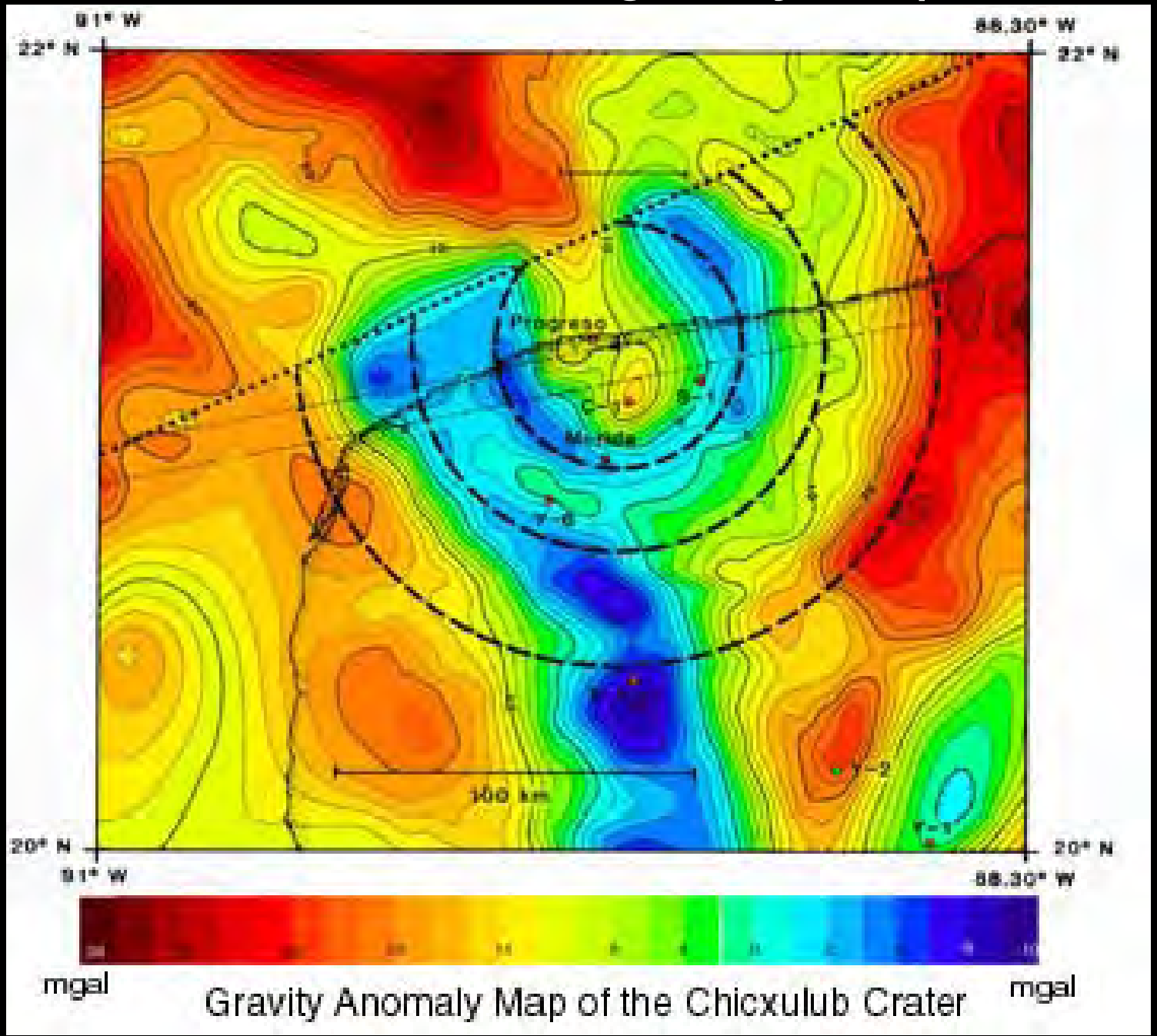
For Earth D projectile ≈ 1/10 – 1/20 D crater

Crater with D = 10 km was formed by ~1 km projectile

Chicxulub crater (astrobleme) location

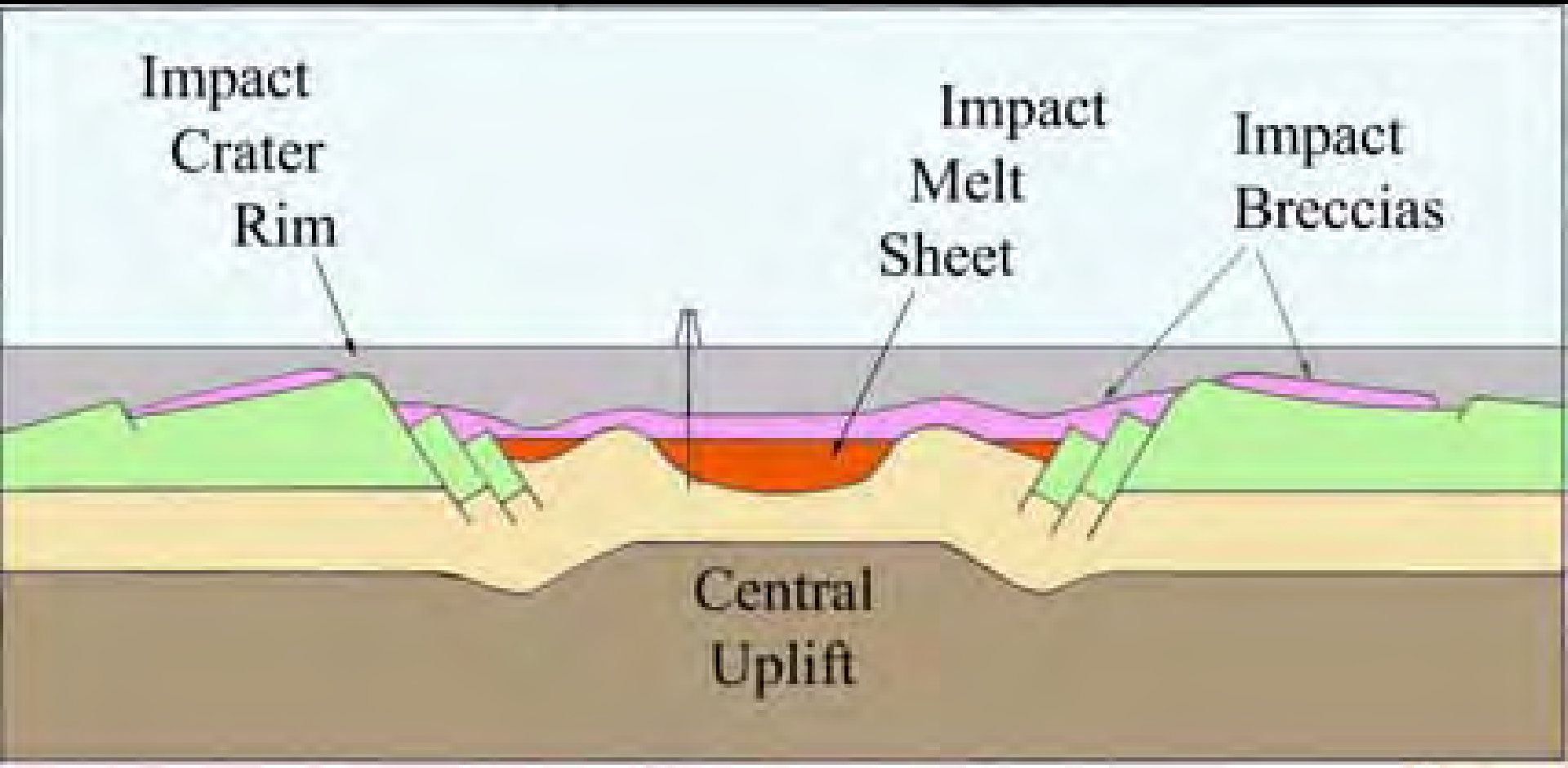


Chicxulub gravity map

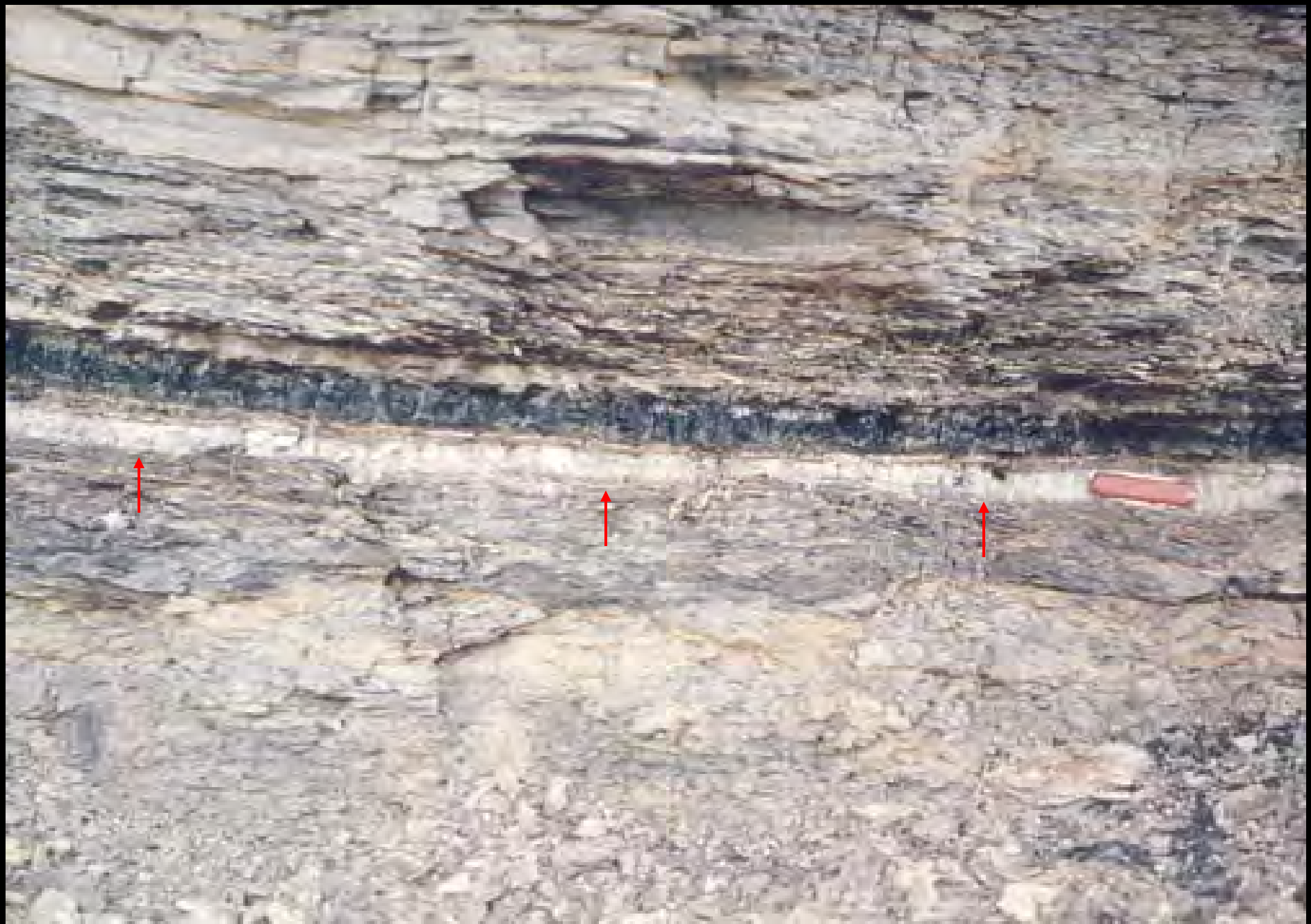


Gravity Anomaly Map of the Chicxulub Crater

Structure of crater Chicxulub

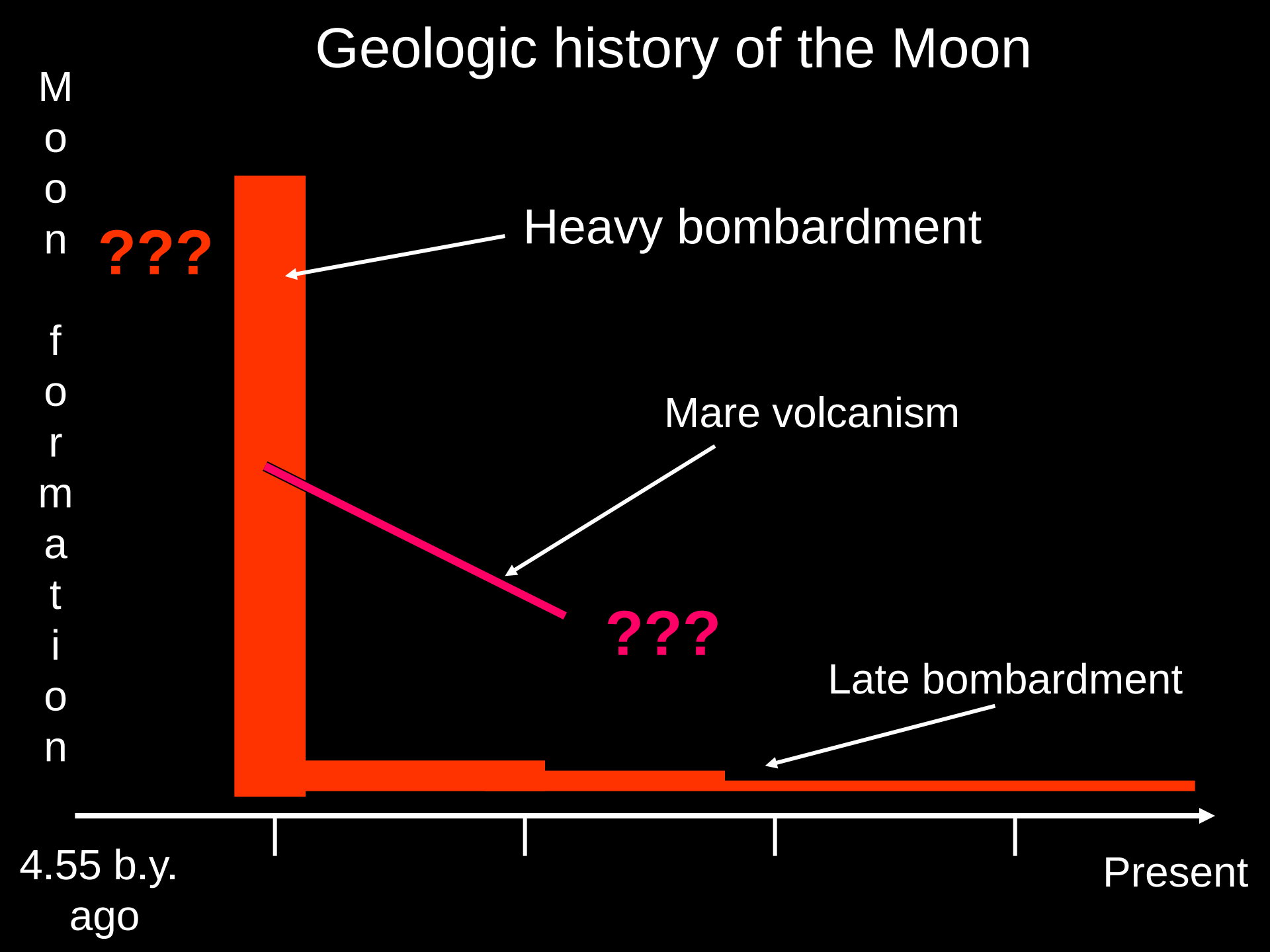


K-T boundary, Raton basin, Colorado, USA



Impact which killed dinosaurs, art by Don Davis

Geologic history of the Moon

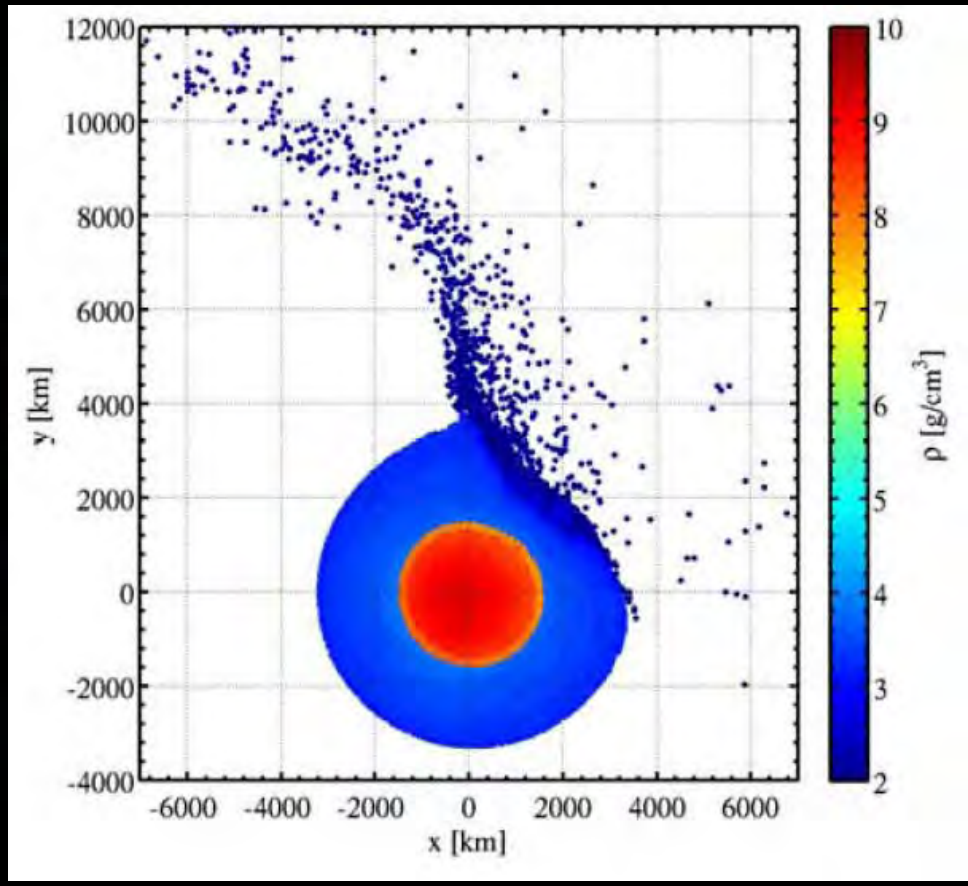


Origin of the Moon: Giant impact hypothesis

Mars-size body

Proto-Earth

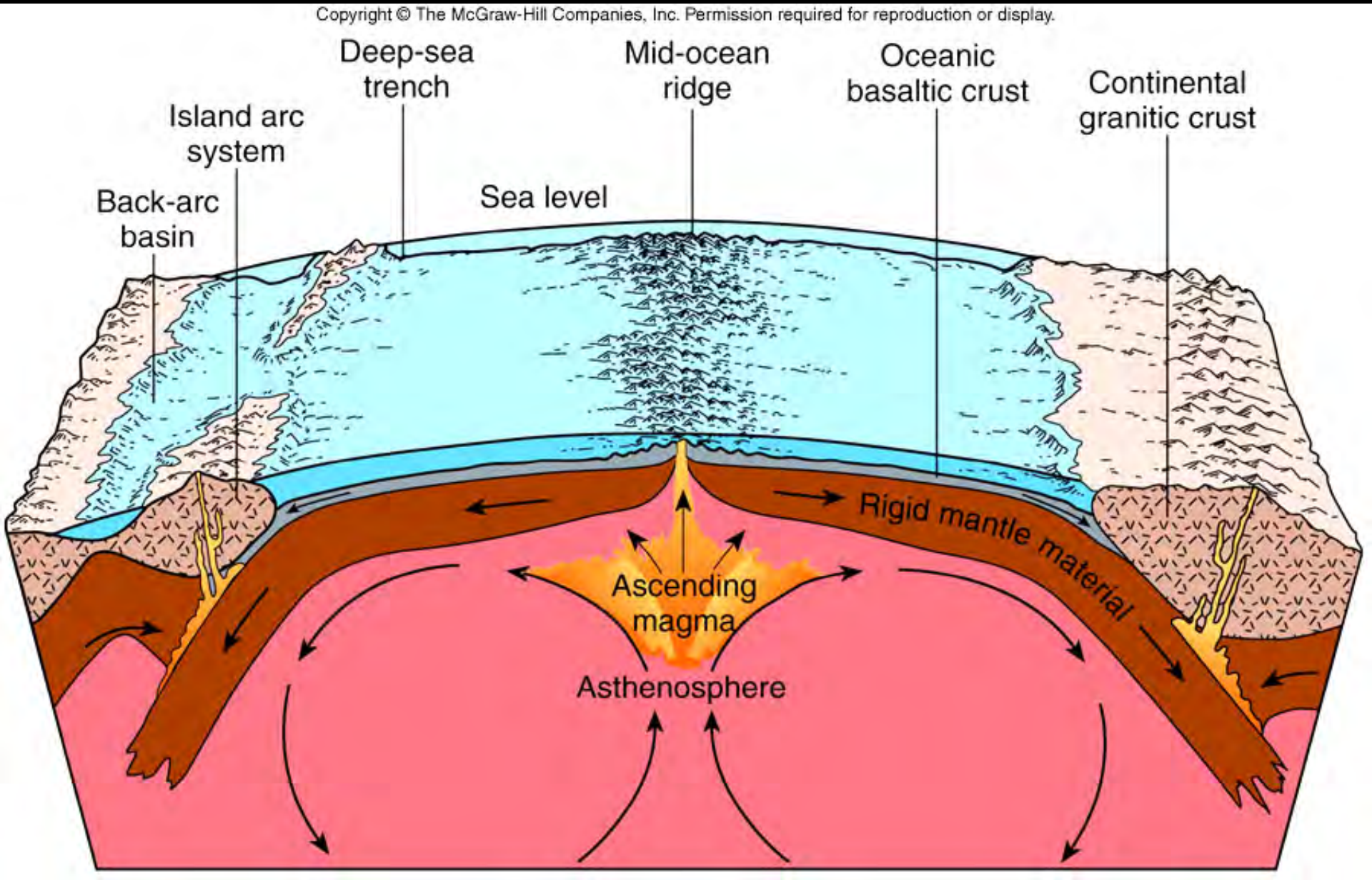
The Moon is formed due to accretion of the impact ejecta on the around-Earth orbit



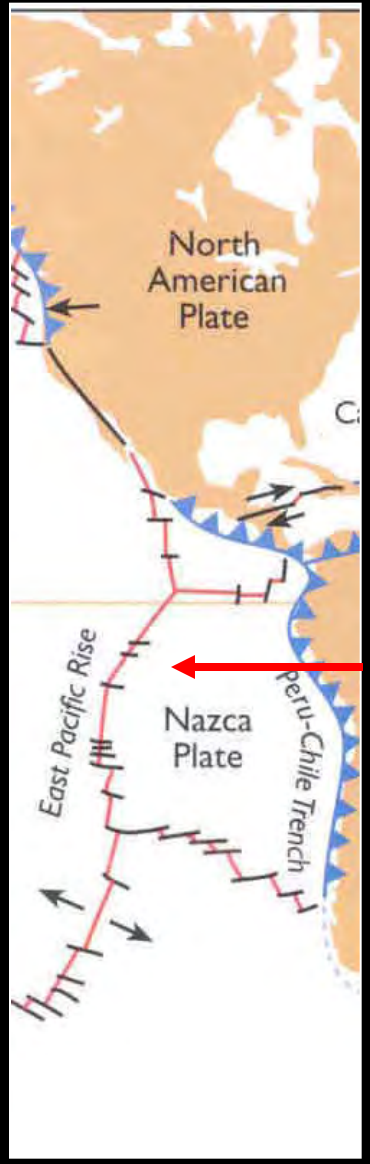
Magmatism (volcanism) on the Solar system bodies

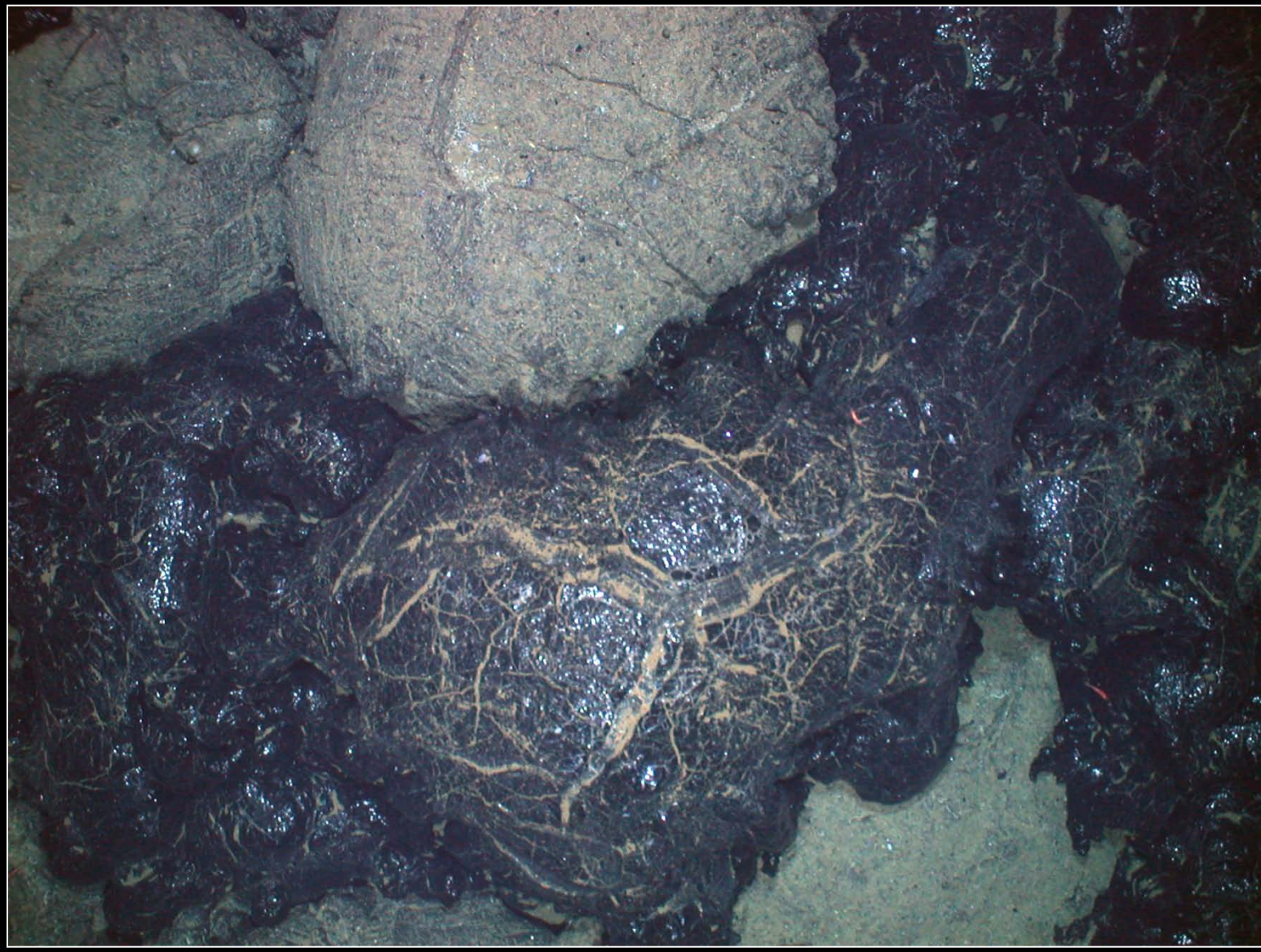
Plate tectonics -
- working heat engine of Earth

How plate tectonic works



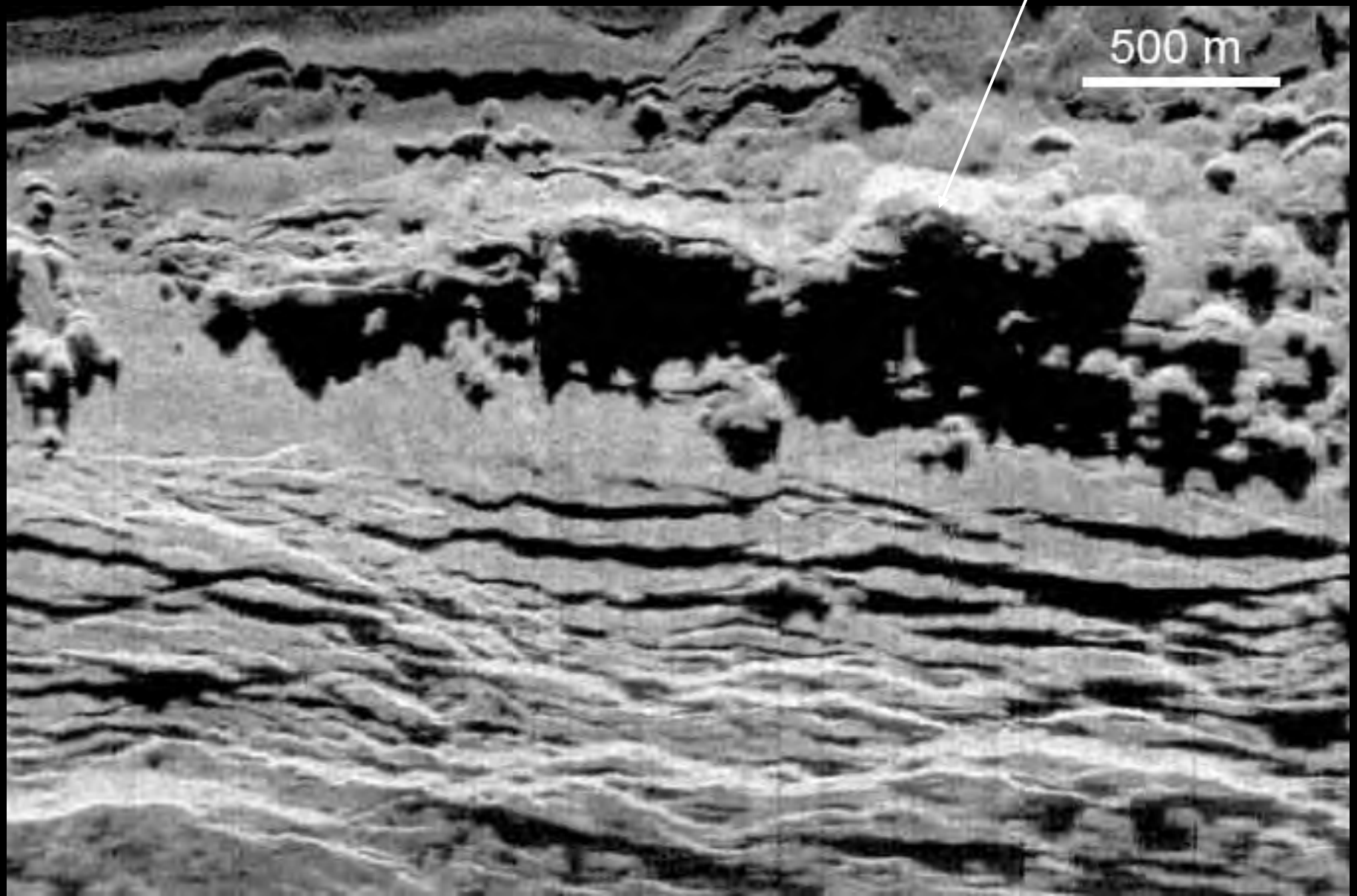
Sea-floor spreading lava eruption: Pillow lavas



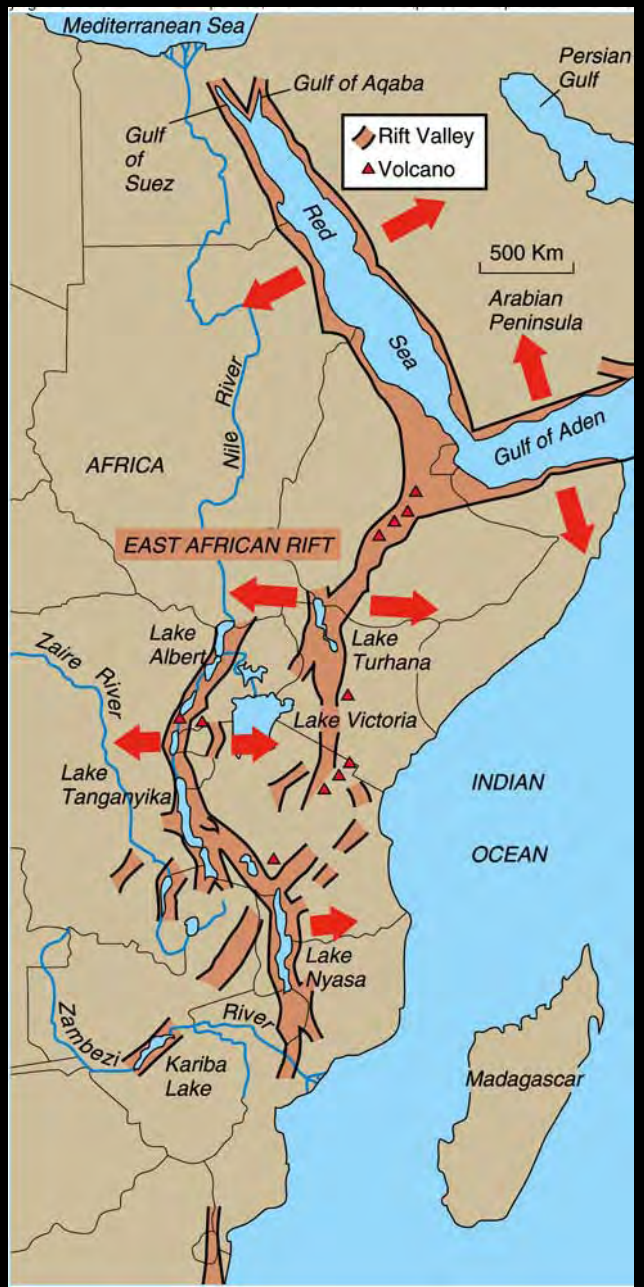


Several meters

Sea-floor spreading: small volcanic ridge at Mid Atlantic Ridge



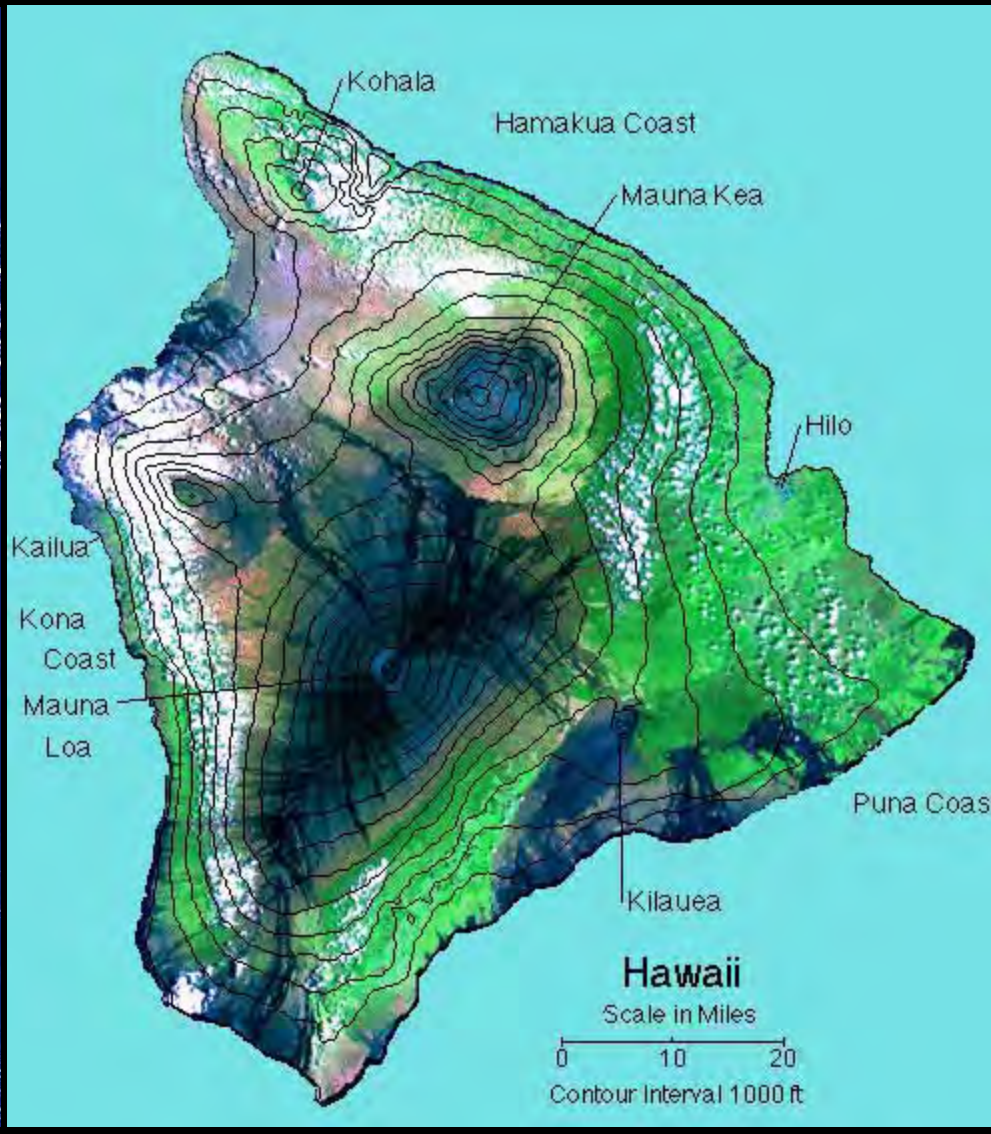
East African rifts



Nyiragongo, East Africa

Hawaii big island: hot spot volcanism

Landsat image



Map

Hawaii, Mauna Loa summit

Caldera Kilauea eruption

Mauna Loa eruption

Hawaii, aa and pahoehoe lavas

Lava fountaining forms cinder cones, Hawaii

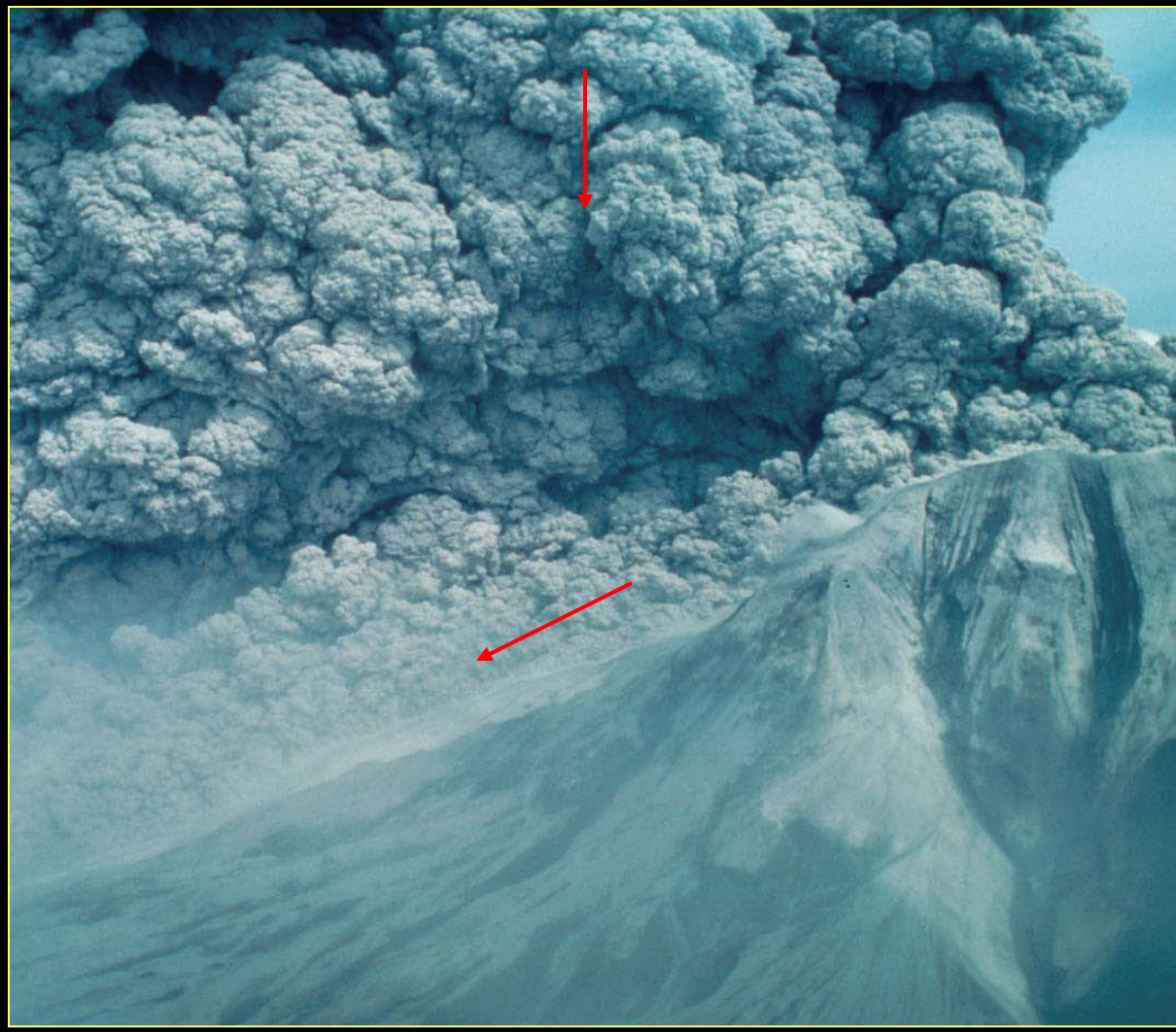
USGS photo

Cinder cone and Mauna Kea volcano behind

USGS photo

St. Helens volcano: pre eruption

St. Helens blast and nuee ardente
May 18, 1980



Blast

Nuee ardente

USGS photo

St. Helens pyroclastic tongue

USGS photo

St. Helens pyroclastic deposit

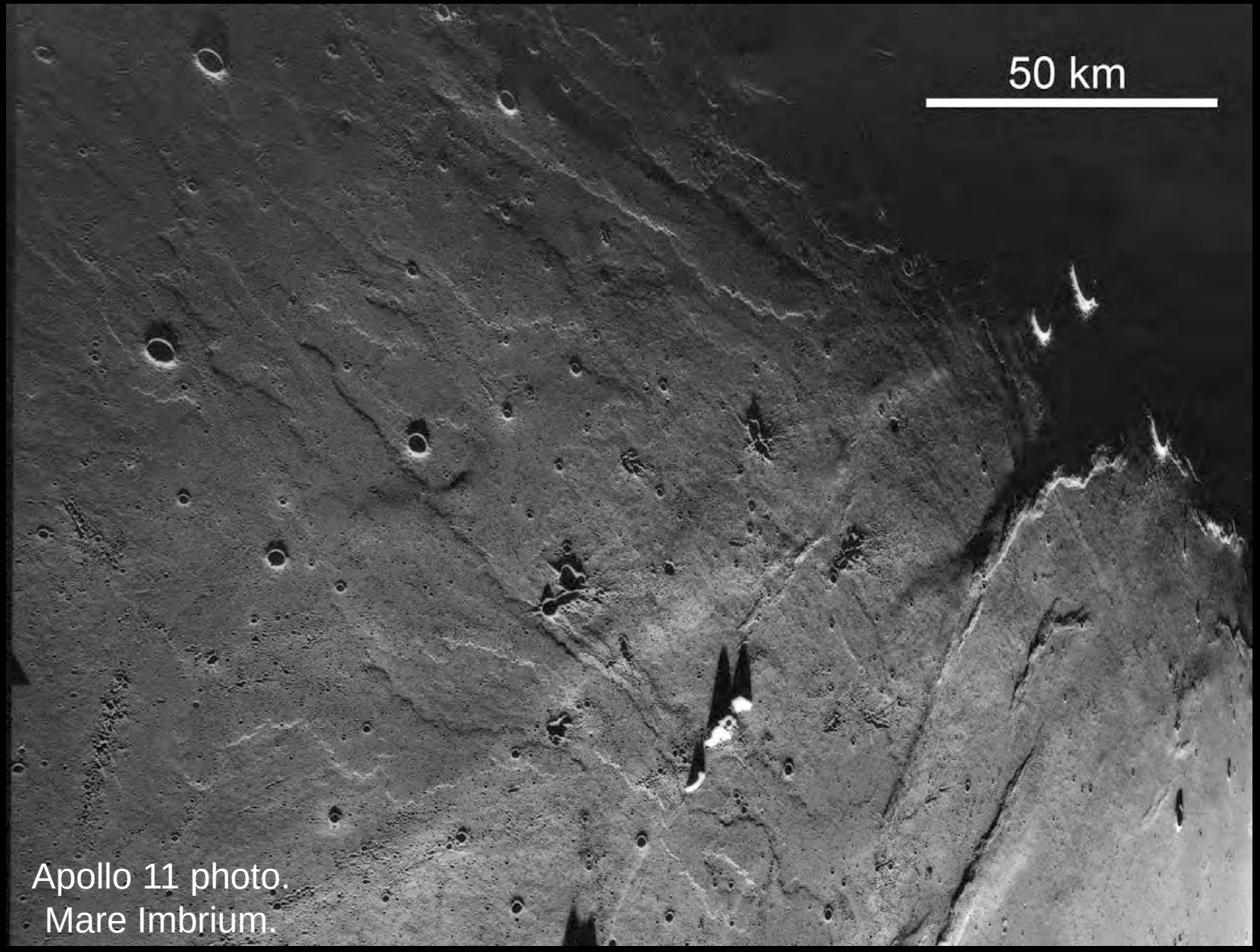
St. Helens dome, August 1981

Lunar maria

Basaltic lavas

Telescopic image

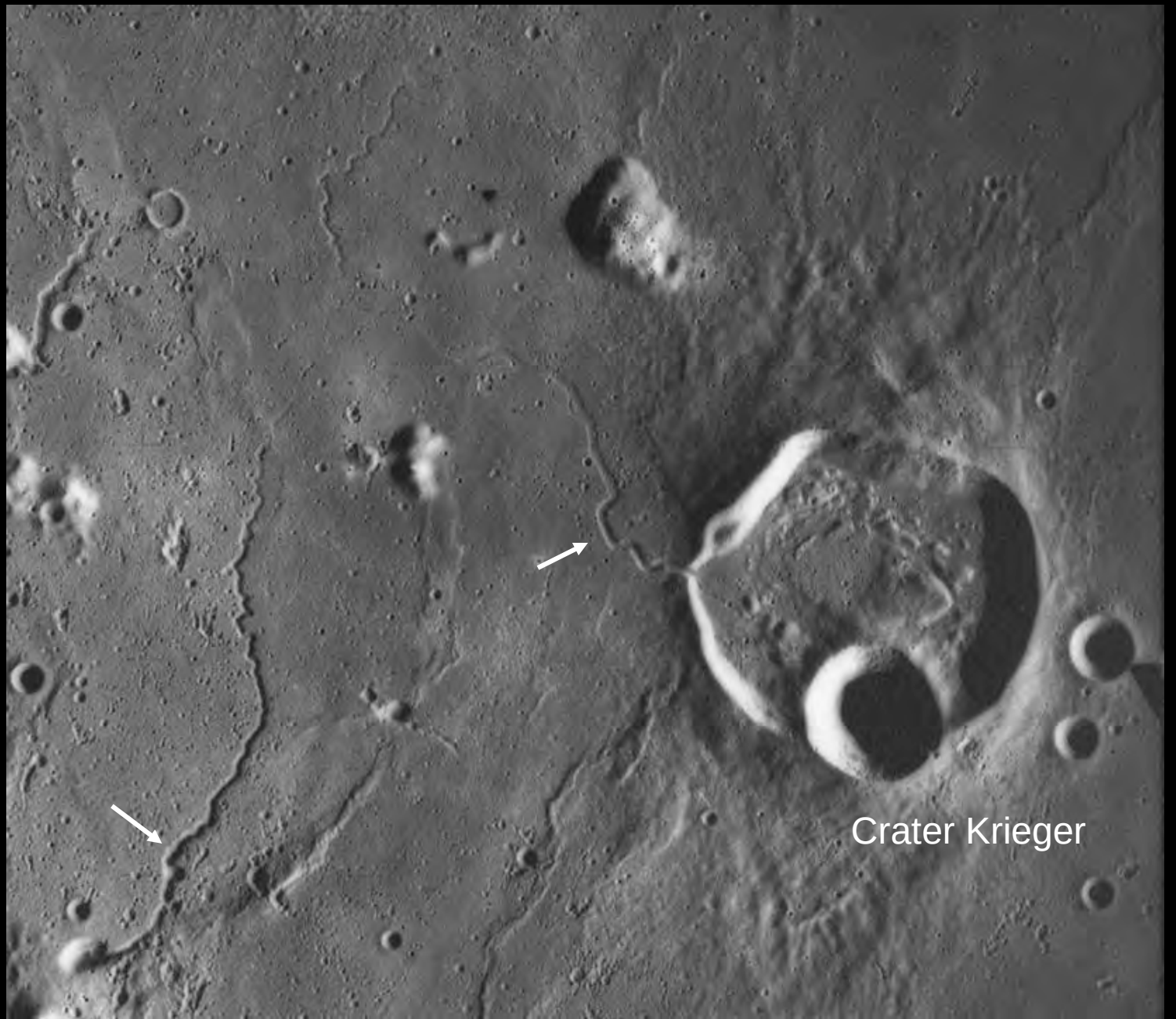
Lunar volcanism



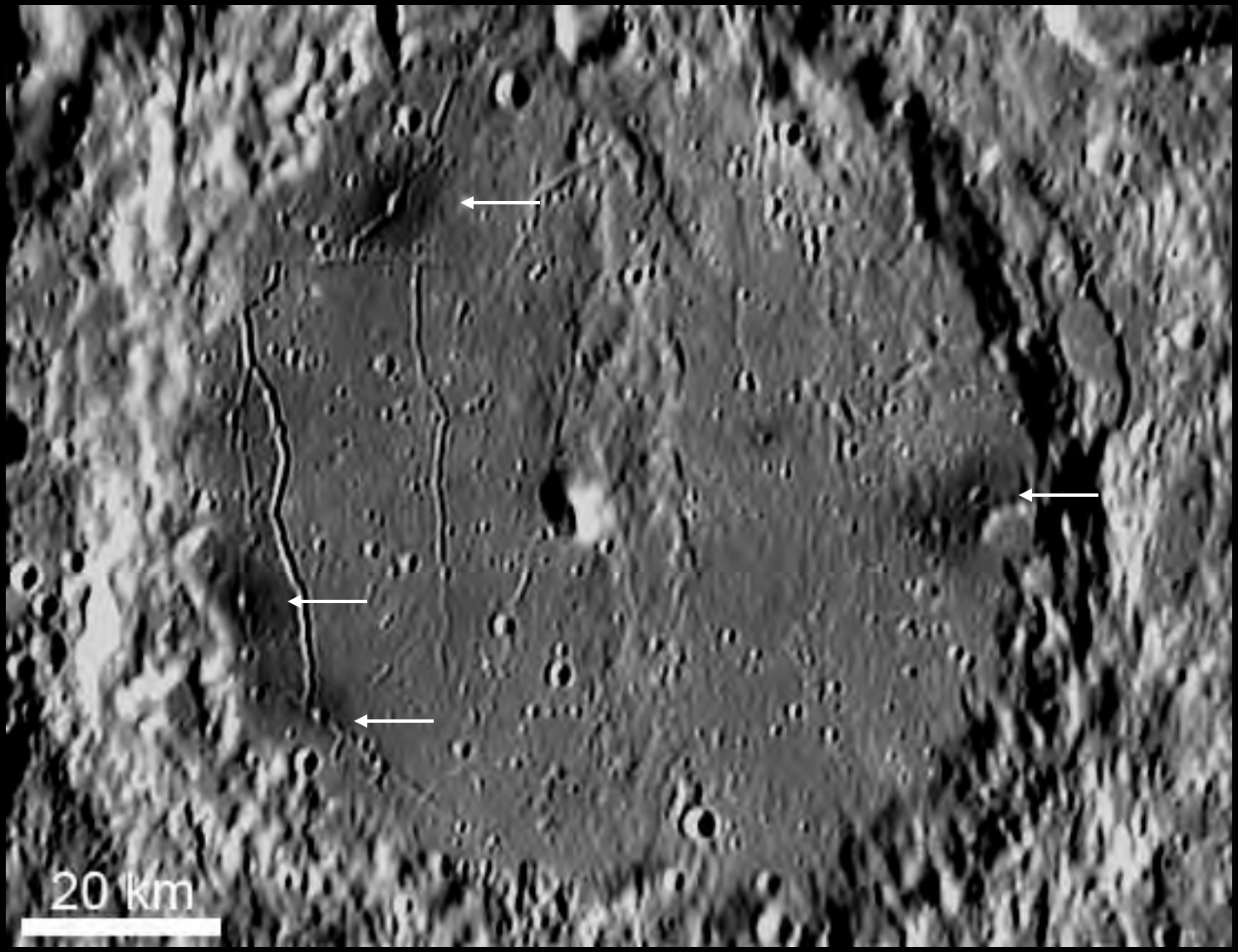
Apollo 11 photo.
Mare Imbrium.

Plains-forming basaltic lavas make maria.

Sinuous rilles – erosion by hot lava flow

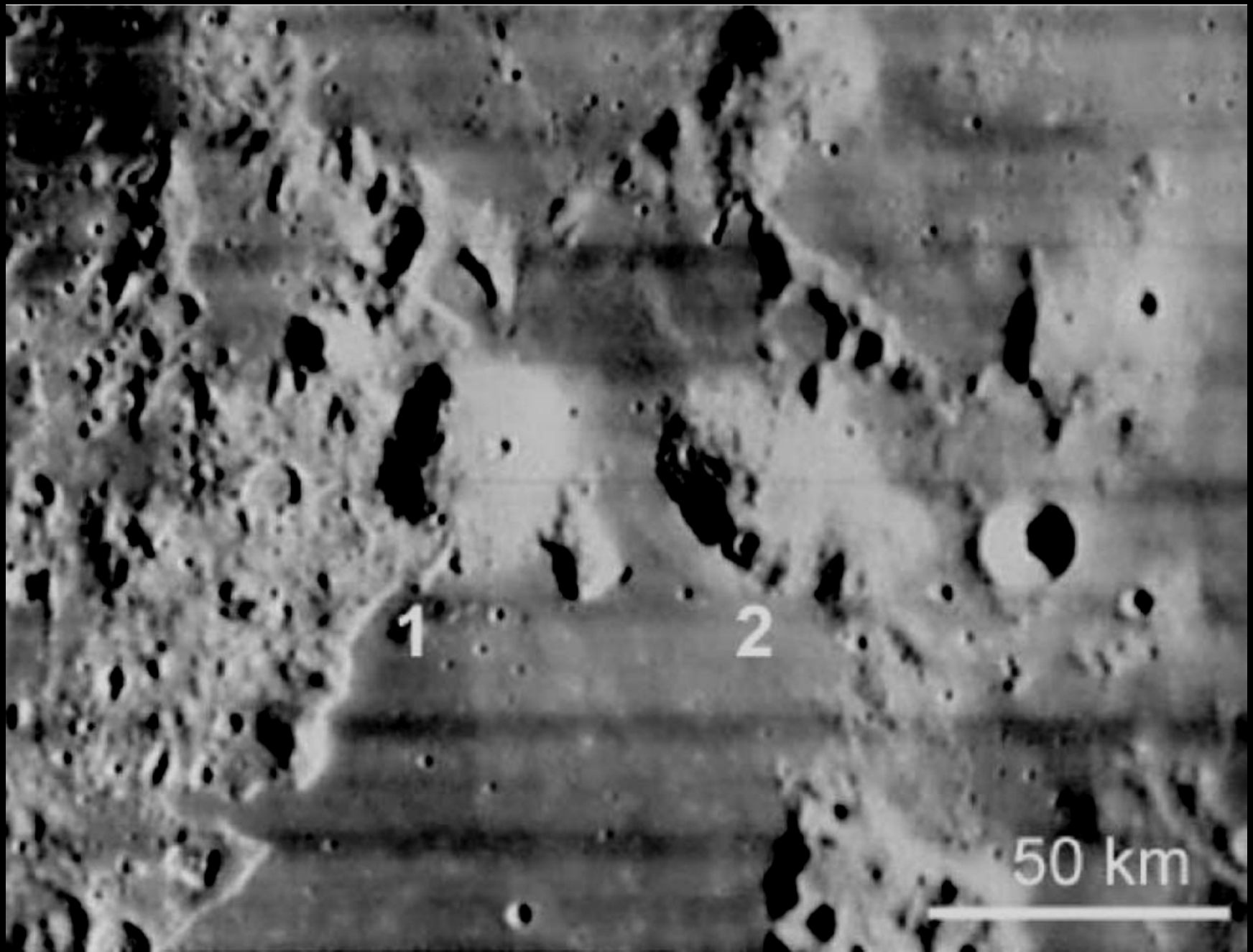


108 km crater Alphonsus has on its floor fractures and small craters with dark halo – pyroclastic deposit?

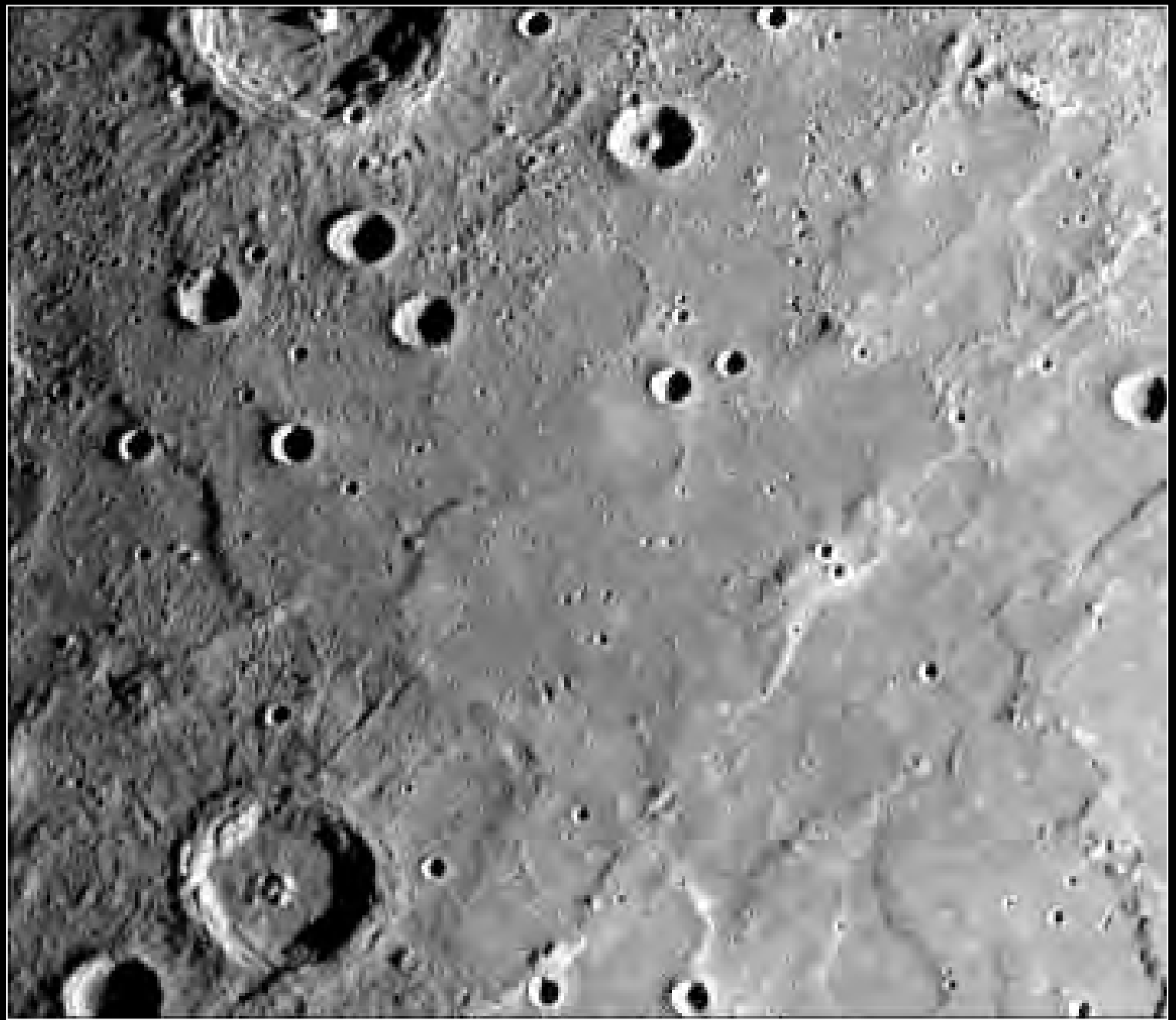


In 1958 Soviet astronomer N. Kozyrev observed here a gas release

Gruithuisen domes –non-basaltic volcanism?

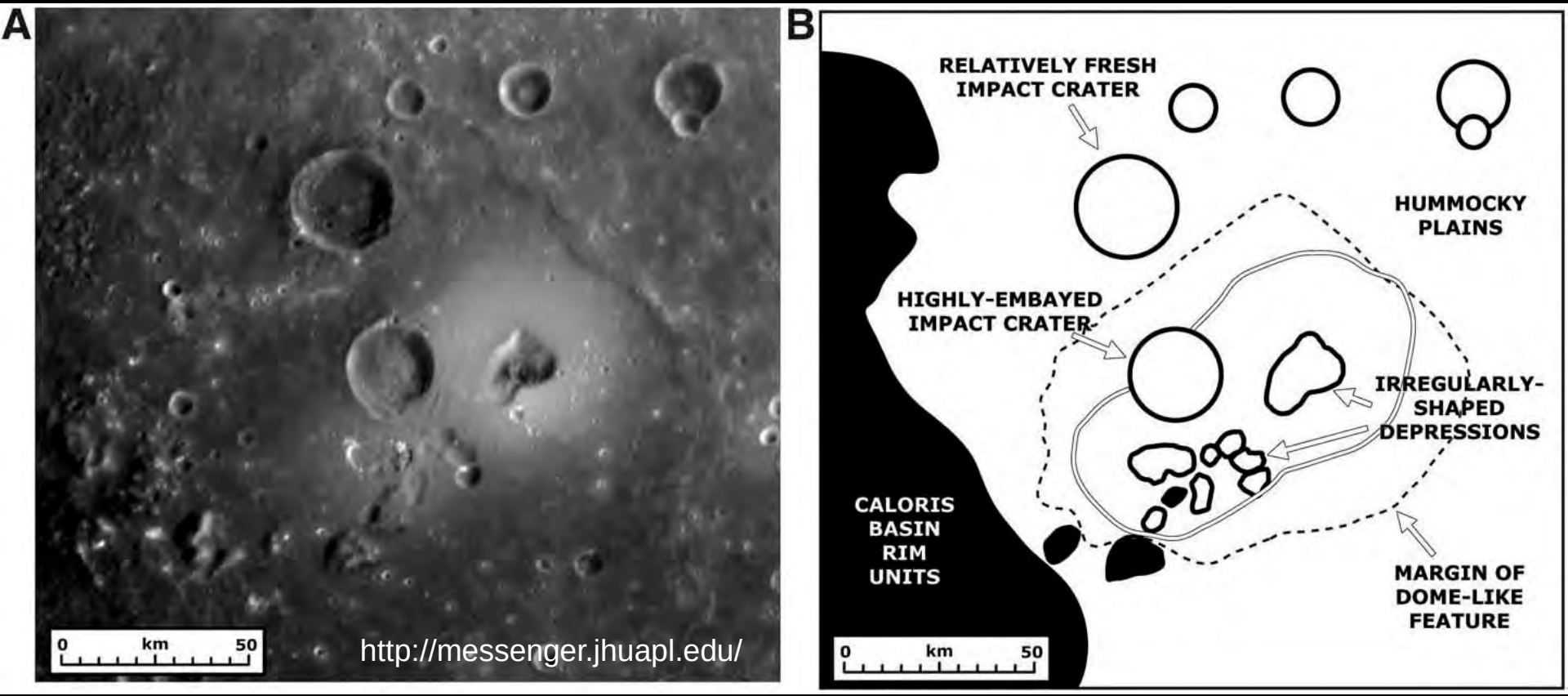


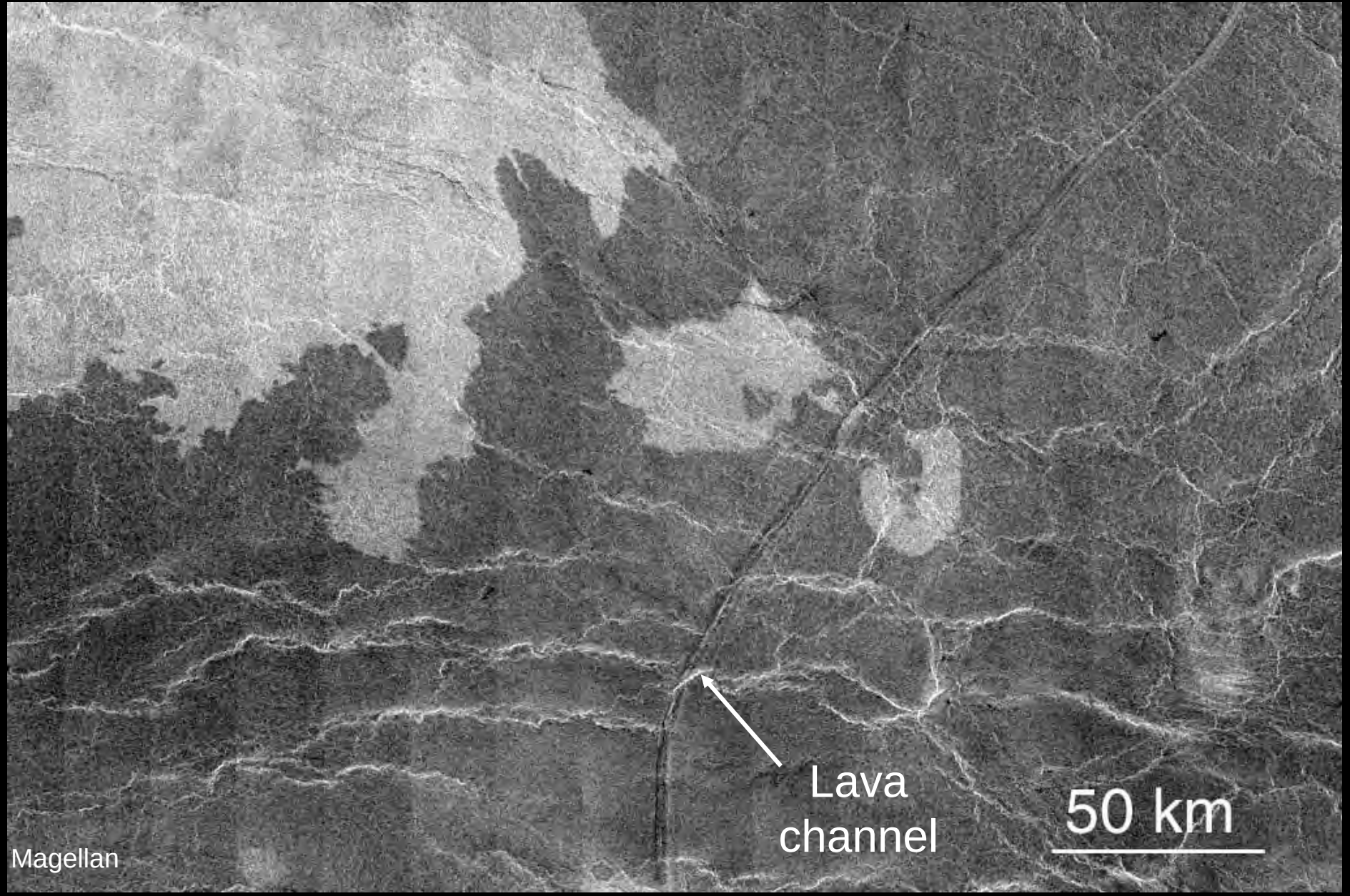
Mercury: Smooth plains resembling lunar maria



Volcano in Caloris basin, Mercury

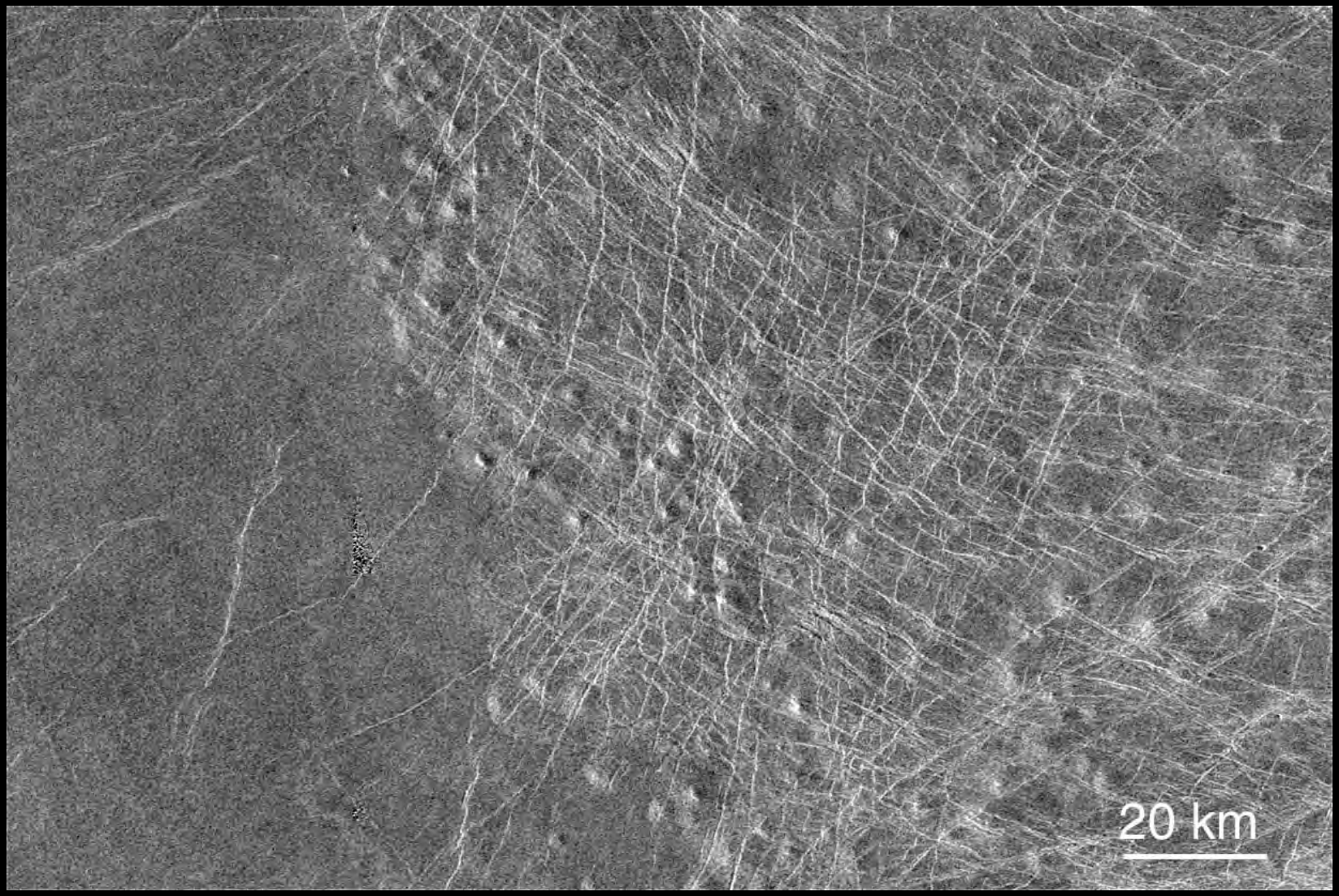
- On volcano are seen irregular rimless depressions
- There are rather large impact craters aroun the volcano
- On the volcano surface are seen onle small craters => large difference in time
- Source of the lava is not the impact melt





Venus: Plains made of basaltic lavas. Radar bright lavas are probably close to the aa type.

Venus: Shield volcanic plains

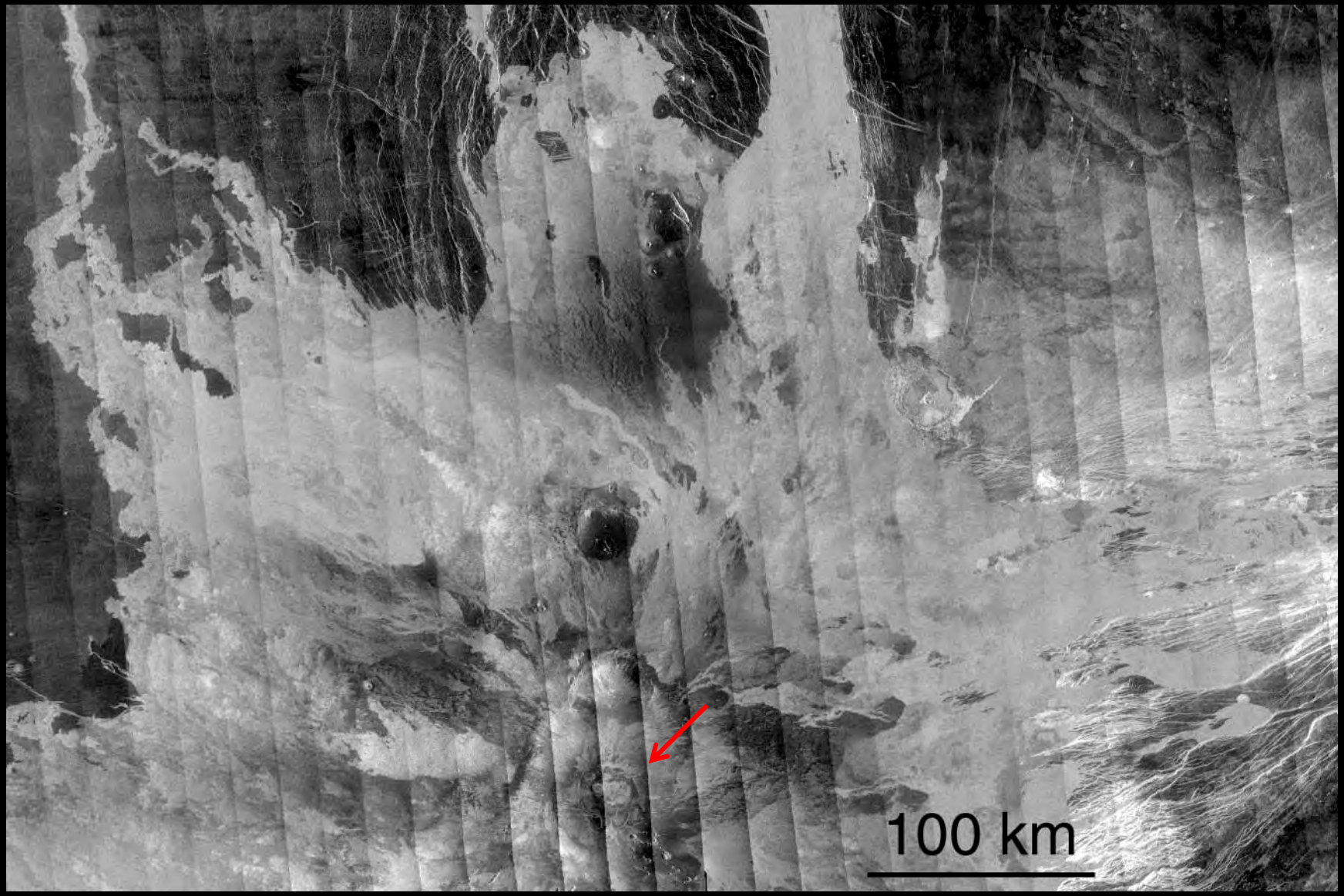


Volcanic shields with gentle (3-5 deg) slopes
Probably formed by basaltic lavas

Lobate lava plains

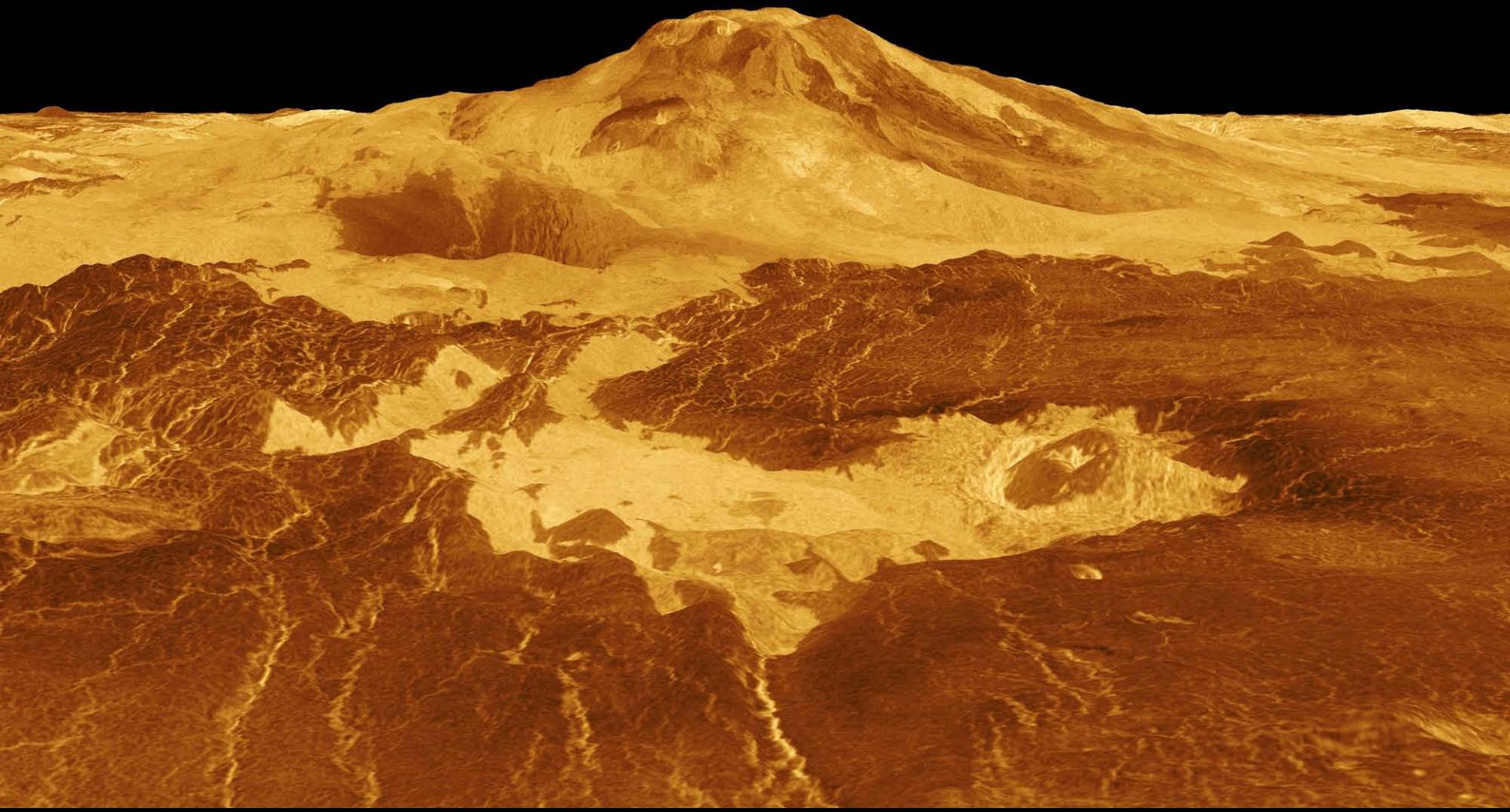
Volcanic flows with rather rough (aa) surface,
Superposed on plains with wrinkle ridges and shield plains

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



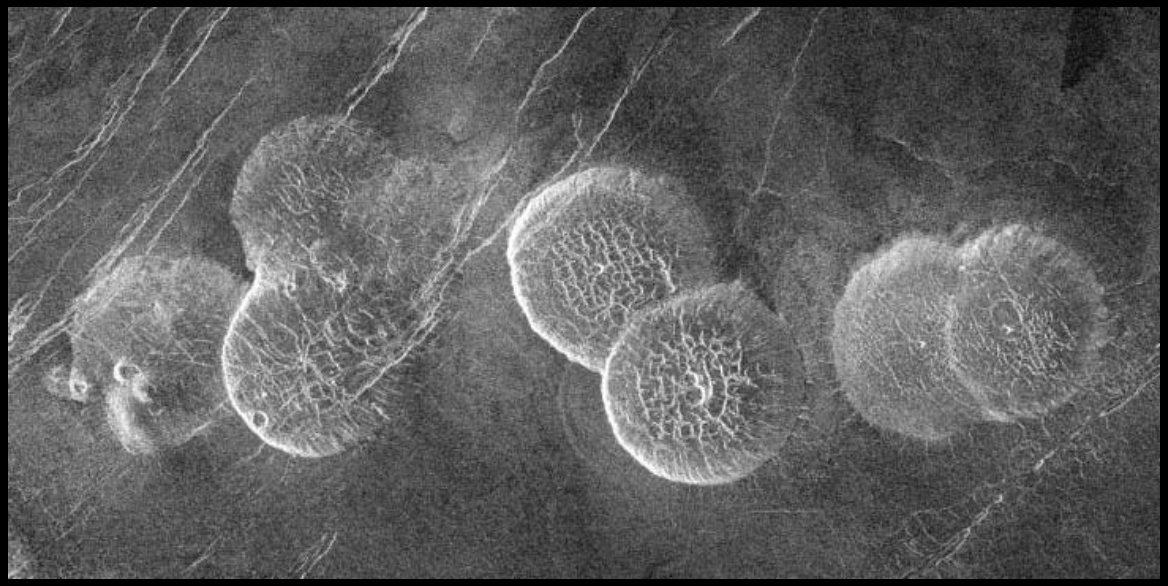
Maat slopes are covered by radar bright lobate flows superposed on surrounding regional volcanic plains

Maat Mons volcano – perspective view



Vertical exaggeration ~ 20 : 1

Rare type of volcanic constructs on Venus: steep-sided domes



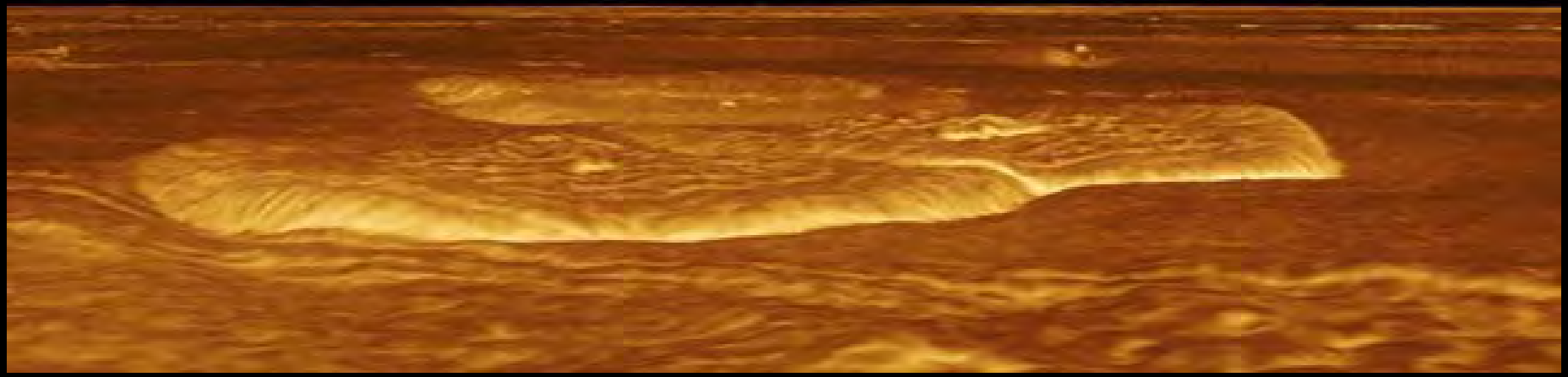
Tens km in diameter,
Hundreds meters high,
Steep-sided:

=> Viscous lavas

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

or

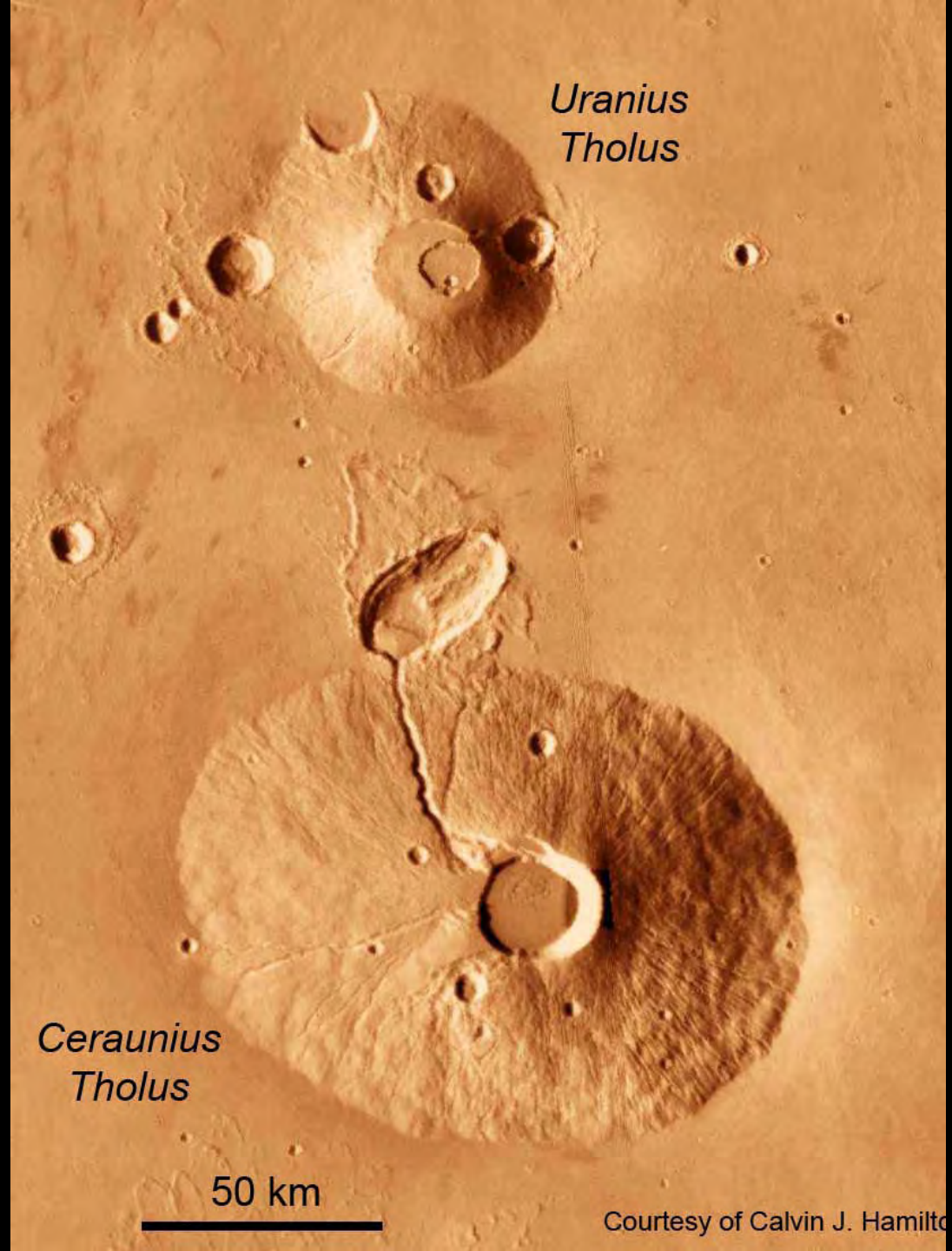
=> **Basalt with gas bubbles?**



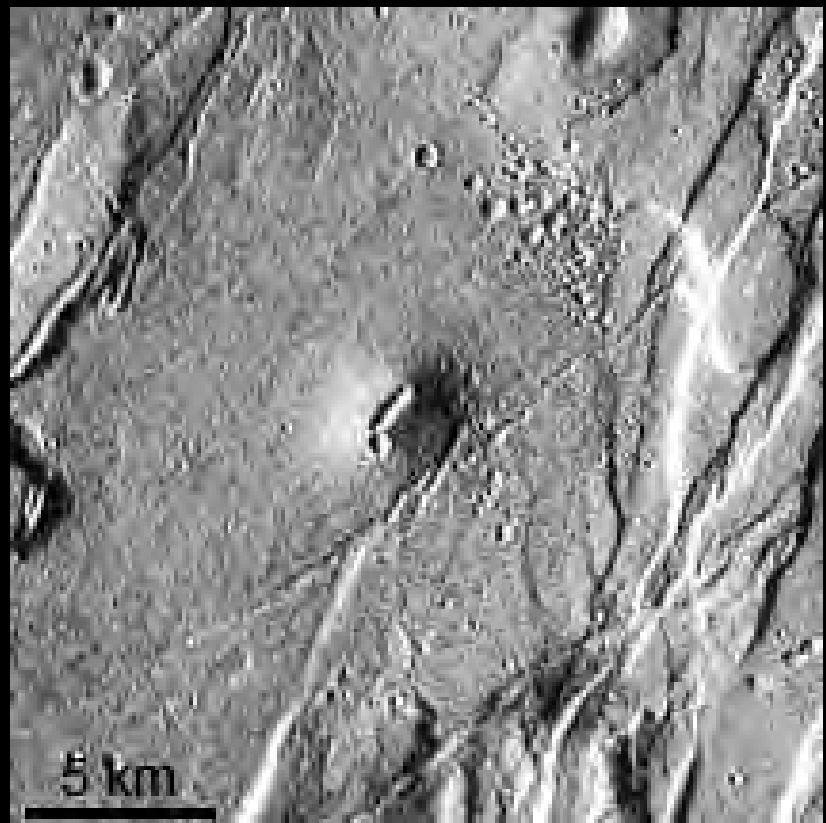
Mars: Olympus Mons, 600 km across, 21 km high

Фото НАСА, Викинг

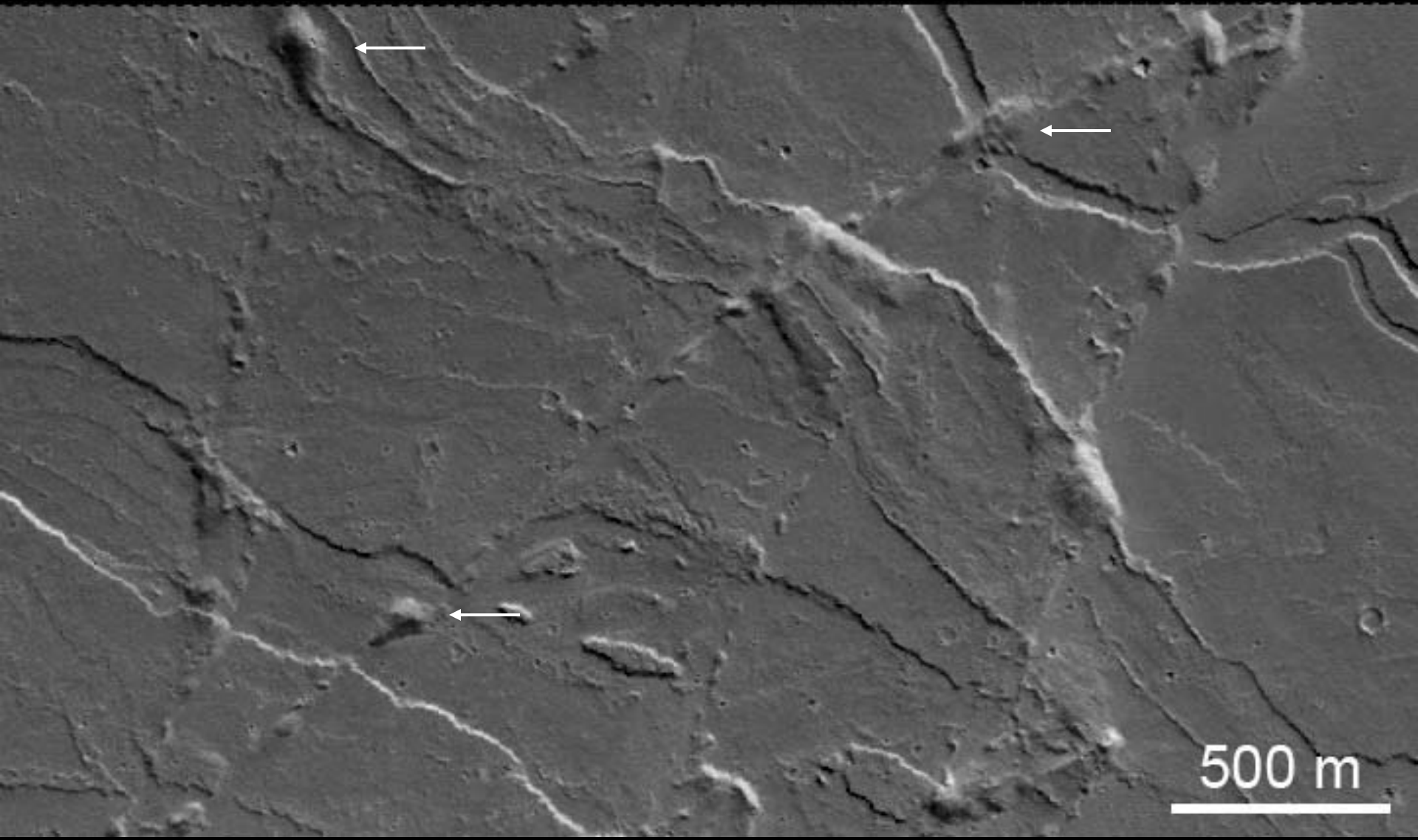
Intermediate and small volcanoes of Mars



Courtesy of Calvin J. Hamilto



Cinder cones on the surface of Mars



Volcanism on Io: closest to Jupiter Galilean satellite of the planet

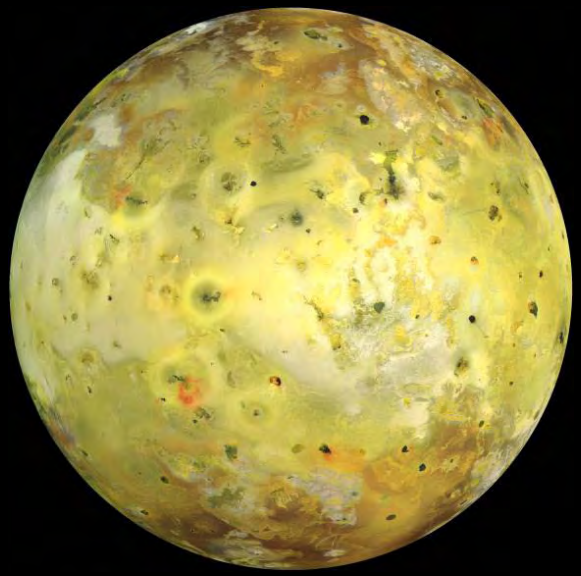


Image taken by Galileo

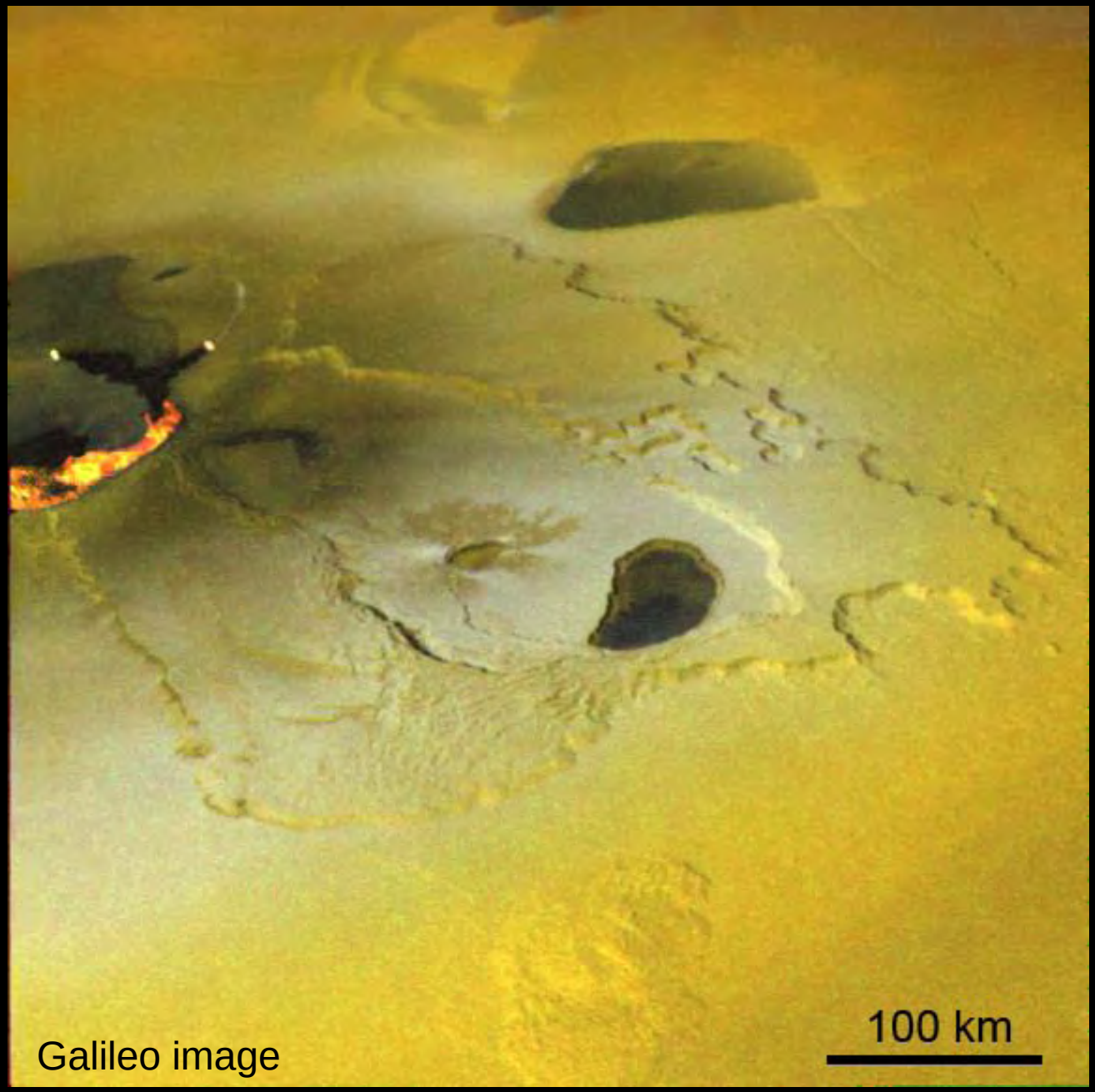
Distance to center of Jupiter ~6 R Jup.

Tidal heating
Plumes of volcanic eruptions
Orange color – sulfur
But lavas are basaltic
No impact craters
=> very young surface

The eruption plume height is 160 km

Voyager 1 image

Io: Chain of volcanic calderas Twashtar



Galileo image

Europa – second Galilean satellite of Jupiter – faults, domes and reddish spots and bands

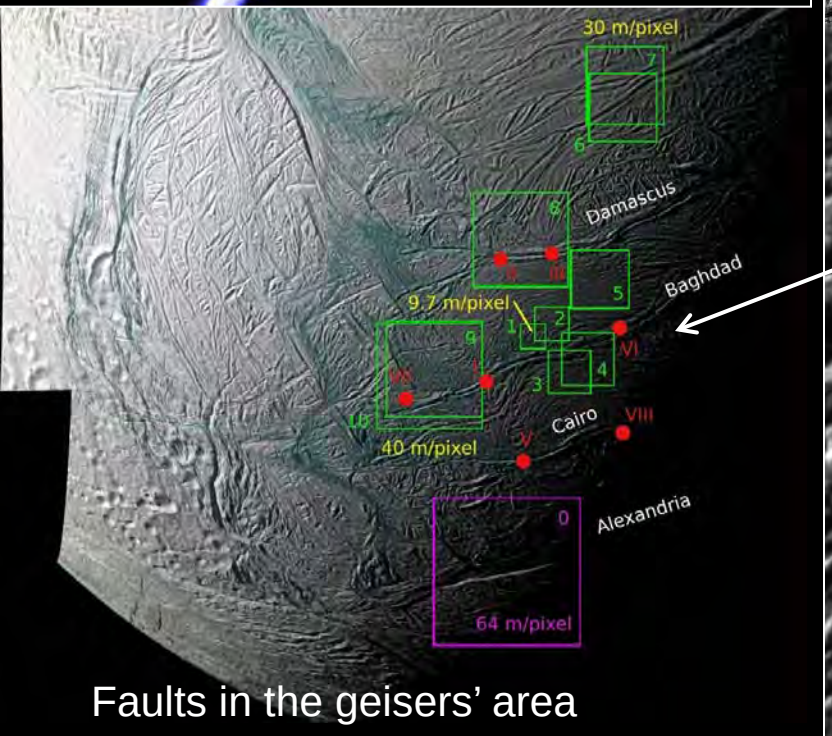
Multiphase tectonics / water-ice (cryo) volcanism

Снимки Cassini

Enceladus: Soth pole

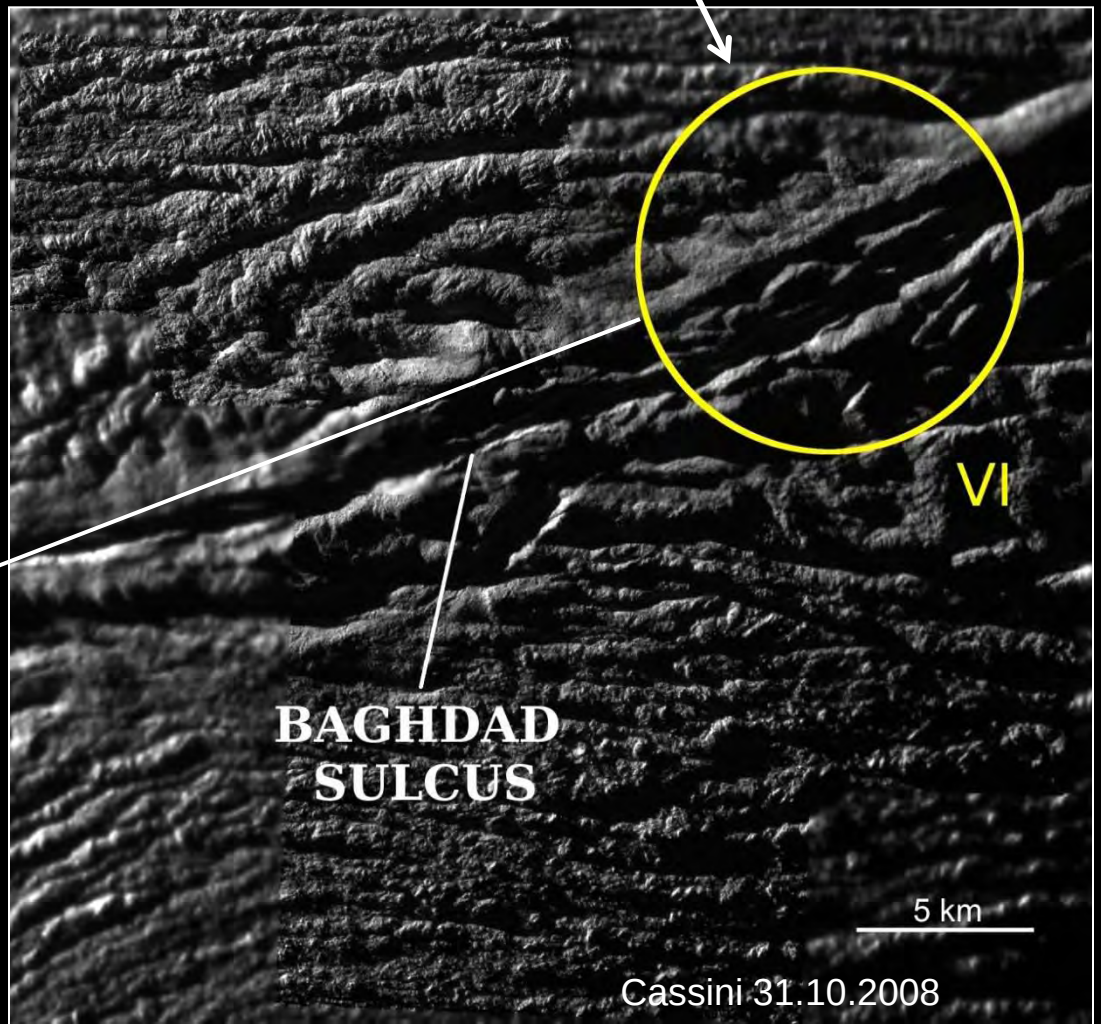
Geisers of H_2O vapor

=> Result of tidal heating



Faults in the geisers' area

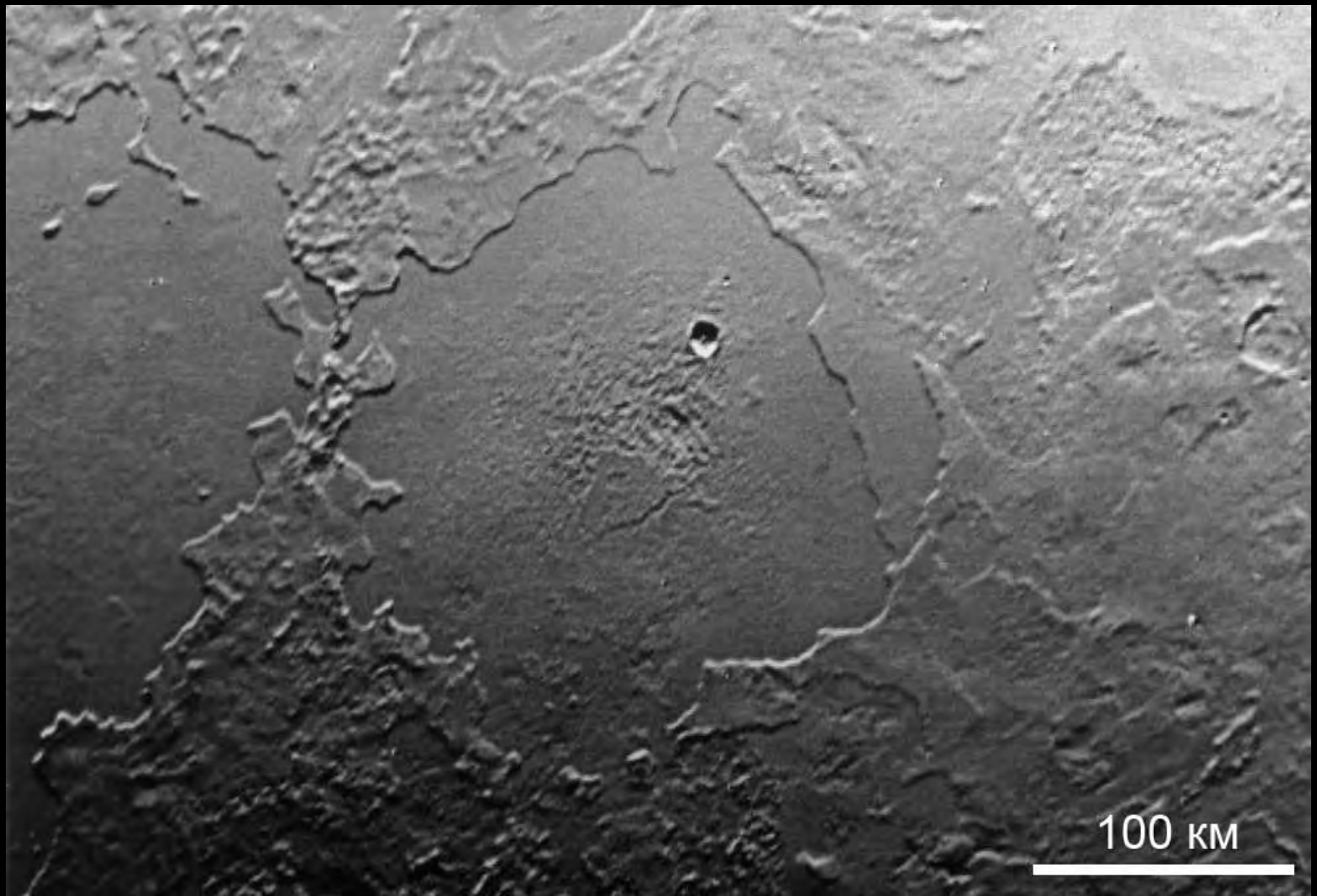
Area of source of geiser #6

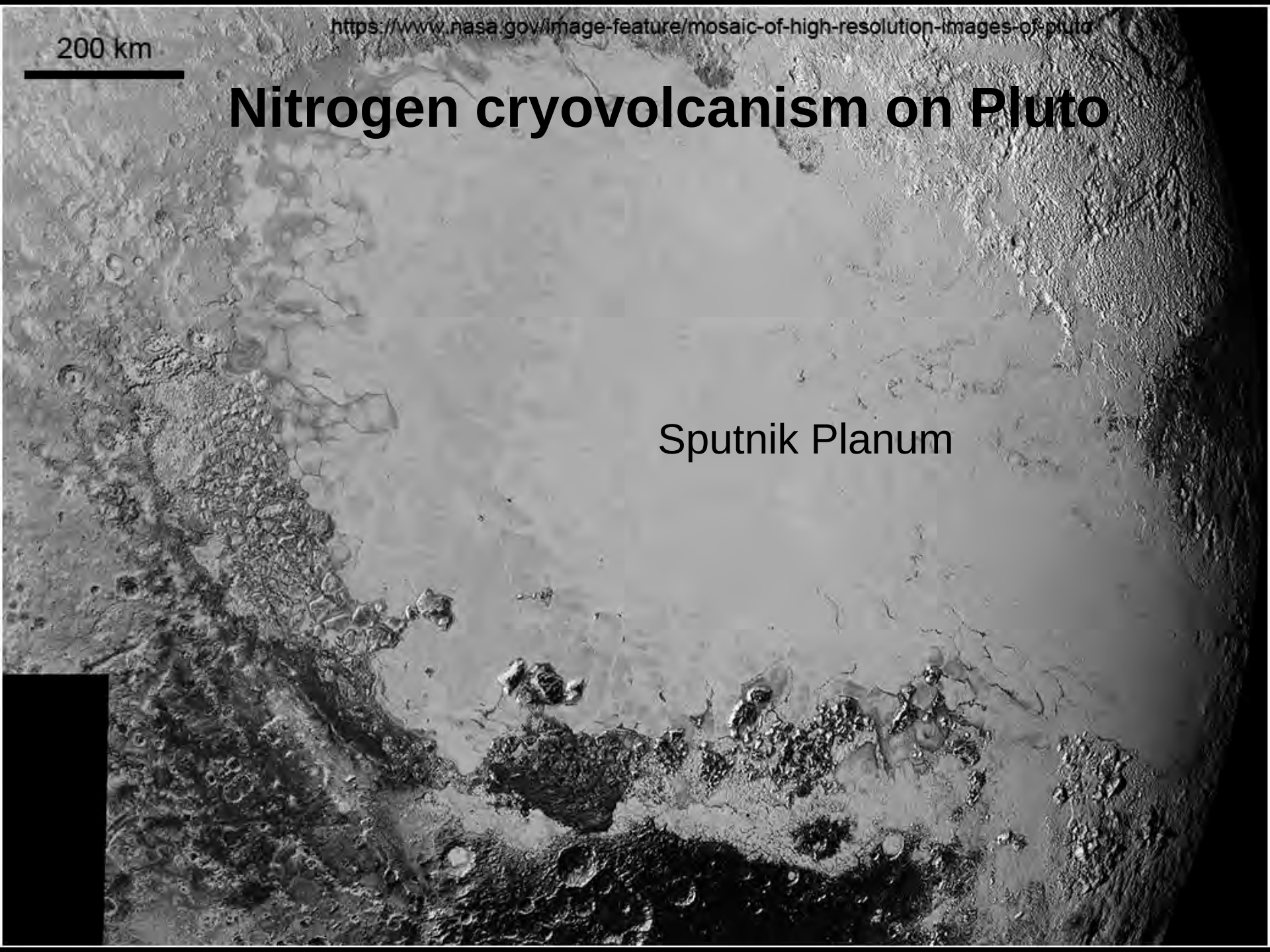


Cassini 31.10.2008

Triton – satellite of Neptune

Plains – products of water-ice (cryo) volcanism

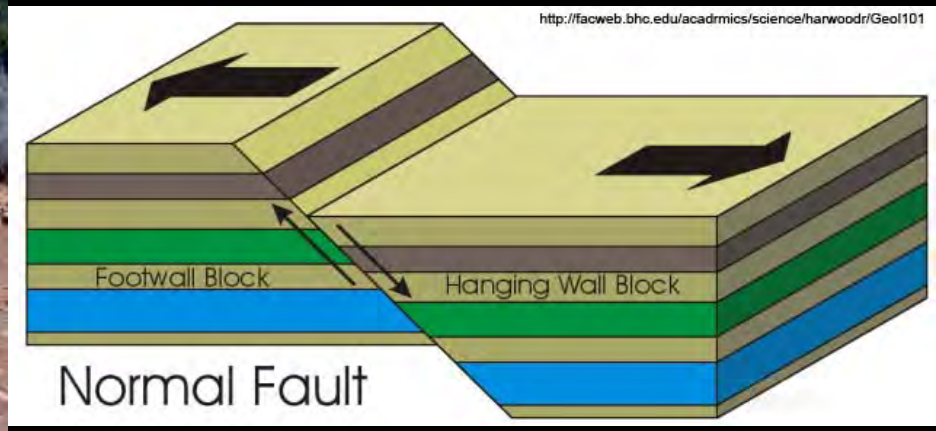



https://www.nasa.gov/image-feature/mosaic-of-high-resolution-images-of-pluto
200 km
Nitrogen cryovolcanism on Pluto
Sputnik Planum

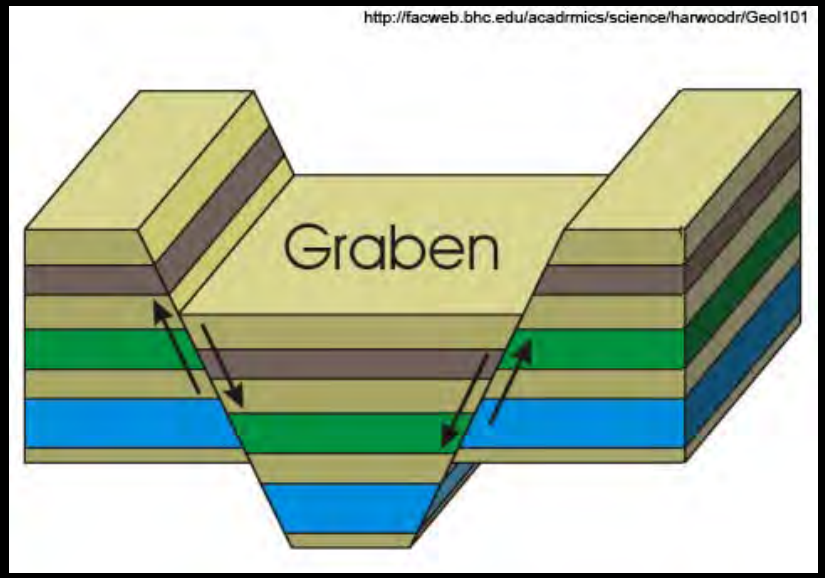
Tectonism

Spreading: The Read Sea rifts and Aqaba Bay

Extension structures: faults and graben

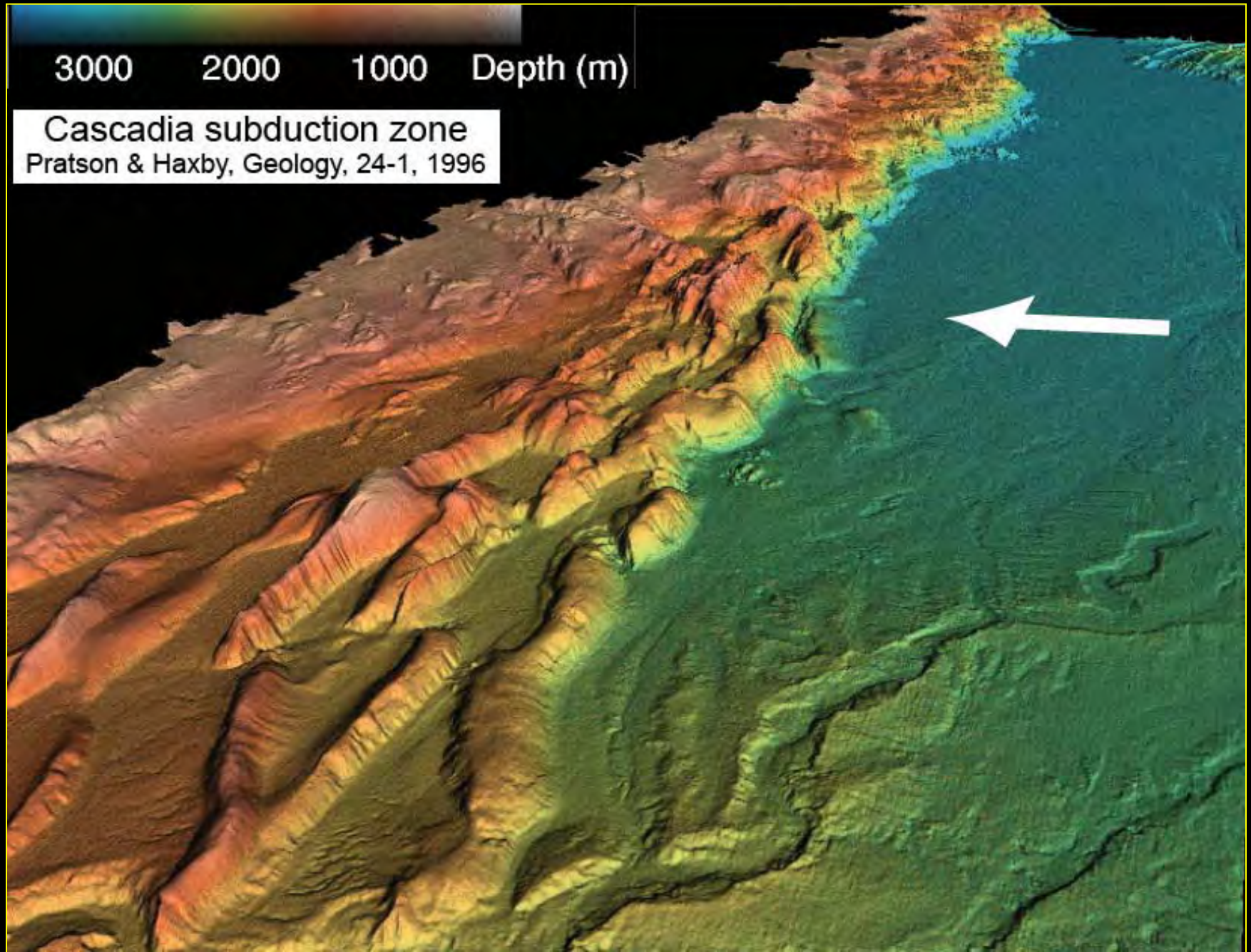


Faults

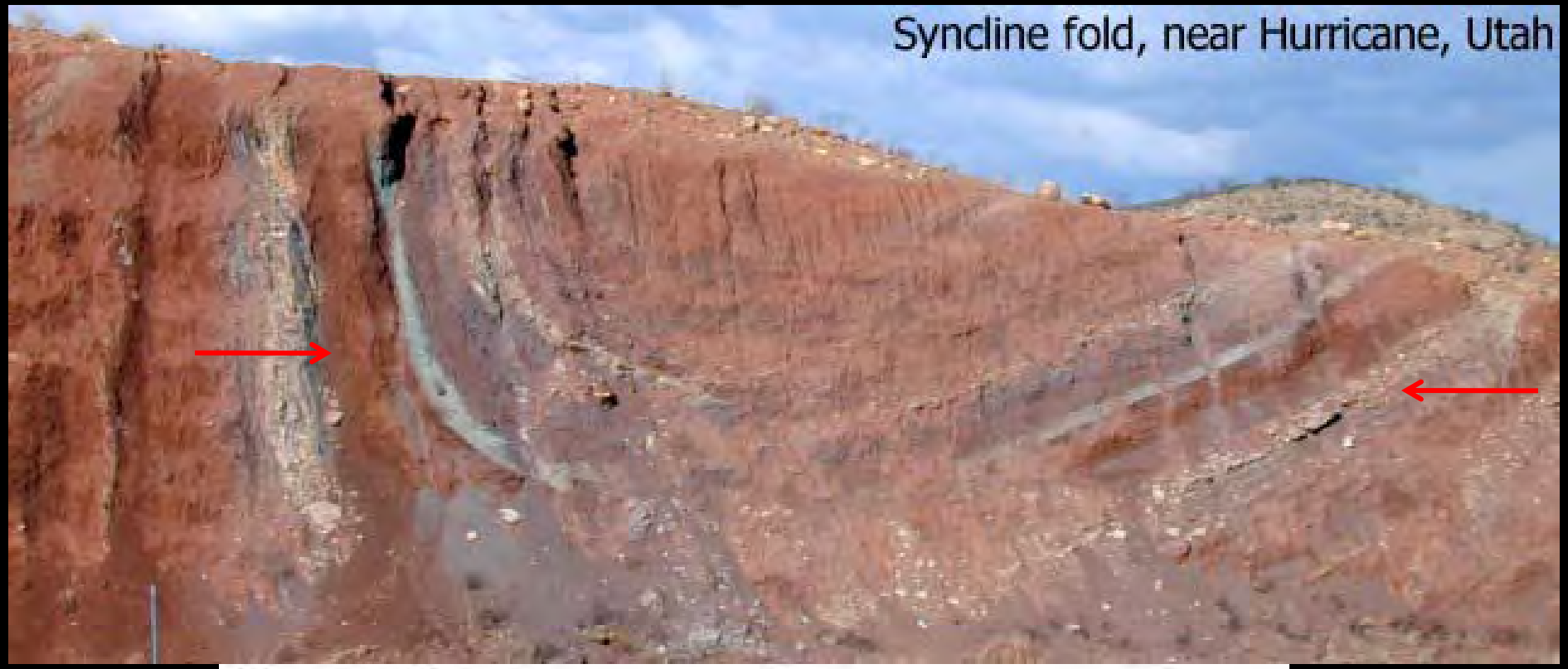


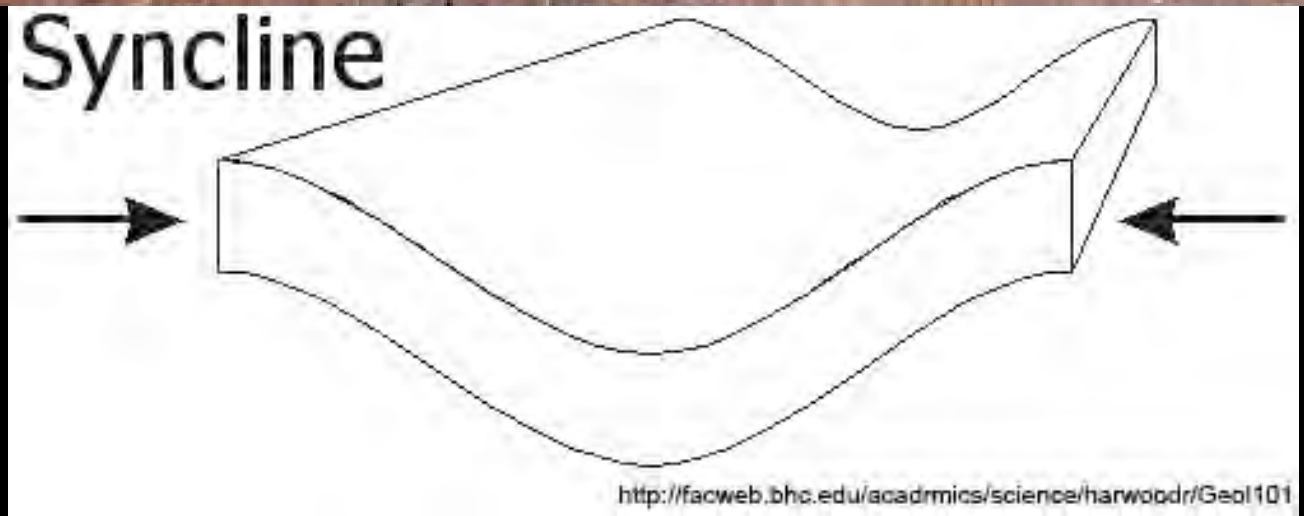
Graben

Subduction zone: Compresion: Cascades

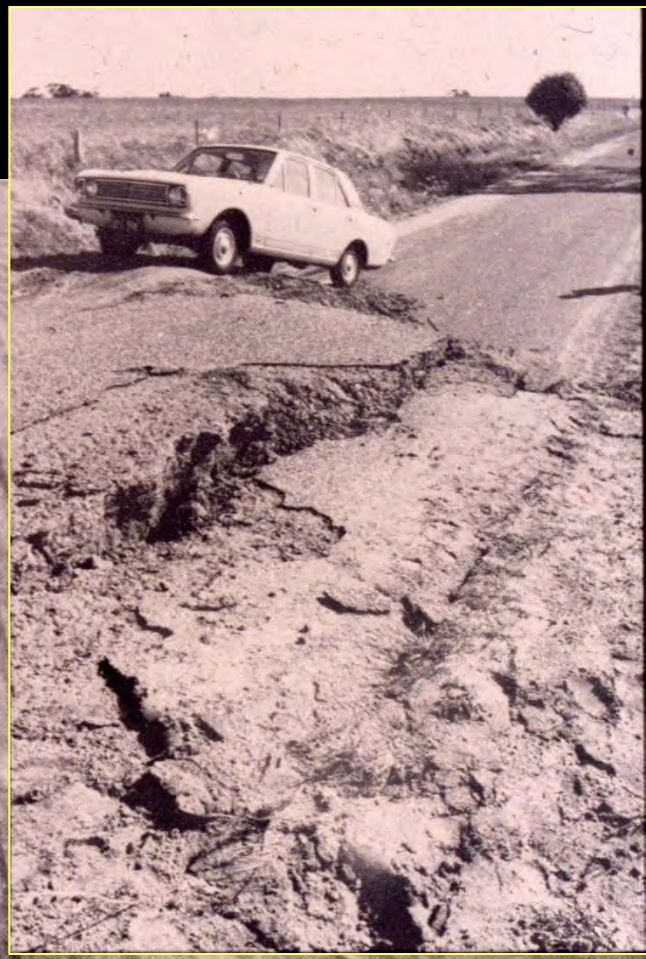


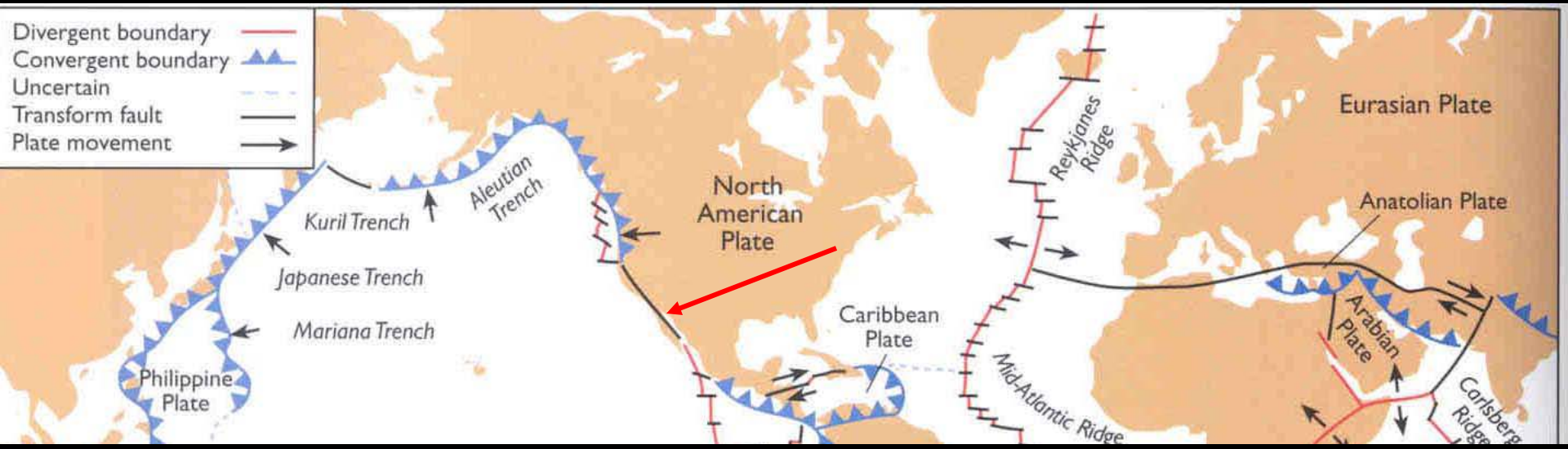
Compression structures: folds



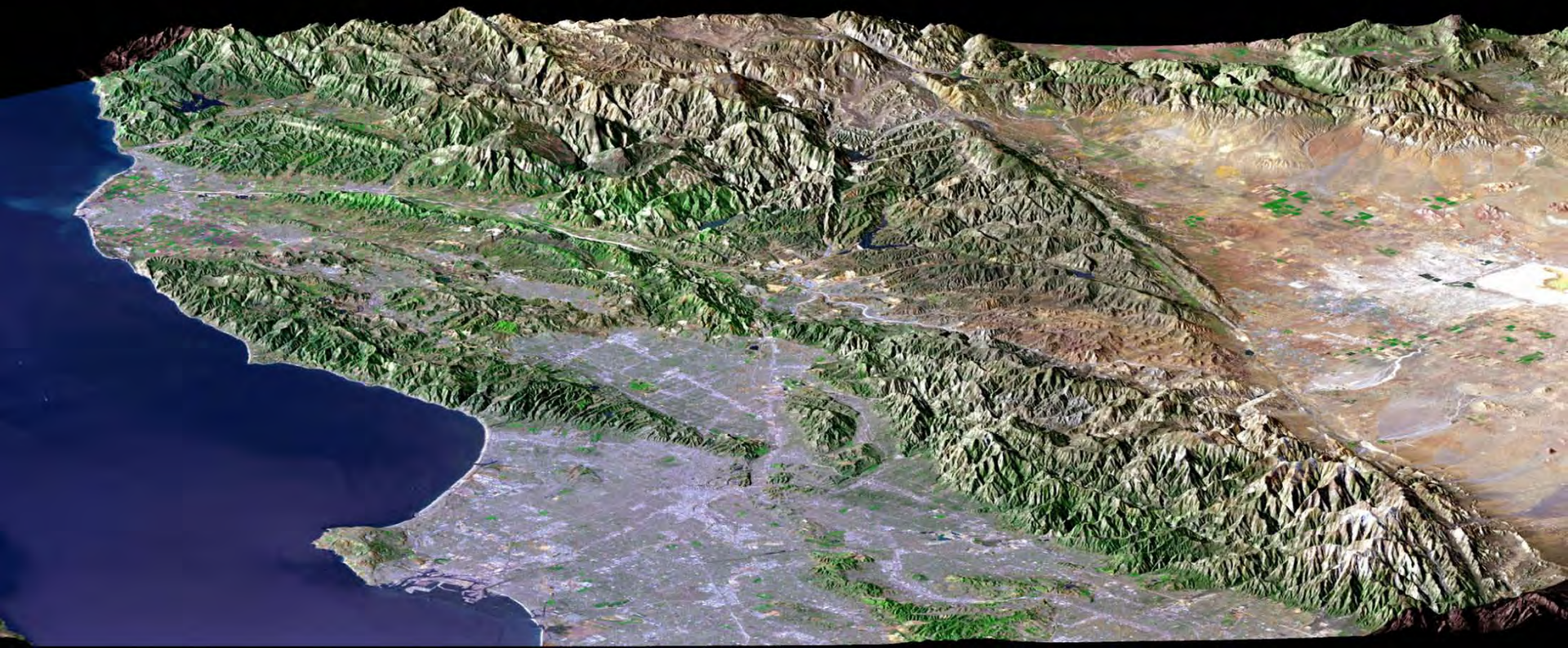


Meckering faults, Australia –
- analogs of lunar sinous rilles



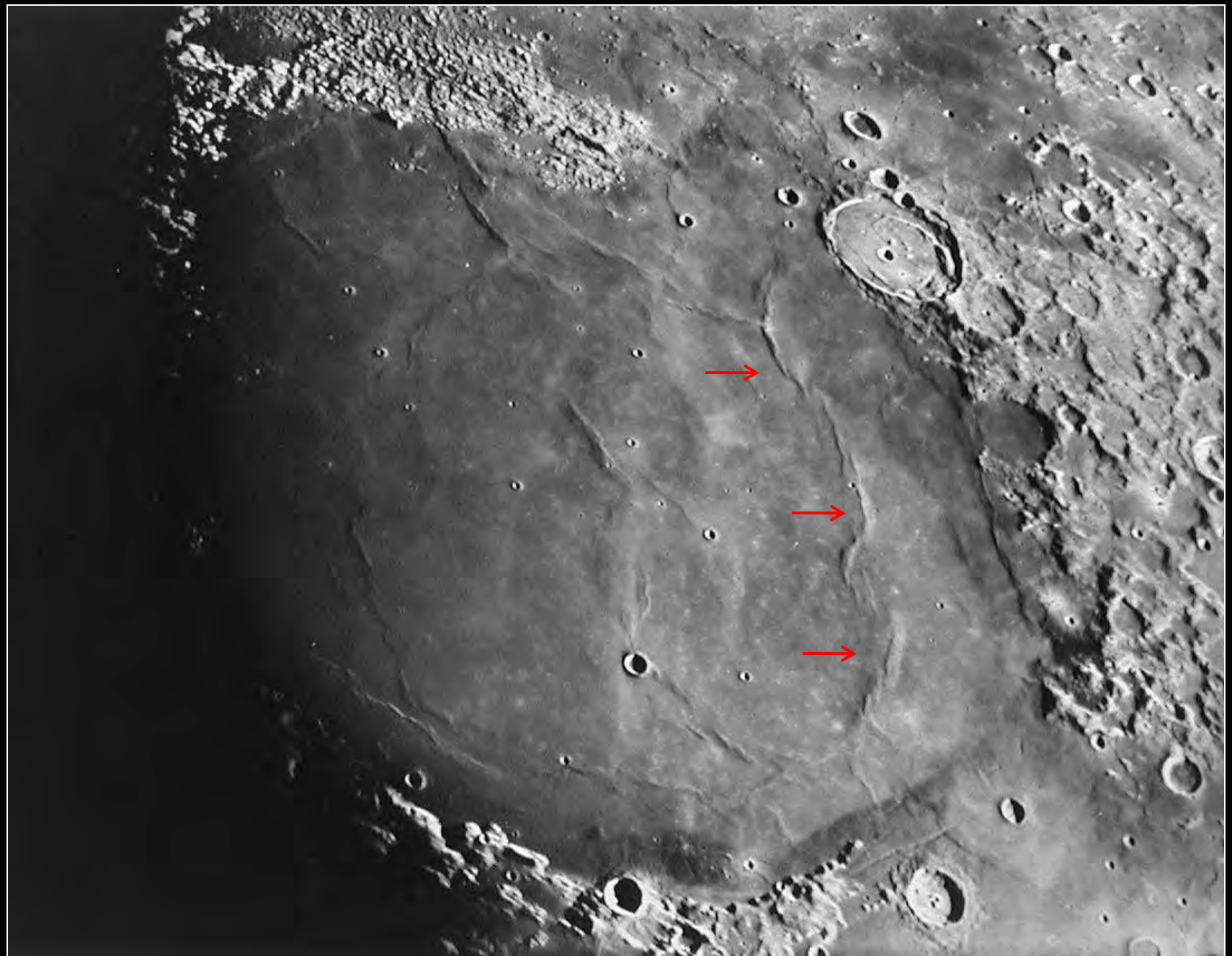


Transform faults St. Andres, California



Lunar graben – structures of extension

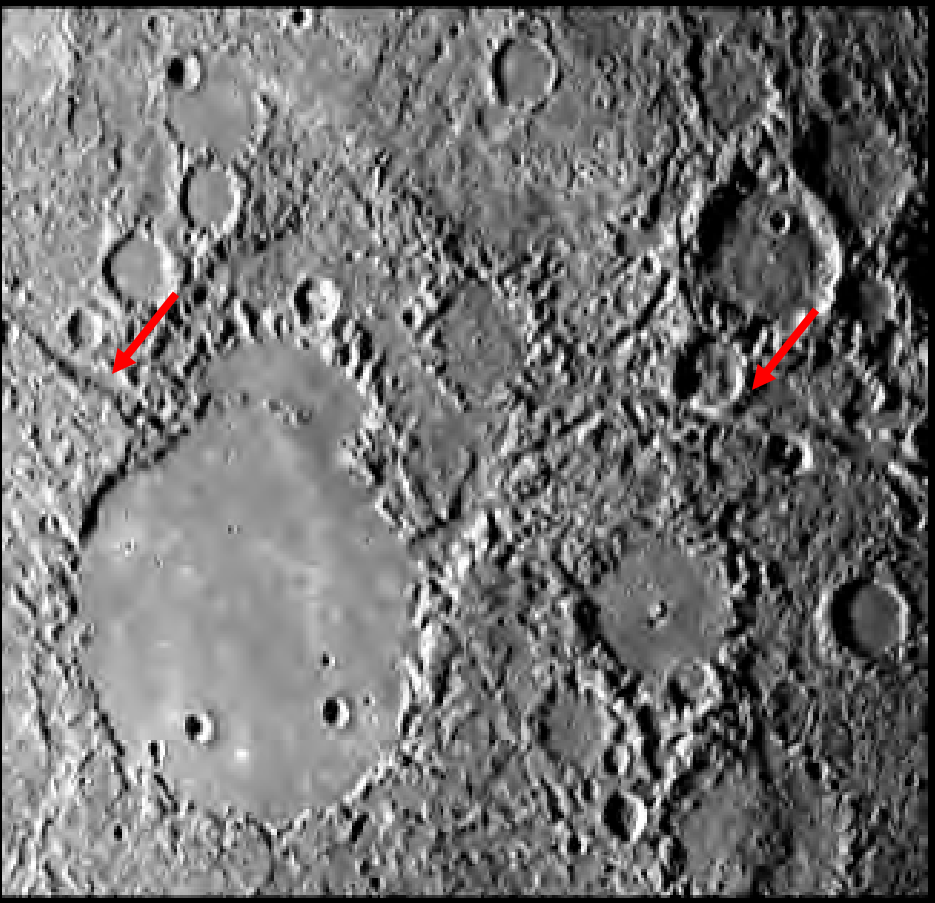
Lunar sinuous rilles: structures of compression



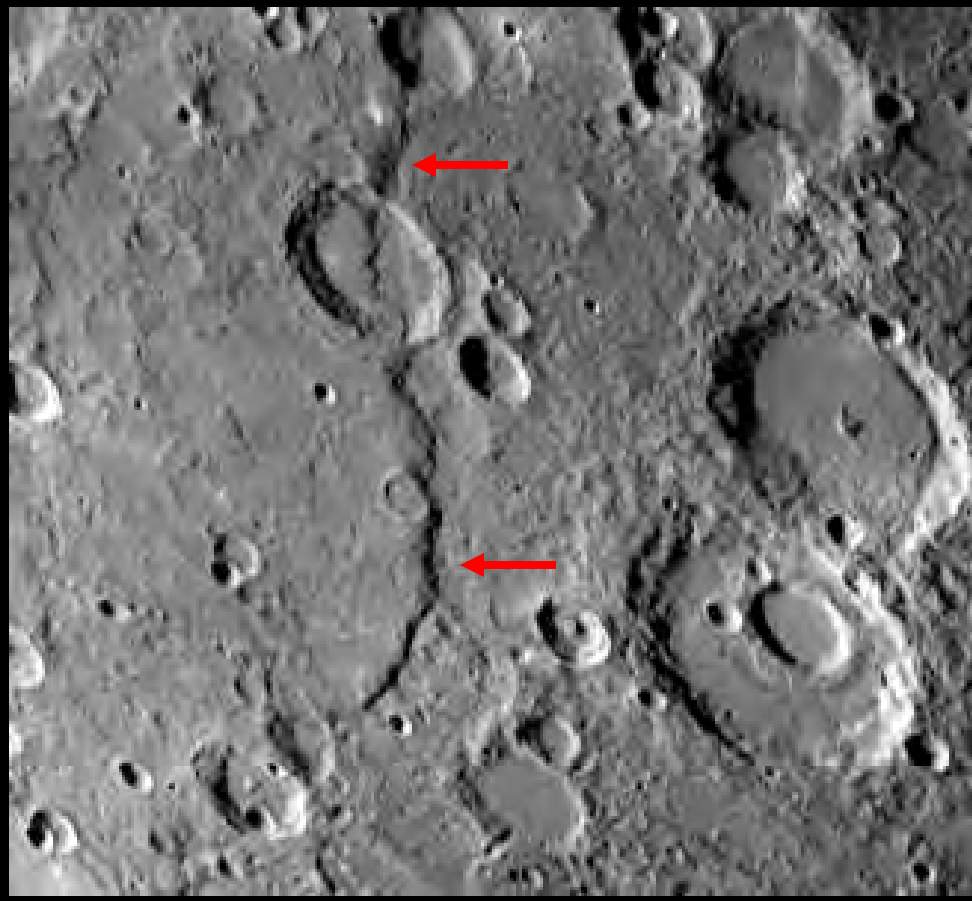
Tectonism of Mercury:

- Ridges and graben
- Long scarps (upthrusts) up to 1-3 km high

=> Compression of planet with decrease of radius by 2 km

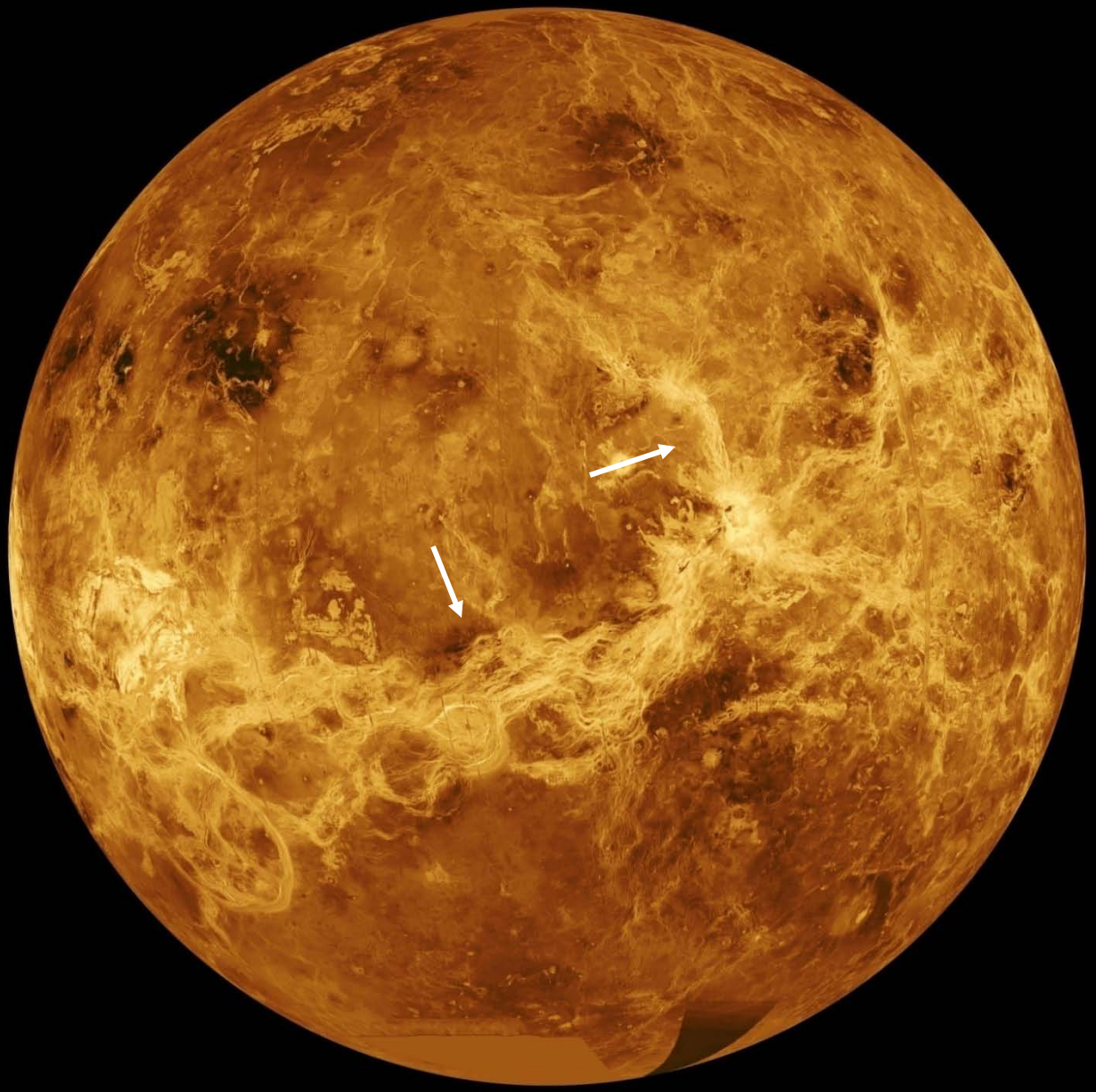


Graben

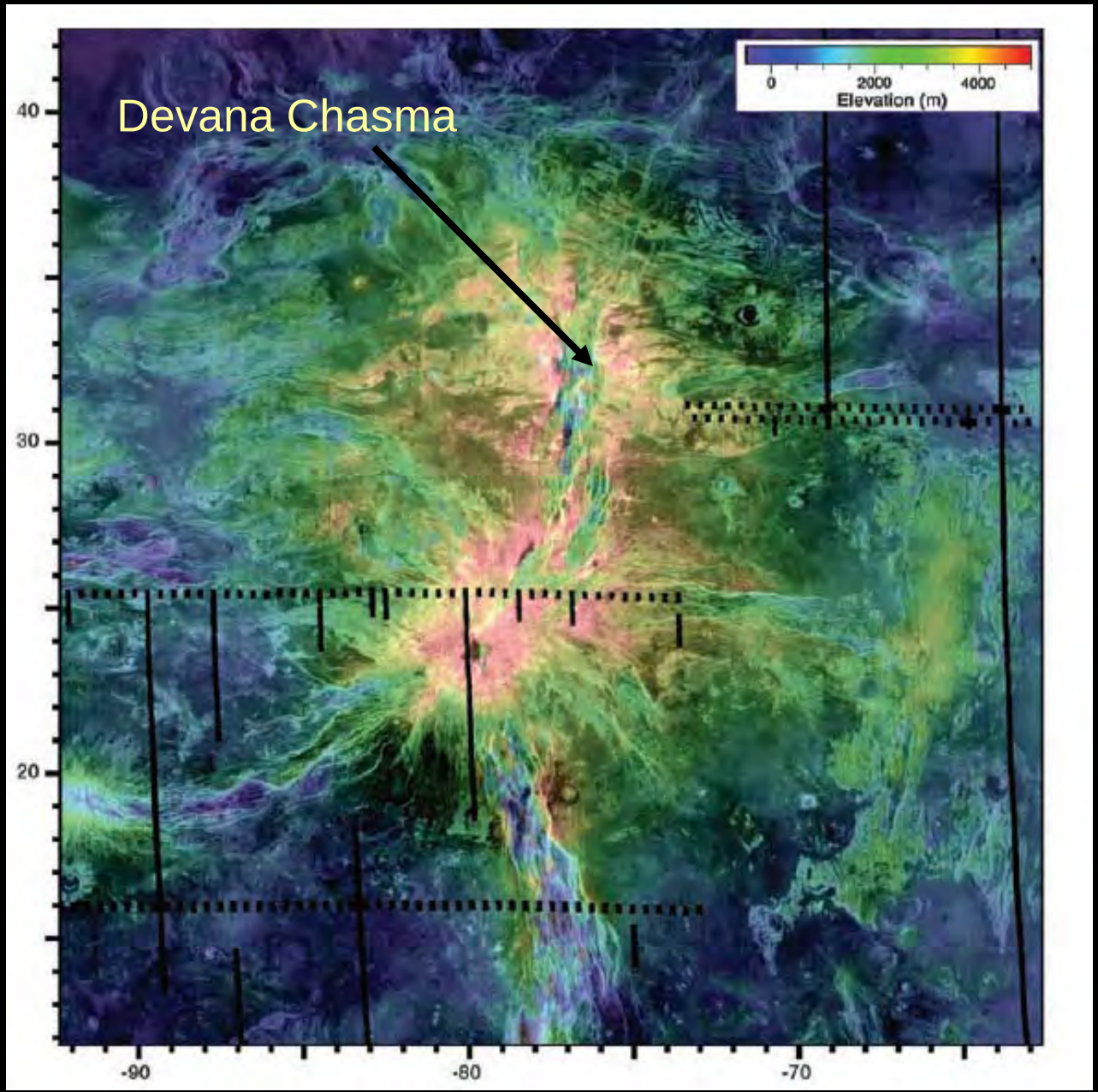


Scarps

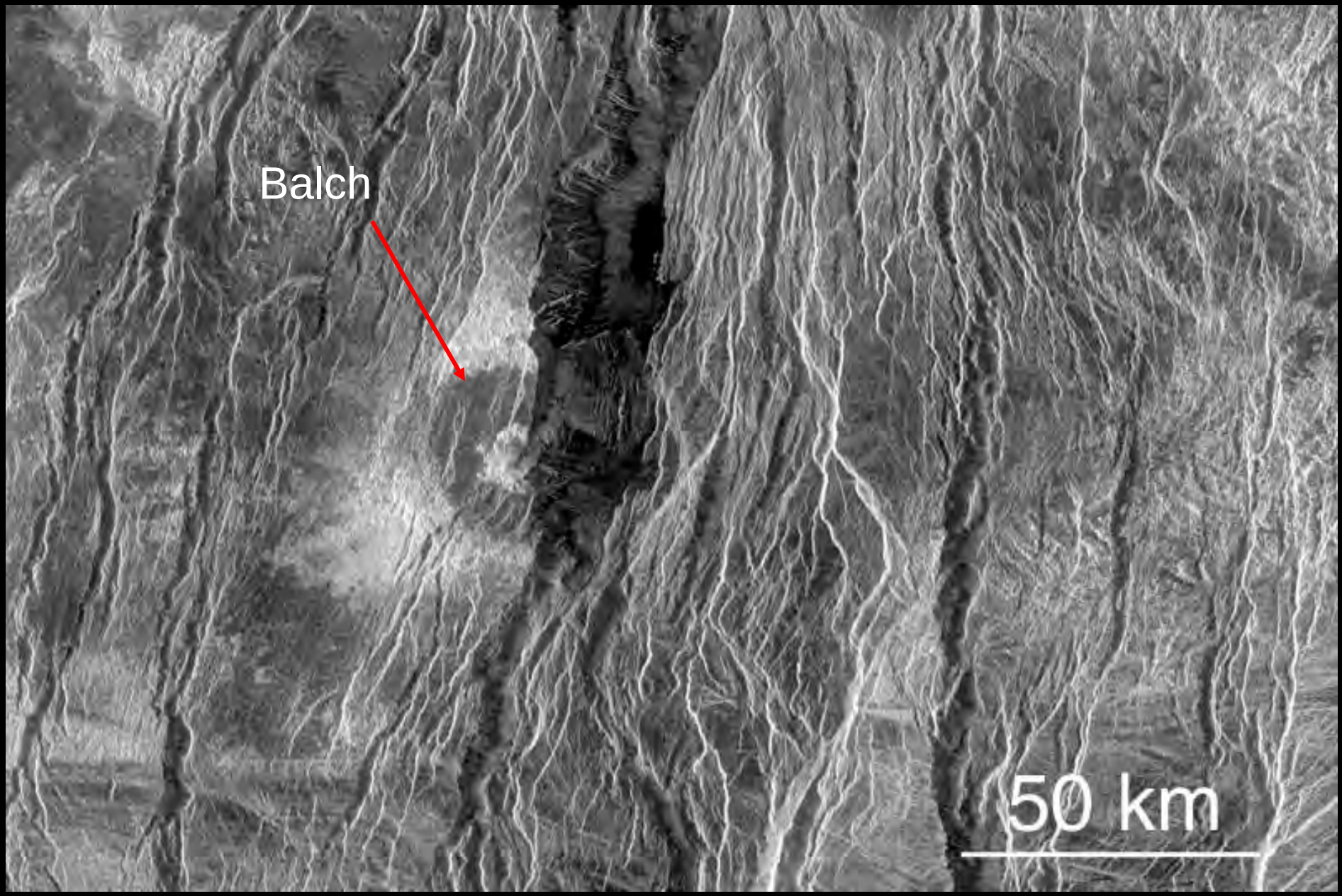
Rift zones of Venus



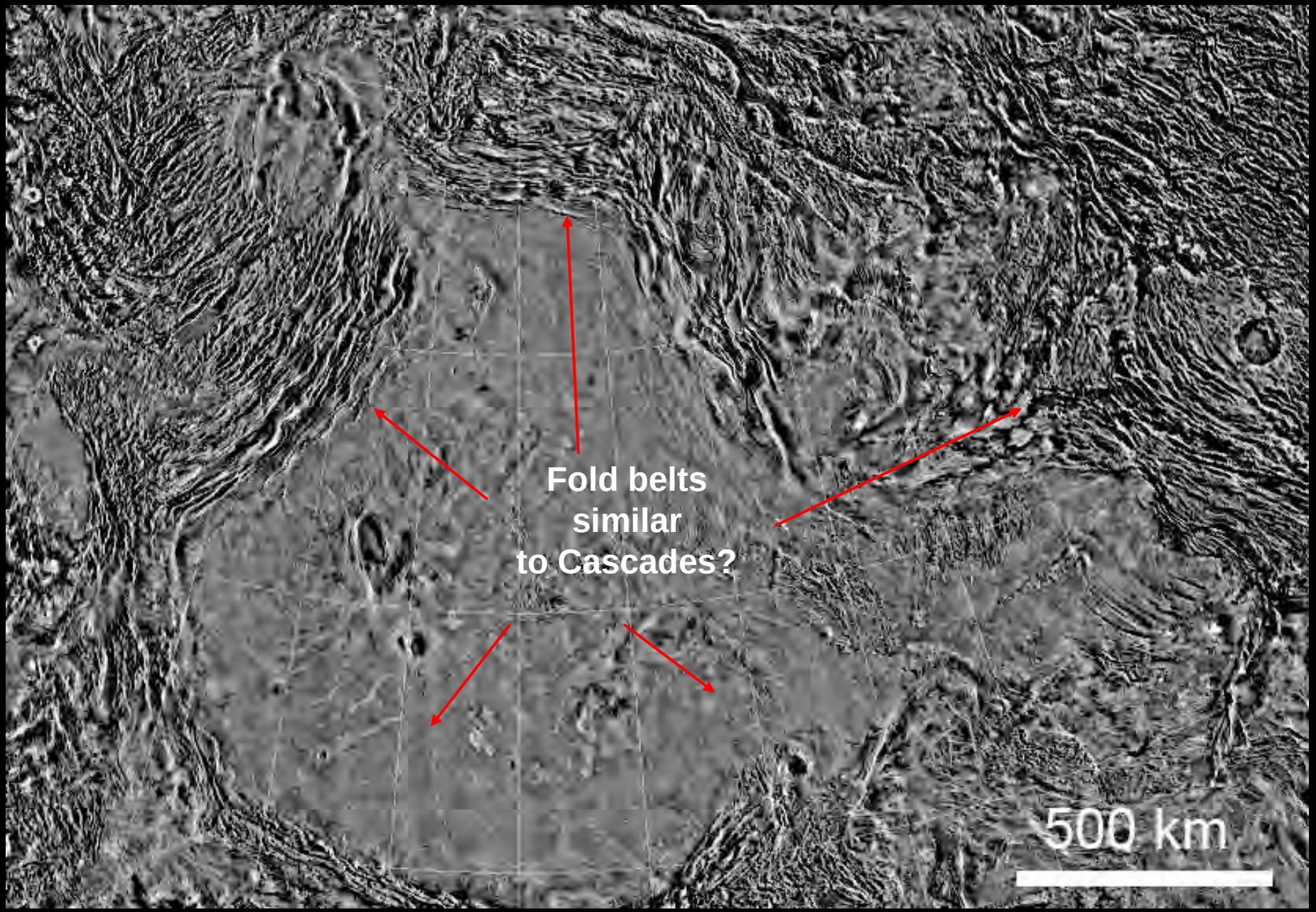
Beta Regio – tectonic uplift, cut by Devan rift



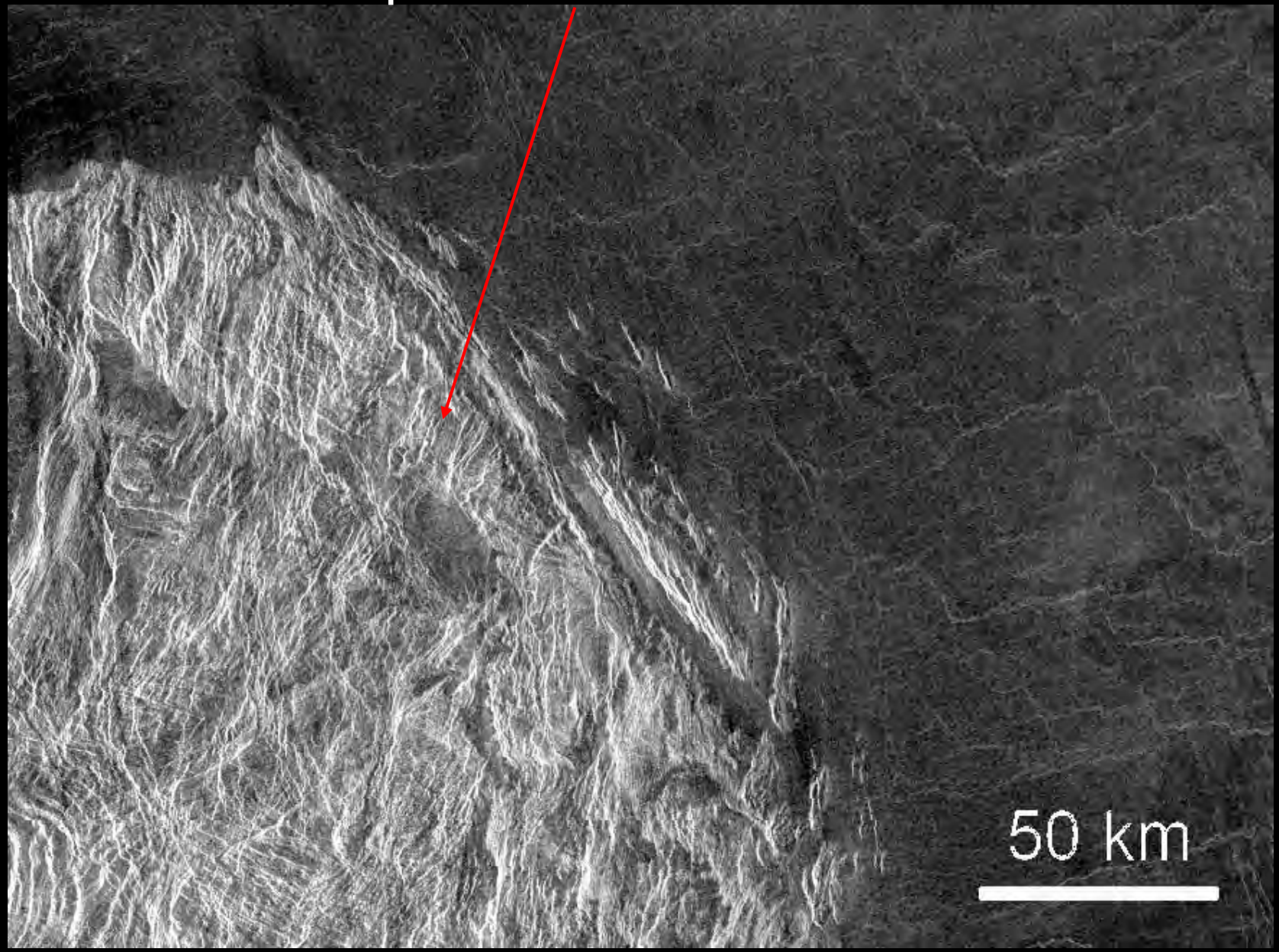
Devana rift and impact crater Balch



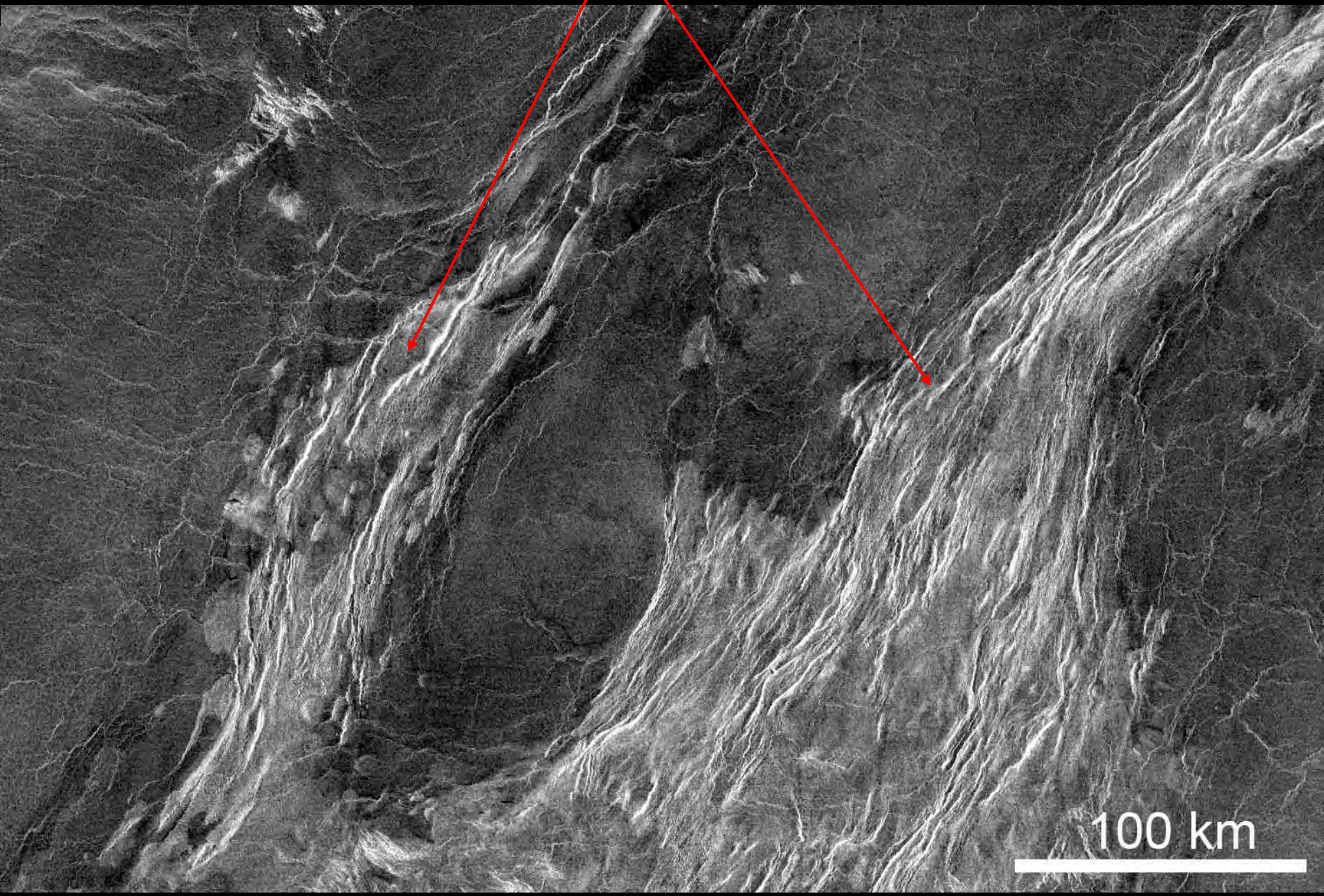
Lakshmi plateau and mountain belts around



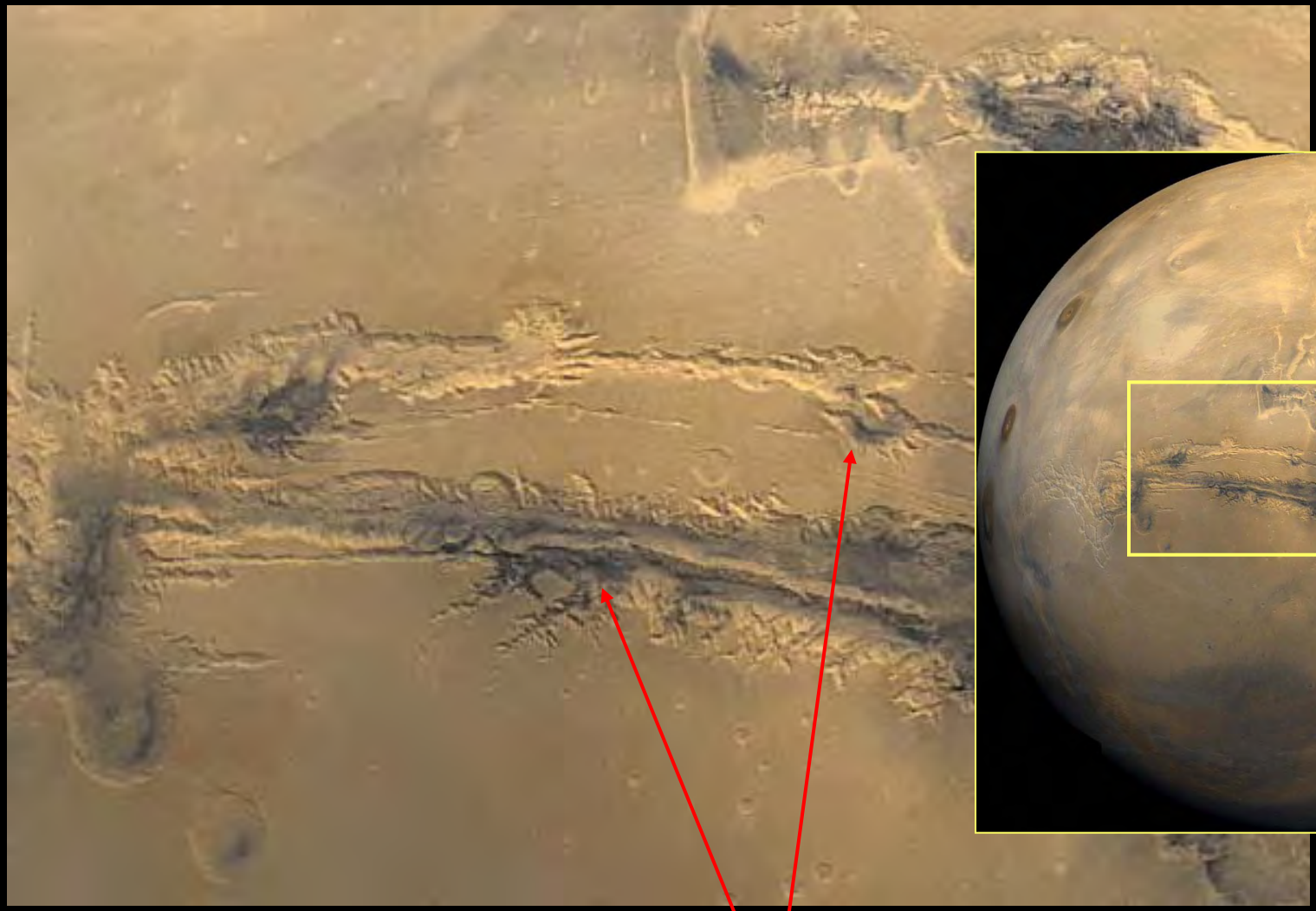
Venus: Tesserae: multiphase tectonism
Compression and extension

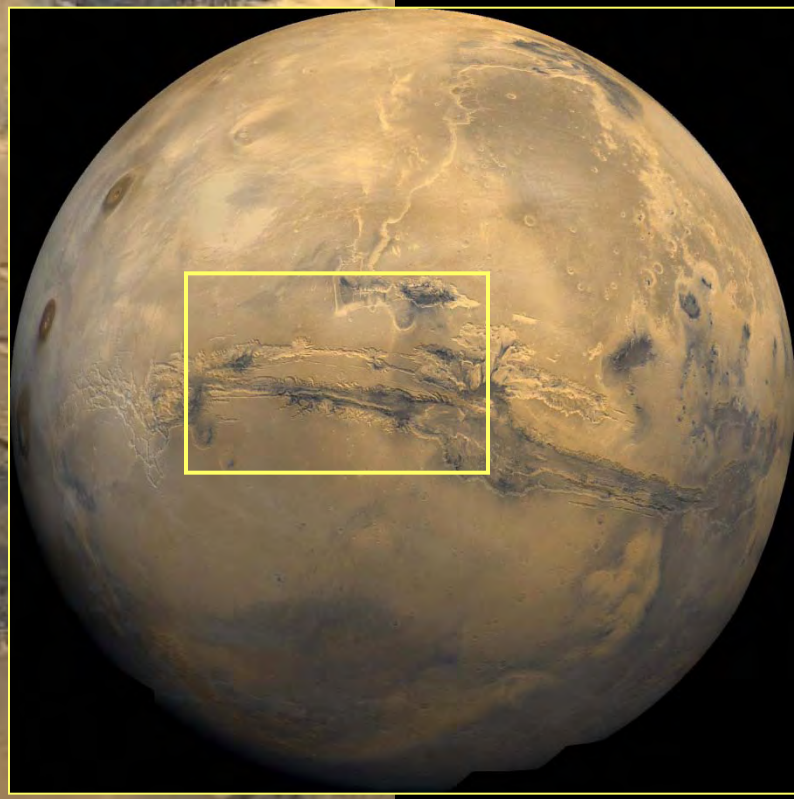


Venus: Ridge belts: Compression



Tectonism of Mars:
Mostly extension, partly compression

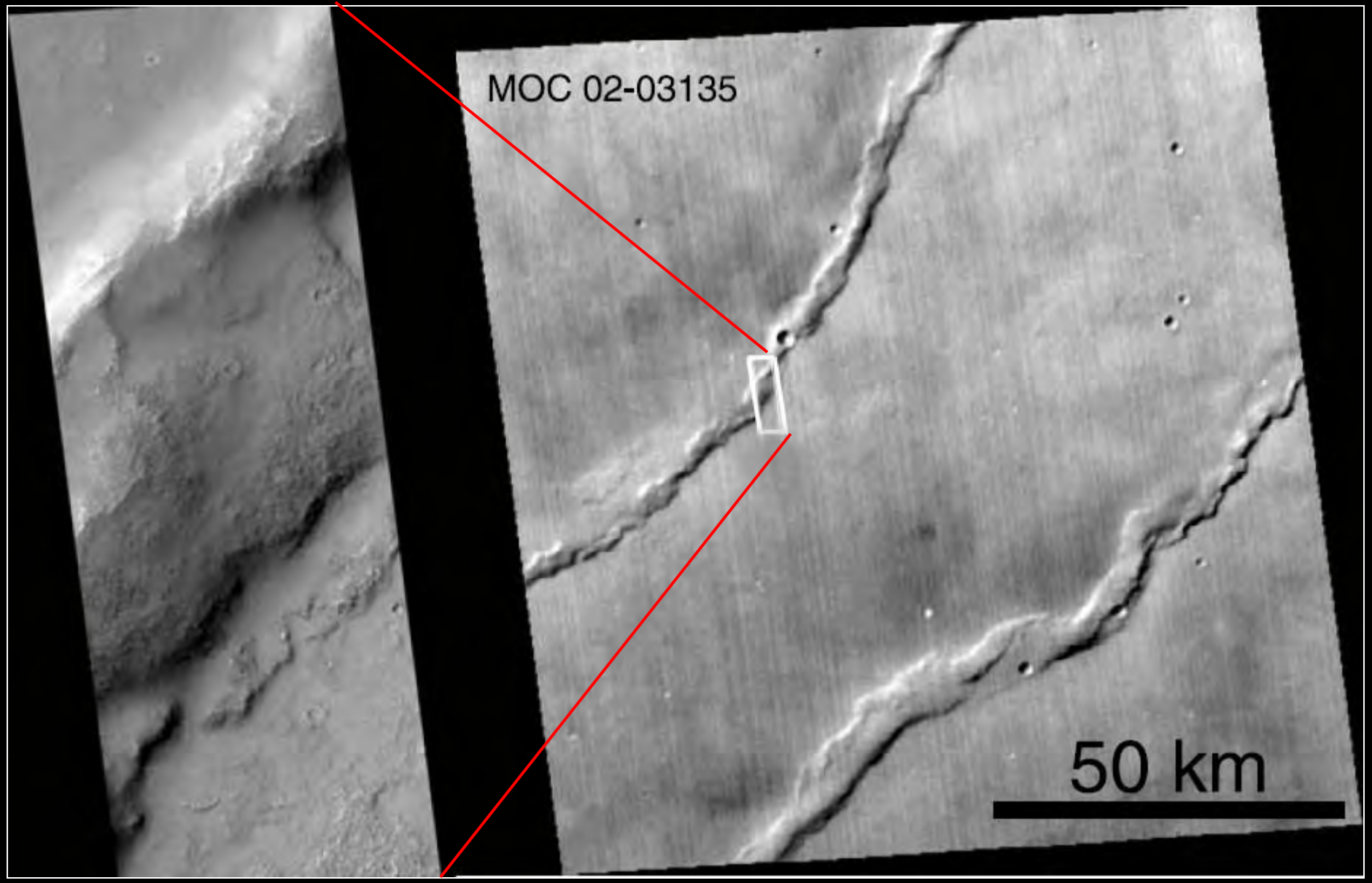




Valles Marinares – Rift zones

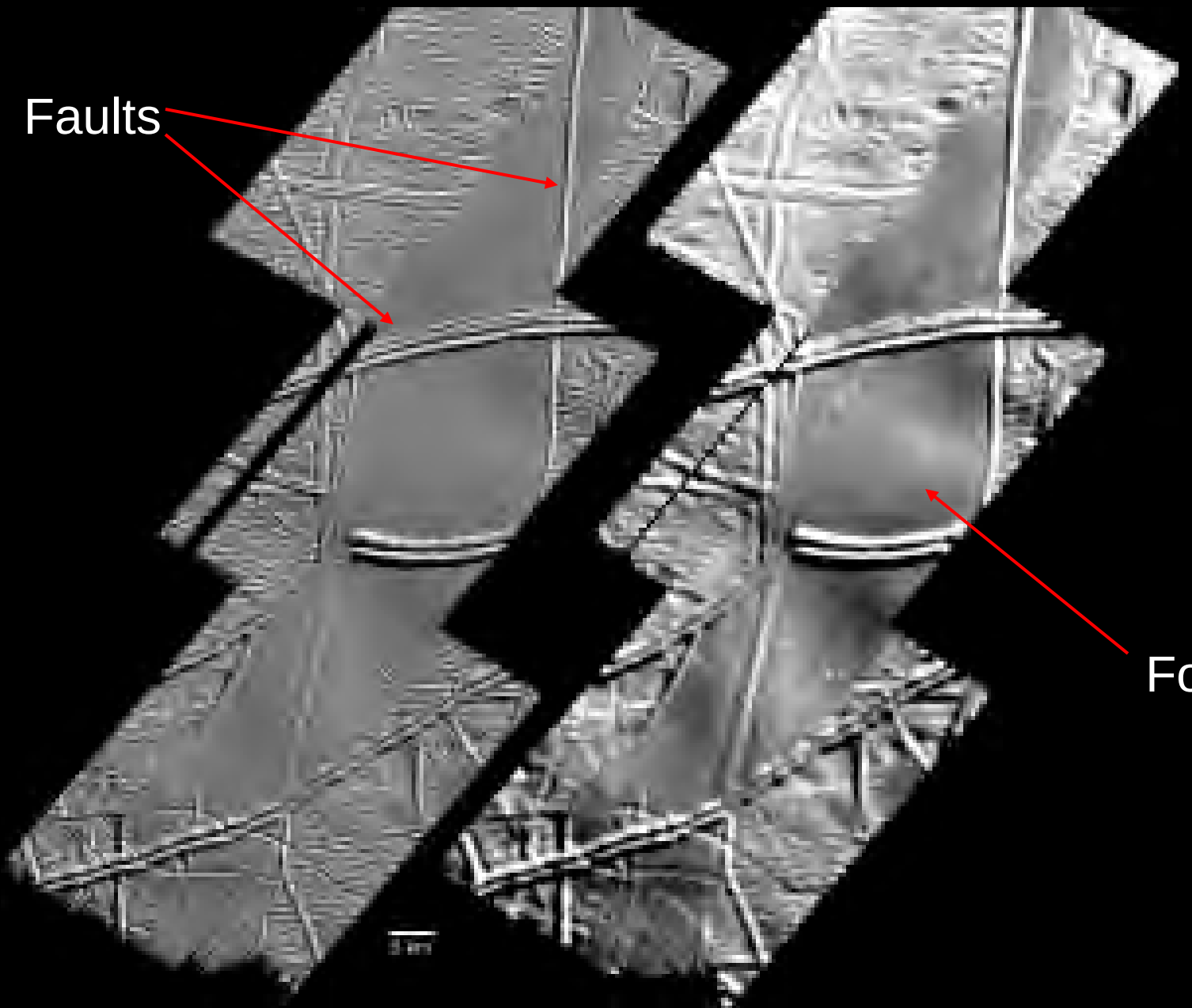
Mars: Graben parallel to Valles Marinares

Mars: Sinuous rilles indicate on compression

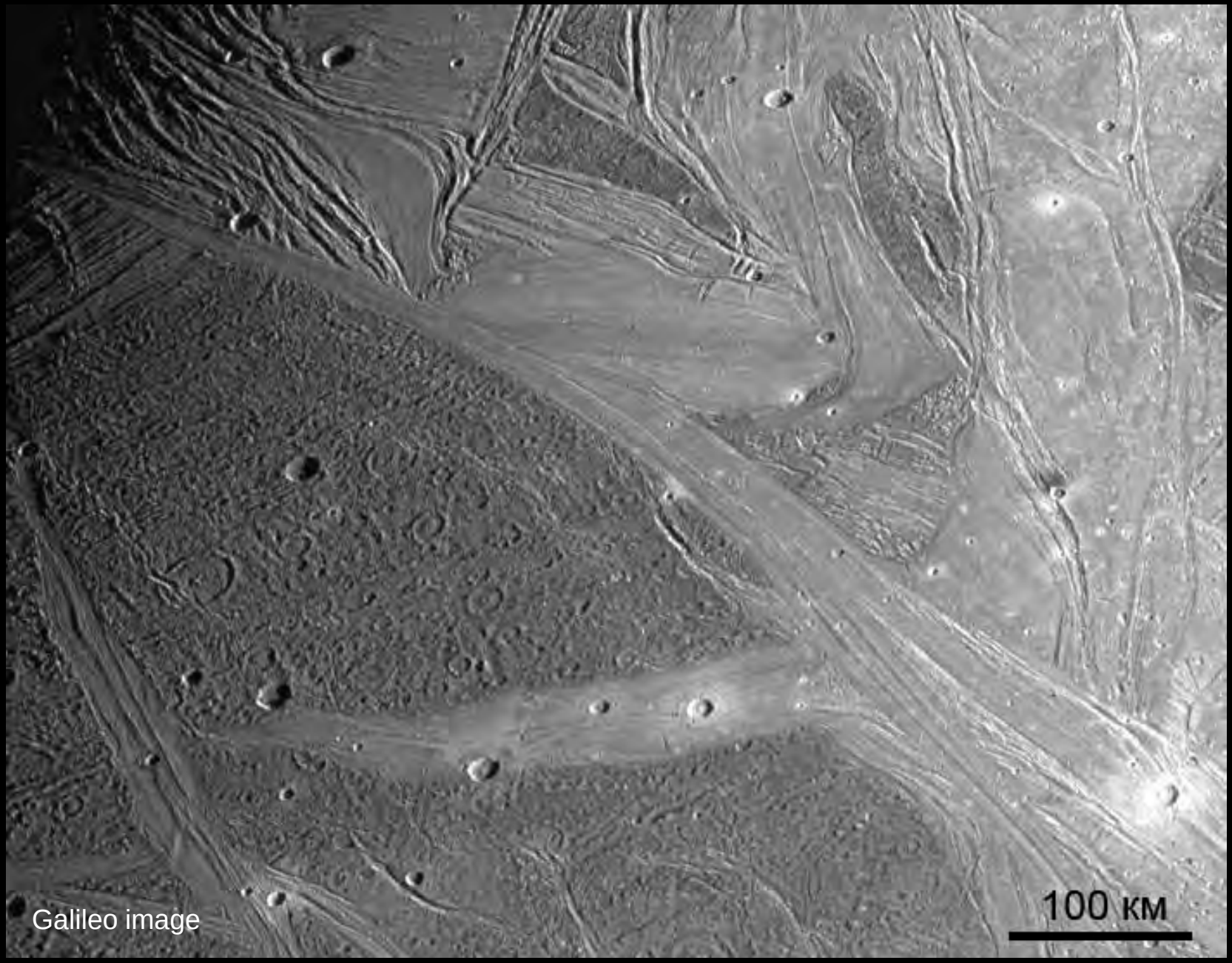


In morphology and size are close to those of the Moon and Venus

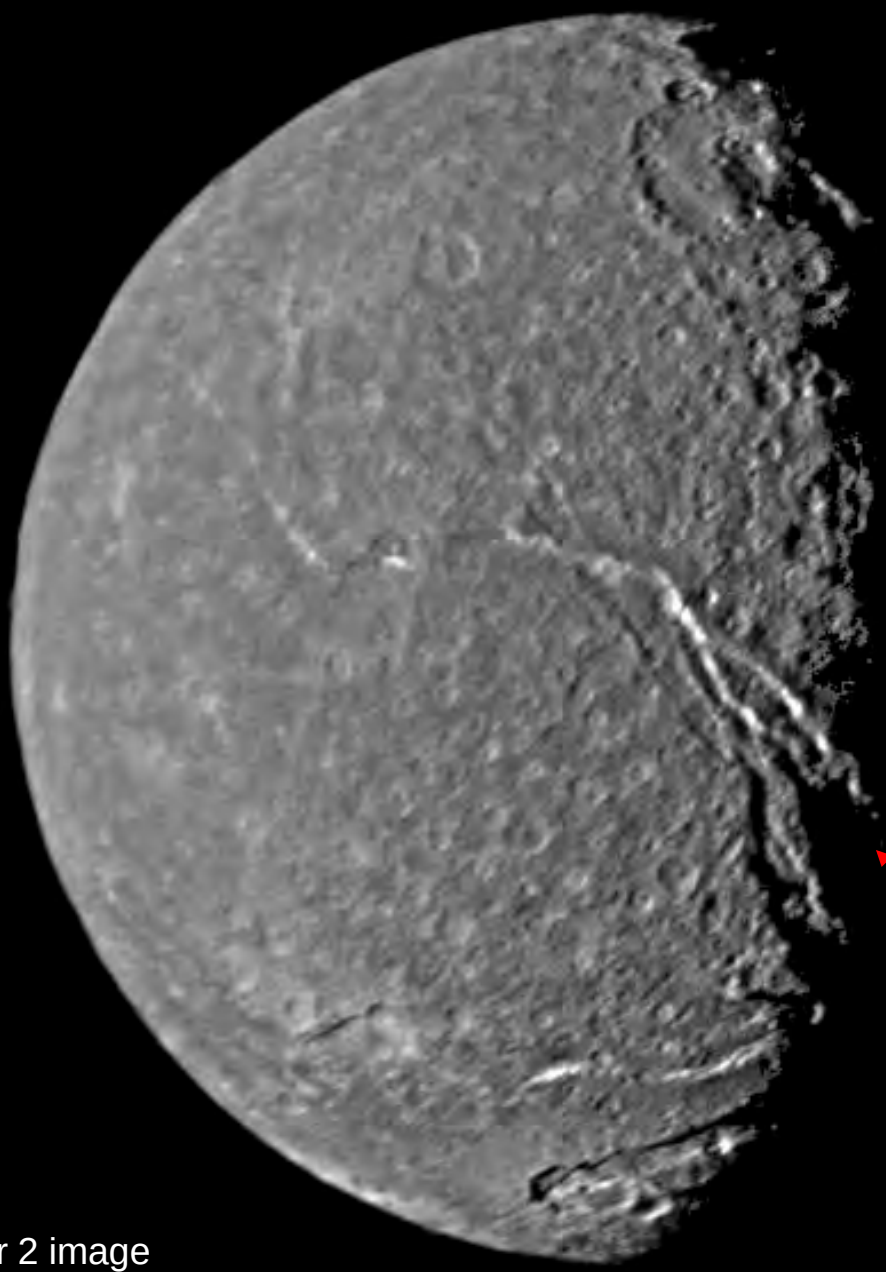
Europa: Faults and folds



Faults on Ganimede



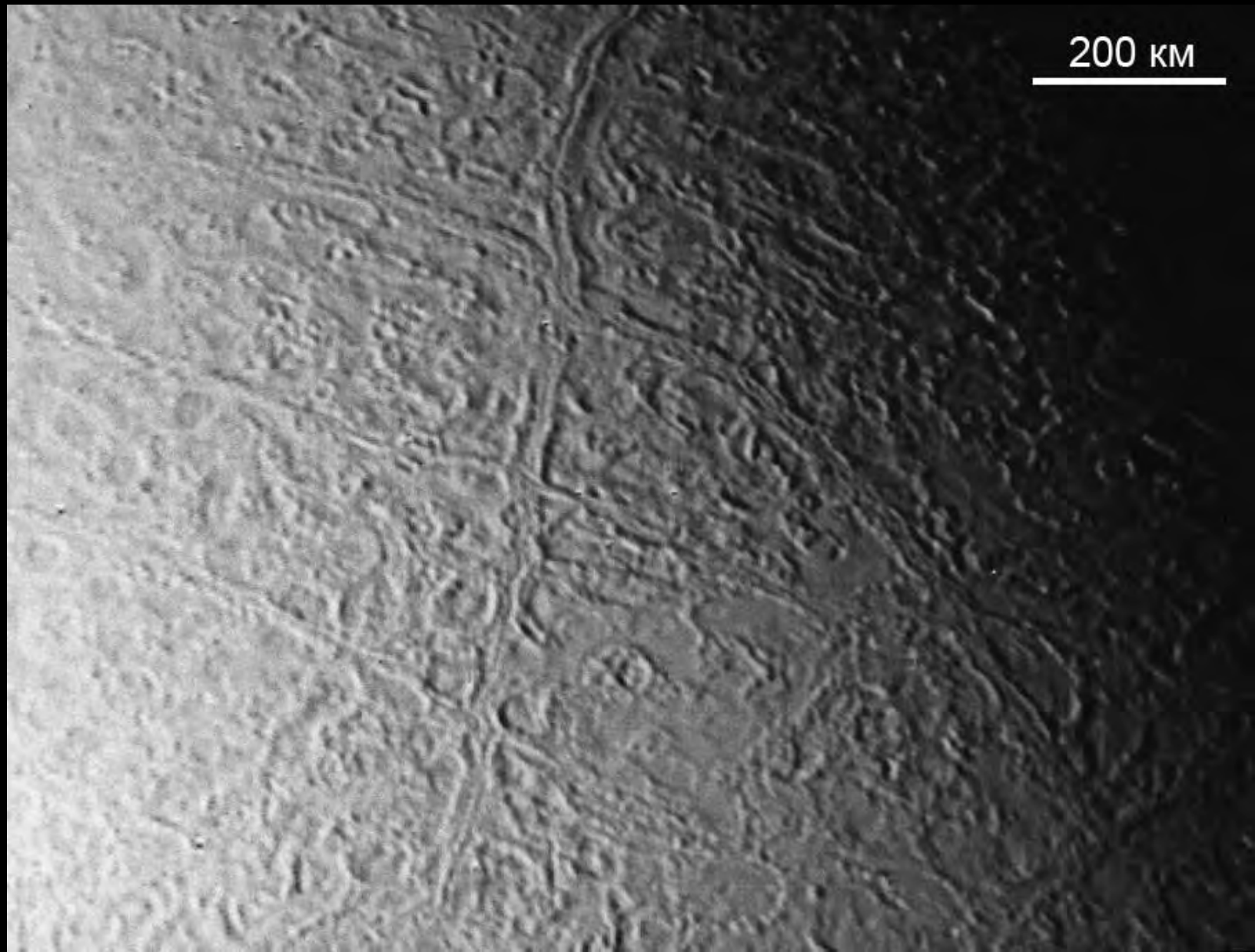
Titania (D = 1580 km) – satellite of Uranus



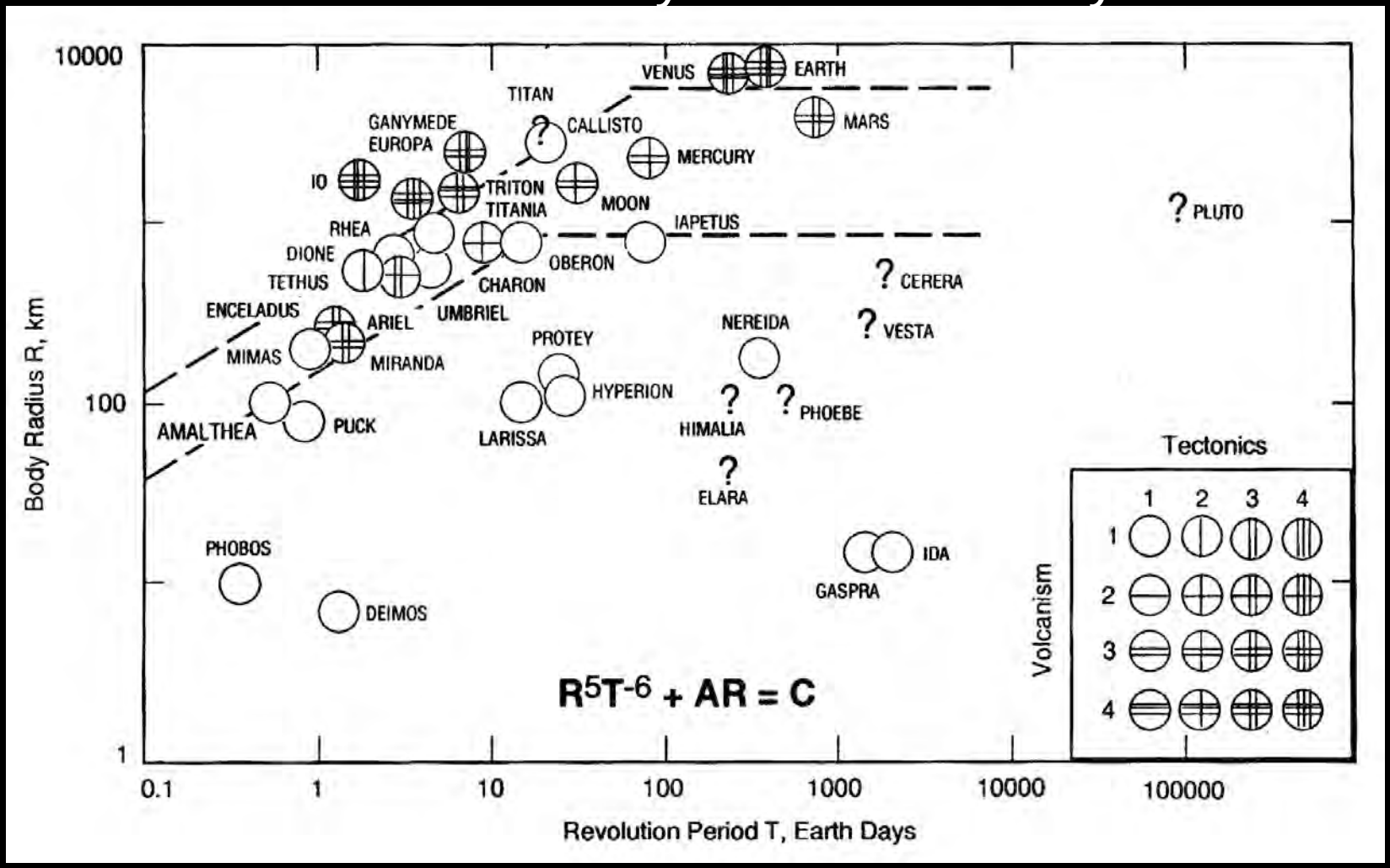
Voyager 2 image

Triton – satellite of Neptune

Tectonic deformations in the cantalupa terrain



Presence / intensity of magmatic and tectonic activity on planets / satellite is a function of their sizes and tidal disturbances by the central body



Impact processes were and are in work, but their traces are well seen only where other geologic processes are weak

Sputnik 1 launch, October 4, 1957

This image was composed by Don Mitchell from the nresreel,
Don Mitchell, www.mentallandscape.com