# Géomorphologie planétaire (SEE)

## UE 4UG25

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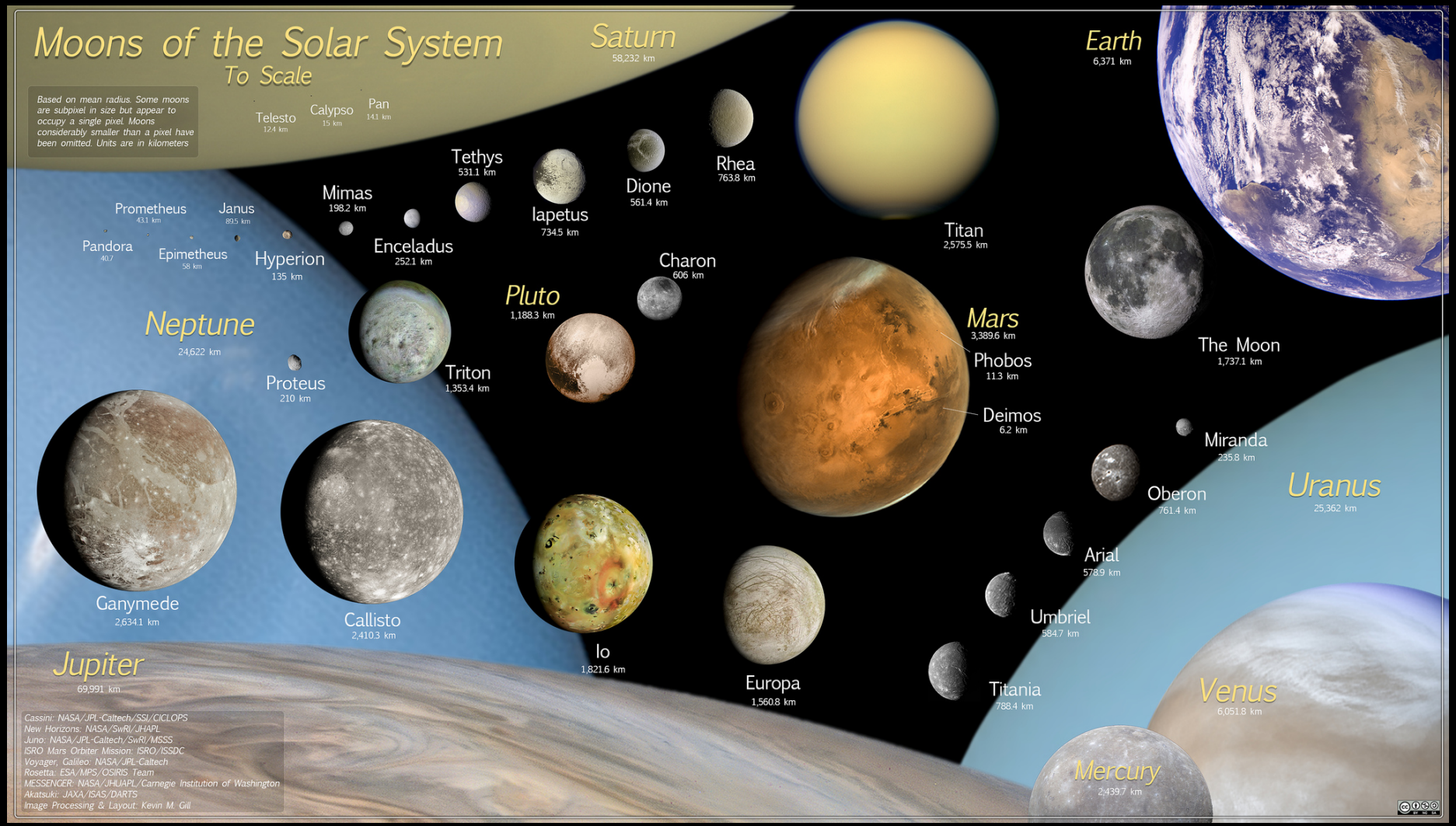
SCIENCES
SORBONNE
UNIVERSITÉ


Moons of the Solar System
To Scale
Based on mean radius. Some moons are subpixel in size but appear to occupy a single pixel. Moons considerably smaller than a pixel have been omitted. Units are in kilometers
Saturn
58,232 km
Earth
6,371 km
Telesto
12.4 km
Calypso
15 km
Pan
14.1 km
Tethys
531.1 km
Rhea
763.8 km
Mimas
198.2 km
Dione
561.4 km
Iapetus
734.5 km
Titan
2,575.5 km
Prometheus
43.1 km
Janus
89.5 km
Pandora
40.7
Epimetheus
58 km
Hyperion
135 km
Enceladus
252.1 km
Charon
606 km
Pluto
1,188.3 km
Mars
3,389.6 km
Phobos
11.3 km
Deimos
6.2 km
The Moon
1,737.1 km
Neptune
24,622 km
Triton
1,353.4 km
Proteus
210 km
Miranda
235.8 km
Oberon
761.4 km
Uranus
25,362 km
Arial
578.9 km
Umbriel
584.7 km
Titania
788.4 km
Ganymede
2,634.1 km
Callisto
2,410.3 km
Io
1,821.6 km
Europa
1,560.8 km
Jupiter
69,911 km
Venus
6,051.8 km
Mercury
2,439.7 km
Cassini: NASA/JPL-Caltech/SSI/CICLOPS
New Horizons: NASA/SwRI/JHAPL
Juno: NASA/JPL-Caltech/SwRI/MSSS
ISRO Mars Orbiter Mission: ISRO/ISSDC
Voyager, Galileo: NASA/JPL-Caltech
Rosetta: ESA/MPS/OSIRIS Team
MESSENGER: NASA/JHUAPL/Carnegie Institution of Washington
Akatsuki: JAXA/ISAS/DARTS
Image Processing & Layout: Kevin M. Gill

# Histoire de Mars à travers les âges

[Elhmann et al. Science 2008]

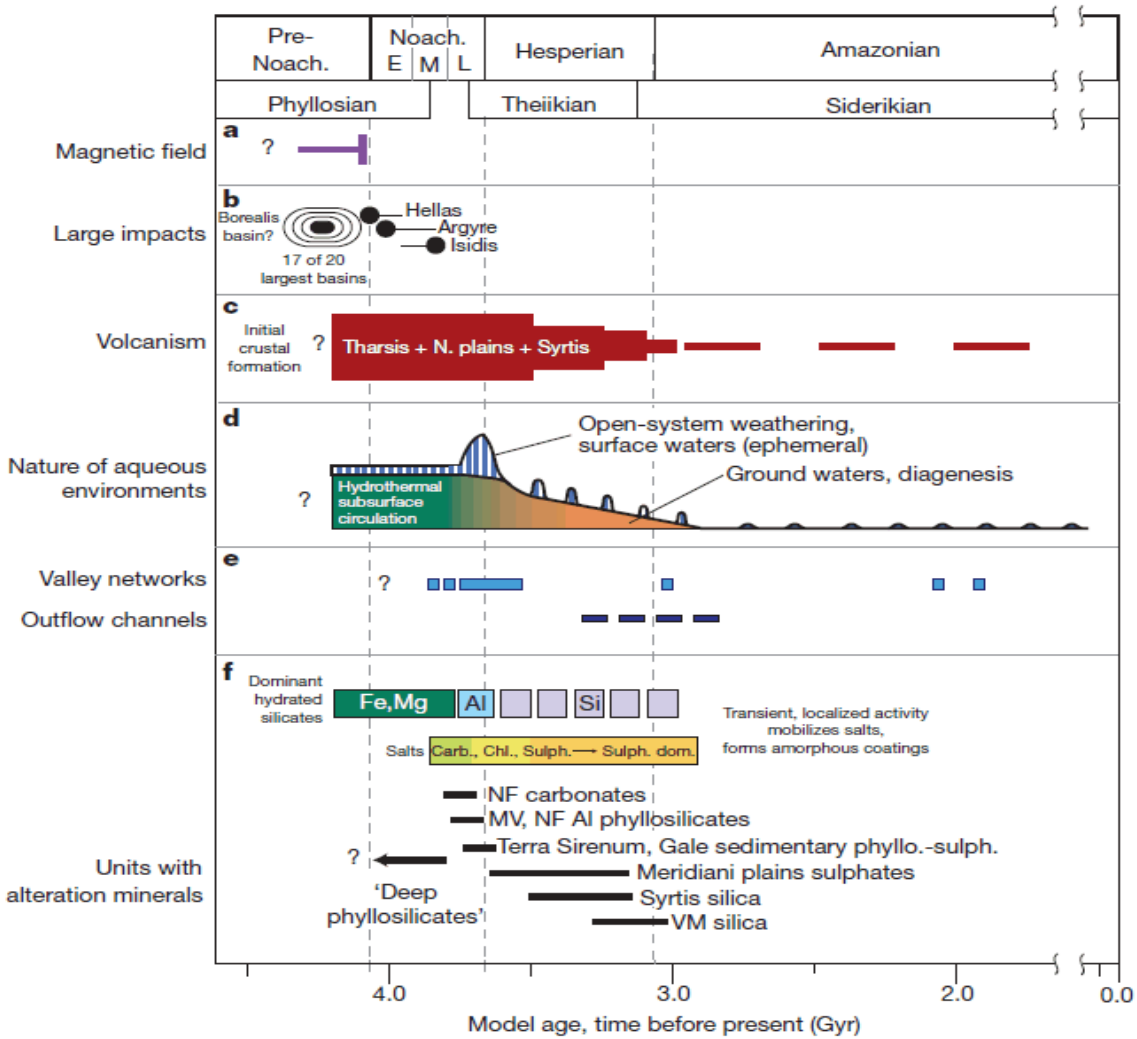



**Figure 4 | Timeline of major processes in Mars history.** **a–c**, Major geological processes influencing water availability, including the presence of a magnetic field[95] (**a**), impact cratering[96,97] (**b**) and volcanism[86,98] (**c**). **d**, Schematic depicting the changing nature of environments hosting liquid water, as implied by the geological evidence discussed herein. **e**, **f**, Evidence of liquid water: timing of valley network and outflow channel activity[15,16] ages of key minerals formed by aqueous alteration (**e**) and important regional units with alteration minerals (**f**). Relative timing is determined using relative crater densities and stratigraphic relationships. Absolute ages of period boundaries[5] have uncertainties of several hundred million years, inherent to extrapolation from cratering statistics[99]. NF, Nili Fossae; MV, Mawrth Vallis; VM, Valles Marineris; Carb., carbonates; Chl., chlorites; Sulph., sulphates.

# Plan

1. Impacts
2. Volcanisme
3. Tectonique
4. Glaciologie
5. Érosion
   - Éolienne
   - Fluviale et lacustre

# Plan

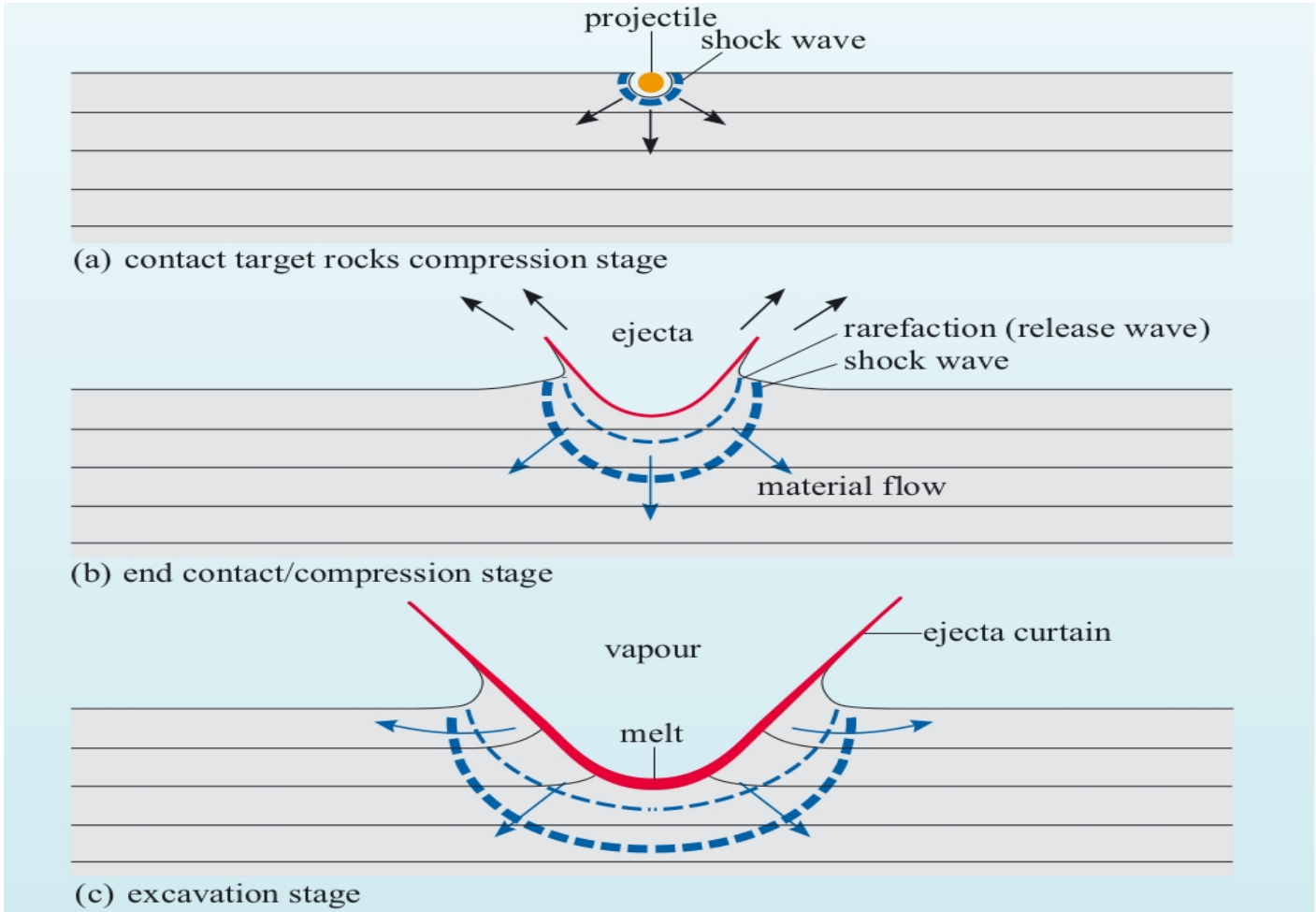
# Impacts et Cratérisation

## Principal mécanisme

- ✎ altération des surfaces des corps sans atmosphère (hors Io, Europe).
- ✎ apport et d'excavation de matériel planétaire
  - formation de satellites par agrégation après collision (Lune, Phobos)
  - apport de volatiles dans les surfaces et atmosphères (SL9 Jupiter)

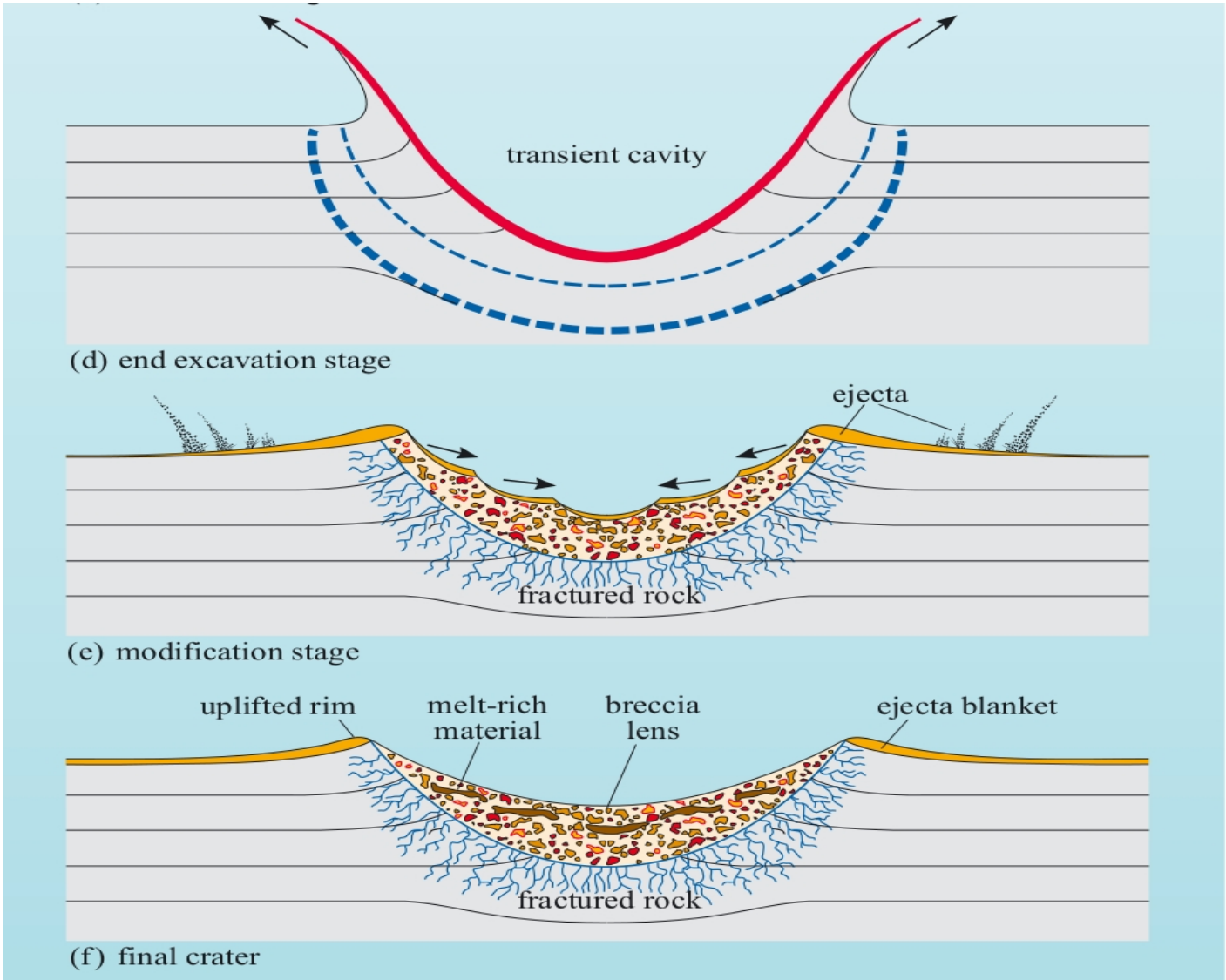
- ☞ **forme, taille** ⇒ propriétés des surfaces planétaires (composition, résistance, stratifications, porosité) et de leurs impacteurs, caractéristiques d'une éventuelle atmosphère
- ☞ **distribution, statistique** ⇒ âge et évolution des surfaces planétaires, population des impacteurs (restes primitifs des planétésimaux de l'accrétion planétaire)
- ☞ **extrêmes** ⇒ évènements catastrophiques (e.g. formation de satellites, modification des paramètres orbitaux de certains corps)

# Development of a simple impact structure




[McBride and Gilmour, An Introduction to the Solar System, 2004 – after Melosh 1989]

# Development of a simple impact structure

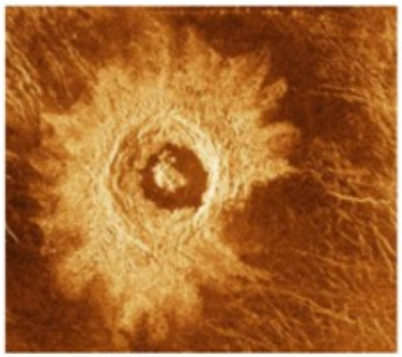



[McBride and Gilmour, An Introduction to the Solar System, 2004 – after Melosh 1989]

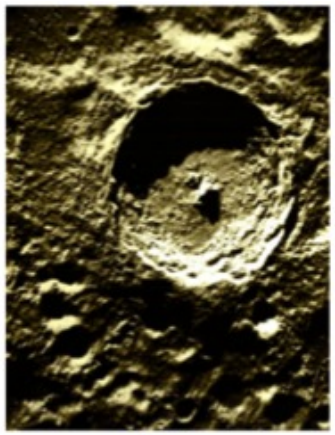
# Bestiaire de cratères

## Simples, secondaires, complexes, à anneaux, bassins d'impact

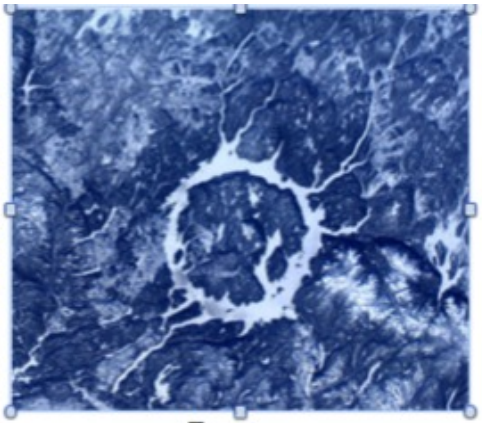
Mercure



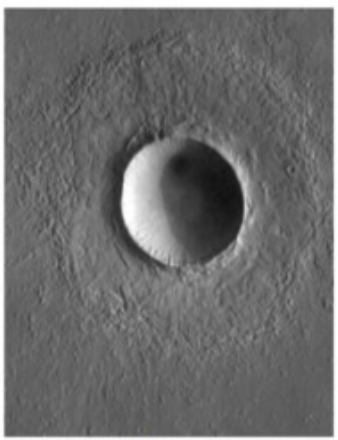
Vénus



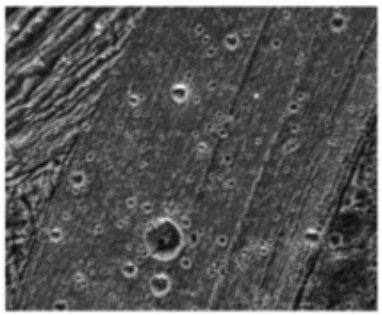
Lune



Terre

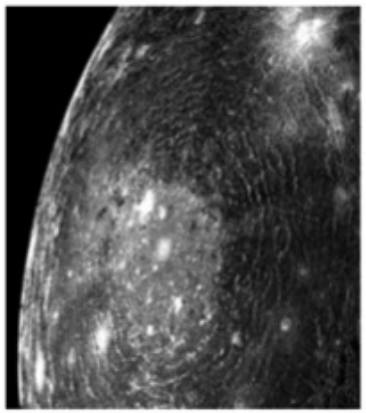


Mars

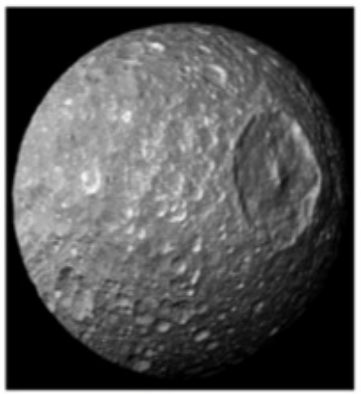


Ganymède

Astéroïde Ida



Callisto

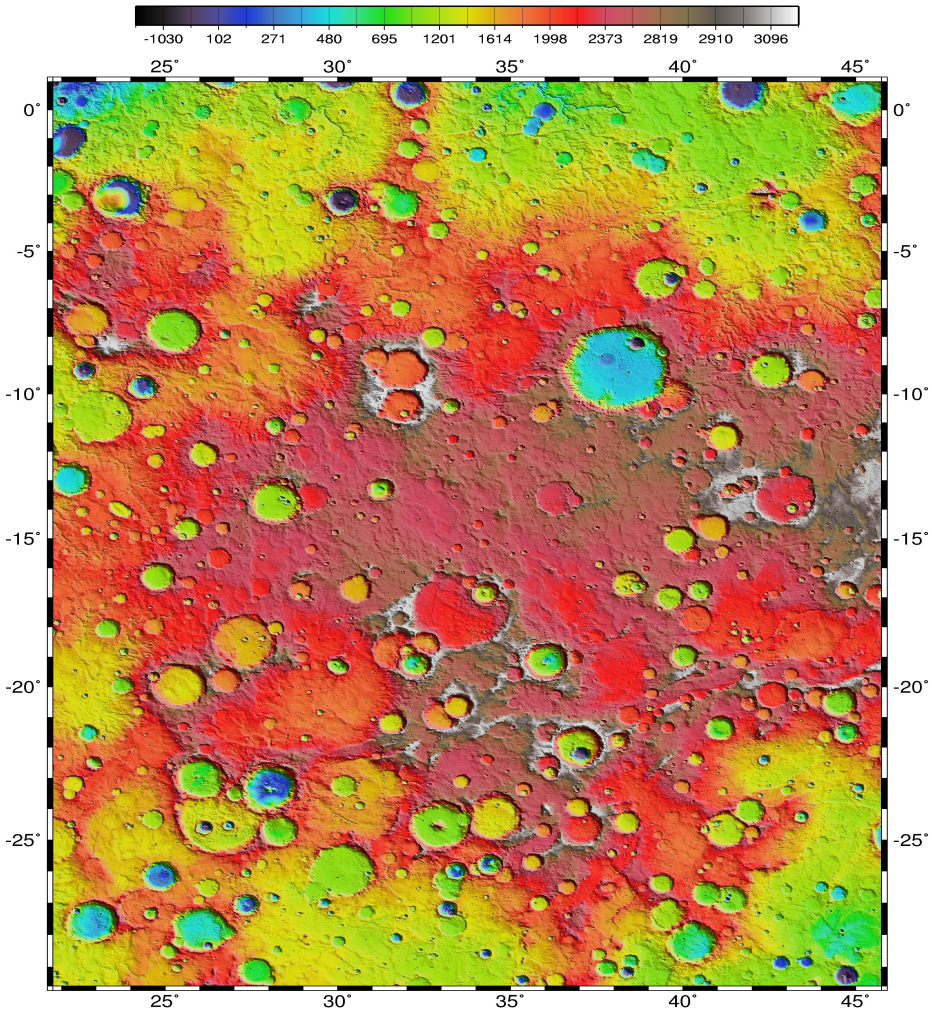


Mimas

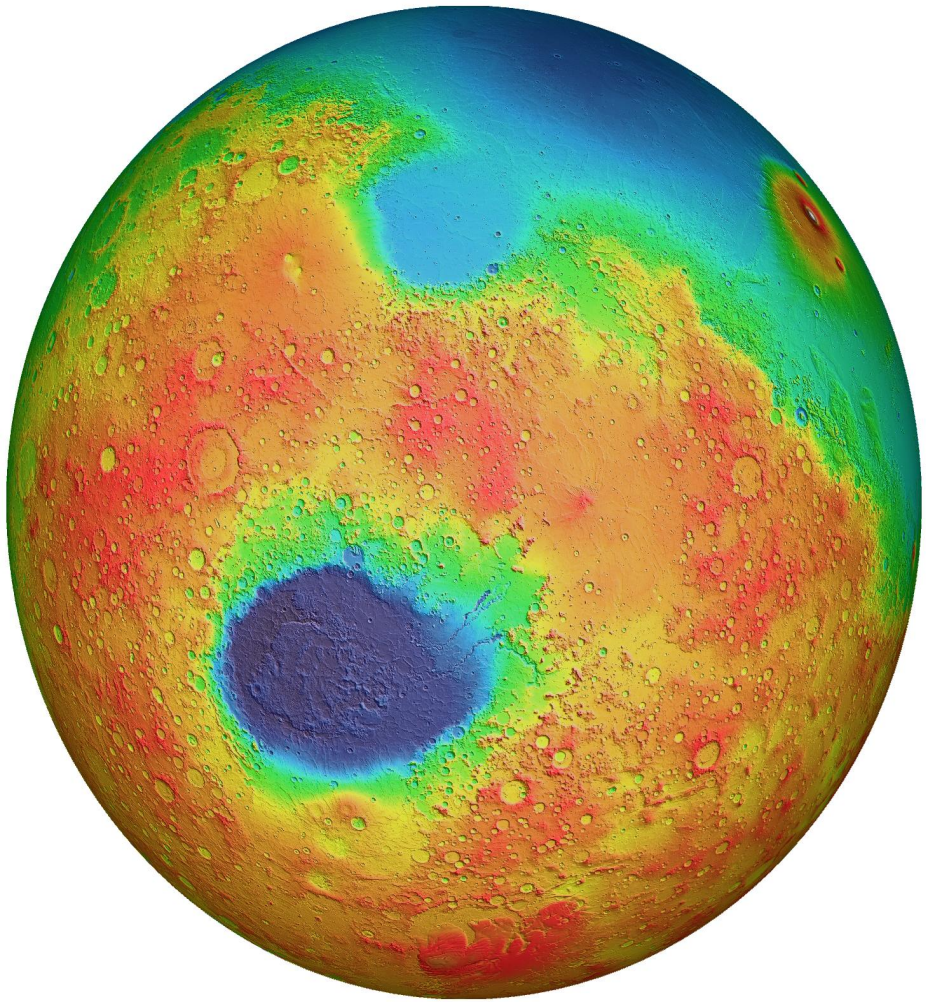
[Assemblage réalisé par Alice Le Gall]

# Craters on Mars (MOLA topography)

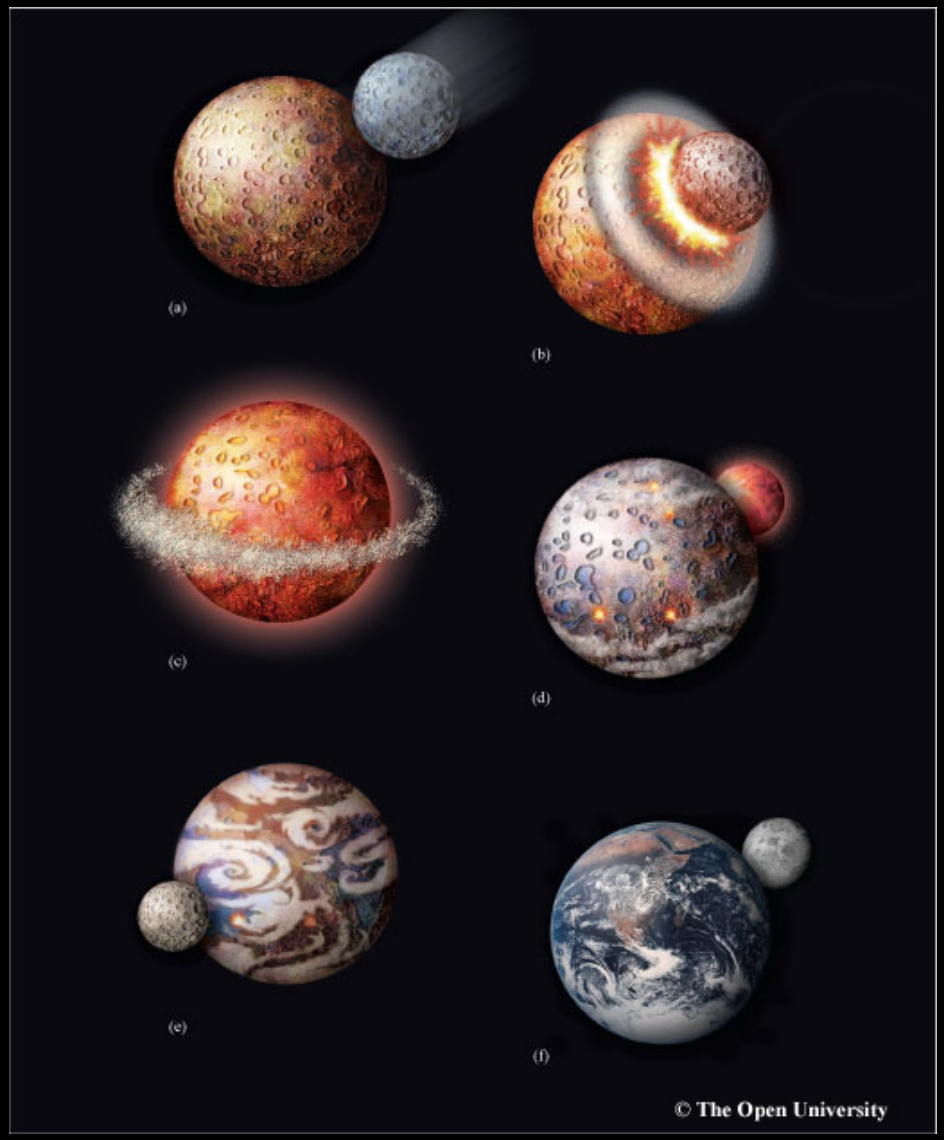
## Noachis Terra




## Hellas crater



# The formation of the Moon




## Science Magazine, October 2013

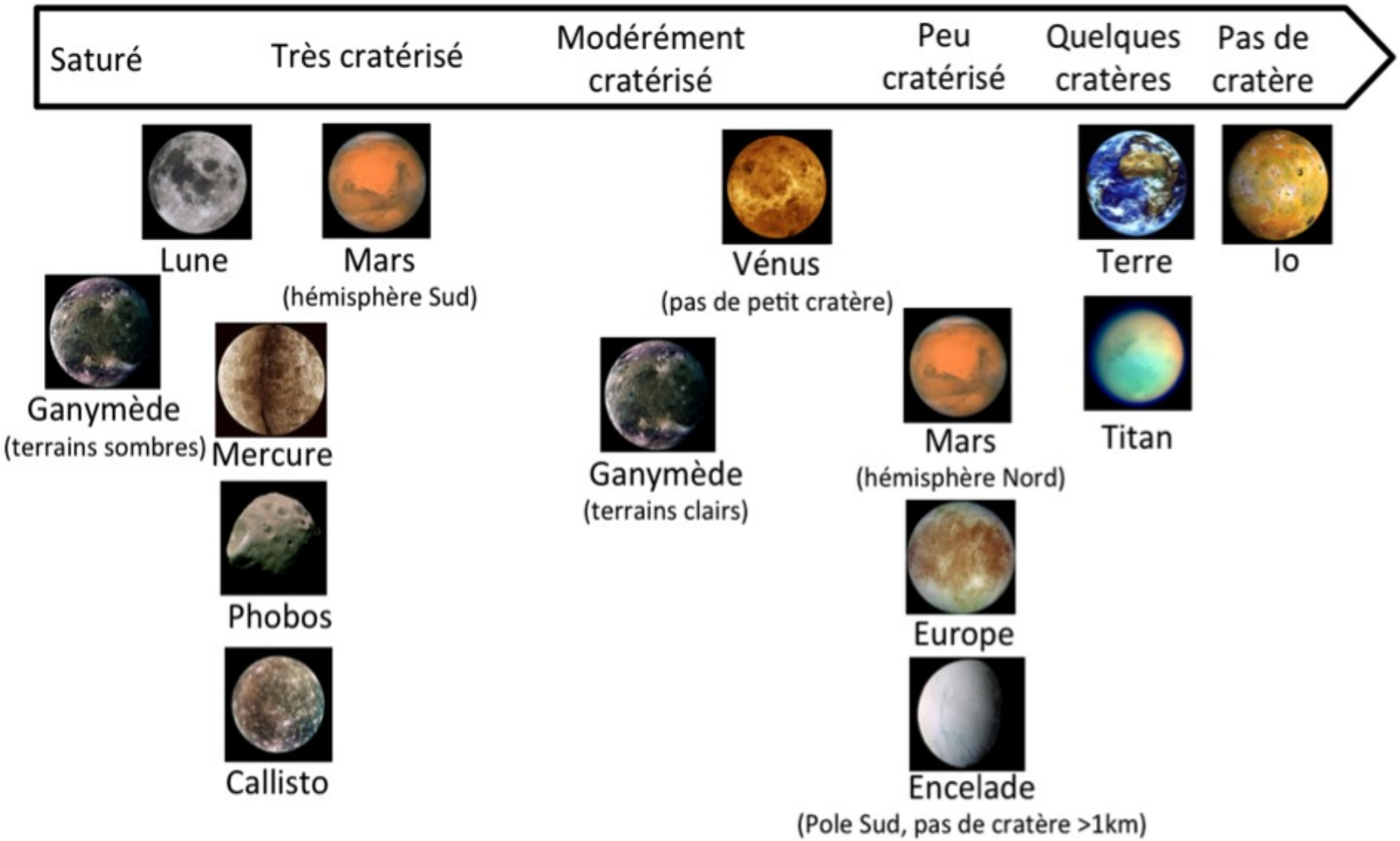
Where did the moon come from? For 3 decades, planetary scientists have agreed that it happened something like this: While the solar system was still forming, a body the size of Mars struck Earth a glancing blow that reduced both to rubble. The cloud of debris reformed itself into the modern Earth and moon. This "giant impact" theory neatly explained why the rocks Apollo astronauts brought back from the moon closely resembled rocks on Earth—or so it seemed at first. Actually, recent computer models show, such a collision wouldn't have scrambled the two bodies together enough to explain the similarity. Meeting last month in London to discuss the problem, scientists agreed that the origin of the moon must have been messier and more complicated than anyone had assumed.

# Types d'éjectas remarquables: Mars et Vénus

[Yuty crater 18 km (Viking)]

[Lavinia craters 37-50 km (Magellan)]

# Degré de cratérisation




[Figure réalisée par Alice Le Gall]

# Datation par comptage de cratères

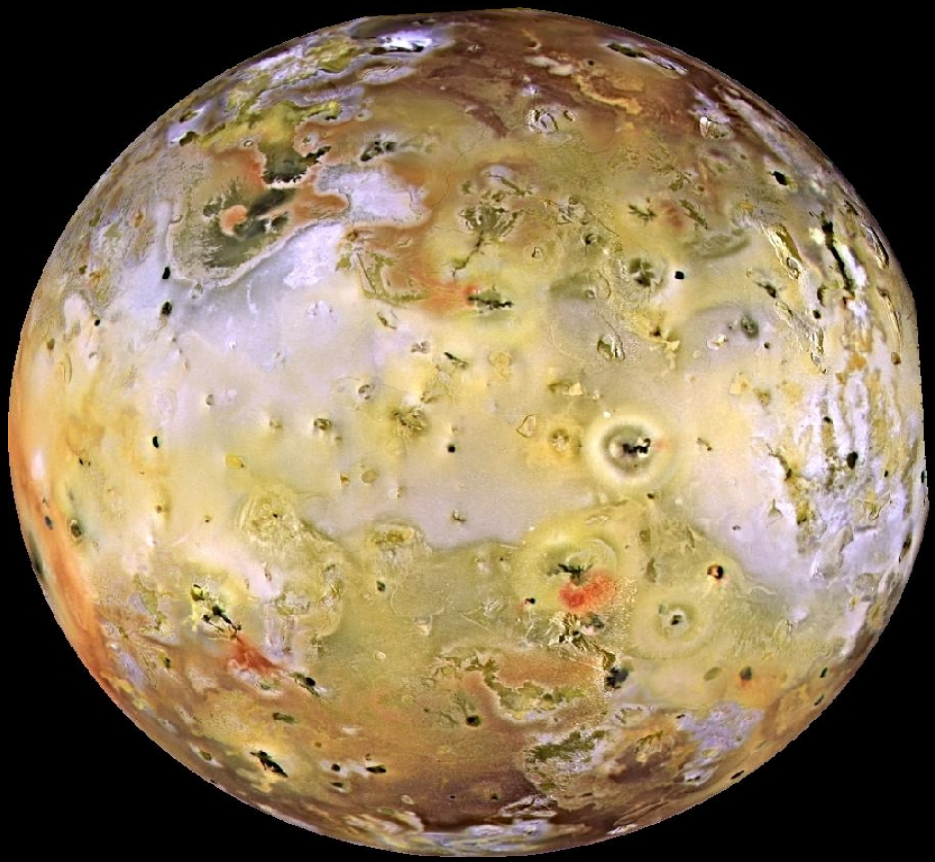
Distribution des cratères (nombre de cratères en fonction de leur taille)

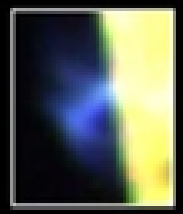
- ✎ Estimation de l'âge relatif des surfaces
  - Plus une surface est cratérisée, plus elle est ancienne.
  - Plus les cratères sont grands, plus ils sont vieux.

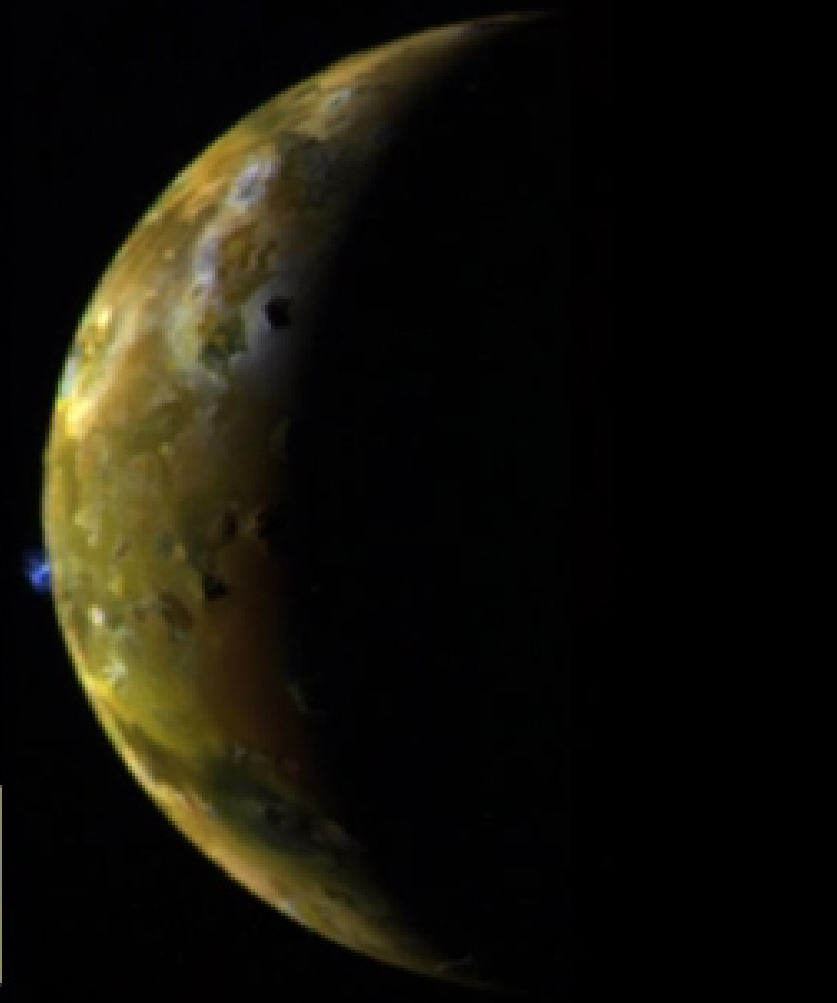
  Taille des projectiles et taux de cratérisation plus importants dans la jeunesse du système solaire ; puis mobilisation de tailles de façon décroissante dans les planétésimaux.
- ✎ Connaissance nécessaire de l'évolution du flux d'impacteurs. Datation radiogéniques d'échantillons lunaires collectés lors des missions Apollo. Mise en évidence du Late Heavy Bombardement il y a 4 milliards d'années.
- ✎ Prise en compte de la présence d'une atmosphère (et de l'évolution de sa densité). Extrapolation sujette à caution.

# Plan

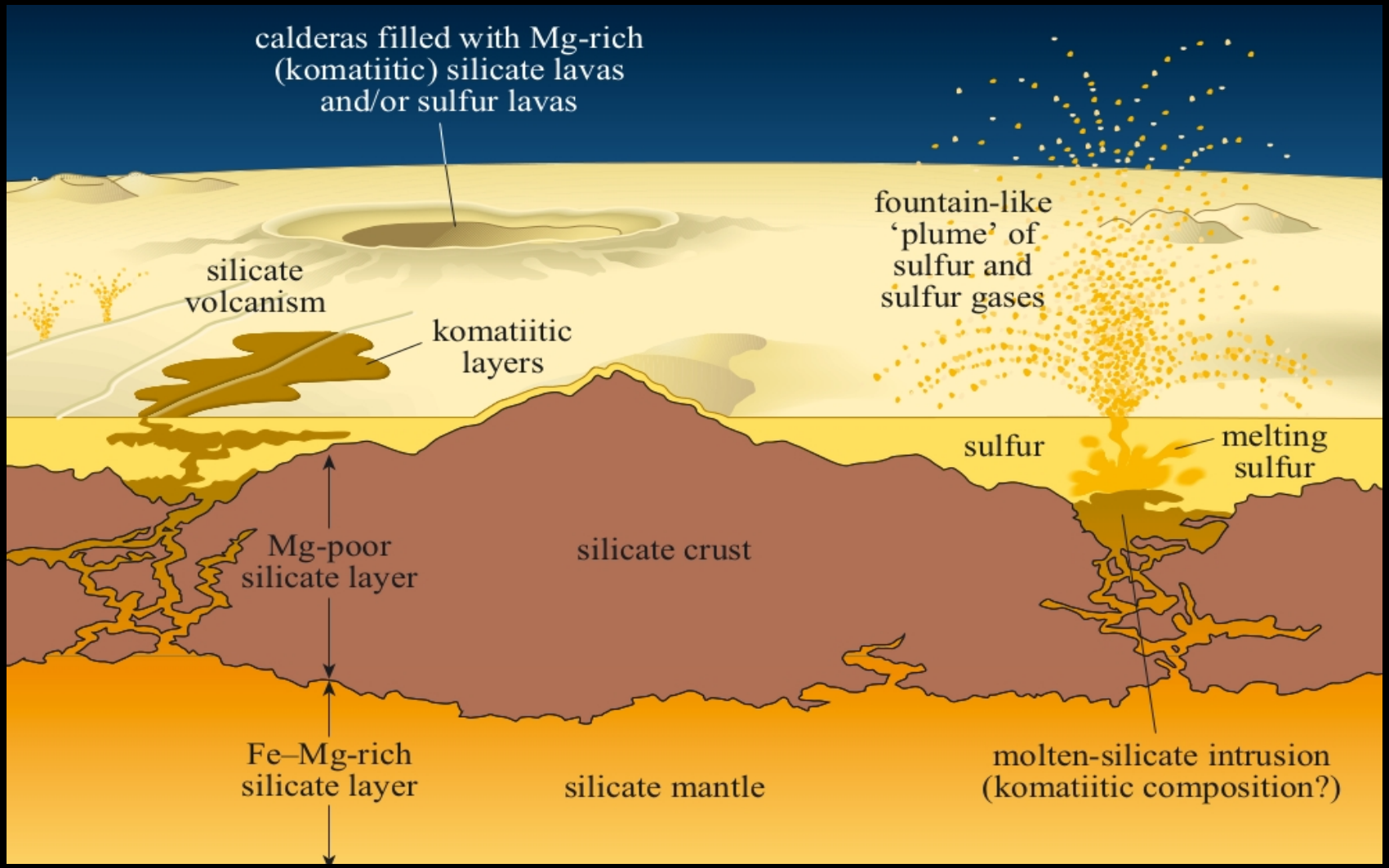
# Io et son volcanisme intense (images Galileo)







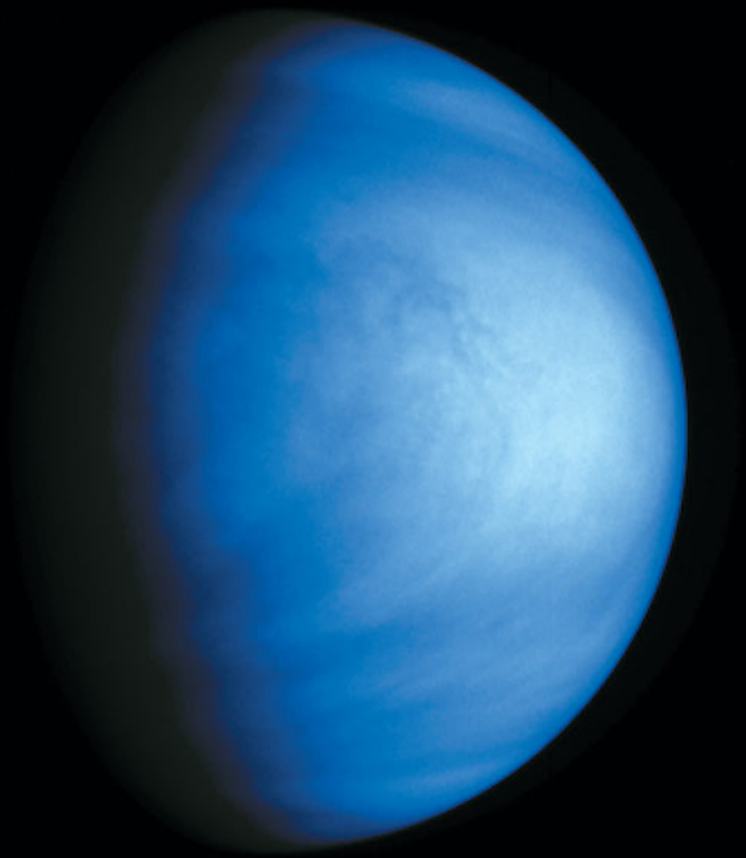
# Io: three different types of eruptions




[McBride and Gilmour, An Introduction to the Solar System, 2004]

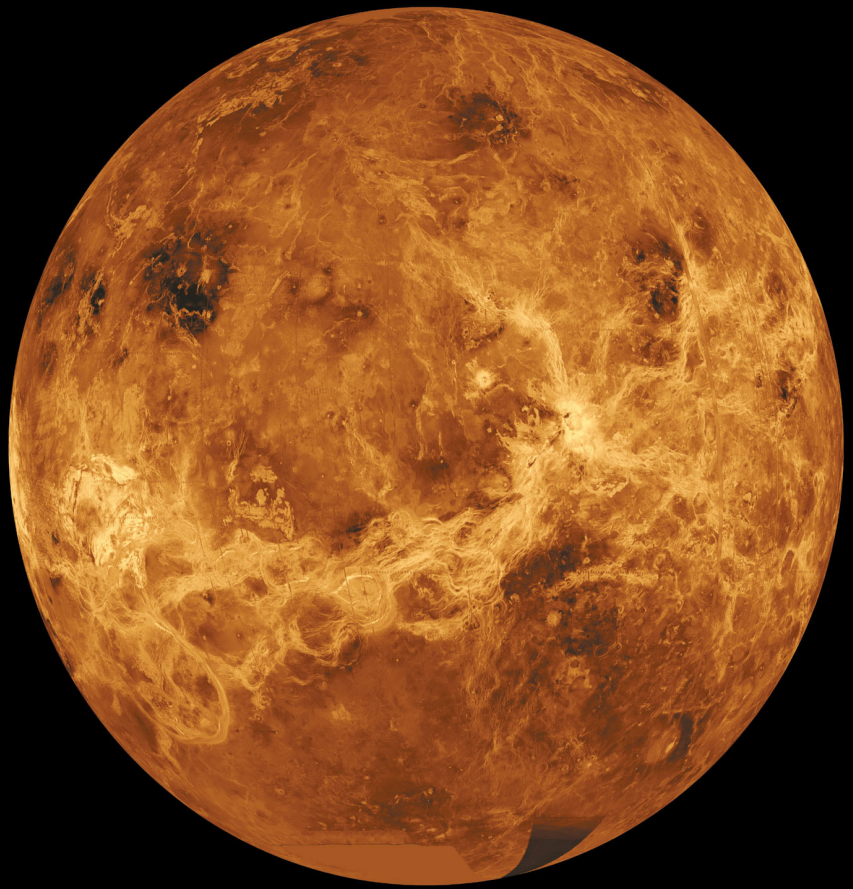
# Vénus

vue par Galileo (image visible fausses couleurs)



Courtesy of NASA

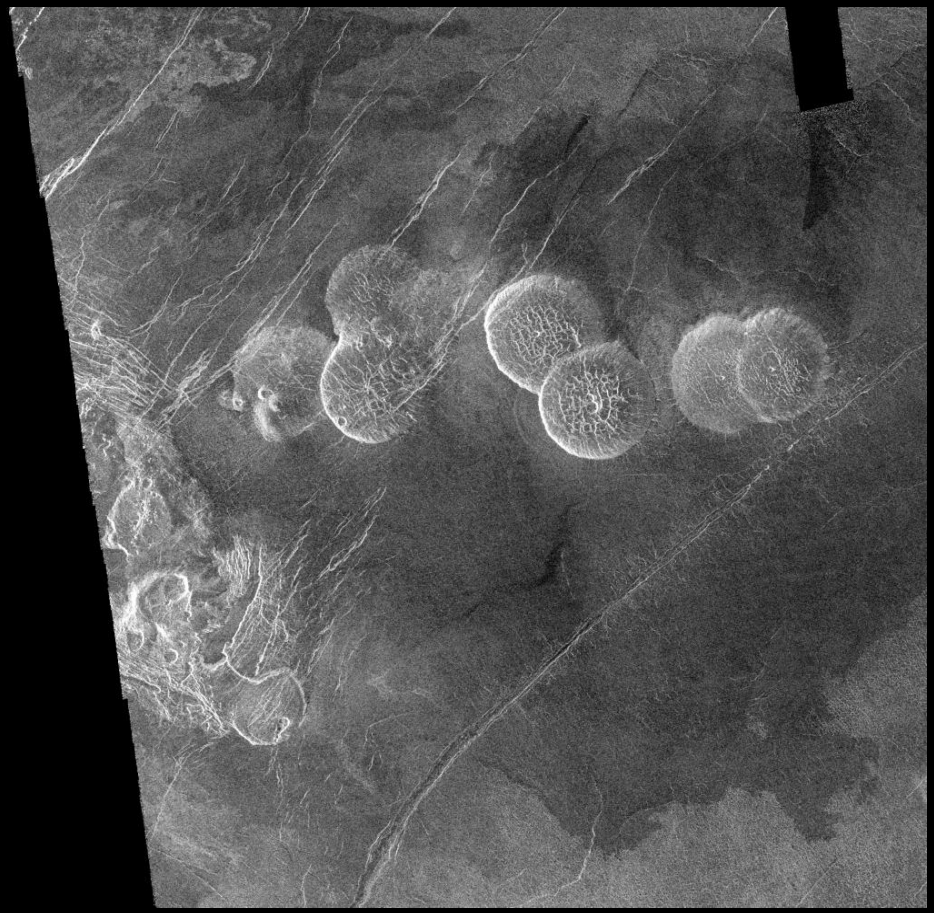
vue par Magellan (cloud-penetrating radar)



Courtesy of NASA

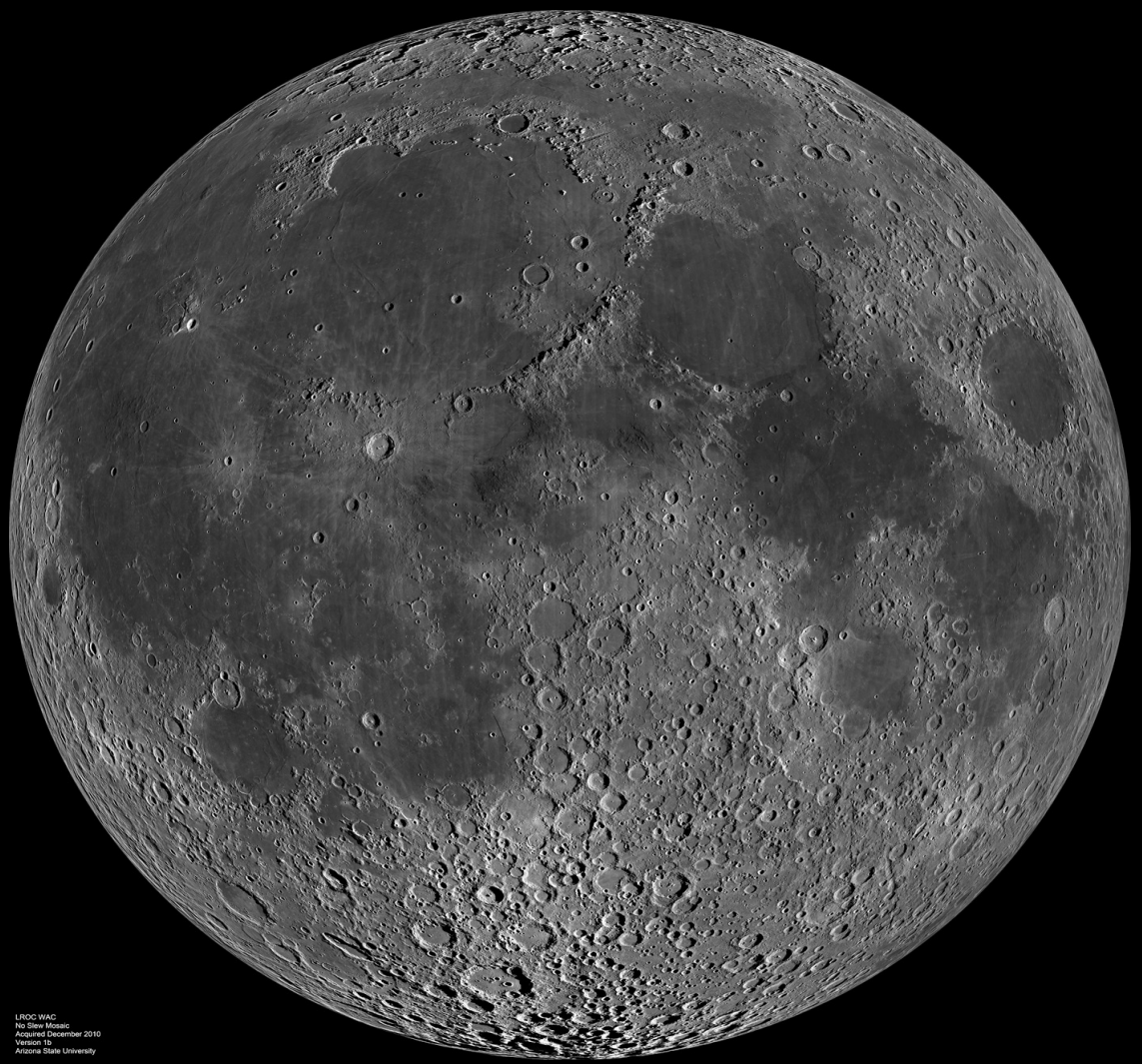
# Volcanisme sur Vénus

"pancake" domes (25 km, 750 m)

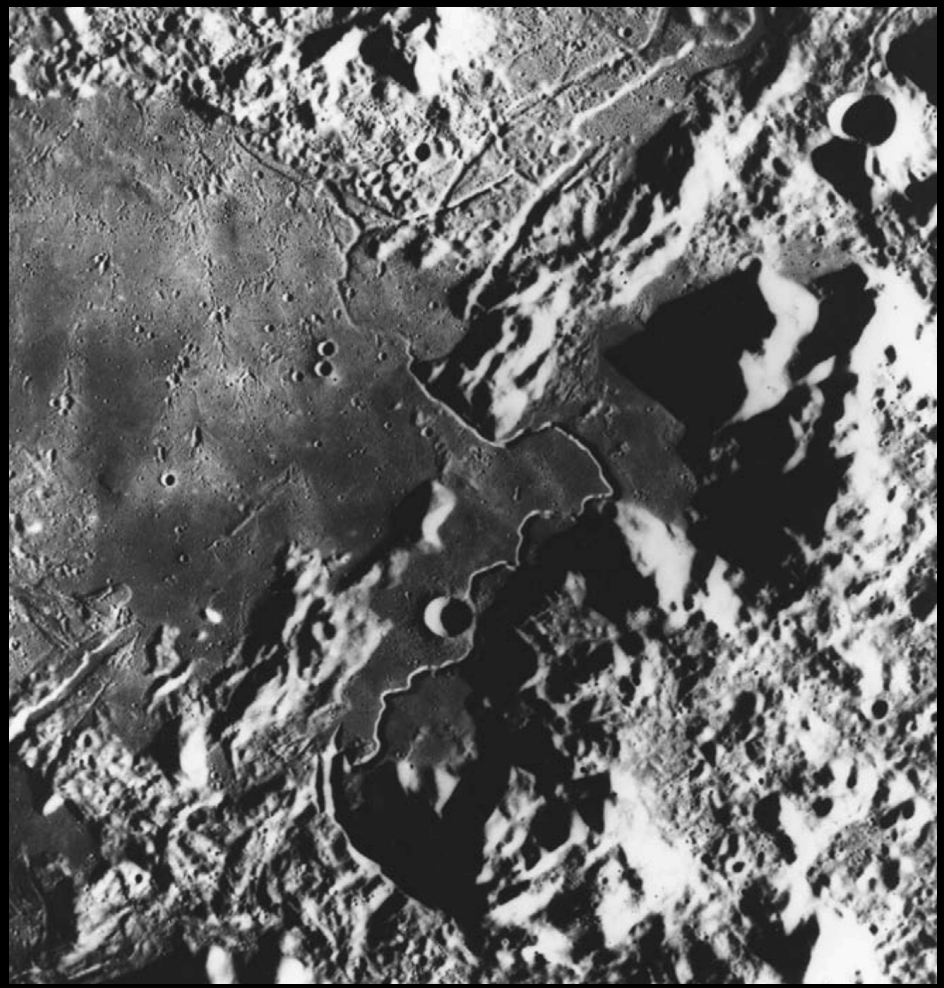


Atete Corona (600 $\times$ 450 km)

# Near-side Moon imaged by LRO in 2010



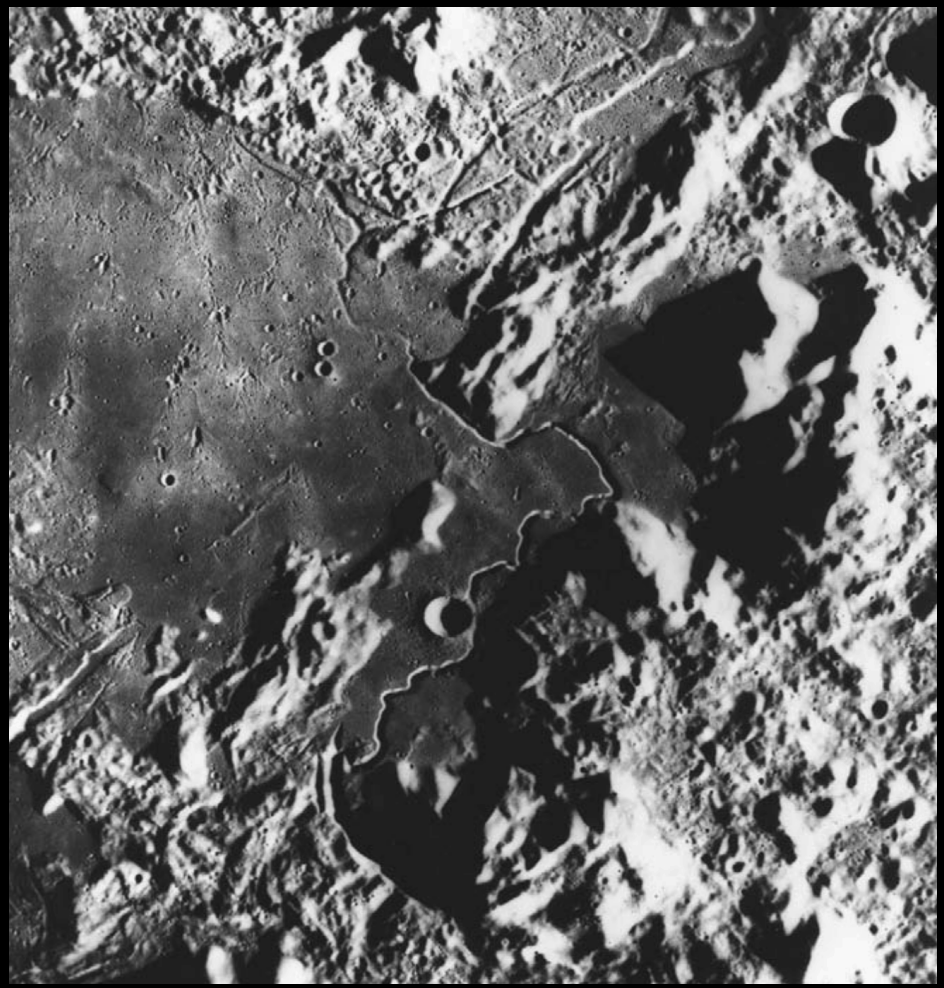
# Moon's Hadley Rille



[NASA Lunar Orbiter IV-102H3 150 $\times$ 150 km scene]

[Photo Apollo 15 (31 July 1971)]

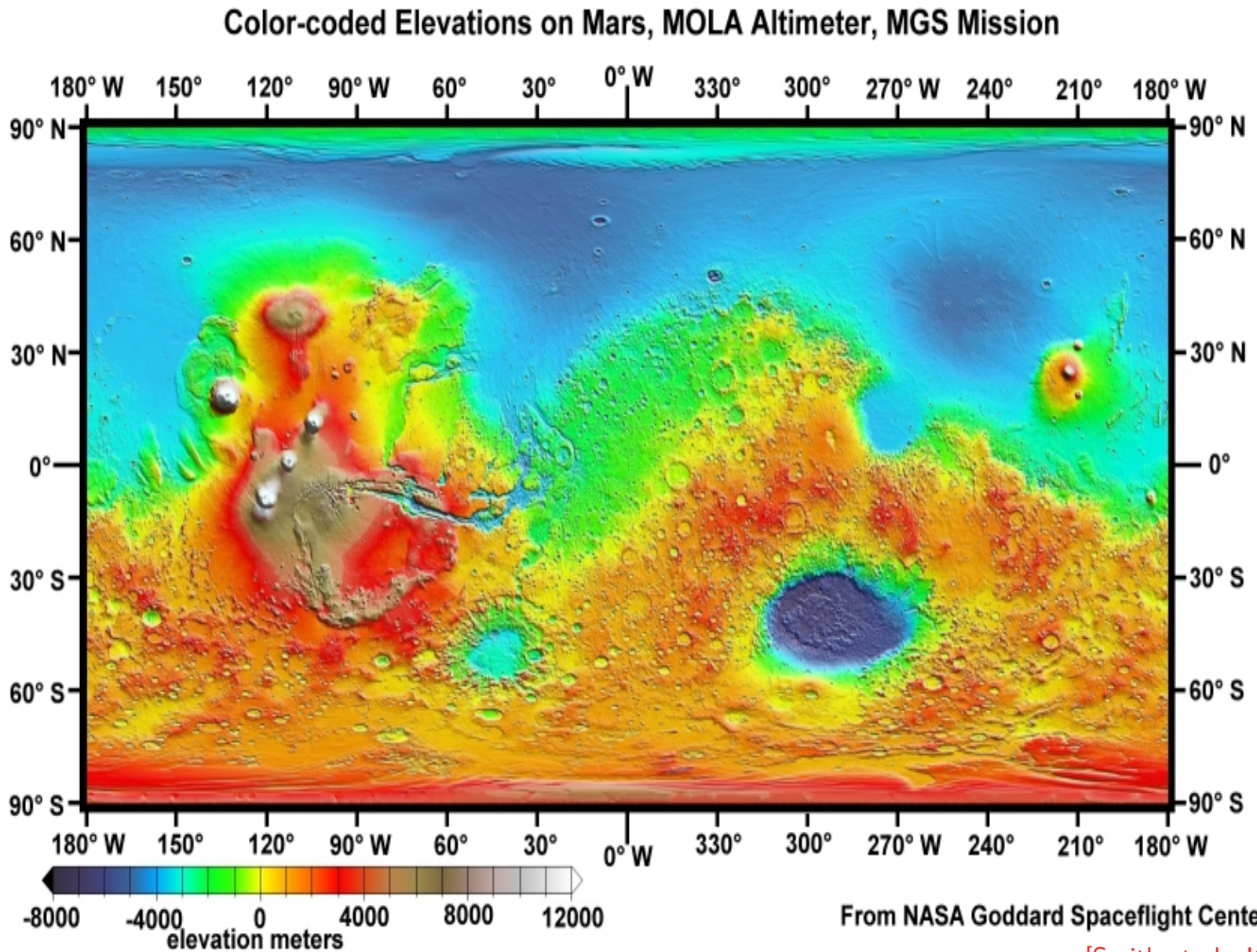
# Moon's Hadley Rille vs. Earth lava channel



[NASA Lunar Orbiter IV-102H3 150 $\times$ 150 km scene]

[Lava channel Hawaii volcano 1984 R.W. Decker USGS]

# Mars' topography by the MOLA altimeter

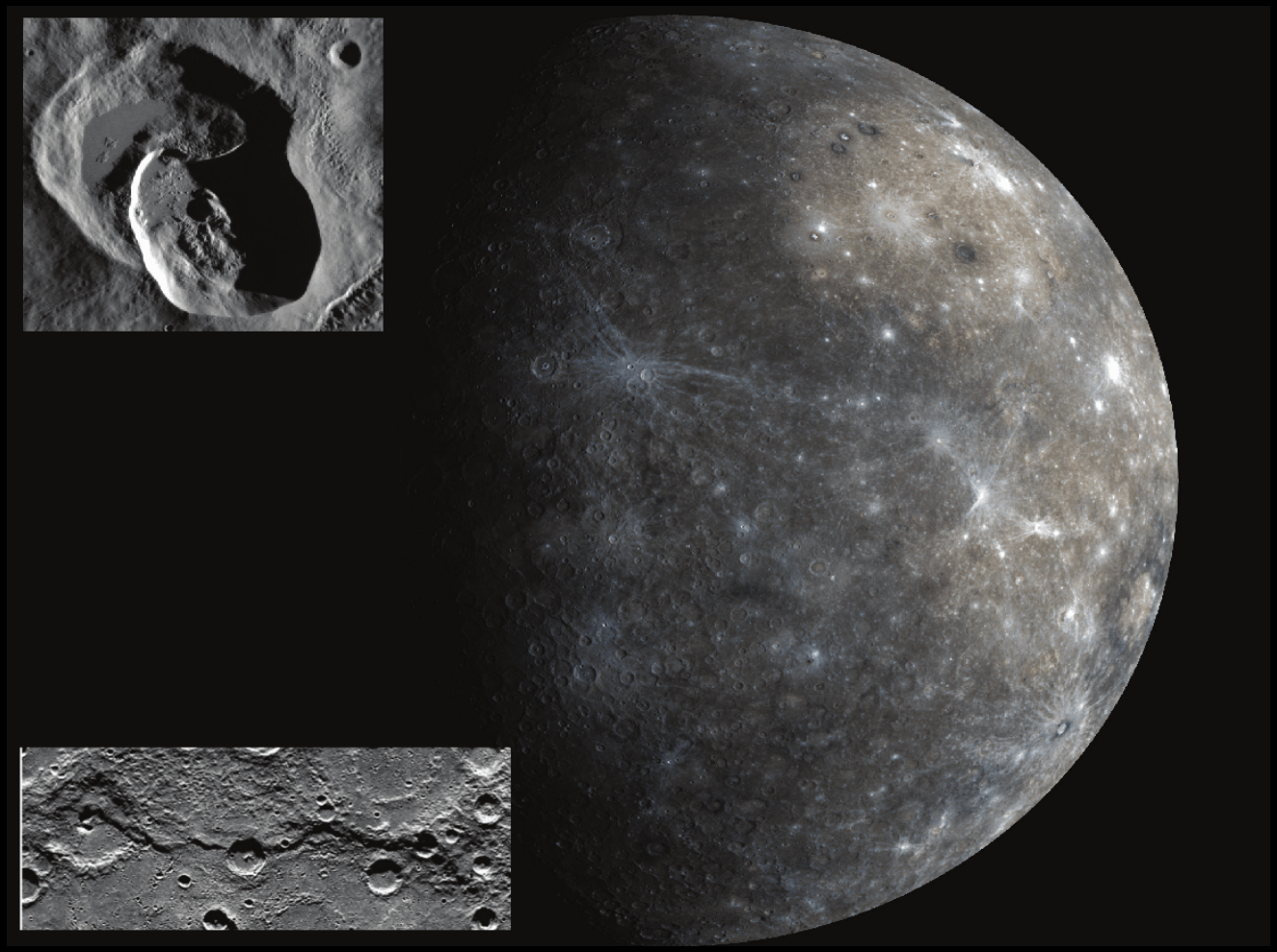



[Smith et al. JGR 2001]

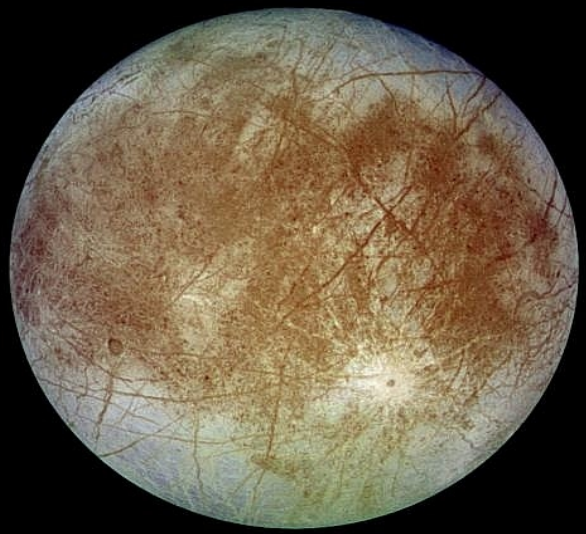
# Plan

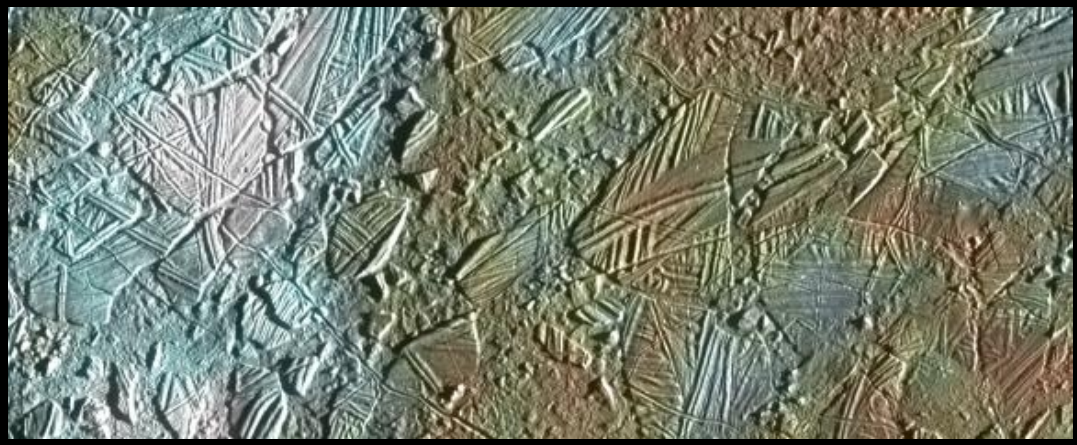
# Mercure

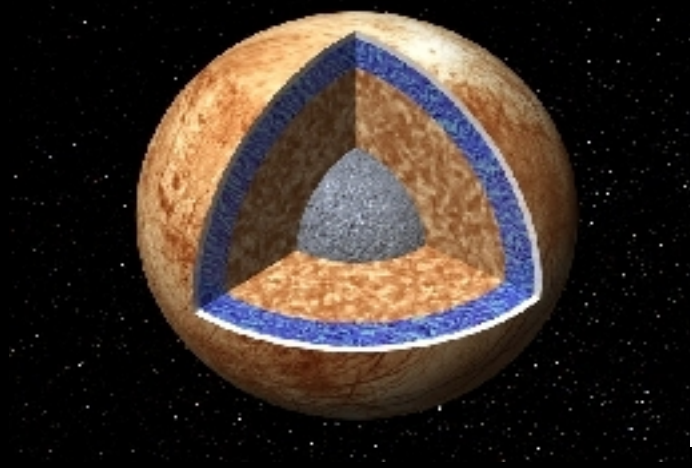
## moisson de découvertes de la sonde MESSENGER

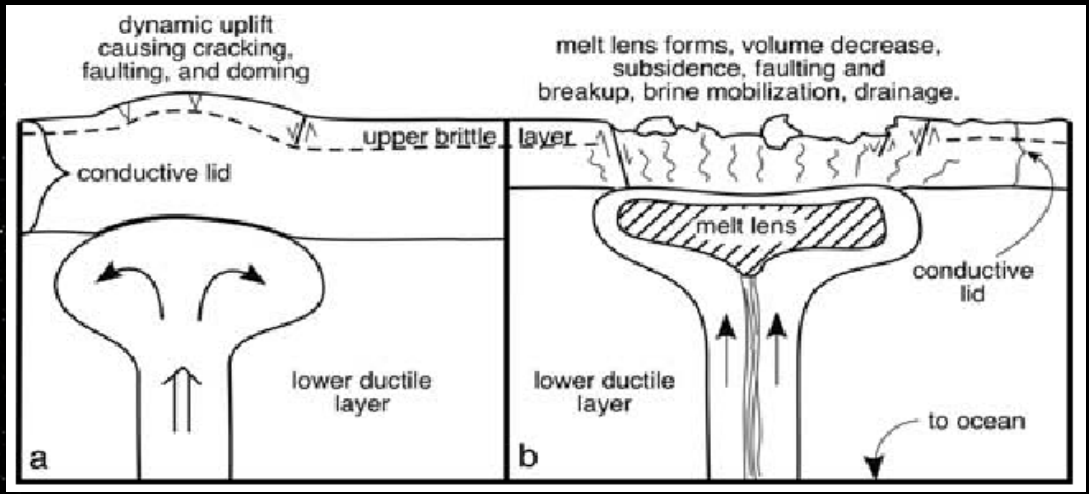


# Europe



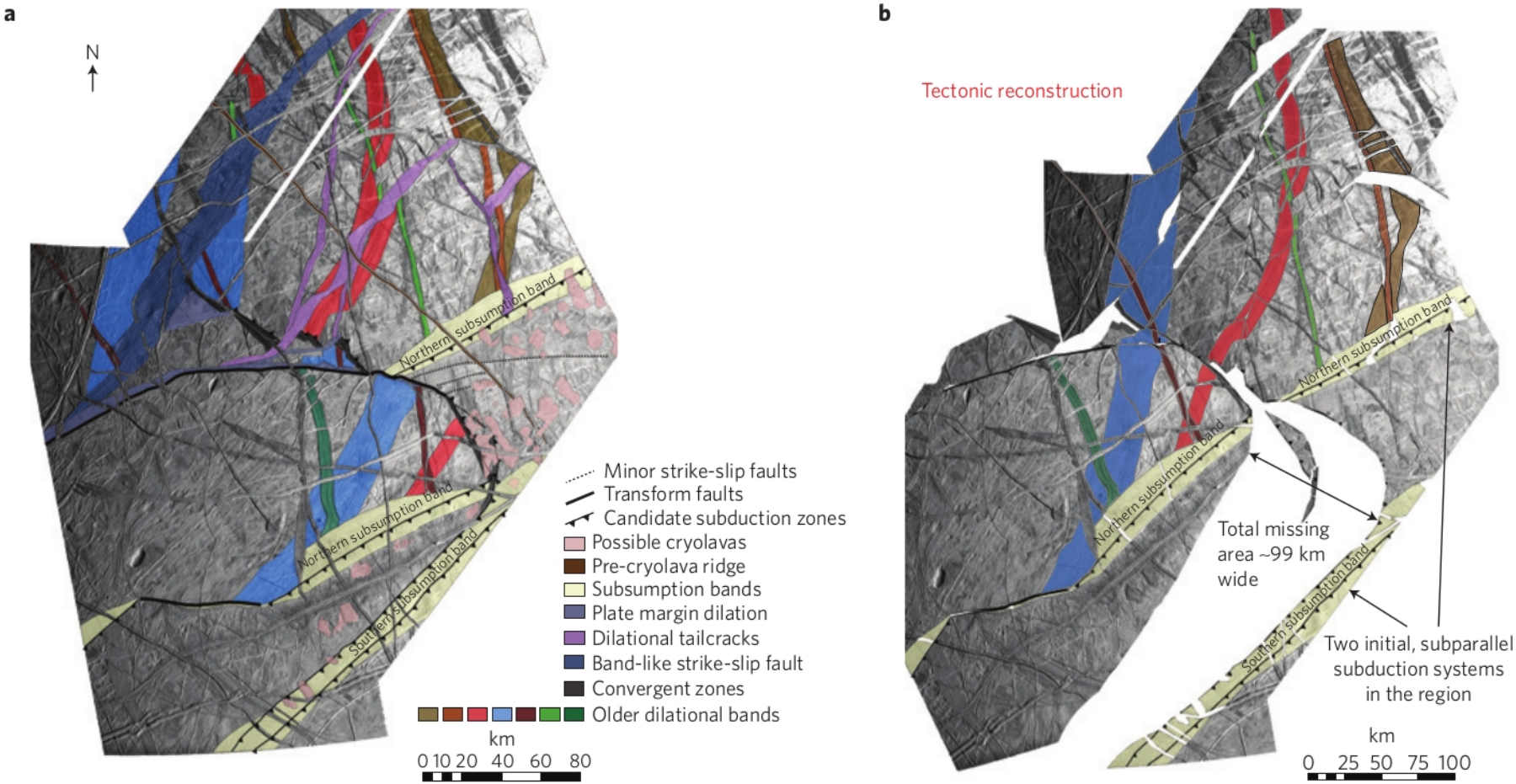







Sotin et al. 2002

# Tectonics on Europa (Galileo images)

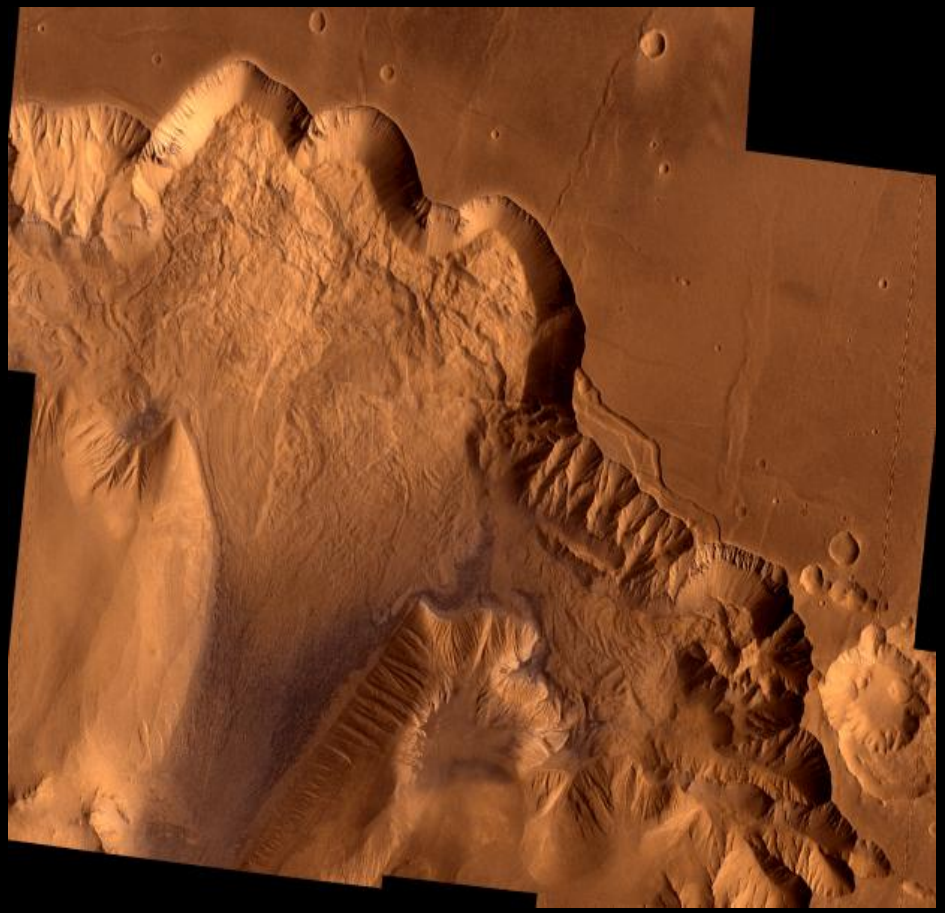



[Katterhorn and Prockter Nature Geoscience 2014]

# Valles Marineris vue par la mission Viking 1976

## Vue globale

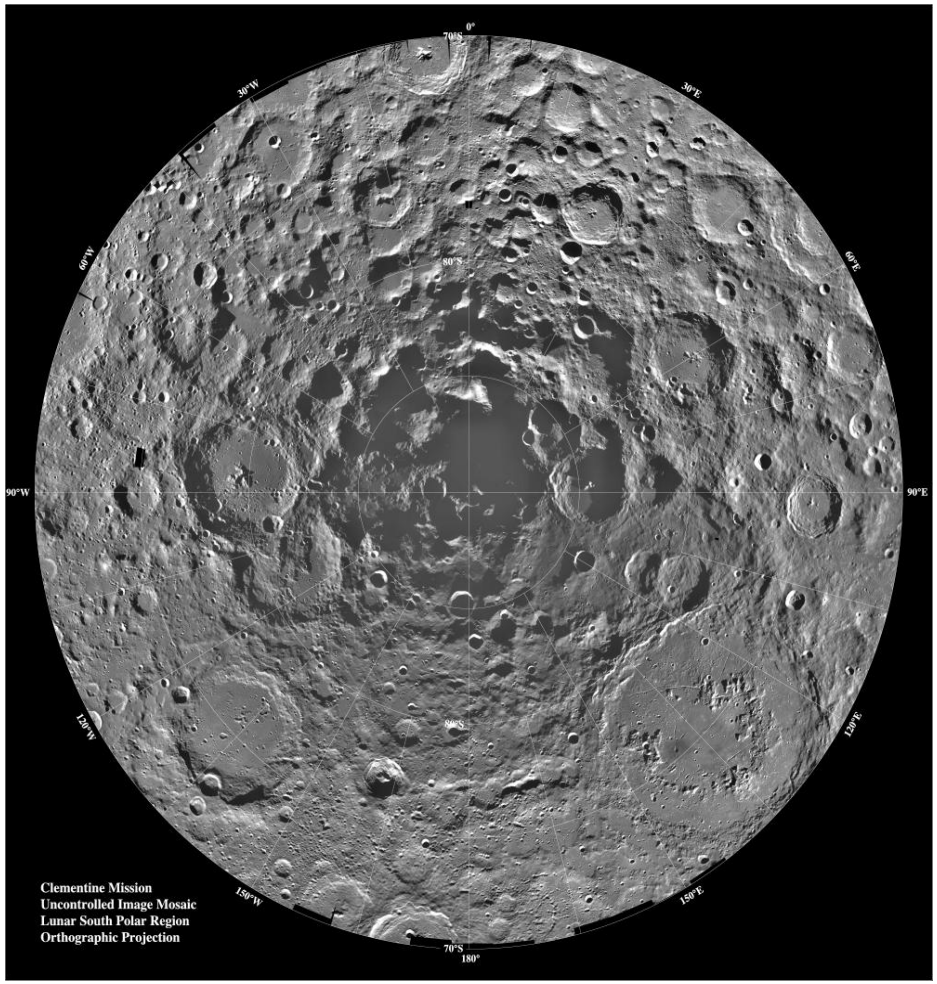
## Ophir Chasma



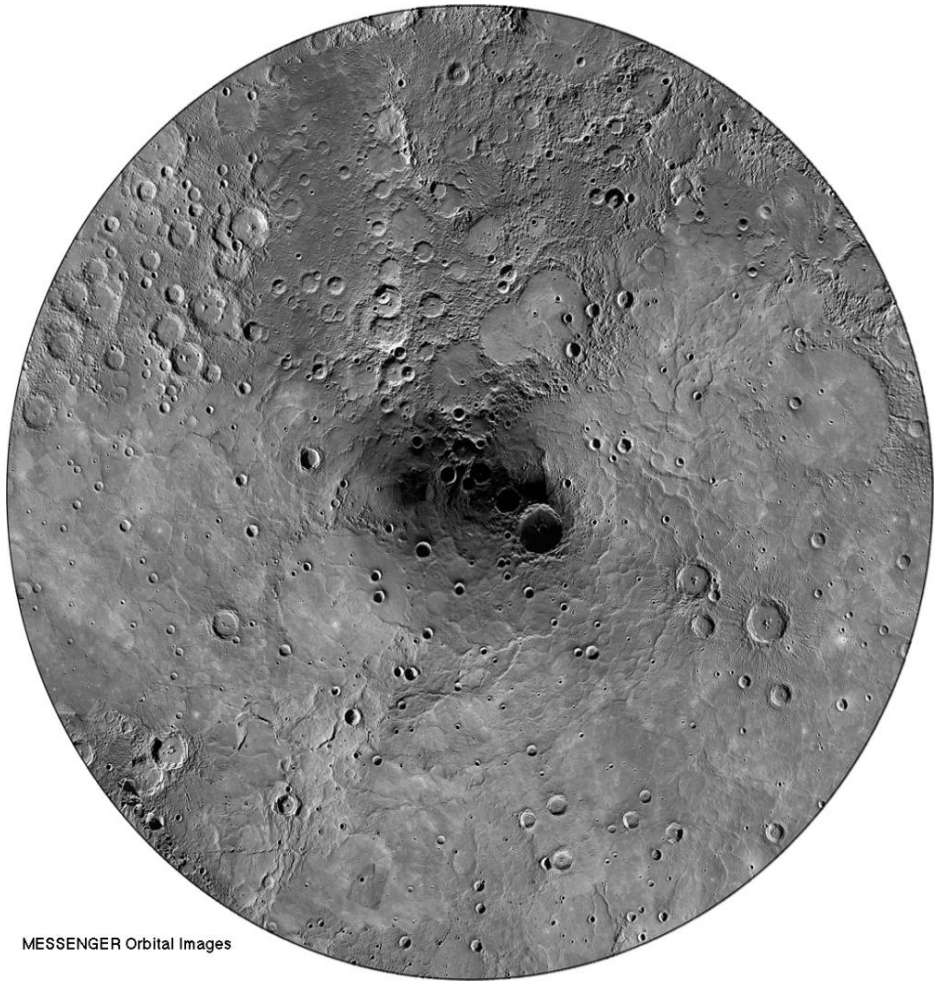
# Plan

# Water ice in permanently shadowed areas

## Moon's south pole



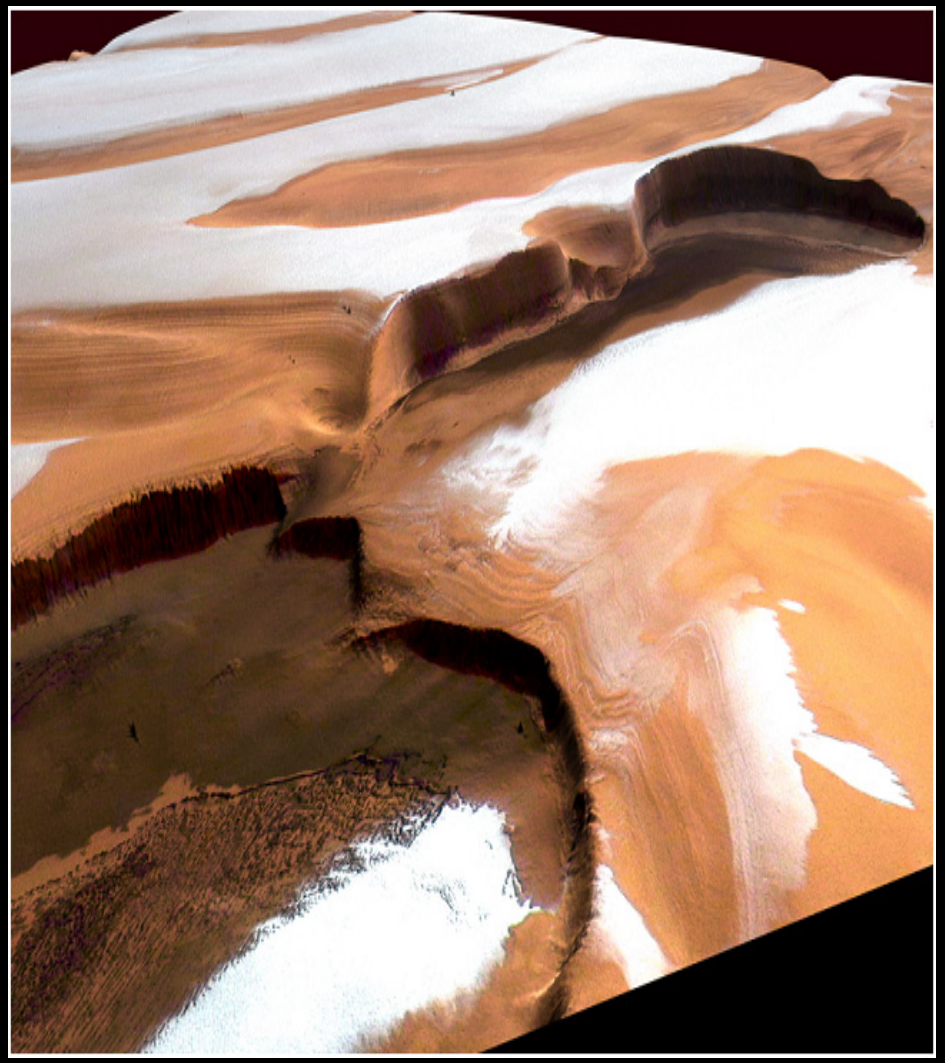

## Mercury's north pole




[PIA00001,PIA16950]

# Martian northern polar cap

[MGS/MOC visible image]



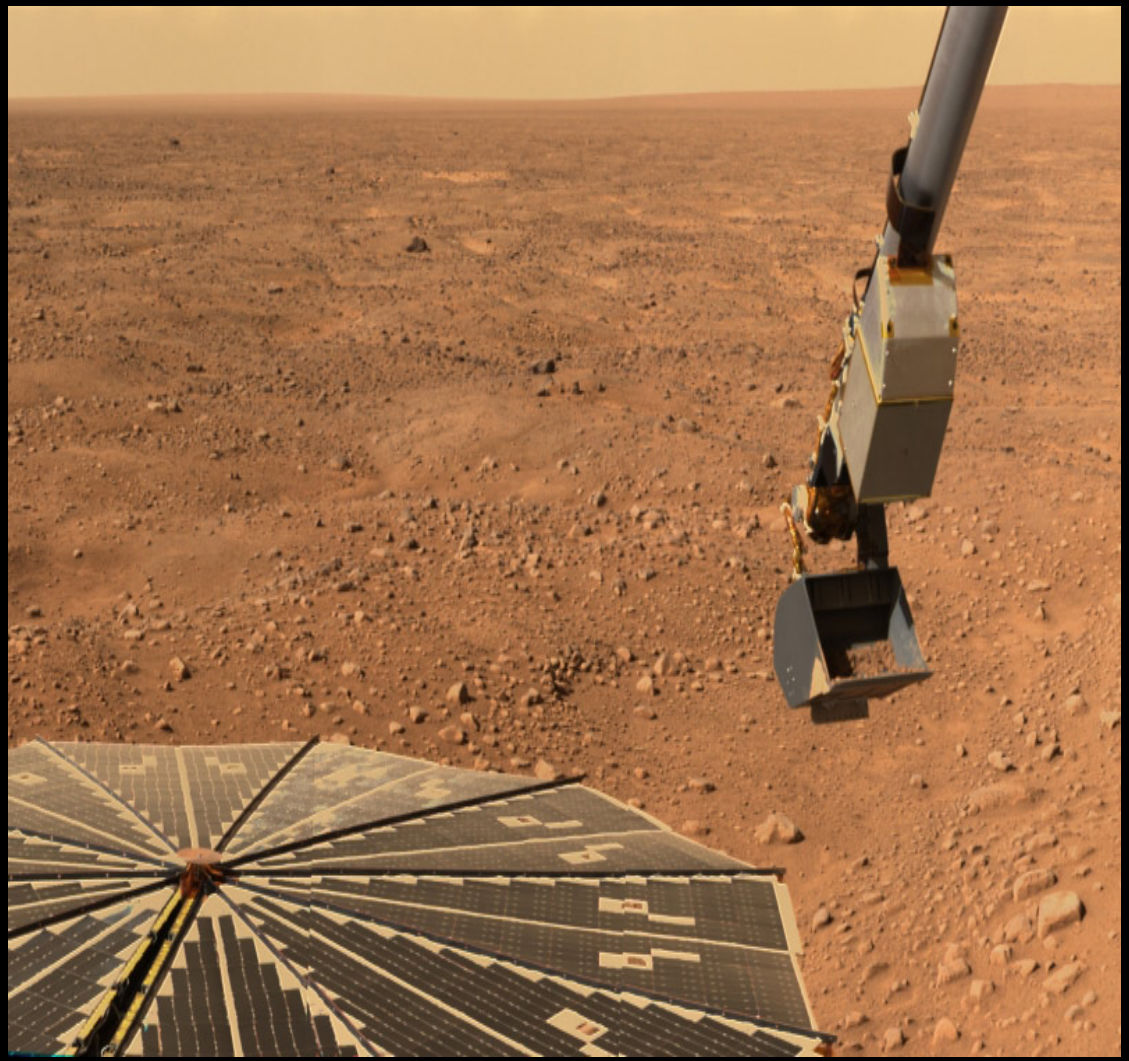
[HRSC visible image (3D-projected)]

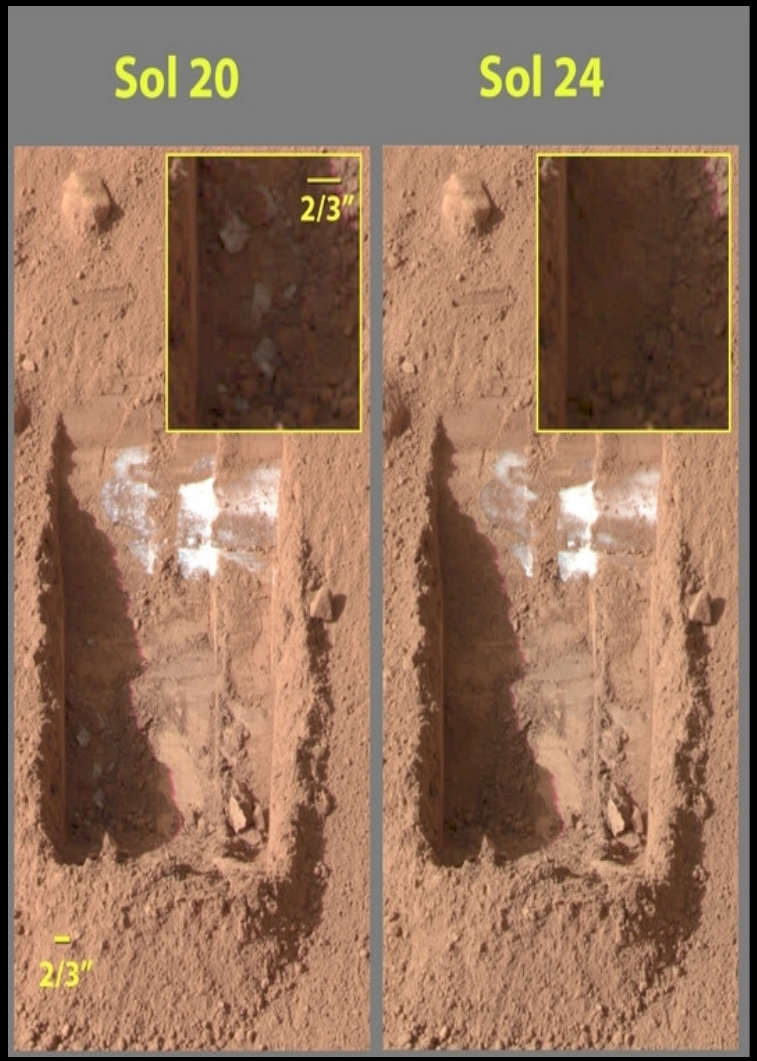
# Polygons in permafrost terrains

## Mars phoenix landing site

## Spitsbergen (Norway)

# Mission Phoenix sur Mars 2009

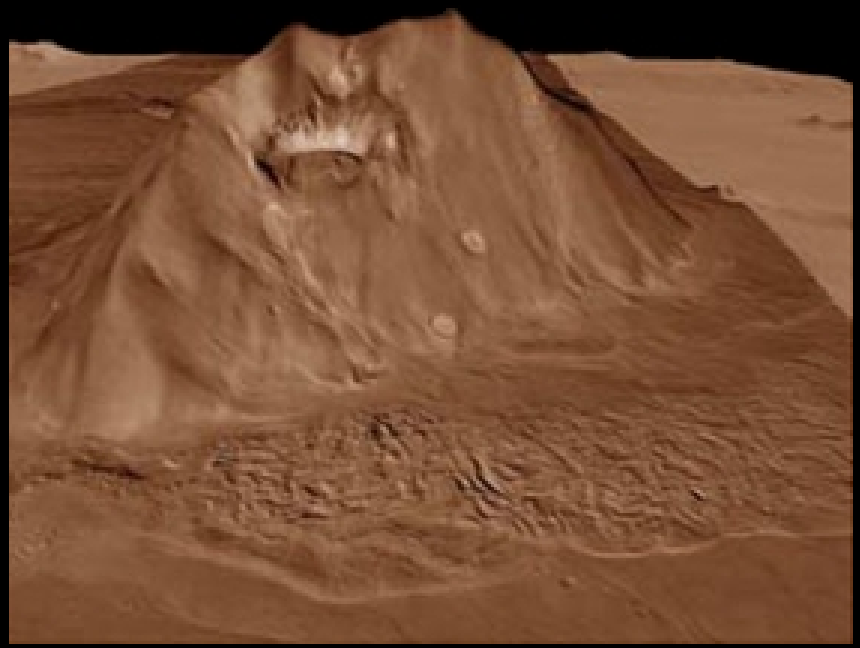




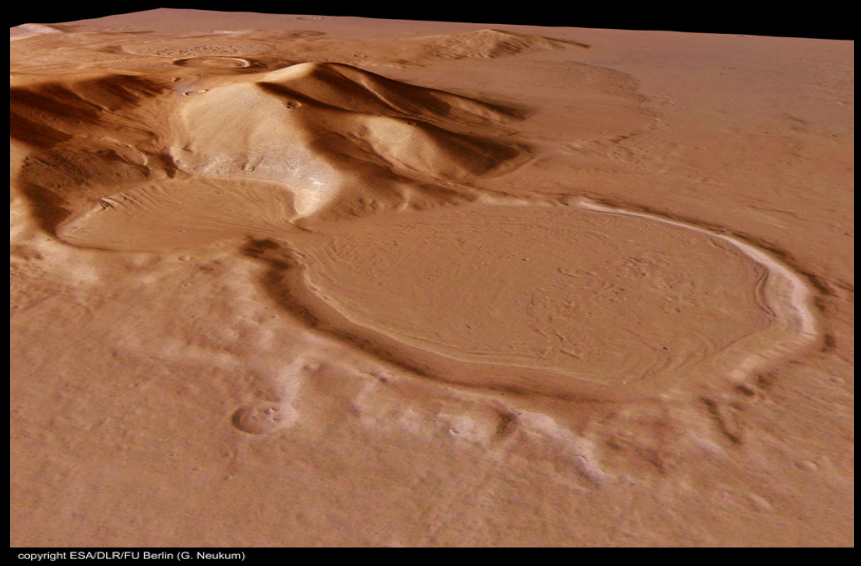
# Ice-related landforms east of Hellas, Mars

## Echoes other young features in Tharsis (Hecates Tholus)

Lobate Debris Apron ($15 \times 1.5$ km)



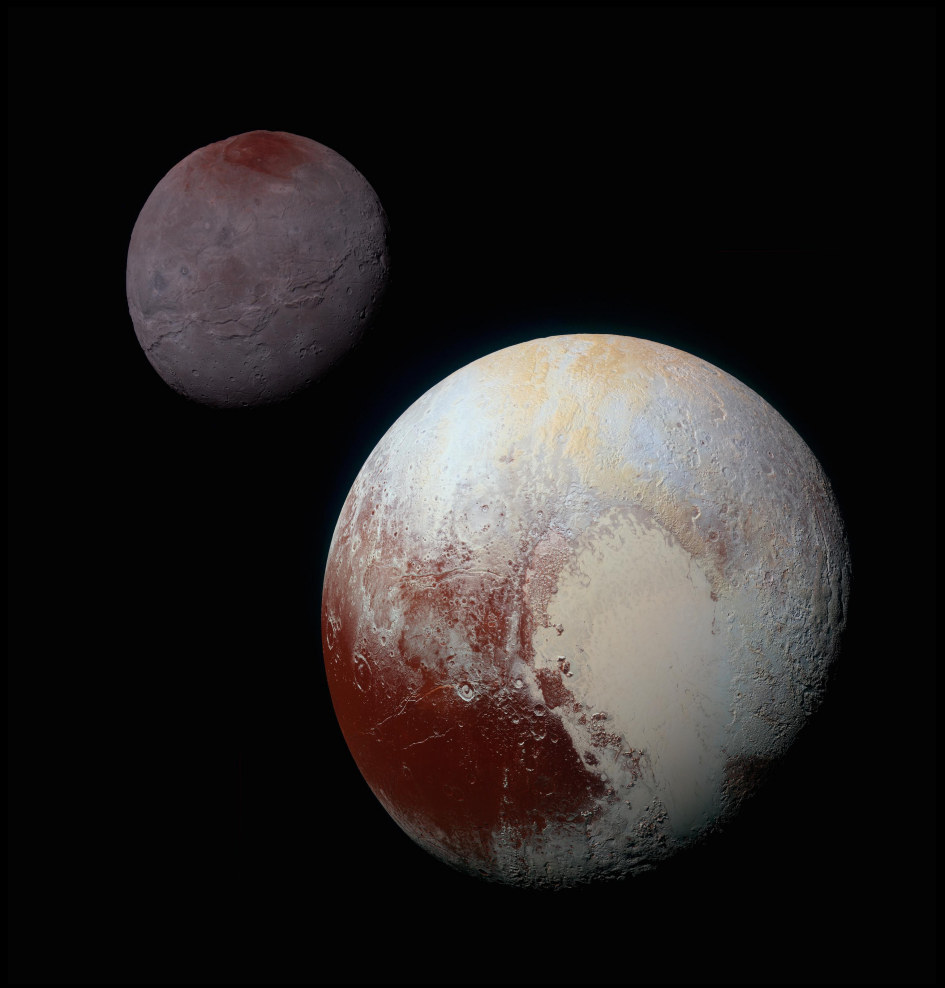
Rock glacier (crater 20 km wide)




[Caméra ESA Mars Express HRSC; Head et al. Nature 2005; Hauber et al. 2008]

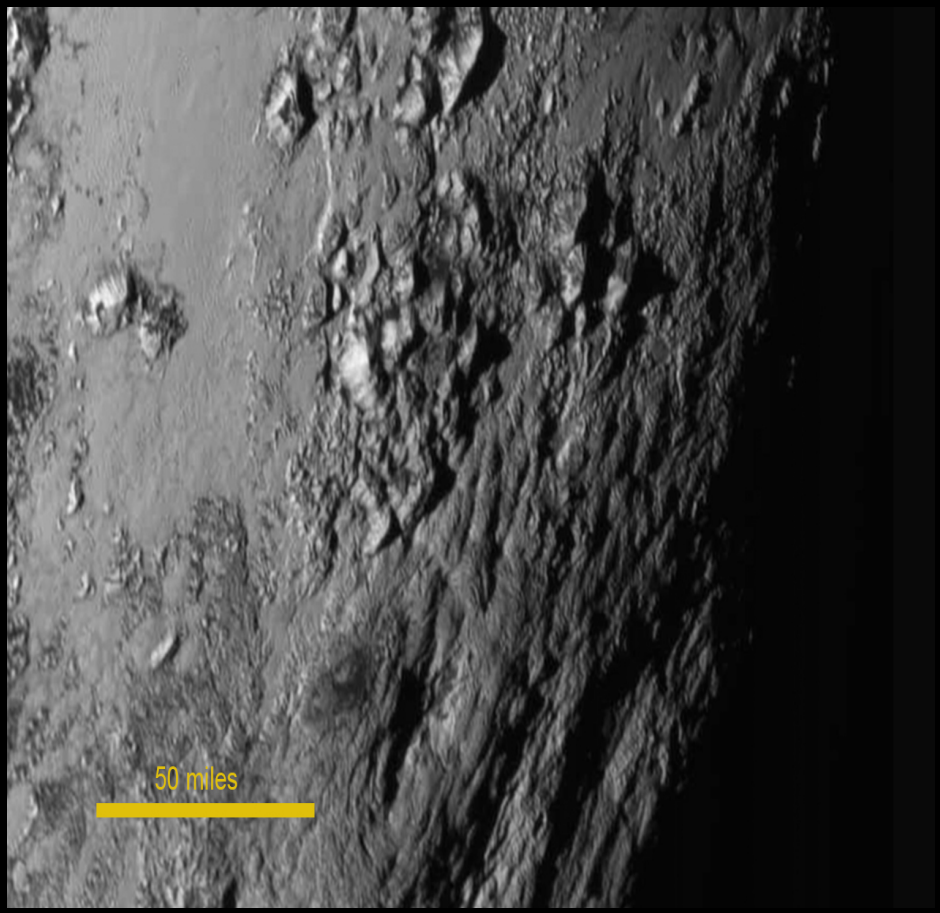
# Survol de Pluton+Charon par New Horizons

14 juillet 2015

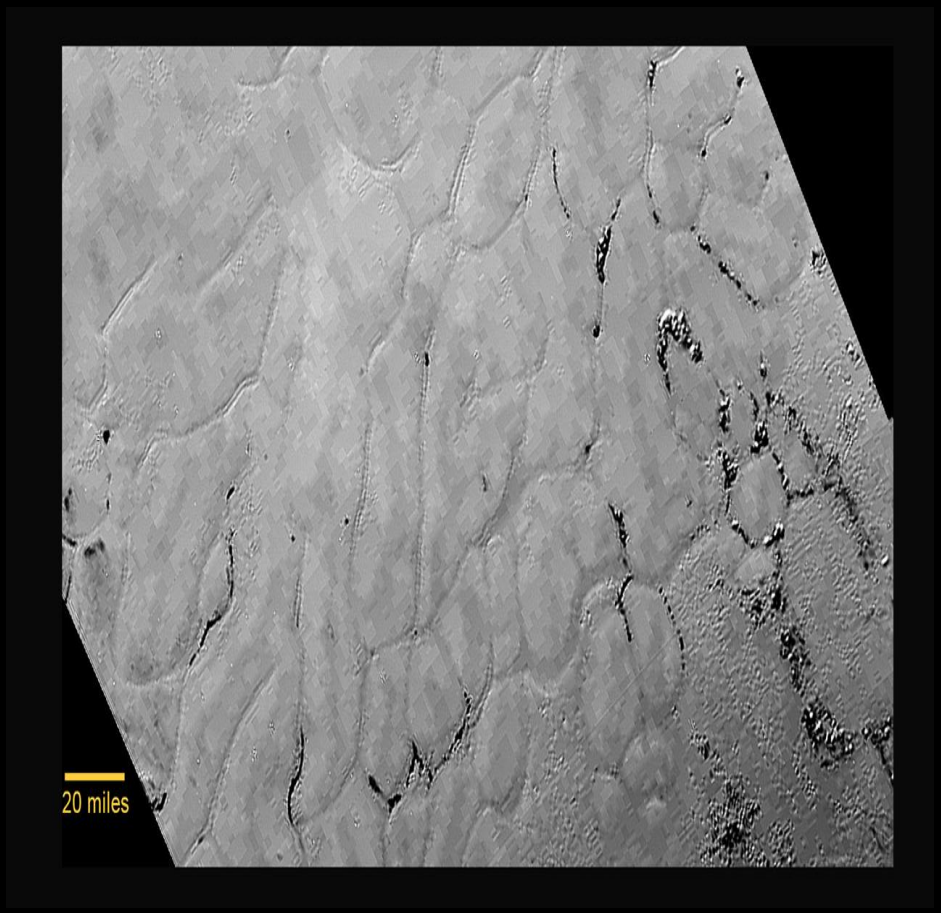



# Au coeur de Tombaugh Regio

## Montagnes glacées ($H_2O$)




## Glaciers Sputnik ($N_2$,CO)

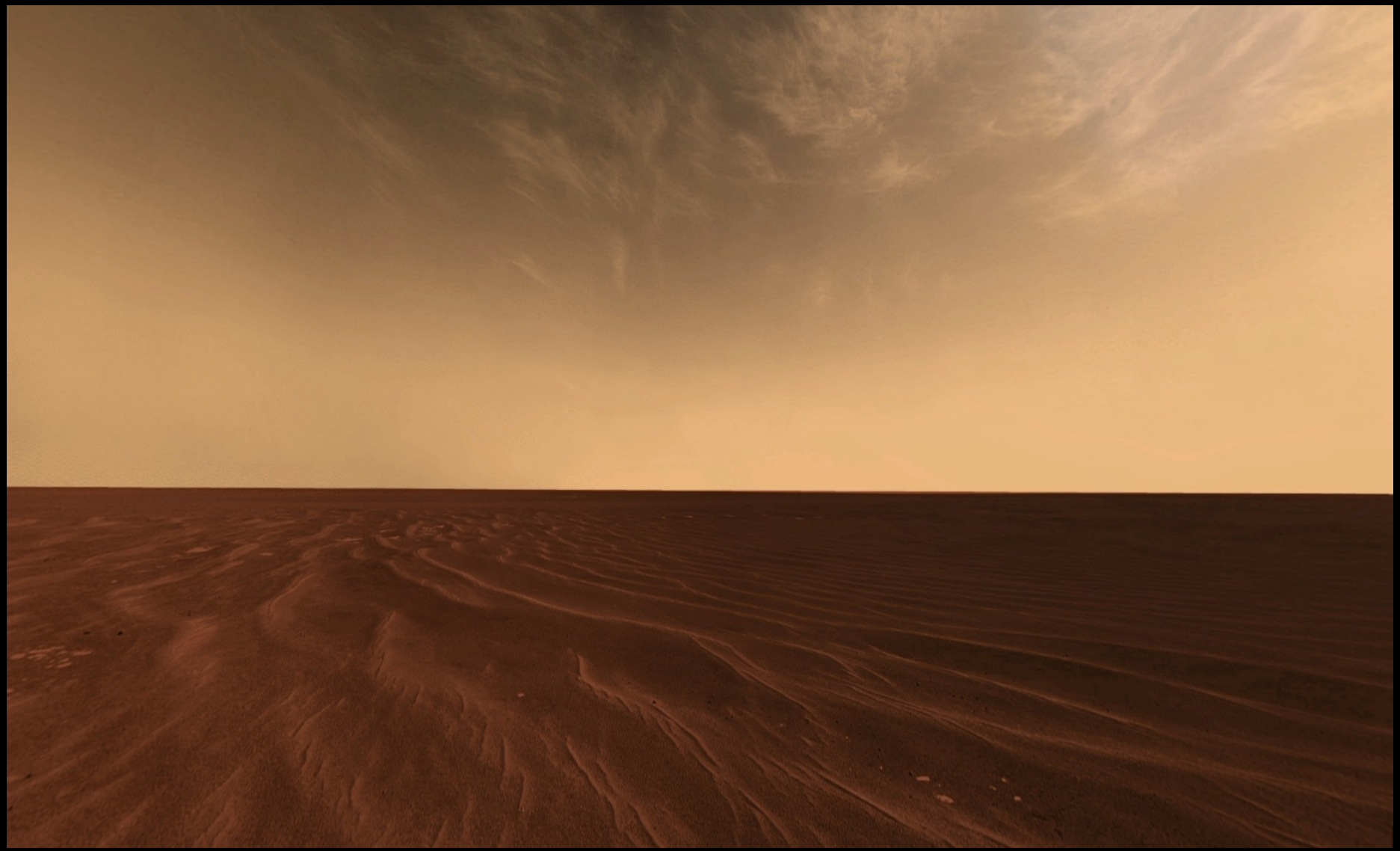



[Images New Horizons]

# Plan

# Plan

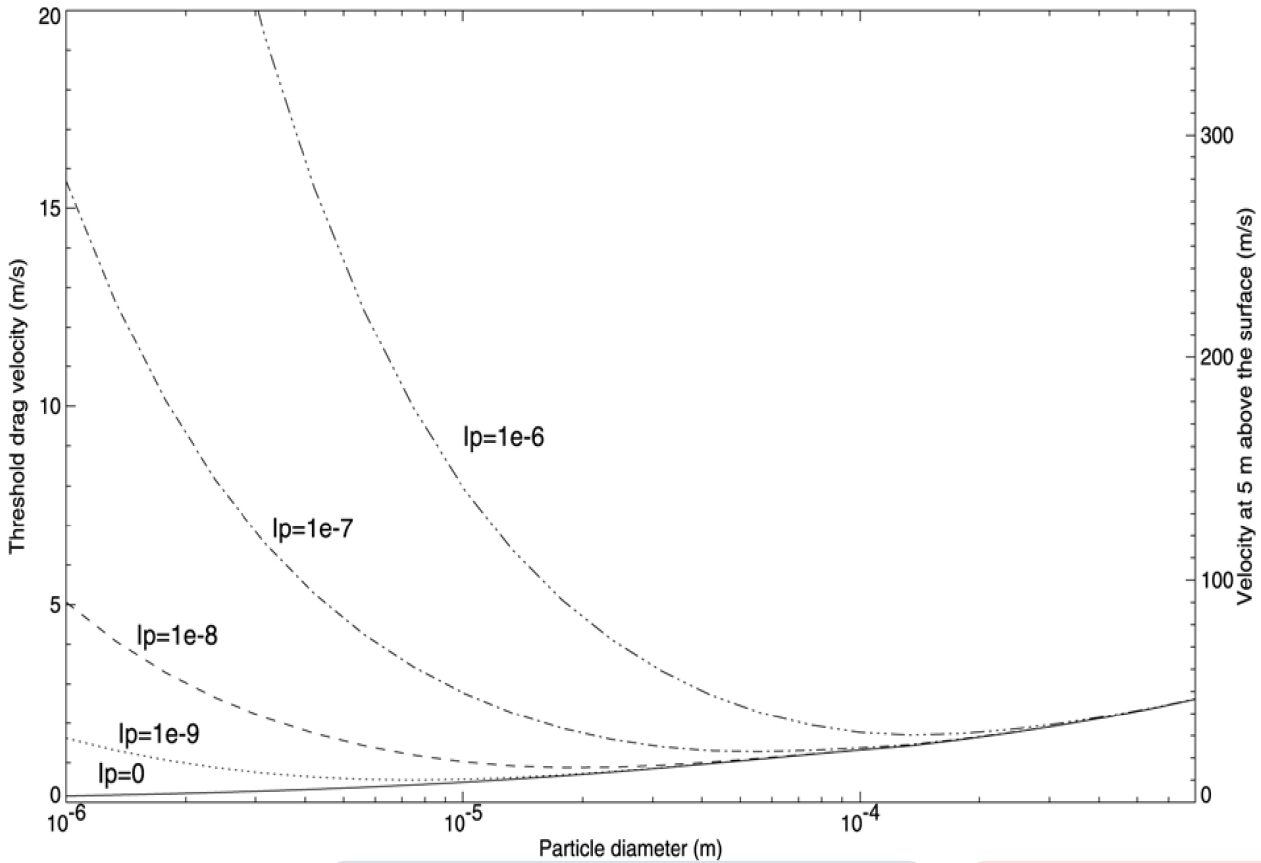
# The Martian environment



[Pancam on Opportunity Rover]

# Soulever des poussières dans une fine atmosphère ?

## Théorie et études soufflerie




Petites particules : Force de cohésion

Taille optimale $100\,\mu$m

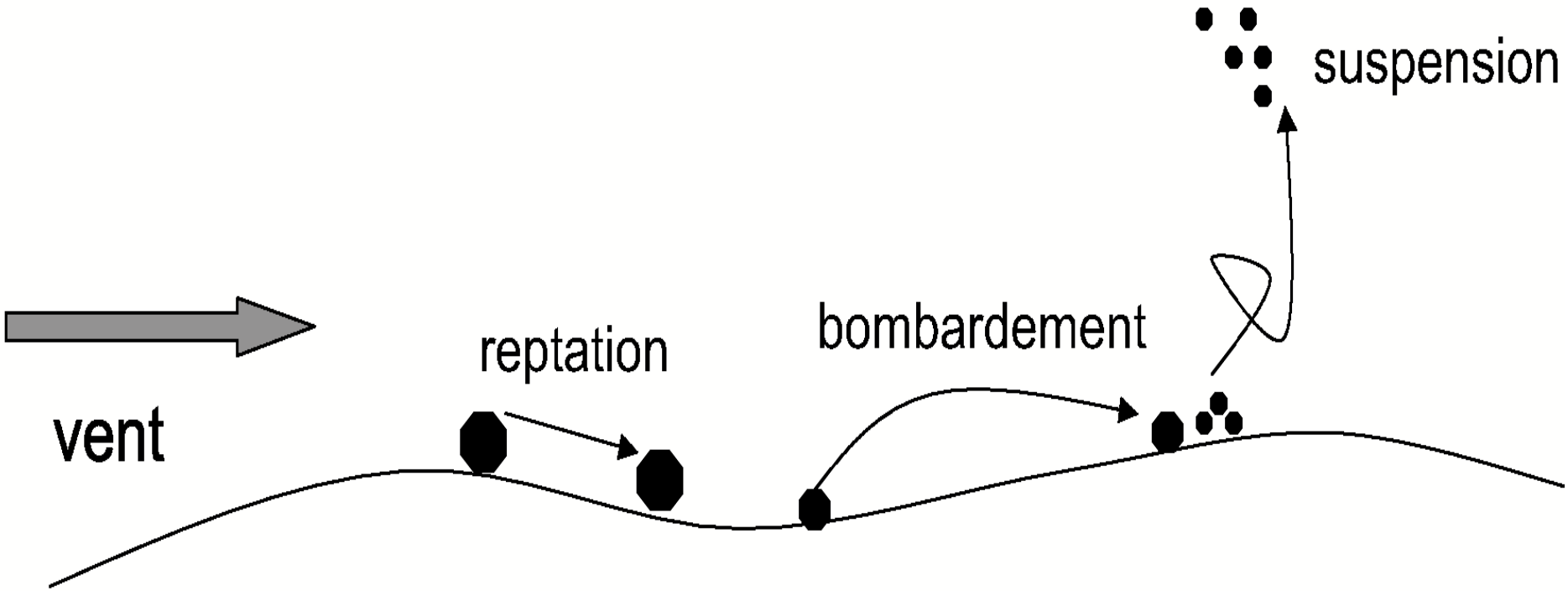
Grosses particules : Force de gravité

[figure from Newman et al. JGR 2002]

# Soulever des poussières dans une fine atmosphère

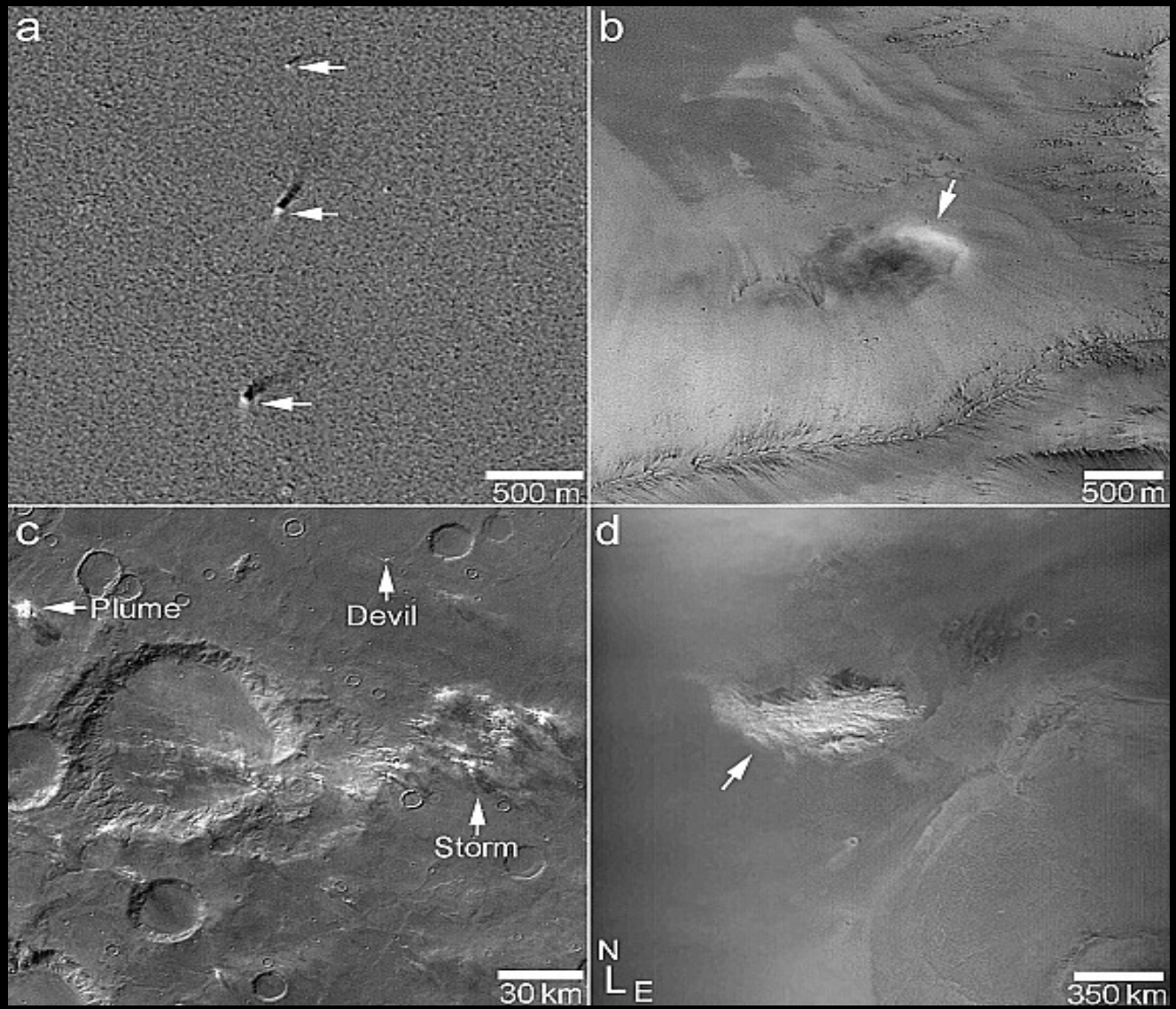
## Phénomène de saltation

Les poussières de $\sim 100\,\mu$m délogent les plus petites particules capables de rester en suspension dans l'atmosphère




[Boucher Springer book 2012]

# How to lift dust on Mars?

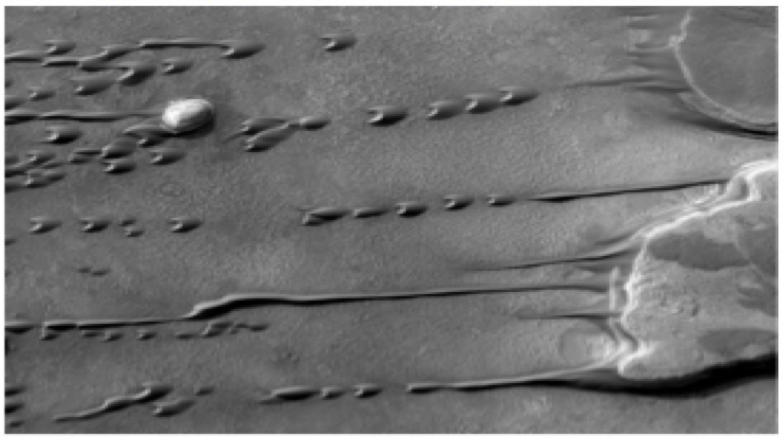


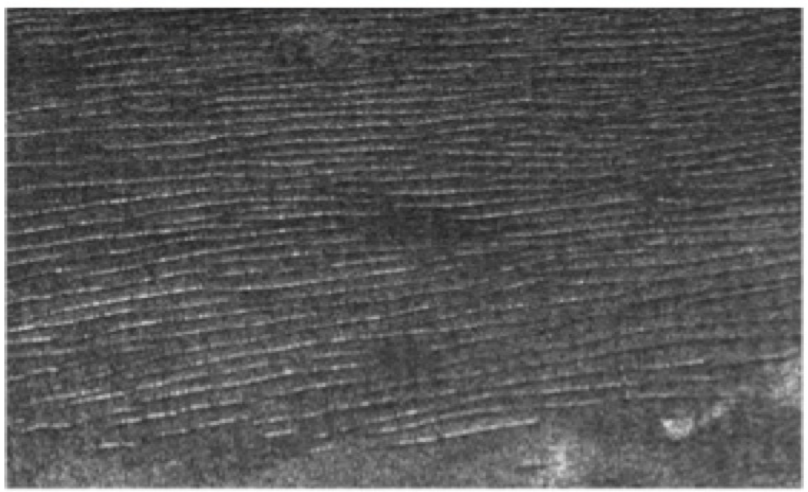

[Cantor et al. JGR 2006]

# Dunes planétaires

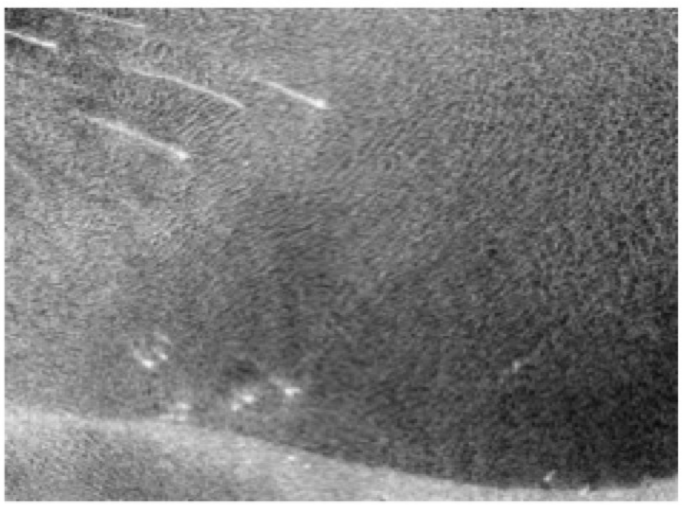
Dunes en étoile sur Terre (Algérie)

Dunes barkhanes sur Mars
(image de la caméra HiRISE/MRO)





Champ de dunes linéaires sur Titan
(image du RADAR de Cassini)



Champ de dunes transverses sur Vénus
(image du RADAR de Magellan)

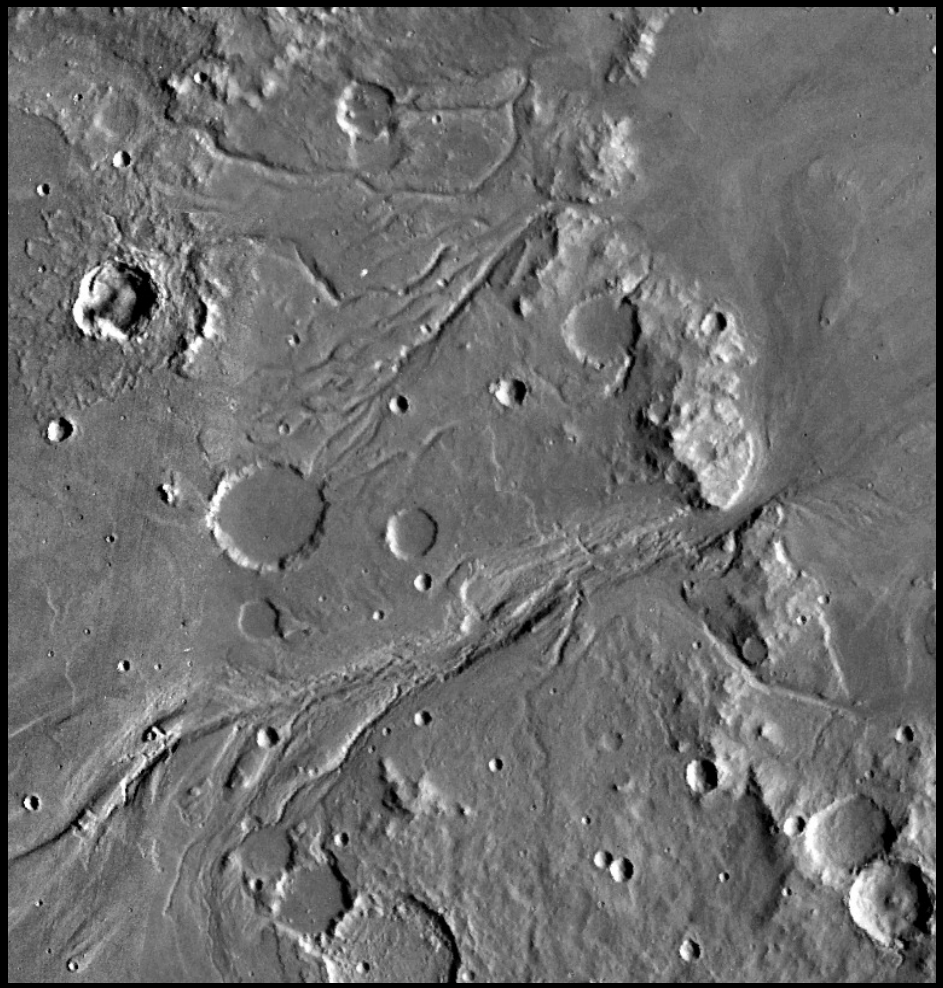
[Figure assemblée par Alice Le Gall]

# Plan

# Mars: structures fluviales

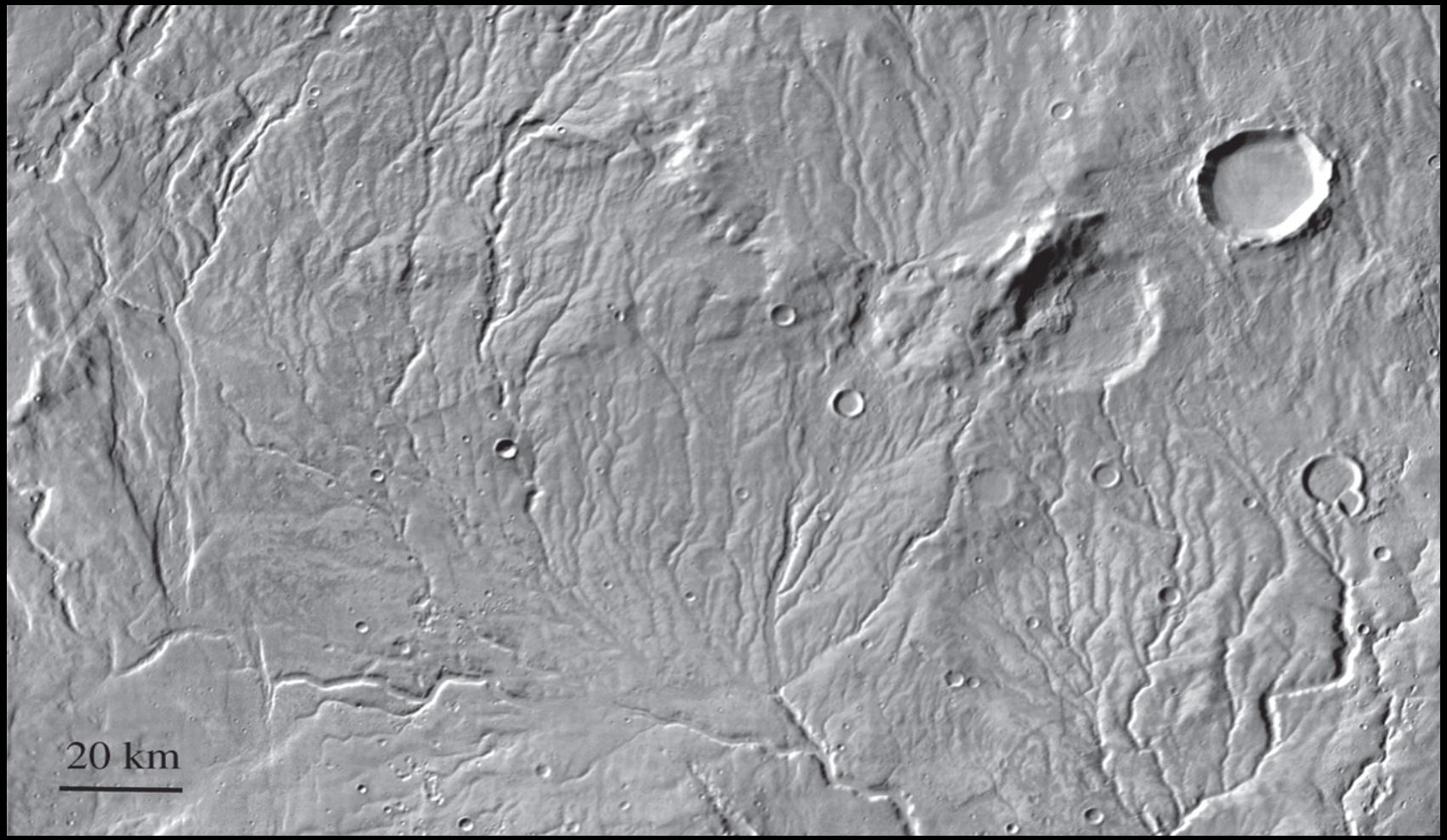
## Valley network, Parana Valles

## Outflow channel, Mariner 9



# Warrego Vallis: valley network

42S, 267E, one of the most densely dissected areas of the planet



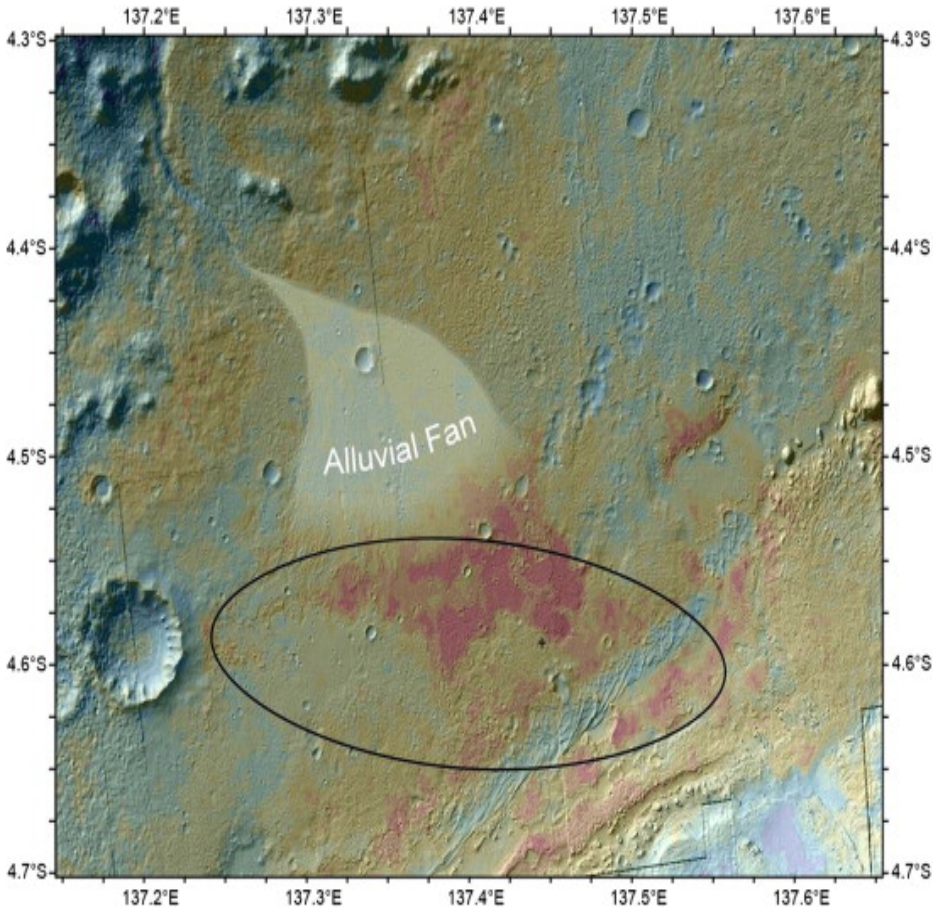

[Carr Phil. Trans. Roy. Soc. A 2012]

# Kasei Vallis: outflow channel

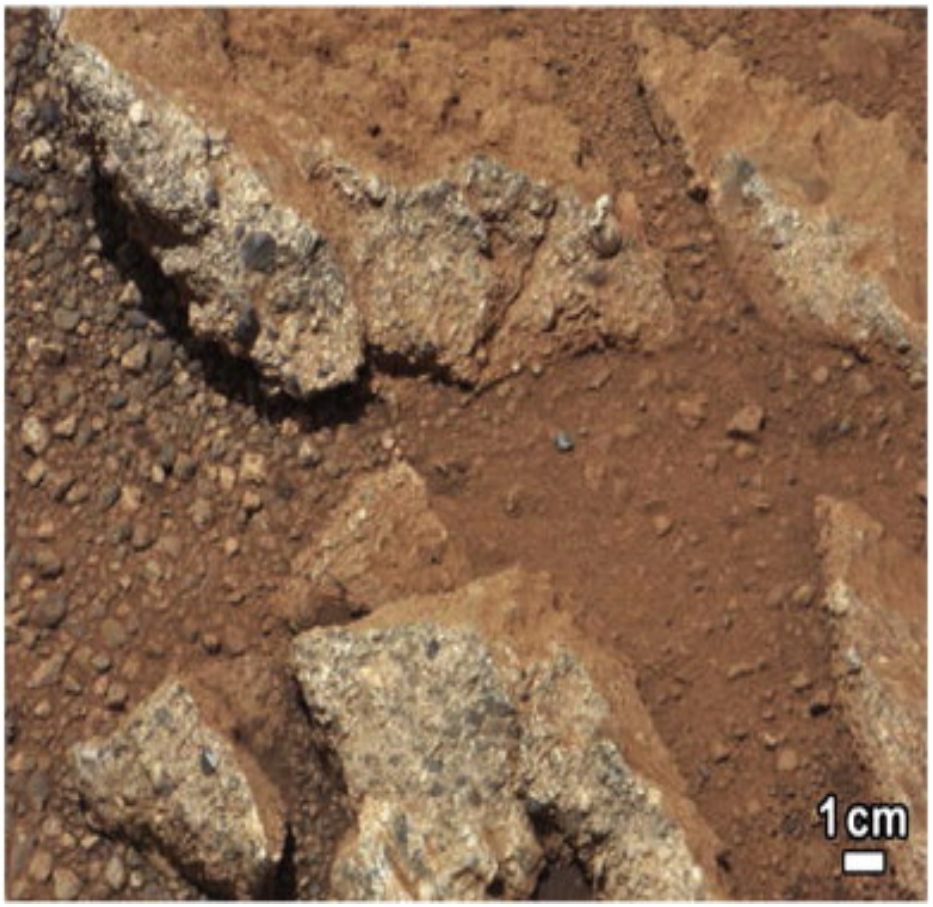

[Carr Phil. Trans. Roy. Soc. A 2012]

# Curiosity in fluvio-lacustrine Gale crater

## Context



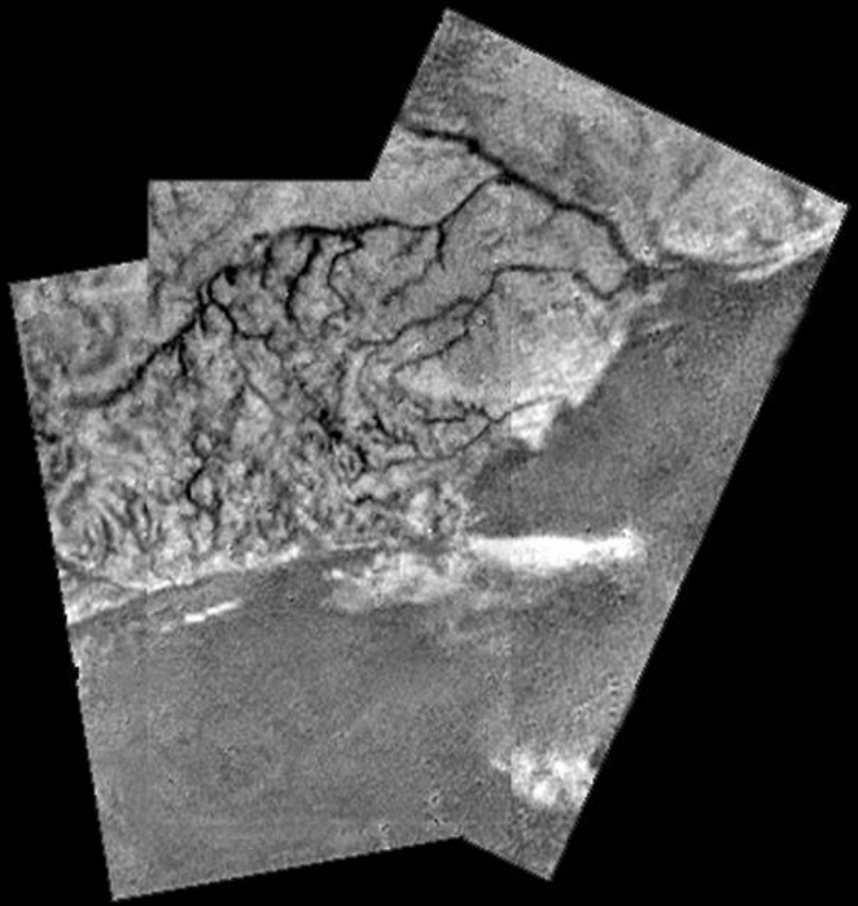

## Terrain Fluvial conglomerates



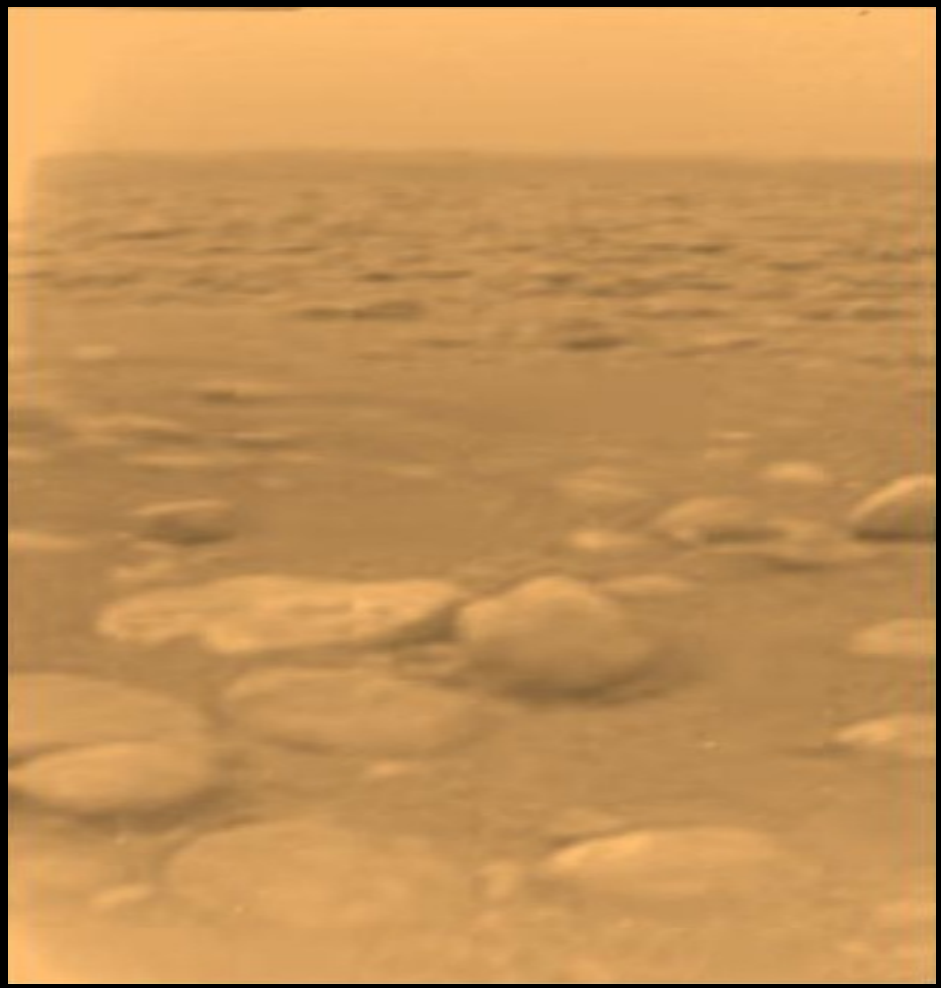

[Williams et al. Science 2013; Baker et al. Geomorphology 2015]

# Titan: imagerie DISR de la sonde Huygens

## Vallées fluviales (scène 15 km)

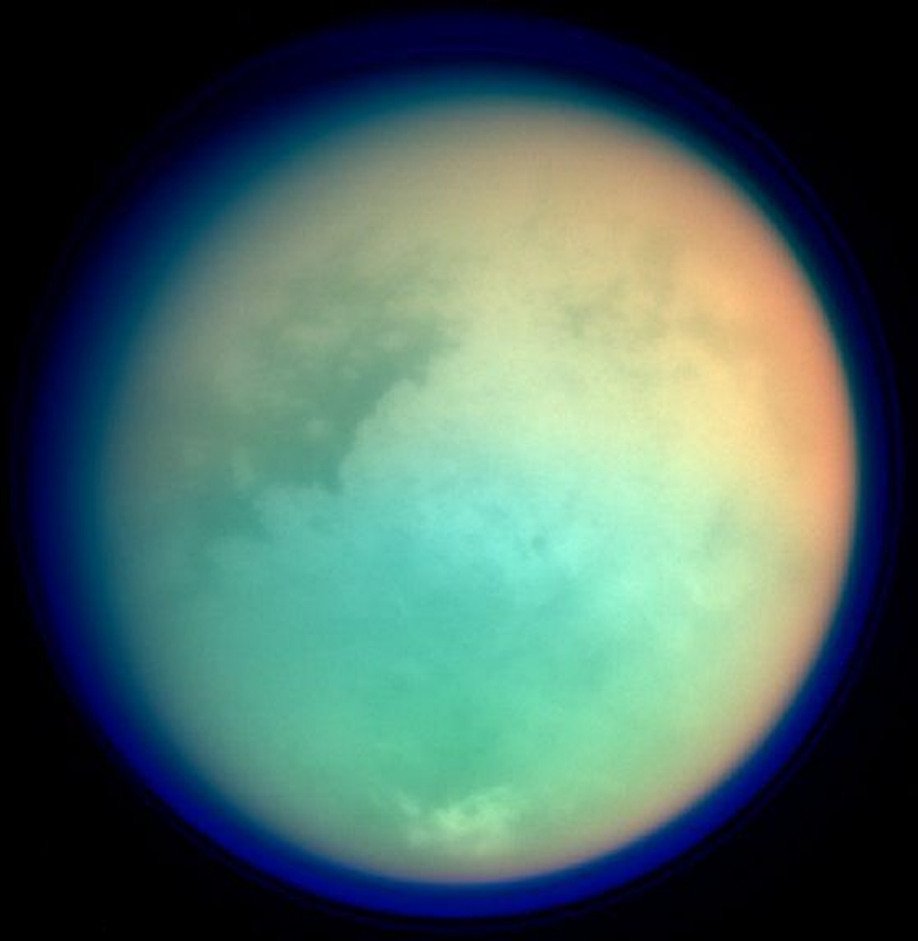


## Surface (galets 5-10 cm)

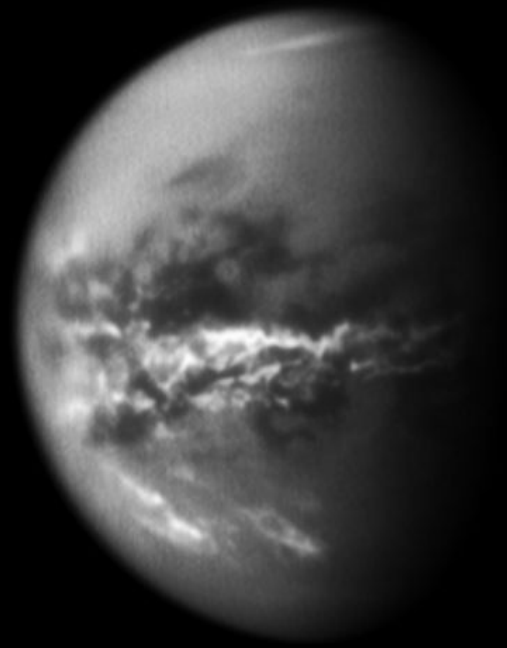


[gauche: PIA07236, droite: PIA07232]

# Sur Titan, nuages et cycle du méthane complet



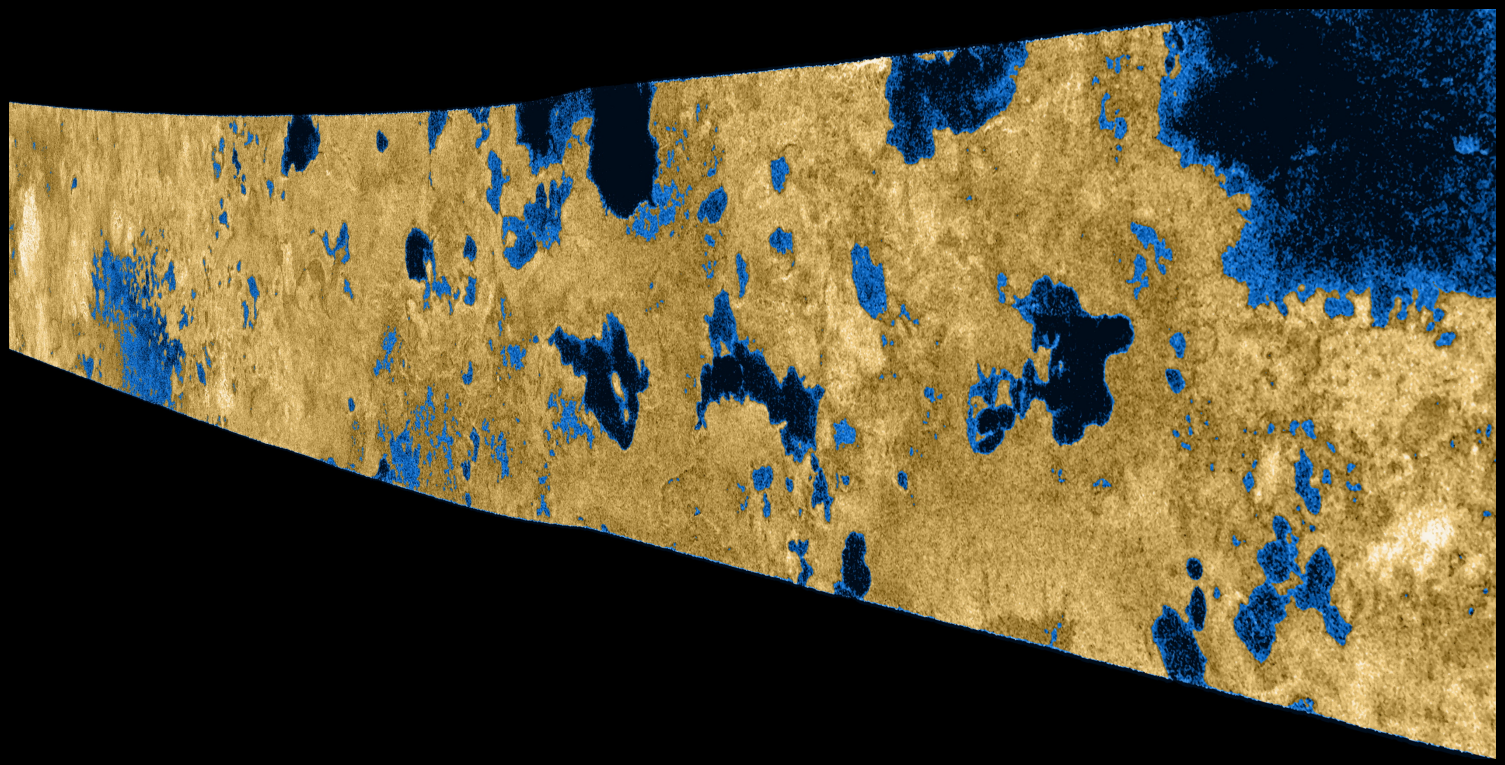
[Cassini-Huygens, 2004]



[Cassini-Huygens, 2010]

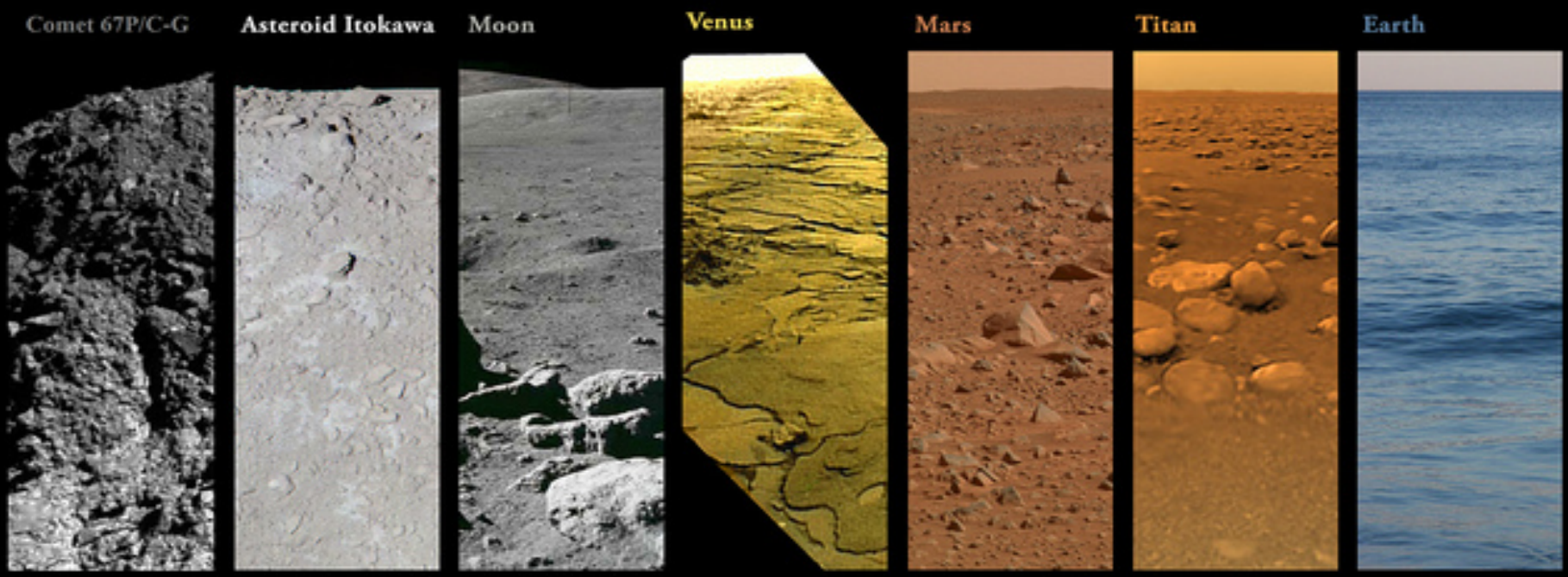
# Des lacs d'hydrocarbures sur Titan

Image radar Cassini. Les lacs sont sombres car rétrodiffusion limitée



[référence PIA09102]

# Distant Horizons - Different Surfaces

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Moon [Apollo 17]: NASA
Venus [Venera 14]: IKI / Don Mitchell / Ted Stryk / Mike Malaska
Mars [Mars Exploration Rover Spirit]: NASA / JPL / Cornell / Mike Malaska
Titan [Cassini Huygens]: ESA / NASA / JPL / University of Arizona
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