Rocky Planets
Interiors and surface geophysics

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G. Vladilo

Experimental techniques to investigate the interiors of Solar System planets

- Mean density
  - Models of internal structure and chemical composition
  - Equation of state (EOS)
- Gravimetric measurements
  - Internal mass distribution
- Magnetic field
  - Distribution and dynamics of conductive material
    - Existence of a metal core in liquid phase

Differentiation of planetary interiors

Process of separation of internal planetary layers
that takes place as a result of the physical and chemical properties
of the material constituents of the layers

The process of planetary differentiation has occurred on
planets, dwarf planets, the asteroid 4 Vesta,
and natural satellites (such as the Moon)

If the body is sufficiently small there is no differentiation

The existence of differentiation
can be used to distinguish major bodies from minor bodies

Differentiation of planetary interiors

- Physical processes
  - The temperature and pressure gradients of planetary interiors drive processes of stratification based on the mean density and the melting point of the materials

The most abundant chemical elements or compounds drive the physical processes of differentiation

The most abundant, high-density chemical elements or compounds, tend to accumulate in a central core

Typically, the core is iron-rich

If the internal temperature is sufficiently high, the core can be melted

The most abundant, low-density chemical elements or compounds lie in external layers (the mantle)

Typically, the mantle is silicate-rich

Depending on temperature and pressure, the mantle can be melted or not

Differentiation of planetary interiors

- Chemical processes
  - Processes of separation of chemical elements or compounds take also place as a result of *chemical affinities*, rather than physical properties
  - Also called processes of <u>fractionation</u>

    The <u>chemical elements or compounds with low abundance</u> are differentiated according to their affinity with the most abundant ones (e.g. iron or silicates), rather than according to their specific weight

    Example: uranium, despite its high specific weight, has affinity with silicates and is found in the mantle rather than in the core

Planetary magnetic fields

- Rocky bodies with magnetic field at the present time
  - Terrestrial planets

    Earth, Mercury

  - Satellites

    Ganymede

- Rocky bodies that presumably had a magnetic field in the past
  - Terrestrial planets

    Mars, Venus (maybe)

  - Satellites

    Moon (maybe)

Magnetic fields of rocky planets

Russel & Dougherty 2010

- Magnetic fields of rocky planets are weak or absent
  - Earth's magnetic dipole moment is the strongest one

Magnetic dipole moment

Mercury

$2\text{-}6 \times 10^{12}$ T m^3

Venus

$< 10^{11}$ T m^3

Earth

$\sim 8 \times 10^{15}$ T m^3

Mars

$< 10^{12}$ T m^3

The magnetic dipole moment is measured in Weber m = Tesla m^3

1 Weber = 1 V x 1 s

A change in flux of one Weber/s will induce an electromotive force of 1 Volt

Magnetic field of the Earth

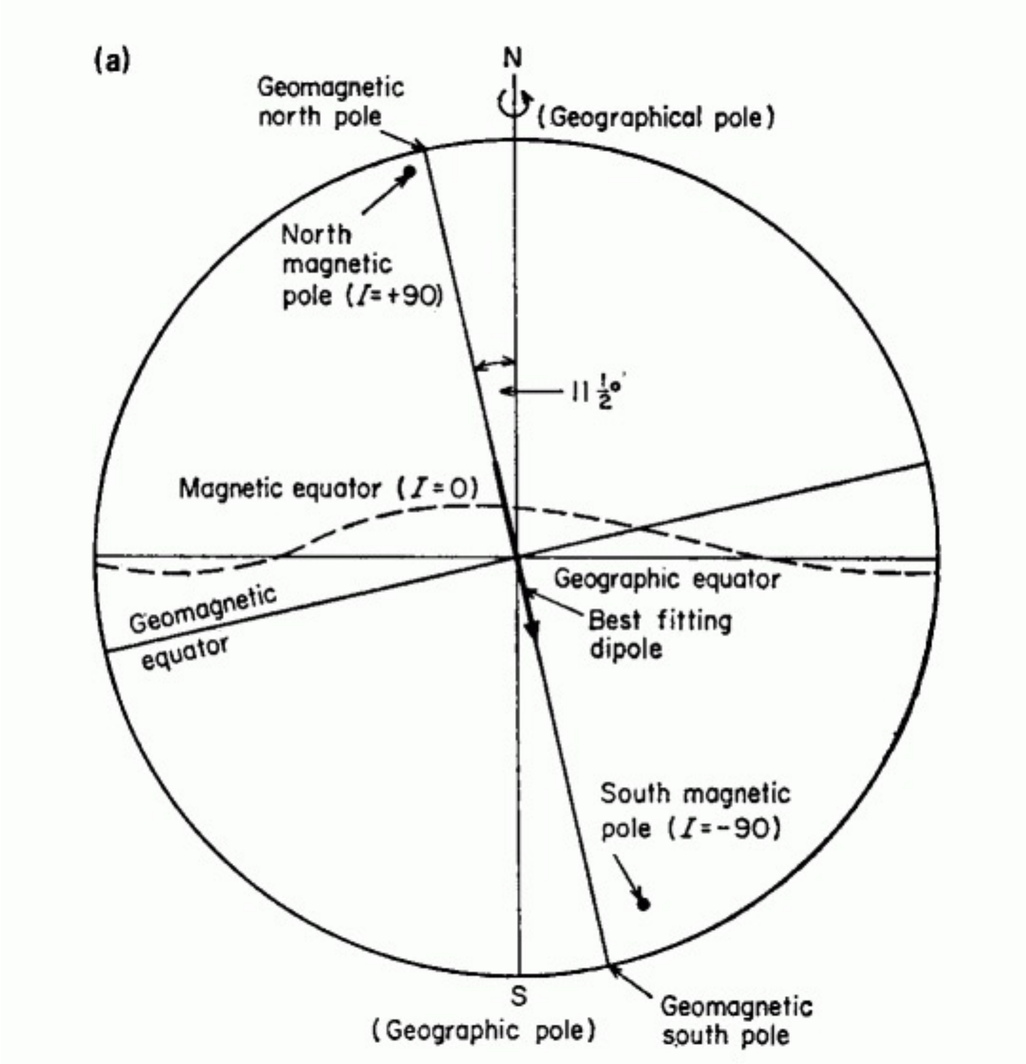
Earth

$M \sim 8\text{x}10^{15}$ T m^3

Currently there is a tilt of ~ 10° with the rotation axis

The tilt gradually changes

Polarity inverts suddenly



Origin of planetary magnetic fields

- Magnetic fields are believed to originate via the dynamo mechanism
- The dynamo mechanism requires the following ingredients
  - Convection of conductive material in liquid state in internal layers with sufficiently large radial extension
  - The convection must be coupled with rotation (Coriolis forces)

  The modelization of this mechanism is extremely difficult

- The fact that Earth's magnetic dipole moment is the strongest one among rocky planets of the Solar System supports the existence of significant amount a liquid, conductive material in the Earth's (outer) core

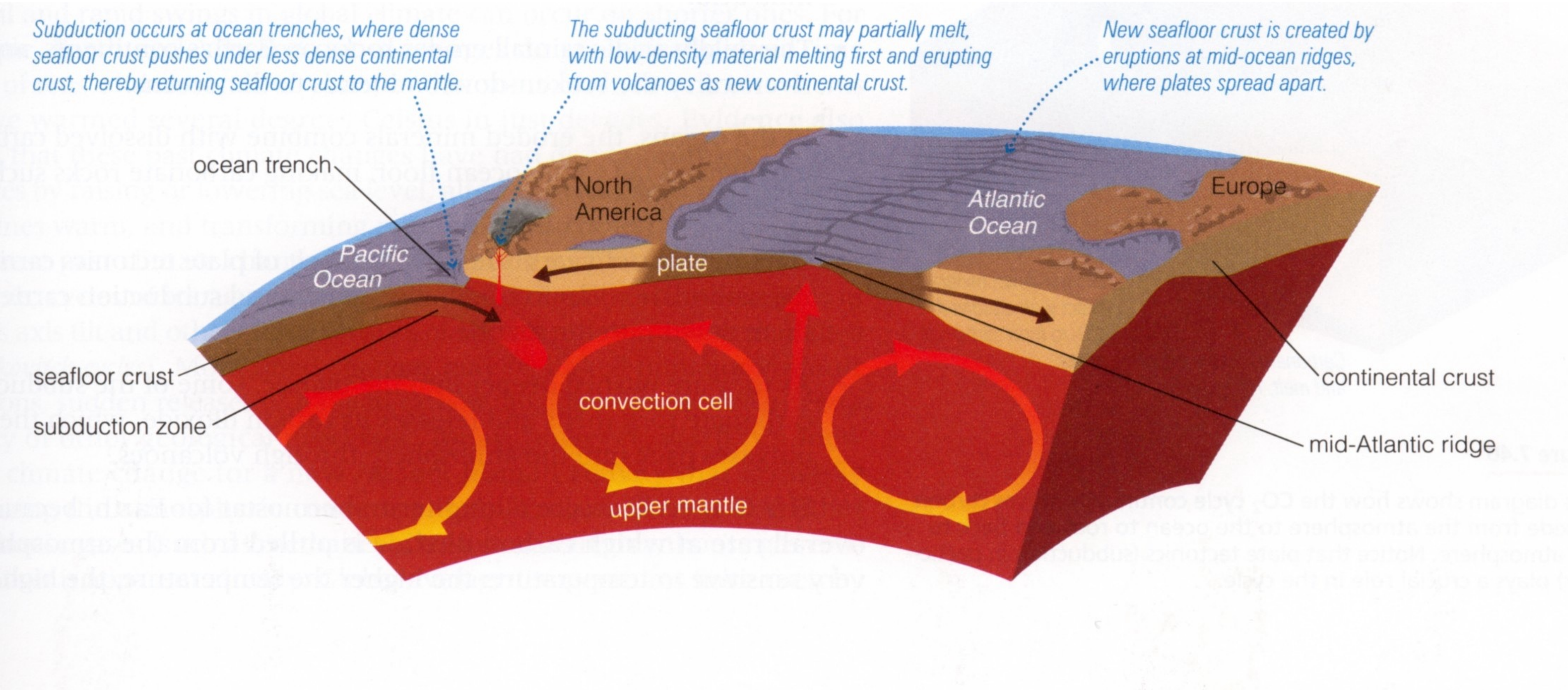
- Planets/satellites may also have induced magnetic fields
  - Interiors of conductive material under the influence of an external magnetic field

Surfaces of rocky planets

- Factors that affect surface properties
  - Geophysical activity
    - Volcanic and tectonic phenomena
      - Tend to recycle oldest portions of the crust
  - Planets with atmosphere
    - Chemical reactions with atmospheric compounds — agenti atmosferici
    - Physical atmospheric processes (e.g. erosion due to wind, weathering)
      - Gradually erode surface features (for instance, impact craters resulting from meteoritic collisions)
      - The atmosphere absorbs high energy particles from space and slows down and alters meteorites/micrometeorites
  - Planets with rarified atmosphere
    - *Space weather*: surface processing induced by high energy particles from the solar wind and galactic cosmic rays
    - For charged particles the effect is stronger if the planets lacks a magnetosphere

Rocky planets with geological activity

- Planets with geological activity
  - The Earth is the only planet in the Solar System showing signs of <u>continuous</u> geological activity up to the present time
  - The activity include tectonic movements and volcanism



Rocky planets with geological activity

- Evidence of past geological activity
  - Mars

    Volcanic activity in the early phases after planetary formation
  - Venus

    Volcanic activity also in recent times, but without tectonics

- Internal energy sources for geological activity
  - Radiogenic heat (main source in the case of the Earth) and fossil heat of planetary formation
  - Planet size is believed to play an important role in the history of geological activity

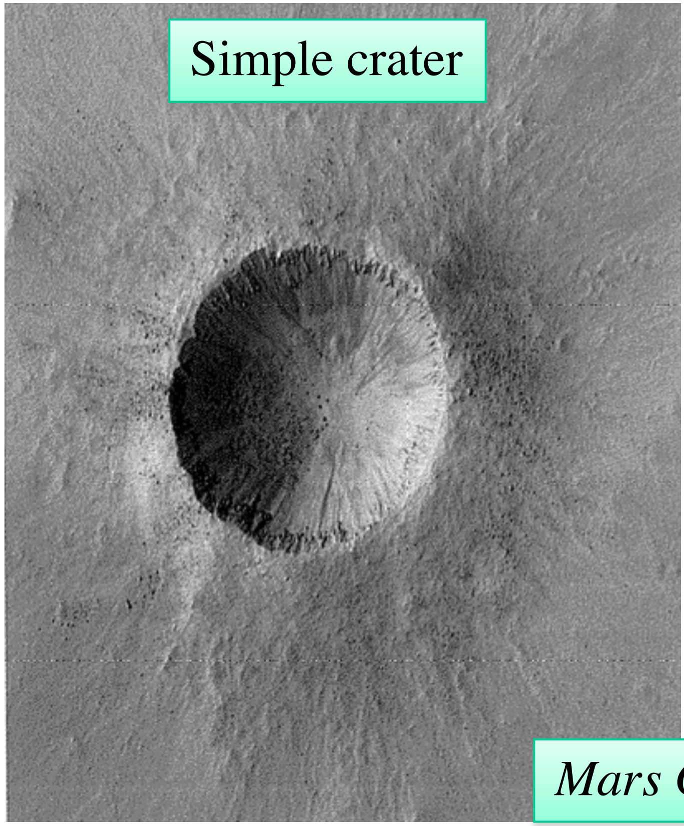
    If the size is small, the interior cools rapidly and is unable to keep its activity along geological time scales

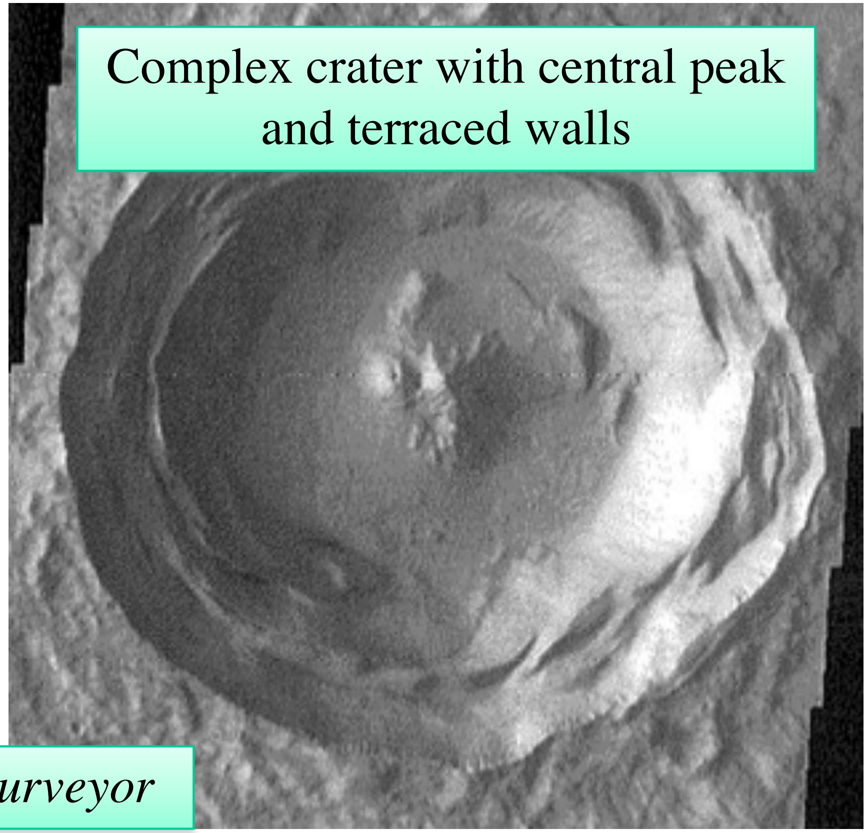
Impact craters

- Impact craters are formed as the result of a collision between a (fragment of) a minor body and the surface of a planet or satellite
- Importance of impact craters
  - The statistics of collisions at different epochs and locations casts light on the dynamical history of the Solar System
  - The morphology of craters casts light on the history of atmospheric and geophysical processes of the surface
  - The ejected material yields information on the underground layers of the planet

Crater shapes

The shapes and depths are correlated with the diameter
The exact dependence is determined by the gravity and the atmospheric properties
With increasing diameter, a transition occurs between simple and complex shapes





Mars Global Surveyor

Impact craters

- On Earth
  - The craters are eroded by atmospheric weathering and, in the long term, are reprocessed by tectonic activity; most craters are relatively young

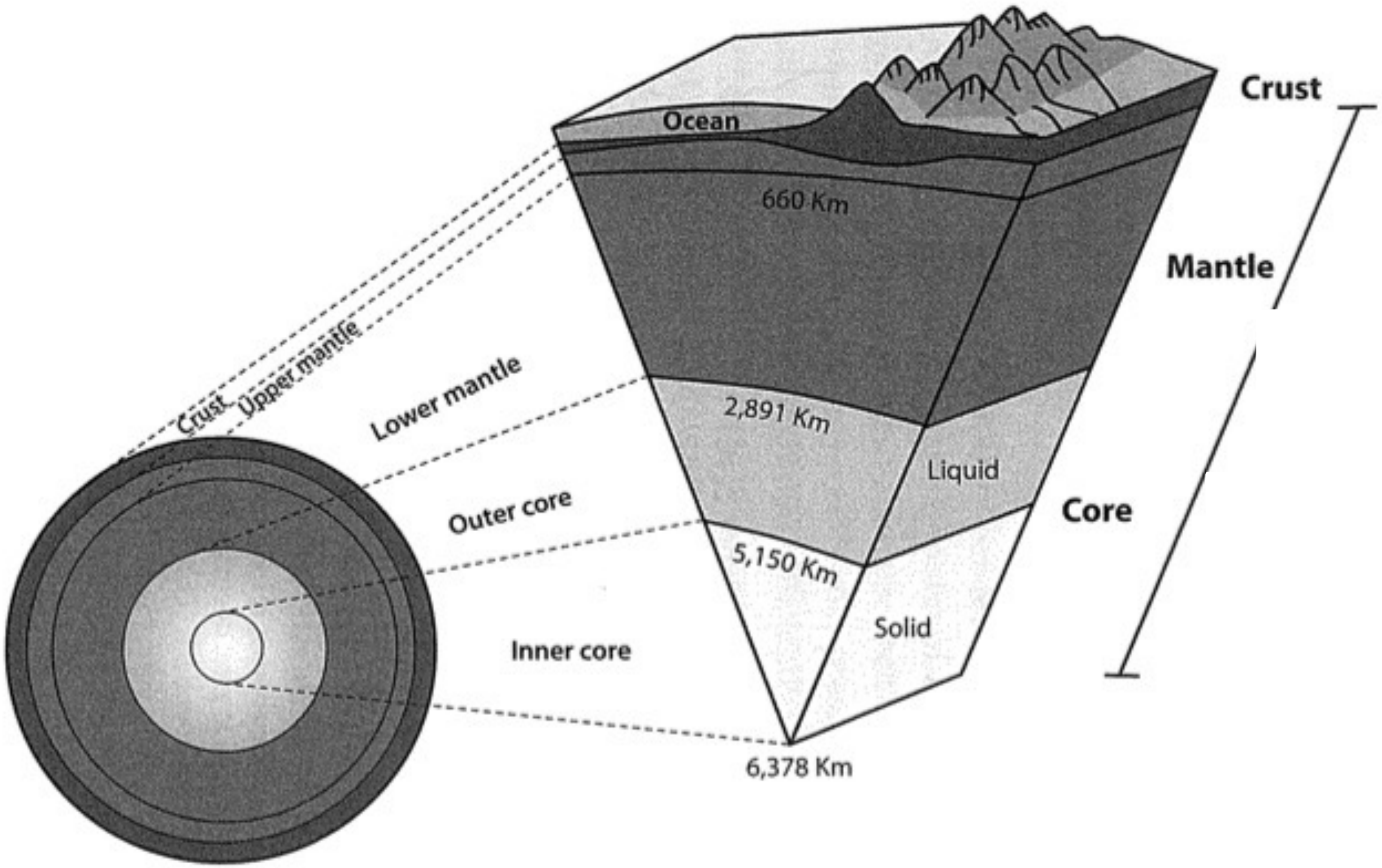
Meteor Crater, Arizona

- Impact craters are common on rocky planets without tectonic activity
  - Impact craters that persist for a long time without weathering or reprocessing can be degraded by subsequent collisions
  - If the atmosphere is absent, impact craters can be "weathered" by the solar wind and/or galactic cosmic rays, especially if the planet lacks a magnetic field

Internal structure and surface geophysics of Mercury, Venus, and Mars

Internal structure of the Earth

Reference for the other rocky planets

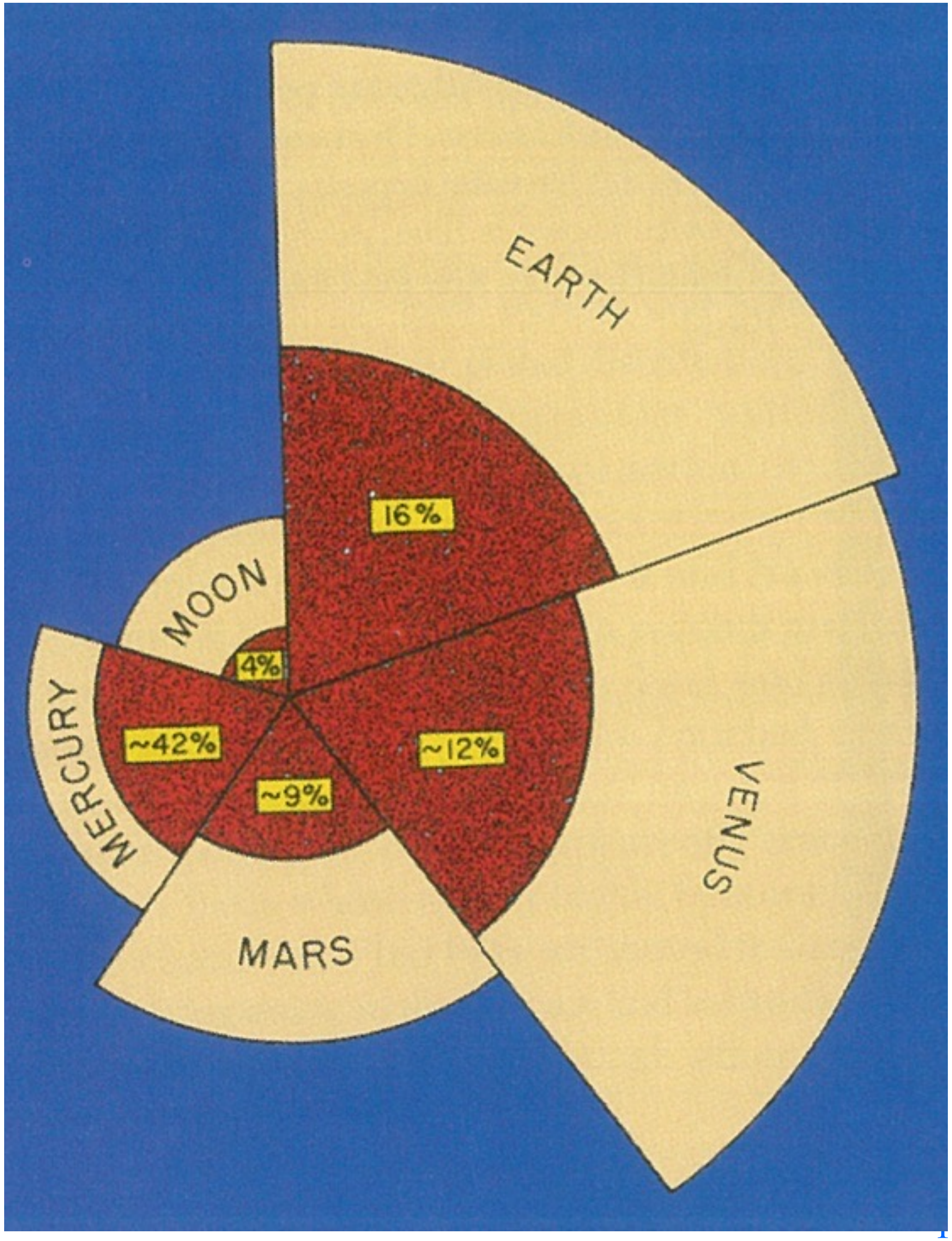


Comparison of terrestrial planet core radii

The sizes are in scale

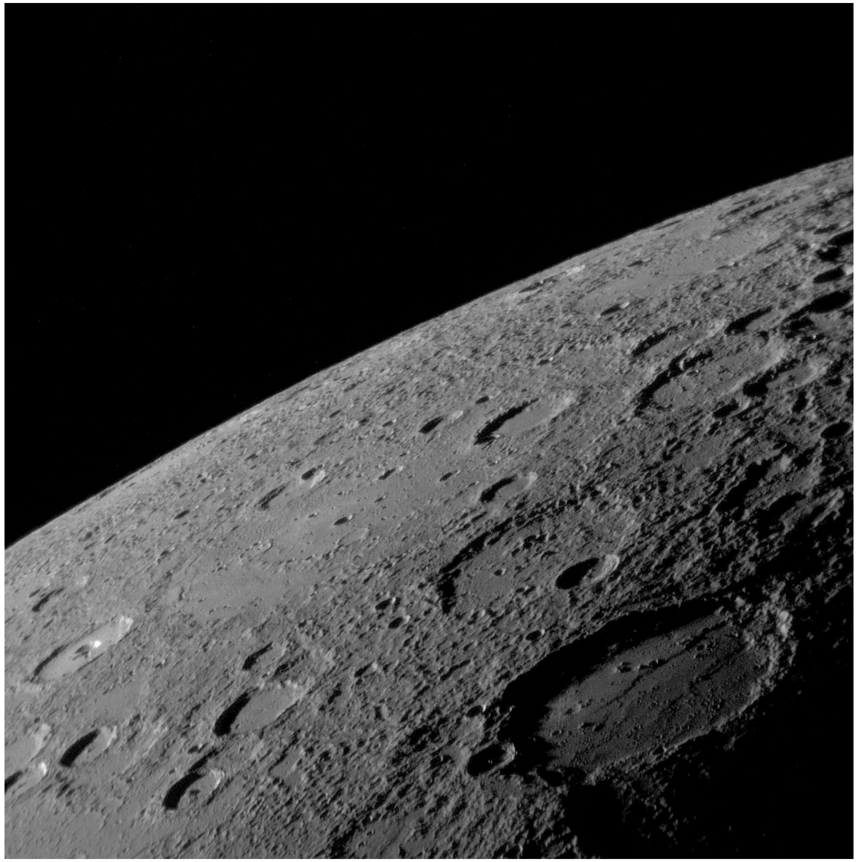
The percent of the total planetary volume of the core is indicated (yellow boxes)

The size of the Moon's core is not known, but the maximum possible size is shown



Mercury

- Mercury provides and example of planetary surface dominated by impact craters
- No atmosphere/hydrosphere, no tectonic reprocessing of the surface
- Craters are only weathered by the solar wind
- In lack of surface reprocessing, older craters can be degradated by more recent ones
- The surface of Mercury provides an excellent record of the dynamical history of impactors in the Solar System



NASA *Messenger*

Mercury internal structure

- High mean density
  - $\rho = 5.4\ g\ cm^{-3}$

    Indicates the presence of an <u>extended metallic core</u> (~3/4 of the radius)

    Thin mantle of silicates
- Magnetic field not completely negligible (~1% of the Earth's one)
    - Discovered by the Mariner probe (1974)
  - Evidence of a liquid metallic core

    Unexpected because the metallic core of a small planet is expected to cool rapidly

Venus surface

Probes have taken a few optical images of the surface in situ, but they do not survive to the harsh temperature conditions

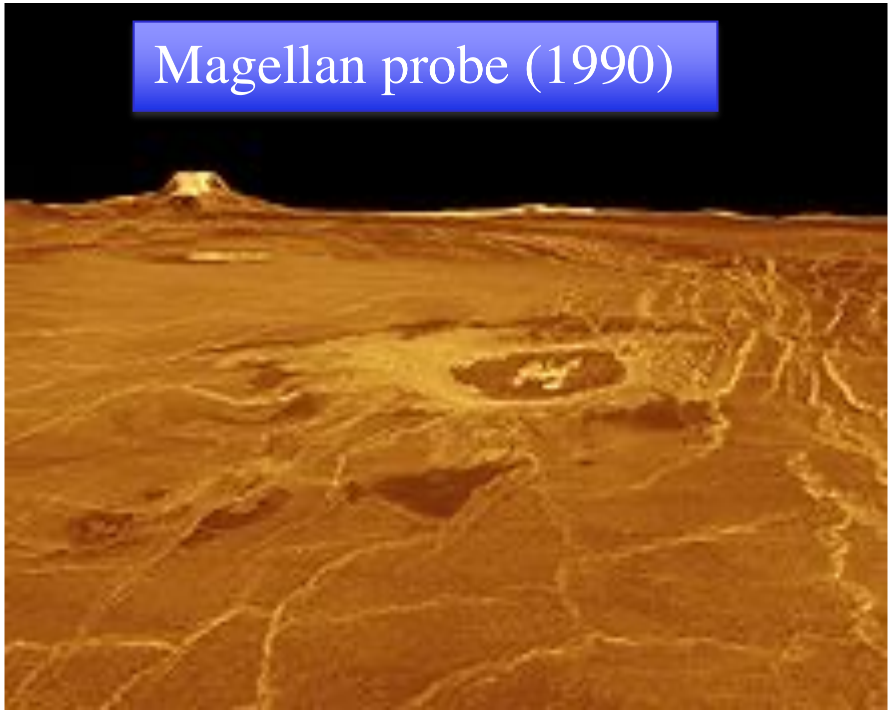
The surface has been mapped with radar techniques (e.g. Magellan probe)

The surface is a dry desertscape interspersed with slab-like rocks and periodically resurfaced by volcanism

No signature of tectonic movements

Impact craters are present, but only with relatively large sizes because the thick atmosphere brakes/evaporates the smallest meteorites

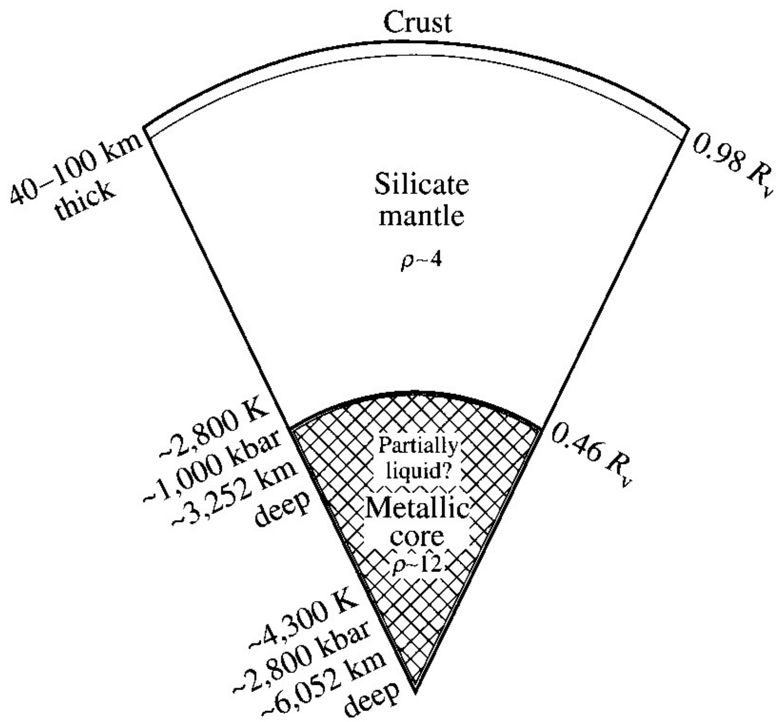
Venera 9 (1975)


Magellan probe (1990)

Venus internal structure

- Venus
  - Without seismic data or knowledge of its moment of inertia, little direct information is available about the internal structure and geochemistry
  - It is believed to have an internal structure broadly similar to that of the Earth
  - However the crusts seem to be much thicker and rigid

    Tectonic movements are inhibited



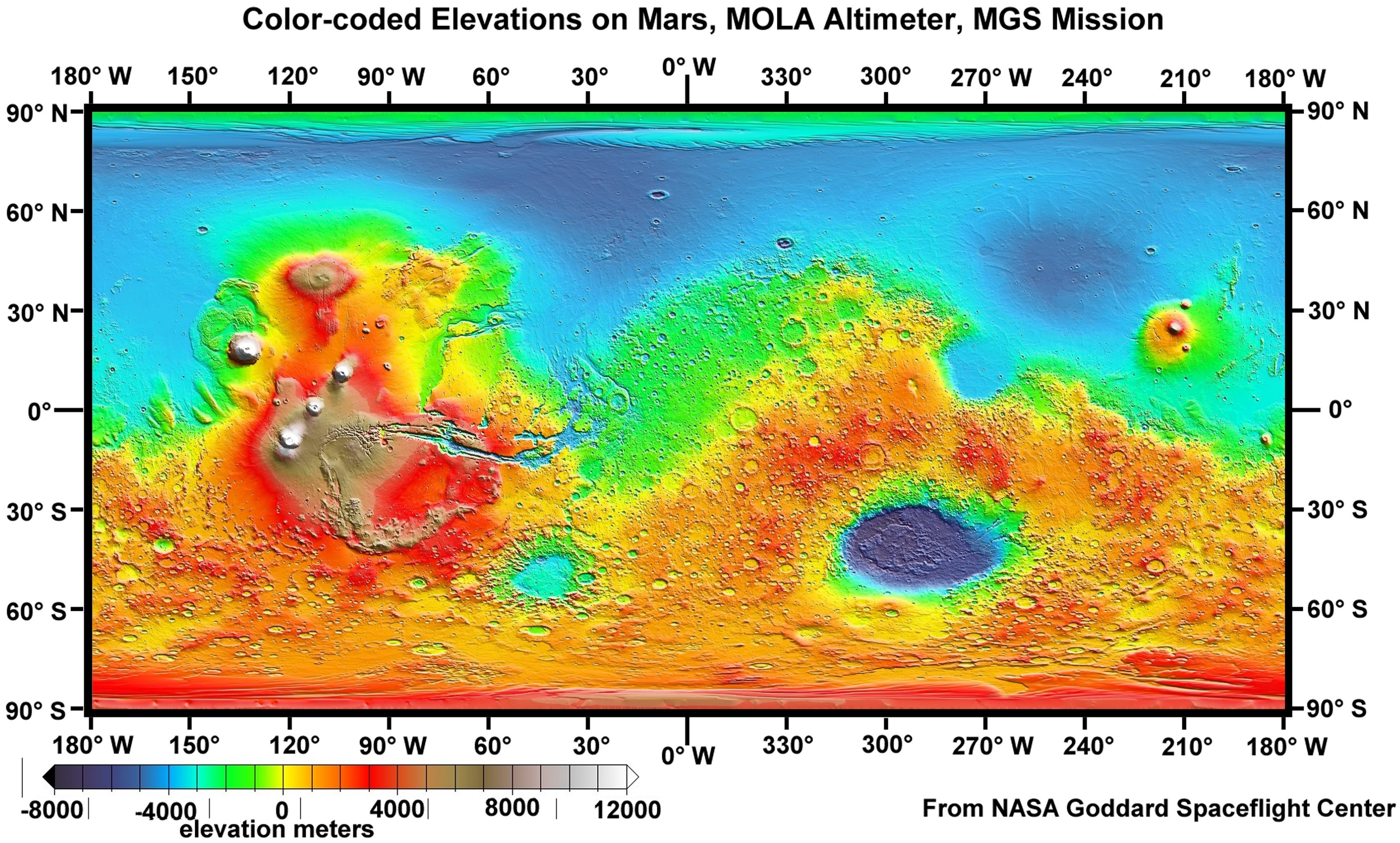
Model of Venus internal structure

Fegley (2005)

Mars surface

Shaped by a variety of processes, featuring impact craters, large volcanos, and flat basaltic zones

Very limited evidence of tectonics



Mars interior

- Mars
  - The interior is modeled with an iron core and a silicate mantle

  - The mantle models use as a reference the chemical composition of martian meteorites

    Based on their isotopic composition, the SNC meteorites collected on Earth are believed to be of martian origin

    Presumably ejected from the upper mantle following a collision of minor bodies on Mars surface, thanks to the low escape velocity of Mars