October 13 2006 Planetary Surfaces

- Main Processes that Shape Surfaces:
  1- Cratering & Microcratering
  2- Volcanism & Tectonics
  3- Atmospheric Effects
     - Weathering & Erosion
     - Chemical & Geochemical Processing

1- Impact Cratering — seen on (nearly) all solid Solar System Surfaces

"astroblemes"

- Flying Rock hits ground
- Sound speed in rock = 3-6 km/s
- Speed of impactor?
  8 → 10 km/s

∴ supersonic impact produces shock waves into rock

→ fluid-like propagation of energy

(not shattered!)

How deep? ~~Approximate as depth of Point Meteorite~~

~~Meteorite density ≈ 1.5× crustal rock~~

— Depth depends on: KE, crust properties, etc

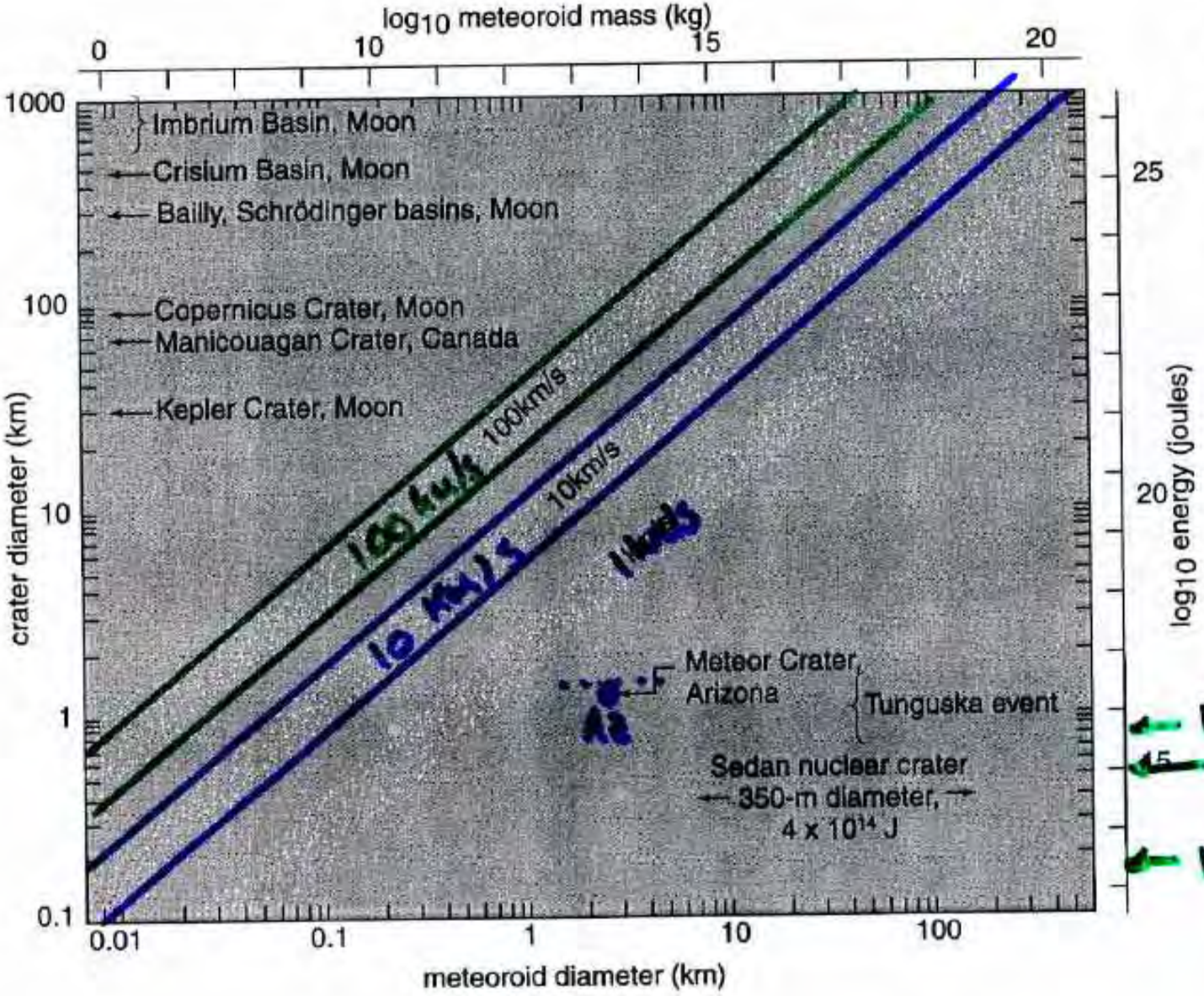


Figure 9-6. The diam
impact crater as a functi
orite size for three differ
velocities. Scale at right
estimated energy requir
each crater. Documente
Earth and the moon are
assumed meteorite dens
(Crater energy and diam
from Baldwin, 1963; Wa
p. 145; Vortman, 1977)

Figure 9-7. Features of impact craters. (**a**) Vertical view of the relatively fresh 90 km lunar crater Copernicus. (Courtesy

General rule of thumb: Figure 9-6

Crater size ∝ impactor diameter

= 5× impactor diameter for 10 km/s impact

30× " " for 100 km/s

1-2× " " " 1 km/s

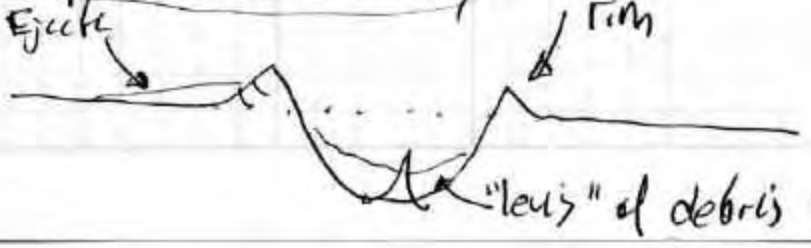
General Crater features

1. (nearly always) Circular primary basin smooth, circular for small (<1 km)
2. Central peak (frozen rebound drop) (larger) — 1.5 EJECTA BLANKET
3. Terraced walls - overturned strata, slumping (larger still)

4 Peak ring / multiring basin / rays (very largest)

(larger depending on planet)

Pictures / Examples on MONDAY



- collect HW3
- Distribute HW4

CRATER DENSITY

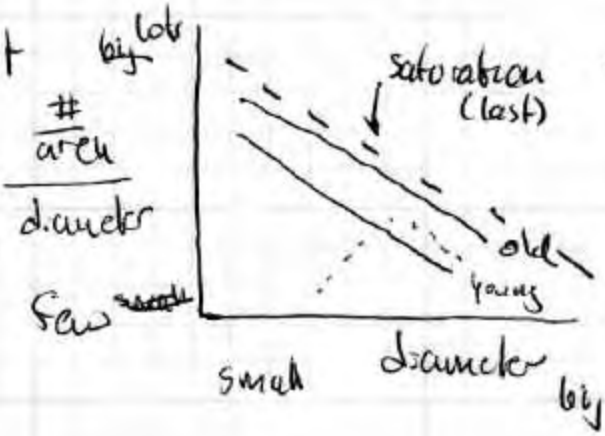
Crater statistics - size distribution
- number density

yield information on - impact history
- surface evolution (resurfacing, via other processes)

Relative Dating of Surfaces

"Crater counts" → more craters, longer exposure to impacts after a resurfacing

general plot



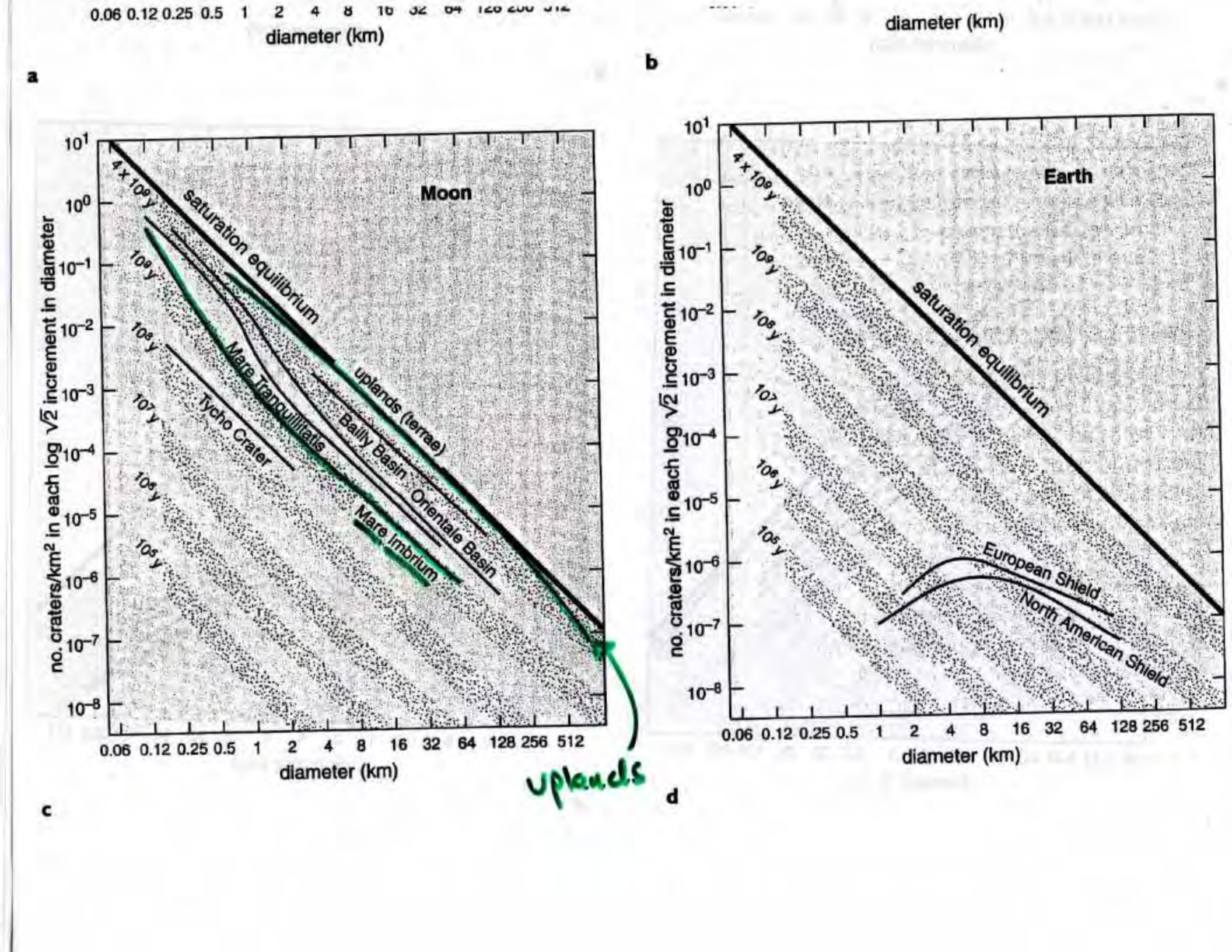
- more small, fewer big
- more overall for older surface

Saturation

$$\int_{\text{small}}^{\text{large}} n(a)\,da \propto 4\pi r^2; \quad n(r) \leq \frac{1}{4\pi r^2}$$

- dotted line → limited life of small craters to erosion

- so crowded that new craters must cover up older ones
- kicks in at ~ 4,000,000 y on inner solar system

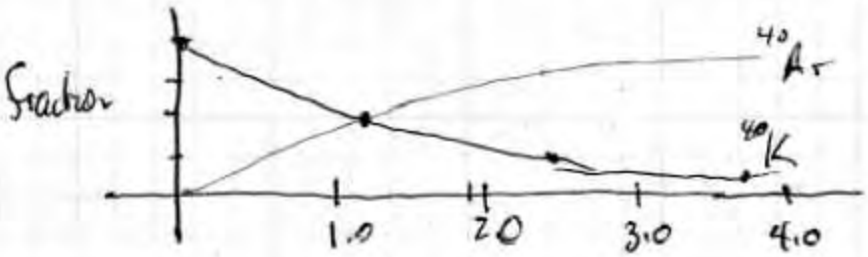

0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512
diameter (km)
a
b
Moon
Earth
4 × 10⁹ y
10⁹ y
10⁸ y
10⁷ y
10⁶ y
10⁵ y
saturation equilibrium
uplands (terrae)
Mare Tranquillitatis
Bailly Basin
Orientale Basin
Mare Imbrium
Tycho Crater
European Shield
North American Shield
no. craters/km² in each log √2 increment in diameter
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512
diameter (km)
uplands
c
d

See figure 9-20 for realistic examples
(equilibrium line is $n = 1/d^2$)

- Can plot curves for various surfaces on planets, but how do you calibrate those relative ages?
- Ans: find ages of rocks on those surfaces; only possible for our moon right now.

Radioisotopic Dating

- ^{40}K decays to ^{40}Ar with a half-life of 1.19 by
- ^{40}Ar is gas, entrained in rock, escapes if rock melts
- $^{40}K/^{40}Ar$ ratio indicates age



MOON ROCKS + crater counts → impact history

p. 132-134, FIGURE 6.6:
- Intense early bombardment
- exponential decay over the past 4×10^9 y

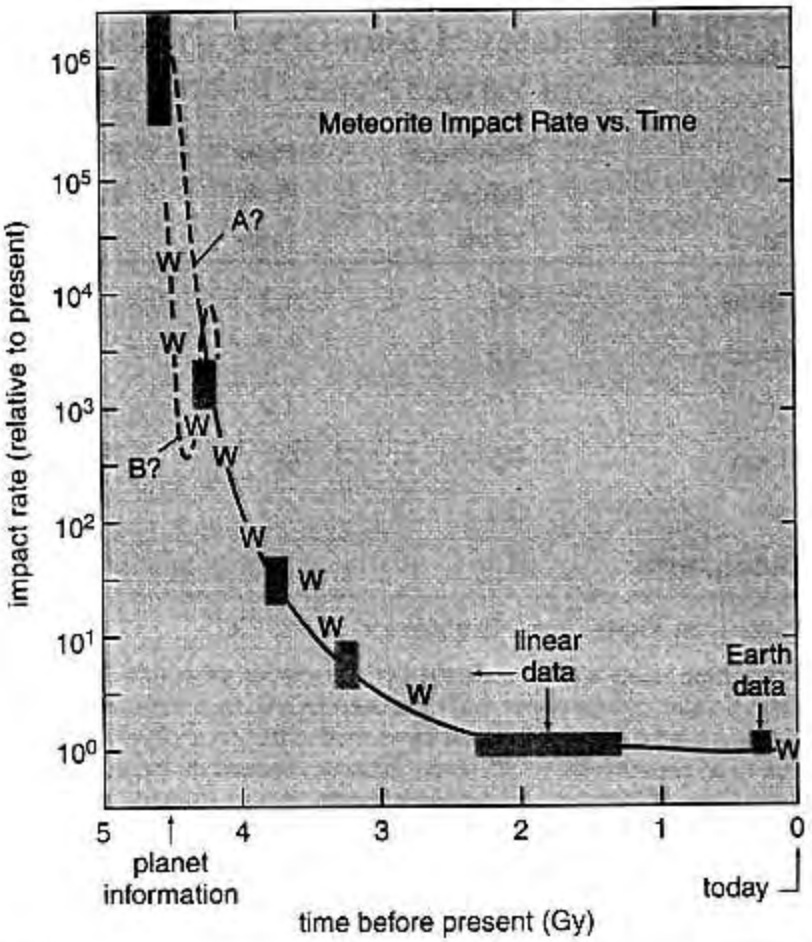


Figure 6-6. The history of impact rates in the Earth-moon system, as derived from terrestrial and lunar data (adapted from Hartmann and others, 1980). Sizes of boxes indicate approximate precision of available data. Two interpretations of earliest cratering, A and B, are discussed in text. Points labeled W mark calculated impact rates at different times, based on an assumed initial swarm of planetesimals with a = 0.9 AU, e = 0.27, $i = 5.7°$. (from Wetherill, 1977a)

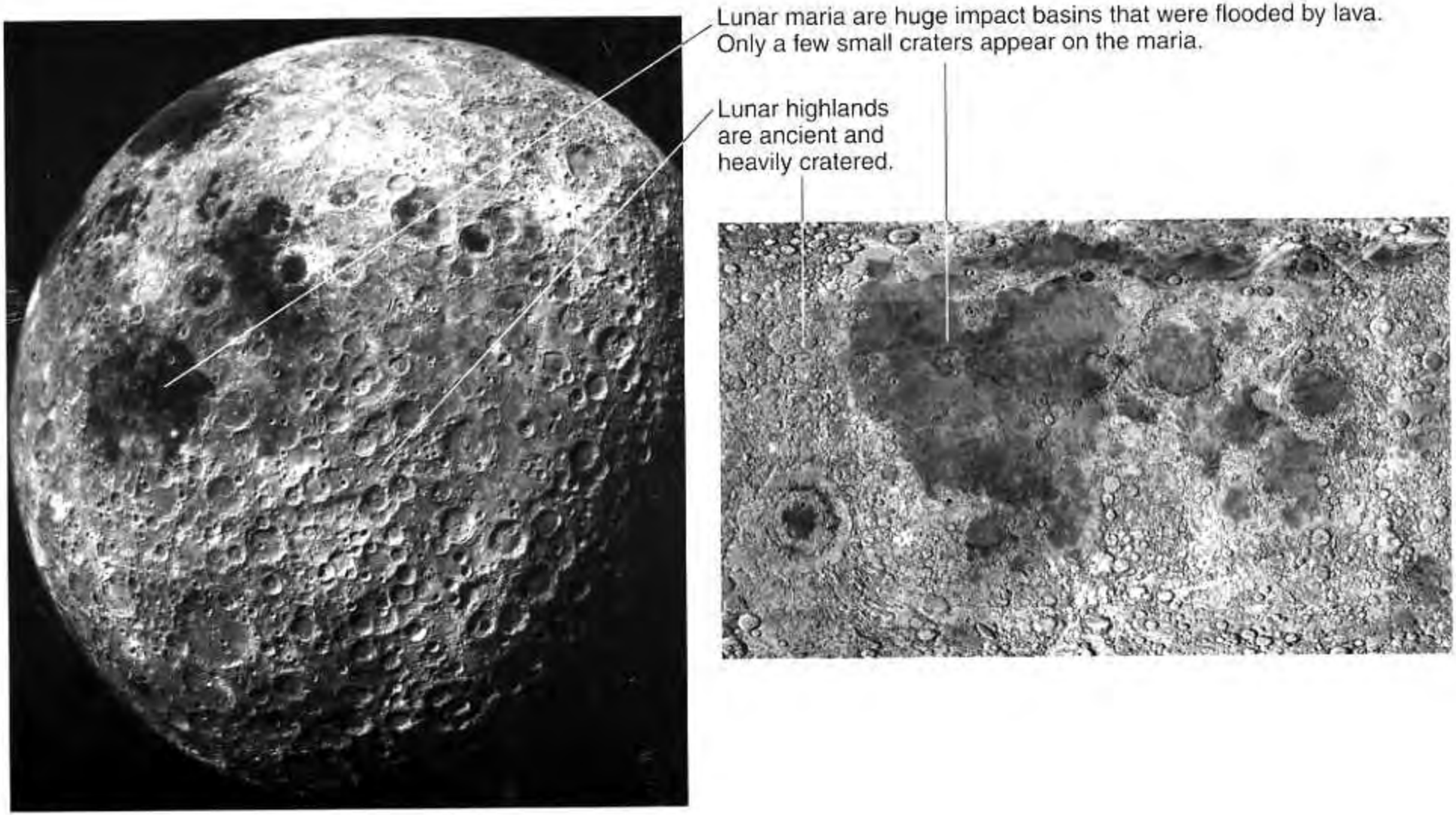
TABLE 6-1 Rates of 2-km Crater Production of Various Planets Relative to Earth

Planet	Minimum likely value	Most likely value	Maximum likely value
Mercury	0.5	1.3	3.3
Venus	0.5	0.7	1.4
Earth	1.0	1.0	1.0
Moon	0.5	0.7	0.9
Mars	0.6	1.3	2.6
Outer planets	?	?	?

Source: Data adapted from Hartmann and others, 1981.

Note: These values are not quite the same as relative meteoroid fluxes, since a crater on one planet may have been formed by a somewhat different-sized meteorite than the same-sized crater on another planet due to an impact velocity difference. Estimates depend on the assumed distribution of Mars-crossing asteroids, Earth-crossing asteroids, short-period comets, long-period comets, and so on.

Figure 10.9 lunar crater dating



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Other Processes Shaping Planetary Surfaces:

Weathering (mostly atmospheric)
- mechanical < wind, water, ice
- thermal (expansion / contraction)
- chemical (oxidation)

- erases craters
- wears down mountains
- pulverizes surface

* = alters surface + atmospheric composition

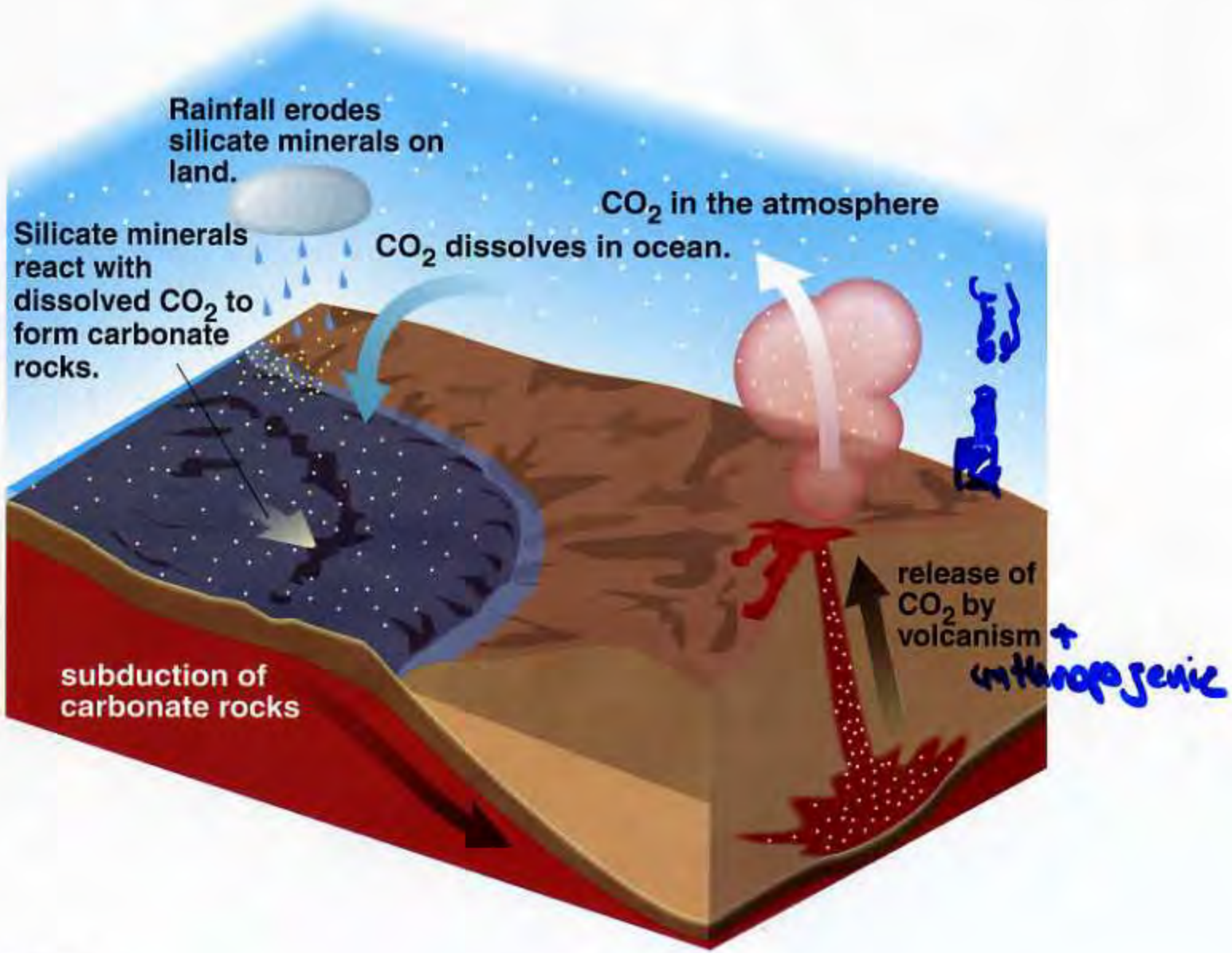
* relevant issue: rate of "erosion"

- depends on size of feature.
  - ↳ generally faster for smaller features
- roughly constant over (recent) geological time

Volcanism & Global tectonics

- motion of low density crustal "plates" floating over dense "fluid" asthenosphere
- signal surface activity: volcanos & earthquakes

Figure 13.18 Recycling of CO_2 and the carbonate-silicate cycle



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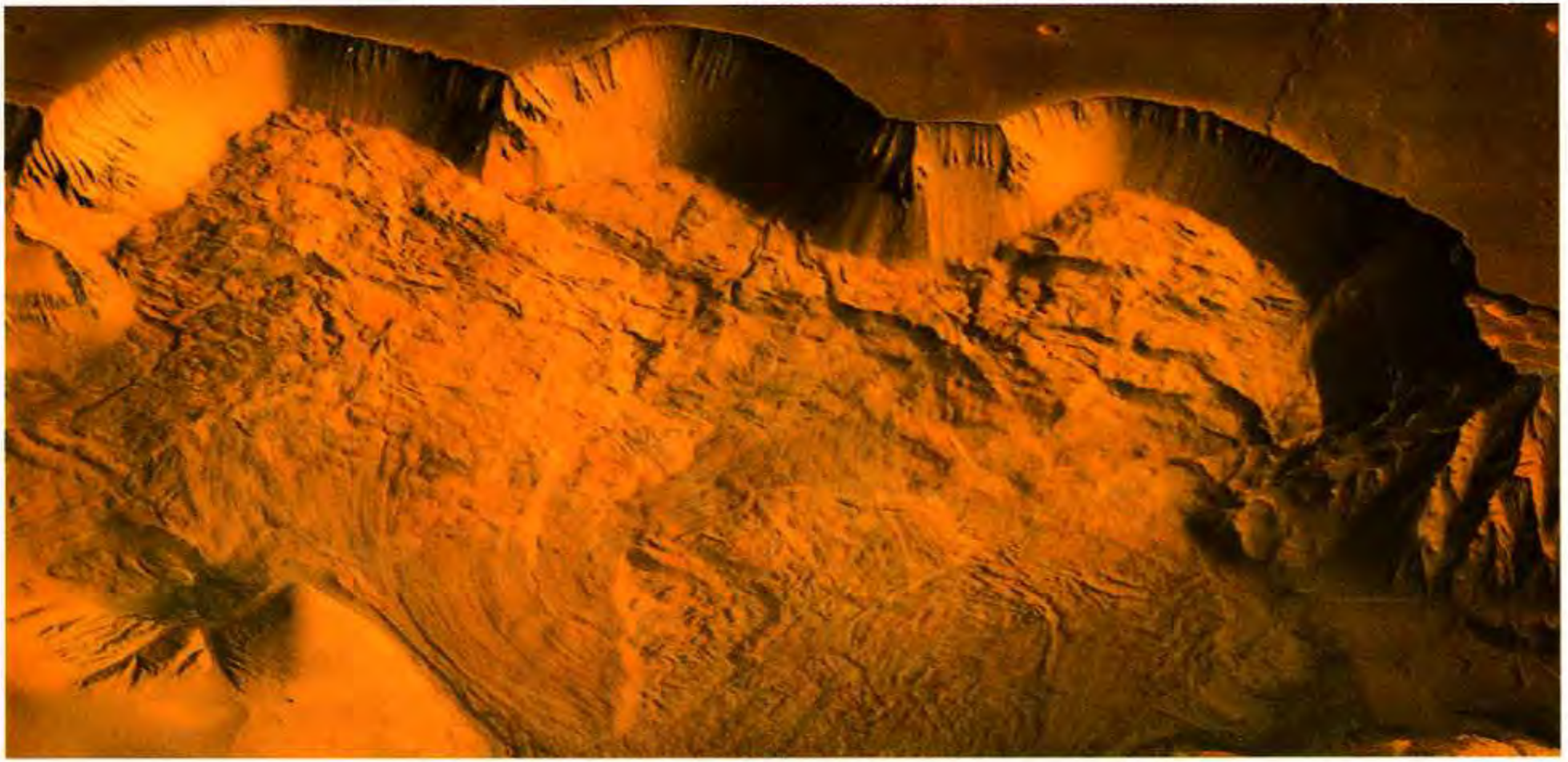
Fraknoi, Voyages Through the Universe, 2/e
Figure 9.17



Landslides, Mars

Harcourt, Inc.

Nanedi Valley Channel, Mars

Harcourt, Inc.

- mountain building
- volcanism (large & small scale fluid-rock flooding)
- earthquakes

Tectonics ("plate tectonics")

- Most of the "action" occurs at plate boundaries
  - Divergence zone upwelling asth. creates new crust, pushing plates apart

i.e. mid-Atlantic ridge

  - subduction zone

- plates meeting, one shoved below the other
- mountain building
- melting low ε plate material → bubble up producing volcanos
- seismic activity

} quakes!

example: "Ring of Fire"

Example: San Andreas

- transform fault sideways slip

Figure 13.11 The mechanism of plate tectonics

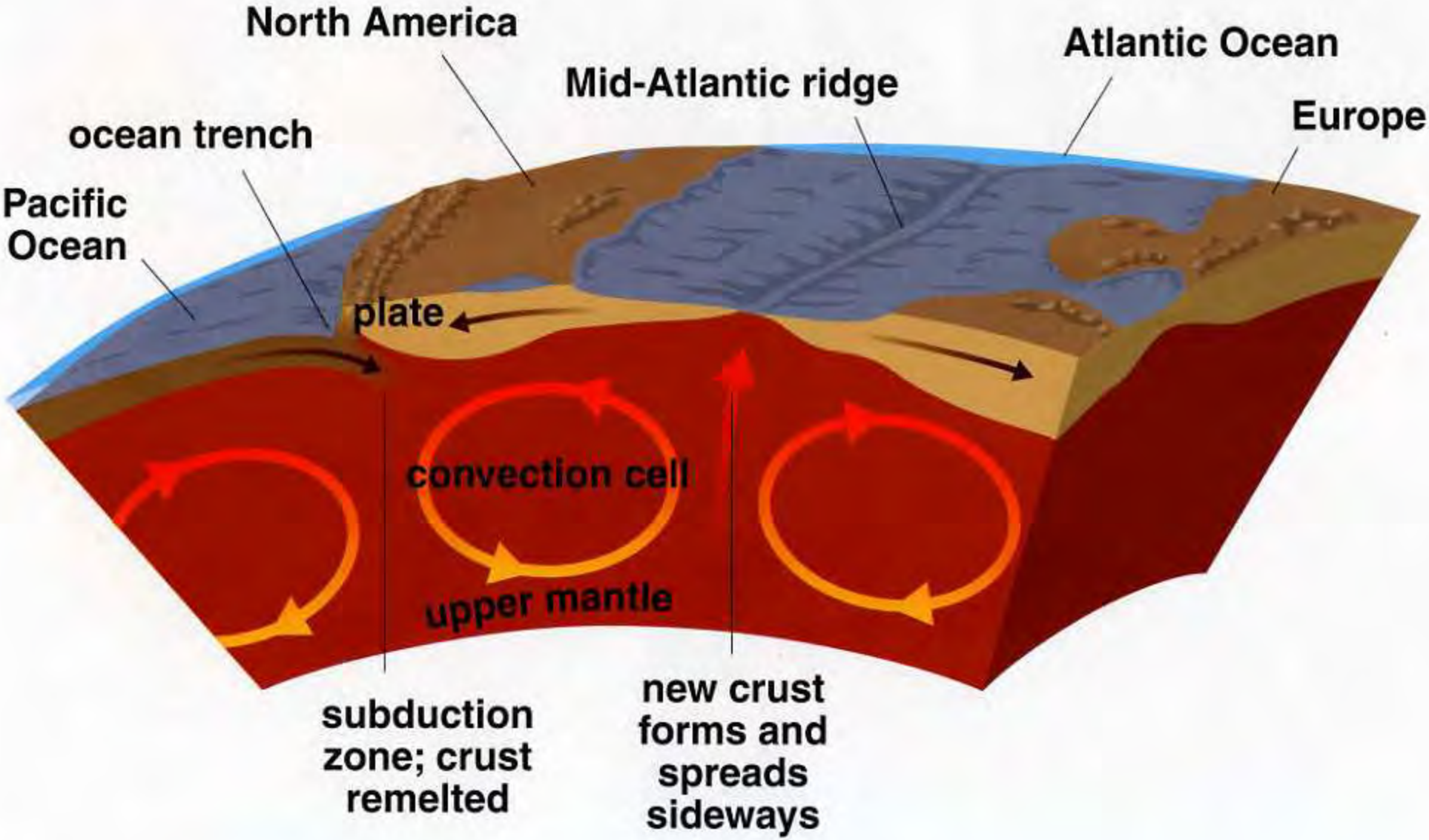


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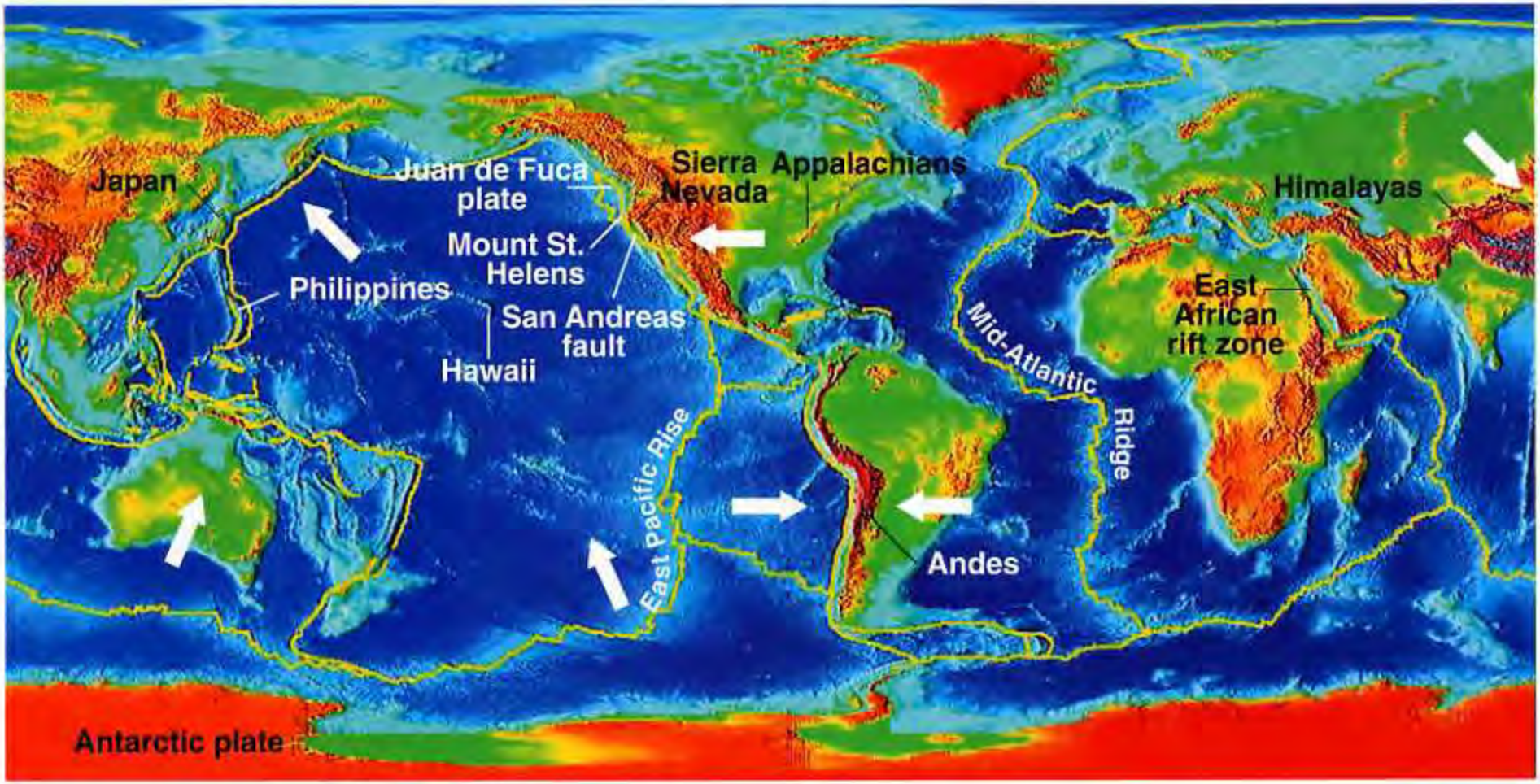
Figure 13.10 Geological map of Earth



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Europa Ice Rafts

* "Tectonics" produces:
  - Mountain Ranges
  - Rift/fault systems
  - Volcanos?

Volcanism

Rise of molten, low density rock to and above surface.

- "Cinder Cones"
  small cratered hills
- Shield Volcanos
  larger, flattened lava structures topped by caldera (collapsed lava source)

* easier-flowing lava → flatter, lesser flow

Composite Volcano
multiple caldera/cones

Mechanics — How big a mountain?

Crushing pressure needed = 3000 atm for igneous rock

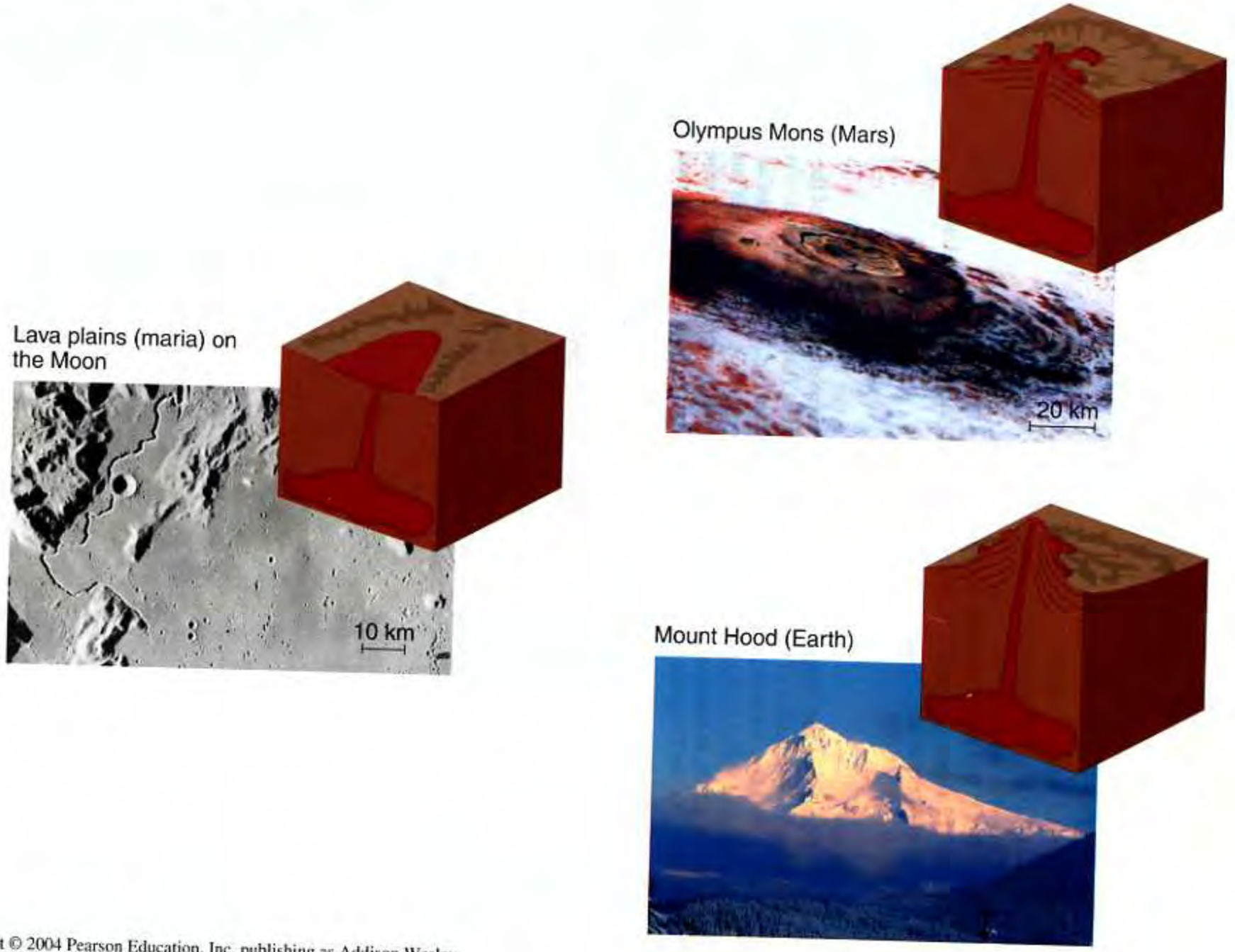
$P = \rho g h$ = force/area from weight

$\rho g h = P$ $\quad h = 7.4\,km \left(\frac{P}{3000\,atm}\right)\left(\frac{9.8\,m/s^2}{g}\right)\left(\frac{4\,g\,cm^{-3}}{\rho}\right)$

$h = 24{,}500\,ft!$

Everest: 8 km

Figure 10.12 lava types



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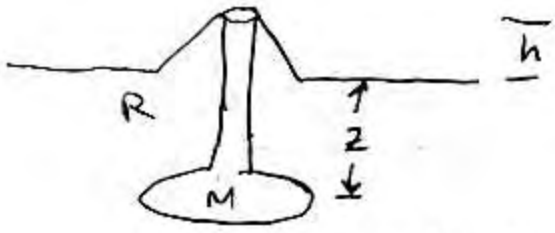
Mars: $g = 3.7\ m/s^2 \rightarrow h = 26\ km$ (comp. w 24 km for Olympus Mons!)

How deep is the Magma Chamber?



$$P = \rho_M g (z + h) = \rho_R g z$$

$$h = \frac{\rho_R - \rho_M}{\rho_M} z = \frac{\Delta\rho}{\rho_M} z$$

density difference between magma & rock

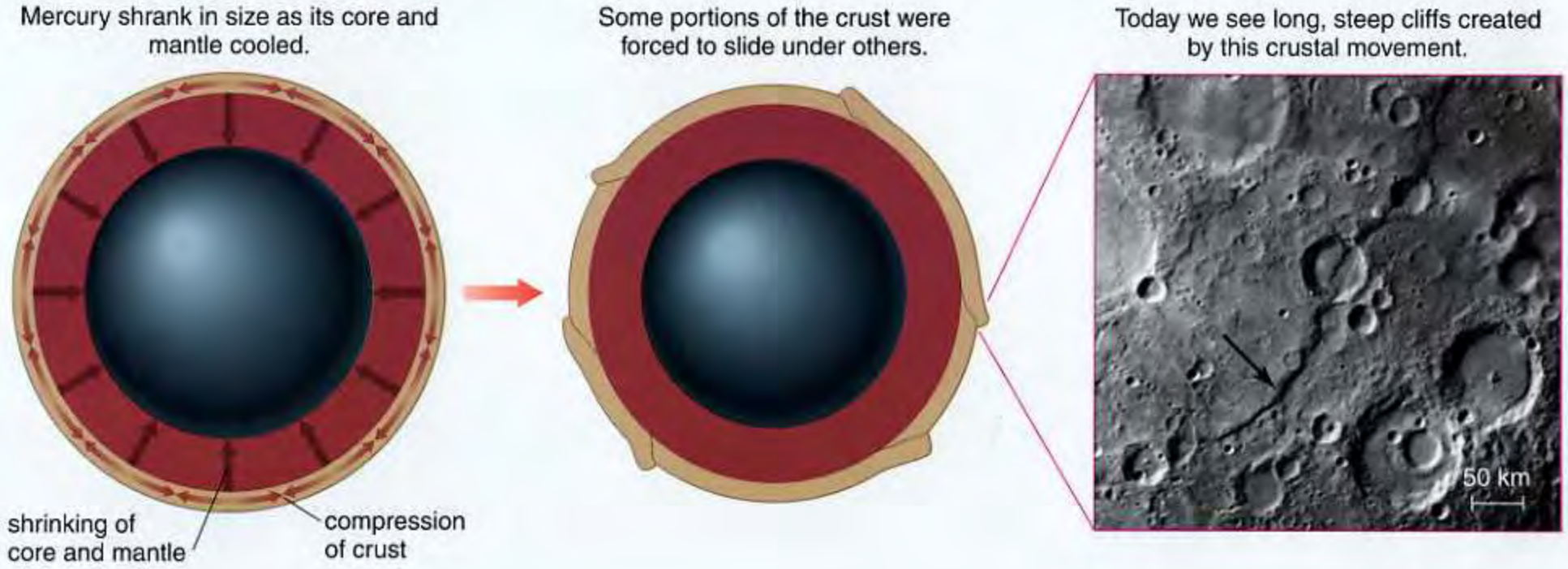
Hawaii $\rho_R = \cancel{3000}\ 3300$

$\rho_M = 2.770$

$h = 9\ km$

$\rightarrow z = 47\ km$

Figure 10.22 Mercury tectonics



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A Quick overview of real Planetary surfaces

Mercury: - craters almost everywhere! Highlands → >4 Gyr
- Caloris Basin: multiringed feature, large impact w/ internal mare
  - ↳ few × 10^9 y.a.
- "shrinkage cracks

Venus: - very few impact craters; young surface
- only craters seen are large
- ridly volcanic surface reflects active internal heat source - ~~tectonic~~
- tallest feature: Maxwellen Montes
  - 11 km (6.8 miles) high
    36,000 ft!
  - (formula value: 27000)

too tall... must be young!

- HW 3 Ret. today
- HW 4 due 10/30
- Proj Ex 1/3 due 11/1
- Exam 2 Nov. 3
- NEOs: space rad.

100 Hg or less

SO_2

Mars:

VIDEO: FLYBY
Ch 3, 6, 7

Mars, oh, Mars...

Figure 10.16a summary of geology

The Role of Planetary Size

Small Terrestrial Planets

cold, solid interior

tectonic and volcanic activity end after a billion years or so

many ancient craters

little outgassing, atmosphere lost due to low gravity

no atmosphere, therefore no erosion

Large Terrestrial Planets

warm, convecting interior

ongoing tectonic and volcanic activity

most ancient craters erased

lots of outgassing

strong gravity retains atmosphere, erosion possible

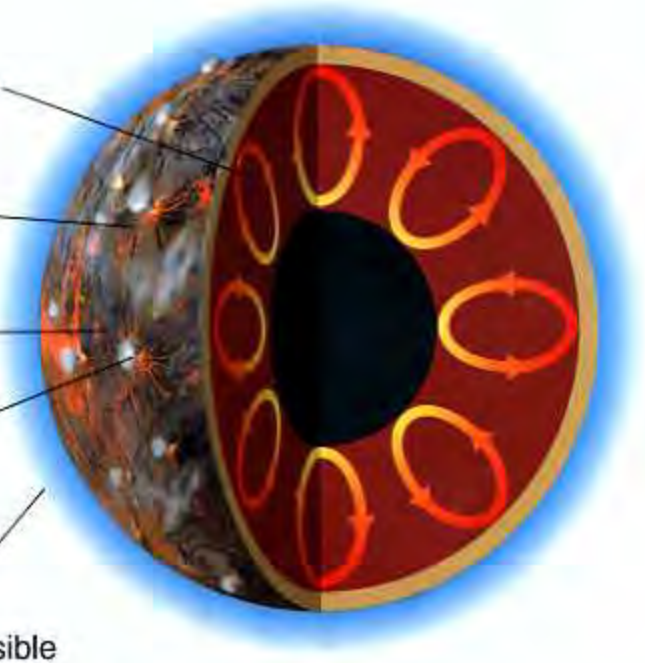

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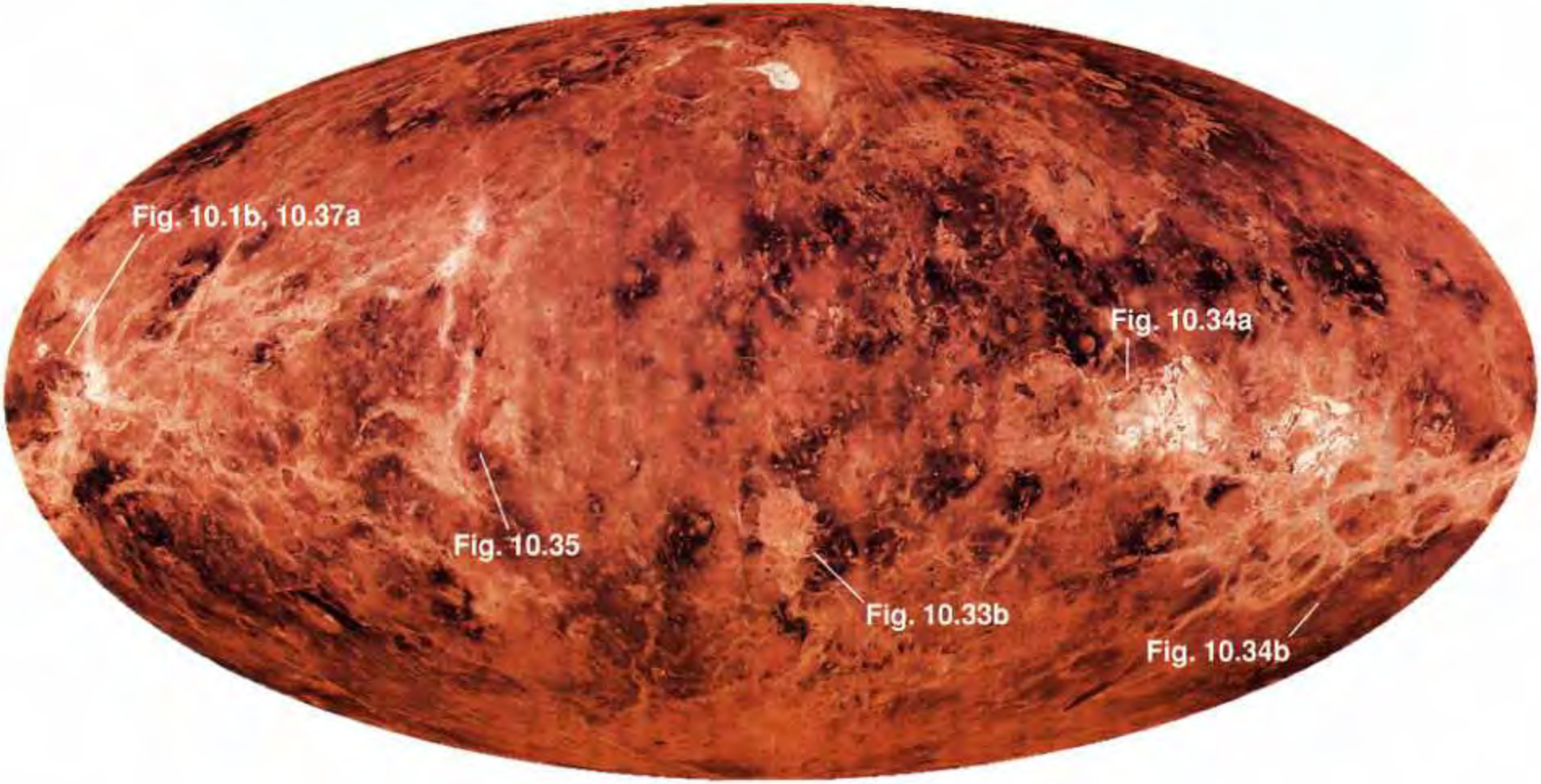
Figure 10.32 Venus global



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