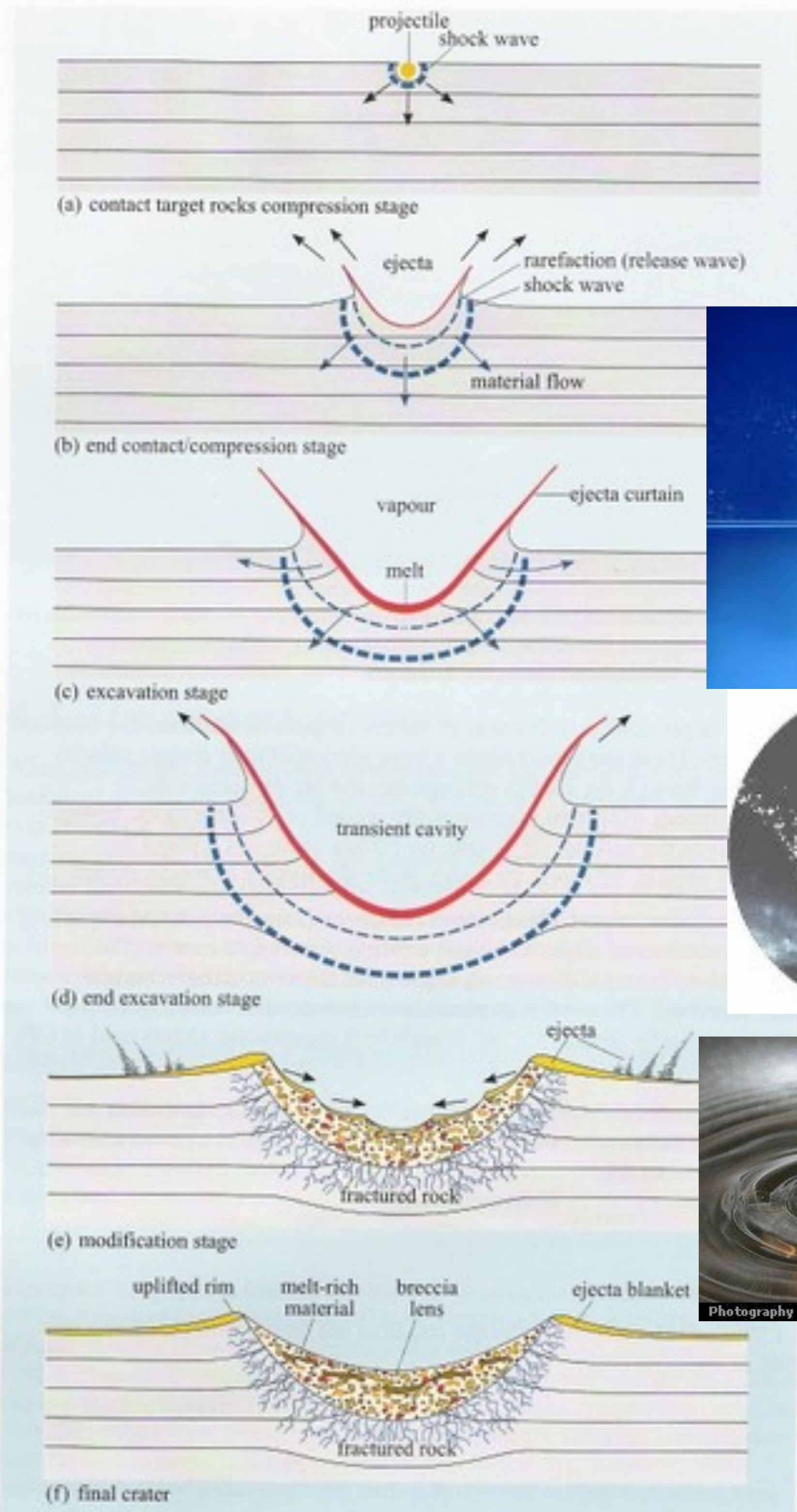
The Cratering Process



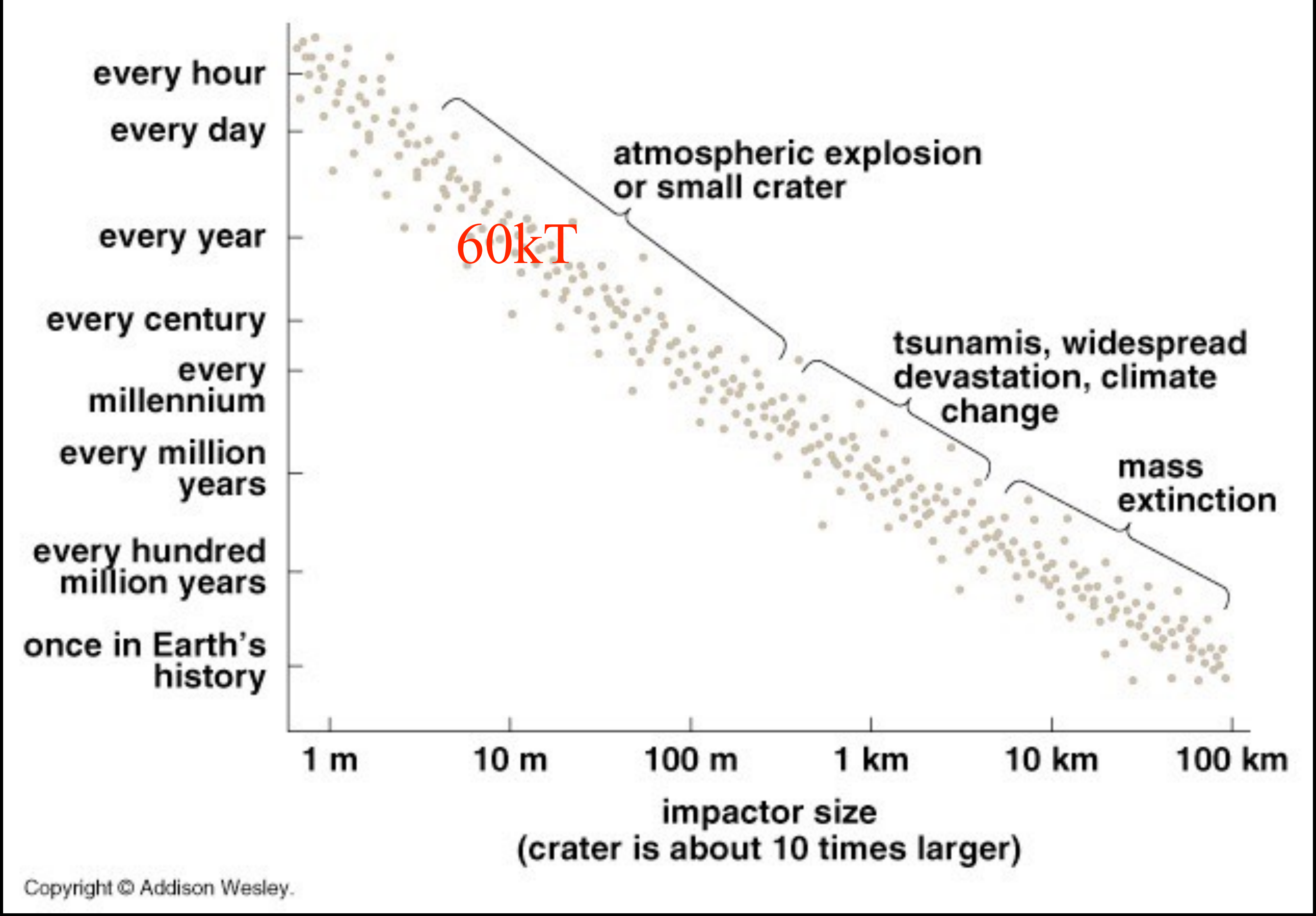
Three Stages:

1. Contact & Compression

2. Excavation

3. Modification

Impact Frequency



Small impact happen much more often than large ones

Impactor Populations

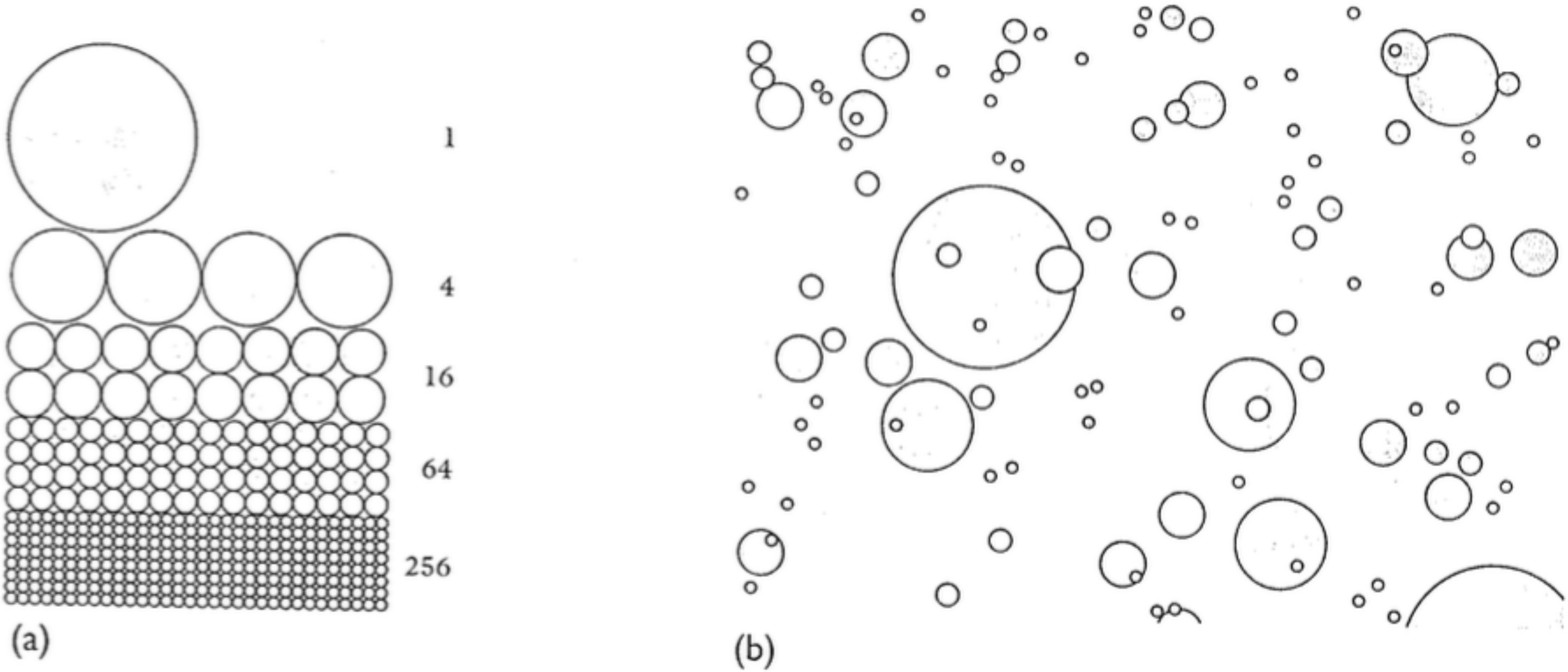


Figure 7.17 **(a)** The relative number of objects that could strike the Moon, according to a law in which the number of objects increases in inverse proportion to the square of the object's radius. **(b)** A random distribution of craters made by the population of objects shown in (a).

Estimate the Power of the Ground to stop a Meteoroid!

How much material must the meteoroid interact with to slow by 50%?

From Physics:
Momentum = (mass) (velocity) is conserved.
So velocity will be halved when mass is doubled.

Now assume that all ground in front of the impactor is plastered onto its surface.

So the impactor will penetrate into the ground by roughly its own diameter. Observed: A few diameters.

Estimate the Power of Air to stop a Meteoroid!

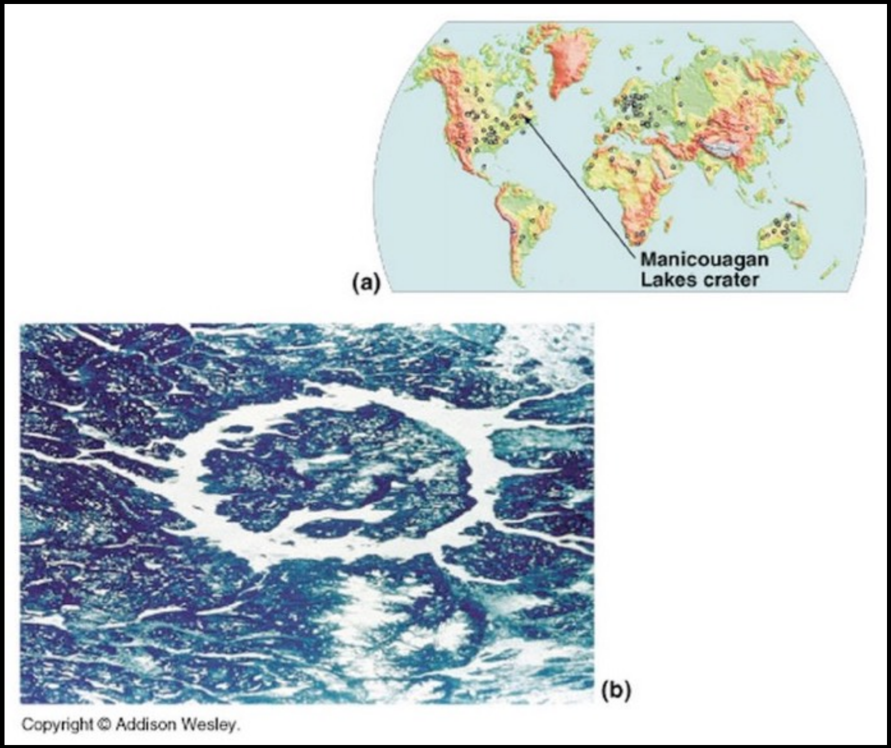
Assume that all air in front of the impactor is plastered onto its surface!

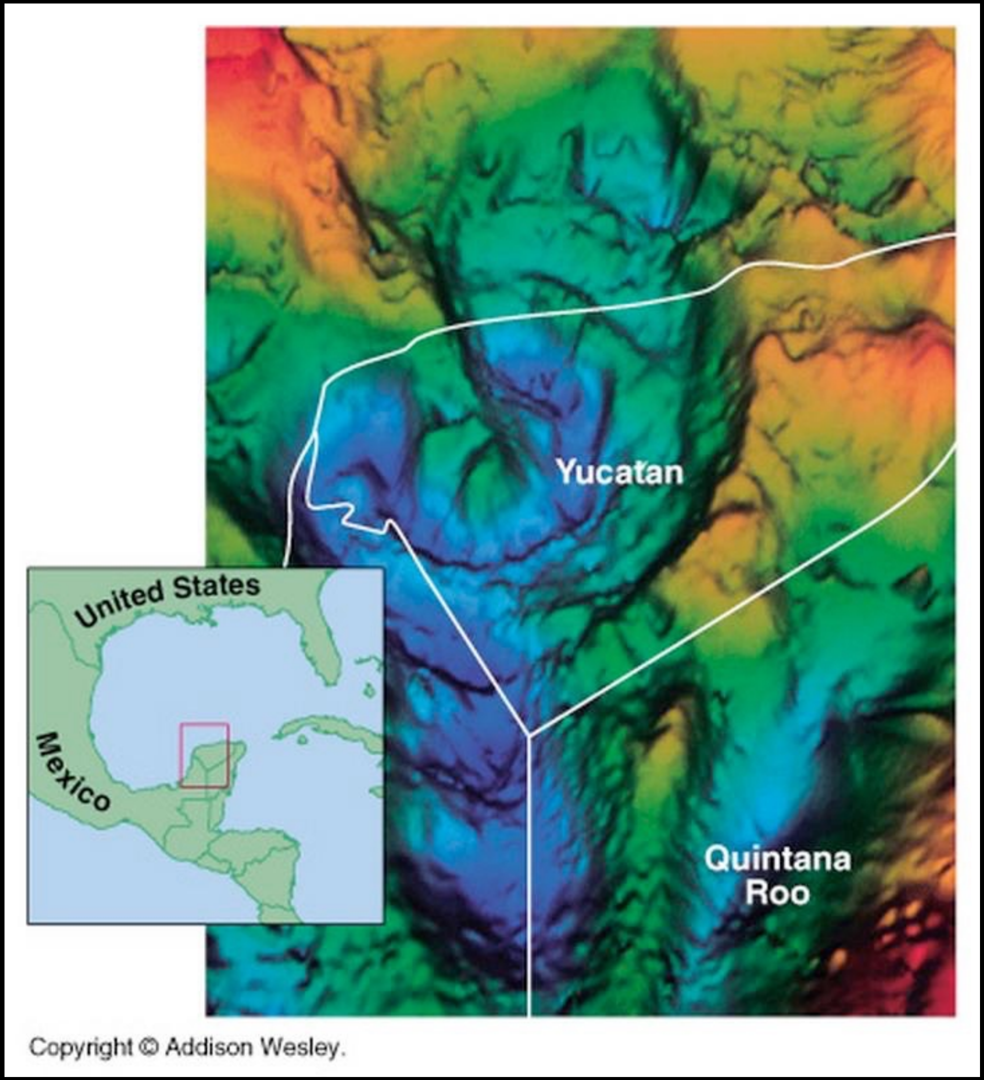
Air is 1/1000 as dense as water and is ~10km thick

So the impactor will penetrate into the ground by roughly 1000 diameters. 10m will make it through the atmosphere.

Observed: Must be ~50-100 m to make it through

Big Impact Craters on Earth





Very Small Craters on Earth

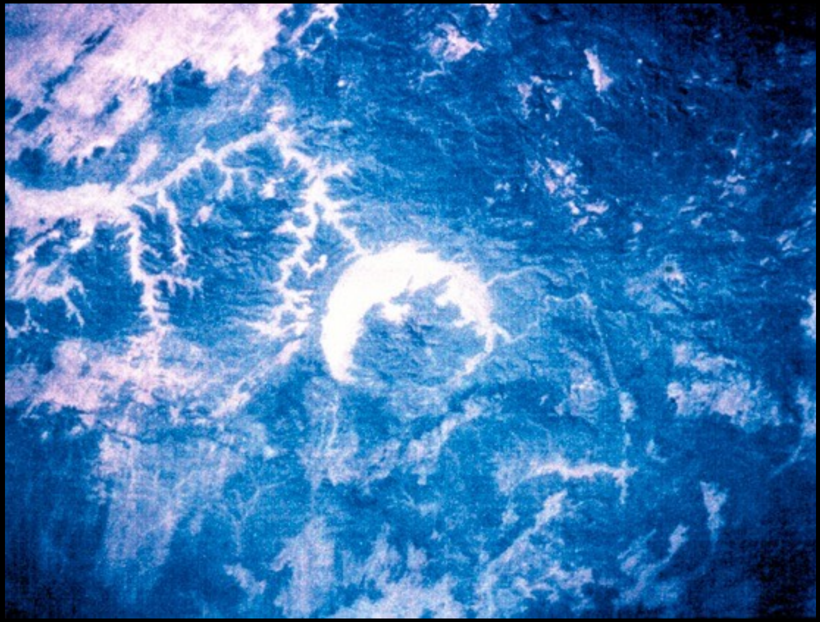
Is your insurance up to date?

At what speed was this impact?

Craters on Earth

Manicouagan, Canada:
100km, 214Myr

Gosses Bluff, Australia:
22km, 142.5Myr

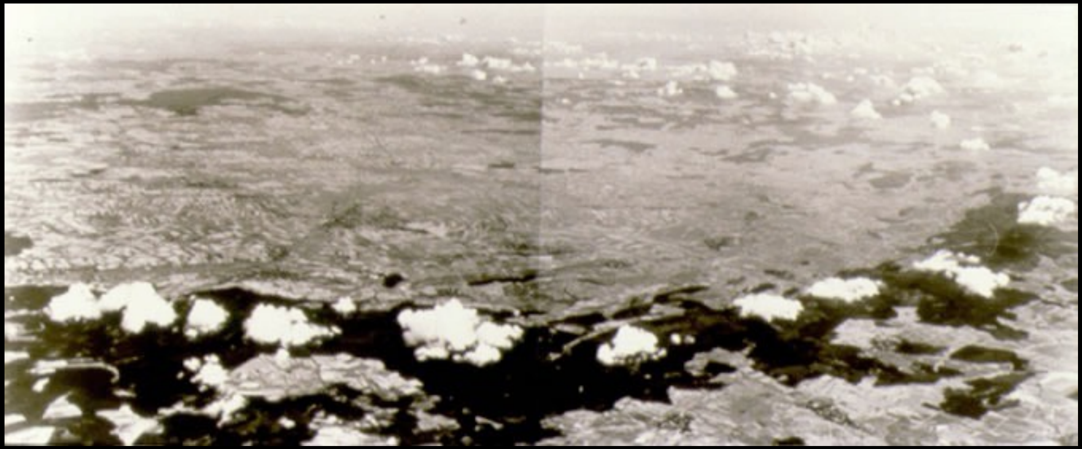


Gwen Fada, Chad:
14km, <350Myr

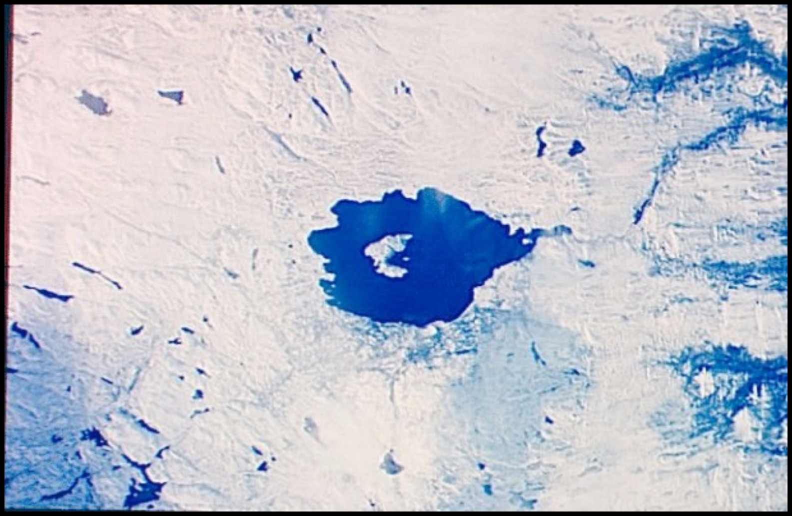
Aorounga, Chad: 10km, <350Myr

Space Shuttle!

Clearwater Lakes, Canada
26km, 290Myr



Ries, Germany
24km, 15Myr



Mistastin Lake, Canada:
28km, 38Myr

Ramgarh, India: 5.5km, unknown

Deep Bay, Canada
5km, 100 +/- 50 Myr

Ouarkziz, Algeria: 4km, <70Myr

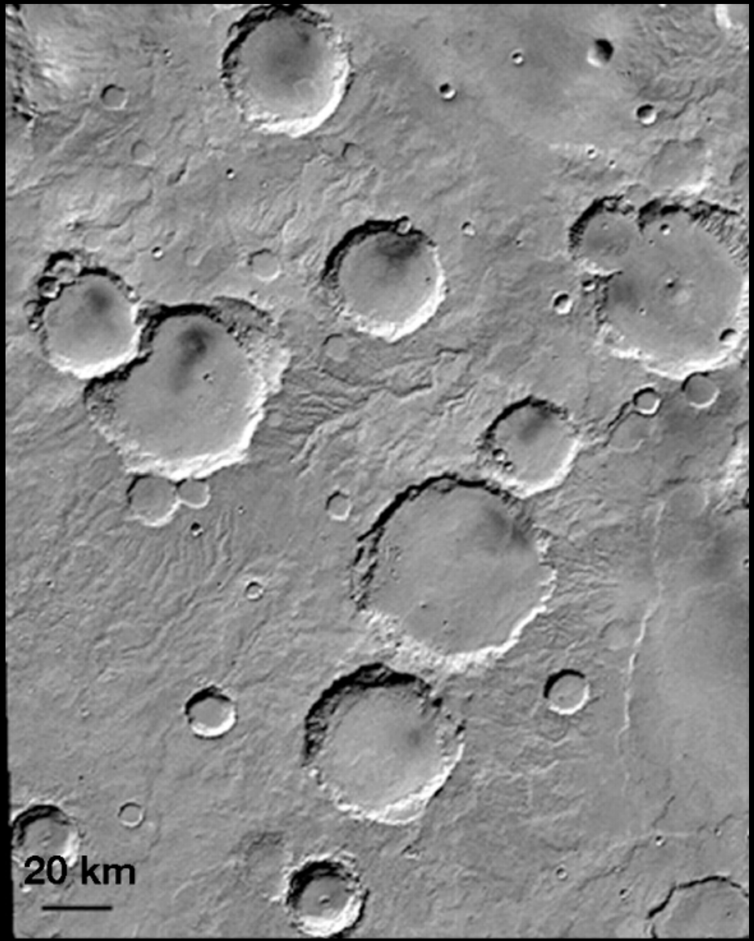
Roter Kamm, Namibia: 2.5km, 3.7Myr

Meteor Crater, Arizona: 1.2km, 49,000 yr

Wolf Creek, Australia: 850m, 0.3Myr

Goat Paddock, Australia: 5km, <55Myr

Craters on Mars

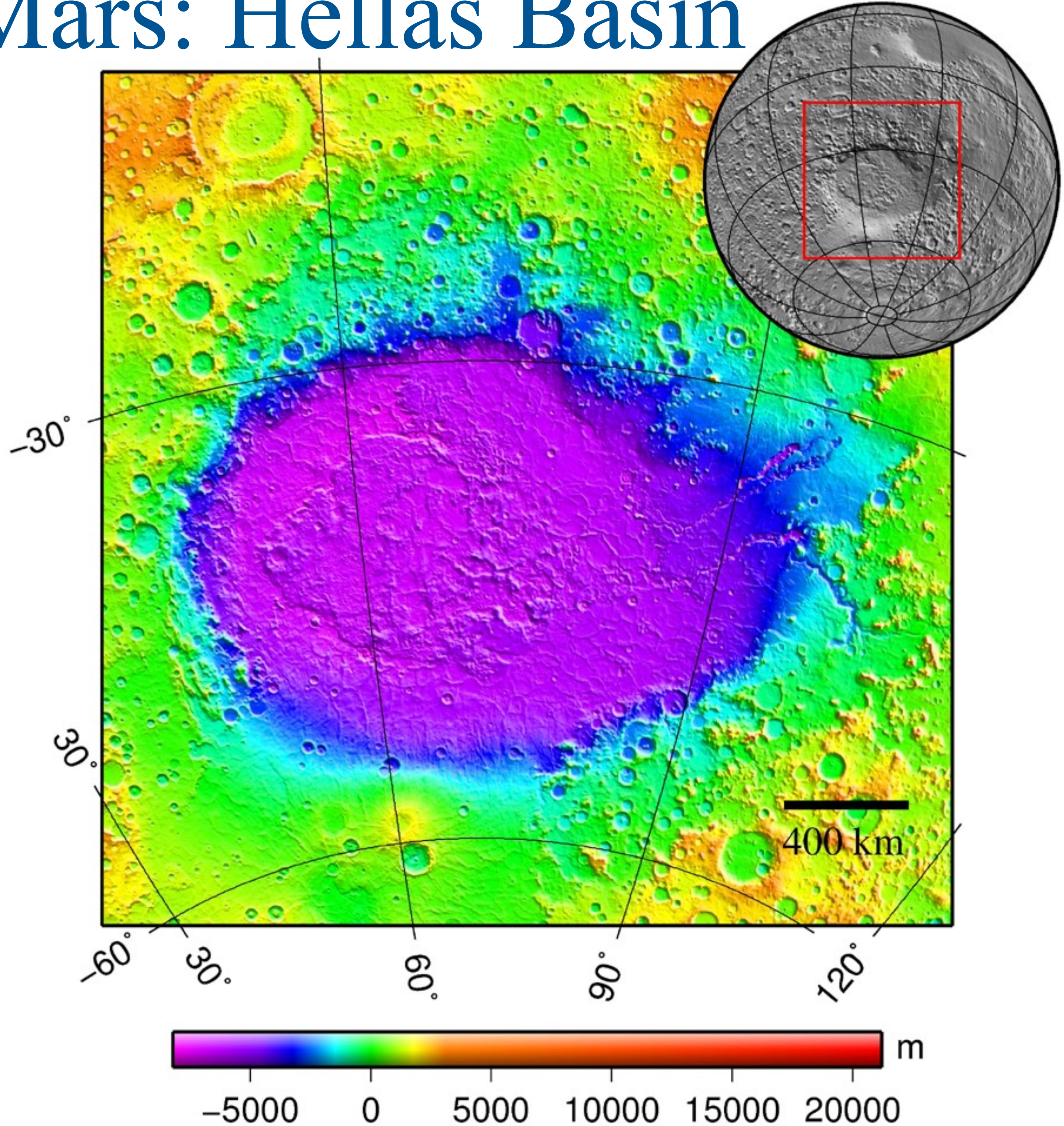


Viking Image, Mars southern hemisphere

Victoria Crater, Mars: 750m

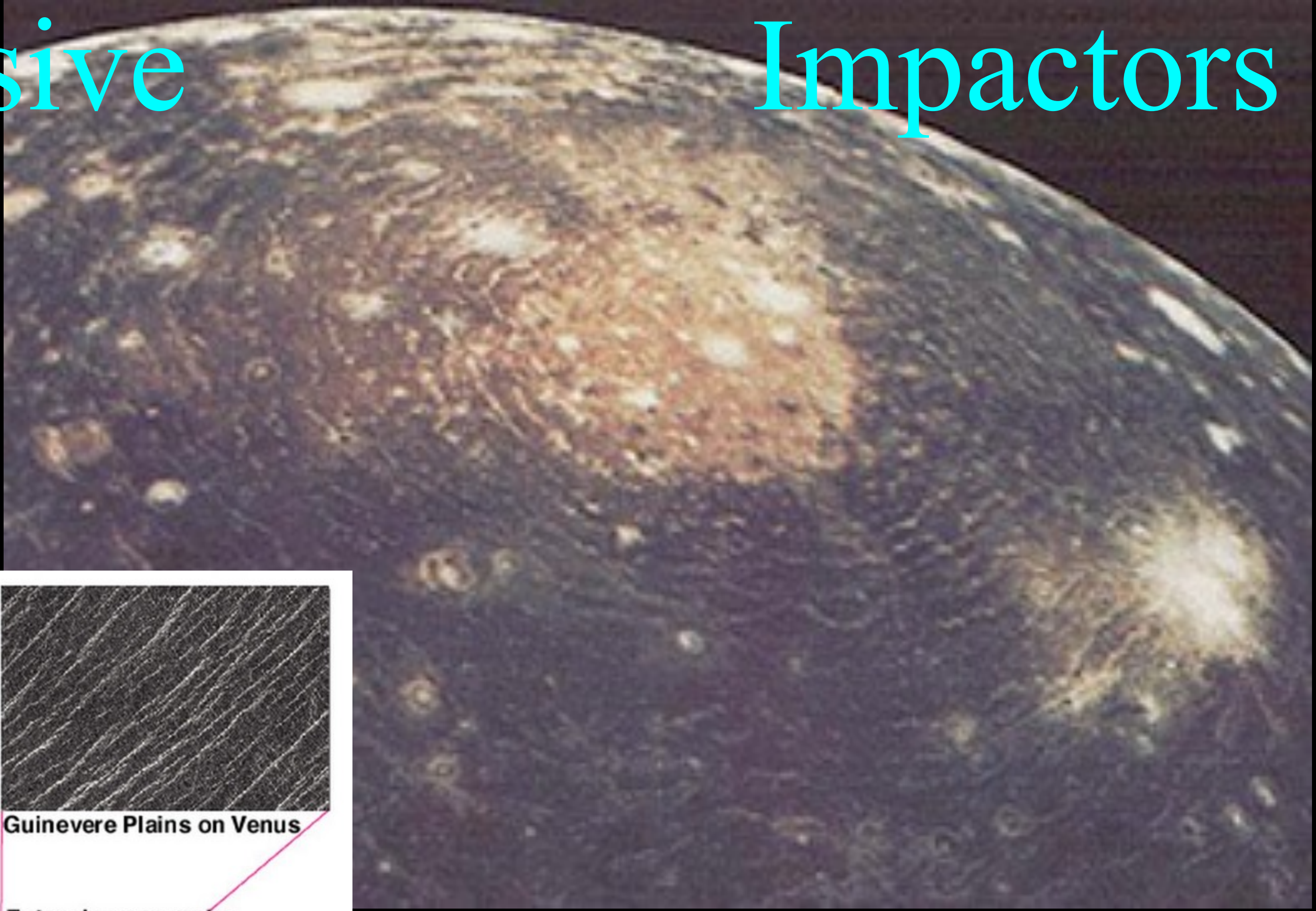
Mars, multiple strikes: 78km x 25km

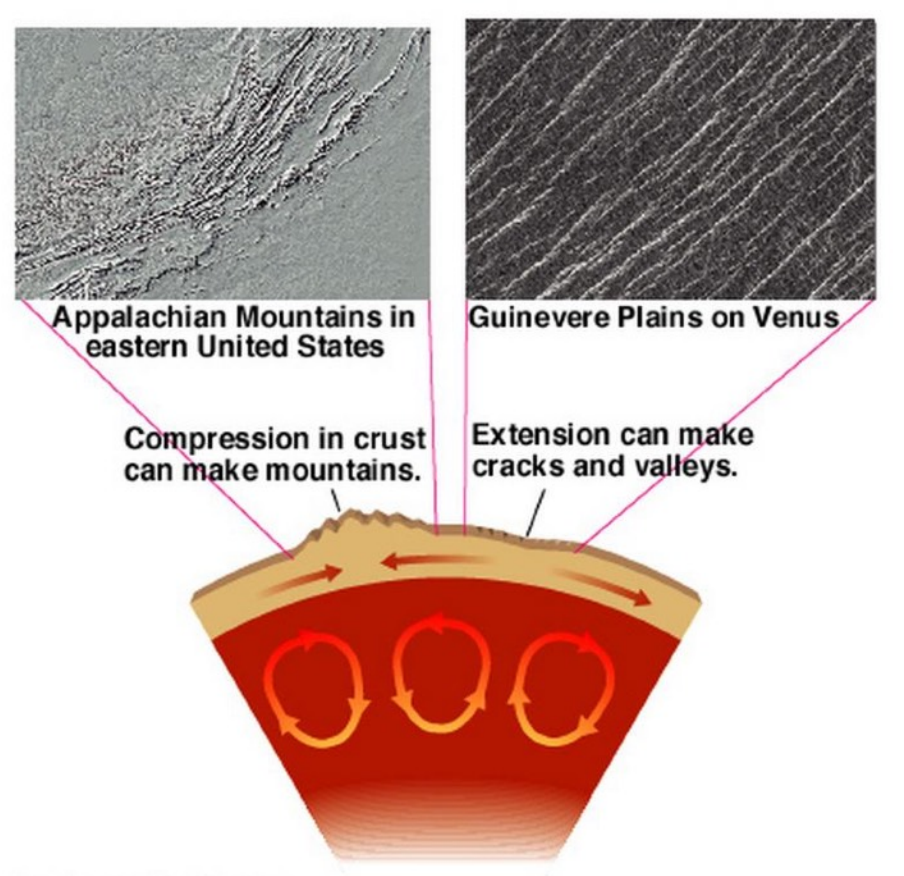
Mars: Hellas Basin



Massive Impactors

Ganymede





Circular features in huge multi-ringed basins are caused by an impactor that penetrates the lithosphere and sets up currents in the mantle.

How a Volcano, Geyser, or lava fountain Works

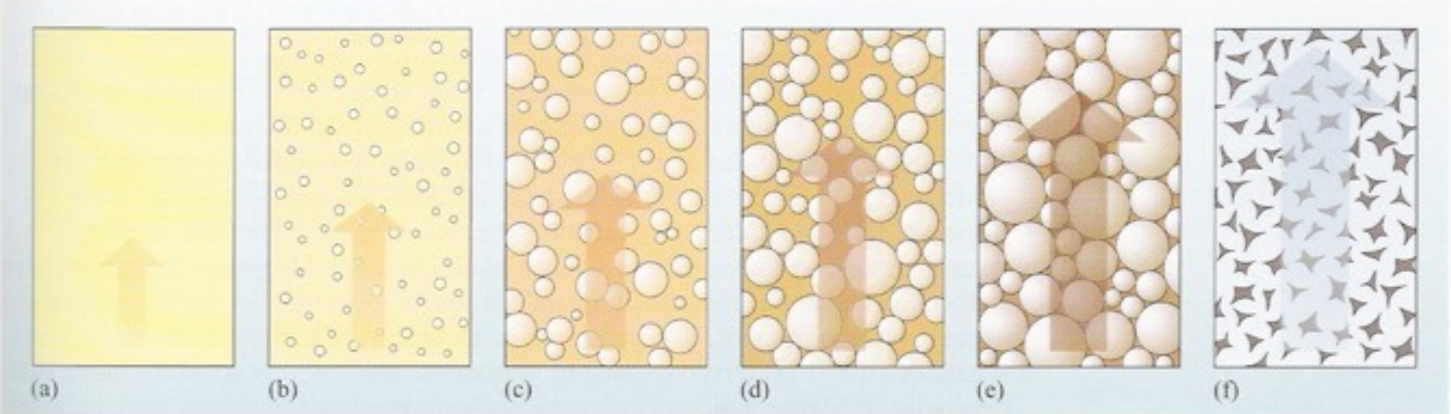
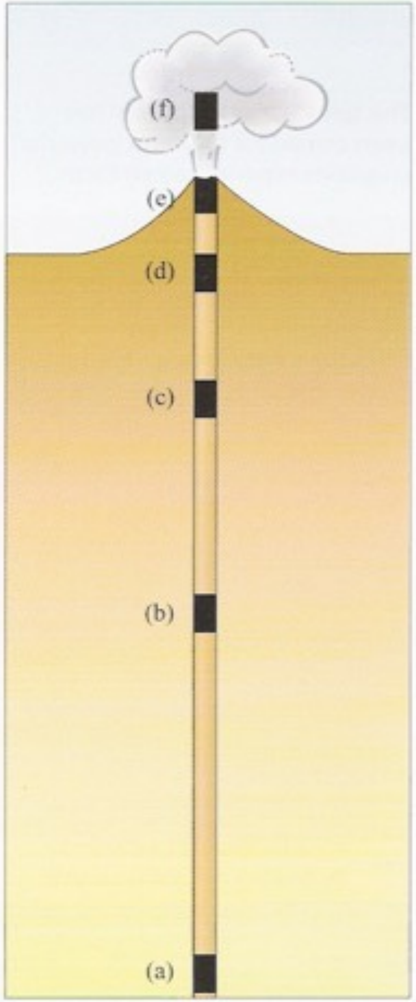


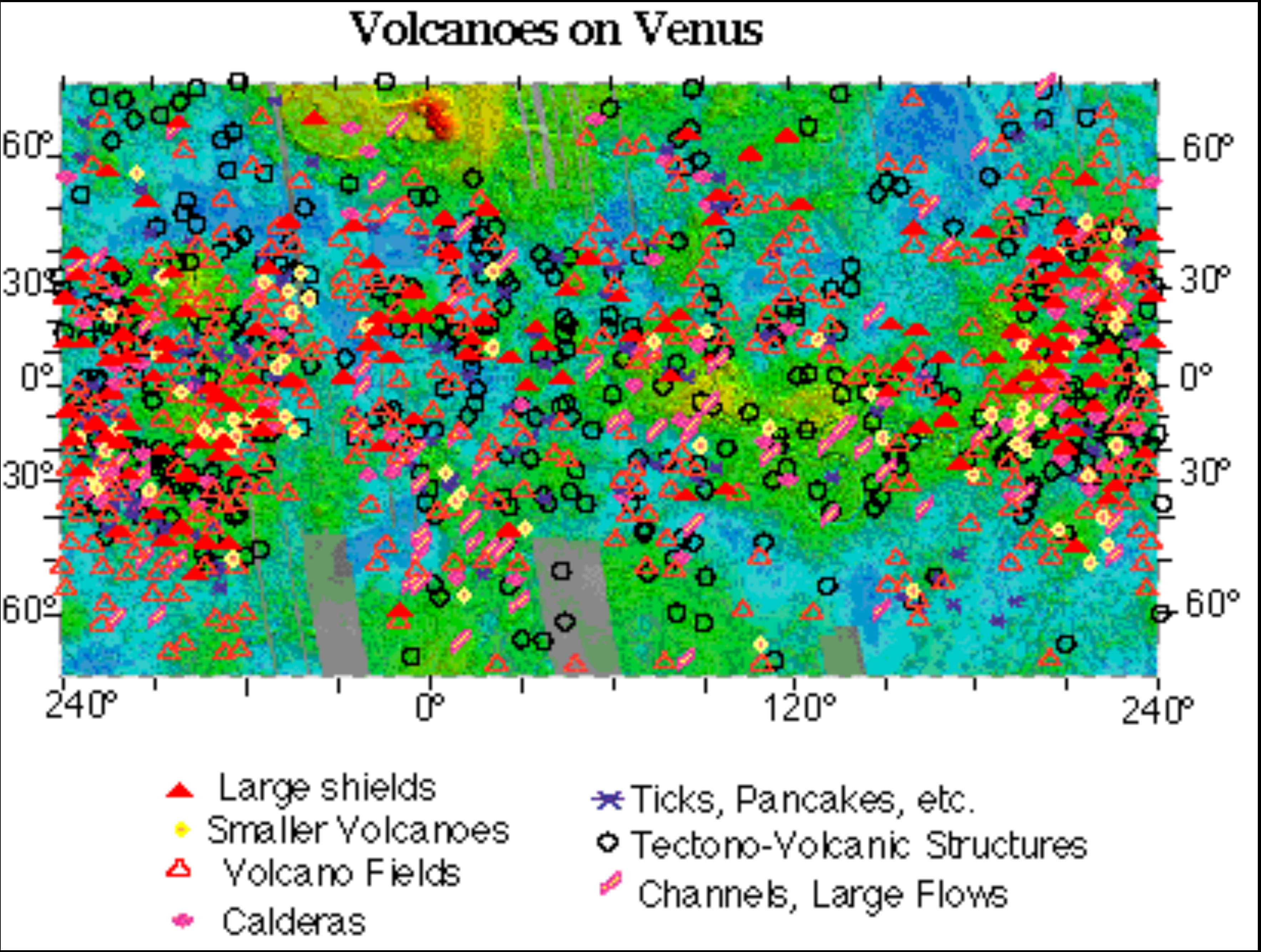
Figure 3.19 Effects of degassing in a volcanic conduit: (a–b) as the magma begins to ascend in the conduit bubbles begin to form, so enhancing the rise of the magma; (b–d) with continued ascent in the conduit additional decompression allows a greater amount of degassing, and so leads to the formation of more bubbles which then coalesce into larger bubbles and further increase the buoyancy; (e) as the rising magma accelerates in the conduit, large amounts of degassing, or else rapid degassing within more viscous magmas, can result in fragmentation and the production of pyroclastic materials (f). Stages (a), (b) and (c) are most typical of the degassing characteristics of less viscous basaltic lavas, or else gas-poor magmas, whereas stages (d), (e) and (f) are more typical of the degassing of gas-rich, or highly viscous magmas such as rhyolite.



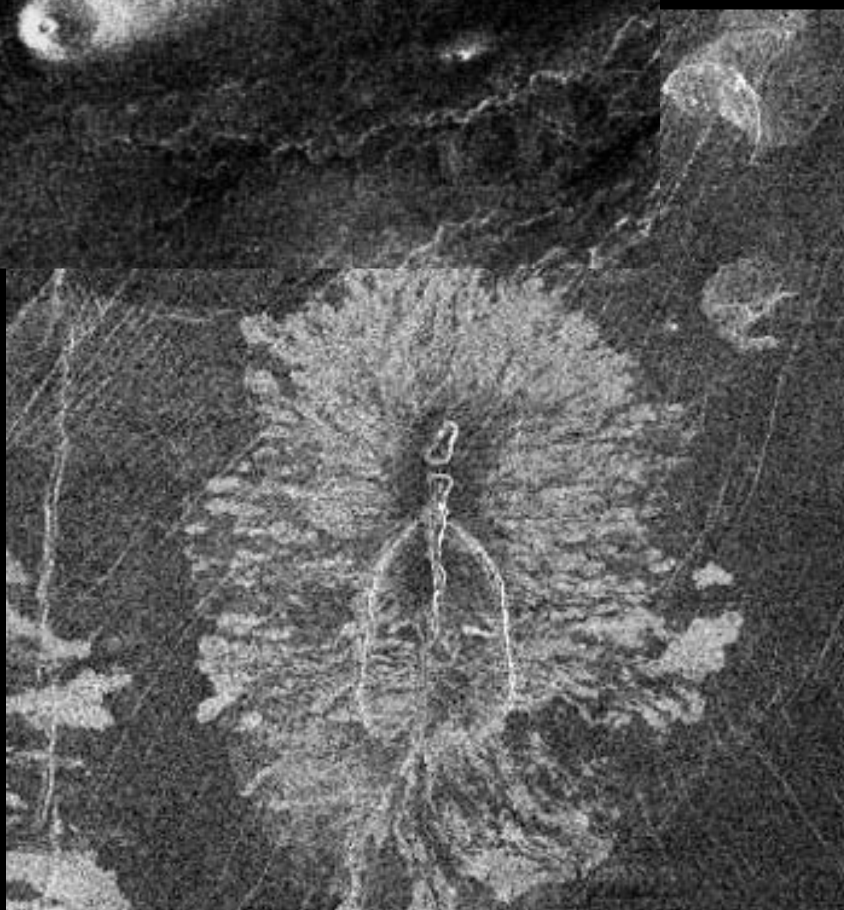
So, volcanologically speaking, what are the differences between these styles of eruption? To understand this, it is necessary to consider what happens as the magma approaches the surface. The ascent of magma is driven partly by buoyancy because partial melting typically produces liquids of different composition and lower density than the source, and partly by pressure because these liquids will flow towards the surface away from the higher pressures at depth. Buoyancy is further augmented because the magma will be hotter than the surrounding rocks as it rises surfacewards. Also, during magma ascent, pressure is reduced allowing any gases dissolved in the magma to expand and form bubbles (Figure 3.19). This bubble formation serves to make the magma even less dense and so more buoyant, thus further accelerating its ascent. Bubbles continue to expand as they rise in response to further decrease in confining pressure until they reach the surface where the gases escape into the atmosphere. If the magma is not viscous, then bubble escape may take place in an uninhibited, more gentle fashion, producing lavas with preserved bubbles, or causing fire fountaining in those cases where the gas content is higher.

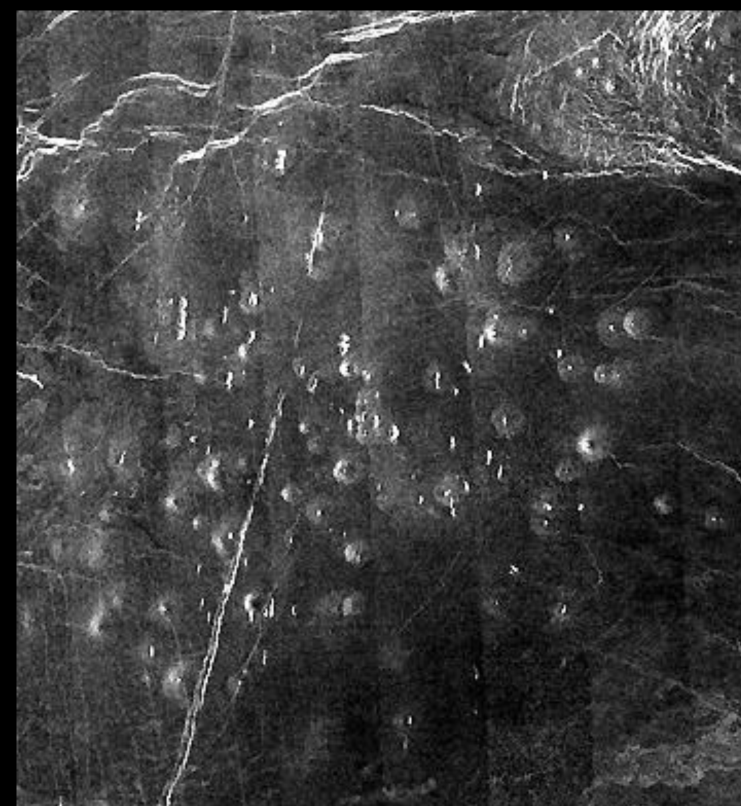
However, if the lava is viscous, such as that arising from magmas with a higher silica content, this expansion and release of gas cannot take place as easily. As a result, the magma reaches the surface containing highly pressurized bubbles which

Volcanos on Venus

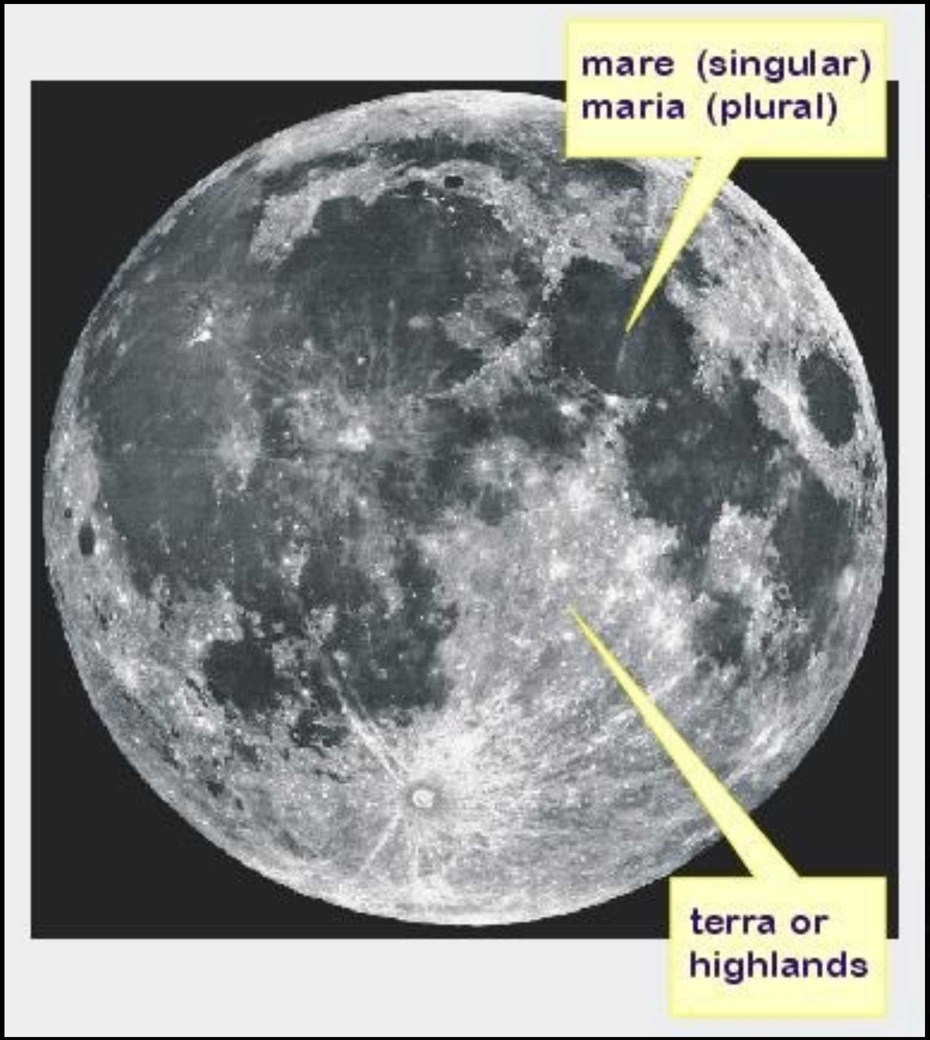


Volcanos on Venus





Moon and Mercury



Mare are 3.8-3.2 Gyr old

Continental Flood Basalt Province

huge flows could be created gradually over decades, their crusted surfaces allowing the molten lava beneath to be transported tens or even hundreds of kilometres from the eruptive source via **lava tubes**. Moreover, this model allows the flexible, crusted-over flow to undergo **lava inflation** from within. A basalt flow may begin at its tip as only a few centimetres thick, but with a continuing supply of lava it can, over time, inflate to a thickness of several tens of metres (Figure 3.17).

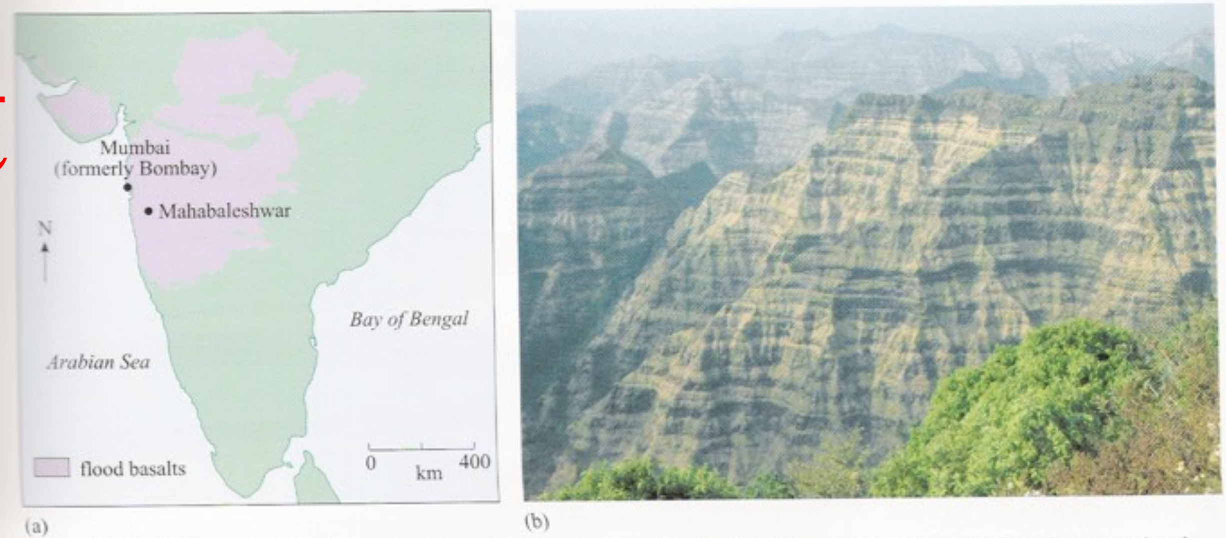


Figure 3.15 (a) The areal extent of the Deccan Traps continental flood basalt province (CFBP). Much of northwest peninsular India is covered by these 64–67 million-year-old basalt lavas, which reach a maximum thickness of 2.5 km inland of Mumbai. (b) Panoramic view across approximately 1 km thickness of Deccan lava flows, Elphinstone Point, Western Ghats, Mahabaleshwar. ((b) Mike Widdowson/Open University)

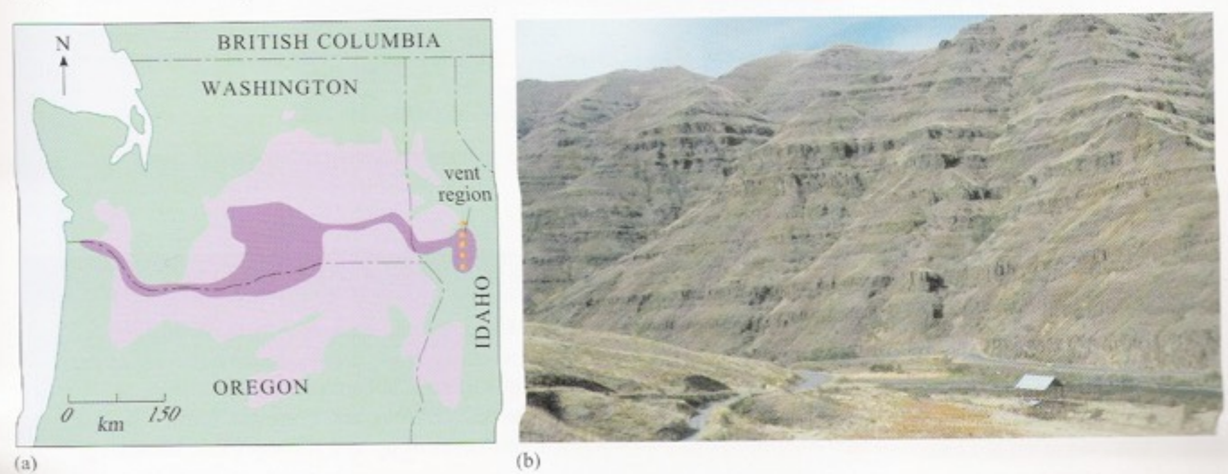


Figure 3.16 (a) The Columbia River continental flood basalt province, covering parts of Washington, Oregon and Idaho. Much of this province was erupted between 14 million and 17 million years ago, and contains some of the largest flows and flow fields yet identified on Earth. The deep purple area defines the source and extent of the 14 million-year-old Pomoma flow that can be traced for over 550 km from its source. (b) Layers of stacked lava flows in the Columbia River province of the Columbia River. The flows shown represent just a small thickness of the voluminous and rapidly erupted Grande Ronde Formation part of the succession. ((b) Steve Self/Open University)

What is Happening on Io?

Moreover, recent ideas also postulate that the rise of this hot silicate magma through Io's differentiated crust can, in some instances, cause rapid melting of the overlying sulfur-rich layers (Figure 3.39). The resulting release of gases and liquids produced in this manner would be rather like a volcanic geyser on Earth, except that on Io the fountain would consist of liquid and vaporized sulfur, rather than water! If this explanation of Io's spectacular volcanism is correct, these types of eruption are probably more akin to continuous, long-lived 'fountains' (some lasting months or years) than 'eruption plumes' produced by the type of short-lived explosive volcanoes observed on Earth.

plateau and valleys covered in sulfur. The image shows a regi[on] 250 km across. (NASA)

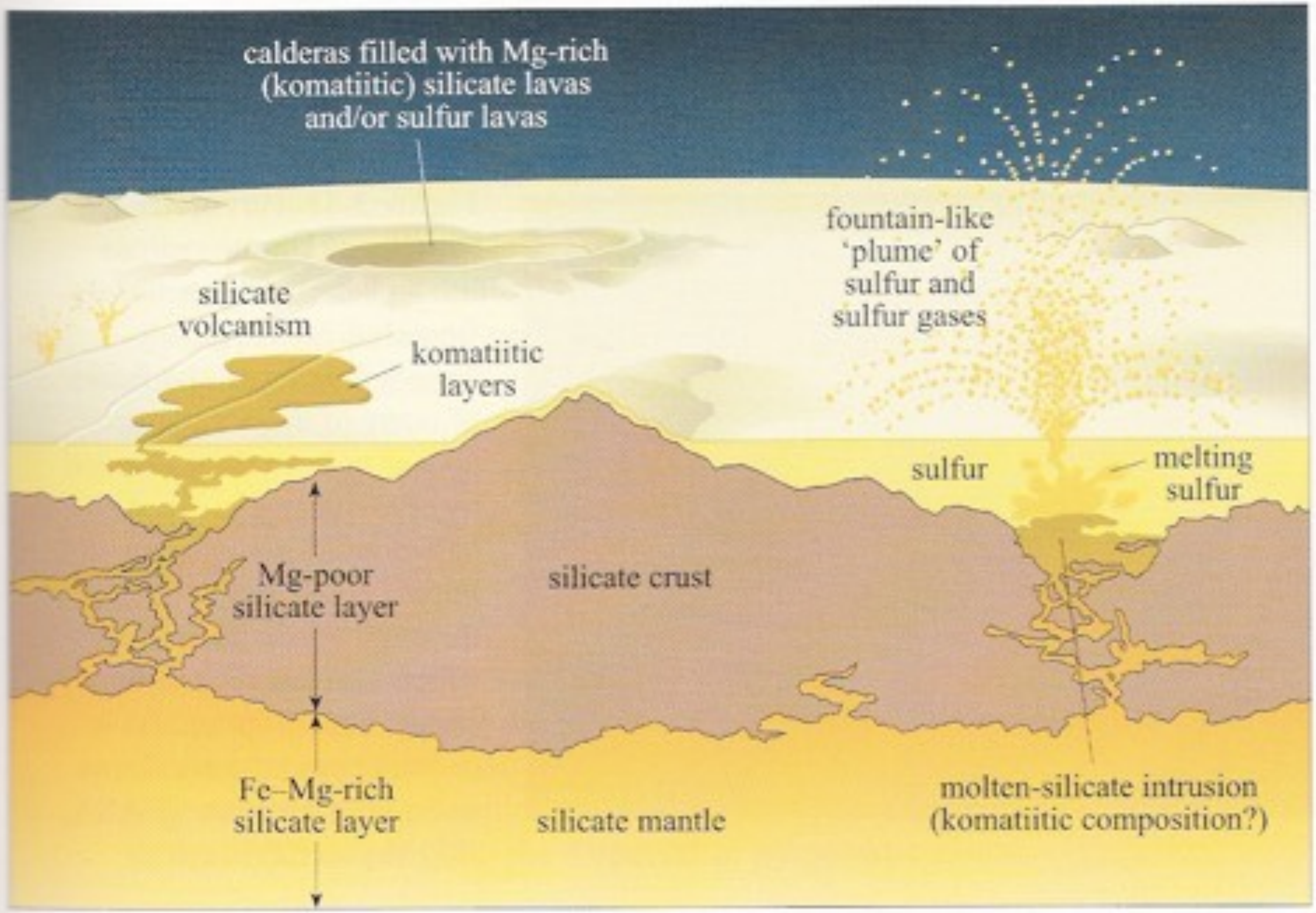
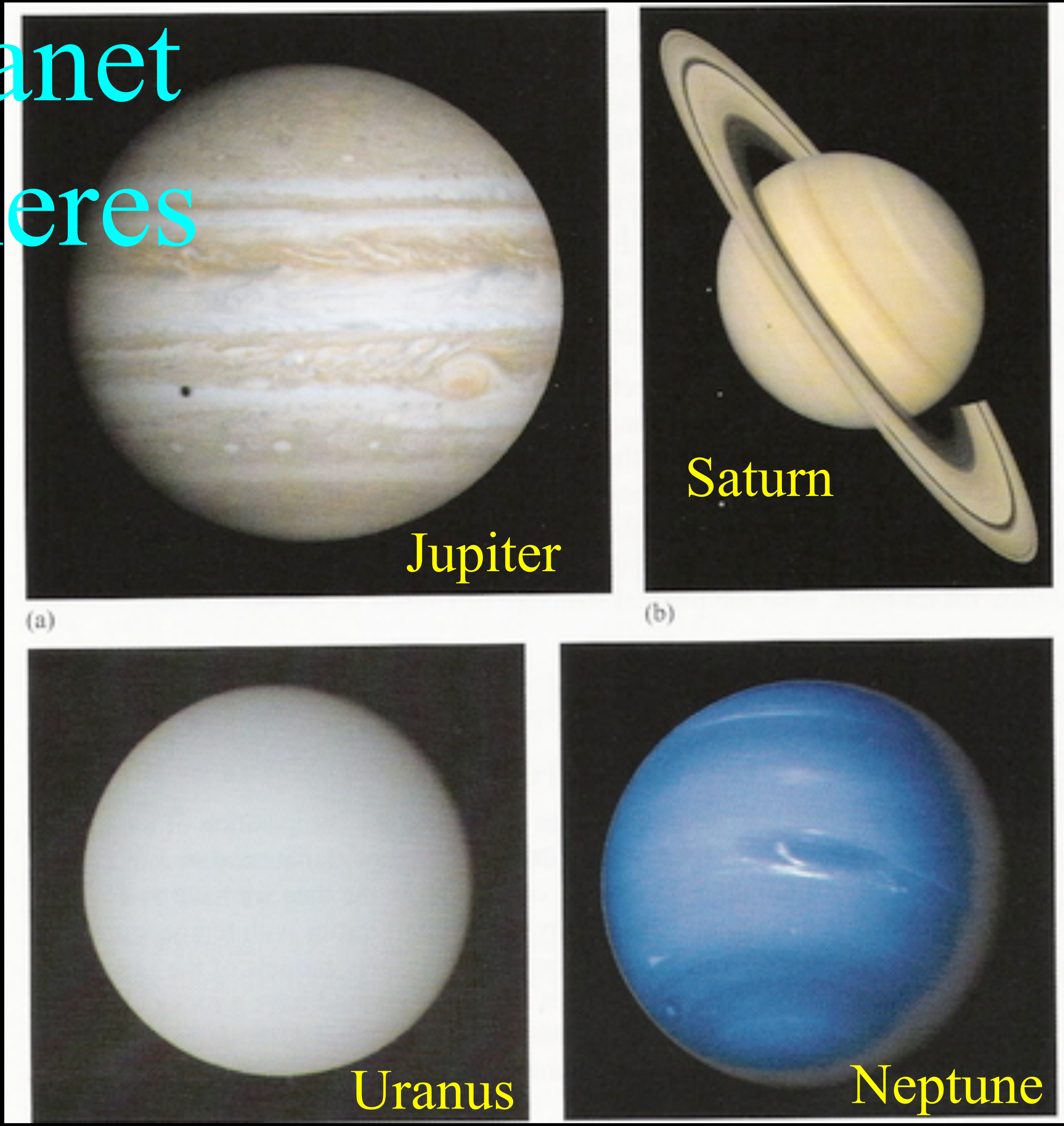


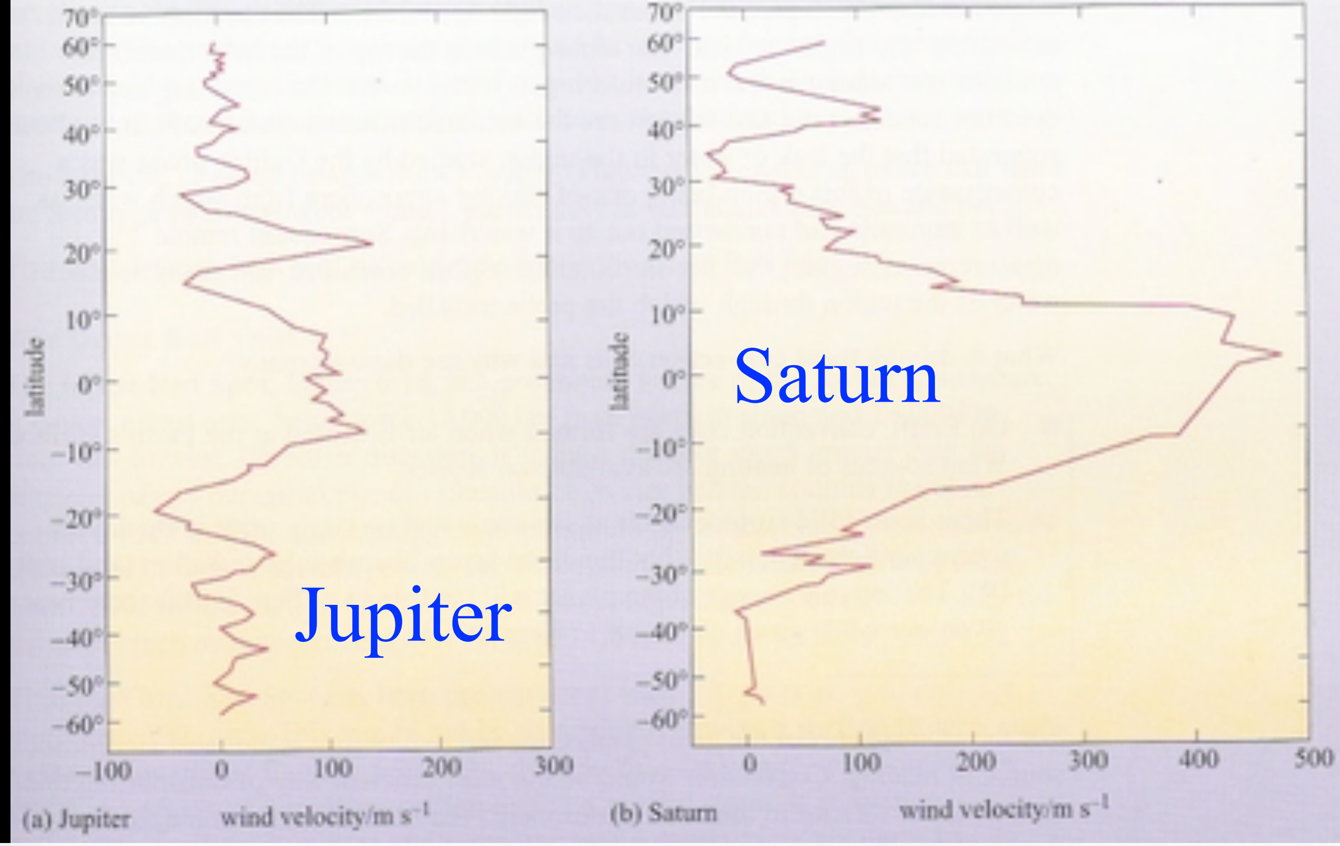
Figure 3.39 Schematic detail (... to scale) of the layers comprisi[ng] Io's upper mantle and crust (i.e. lithosphere). As described, different types of magmatism a[nd] associated volcanism are caus[ing] resurfacing of this Jovian satel[lite] and so aiding in further differentiation of its upper man[tle] and crustal layers (see also Section 2.5.6).

Giant Planet Atmospheres

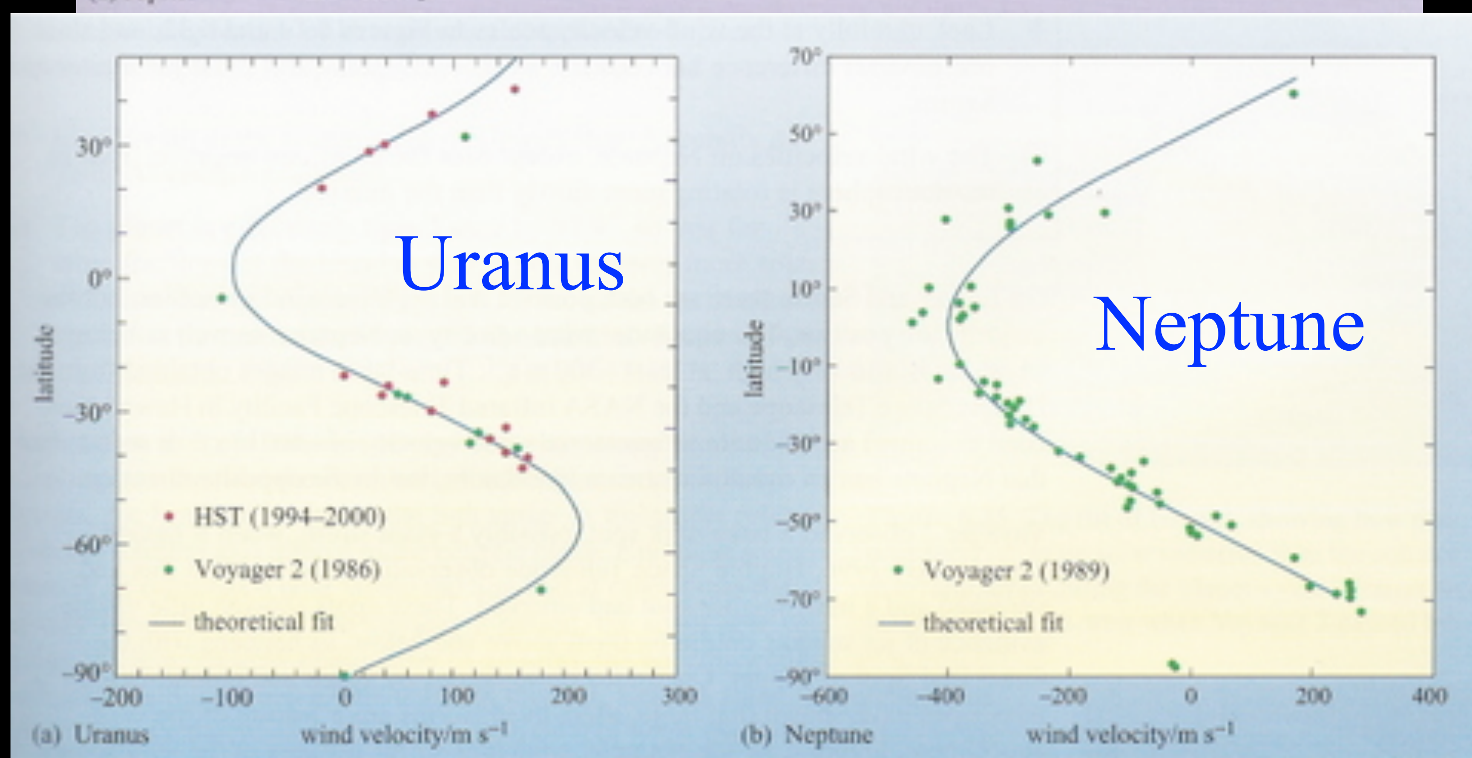
Some features are similar to Earth weather patterns



Wind Speeds



Jupiter
Saturn
latitude
wind velocity/m s⁻¹
(a) Jupiter
(b) Saturn



Uranus
Neptune
latitude
HST (1994–2000)
Voyager 2 (1986)
theoretical fit
Voyager 2 (1989)
theoretical fit
wind velocity/m s⁻¹
(a) Uranus
(b) Neptune

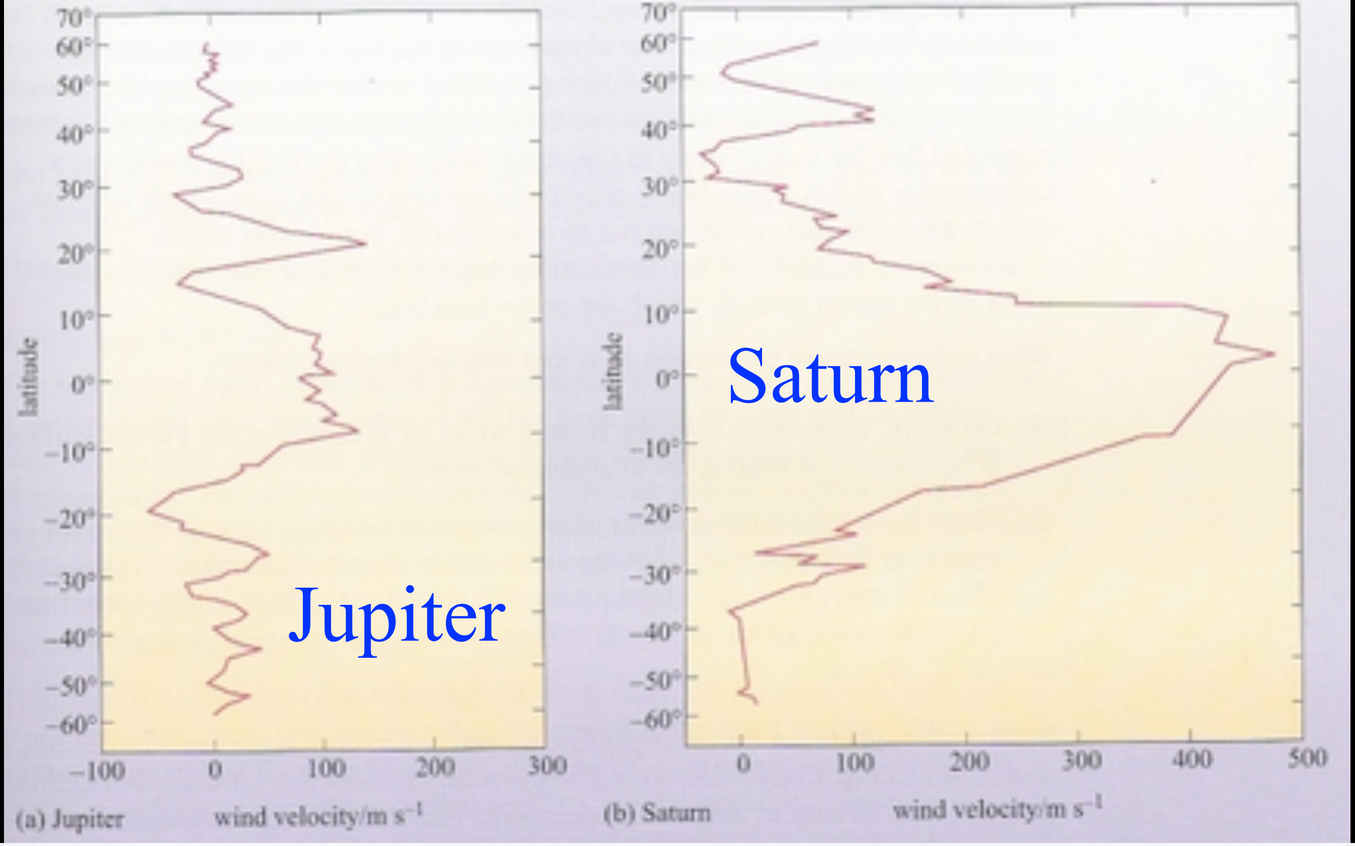
Wind Speeds

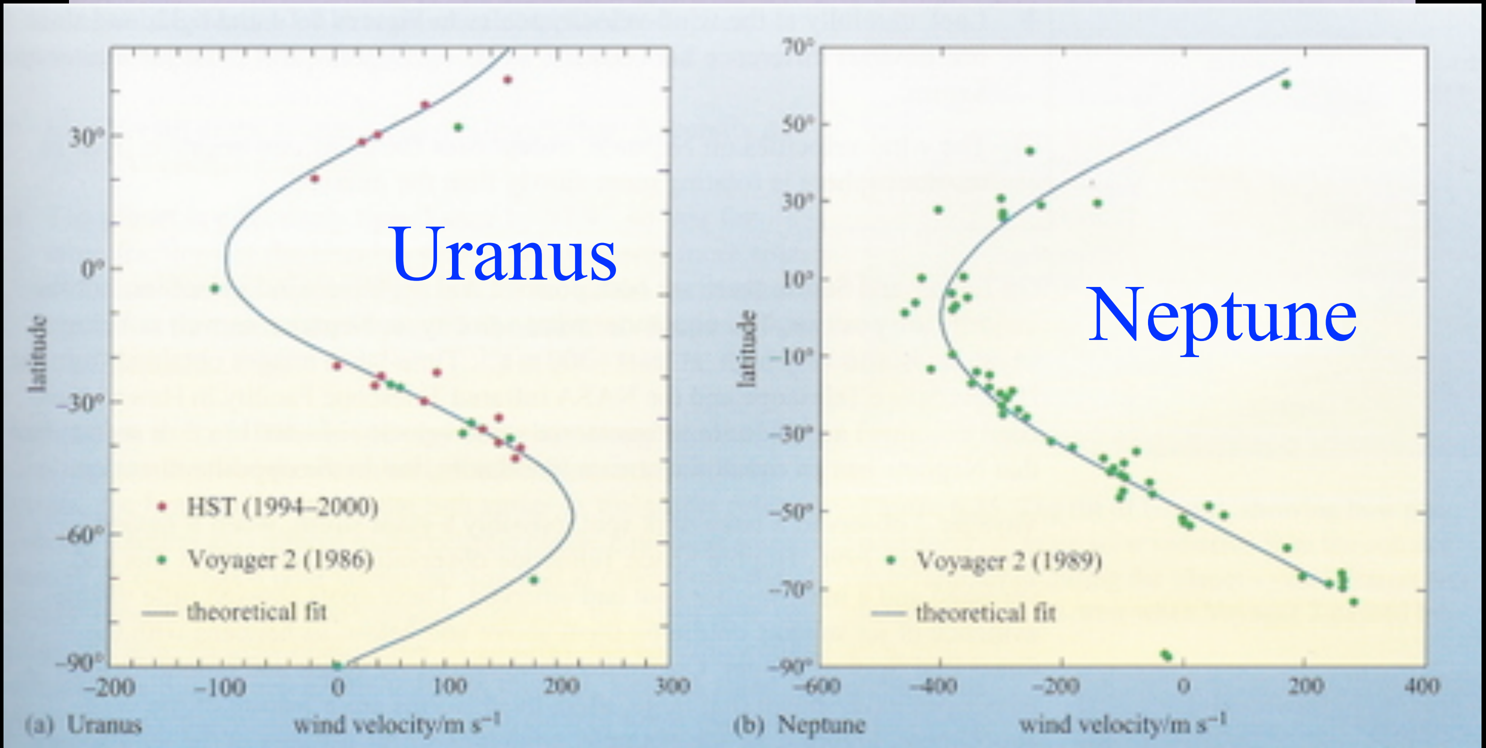
From tracking cloud features.

Interesting patterns.

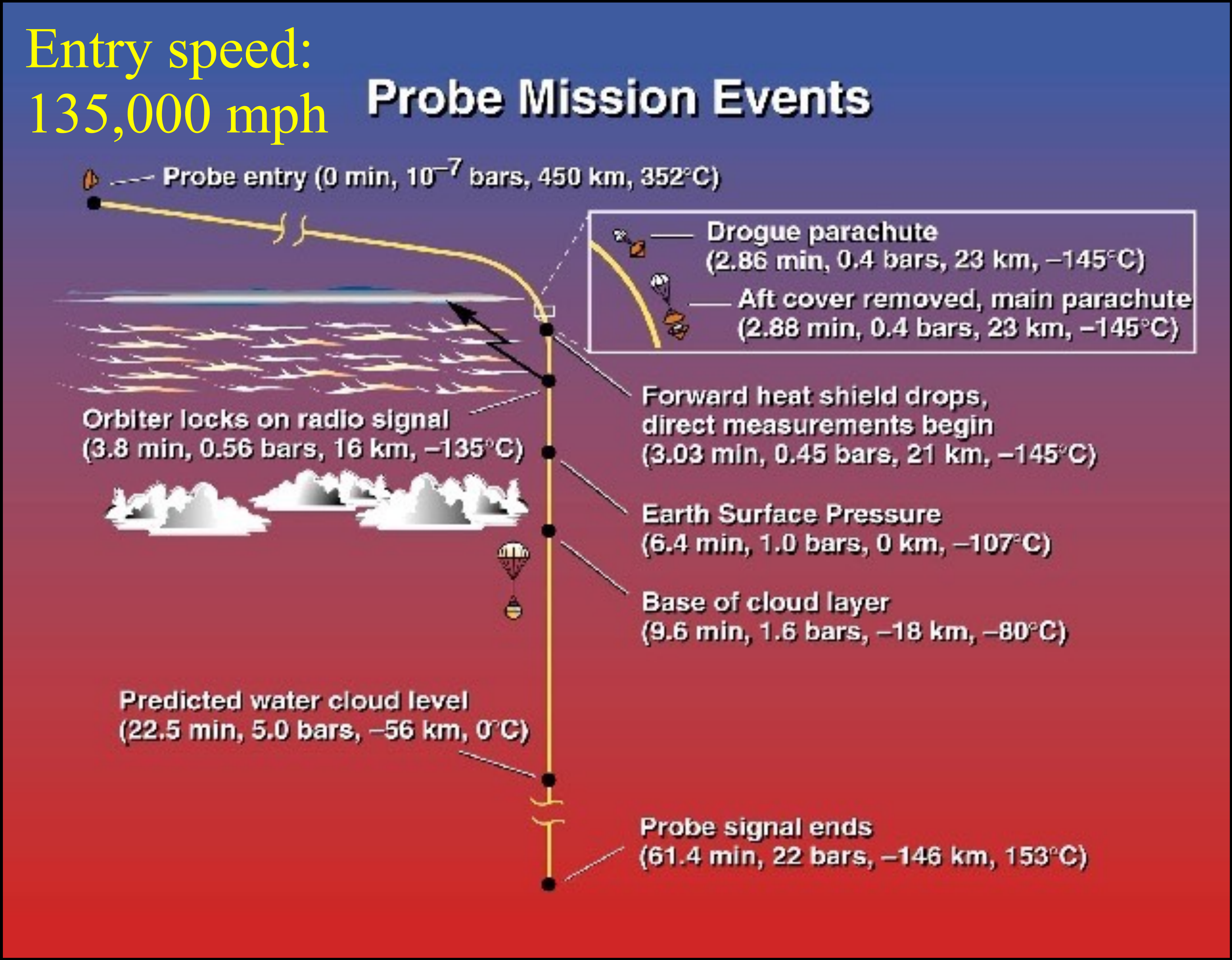
Link to Hadley cells for Jupiter.

No clear explanation for differences.

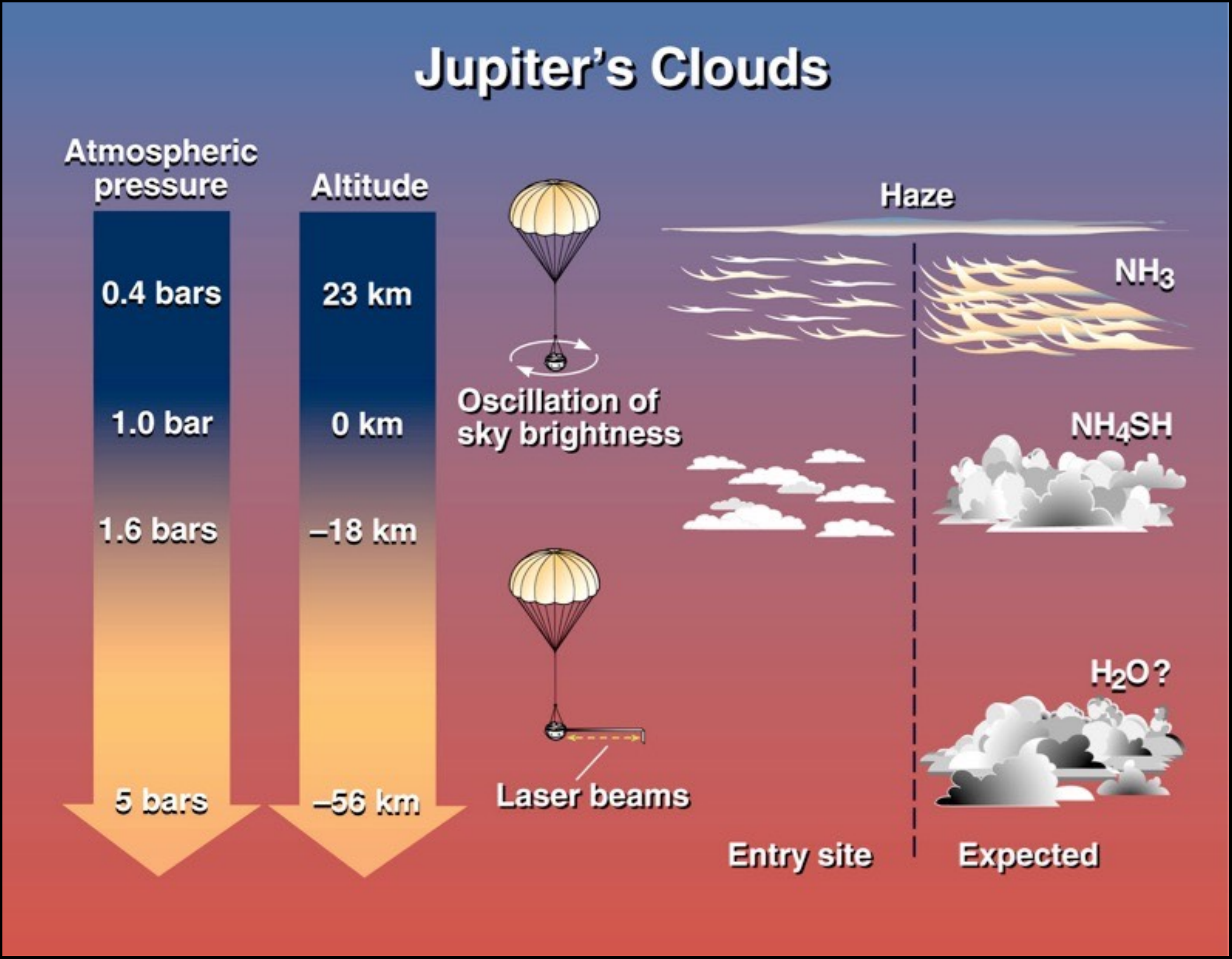




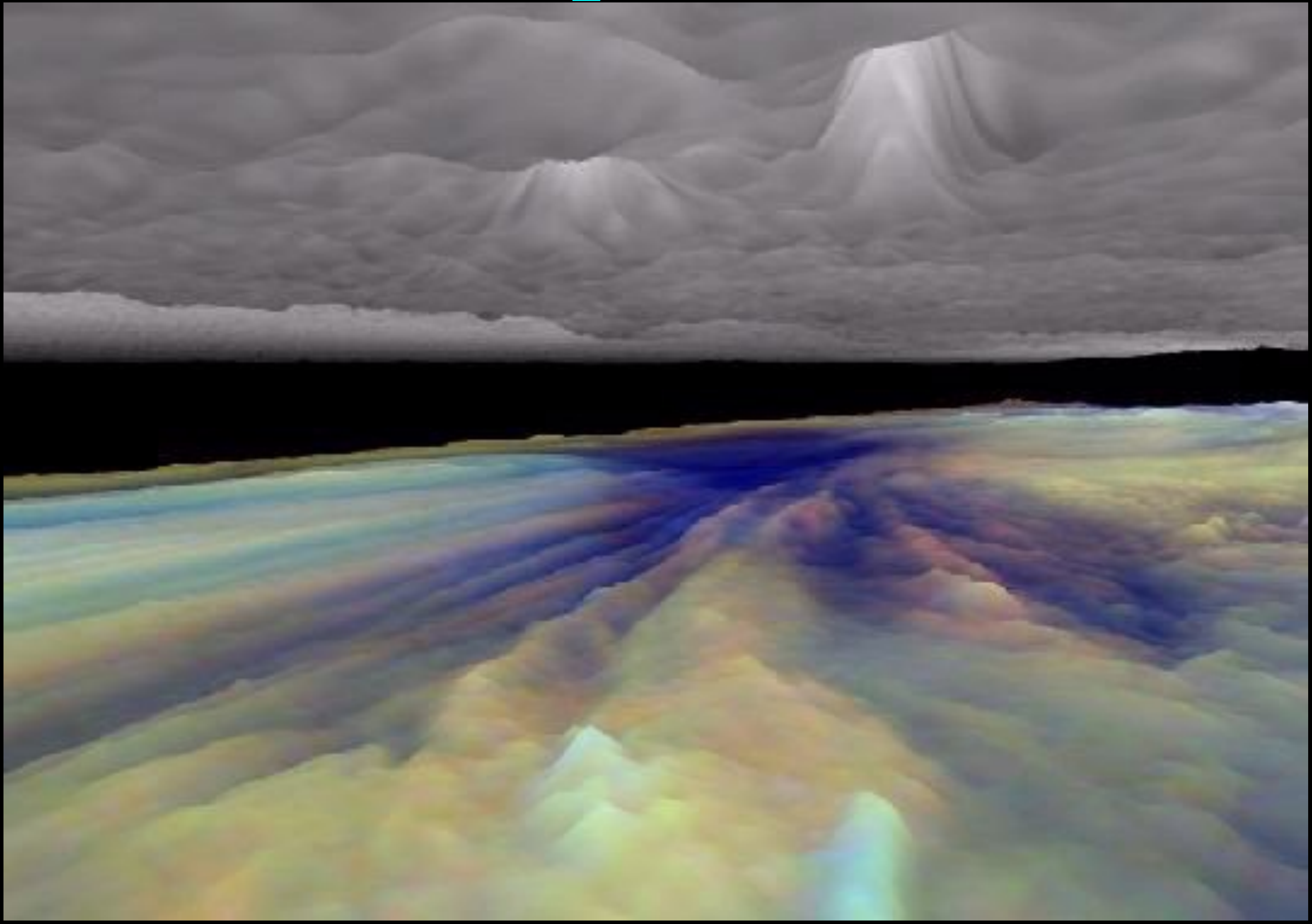
Galileo Probe: 1995



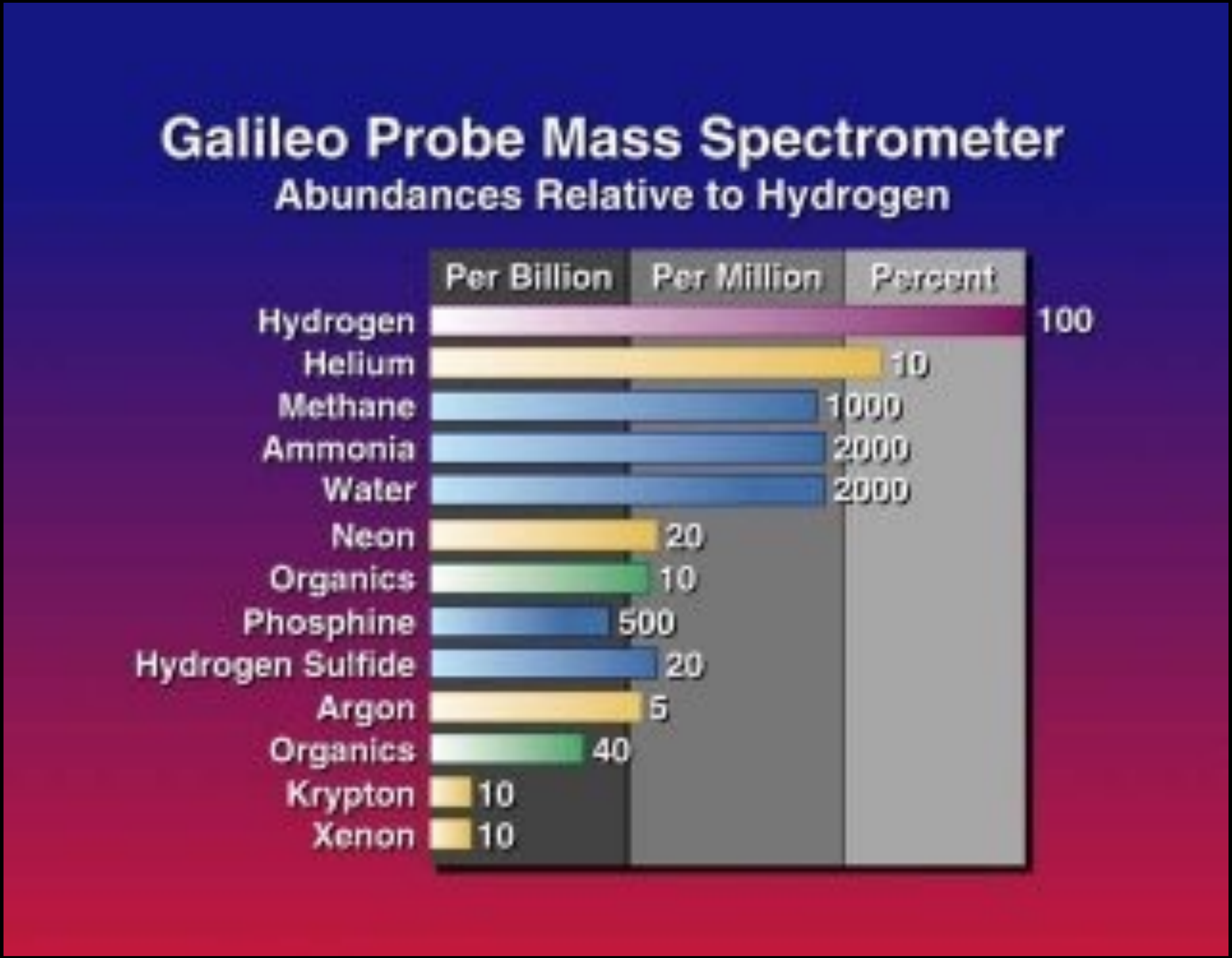
Results from Galileo Probe



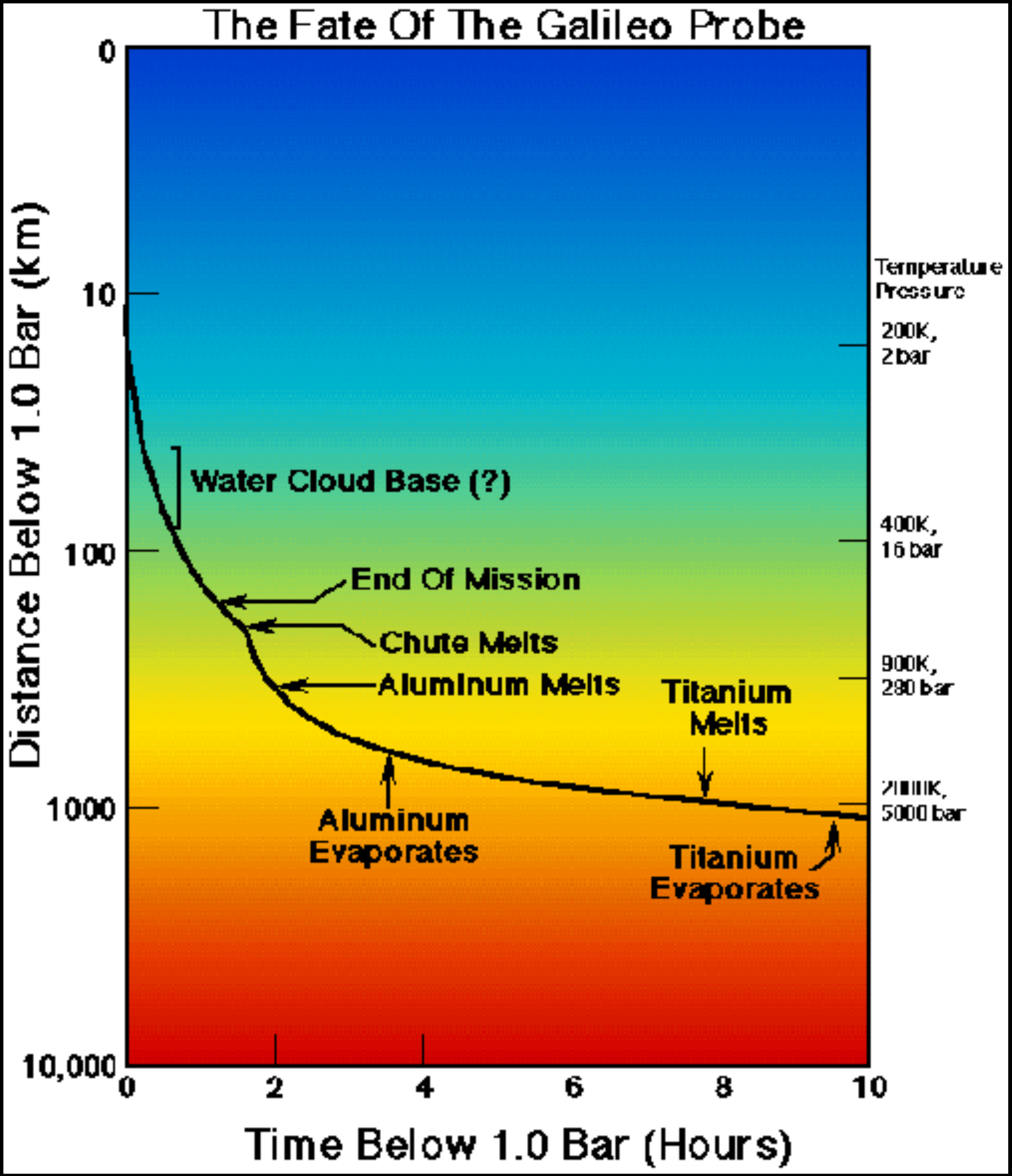
Between Jupiter's Clouds



Jupiter Composition



Galileo Probe's Descent

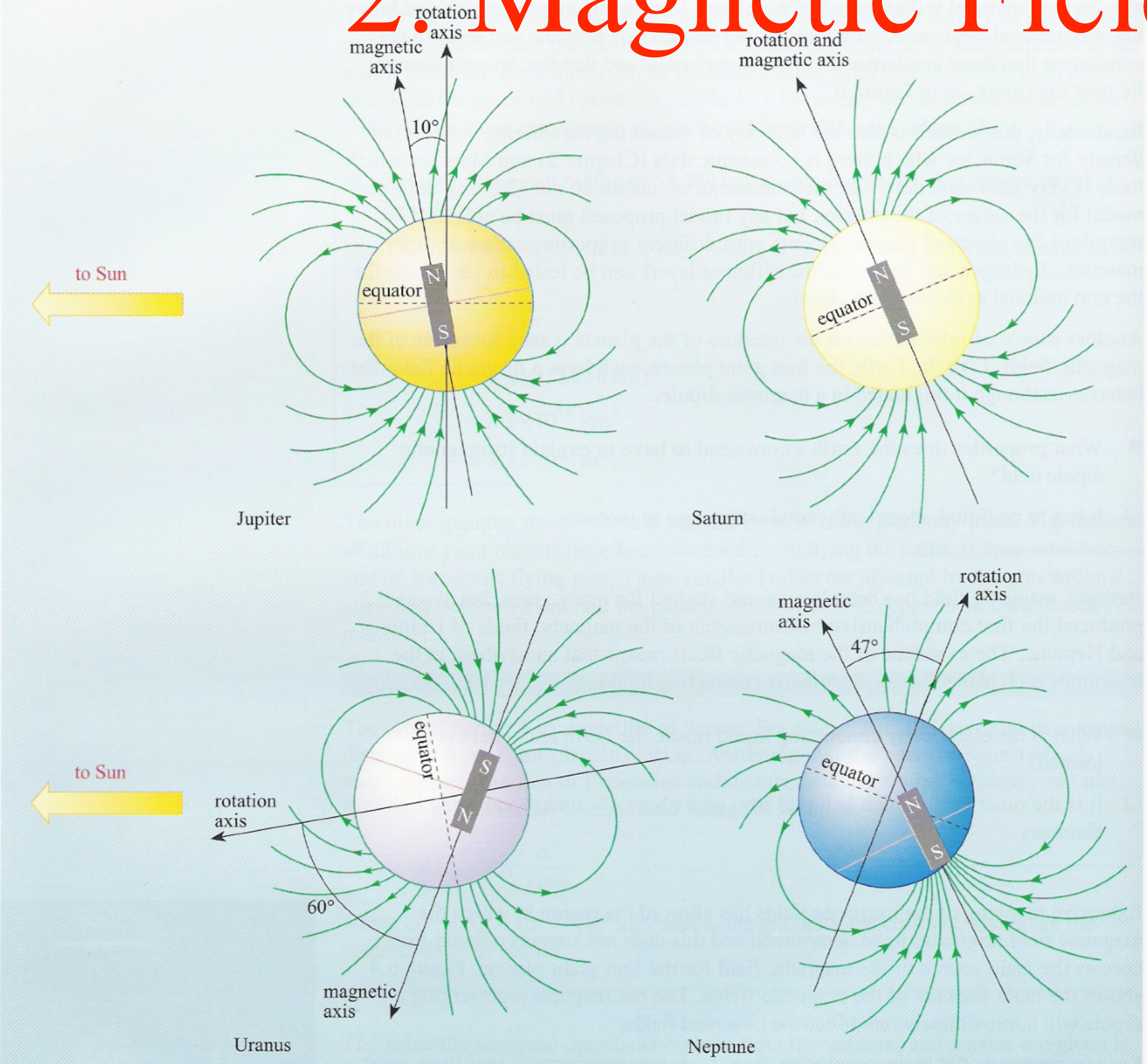


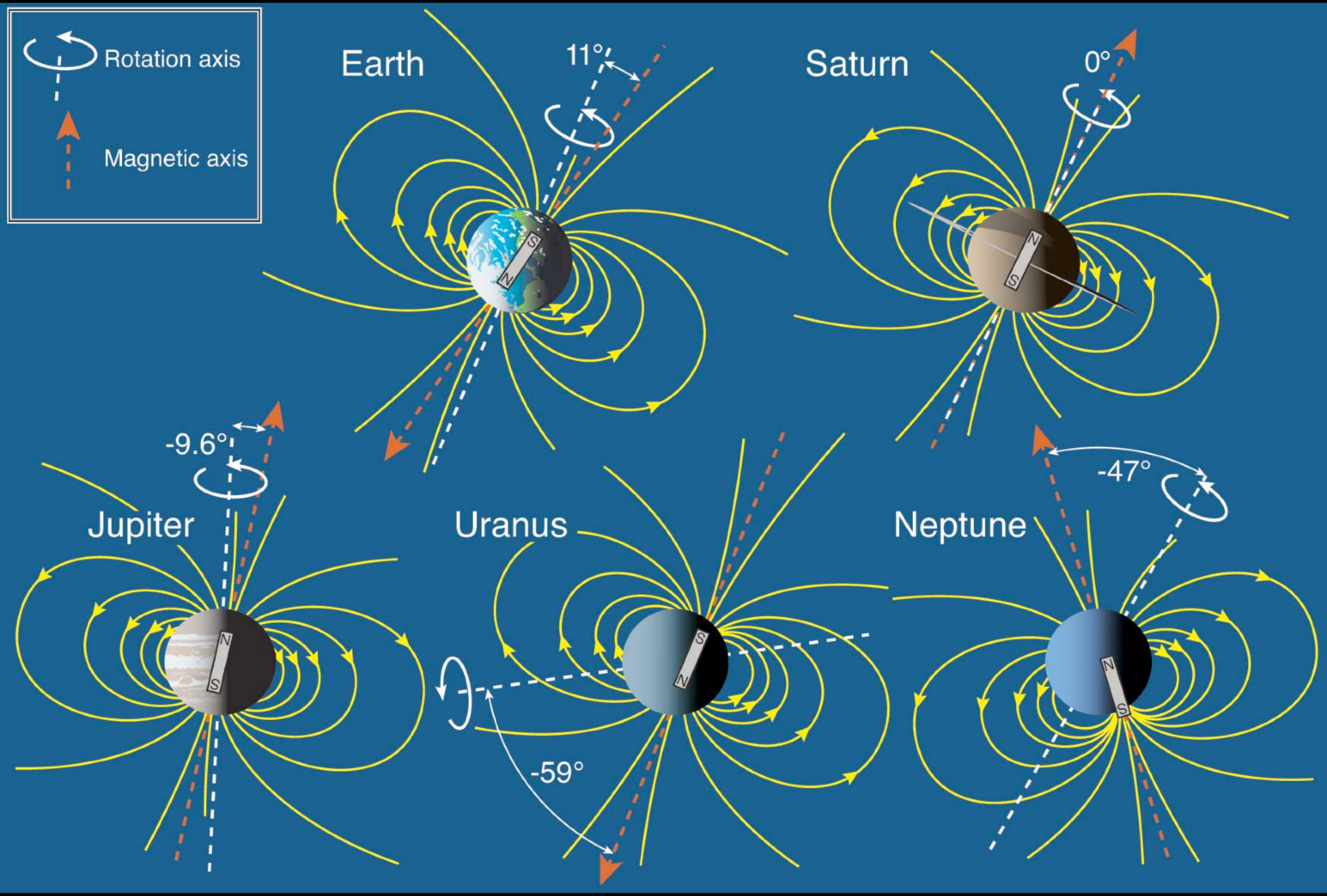
How do we know about Giant Planet Interiors?

Planet	Average Distance from Sun (AU)	Mass (Earth masses)	Radius (Earth radii)	Average Density (g/cm^3)	Bulk Composition
Jupiter 	5.20	317	11.2	1.33	Mostly H, He
Saturn 	9.53	90	9.4	0.70	Mostly H, He
Uranus 	19.2	14	4.11	1.32	Hydrogen compounds and rocks, H and He
Neptune 	30.1	17	3.92	1.64	Hydrogen compounds and rocks, H and He

1. Average Density hints at composition

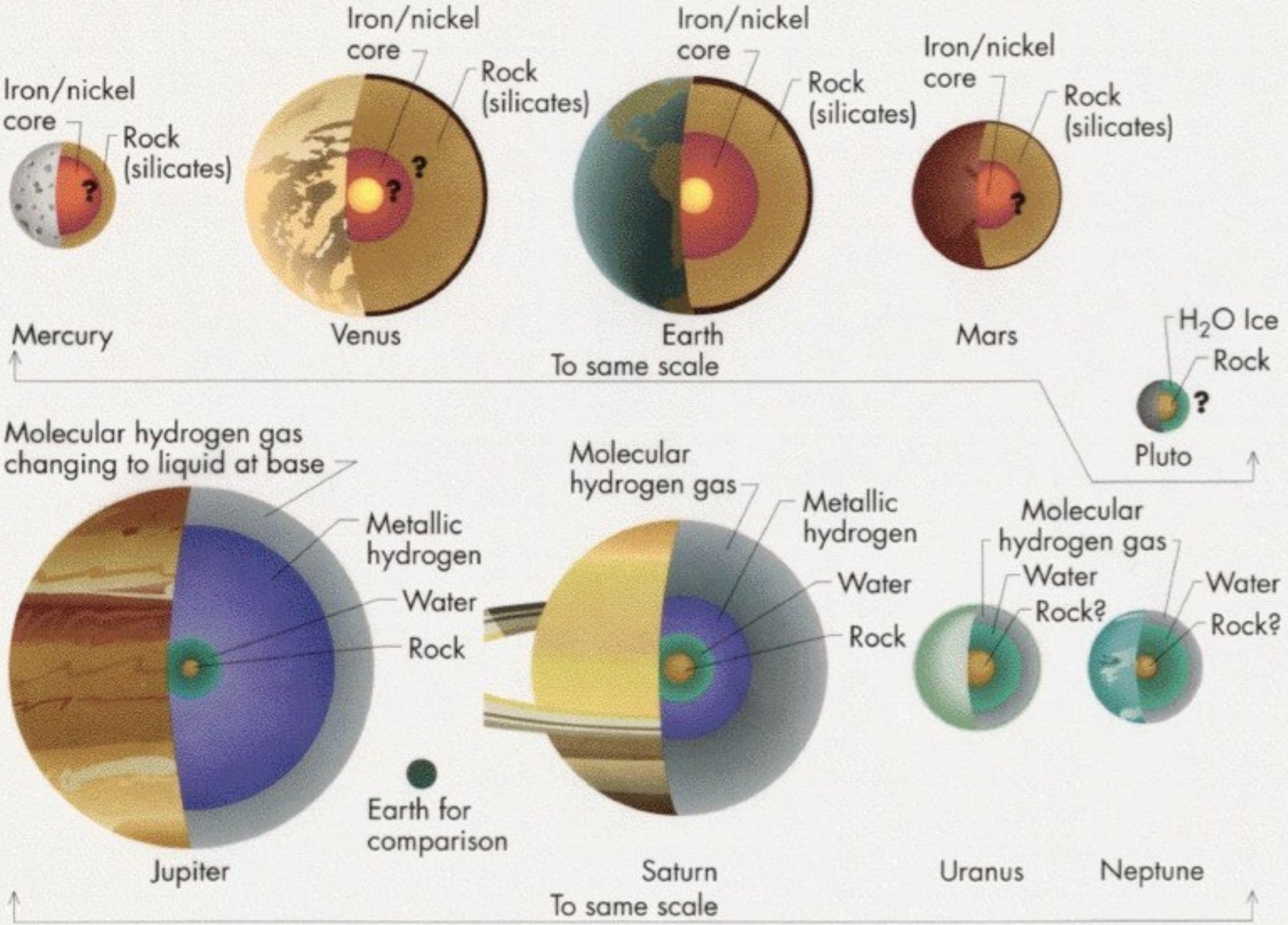
2. Magnetic Fields

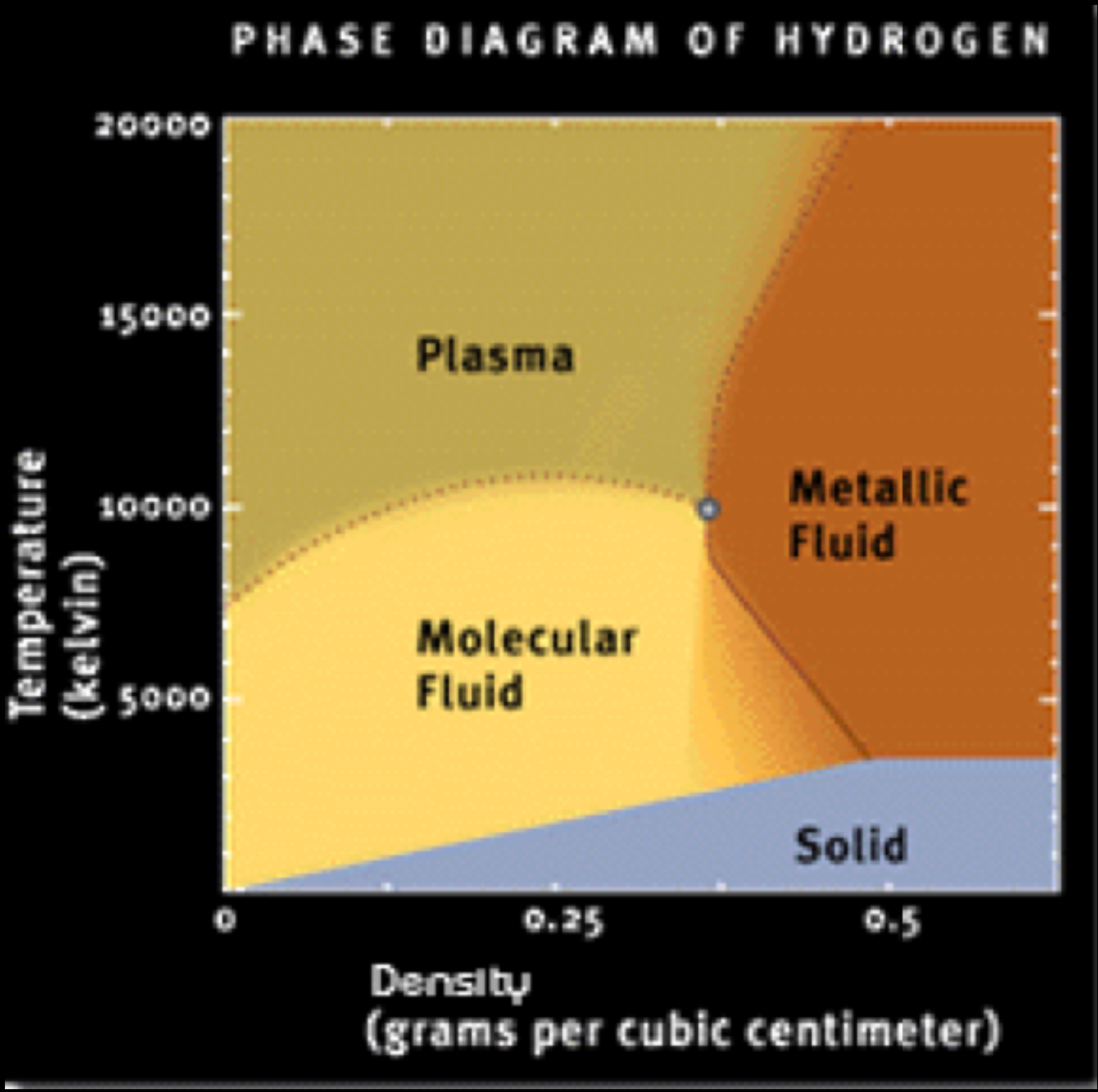




Rotation axis
Magnetic axis
Earth
11°
Saturn
0°
Jupiter
-9.6°
Uranus
-59°
Neptune
-47°
N
S

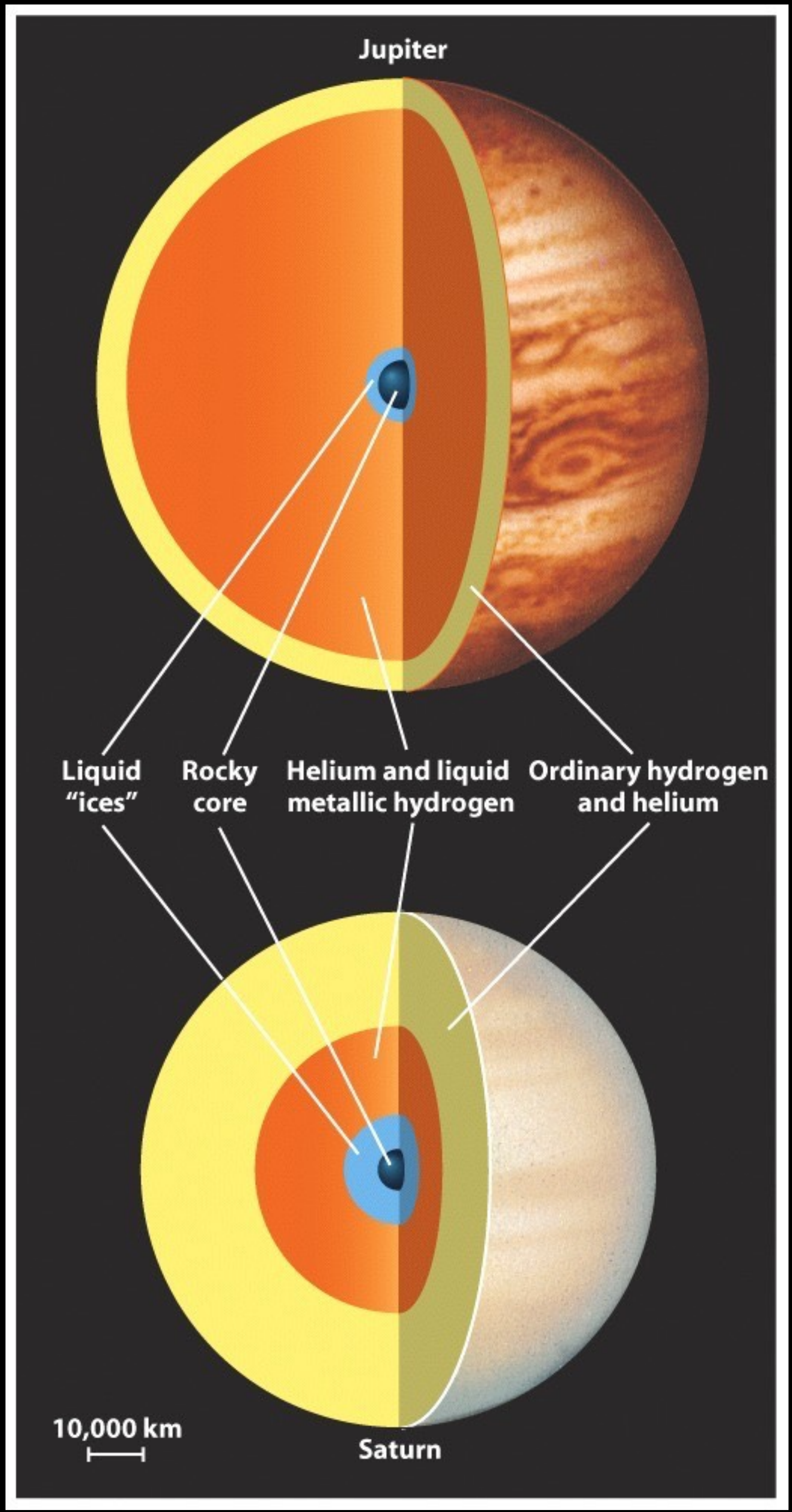
Planetary Interiors



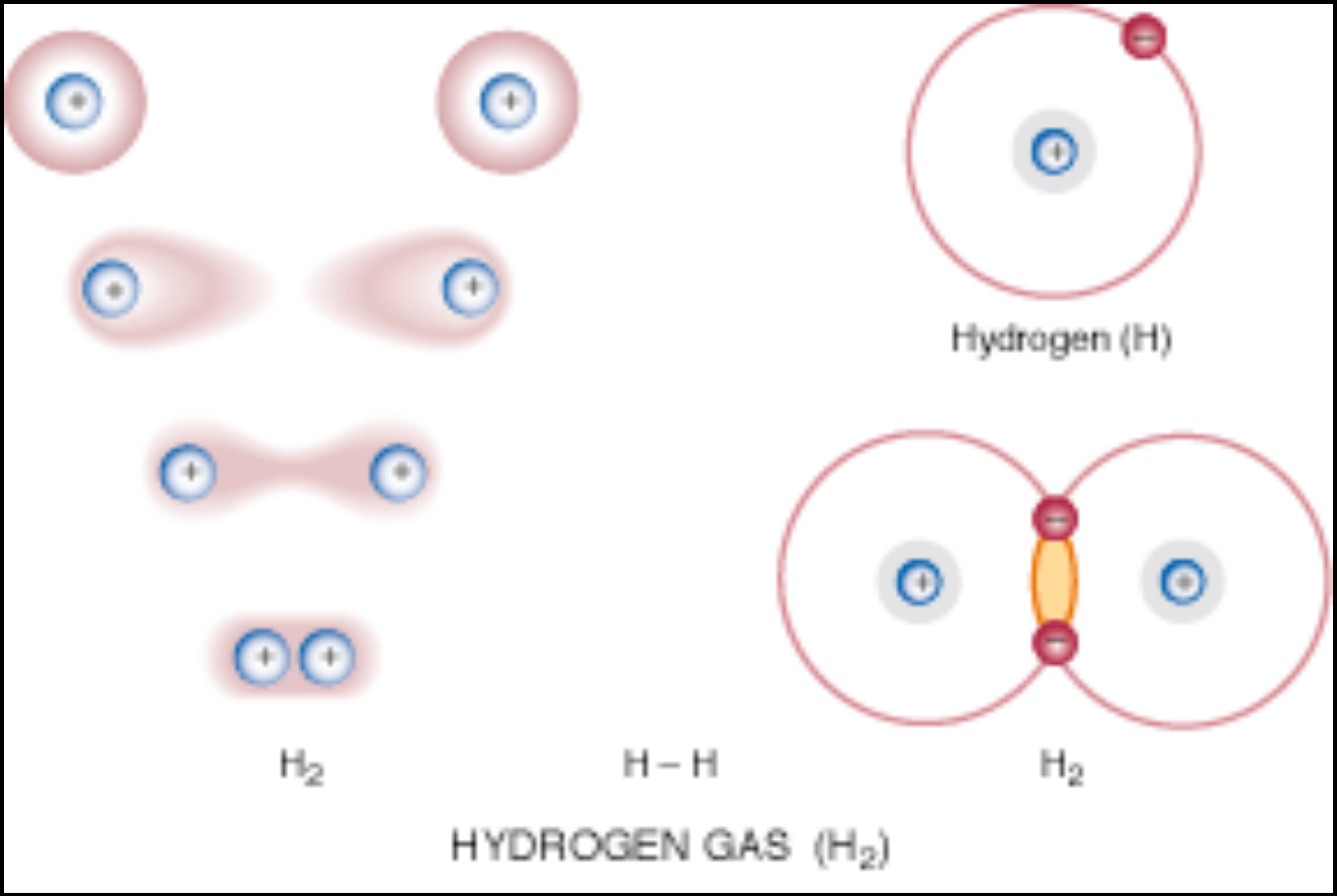


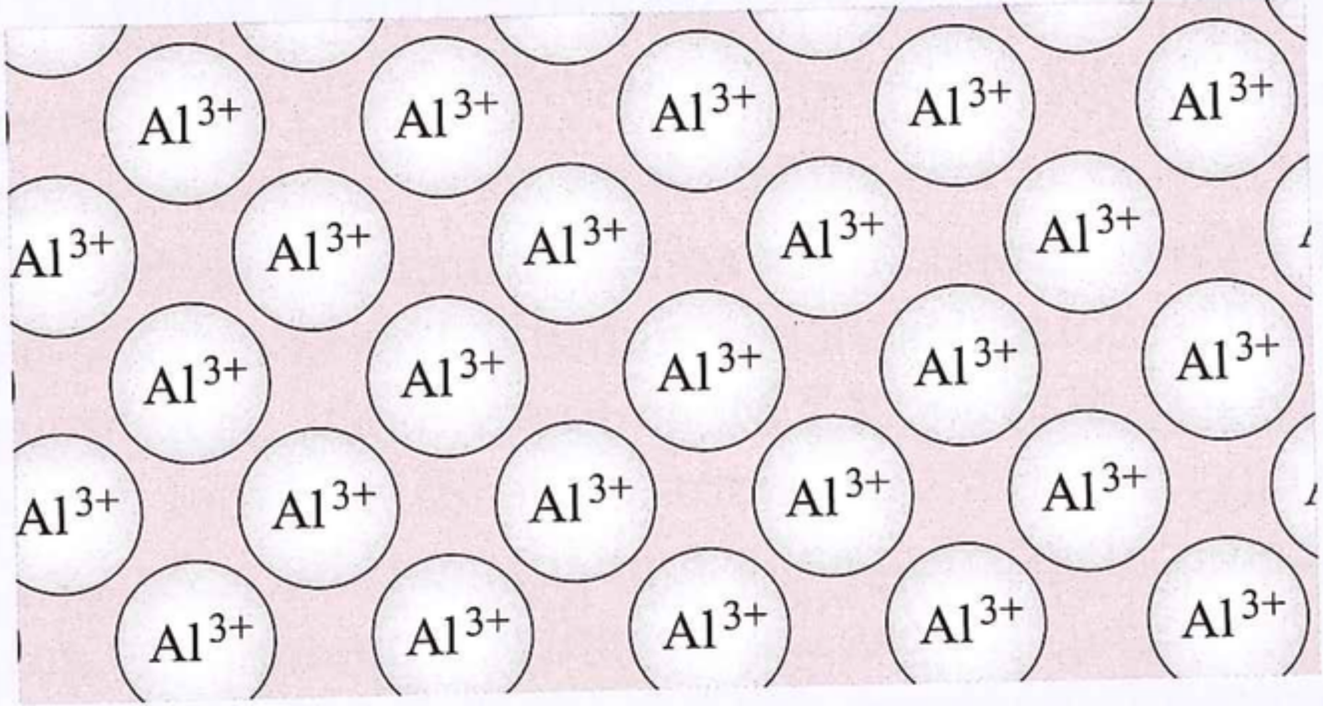
PHASE DIAGRAM OF HYDROGEN
20000
15000
10000
5000
Temperature (kelvin)
Plasma
Metallic Fluid
Molecular Fluid
Solid
0
0.25
0.5
Density (grams per cubic centimeter)

Why is the Ordinary H and He layer thinner on Jupiter?



Molecular Hydrogen

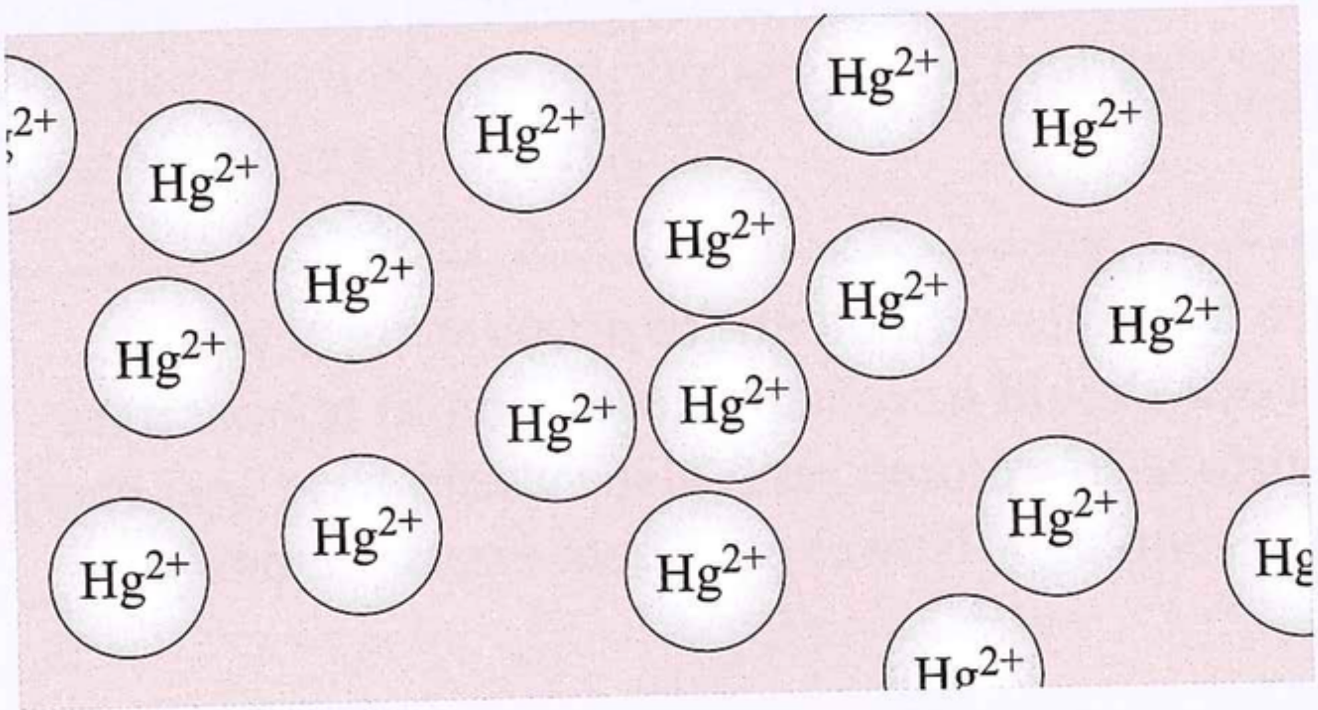




Solid

Figure 6.6 Aluminium ions (Al^{3+}) arranged as though in a crystal of aluminium. The electrons 'lost' from the atoms wander freely through the solid.

Metallic Substances



Liquid

Figure 6.7 Mercury ions (Hg^{2+}) arranged as though in liquid mercury. The 'lost' electrons are free to travel through the liquid, but the arrangement of the ions is less regular than in solid aluminium.

Deep Interiors