2. The Earth as a Planet

2.1 Earth's Neighborhood

Earth, our home and the '3rd Rock from the Sun', is also called the 'Lonely Planet' because, to our knowledge as yet, earth is the only planet with the evidence of life. It is also called the 'Blue Planet' because of the abundance of water on Earth's surface.

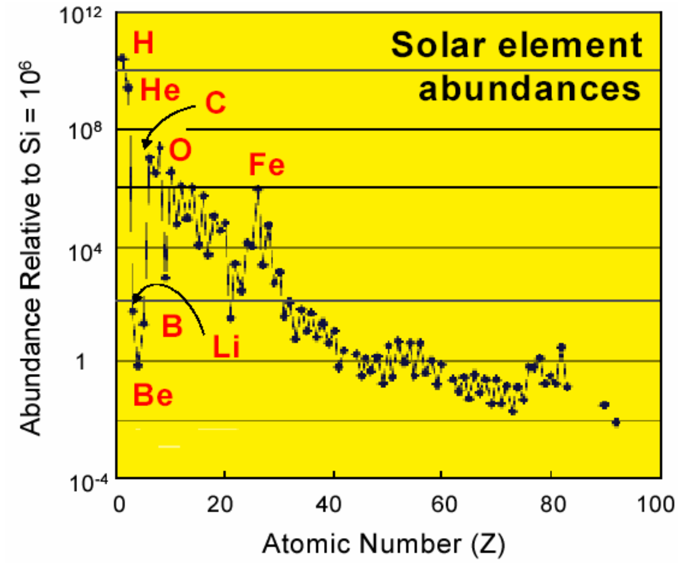
These two websites provide excellent information about the Solar System.

Members of the Solar System:

	Orbital Radius (10^3 Km)	Sideral Period (days)*	Axial Rotation (days)	Equatorial Radius (10^3 Km)	Mass (relative to Earth)	Density (Kg/m^3)
Sun	…	~240 Ma	25.38§	696.00	333×10^3	1409
Mercury	57.91	87.97	59	2.42	0.05	5410
Venus	108.21	224.70	244.3†	6.15	0.82	4990
Earth	149.60	365.26	0.997	6.38	1.00	5517
Mars	227.94	686.98	1.026	3.40	0.11	3940
Asteroids	…	…	…	…	…	…
Jupiter	778.34	4332.59	0.410§	71.40	317.89	1330
Saturn	1427.01	10759.20	0.426	59.65	95.14	706
Uranus	2869.60	30685	0.451†	23.55	14.52	1700
Neptune	4496.70	60190	0.625	22.40	17.46	2260
Pluto	5900	91×10^3	6.390	2.95	0.10	5500?

*excepting that for Sun §at equator, as the period varies with latitude †retrograde

Compositionally, only few of the elements in the Periodic Table actually dominate the Solar System. Of these, three groups of elements form its major constituents:



- the gaseous elements H and He (e.g., Sun, Jupiter and Saturn),
- the ice-forming elements C, N, O that occur as solid NH3 (ammonia) and CH4 (methane) and H2O (ice) (e.g., Uranus, Neptune), and
- the rock-forming elements Mg, Fe and Si (e.g., the inner or terrestrial trial planets — Mercury, Venus, Earth, Mars) and the asteroids and Moon

Member of Solar system	Dominant chemistry
Sun, Jupiter, Saturn	Hydrogen, Helium
Uranus, Neptune	Carbon, Nitrogen, Oxygen
Mercury, Venus, Earth (and Moon), Mars, Pluto and Asteroids	Iron, Silicon, Magnesium, Potassium, Aluminum, Calcium, Sodium

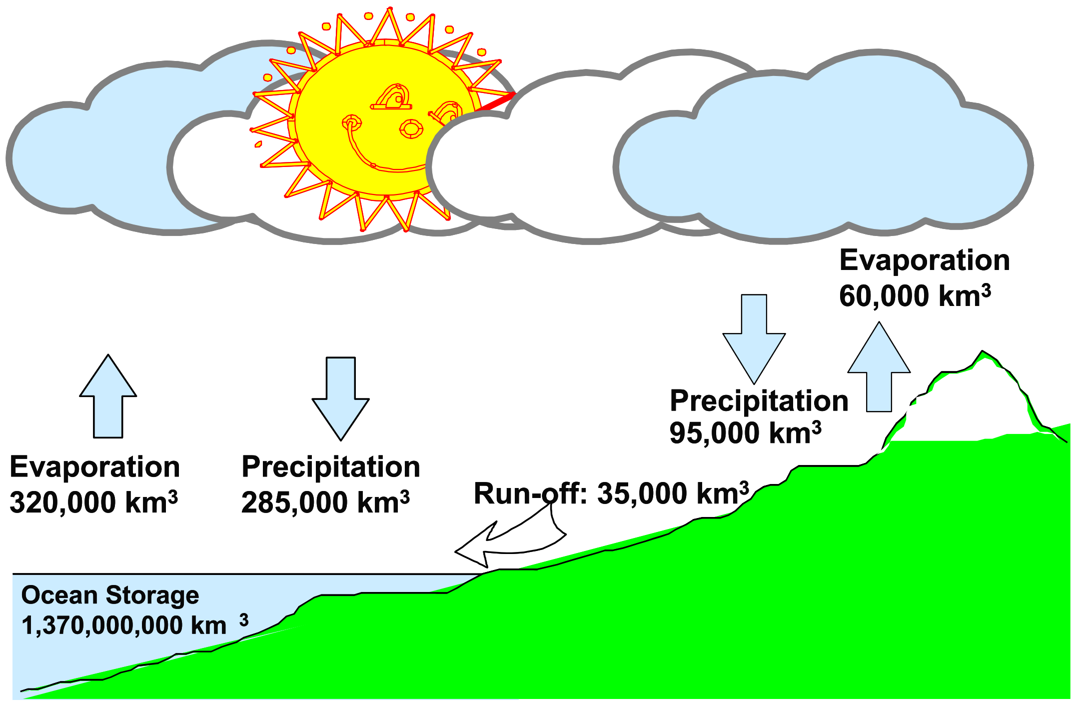
2.2 What makes Earth the “Water Planet”?

Clearly, were the supply of hydrogen and oxygen the principle reason why Earth has such an abundance of water (H_2O) then the other members of the Solar System too should have had abundant supplies of water. That is not the case, however.

Two reasons combine to explain why water, which should occur all over the Solar System wherever the temperatures are between 0ºC and100ºC, is abundant on Earth but a rarity elsewhere: (a) hydrological cycle and (b) plate tectonics.

■ The Hydrological Cycle

Of these, hydrological cycle is the continuous recycling of water between oceans, atmosphere and land. As the run-off from land would eventually fill up the ocean basins and level the land, hydrological cycle carries the seeds of its own destruction because the resulting smoothening of the surface eventually translates into the drying up of the Earth.



Note that oceans lose more water by evaporation than is returned by precipitation, while the opposite occurs on land. The run-off from land thus completes this hydrological cycle.

One can thus think of the hydrological cycle as comprising two sub-cycles. In the case of land, P (precipitation) = E (evaporation) + R (run-off) whereas, in the case of the oceans, E = P + R.

Two problems, both prescriptions for the drying up of the oceans and the diminution of hydrological cycle, arise therefore:

– What if atmosphere retained some water, instead of returning all the evaporation back as precipitation? One possibility is that we may then end-up with a foggy Earth, as was perhaps the case in the Devonian times, known as the “Age of the Fish”, when the overall climate was appreciably arid. Be that as it may, the run-off from land is then likely to be less, so that oceans should eventually dry up.

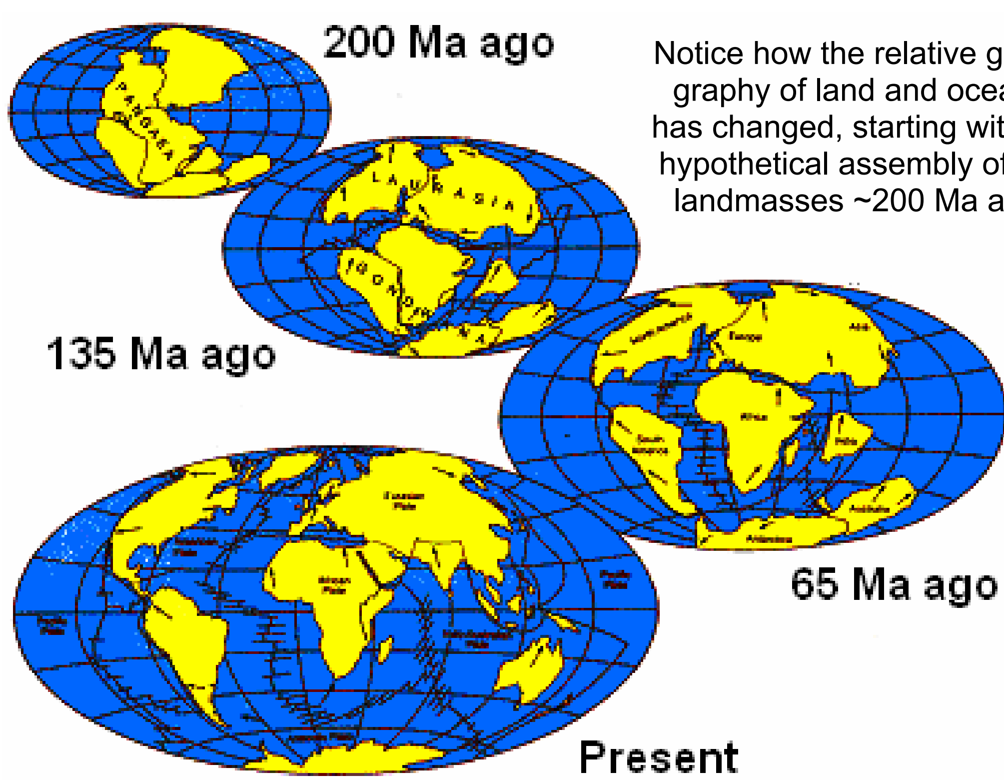
– The run-off from land also erodes the rocks and eventually deposits this eroded material in the oceans, to the tune of about 15 billion metric tons per year. As shown alongside, this should take no more than ~200 Ma to fill up the ocean basins. Run-off is thus likely to flatten the land, by way of erosion, as also the ocean basins by way of filling it up.

<u>Time run-off needs to fill ocean basins</u>?

Sediments deposited into the oceans	=	15×10^9 tons/year
	=	15×10^{12} kg/yr
	=	7.5×10^9 m^3/yr for an average sediment density of 2 g/cm^3 or 2000 kg/m^3.
Total volume of the world ocean	=	1.37×10^9 km^3
	=	1.37×10^{18} m^3
∴ Time needed for run-off to fill ocean basins	=	$\dfrac{1.37 \times 10^{18}\ \text{m}^3}{7.5 \times 10^9\ \text{m}^3/\text{yr}}$
	=	182.7×10^6 yr or ~180 Ma

■ Plate Tectonics:

Plate tectonics, on the other hand, involves the creation of new surface area, as ocean basins that form from incessant volcanic injections at the spreading submarine ridges, and an equal surface area is lost in the folded mountain belts and deep sea trenches.



Notice how the relative geography of land and oceans has changed, starting with a hypothetical assembly of all landmasses ~200 Ma ago.

Plate tectonic thus explains why the ocean floor …

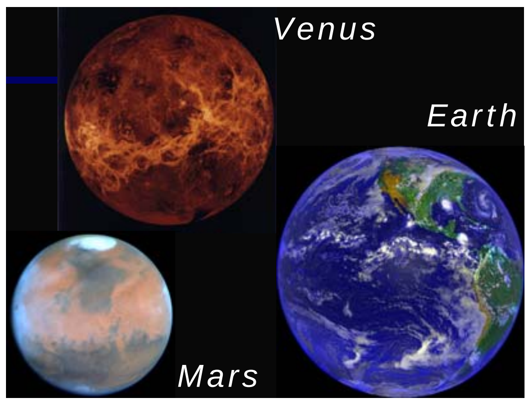
– is made up of basalt, a volcanic rock, and
– is very young, with rocks up to 200 Ma in age, compared to up to 4 Ga old rocks on land; even though Earth's overall surface area does not seem to have changed appreciably over the Earth's history.

Four reasons have thus combined to make the Earth the water planet:

– temperatures over most of the Earth's surface are between 0ºC and 100ºC,
– temperature gradient in the troposphere is steep enough to allow the precipitation of atmospheric moisture,
– the hydrological cycle has been perennially present, and
– plate tectonism has occurred throughout, ever since the oceans first evolved 3.7-4 billion years (Ga) ago.

2.3 Earth, Venus and Mars:

Water is abundant on the Earth, but not on Venus and Mars. This is because of their significantly different atmospheres and because of the presence or absence of plate tectonic activities.



■ Indeed, considering the vast distances in Solar System, Venus, Earth and Mars are in about the same vicinity relative to the Sun, compared to the Jovian and the outer planets. Venus is closer to Sun than Earth, of course, and Mars is farther. But the surfaces of these three neighboring planets receive about the same amounts of solar heat, as shown below.

	Relative distance from the Sun	Solar heat received …		Expected surface temperature	Observed surface temperature
		at the planetary location	on the planetary surface		
Venus	0.72 AU	~2500 W/m^2	~650 W/m^2	323º K	730º K
Earth	1.00 AU	~1360 W/m^2	~680 W/m^2	276º K	281º K
Mars	1.52 AU	~ 600 W/m^2	~600 W/m^2	215º K	215º K

Nonetheless, while the expected and observed temperatures on the surfaces of Earth and Mars are comparable, the Venutian surface is far hotter than what is expected. Clearly, the Venutian surface is too hot and the Martian surface is too cold to have water although, judging from their comparable overall densities, the three planets have comparable chemical compositions.

	Planetary Composition	Atmospheric	
		Compo-sition	Density (Earth = 1)
Venus Earth Mars	Rocky with metallic core	C, O N, O N, O ?	90.00 1.00 0.01

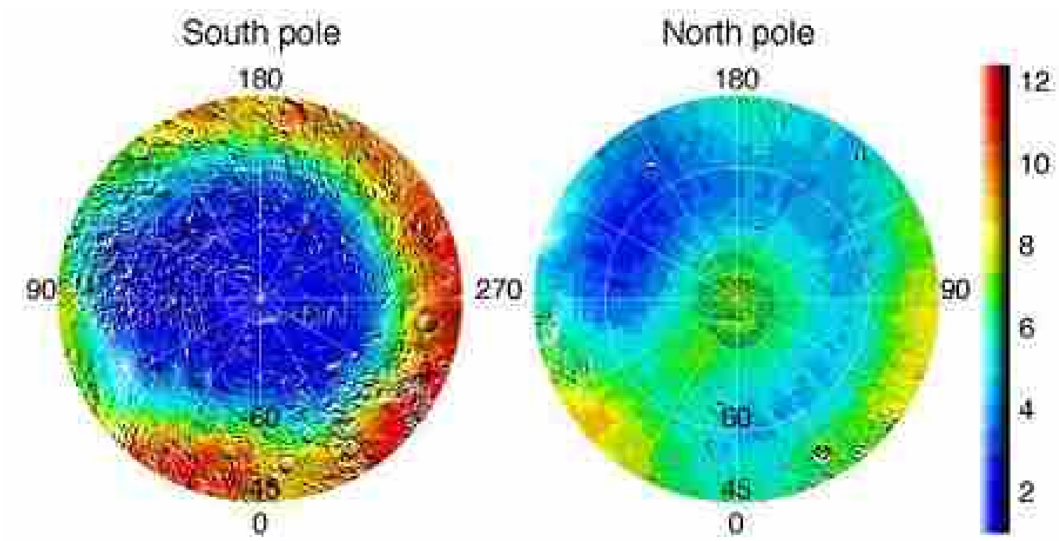
- Another peculiarity of Venus, unlike the situations on Earth and Mars, is that its average day-time temperature is about the same (~450ºC) as its mean night-time temperature. This is because the lengths of day and year are about the same on Venus, i.e., the planet takes 244.3 Earth-days to complete one spin on its axis but 224.7 Earth-days to complete one orbit about the Sun, and therefore has the same face turned towards Sun all the time.

- Dissimilar atmospheric compositions also explain why this does not make only the almost permanently Sun-facing day-side of Venus burning hot and the almost permanently Sun-averting night-side of Venus freezing cold. Earth's atmosphere, a ~110 km thick gaseous halo that encases the planet, now comprises ~78% Nitrogen and ~21% Oxygen, but was nearly 90% CO_2 until about 1.25 Ga ago. The atmosphere of Venus, on the other hand, is similar to what the Earth's atmosphere was probably like ~3.5 Ga ago. It has ~90 times the density of Earth's atmosphere, and is ~95% CO_2. Since this traps the Solar heat that is received on that planet's surface, Venus is also called the "Greenhouse Planet". Mars, on the other hand, has a very thin atmosphere.

- How about Mars? This planet is located at ~1.5 AU where the mean solar heat received is ~600 W/m^2, compared to ~1.3 kW/m^2 received at Earth's location. Solar heat received at the surface of Mars is about the same as that received on the Earth's surface, however, because Mars has a very thin atmosphere which filters little of the incoming solar radiation whereas Earth's appreciably thicker atmosphere allows less than one-half of the incoming radiation to reach the planetary surface.

- As for Mars, there is good evidence that water was once abundant enough on the planet to have produced the land-forms that we now see but now remains confined, at best, to the subsoil and the polar ice cap. The question, then, is as to how and why might Mars have lost its hydrological cycle.

Some images of the Martian surface, as obtained by the Pathfinder and subsequent missions.



In these false-color maps of the Martian poles, deep-blue indicates soil enriched by hydrogen. The south pole is surrounded by icy □errain. The north pole contains water-ice, too, but it is hidden for the moment by a wintertime layer of carbon dioxide frost.
(http://science.nasa.gov/headlines/y2002/28may_marsice.htm)

- This is because plate tectonics may well have once occurred on Mars, but no longer does. If it did, then we can argue that Mars lacks the hydrological cycle because it no longer has the plate tectonics to create new ocean basins to replace the ones flattened by the “run-off” component of hydrological cycle.

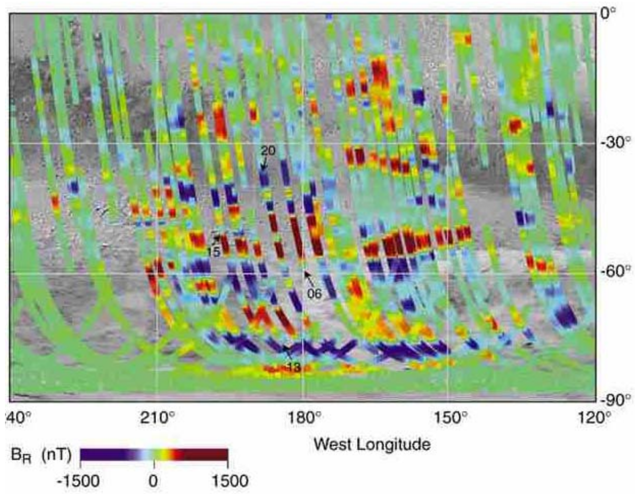


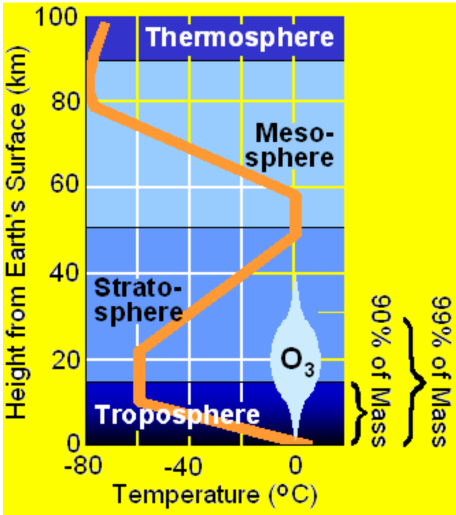
Plate Tectonics on Mars?

This map of magnetic lineations similar to the marine magnetic anomalies observed on the Earth's ocean floor suggests that plate tectonics may well have existed on Mars, at least once upon a time.

Source: http://science.nasa.gov/newhome/headlines/ast29apr99_1.htm

- Indeed, seeking to answer this question by appealing to low density of Martian atmosphere, and argue that its temperature gradient is too gentle to have prevented the escape of atmospheric moisture (unlike the Earth's tropospheric thermal gradient that is steep enough to have retained the hydrological cycle), ignores the fact that a vigorous hydrological cycle may have once existed on Mars.

Temperature profile of Earth's atmosphere



- The presence of hydrological cycle on the Earth, and its absence on Mars, is therefore due as much to the planetary atmospheres as to plate tectonics, while its absence on Venus is entirely ascribable to the structure and composition of Venutian atmosphere and to that planet's retrograde motion.