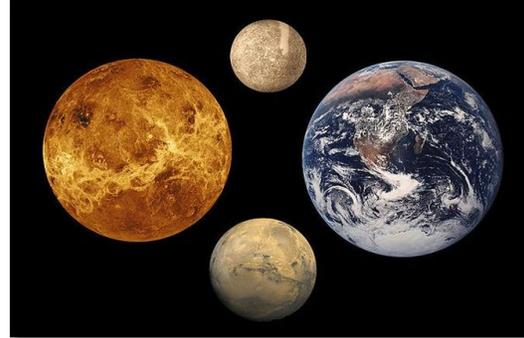


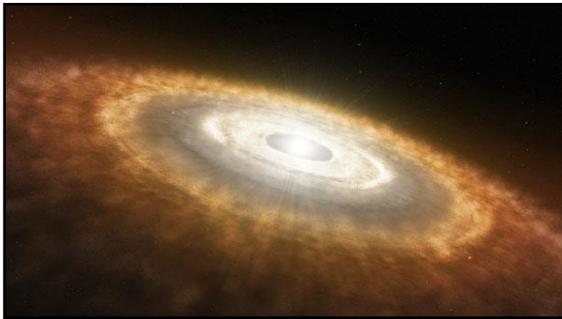


## TEACHER BACKGROUND INFORMATION: THE TERRESTRIAL PLANETS

Terrestrial planets are planets made up of rocks or metals with a hard surface — making them different from other planets that lack a solid surface. Terrestrial planets also have a molten heavy metal core, few moons, and landforms such as cliffs, valleys, volcanoes and craters.



There are four terrestrial planets in our solar system, which also happen to be the four closest to the sun: Mercury, Venus, Earth and Mars. During the creation of the solar system, there were likely more terrestrial *planetoids* or very large asteroids, which probably merged or were destroyed.



Approximately 4.6 billion years ago, the solar system was a cloud of dust and gas known as a *solar nebula*. Gravity collapsed the material in on itself as it began to spin, forming the sun in the center of the nebula.

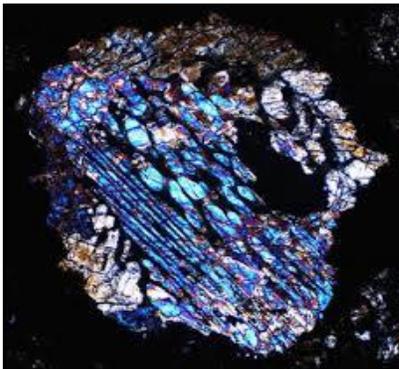
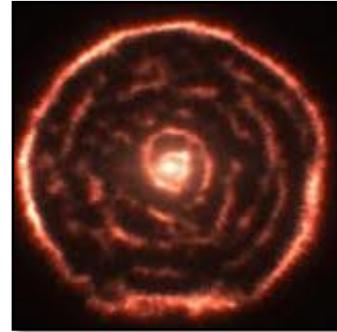
With the birth of the sun, the remaining material began to clump together. Small particles came together, bound by the force of gravity, into larger particles. The *solar wind* swept away lighter elements, leaving only heavy, rocky materials to create smaller worlds like Earth. Farther away from the Sun, the solar winds had less impact on the lighter elements, allowing them to combine into gas giants. In this way, asteroids, comets, planets, and moons were created.





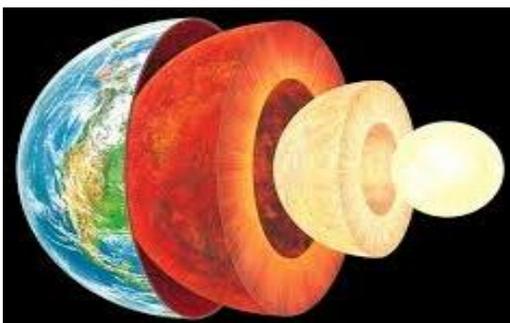
Planets like Earth grew from the collisions of smaller planets, asteroids and minute particles of rock and dust in a process called **accretion**. The smaller planets, often called **planetesimals**, ranged in size from 10s to 100s of kilometers in diameter.

The decay of naturally occurring **radioisotopes** in the interiors of the young planets created heating. In some cases, the heating changed the interior, creating a layered arrangement of recrystallized rock. Deeper layers were changed more severely, while shallower layers were less affected. The uppermost layer of rock was often disturbed by collisions of small asteroids, which created an uneven soil covering over the surface rock layer.



This type of layered interior has been reconstructed from **meteorite** fragments that had fallen to Earth. The debris was created when planetesimals collided and were blown apart, exposing the cores of the bodies and ejecting material out into the inner solar system. Some of the largest fragments produced the heavily cratered surfaces of the Moon, Mars, and other planetary bodies.

Analysis of meteorites indicates that sometime between 4.56 and 4.44 billion years ago a planetary body approximately the size of Mars hit the Earth. It crashed into Earth with such tremendous force that enough material was ejected into space to form the Moon. In addition, the impact caused the Earth to take on its 23 1/2° angle of rotation and heated the remaining Earth to the melting point.

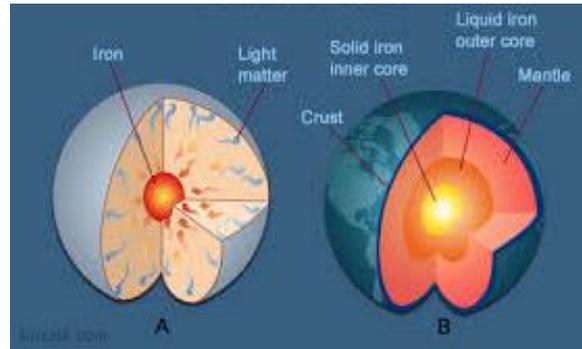


It is this final step, the melting of a significant portion of the Earth's mass during collision, which was responsible for the chemical composition, now observed within the Earth.

Initially, the Earth existed as a more-or-less homogeneous mixture of material.

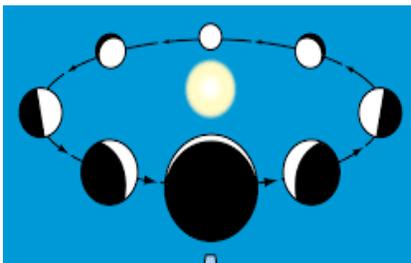
However, the melting that accompanied the Moon-forming collision resulted in large-scale changes in its chemical structure. This change, or **differentiation**, occurred through **chemical segregation** based on **density**.

When the early Earth heated, the heavy element iron (Fe) sank through the abundant lighter elements oxygen (O) and silicon (Si). The metallic **core** of Earth formed first, and then gathered lighter elements around it to form its **crust** and **mantle**. This whole-scale change in the Earth's chemical organization has had major effects on geologic processes ever since. Earth, like the other terrestrial planets, probably collected the more nebulous pieces that would form its atmosphere.



## MERCURY

Mercury is a sunbaked world, with surface temperatures typically sufficient to cook a turkey and humidity levels that make the sub-Saharan desert look excessively humid. This little world is locked in a strange gravitational dance with the Sun, which causes it to rotate on its axis only 1.5 times during its brief 88 Earth-day year. This means 1 day on Mercury stretches across 58.7 Earth days. During its languid rotation, it very precisely keeps its poles pointed straight up and down - there is none of the tilt that on Earth provides us out seasons. This means that its poles never face the Sun and within the depths of its polar craters there are places that only know darkness. In those shadows, Mercury actually has ice. But where the Sun hits there is nothing but baked metallic dirt.



Mercury is the smallest of the eight planets. Mercury's diameter is 3,030 miles (4,878 km), about the size of the continental United States. This makes it about two-fifths the size of Earth. The planet has a mean radius of 1,516 miles (2,440 km), and its circumference at the equator is 9,525 miles (15,329 km). Mercury turns very slowly on its axis, with one side constantly facing the nearby Sun. In fact, the planet spins on its axis once every 58.65 Earth days. Mercury orbits once every 87.97 Earth days, so it

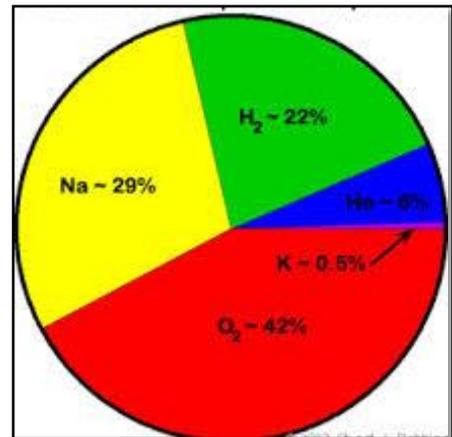
rotates only three times every two Mercury years.

Mercury has a mass of  $330 \times 10^{23}$  kilograms. This mass is contained in a volume of 14.6 trillion cubic miles (60.8 trillion cubic km). The mass and volume of Mercury is only about 0.055 times that of Earth. But because Mercury's small mass is enclosed inside of a tiny body, the planet is the second densest in the solar system, weighing in at 5.427 grams per cubic centimeter, or 98 percent of the density of our planet; only Earth is denser.

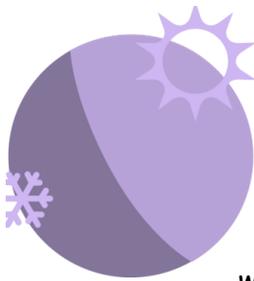
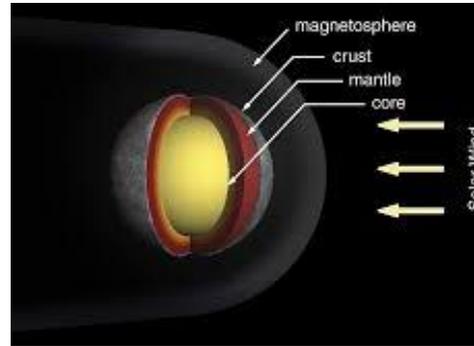


Mercury's surface greatly resembles that of Earth's moon, with craters left over from the heavy bombardment early in the life of the solar system and during the planet's formation. Images taken by orbiting spacecraft show craters ranging from 328 feet (100 m) to 808 miles (1,300 km) across. The planet has numerous steep cliffs or slopes created by faults. Some are as high as 1.86 miles (3 km).

Mercury's small size makes it too weak to hold on to a significant atmosphere, especially with the constant bombardment it receives from the Sun. The planet has a thin atmosphere, but it is constantly blasted into space by the *solar wind*. Without an atmosphere to help stabilize the incoming heat from the sun, the planet boasts some of the most changeable temperature swings in the solar system. Orbiting only a few million miles from the Sun, Mercury is constantly bombarded by *solar weather*. The fast-moving, constantly blowing solar winds bombard Mercury, sending *plasma* down to the surface. The makeup of Mercury's atmosphere is shown in the pie graph at the right.



Mercury was thought to be unable to generate a magnetic field because of its small size and lack of recent geologic activity, suggesting a cold interior. Astronomers now believe that Mercury has a **magnetosphere** similar to the Earth's magnetic field, but with a strength about 1% that of the Earth's. The observed magnetic field may mean that the core of Mercury is at least partially molten. The hydrogen and helium atoms likely come from the sun, streaming in on the solar wind and spreading out through the planet's atmosphere. Water vapor and other elements were probably transported and left behind by impacting comets and meteorites. Eventually, these gases are caught by the solar wind and carried off of the planet. With virtually no atmosphere, Mercury experiences very little in terms of traditional weather.

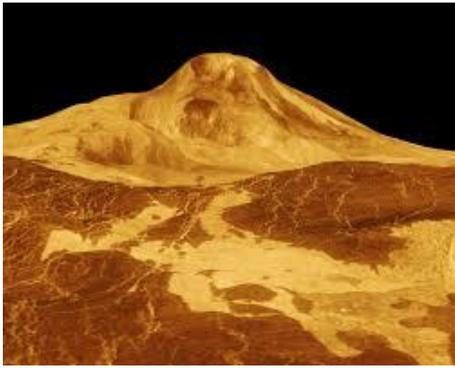


The lack of atmosphere also contributes to the planet's wild temperature extremes. On other planets, the atmosphere functions as a blanket, with the **greenhouse effect** helping to redistribute heat somewhat. But on Mercury, the thin atmosphere does nothing to stabilize the incoming solar energy—and because the distance to Mercury from the Sun is so small, the dayside of the planet feels the heat intensely, while the night side, turned from the sun, only registers the cold. The temperature of Mercury varies from day to night, but the planet only changes slight during its seasons. The planet stands essentially straight up and down in relation to its orbit, with no tilt to put one hemisphere closer than the other. Temperatures can reach 800 °C in the daytime and plunge to -180 °C at night.

## VENUS

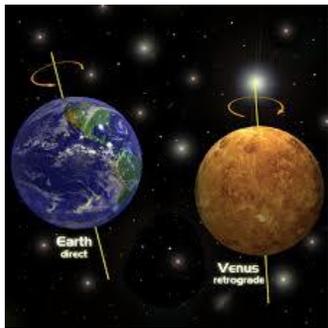
Venus, the second planet from the Sun, and Earth are often called twins because they are similar in size, mass, density, composition and gravity. However, the similarities end there. Venus is the hottest world in the solar system, despite the fact that it is not the planet closest to the Sun. Temperatures reach 870 degrees Fahrenheit (465 °C), more than hot enough to melt lead. Probes that scientists have landed there have survived only a few hours before being destroyed.





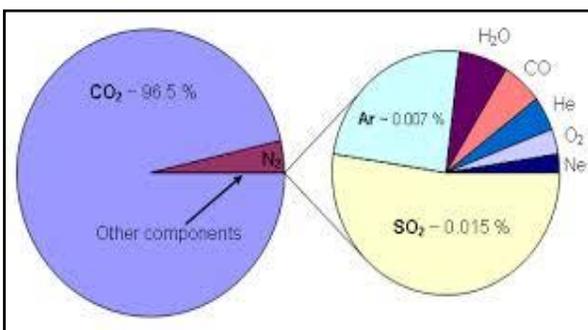
The surface of Venus is extremely dry. During its evolution, ultraviolet rays from the Sun evaporated water quickly, keeping it in a "prolonged molten state" longer than Earth's. There is no liquid water on its surface today because the scorching heat created by its ozone-filled atmosphere would cause any to boil away. About two-thirds of the Venusian surface is covered by flat, smooth plains that are marred by thousands of volcanoes, some of which

are still active today and six mountainous regions make up about one-third of the Venusian surface.



Venus takes 243 Earth days to rotate on its axis, the slowest of any of the major planets. The north pole of Venus is "upside down" relative to its orbit. Venus also has a very small tilt of only 3.39 degrees with respect to the sun, compared to 23.4 degrees on Earth. On our planet, it is the tilt that provides us with the change in seasons; the hemisphere slanted closer to the sun feels the heat of spring and summer. The lack of significant tilt causes only slight temperature variations from the equator to the poles and means that even if Venus got rid of its overheated atmosphere, it would still feel fairly consistent temperatures year round.

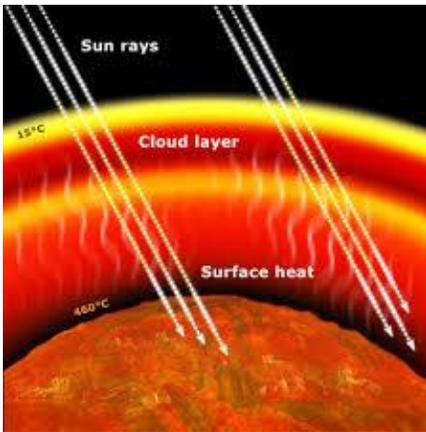
Some planets, like Earth, Mercury, Jupiter and Saturn, have magnetic fields created by their iron core. The **magnetic field** that protects Earth extends from the inner core out to where it meets charged particles coming from the Sun, also known as **solar wind**. The magnetic field shields the atmosphere from the high-energy particles coming from space. Because of its sluggish spin, Venus' metal core cannot generate a magnetic field similar to Earth's. As a result, Venus lacks a true magnetosphere and what it does have is measured at -100,000 when Earth is 1. The differences that have been observed may explain the fact that some gasses and water were lost from the Venusian atmosphere.



Venus has a hellish atmosphere consisting mainly of carbon dioxide with clouds of sulfuric acid. Scientists have only detected trace amounts of water in the atmosphere. The atmosphere is

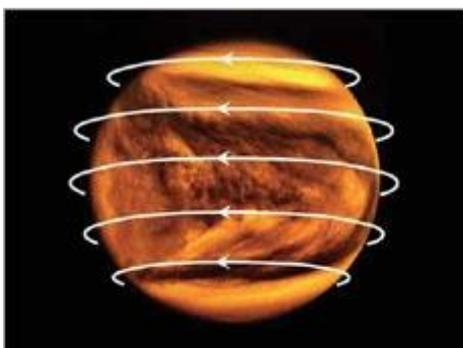
heavier than that of any other planet, creating a surface pressure 90 times that of Earth. Someone standing on the ground on Venus would experience air about 90 times heavier than Earth's atmosphere; pressures are similar to diving 3,000 feet beneath the ocean.

Venus' distinction of being the hottest planet in the solar system is entirely the fault of its atmosphere, which is made up almost completely of carbon dioxide. Nitrogen exists in small doses, as do clouds of sulfuric acid. The air of Venus is so dense that the small traces of nitrogen are four times the amount found on Earth, although nitrogen makes up more than three-fourths of the terrestrial atmosphere.



This composition causes a *runaway greenhouse effect* that heats the planet even hotter than the surface of Mercury. When the rocky core of Venus formed, it captured much of the gas gravitationally. In addition to warming the planet, the heavy clouds shield it, preventing visible observations of the surface and protecting it from bombardment by all but the largest meteorites. Although Venus and Earth are similar in size, the most Earth-like atmosphere in the solar system occurs 30 to 40 miles (50 to 60 kilometers) above the surface of Venus. Both oxygen and hydrogen rise above the heavier gas layer covering the ground, and the pressures are similar to our planet.

Venus' atmosphere acts like a thermal quilt, 93 times denser than Earth's and made up mostly of carbon dioxide and sulfur dioxide. These conditions make it awfully hard to hold on to the oceans and seas that served as the incubators for all terrestrial life. If you could collect all of the water on Earth and distribute it evenly around the planet, it would make a global ocean 1.9 miles (3 km) deep. Do the same with the trace amounts of water in the Venusian atmosphere, and the depth of your ocean would be just 1.8 in. (3 cm).

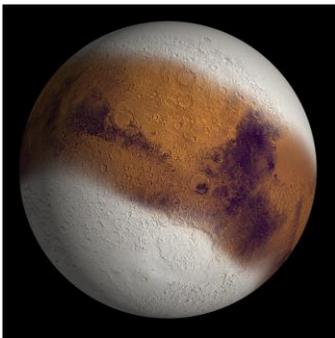
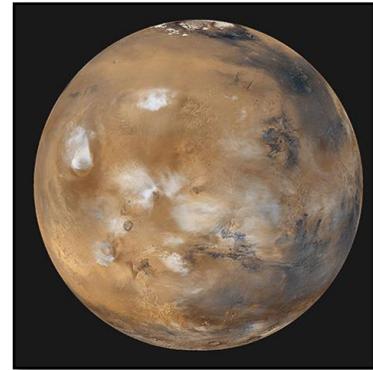


The clouds of Venus appear to be bright white or yellow. Unlike Jupiter or Saturn, there are no discernable bands or storms visible to the naked eye. Winds of about 224 mph (360 kph) keep the clouds of Venus in constant motion. Though the planet spins slowly, the clouds zip around the top of the planet every four days. But wind

speeds drop closer to the surface, where they only move a few miles per hour.

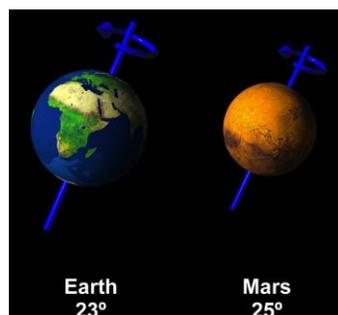
## MARS

Mars is the fourth planet from the sun. It earned its nickname of the 'Red Planet' from the red dust that covers its surface. Back when there was more water around on Mars, the iron-rich rocks on the surface oxidized (rusted), turning a reddish brown color. When the reddish brown dust gets blown up into the atmosphere, the whole planet takes on a reddish hue.

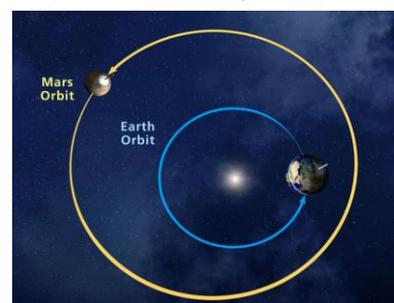


Liquid water currently cannot exist on the Martian surface for any length of time. This means that although this desert planet is just half the diameter of Earth, it has the same amount of dry land. Vast deposits of what appear to be finely layered stacks of water ice and dust extend from the poles to latitudes of about 80 degrees in both hemispheres. On top of many of these layered deposits in both hemispheres are caps of water ice that remain frozen all year round. Additional seasonal caps of frost appear in the wintertime. These are made of solid carbon dioxide, also known as "dry ice," which has condensed from carbon dioxide gas in the atmosphere. In the deepest part of the winter, this frost can extend from the poles to latitudes as low as 45 degrees, or halfway to the equator.

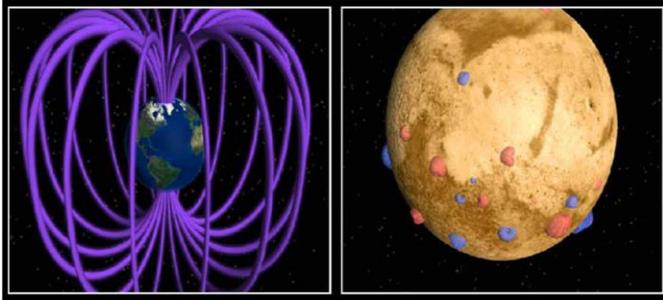
Mars is much colder than Earth, in large part due to its greater distance from the sun. The average temperature is about minus 80 °Fahrenheit (- 60° C), although they can vary from -195 °F (-125 °C) near the poles during the winter to as much as 70 °F (20 °C) at midday near the equator. The carbon-dioxide-rich atmosphere of Mars is also roughly 100 times less dense than Earth's on average, but it is nevertheless thick enough to support weather, clouds and winds. The density of the atmosphere varies seasonally, as winter forces carbon dioxide to freeze out of the Martian air.



The axis of Mars, like Earth's, is tilted with relation to the sun. This means that, the amount of sunlight falling on certain parts of the planet vary widely during the year, giving Mars seasons. However, the seasons



that Mars experiences are more extreme than Earth's because its elliptical, oval-shaped orbit around the sun is more elongated than that of any of the other major planets. When Mars is closest to the sun, its southern hemisphere is tilted toward the sun, giving it a short, very hot summer, while the northern hemisphere experiences a short, cold winter. When Mars is farthest from the sun, the northern hemisphere is tilted toward the sun, giving it a long, mild summer, while the southern hemisphere experiences a long, cold winter.

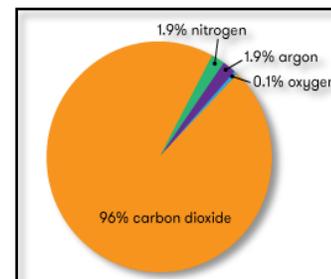


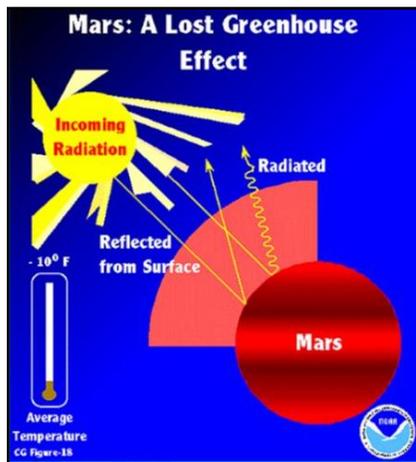
Earth's magnetic field is generated by an **active dynamo**—a hot core of molten metal. The magnetic field surrounds Earth and is considered global (image on left). The various Martian magnetic fields do not encompass the entire planet and are local (image on right). The

Martian dynamo is extinct, and its magnetic fields are "fossil" remnants of its ancient, global magnetic field. This, however, does not mean that Mars does not have a magnetosphere; simply that it is less extensive than that of the Earth and provides no protection from the Sun's radiation. Any life forms on the surface would constantly be bombarded with cosmic rays. In addition, much of the gas lost from the Martian atmosphere, was probably stripped away by the solar wind, which was able to reach the atmosphere as Mars cooled and lost its magnetic field and protective magnetosphere. Water was probably lost as well, as the ultraviolet light broke apart any water molecules in the atmosphere and the lightweight hydrogen escaped into space.

Mars has a thin atmosphere — too thin to easily support life as we know it. The Martian atmosphere is around 100 times thinner than Earth's, which means air pressure is significantly less on Mars than on Earth, so there is basically no air to breathe, and not enough pressure to keep bodily fluids in a normal liquid state. The gases dissolved in a human's bloodstream would start to escape— their blood would probably literally boil.

Just as much of an issue is the composition of what little atmosphere there is on Mars. The thin Mars air is radically different and basically toxic. The atmosphere of Mars is about 100 times thinner than Earth's, and it is 95 percent carbon dioxide.





Temperatures on Mars are much lower than Earth's, not only because it's farther from the sun, but because a thinner atmosphere does not support a strong *greenhouse effect*. Some scientists think that Mars may be the victim of a runaway greenhouse effect in the opposite sense of Venus. As water ice froze the planet became more and more reflective and its atmosphere thinner and thinner, freezing more and more water and eventually carbon dioxide as well.

Despite the fact that the atmosphere is more than 95 percent  $CO_2$  by volume, almost all of it is locked up in the Martian rocks. Mars does have a greenhouse effect, but it's very weak because the Martian atmosphere is so thin, and as a result, heat from the Sun goes back into space.

Despite its thin atmosphere, Mars still has a weather system. Martian weather phenomena are the result of its extreme seasonal changes. Polar temperatures at the winter pole drop so low (about  $-130^{\circ}C$ ) that carbon dioxide condenses into dry ice at the polar cap; frozen carbon dioxide at the summer pole *sublimates* into carbon dioxide gas. The atmospheric pressure therefore increases at the summer pole and decreases at the winter pole, driving strong pole-to-pole winds. Storms on Mars can engulf the entire planet.

Giant dust devils routinely kick up the oxidized iron dust that covers Mars' surface. The dust storms of Mars are the largest in the solar system, capable of blanketing the entire planet and lasting for months. One theory as to why dust storms can grow so big on Mars has to do with heat transfer by *convection*. Airborne dust particles absorb sunlight and warm the Martian atmosphere in their vicinity. Warm pockets of air flow toward colder regions, generating winds. Strong winds lift more dust off the ground, which in turn heats the atmosphere more, raising more wind and kicking up more dust. At times, it even snows on Mars. Martian snowflakes, made of carbon dioxide rather than water, are thought to be about the size of red blood cells. The north and south polar regions of Mars are capped by ice, much of it made from carbon dioxide, not water.





The bulk of Mars's surface is made of *basaltic silicate rock*, very similar to the rocks of Earth's oceanic crust. It's thought that the crust of Mars is just one piece, so no tectonic plates floating around causing interesting things like *subduction zones* and earthquakes as found here on Earth. There are some rocks that show striped magnetic reversals, which indicates that once upon a time Mars had plates that spread apart like the mid-ocean ridges on Earth do today, and a magnetic field that flipped directions

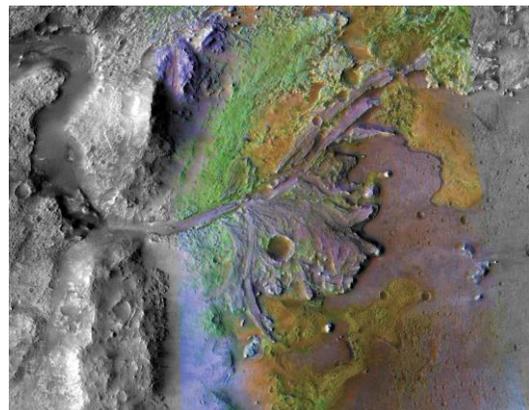
Mars does have the largest volcano in the solar system, *Olympus Mons*, which is no longer active. It is the lack of tectonic activity that has resulted in Mars's atmosphere being so thin: it's thought that carbon dioxide was pulled from the atmosphere to make carbonate rocks and without any tectonic processes to recycle the rocks and de-gas the carbon dioxide into the atmosphere, it stayed bound up in the carbonate rocks.



There are other rocks and structures on Mars that look like they could only have formed with the presence of water—large amounts of it. There are what appear to be layered sedimentary rocks (rocks made from grains of sand and dirt, usually laid down underwater then stuck together to make a rock) and possibly conglomerates (rocks made from pebbles and chunks of other rocks

as well as sand and dirt-sized grains all stuck together).

Observations of Mars indicate that rivers and oceans may have been prominent features in its early history. Billions of years ago, Mars was a warm and wet world that could have supported microbial life in some regions. But the planet is smaller than Earth, with less gravity and a thinner



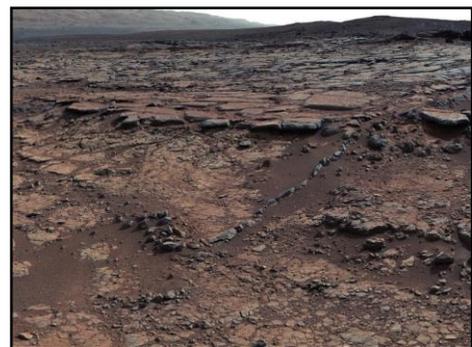
atmosphere. Over time, as liquid water evaporated, more and more of it escaped into space, allowing less to fall back to the surface of the planet. Vast deposits of water appear to be trapped within the ice caps at the north and south poles of the planet. Each summer, as temperatures increase, the caps shrink slightly as their contents skip straight from solid to gas form, but in the winter, cooler temperatures cause them to grow to latitudes as low as 45 degrees, or halfway to the equator. The caps are an average of 2 miles (3 kilometers) thick and, if completely melted, could cover the Martian surface with about 18 feet (5.6 meters) of water.

Frozen water also lies beneath the surface. Scientists discovered a slab of ice as large as California and Texas combined in the region between the equator and North Pole of the Red Planet. The presence of subsurface water had long been suspected but required the appearance of strange *layered craters* to confirm. Other regions of the planet may contain frozen water, as well. Some high-latitude regions seem to boast patterned ground-shapes that may have formed as permafrost in the soil freezes and thaws over time.



*Riverbeds and gullies* indicate that water ran, at least briefly, across the surface of Mars. A hundred times more water may have flowed annually through a large channel system known as Marte Vallis than passes through the Mississippi River each year, according to estimates. The gullies themselves are smaller, likely forming during brief torrential rainstorms when fast-moving water could have carved them across the land.

On Earth, the land around rivers and lakes is wetter, made up of mud and clays. Such deposits exist on Mars as well, trapping water and indicating where larger bodies may have once existed. Organic carbon is seen much more in clay and muds than it is in sandy material. And the *Sheepbed mudstone* (right) already has been identified as the remnant of an ancient habitable lake.



Water may seem like a very common element to those of us on Earth, but it has great value. In addition to understanding how Mars may have changed and developed over time, scientists hope that finding water will help them to find something even more valuable — life, either past or present. Only Earth is known to host life, and life on our planet requires water. Though life could conceivably evolve without relying on this precious liquid, scientists can only work with what they know. Thus they hope that locating water on celestial bodies such as Mars will lead to finding evidence for life.