The Terrestrial Worlds: Mercury, Venus, Earth, Moon, & Mars

What do these worlds have in common?

What causes the differences?
Earth’s Skin, the Crust

The crust is **4-60 km thick**. Earth’s radius is 6378 km, so the crust is a thin layer comparable to the skin of an apple.

The crust floats on the mantle, which floats on top of the metal core.
Floating Pieces of Crust

Earth’s crust is broken into many tectonic plates, each sliding on top of the convecting mantle.
Plate Tectonics

The continents ride along on the plates, so they have moved over the course of Earth’s history.

- 200 million years ago
- 120 million years ago
- Present
- 150 million years from now
Floating Pieces of Crust

Their movement also controls the formation of most types of terrain on the planet.

New crust forms where plates pull apart. Volcanic activity can occur where plates come together.
Plate Tectonics

While evidence of plate tectonics is everywhere on Earth, planetary scientists have yet to find any convincing evidence of this process on any of the other terrestrial planets.

It appears plate tectonics requires 2 conditions:

1. A hot, convecting interior carrying the crust,
2. A thin crust that can crack, break, and bend.

Venus also appears to satisfy #1, but its crust appears to be far too thick and brittle (no on #2).
Surface Features on the Moon

The near side of the Moon shows two main types of terrain: heavily cratered and dark and smooth.
Surface Features on the Moon

The farside of the Moon (the hemisphere facing away from Earth), appears very different than the nearside.

Heavily cratered in appearance, with fewer dark, smooth regions.
Surface Features on the Moon

The brighter terrain is known as the cratered highlands.

This terrain dates back to the period of heavy bombardment early in the history of the Solar System.

It lies, on average, a few km higher than the dark terrain.
Surface Features on the Moon

Highlands on the Moon’s surface are more than 3 billion years old. Note the numerous craters of various sizes.

Image taken during Apollo 11 flight
Impact Craters

Craters are typically about 10 times as wide and twice as deep as the object creating them, e.g.

A 100-kilometer wide crater is typically formed from the impact of a 10-kilometer wide object.

The crust at the impact point is shattered.
Ejecta and Rays

Rock at the impact site is pulverized, blasted out, landing on the surrounding surface. This scattered material is called ejecta.

Rays, streaks of ejecta, radiate outward from large, young craters.
The Lunar Surface

Regolith is the thick layer of pulverized rock generated by continuous impacts by small objects.

This continual impact rounds and smoothes the surface features on the Moon.

Today, it is the only erosion on the Moon.
Some craters are small.

These are a few meters wide.
Craters on the Moon

Some craters are big. Copernicus is 90 km wide.

About the size of the Phoenix metro area
Craters on the Moon
Some craters are colossal. The Orientale Basin is 600 km wide. It is called an impact basin.

Bigger than Arizona
Surface Features on the Moon

The large dark flat areas are called **maria**.

Early observers thought they were bodies of water, hence the name (*mare*, Latin for sea).
Craters on the Moon

The maria are impact basins that flooded with lava early in the Moon’s history. Many maria are round, a sign that they are craters that flooded with lava.

Oceanus Procellarum is one big mare formed from several adjacent basins.

The Moon’s near side is about 4 km lower, so magma filled basins on the near side but not the far side.
Volcanism on the Moon

More than 3 billion years ago, the Moon had active volcanoes and lava flows that flooded the maria.

Rilles are valleys carved by flowing lava. They are generally found at the edges of maria.
Water on the Moon

Several robotic missions in 2009 found evidence of water on the Moon's surface:

1. A very small amount of water was detected across the day side of the Moon. The origin of this water is currently not known, but may be due to occasional comet impacts or solar wind.

2. The LCROSS mission crashed into the bottom of a crater near the Moon’s South Pole. The crater bottom is in permanent shadow, so it is extremely cold. It was hoped craters like these trapped ice delivered by comet impacts.
Water on the Moon

Oct. 2009: a Centaur rocket booster struck Moon inside Cabeus crater. Impact was observed by the Lunar CRater Observing and Sensing Satellite (LCROSS) for the next 4 minutes until it impacted.

Nov. 2009: NASA team announced 100 liters of water in ejecta from 20 meter wide crater.

Origin: comet impacts? Possible detection of other compounds, too.
Mercury shares many geological features with our Moon: heavy cratering with some volcanism.

Images from recent MESSENGER flybys in 2007-8.
Mercury: Heavily Cratered

Craters are very common on Mercury. However, notice smoother terrain between the craters.

Images from Mariner flybys in 1973-4.
Mercury: Some Volcanism

With no air or water, erosion is not possible. The older craters were erased by large lava flows.

Images from Mariner flybys in 1973-4.
MESSENGER at Mercury

MESSENGER achieved orbit on March 17, 2011.

Eleven instruments will provide new, high quality data of Mercury’s surface and interior:

• When did volcanic activity occur? Still ongoing?
• How much volcanic activity was there?
• What minerals make up Mercury’s crust?
• What is Mercury’s interior like? Why so dense?
• How does Mercury generate a magnetic field?
Venus

Venus is permanently shrouded in clouds. Mapping the planet requires radar.
Exploration of Venus

In May 1989, NASA launched *Magellan*. The goal of this mission was to radar map the entire surface of Venus at high resolution.

The mission was a big success and lasted until 1994, when the spacecraft entered Venus’ atmosphere.
Exploration of Venus

Magellan map of Venus
The Surface of Venus

Surprise! Only about 1000 craters were found.

They are randomly distributed across the surface: the whole crust is approximately the same age!

At the cratering rate measured for the Moon, the number of craters on Venus’ surface would take between 500 million to 1 billion years to build up.

Venus appears to be as volcanic as Earth, paving over the entire planet many times since its birth.
Craters on Venus

The thick atmosphere prevents smaller impactors from reaching surface: no craters smaller than 3 kilometers diameter have been found.

A note about Magellan maps: These are not photos, but radar images. Bright means rough and dark means smooth.
Volcanoes on Venus

Other than craters, the surface of Venus is covered in volcanic activity. Any volcanoes active today?

We haven’t seen any evidence yet, but there are lots of reasons to believe they must be.

Pancake domes

slow eruption of thick lava like pancake batter
Volcanoes on Venus

Larger types of volcanic activity produce coronas (Latin for *crown*). These are characterized by circular sets of faults from the breaking of the crust as magma pushes up from the mantle.

Lots of volcanic activity, like pancake domes, are found on and around coronas.
The Evolutionary History of Venus

Recall that Earth’s crust is broken into plates and plate tectonics recycles surface rock back into the mantle.

The presence of water in the rocks of Earth’s crust makes the plates flexible. They bend and sink.

Venus is a dry planet. The absence of water on Venus makes the rocks (and the crust in general) stronger and more brittle.
The Surface of Mars

The lighter, rusty-colored terrain is coated in dust. The darker terrain is volcanic rock and sand. Looking at surface elevation shows more details.
The 1996 *Mars Global Surveyor* mission produced this elevation map (red/white high, blue low).

The Surface of Mars

The 1996 *Mars Global Surveyor* mission produced this elevation map (red/white high, blue low).
The southern highlands date back as much as 4 billion years. The Rovers landed in the highlands.
Ancient Impact Basins

Mars, like the Moon and Mercury, has impact basins formed from giant impacts long ago.
Cratering on Mars

Impact craters on Mars are often heavily eroded and show splashed ejecta, like an impact into mud.
There are several giant volcanoes and a huge canyon system known as Valles Marineris.
The Martian Grand Canyon

Valles Marineris (Mariner Valleys) form the Grand Canyon of Mars. They stretch 4000 km across the surface of Mars, up to 200 km wide, and up to 7 km deep in places.

Earth’s Grand Canyon to scale.
Volcanoes on Mars

Olympus Mons is the largest volcano in the Solar System. It would completely cover Arizona. It is 700 km in diameter and 27 km high.

The caldera (central crater) is 70 km in diameter.

These volcanoes are tall enough to stick out of the atmosphere.

Note: clouds surrounding base of Olympus Mons
Volcanoes on Mars

While the largest volcanoes on Mars dwarf any of the mountains or volcanoes on Earth, they formed in a very similar way.

The giant Martian volcanoes are shield volcanoes formed by many eruptions of lava down their sides. The Hawaiian islands are shield volcanoes.
Volcanoes on Mars

The growth of the Hawaiian islands is controlled by the movement of the crust over the hot spot that supplies the lava.

The formation of Mars’ large shield volcanoes could only happen if the crust didn’t move and a hot spot fed the same volcano for a long time.

This means that there was probably no plate tectonics on Mars when these volcanoes formed.
Giant carved canyons known as **outflow channels** flow out of Valles Marineris to the north and east.
Outflow Channels

Detailed views of these outflow channels indicated they were cut by enormous flows of water.
Outflow Channels

How long ago did these huge flow of water occur?
Exploring Mars: Mars Rovers

Spirit landed in *Gusev Crater* hoping to find layers formed in an ancient lakebed. After a year of driving, it finally found salt deposits and other minerals that only form in water…
Exploring Mars: Mars Rovers

Spirit’s view from the top of Husband Hill:
Exploring Mars: Mars Rovers

Spirit looking back the route it took up the hills...
Exploring Mars: Mars Rovers

Spirit is stuck in very fine powdery soil. Now dead.
Exploring Mars: Mars Rovers

Opportunity investigated its landing place, finding hematite (grey iron oxide) and then drove to a larger crater nearby. It then spent several months driving into the crater and making measurements:
Opportunity sent back data showing that the layers in the rock were formed as the climate at this location on Mars dried out:
Opportunity then drove to a larger crater, Victoria, and attempted to drive inside. Rather than risk getting stuck, the rover team decided to drive on:
Exploring Mars: Mars Rovers

Opportunity was photographed from orbit by a new arrival, Mars Reconnaissance Orbiter, in Jan. ‘07:
Exploring Mars: Mars Rovers

Opportunity was photographed from orbit by a new arrival, Mars Reconnaissance Orbiter, in Jan. ‘07:
Opportunity took a “road trip” to Endeavor crater, about 10 kilometers (6 miles) away.

On the way, the rover found meteorites, small craters, and other interesting sights to see…
Exploring Mars: Mars Rovers

As of fall 2011, Opportunity arrived at Endeavor:

Endeavor Crater is 22 kilometers across and the largest crater Opportunity rover has explored.
Water on Mars? YES!

Water is present in large quantities, but it’s frozen!

• The Mars Rovers have found minerals that prove water was on the surface in the ancient past,

• Mars Express’ radar found Texas-size areas of ice under both the north and south poles, and in what look like buried glaciers closer to the equator,

• Phoenix Lander has found ice in the Martian arctic buried by just centimeters of soil and rock.
Three Generations of Mars Rovers

Left: Mars Exploration Rovers – Spirit & Opportunity

Middle: Sojourner Rover carried aboard Pathfinder (1997)

Right: Mars Science Lab (MSL), arrival summer 2012
Mars Science Lab “Curiosity” landing site

In summer 2011, the landing site for Curiosity was chosen. Gale crater has interesting deposits in its floor that appear to have been carried by liquid water.

- Water-carved valleys
- Fan of deposited soil
- Water-related minerals
Data resources for Mars:

Google Mars: http://mars.google.com
Mars Global Surveyor: http://mars.jpl.nasa.gov/mgs/
Mars Odyssey: http://marsprogram.jpl.nasa.gov/odyssey/
Mars Rovers: http://marsrovers.jpl.nasa.gov
Mars Express: http://sci.esa.int/marsexpress
Mars Phoenix Lander: http://phoenix.lpl.arizona.edu/index.php
Mars Science Lab: http://marsprogram.jpl.nasa.gov/msl/
(newest rover, launch window opens November 25, 2011)