Colorized radar mosaic of Venus as imaged by the Magellan spacecraft.
Of all the terrestrial planets, Venus is closest in size to the Earth:

Mean Radius: 6,051 km (0.95 Earths)

Mass: $4.87 \times 10^{24}$ kg (0.815 Earths)

Mean Density: 5.204 g/cm$^3$

Surface Temperature: $\sim 377 - 487^\circ$C

Atmosphere: Primarily CO$_2$

Surface Pressure: $\sim 93$ bars (Earth is 1 bar)

Surface Gravity: 0.88 Earth gravity

Venus has no natural satellites
Venus vs. Earth

The mass, density, and distance from the Sun for Venus are very similar to Earth.

Original composition of Venus was likely similar to that of Earth.

Therefore, the rates of internal heat generation that produce volcanism and tectonics were possibly similar.

However, the climate of Venus is very different: surface is extremely hot, atmospheric pressure is very high, and surface lacks water.

In addition, Venus has no intrinsic magnetic field and no moons.

Though Venus is often considered the ‘twin planet’ to Earth, it has clearly followed a very different evolutionary path.....Why?
The atmosphere of Venus is extremely dense and has a pressure of >90 bars.

Atmosphere is primarily CO$_2$, though some N$_2$ is present.

Venus also exhibits clouds (image below) made of sulfuric acid.

The atmosphere of Venus is too thick to see through with visible, near-infrared, or thermal wavelengths, so we must use radar systems to image the surface.

The **Magellan** mission was launched in 1989 and was the most recent NASA mission to explore our closest neighbor.

More recently, the European Space Agency’s **Venus Express** mission has been studying the atmosphere and plasma environment of the planet since 2006.
Climate & weathering are intimately linked.

Increased temperatures and increased precipitation lead to strong chemical weathering. (e.g., the tropics)

In contrast, cold and dry regions are dominated by physical weathering. (e.g., polar regions)

However, even very thin films of water on rocks/minerals can cause chemical weathering over long periods of time.

The Atacama desert in Chile is the driest place on Earth, but chemical weathering still takes place, just at very slow rates.
The amount of CO$_2$ on Earth is regulated by a ‘negative feedback cycle’ consisting of several parameters:

Various factors will work to move the atmosphere/ocean system back to an equilibrium point.

Example: If atmospheric CO$_2$ increases due to more volcanic eruptions, then the climate will get warmer and weathering rates will increase. This will cause more CO$_2$ and cations to be dissolved in the oceans, which then leads to precipitation of carbonate minerals, thus ‘removing’ CO$_2$ from the atmosphere.
The ‘Greenhouse’ Atmosphere of Venus

CO₂ is released into the atmosphere by volcanism, and it is a known greenhouse gas. If there is no mechanism to remove this CO₂ (that is, if there is no ocean/water to precipitate carbonates) then the CO₂ simply continues to build up in the atmosphere and the process continues unabated.

Thick SO₂ and sulfuric acid droplets reflect much of the sunlight back out into space, preventing us from viewing the surface.

The atmosphere also absorbs and much of the emitted radiation, keeping the planet very warm.
Although far from proven, a long standing theory for Venus is that it once had an atmosphere similar to that of Earth and possibly even an ocean.

Volcanic outgassing was fast enough that the CO$_2$ levels rose too quickly to be compensated by mineral precipitation, so the H$_2$O from the oceans began to evaporate. H$_2$O vapor is a much stronger greenhouse gas than CO$_2$.

The increase in these atmospheric gases led to a runaway effect that promoted the continued evaporation of H$_2$O until all of it had escaped. This produced a CO$_2$ rich atmosphere and effectively stopped the negative CO$_2$ feedback cycle (remember the question on Homework 1).

Whether or not this scenario is true can be debated, because it is not clear if Venus and Earth had the same water contents in their early history.

Regardless, Venus provides an interesting test case to see how a planet similar in size and composition to Earth can evolve due to a runaway greenhouse effect.
The Soviet Venera 9 and 10 spacecraft landed on Venus in October 1975. They and were the first landers to return images of the venusian surface.

The Venera 9 landing site (top images) shows the presence of slabby, possibly layered rocks. They range from 20-70 cm across. It is unclear if they are lavas, impact breccias, or something else.

The Venera 10 landing site (bottom images) shows fewer boulders and instead appears to be dominated by plains material that are covered with fine-grained regolith (soil).

Both spacecraft landed near the region of Beta Regio.
The Soviet Venera 13 and 14 spacecraft landed on Venus in March 1982 and were the first landers to return color images of the surface.

These locations looked more similar to the Venera 10 landing site than the Venera 9 site.

These landers measured the soil with an X-ray fluorescence (XRF) spectrometer and attempted compressibility studies of the soil.

Venera 14 had the unfortunate luck that its probe arm deployed onto the camera lens cover that had been ejected from the spacecraft....oops!
The Interior of Venus

Internal structure similar to Earth: a metallic core is likely present

But we don’t know the size of the core! (because we don’t have good information on the moment of inertia).

Venus has no magnetic field (no dynamo exists).

**But the core may be partially molten.**

A dynamo requires convection, so maybe Venus lacks a strong enough thermal or chemical gradient for a dynamo to exist.
Mean density of Venus is similar to Earth. Venus was formed from the same starting materials in solar nebula.

Thus, the abundances of major chemical elements (Si, Ti, Al, Fe, Mg, Ca) are likely similar to Earth.

Currently, our best estimate of the bulk composition of Venus is to assume it is similar to Earth.

The crust of Venus is relatively uniform in thickness, with an average of ~30 km.
Venus exhibits volcanic plains, channels, volcanoes, coronae and tesserae.

The crust is dry, which makes it very rigid.
Large volcanoes are supported for long times by the crust.

Venus is effectively one large plate, quite different from the wet multiple plates present on Earth that give rise to continental crust.
The Surface of Venus: Volcanic Plains

Lots of smooth, volcanic regions with low relief, similar to the seafloor on Earth.

These plains cover ~80% of the surface and were likely emplaced by extensive lava flows.

The plains appear to have formed over large regions on relatively short timescales, though there is some debate about this.

Atalanta Planitia

Smooth Plains
Some regions in the volcanic plains exhibit regularly spaced faults, often intersecting at high angles (see left).

On Earth, such faulting is typically only observed near plate boundaries, yet Venus does not have plate tectonics!

On Venus, the crust fractures because it is dry, whereas the crust on Earth is ‘wet’.
The Surface of Venus: Channels

The plains of Venus exhibit ~200 channels, yet there is no water on Venus.

The channels are often sinuous and exhibit meanders that are reminiscent of meandering streams on Earth.

**Looks can be deceiving!**

These channels are caused by thermal erosion due to lava flows.

The lava was likely of very low viscosity (possibly carbonate-rich) and flowed like water.

The longest channel stretches for ~6800 km, longer than the Nile!

However, it is only 1 km wide and 20 m deep.
The Surface of Venus: Channels
There are over a million small shield volcanoes on the surface of Venus, many of which resemble seamounts on the Earth.

This reinforces the idea that volcanism on Venus is largely basaltic.

Some of these volcanoes likely formed over mantle hotspots/plumes, and many of these regions have also experienced uplift due to large rising bodies of magma.

The Maat Mons volcano, the tallest one on Venus at 8 km above the plains.
Lava domes on Venus can look like pancakes. They are formed by viscous lavas.

Radial and concentric fractures are common on these features and they are much larger than typical terrestrial lava domes.

On Earth, only silica-rich (rhyolitic) magmas produce such features. Is the same true of Venus?
The Surface of Venus: Highlands

Venus also has highlands that resemble mountain chains. They represent compression and extensional forces.
Mountains/highlands may form by the sinking of cold plumes downward through the mantle. This process would drag the crust with it and cause it to buckle and fracture.

Over time, this could lead to crustal thickening and formation of highland plateaus. In contrast, areas of magma upwelling make the crust bulge outwards and can cause extensional features.

Mountain belts near Lakshmi Planum.
Ring-like features, called coronae, are present on Venus that have no analog on Earth or elsewhere in the Solar System. These are believed to be volcano-tectonic features.
Ring-like features, called coronae, are present on Venus that have no analog on Earth or elsewhere in the Solar System. These are believed to be volcano-tectonic features. These structures consist of concentric rings of grooves and ridges, with the largest feature being up to 2500 km in diameter.

These features are likely the surface expression of the upwelling of hot mantle material, possibly similar to mantle plumes on Earth.
Based on crater counts, the average age of the crust on Venus is only 500 million years.

Major volcanic activity took place at that time, forming extensive lava flows that covered (resurfaced) the older rocks/crust.

Apparently, little has happened on Venus since this global resurfacing event.

The lack of impact craters on Venus also makes it difficult to determine the relative ages of different terrains, thus the stratigraphic record of Venus is poorly understood.
Crater Retention Age on Venus

Note that the curve below ‘rolls off’ for small craters.

This suggests that something has occurred to bury them.
Example Geologic Map of Venus
Example Geologic Map of Venus