

Lecture Tutorials

*For Introductory Astronomy
Solar System*

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Earth and the Moon

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Earth's Tectonic Plate Boundaries

Part 1: The Plate Boundaries

Read the brief descriptions about what happens at each of the plate boundaries.

- 1) Draw arrows on each diagram (side view and overhead view) indicating the direction of plate movement.
- 2) Circle the landforms listed in the final column that occur at each plate boundary
- 3) Label the landforms in each diagram (side view and overhead view).

	What Happens	Diagram of Plate Boundary (the heavy line is the plate boundary)	Landforms
Divergent	Two tectonic plates move apart and magma erupts to form a high area between the plates.	<p>(side view)</p> <p>(overhead view)</p>	<p>Ocean ridge</p> <p>Volcanoes</p> <p>Subduction trench</p>
Convergent	Two tectonic plates move toward each other, and one plate is pushed under the other plate.	<p>(side view)</p> <p>(overhead view)</p>	<p>Ocean ridge</p> <p>Volcanoes</p> <p>Subduction trench</p>

Part 2: Finding Plate Tectonics on Other Planets

4) Circle one or two features that you would use to determine whether other distant planets have plate tectonics. Explain why you chose which one(s) you did.

Divergent ridges

Volcanoes

Subduction trench

The features found on the surface of a planet or moon gives clues about that planet or moon. For example, it is impossible to see wind, but it creates sand dunes. Interpretation of Earth's features is the first step to interpreting features on other planets.

Part 1: Features

1) How did these sand dunes form?

2) Would it be possible for these sand dunes to form on a planet:

a) with no atmosphere? Yes or No

b) with no liquid water? Yes or No

Explain.



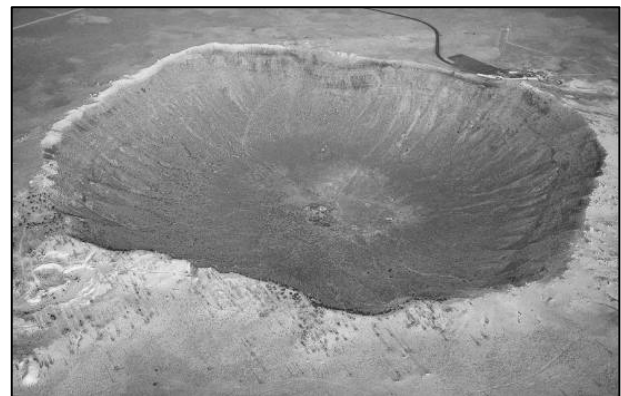
3) How did this impact crater form?

4) Would it be possible for an impact crater to form on a planet:

a) with an atmosphere? Yes or No

b) with a hot, molten interior? Yes or No

Explain.



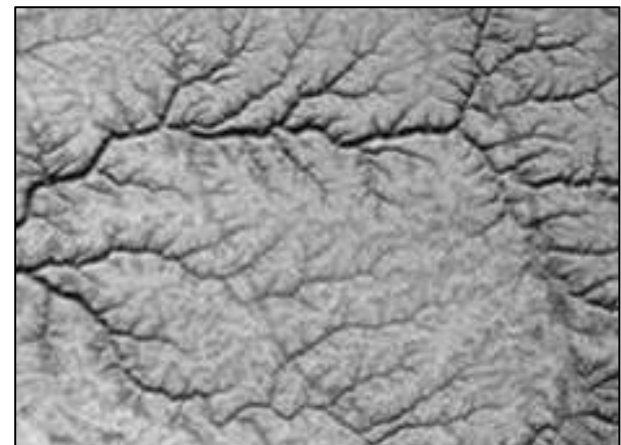
5) How did these stream beds form?

6) Would it be possible for stream beds to form on a planet:

a) with no hot, molten interior? Yes or No

b) with no liquid? Yes or No

Explain.



7) How did this volcano and lava flows form?

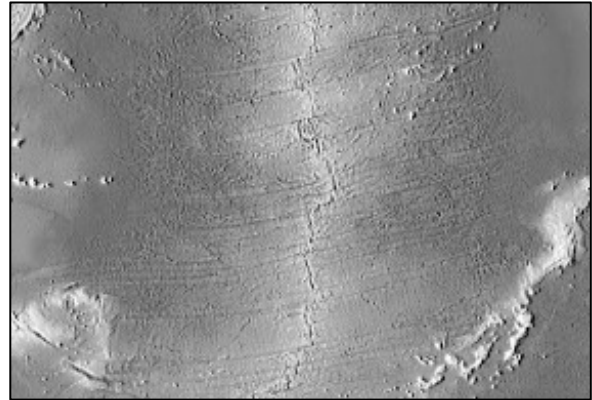


8) Would it be possible for volcanoes and lava flows to form on a planet:

- a) with no liquid water? Yes or No
- b) with no hot, molten interior? Yes or No
- c) with no atmosphere? Yes or No

Explain.

9) How did this divergent ridge form?



10) Would it be possible for this divergent ridge to form on a planet:

- a) with no hot, molten interior? Yes or No
- b) with no liquid water? Yes or No

Explain.

11) Two students are discussing their answer to the previous question.

Student 1: *A divergent ridge is formed by two plates moving apart because of plate tectonics. You need a hot, molten interior in order to form the convection currents that cause plate tectonics.*

Student 2: *But I thought divergent ridges only form in the middle of oceans. Without an ocean, the plates can't move apart, so you need both a hot, molten interior and liquid water.*

Do you agree or disagree with one or both students? Explain your reasoning.

12) Imagine a new planet is discovered that has sand dunes, impact craters, stream beds, volcanoes and plate tectonics. Circle what we can figure out about that planet:

It has an atmosphere

It has liquid

It has a hot molten interior

Explain.

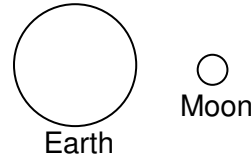
Earth has auroras because it has a hot interior that rotates forming a magnetic field that forces the solar wind toward the poles where it interacts with our atmosphere. Earth has an atmosphere because its large mass gives it a gravitational pull that is strong enough to affect gas.



Here we will consider if the Moon has auroras.

The Moon formed when a large object hit Earth and material “splattered” into space. The lighter material (gas) drifted away and the heavy, rocky material eventually formed the Moon.

The Moon's mass is 6% Earth's mass.



1) Does the Moon have a much stronger or much weaker force of gravity than Earth? _____
Explain.

2) Does the Moon have an atmosphere like Earth? _____
Explain.

The relatively small size of the Moon also means that its interior has cooled.

3) Does the Moon currently have a magnetic field? _____
Explain.

4) Knowing the cause of Earth's auroras, explain two reasons why the Moon does not have auroras.

5) The Moon's diameter is 3,500 km diameter, Mercury's diameter is 4,900 km, and Earth's diameter is 12,800 km. Suppose someone proposes a mission to go study the auroras on Mercury because it is so close to the Sun. Would you fund this mission? Explain.

The Moon's Crater History

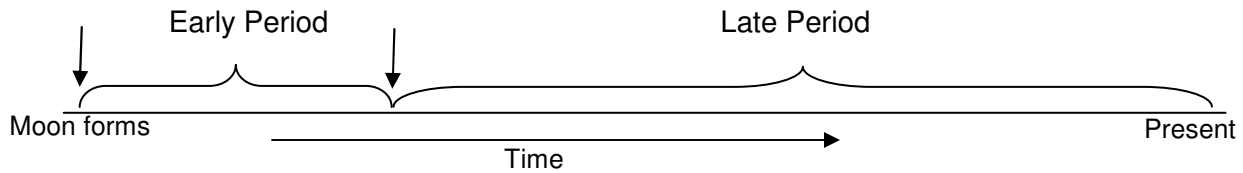
Part 1: Posing a Question

Did the rate of impact crater formation on the Moon change (increase or decrease) over time?

Part 2: Hypothesis

To determine how the impact rate changed over time, we will look at two different periods of time. We will look at the Early Period recorded in highland rocks formed when the Moon formed, and the Late Period recorded in mare basalt lava flows that formed .7 billion years later.

1) On the timeline, label the arrows as "highlands form" and "basalt erupts".



2) Which was longer? (circle one) Early Period Late Period

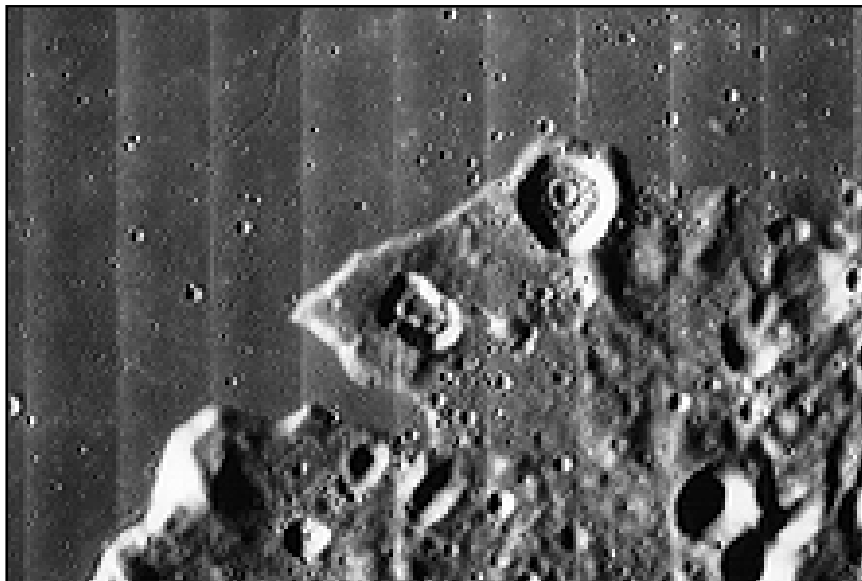
3) Now state a hypothesis. If the rate (number of craters per year) stayed constant, which of these periods would you expect to have recorded the most impact craters total? (circle one)

 Early Period Late Period

Part 3: Collecting Data

The rougher surface is highlands (Early Period + Late Period) and the smoother surface is mare basalt (Late Period only). In this photo, the area covered by the mare basalt is essentially the same as the area covered by the highlands.

4) Estimate the number of craters on each surface that are larger than this dot: ○
Do not take more than 1 minute to count!



Mare basalt
(Late Period only)

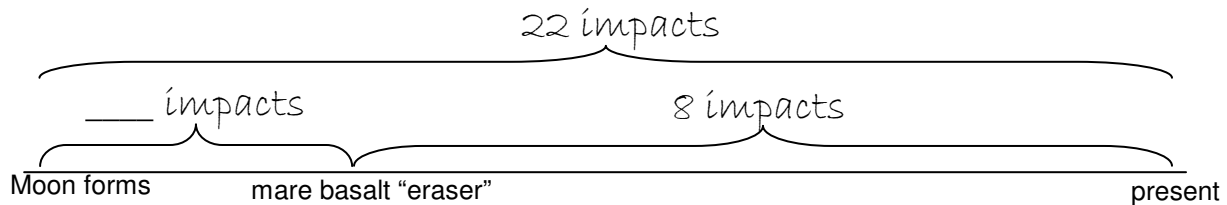
Highlands
(Early + Late Period)

The Moon's Crater History

To simplify the next discussion, for the rest of the exercise we will use a count of 22 impacts for the highlands and 8 impacts for the mare basalt.

22 impact craters formed on the area of the highlands since the Moon formed (Early + Late Period). 22 impact craters probably formed on the area of the mare basalt – except the lava flows erased some of them! 8 impact craters are visible on top of the mare basalt lava flow (Late Period only). How many impact craters are probably hidden under the mare basalt lava flow?

5) With 22 impacts total, and 8 impacts since the mare basalt, write in the diagram below how many craters are hidden beneath the basalt.



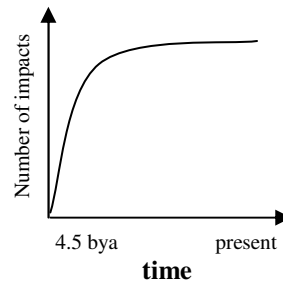
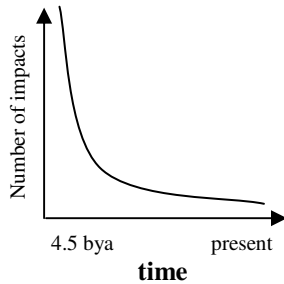
6) Compare your results to your answers to Question #2 and #3.

Did the rate of impact crater formation stay constant? _____

Part 4: Discussion

7) The number of impacts per billion years has (circle one) increased decreased

8) Circle the graph that best represents the impact rate (number of impacts over time).



9) Why were there so many meteor impacts soon after the formation of the Moon, but later the number of meteor impacts per billion years is so small? (think about how the Moon formed)

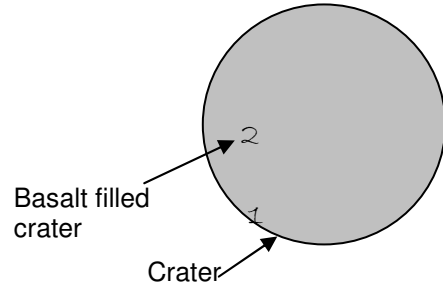
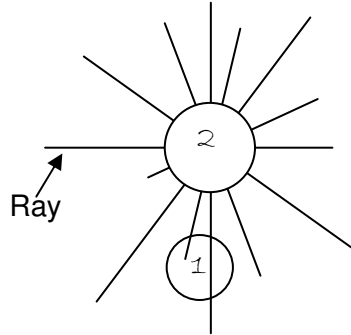
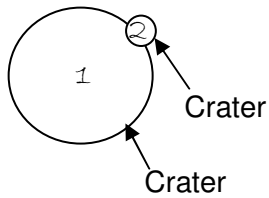
10) Estimate the number of craters that will form in the area shown on the previous photograph in the next billion years.

Craters: The Order of Events

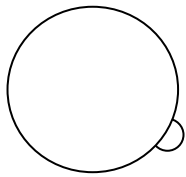
Part 1: Crater Relative Ages

The following are craters and basalt on the Moon's surface. In each scenario determine the order of events and label them with the first event as "1", the second as "2" and so on until you have labeled all of the events. An event may be crater formation or mare basalt eruption. A crater with rays is fairly young, but there may be younger craters without rays. Basalt is shown as a filled-in gray area.

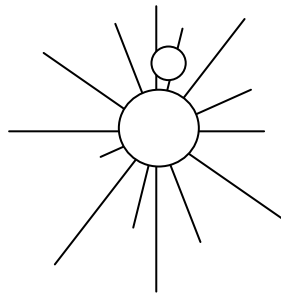
Examples:



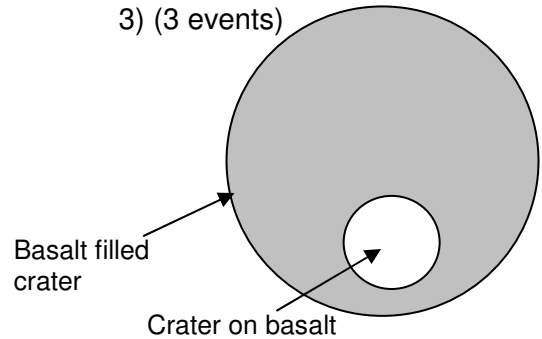
1) (2 events)



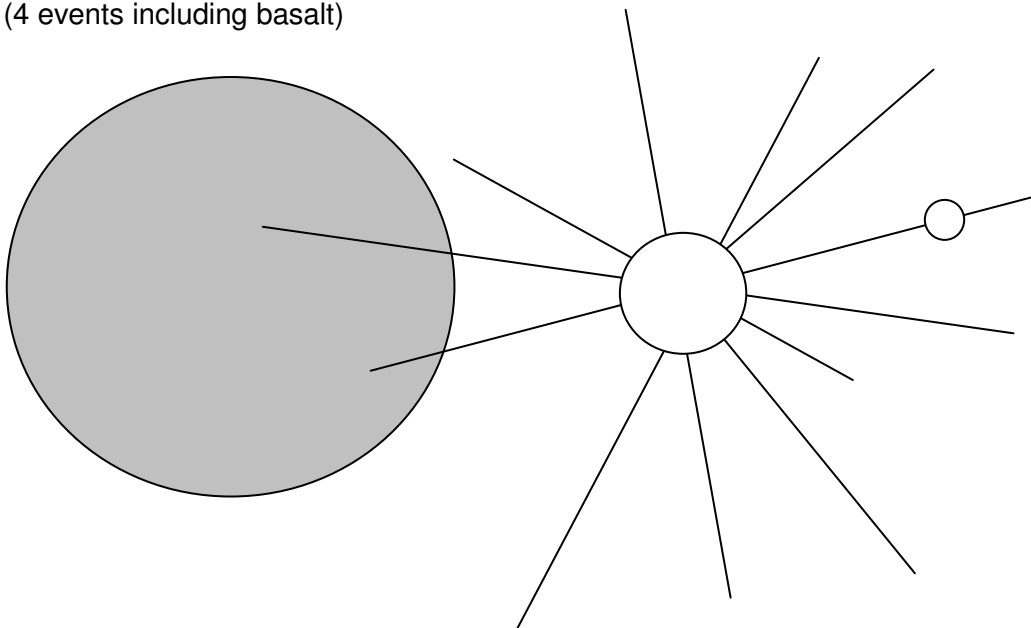
2) (2 events)



3) (3 events)



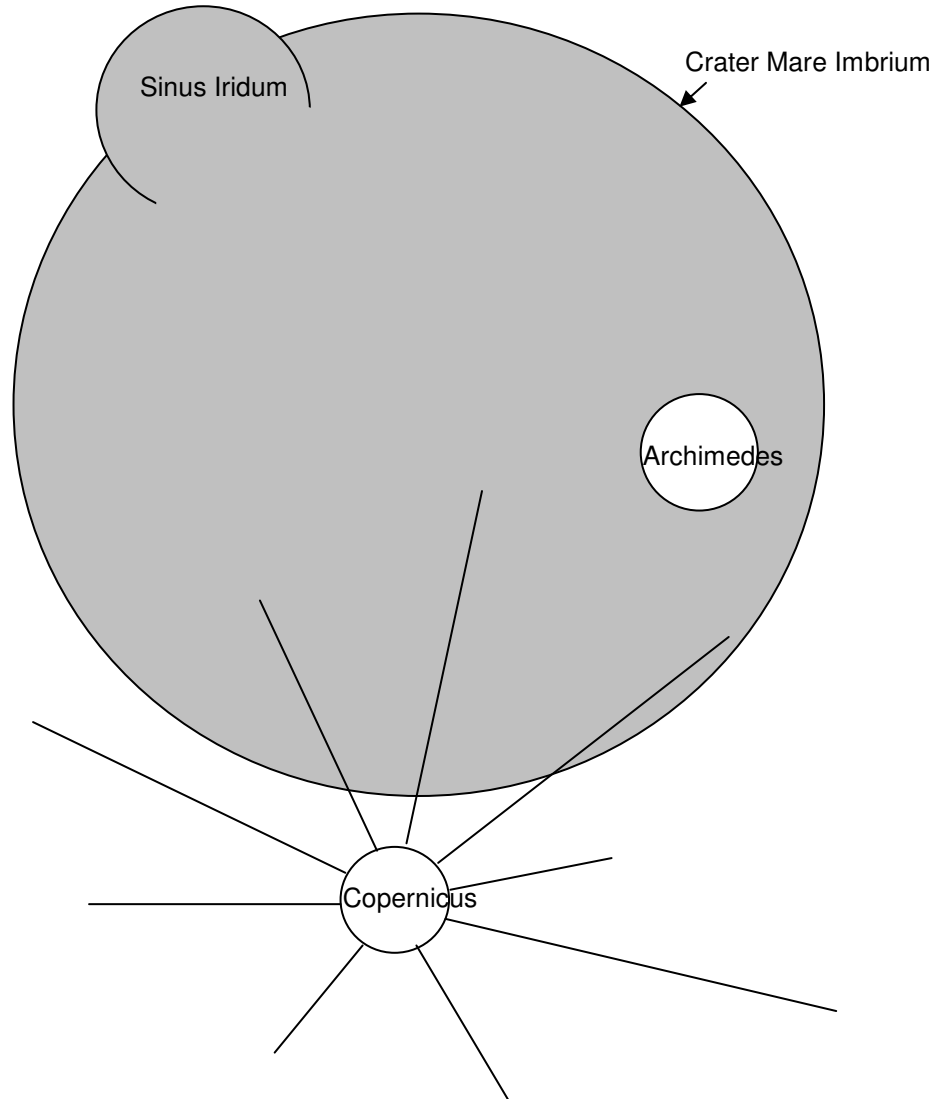
4) (4 events including basalt)



Craters: The Order of Events

The diagram below shows a portion of the surface of the Moon.

- 5) Use the same techniques to determine the relative ages of the events. The creation of four craters named Copernicus, Sinus Iridum, Mare Imbrium, Archimedes, and the flooding of the basalt.



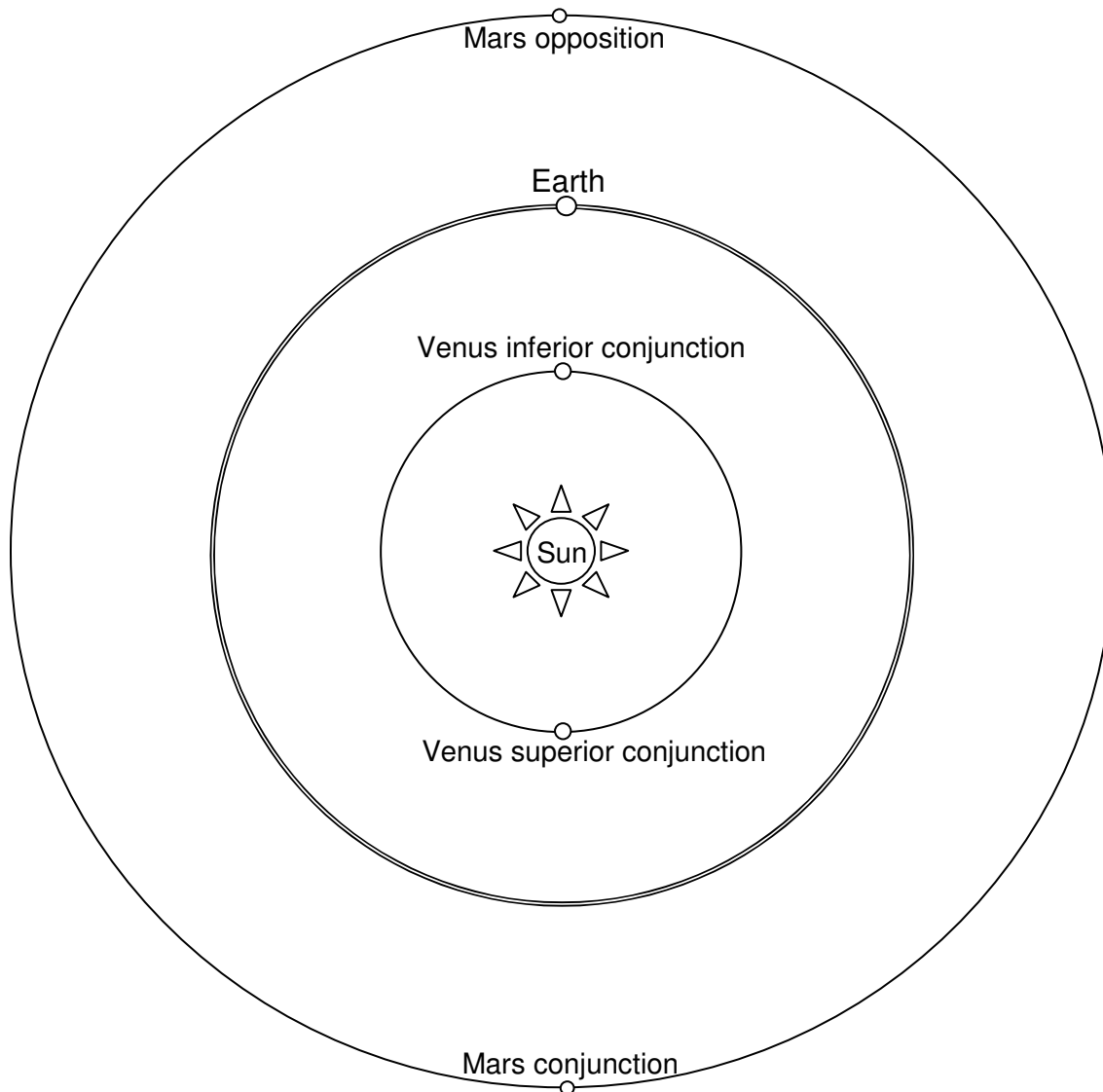
Oldest (first) _____

Youngest (last) _____

Part 1: View from above

Below is a representation of the Sun, and the orbits of Earth, Venus and Mars (not to scale!). We will look at the positions of Venus and Mars – one planet closer to the Sun, and one farther.

- 1) For each location of Venus and Mars, shade in the side of the planet not lit by the Sun, and label the planet “good view” or “can’t see” for an observer on Earth when Earth is in its labeled position.



Write your answers to the following questions on the diagram.

- 2) Next to Mars conjunction, explain why it is impossible for astronomers on Earth to view Mars.
- 3) Next to Venus in inferior conjunction, explain why it is impossible to view Venus
- 4) Draw and label Venus's best position(s) for a viewer on Earth to see it and explain why.
- 5) Next to Mars opposition, explain two reasons why this is the best time to view Mars.

6) When Mars is at opposition, the view from Earth will show Mars to be in what phase?

(shade in the circle)



7) What time(s) of night would be the best time to view Mars in opposition?
(it may help to draw a person on Earth in the diagram)

just before sunrise midnight just after sunset

Explain.

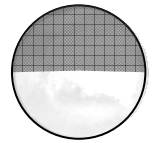
8) If you were standing on Mars at this time (opposition), could you see Earth? yes no

9) For which other planets would these answers be the same as your answers for Mars?

Mercury Venus Jupiter Saturn Uranus Neptune

10) Two students are discussing how Mars looks from Earth at opposition.

Student 1: *As seen in the diagram, only half of Mars is lit by the Sun, so I drew it half lit and half in shade.*



Student 2: *The view you drew is from directly above Mars. Our view from Earth is different. We have to look directly away from the Sun to see Mars at opposition, so we see only the lit side.*



Do you agree or disagree with one or both students? Explain your reasoning for each.

11) When Venus is in inferior conjunction, the view from Earth will show Venus to be in what phase?

(shade in the circle)



12) If you were standing on Venus at this time, could you see Earth? yes no

13) What time(s) of night would be the best time to view Venus?
(it may help to draw a person on Earth in the diagram)

just before sunrise midnight just after sunset

Explain.

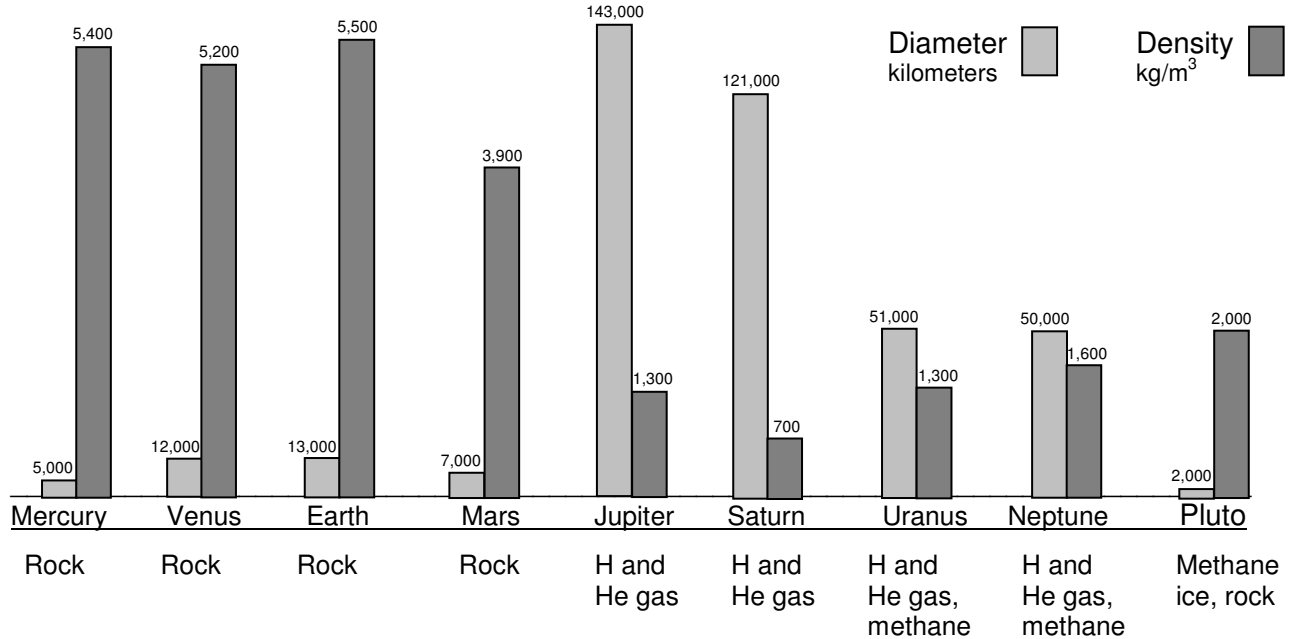
14) For which other planets would these answers be the same as your answers for Venus?

Mercury Mars Jupiter Saturn Uranus Neptune

Terrestrial Planets Vs Jovian Planets

Part 1: Density vs Diameter

The diameter and density for the planets and Pluto have been plotted on a bar graph. Listed below each planet is the composition.



1) Divide the planets (not Pluto) into two groups based on the density, diameter and composition.

Group 1

Group 2

Diameter: small or large

small or large

Density: high or low

high or low

Composition: rock or gasses

rock or gasses

Planet Names:

2) Label the group of larger, low density gassy planets “Jovian planets” and the group of smaller, high density, rocky planets “Terrestrial planets”.

3) Does Pluto fit exactly with either of the groups? Explain.

Rock Types on Other Planets

On Earth there are igneous, sedimentary, and metamorphic rocks. Understanding the way they formed allows us to determine whether or not we are likely to find them on other planets.

1) Match the rock type with the correct statement describing its formation.

- _____ Found where the atmosphere or liquid water causes erosion and movement of rock pieces
- _____ Found mostly near convergent tectonic plate boundaries where the temperature and pressure can be very high.
- _____ Found in places where the interior is so hot that rock melts

On the Moon, the first rocks to form when it was molten were the outermost low-density rocks that cooled to form the highlands. Then molten rock filled in the lower areas and cooled. This rock is called the mare basalt.

2) Based on these descriptions, of what type of rock are the highlands and mare basalt composed?

Highlands:	igneous	sedimentary	metamorphic
Mare basalt:	igneous	sedimentary	metamorphic

Planet	Water	Atmosphere	Molten interior	Plate Tectonics
Mercury	no	no	early only	no
Venus	no	thick	yes	no
Earth	liquid, ice	medium	yes	yes
Moon	no	no	early only	no
Mars	ice	thin	for a while, no more	no

3) Where in our solar system might we find igneous rocks? Explain your choice based on what factors are necessary for an igneous rock to form.

4) Where in our solar system might we find sedimentary rocks? Explain your choice based on what factors are necessary for a sedimentary rock to form.

5) Where in our solar system might we find metamorphic rocks? Explain your choice based on what factors are necessary for a metamorphic rock to form.

6) What is the most common rock type in the Solar System? _____

Part 1: Planet Features

1) What feature requires a planet to have a hot, molten interior?

dunes impact craters stream beds volcanic lava flows

2) What feature requires a planet to have an atmosphere?

dunes impact craters stream beds volcanic lava flows

3) What feature requires a planet to have liquid on the surface?

dunes impact craters stream beds volcanic lava flows

4) What feature does not require a planet to have any particular characteristics?

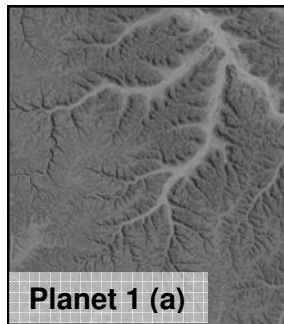
dunes impact craters stream beds volcanic lava flows

The following images are of three different Earth-like planets (Mercury, Earth, and Mars). All the images are of the solid, rocky surface and were taken by NASA spacecraft.

5) Examine these images and identify the type of surface feature shown: sand dunes, impact craters, stream beds, lava flows.

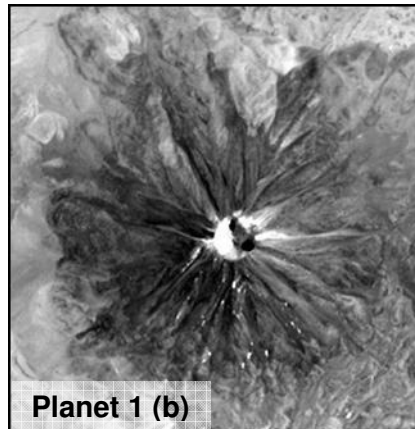
6) For each planet, write down what you can determine about the planet based on those images (if it has an atmosphere, a molten interior, or liquid on the surface).

Planet 1



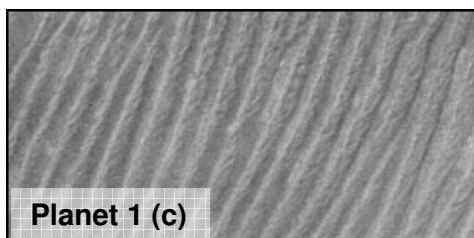
Planet 1 (a)

Feature: *Stream beds*



Planet 1 (b)

Feature:



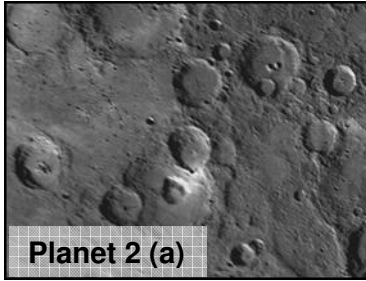
Planet 1 (c)

Feature:

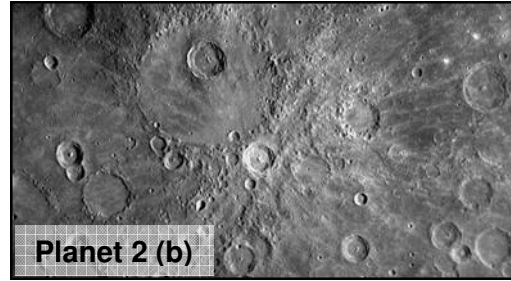
What I know about this planet:

Planet Surface Features

Planet 2



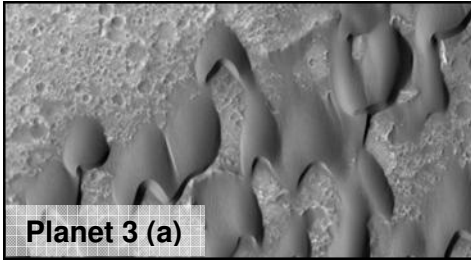
Feature:



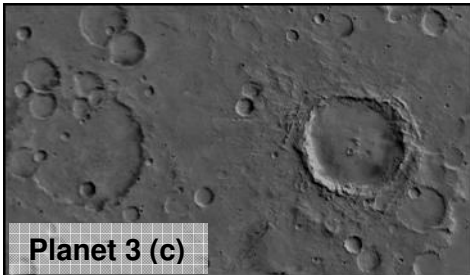
Feature:

What I know about this planet:

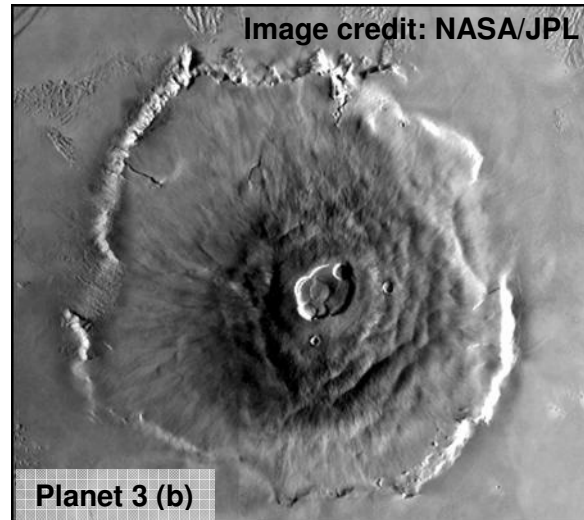
Planet 3



Feature:



Feature:



Feature:

Feature:

Notice that the presence of some impact craters indicates that this feature has not been modified for millions of years!

What I know about this planet:

Mars has an atmosphere, and it once had a hot, molten interior and liquid water (although not any more). Mercury does not have an atmosphere, liquid water, or a hot, molten interior.

7) Using the information given, label each of the planets as Earth, Mercury, or Mars.

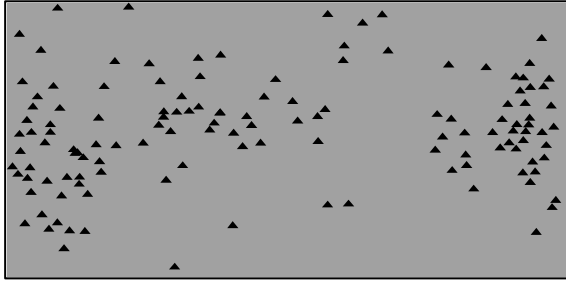
8) The Moon is completely covered in craters. What can you determine about the Moon based on this information?

Volcanoes on Other Planets

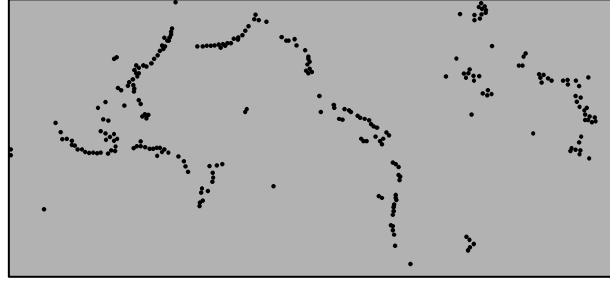
Part 1: Observing Volcano Distribution

When a scientist makes a discovery, it helps to have as many different sources as possible confirm that discovery. Here we will look at two ways to determine the types of volcanoes on other planets.

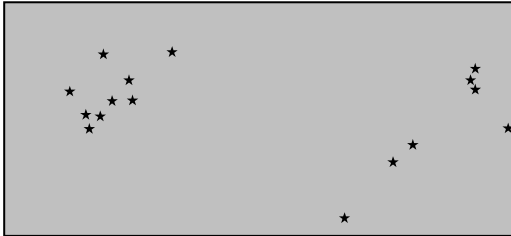
- 1) Examine the maps of volcanoes on Mars, Venus, and Earth. Take 1 minute to describe what kinds of patterns (or lack of patterns) you see in the location of volcanoes on each planet.



Volcanoes on Venus (triangles)



Volcanoes on Earth (dots)



Volcanoes on Mars (stars)

Part 2: Analysis

Two locations at which volcanoes form are at randomly-distributed hotspots or lined up along tectonic plate boundaries. A single planet might have both types of volcanoes.

- 2) Why do the volcanoes on Earth form where they do? hot spots plate tectonics
Explain how your answer is related to your observations about the maps.

- 3) Why do the volcanoes on Venus form where they do? hot spots plate tectonics
Explain how your answer is related to your observations about the maps.

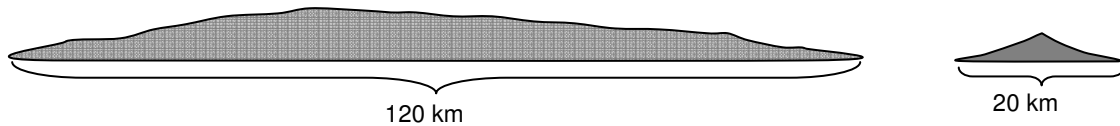
- 4) Why did the volcanoes on Mars form where they did? hot spots plate tectonics
Explain how your answer is related to your observations about the maps.

- 5) Which planet(s) has/have plate tectonics? Venus Earth Mars

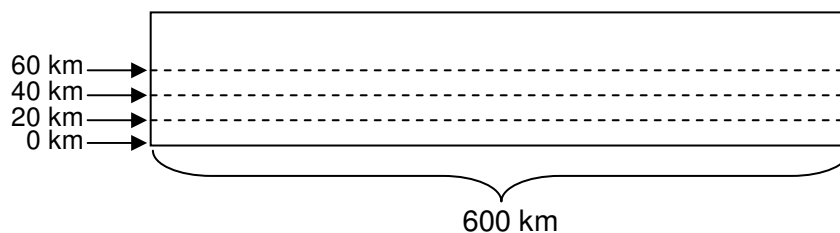
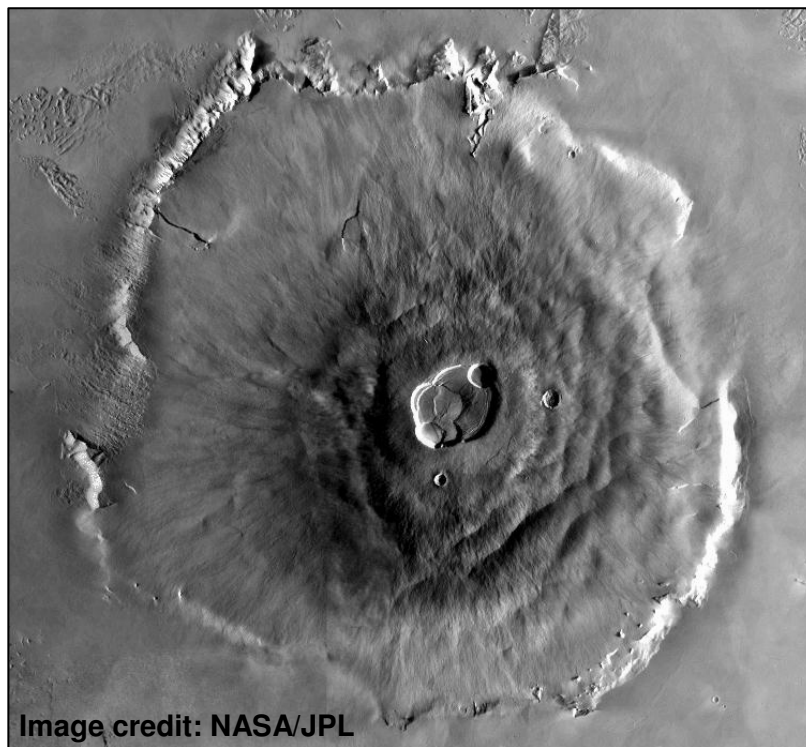
Volcanoes on Other Planets

Another way to determine the cause of volcanoes on other planets is to compare the two types of volcanoes on Earth with volcanoes on other planets. Plate tectonic volcanoes on land (e.g. Mount St. Helens) have steep slopes, and hot spot volcanoes (e.g. Hawaii) have gentle slopes.

- 6) Look at the profile of volcanoes on Earth drawn to scale. Label the two volcanoes as “hot spot volcano” or “plate tectonic volcano”.



Below is a satellite image of Olympus Mons, an example of a volcano on Mars. This volcano is approximately 25 km tall and 600 km wide. It is possible to use satellite information to create a profile like the ones of Earth shown above.



- 7) Use the information about the height and width of the volcano to sketch the profile of this volcano (like the ones of volcanoes on Earth shown in Question 6) on the graph above.

Volcanoes on Other Planets

- 8) Based on the profiles, is the volcano on Mars a hot spot volcano or a plate tectonic volcano? Explain.

You used two methods to determine the type of volcanoes found on Mars: the distribution of volcanoes to determine the likely source of volcanism, and the profile of an individual volcano.

- 9) Do your two data sets agree? If they do not agree, what might cause the difference?

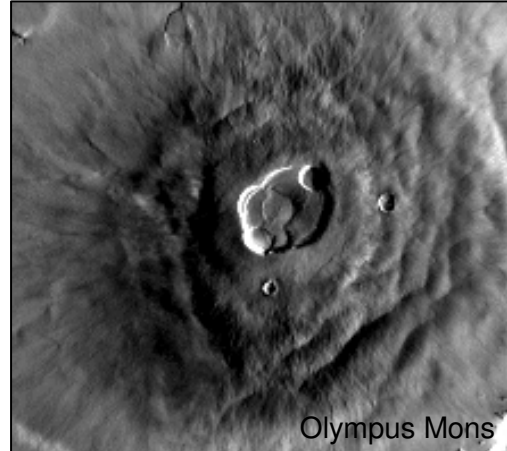
- 10) Why is it helpful for a scientist to have two or more different data sets when giving evidence to support a discovery?

Part 1: Surface Features

In order to understand the climate of Mars, we need to understand how the geologic history, atmosphere, and climate of Mars are all related.

This is a photo of Olympus Mons, a volcano on Mars.

- 1) How can you tell there has not been an eruption for a long period of time?

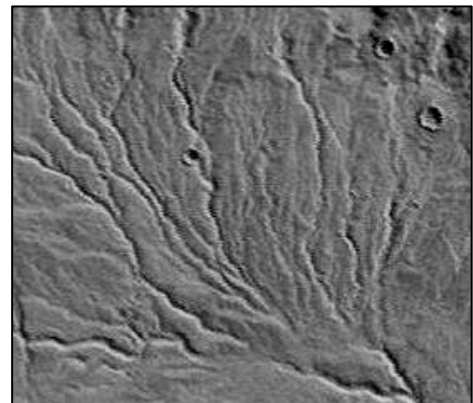


- 2) Based on this photo, does Mars currently have a hot, molten interior? Yes No

- 3) Did Mars have a hot, molten interior in the past? Yes No

This is a photo of some dried stream beds on Mars.

- 4) How can you tell that this river system on Mars has not had flowing water for millions of years?



Part 2: Causes of Interior Heat vs Surface Heat

It is very important to understand the causes of a hot interior compared to the causes of a hot surface.

- 5) Which does the Sun heat? the interior (core) of a planet the surface of a planet

- 6) Does the distance of a planet from the Sun affect the heat of the interior? Why or why not?

- 7) Why are Earth's and Venus' interiors still hot, but the interior of Mars and Mercury have cooled, even though they all formed at the same time 4.6 bya and Mercury is the closest planet to the Sun?

The temperature of the interior is related to planet size. Next we need to determine what affects the temperature of the surface.

- 8) Look at the map of volcanoes on Mars. Is it likely that the heat from the lava from these volcanoes was enough to heat the surface and melt all the ice that formed water in the rivers on Mars?



Yes No

If lava did not heat the whole surface, something else did. When Mars had a hot molten interior, volcanoes also emitted greenhouse gasses (e.g. CO₂) into the atmosphere.

- 9) Use the following terms to explain the causes and effects of the listed items below.
(liquid water on surface, active volcanoes, CO₂ in the atmosphere, warmer climate)

A hot molten interior caused:

Volcanoes erupted causing:

Greenhouse gasses in the atmosphere caused:

A warmer atmosphere caused:

Part 3: Predicting Surface Features

The warm interior meant volcanoes erupted greenhouse gasses which kept the surface of Mars warm enough for there to be liquid water. Now that the interior of Mars is cool and solid, there is less greenhouse gas in the atmosphere so the whole surface is cooler.

- 10) Circle the features that were forming on the surface of Mars billions of years ago.

volcanoes sand dunes rivers lakes craters

- 11) Circle the features that are forming on the surface of Mars right now.

volcanoes sand dunes rivers lakes craters

- 12) How was early Mars different than Mars today?
(Why is your answer to question 11 different than your answer to question 12?)

Other Moon's Surface Features

The moons of planets in our solar system have features that form the same way as features on terrestrial planets. Two other parameters can affect the surface features on other moons.

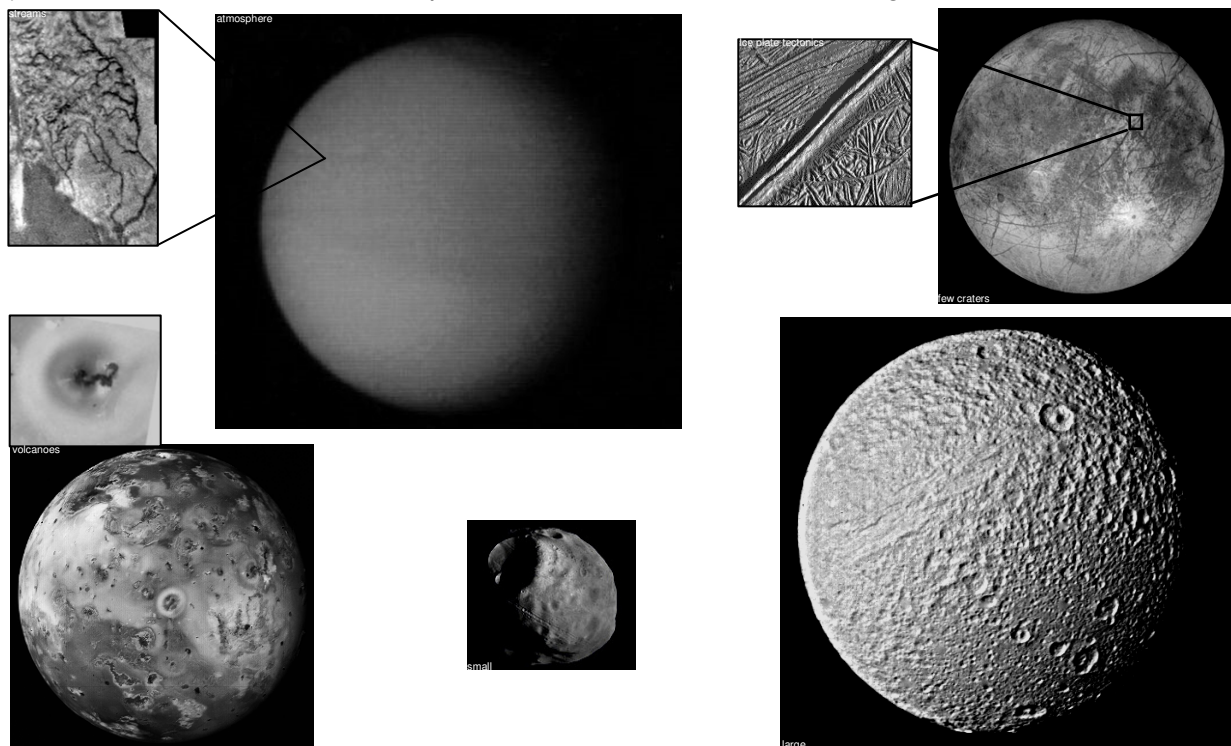
1. Strong tides can cause a hot, molten interior, even on a small moon.
2. Liquids other than water can occur on moons that are too cold for liquid water.

1) What features would you expect on the surface of each moon? You may repeat answers.

Choose from: many craters few craters stream beds divergent ridges volcanoes

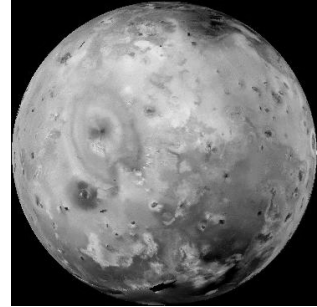
- a. Typical small moon: An asteroid captured by the gravitational field of a planet. Not large enough to be a spherical moon.
- b. Typical large moon: A geologically inactive moon that does not experience strong tidal forces. This moon is large enough to have enough gravity to be a spherical moon.
- c. Io: Orbits very near Jupiter (a Jovian planet) and is strongly affected by the tidal forces of Jupiter. The tidal forces cause heat that escapes at the surface.
- d. Europa: Orbits close to Jupiter, so that there are strong tidal forces. Cracks in the surface ice can be seen where liquid water has recently welled up. Liquid water beneath the ice may be heated by volcanic vents.
- e. Titan: One of Saturn's moons. It is too cold for there to be liquid water on the surface, but it is the correct temperature for liquid methane to exist. This liquid methane evaporates and creates cloud cover over the surface.

2) Write the name from the description above next to each of the images of moons below.

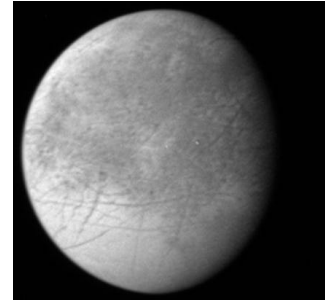


Other Moon's Surface Features

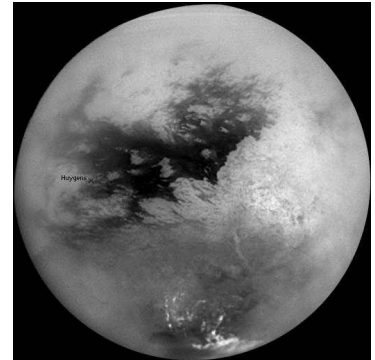
3) Why does Io have very few craters?



4) Why does Europa have very few craters?



5) Why does Titan have very few craters?



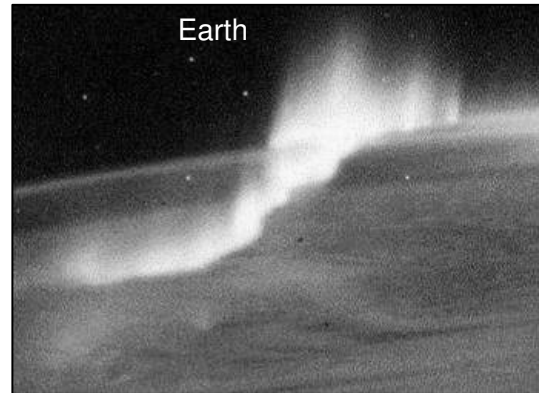
You have been commissioned by NASA to find life elsewhere in the solar system. Both Titan and Europa have important characteristics when searching for life.

- a) liquid,
- b) the right composition molecular building blocks
- c) an energy source (sunlight or internal heat)

6) Which of these two moons would you explore first, and why?

Part 1: Auroras

Any planet might have auroras if it has a magnetic field and an atmosphere. Earth has a magnetic field caused by a rotating molten iron core. The hydrogen in the core of Jupiter acts as a liquid metal and also creates a magnetic field.



1) Based on this information, does Jupiter have auroras at the North and South poles? Explain your decision.

2) Consider the following discussion between these students.

Student 1: *The interior of a Jovian planet is squished very dense and the hydrogen acts like a liquid metal creating a magnetic field. However, I do not think there is an atmosphere, so there cannot be any auroras.*

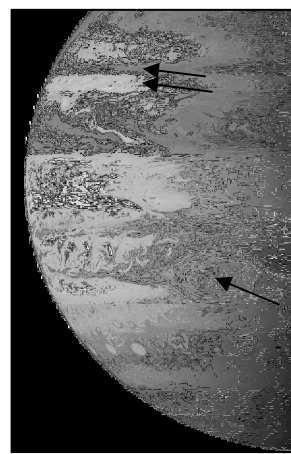
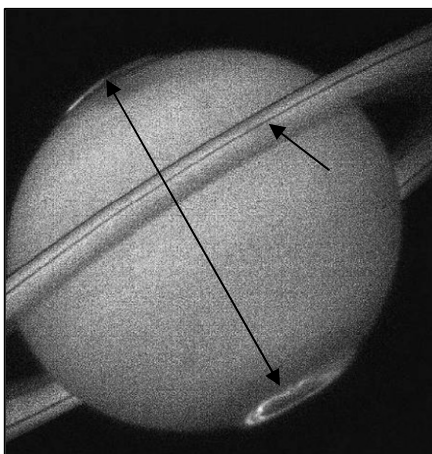
Student 2: *Jovian planets do have atmospheres. I heard they are made completely of gasses, so a spacecraft could fly in one end and out the other. Since they are composed only of a gas atmosphere, there cannot be a magnetic field, so there are no auroras.*

Student 3: *The interiors of the Jovian planets are so squished they act like liquid metals, but the outer gasses are like an atmosphere. I think Jovian planets probably do have auroras.*

Do you agree or disagree with these students? Explain your reasoning.

Part 3: Jovian Planet Features

3) For the arrows in the photos below, identify the feature and write down the processes that created it.



Asteroids, comets and meteoroids are lumps of material in our solar system. They are different from each other in size, location of formation and type of orbit around the Sun.

Meteoroid: Small objects ($\approx \leq 100$ meters) composed of rock and/or iron that orbit the Sun in the inner solar system where it was too hot during formation for ices to form.

Asteroids: Large objects (≥ 100 meters) composed of rock that generally orbit the Sun between Mars and Jupiter (inner solar system). Asteroids are too small to be planets, but they are much larger than meteoroids.

Kuiper Belt Objects: (KBO's) Large objects composed of rock and ice that orbit the Sun from Pluto's orbit at 40 AU out to 500 AU. KBO's are generally too small to be planets (few over 2,000 km).

Comets: When the orbit of a KBO is so elliptical that it comes into the inner solar system, we call it a comet. When it is near the Sun, the solar wind hits the rock and ice, and the ice evaporates to form a coma and tail around the nucleus.

1) Based on their composition, how do we know that comets must have formed in the outer solar system with other Kuiper Belt Objects, even though their orbit also brings them to the inner solar system? Briefly explain your decision based on temperature.

2) Explain if each of these objects is orbiting the Sun, a planet or some other object.

Meteoroid

Asteroid

KBO

Comet

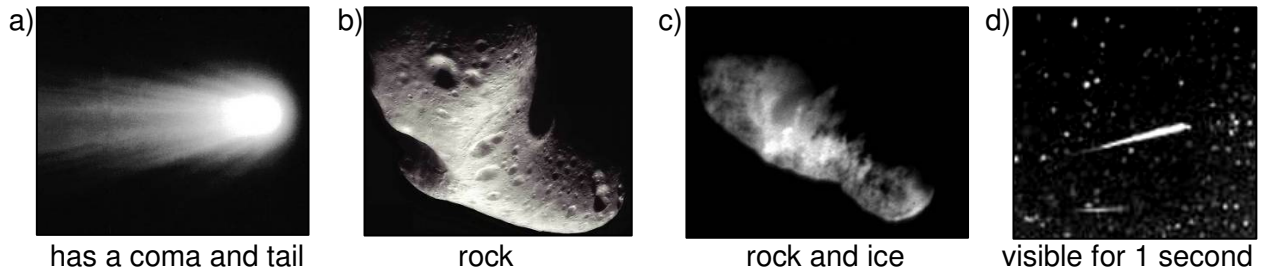
3) Consider the following discussion between these students.

Student 1: *These objects do not orbit planets, they orbit the Sun. If they were sitting still, their gravitational attraction to the Sun would pull them in.*

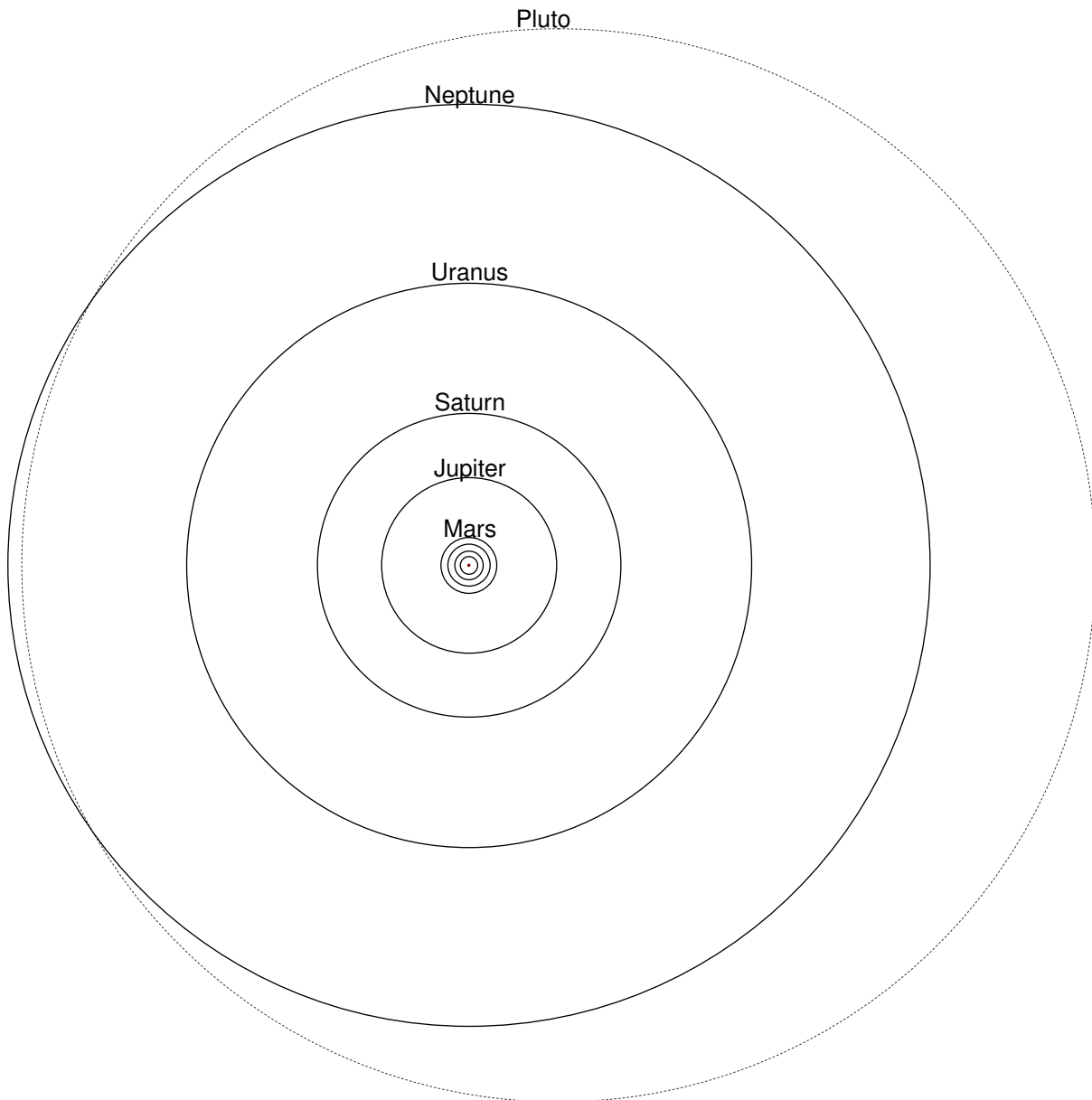
Student 2: *I agree that these objects do not orbit planets. If they did, they would be called moons. However, I think these objects are not orbiting anything. They are floating in the space between the planets.*

Do you agree or disagree with all or part of these statements? Explain your reasoning.

4) Label each image as an meteoroid, asteroid, KBO, or comet.



5) This is a diagram of the Solar System. Draw and label one example orbit for a meteoroid, an asteroid, a KBO and a comet.

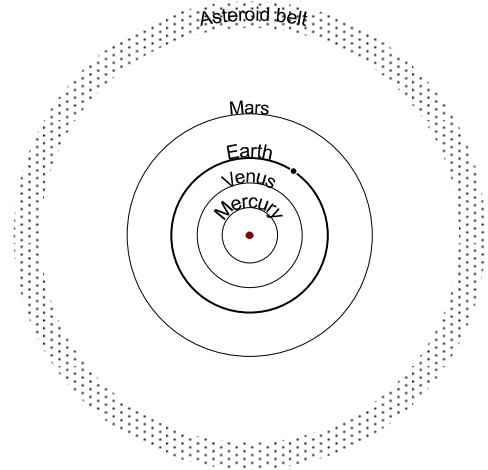


Asteroid Impacts

One estimate indicates there are around 10,000 asteroids larger than 1 km. There is usually over 1 million km between asteroids. Asteroids are so few and far between, that you could stand on one asteroid, and you would need a telescope to see the nearest neighbor asteroid.

- 1) To the best of your ability, draw a scale model of two asteroids at an average distance apart.
- 2) If a 1 km diameter asteroid is represented with a 1 mm grain of sand • how far away would the next asteroid be if in real life it is 1,000,000 km away?
 - a) 100 mm (4 inches)
 - b) 10,000 mm (10 yards)
 - c) 1,000,000 mm (1,000 yards)
- 3) Compare this result with your drawing and explain any difficulties you might have with accurately drawing two asteroids to scale.

- 4) The inner solar system is often drawn as shown. However, if Earth was the size indicated, the Sun should be the size of a baseball 30 feet away. What would you need to change to make this an accurate representation of the asteroid belt?



- 5) From Earth, we have sent many spacecraft to other planets. For which planets do our spacecraft travel through the asteroid belt? (circle all that apply)
Mercury Venus Mars Jupiter Saturn Uranus Neptune None of these
- 6) For which planets is it necessary for spacecraft to take extra precautions (e.g. guided flight path) to avoid the asteroids in the asteroid belt? (circle all that apply)
Mercury Venus Mars Jupiter Saturn Uranus Neptune None of these
- 7) Consider the following discussion between these students.

Student 1: *I think we need to avoid the asteroid belt for the Jovian planets because they are the ones on the other side of the asteroid belt.*

Student 2: *Because the asteroids are so few and far apart in the asteroid belt, we do not need to worry about avoiding the asteroid belt for any of the planets. If we need to, we can fly straight through!*

Do you agree or disagree with all or part of these statements? Explain your reasoning.

Part 1: Comparison to Terrestrial and Jovian Planets

You are on a committee to determine whether or not to classify Pluto as a planet.

Some facts about Pluto:

- diameter is 2,320 km (large enough to be round)
- orbit averages 40 AU (which is in the Kuiper Belt)
- composed of rock and ice.



1) Circle the characteristics the Terrestrial planets have in common.

- | | | | | |
|--------------|--------------------------|-------------------|------------------|-----------|
| high density | main composition is rock | small in diameter | small orbit size | has rings |
| low density | main composition is gas | large in diameter | large orbit size | no rings |

2) Circle the characteristics the Jovian planets have in common.

- | | | | | |
|--------------|--------------------------|-------------------|------------------|-----------|
| high density | main composition is rock | small in diameter | small orbit size | has rings |
| low density | main composition is gas | large in diameter | large orbit size | no rings |

3) Which of the characteristics does Pluto share with each of these groups?

similar to Terrestrial planets:

similar to Jovian planets:

not similar to either Terrestrial or Jovian planets:

In 2006 a panel of Astronomers met to determine the criteria used to define a planet. The three main parameters they came up with are that the object must:

- orbit the Sun
- be large enough to be round (small objects are lumpy/potato shaped)
- clear its orbit free of debris (not in the asteroid belt, not in the Kuiper Belt, etc)

4) Given this information, is Pluto a planet? Yes No
If yes, explain if it is terrestrial or jovian. If no, explain why not.

Part 2: Comparison to Kuiper Belt Objects

A Kuiper Belt Object (KBO):

- orbits the Sun between 40AU and 500AU (beyond the orbit of Neptune)
- is composed of rock and ice
- is not large enough to be round (<1,000 km) and is therefore lumpy/potato shaped

5) Given this information, is Pluto a KBO? Yes No
Explain.

Part 3: Comparison to Dwarf Planets

The panel of astronomers defined a new category of planet called “dwarf planets”.

A dwarf planet:

- orbits the Sun
- is large enough to be round (roughly 1,000 km in diameter or large)
- has not cleared its orbit free of debris (is in the asteroid belt or in the Kuiper Belt)

A photograph of **Ceres** is shown to the right (933 km diameter). It has an orbit at 2.8 AU from the Sun, within the asteroid belt between Mars and Jupiter.

6) Should Ceres be called a planet, an asteroid, or a dwarf planet? Explain.



A photograph of **Ida** is shown to the right (50 km diameter). It has an orbit at 2.9 AU from the Sun, within the asteroid belt between Mars and Jupiter.

7) Should Ida be called a planet, an asteroid, or a dwarf planet? Explain.



A photograph of **Eris** is shown to the right (2,400 km diameter). It has an orbit that averages 96 AU from the Sun and is large enough to be round although we don't yet have clear enough images to confirm this.



Eris
(best image)

8) Should Eris be called a planet, an KBO, or a dwarf planet? Explain.

Part 4: Making a decision

9) As a committee, decide how to classify Pluto. Use the space below to explain the deciding factors. (Note that Pluto itself has not changed. It is only a human classification that has.)

Part 1: Understanding Previous Missions

Below is a condensed list of major American missions. Parentheses indicate the arrival year if different than the year sent.

- 1962 – 1971 – Mariner series. Flybys past **Venus** and **Mars**
- 1969 – 1972 – Apollo series; humans on the **Moon**
- 1972 – Pioneer 10 to **Jupiter** (1973) flyby
- 1973 – Mariner 10 to **Mercury** (1974)
- 1973 – Pioneer 11 to **Jupiter** (1974) and **Saturn** (1979) flyby
- 1975 – Viking I and II orbiters each with a lander to **Mars** (1976)
- 1977 – Voyager I and II to **Jupiter** (1979) and **Saturn** (1980) **Uranus** (1986) and **Neptune** (1989) flyby
- 1978 – Pioneer Venus Orbiter to **Venus**
- 1989 – Galileo to **Jupiter** (1995)
- 1989 – Magellan to **Venus** (1990) (radar altimeter)
- 1994 – Clementine orbiter to the **Moon**
- 1996 – Mars Global Surveyor orbiter to **Mars** (1997)
- 1996 – Pathfinder and Sojourner rovers to **Mars** (1997)
- 1997 – Cassini orbiter to **Saturn** (2004) (Huygens probe (lander) to **Titan**)
- 2001 – Mars Odyssey orbiter to **Mars**
- 2003 – Spirit rover and Opportunity rover to **Mars** (2004)
- 2003 – Mars Express orbiter to **Mars**
- 2004 – Messenger to **Mercury** (2008)
- 2005 – Mars Reconnaissance Orbiter to **Mars** (2006)
- 2006 – New Horizons to **Pluto** (2015)
- 2007 – Phoenix to **Mars** (2008)

- 1) Where have we sent the most missions? (circle) Mercury Venus Mars Jupiter Saturn
- 2) What is one advantage of sending a rover? In what cases might an orbiter be better?

The Cassini mission included a lander for its moon Titan which has an atmosphere and liquid methane. This is the first moon besides our own on which we have landed a space craft.

- 3) Why is NASA interested in landing on Mars and Titan when we still haven't landed on Mercury's surface?

Part 2: Funding Missions

- 4) For each pair of proposals, state which proposal you would fund. For the proposals you do not fund, explain how to improve the proposal. Explain your reasoning in terms of **a)** the benefits of using an orbiter vs. lander vs. rover, **b)** our current knowledge about the planets, and **c)** funding (could you learn the same amount for less money?).

Project Uno:

A lander to Jupiter to understand more about volcanoes, sand dunes and how rocky landforms are eroded by rain.

Project Eins:

An orbiter to Venus to study the atmospheric environment and greenhouse warming.

Project Dos:

An orbiter to Mercury to map the topography and learn more about the geology, interior structure and craters.

Project Zwei:

A rover to Titan to photograph the whole surface and understand the atmosphere and global environment.

Project Tres:

An orbiter to Uranus to learn more about Jovian storms.

Project Drei:

A lander to Mars to drill into the ground to look for frozen or liquid water.

Project Quatro:

A rover to Venus to study the formation of volcanoes.

Project Vier:

A lander to Europa to use seismic waves to learn about the thickness of the ice.

Part 3: Proposing future missions

NASA adopted a plan called “Faster, Better, Cheaper” in the 1990’s due to budget cuts. It began funding smaller proposals and reduced its funding for large scale proposals. Now, the missions cost about the same to send as it does to make a large-budget movie!

- 5) Outline your own proposal for a mission to a planet or other moon in our Solar System. Discuss whether you would send an orbiter, lander or rover as well as any instruments you would want to include. Most importantly, explain why your project should be the one that gets funded!