VIII. ASTRONOMY: THE TERRESTRIALS

A. The next few lectures deal with the terrestrial planets (with the exception of the Earth). I'll begin with a brief summary of their properties.

1. Consider Mercury, Venus, Earth, and Mars in this order.
   a. Their orbits have semimajor axes of 0.4, 0.7, 1.0, and 1.5 A.U.
   b. Their orbital periods are 0.24, 0.62, 1.0, and 1.88 years.
   c. Their radii are 0.38, 0.95, 1.0, and 0.53 times that of Earth.
   d. Their masses are 0.055, 0.82, 1.0, and 0.11 times that of Earth.
   e. Their average densities are 5.4, 5.2, 5.5, and 3.9 g/cm^3.
   f. Their rotation periods are 59, 243, 1.0, and 1.03 days.
   g. Their rotation axes are tilted by 0.0^0, 177^0, 23.5^0, and 25.2^0.

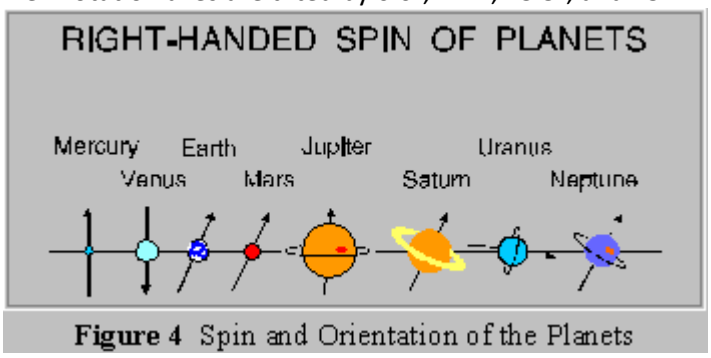
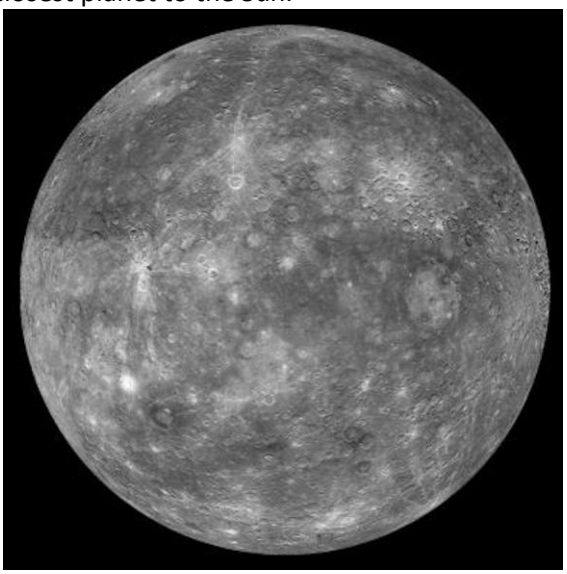


Figure 4 Spin and Orientation of the Planets

   h. They have 0, 0, 1, and 2 moons.
   i. For reference, Earth's radius is 6400 km, it's mass is 6.0 X 10^{24} kg, and 1 A.U. = 1.5 X 10^8 km.

2. In words, the terrestrial planets are close to the Sun, small, not very massive but dense, and have few moons. They have rocky outer parts and iron cores.

B. Mercury is the closest planet to the Sun.



1. It is difficult to study from Earth, because it always appears near the Sun in the sky.
   a. It is seen low above the horizon, shortly before sunrise or after sunset, and usually looks blurry due to turbulence in the Earth's atmosphere.

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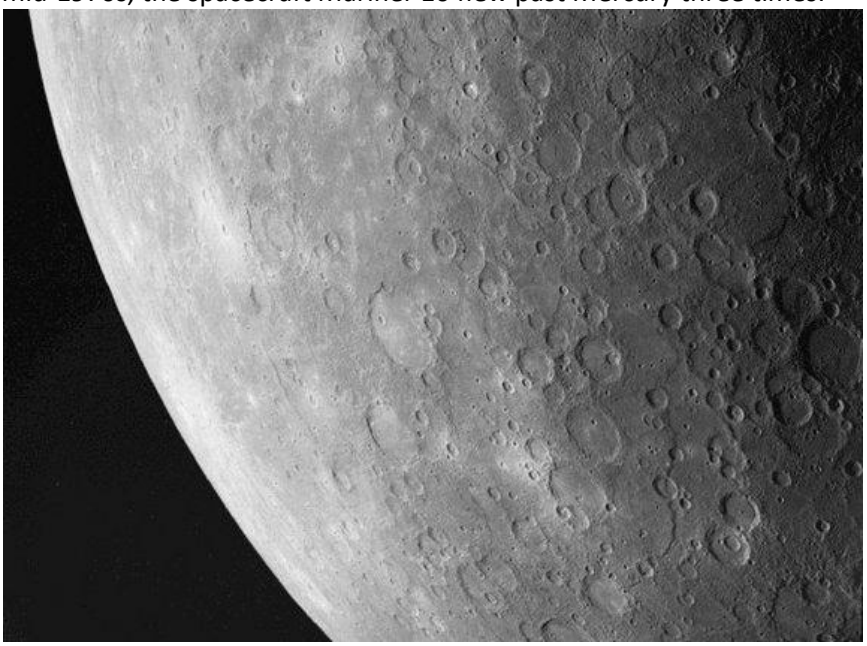
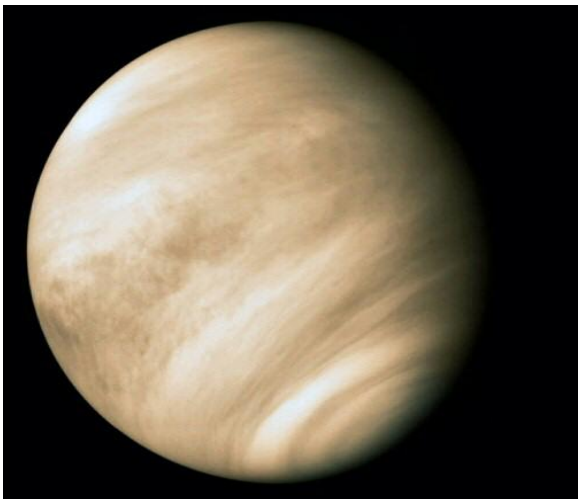
b. Surface features are hard to discern, so the true rotation period was unknown .
. for a long time; in fact, it was thought to be synchronous with the orbital period.
c. The rotation period was finally measured with radar, using the Doppler effect.
d. Mercury's rotation periiod of 59 days, together with it's orbital period of 88
.. days, leads to a day and night cycle of 176 Earth days.
e. Thus, there are 88 consecutive days of scorching sunlight, followed by an equal interval of darkness.
f. The high eccentricity of Mercury's orbit produces large variations in the Sun's angular size and irregularities in the Sun's motion across the sky.

2. Mercury has only a smidgin of an atmosphere. Consequently, the temperature extremes are enormous: 430 ^{0}C during the day, and -170^{0}C at night.
3. In the mid-1970s, the spacecraft Mariner 10 flew past Mercury three times.



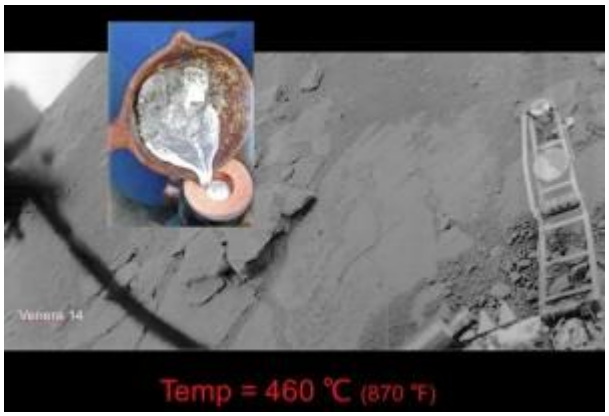
a. Photographs showed very heavily cratered terrain, like that of the Moon.
b. There is no evidence for current plate tectonics.

C. Venus, the second planet from the Sun, is easily visible as a very bright evening or morning "star".

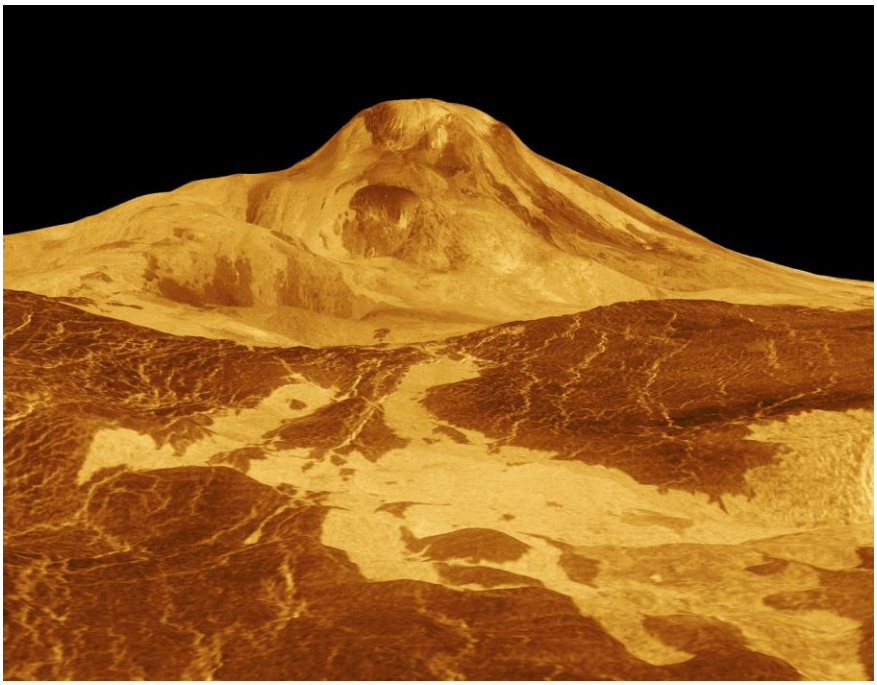


1. It is shrouded in highly reflective clouds that keep much of the sunlight out.
   a. Thus, despite it's proximity to the Sun, it had been considered as possibly having a hospitable environment, perhaps with hot, steamy jungles.
   b. This together with the near equality in size with Earth, led to an early view of Venus as Earth's "sister planet".
2. However, we now know that Venus has a very thick atmosphere, with a surface pressure 90 X that on Earth (i.e. 90 atmospheres).

   a. The atmosphere composition is 96% carbon dioxide (CO_2) and ≤ 4% nitrogen molecules (N_2).
   b. Earth is believed to have roughly the same total amount of CO_2, but it is mostly trapped in rocks (in the form of carbonates).
   c. Even clouds of Venus are toxic, consisting largely of sulfuric acid.
3. The high temperature is a consequence of an extreme version of the "greenhouse effect".



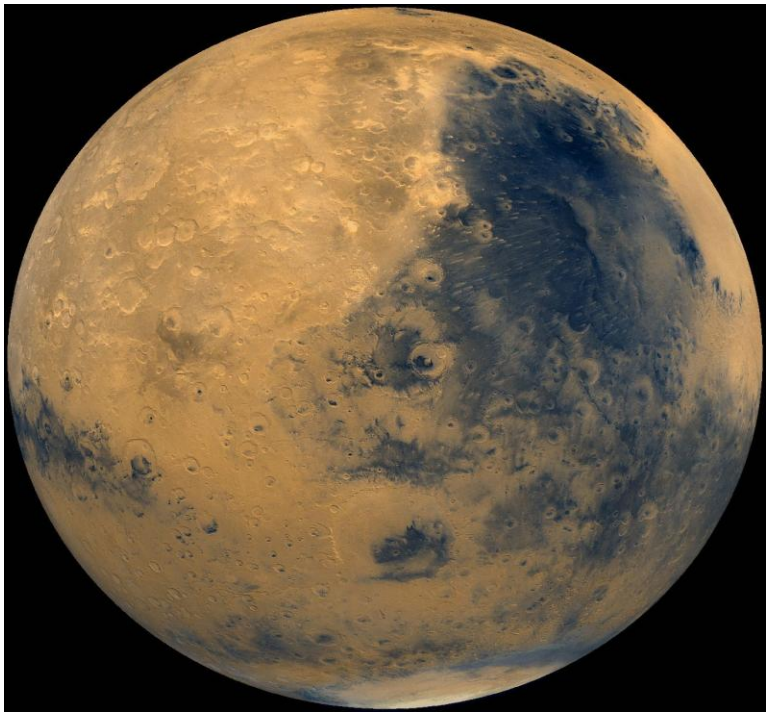
   a. The fraction of visible sunlight not reflected by the high clouds is able to penetrate the thick atmosphere and heat the planet's surface.
   b. There are two large "continents" 2-3 km above the plains.
   c. Unlike Earth, the crust consists of only one thick plate.



D. Mars, the fourth planet, is named after the god of war, largely because of it's ruddy color

1. Observations from Earth, the Hubble Space Telescope, and spacecraft that visited Mars have revealed the following properties.

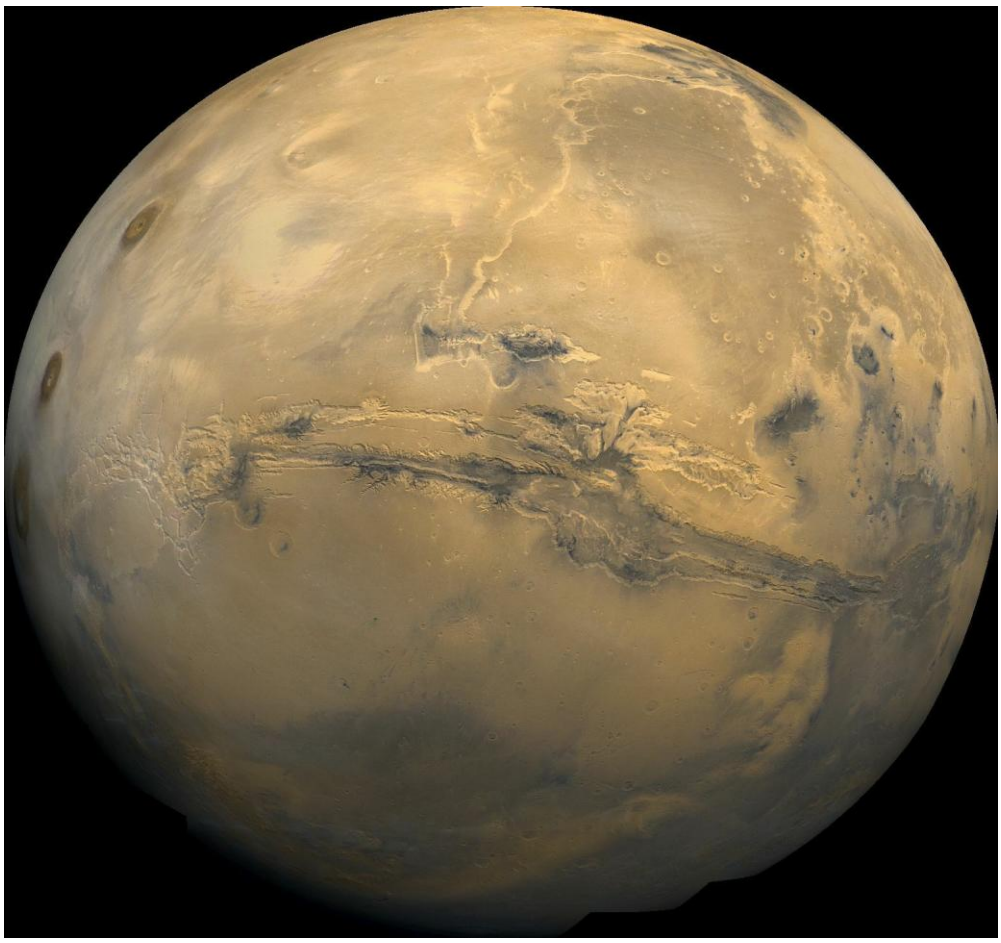
    a. It has 2 tiny (about 20 km diameter), irregularly shaped moons (Phobos and Diemos).
    b. The reddish color of Mars is due to iron oxides (rust) on it's surface, not blood.



    c. There are 2 polar caps consisting mostly of CO_2, but also some water ice.

They grow and shrink with the seasons.

d. The atmosphere of Mars is thin (only 1% of Earth's), and consists mostly (90%) of CO_2.
e. Occasionally, strong winds kick up major dust storms.
f. Temperatures are generally low (-130^0C to 27^0C). The highest temperatures are rare, occurring when Mars is closest to the Sun in it's quite eccentric orbit.
g. Parts of Mars are rather heavily cratered, but others are not.
h. There are some canyons, one of which (Valles Mariners would stretch across the continental United States.



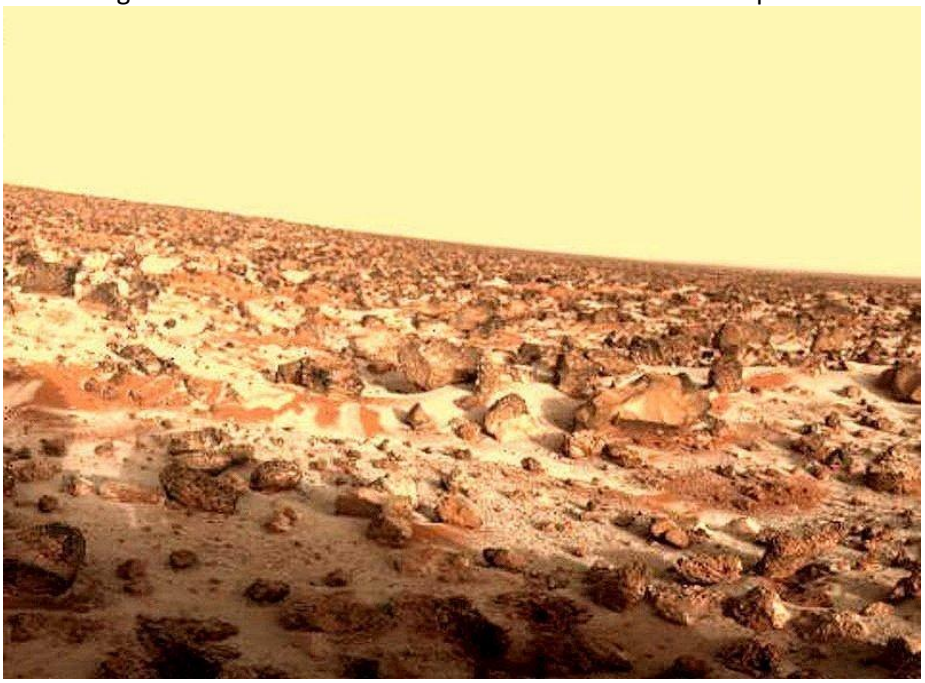
i. There are volcanoes, one of which (Olympus Mons) is the largest in the Solar System.
j. There is currently no active volcanism or plated tectonics.

2. The most stunning discovery of the early spacecraft missions was dry river beds.
   a. Many look very similar to those on Earth, and imply that water used to be present.
   b. Some other land formations also suggest the presence of running water in it's early history and evidence for subsurface water (permafrost) .
   c. Data from the Mars Pathfinder mission, which landed on July 4th, 1997 and placed the rover Sojourner on Mars's surface, strengthen this conclusion.

i) Rocks are scattered over a large area in a manner reminiscent of flood plains.

ii) However, no actual sediments were found.

d. Most recently, (1998), detailed maps from the Mars Global Surveyor show terracing and other evidence that water was abundant in the past.

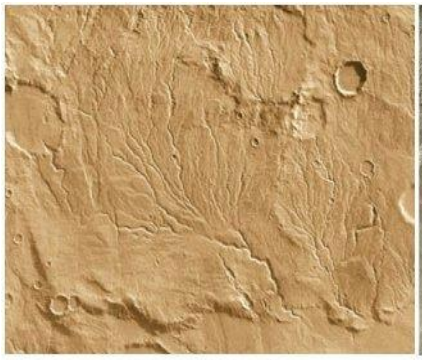


e. Water is also the main component of the permanent polar) component of the caps, as opposed to the frozen carbon dioxide ("dry ice") component of the polar caps, which comes and goes seasonally.

. 3. The atmosphere pressure on Mars is now so low that liquid water cannot exist anywhere on the surface.

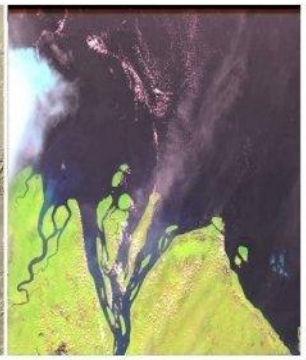
a. The implication is that Mars had a thick, warm atmosphere long ago, and abundant water flowed freely. Mars may have closely resembled the Earth in appearance.

b. Evidence such as the number and distribution of craters on the dry rivers and flood plains suggests that Mars had a hospitable climate for a little over 1 billion years after it formed.



1. Valley Networks

2. River Delta on Mars



River Delta on Earth

3. Sediments

4. Festoons

5. Hydrated Mineral

c. What happened to the atmosphere and water is not fully known but evaporation was probably on significant process.
   i) Partial loss of the atmosphere through evaporation would have led to colder overall temperatures and the freezing of water and CO_2.
   ii) There would consequently be even less greenhouse heating, and hence even colder temperatures. This positive feedback mechanism may have led to the inverse of what happened on Venus.

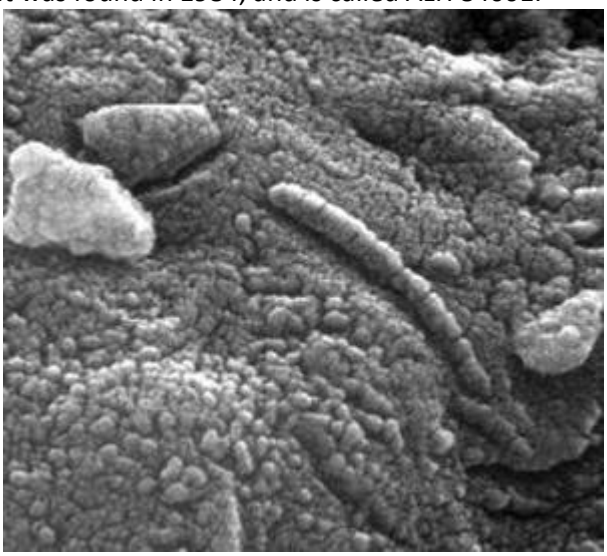
d. We know that some water, perhaps even a large quantity, is now trapped in the polar ice caps and probably in permafrost.

4. Humans have long been fascinated with the possibility that Mars is (or once was) inhabited.
   a. In 1877, the Italian astronomer Giovanni Schiaparelli described “canali” (channels) on Mars.
   b. Many science fiction novels (e.g. “The War of the Worlds”), movies, and cartoons were based on the idea of hostile aliens from Mars.
   c. Percival Lowell was fascinated by the prospect of an ancient civilization on Mars. He drew detailed maps of Mars that showed an elaborate system of canals, presumably built to bring water to arid regions.
   d. We now know that the canals were an illusion; there is no evidence that any intelligent forms of life ever lived on Mars.
5. One of the major missions of the two Viking missions, which landed on Mars in the mid-1970s, was to search for life on Mars.
   a. Several experiments were done. For example, soil samples were placed into a liquid full of nutrients, to see if life processes might be detected.
   b. There was considerable excitement when at least one of the tests suggested

the presence of life, but further investigation showed that the reactions were unlikely to be of biological origin.

c. Viking didn't even detect any organic compounds on the surface of Mars (although if deposited long ago, these would have been destroyed by the Sun's UV radiation).

6. In 1996, analysis of a Martian meteorite found in the Earth's Antarctic revealed possible evidence for ancient primitive (microbial) organisms.
   a. The chunk of rock, estimated to be about 4.5 billion years ago by a collision. There is little doubt that the rock is from Mars, based on analysis of gases trapped within it.
   b. The meteorite landed in Antarctica about 13,000 years ago.
   c. It was found in 1984, and is called ALH 84001.



   d. The meteorite contains carbonate globules, which generally form in liquid water.
   e. Within them polycyclic aromatic hydrocarbons (PAHs) are found. Although PAHs can be formed in a number of way other than by life, and are sometimes seen in normal meteorites, these particular ones were relatively unusual.
   f. Magnetite, a mineral produced by some types of bacteria, is also seen.
   g. Substances typical of chemical disequalibrium (pyrrhotite) are adjacent to each other. This is unusual in the absence of life.
   h. Photographs show tube-like organisms that resemble "nanobacteria" on Earth.
   i. Although none of these findings definitively imply the presence of life, taken together they are certainly intriguing (but still not compelling).
   j. Some researchers have challenged the conclusions on a number of grounds. For example, they cite evidence for contamination of the meteorite by substances on Earth.
   k. The original research team has responded to these criticisms with reasonabe counter-arguments, and stand by their original announcement. Nevertheless, the results are controversial, and additional tests are necessary; most scientists are skeptical at the time.
   l. As Carl Sagan has said, "extraordinary claims require extraordinary evidence." Ejection from the Earth requires so much energy that the rock generally melts.

E. Questions:

1. Show why Mercury always appears quite near the Sun, as seen from Earth.

2. Explain why Mercury's day/night cycle is very long, and why it's surface goes through an extreme range of temperatures.

3. State the main properties of the surface and atmosphere of Venus.

4. Explain what causes the greenhouse effect, and why Earth has not suffered a runaway greenhouse effect.
5. List some characteristics of the surface and atmosphere of Mars.

. 6. Summarize the evidence for past liquid water on Mars.

7. Describe the controversial evidence for primitive life on ancient Mars, announced in 1996.

8. Do you think the evidence for global warming of Earth is strong? Will it be too late To reverse the trend, if and when the effect becomes so large that it's presence is unambiguous?

9. How convincing do you find the meteoritic evidence for ancient microbial life on Mar?

10. Would it be possible to "terraform" Mars in the future so that it's climate Becomes suitable for humans?