Name:____________________
Date:____________________

1 The History of Water on Mars

1.1 Introduction

Scientists believe that for life to exist on a planet (or moon), there must be liquid water available. Thus, one of the priorities for NASA has been the search for water on other objects in our solar system. Currently, these studies are focussed on three objects: Mars, Europa (a moon of Jupiter), and Enceladus (a moon of Saturn). It is believed that both Europa and Enceladus have liquid water below their surfaces. Unfortunately, it will be very difficult to find out if their subsurface oceans harbor lifeforms, as they are below very thick sheets of ice. Mars is different. Mars was discovered to have polar ice caps more than 350 years ago. While much of the surface ice of these polar caps is "dry ice", frozen carbon dioxide, we believe there is a large quantity of frozen water in the polar regions of Mars.

Mars has many similarities to Earth. The rotation period of Mars is 24 hours and 37 minutes. Martian days are just a little longer than Earth days. Mars also has seasons that are similar to those of the Earth. Currently, the spin axis of Mars is tilted by 25° to its orbital plane (Earth's axis is tilted by 23.5°). Thus, there are times during the Martian year when the Sun never rises in the northernmost and southernmost parts of the planet (winter above the "arctic circles"). And times of the year in these same places where the Sun never sets (northern or southern summer). Mars is also very different from the Earth: its radius is about 50% that of Earth, the average surface temperature is very cold, −63 °C (= −81 °F), and the atmospheric pressure at the surface is only 1% that of the Earth. The low temperatures and pressures mean that it is hard for liquid water to currently exist on the surface of Mars. Was this always true? We will find that out today.

In this lab you will be examining a notebook of images of Mars made by recent space probes and looking for signs of water. You will also be making measurements of some valleys and channels on Mars to enable you to distinguish the different surface features left by small, slow flowing streams and large, rapid outflows. You will calculate the volumes of water required to carve these features, and consider how this volume compares with other bodies of water.

Figure 1: A dendritic drainage pattern in Yemen (left), and an anastomosing drainage in Alaska (right).

2 Water Flow Features on Mars

The first evidence that there was once water on Mars was revealed by the NASA spacecraft Mariner 9. Mariner 9 reached Mars in 1971, and after waiting-out a global dust storm that obscured the surface of Mars, started sending back images in December of that year. Since that time a flotilla of spacecraft have been investigating Mars, supplying insight into the history of water there.

2.1 Warrego Valles

The first place we are going to visit is called "Warrego Valles", where the "Valles" part of its name indicates valleys (or canyons). The singular of Valles is Vallis. The location of Warrego is indicated by the red dot on the map of Mars that is the first image ("Image #1") in the three ring binder.

The following set of questions refer to the images of Warrego Valles. Image #2 is a wide view of the region, while Image #3 is a close-up.

1. By looking at the morphology, or shape, of the valley, geologists can tell how the valley was formed. Does this valley system have a dendritic pattern (like the veins in a leaf) or an anastomosing pattern (like an intertwined rope)? See Figure 1. (**1 point**)

2. Overlay a transparency film onto the **close-up** image. Trace the valley pattern onto the transparency. How does a valley like this form? Do you think it formed slowly over time, or quickly from a localized water source? Why? (**3 points**)

3. Now, on the wide-field view, trace the boundary between the uplands and plains on your close-up overlay (the transparency sheet) and label

the Uplands and the Plains. Is Warrego located in the uplands or on the plains? (**2 points**)

4. Which terrain is older? Recall that we can use crater counting to help determine the age of a surface, so let's do some crater counting. *Overlay the transparency sheet on the wide-view image.* Pick out two square regions on the wide view image (#2), each 5 cm $\times$ 5 cm. One region should cover the smooth plains ("Icaria Planum") and the other should cover the upland region. Draw these two squares on the transparency sheet. Count all the impact craters greater than 1 millimeter in diameter within each of the two squares you have outlined. Write these numbers below, with identifications. Which region is older? What does this exercise tell you about when approximately (or relatively) Warrego formed? (**5 points**)

5. To figure out how much water was required to form this valley, we first need to estimate its volume. The volume of a rectangular solid (like a shoebox) is equal to $\ell \times w \times h$, where ℓ is the length of the box, h is the height of the box, and w is the width. We will approximate the shape of the valley as one long shoebox and focus only on the main valley system. *Use the close-up image for this purpose.*

   First, we need to add up the total length of all the branches of the valley. Note that in the close-up image there are two well-defined valley systems. A more compact one near the right edge, and the bigger one to the left of that. Let's concentrate on the bigger one that is closer to the middle of the image. Measure the length, in millimeters, of each branch and the main trunk. Be careful not to count the same length twice. Sometimes it is hard to tell where each branch ends. You need to use your own judgment and be consistent in the way you measure each branch. Now add up all your measurements and convert the sum to kilometers. In this image 1 mm = 0.5 km. What is the total length ℓ of the valley system in kilometers? Show your work. (**3 points**)

6. Second, we need to find the average width of the valley. Carefully measure the width of the valley (in millimeters) in several places. What is the average width? Convert this to kilometers. Show your work. (**2 points**)

7. Finally, we need to know the depth. It is hard to measure depths from photographs, so we will make an estimate. From other evidence that we will not discuss here, the depth of typical Martian valleys is about 200 meters. Convert this to kilometers. (**1 point**)

8. Now find the total valley volume in km^3, using the relation $V = \ell \times w \times$

h. This is the amount of sediment and rocks that was removed by water erosion to form this valley. We do not know for sure how much water was required to remove each cubic kilometer, but we can guess. Let's assume that 100 km^3 of water was required to erode 1 km^3 of Mars. How much water was required to form Warrego Valles? Show your work. (**5 points**)

Image #4 is a recent image of one small "tributary" of the large valley network you have just measured (it is the leftmost branch that drains into the big valley system you explored). In this image the scientists have made identifications of a number of features that are much too small to see in image #3. Note that these researchers traced the valley network for this tributary and note where dust has filled-in some of the valley, or where "faults", cracks in the crust of the planet (orange line segments), have occurred. In addition, in the drawing on the right the dashed circles locate very old craters that have been eroded away. Using all of this information, you can begin to make good estimates of the age, and the sequences of events. Near the bottom they note a "crater with lobate ejecta that postdates valleys." This crater, which is about 2 km in diameter, was created by a meteorite impact that occurred after the valley formed. *By doing this all along all of the tributaries of the Warrego Valles* the age of this feature can be estimated. Ansan & Mangold (2005) conclude that the Warrego valley network began forming 3.5 billion years ago, from a period of rain and snow that may have lasted for 500 million years.

Clean-off transparency for the next section!

2.2 Ares and Tiu Valles

We now move to a morphologically different site, the Ares and Tiu Valles. These valleys are found near the equator of Mars, in the "Margaritifer Terra". This region can be found in the upper right quadrant of image #5 and is outlined in red. Note that the famous "Valles Marineris", the "grand canyon" of Mars (which dwarfs our Grand Canyon), is connected to the Margaritifer Terra by a broad, complicated canyon. In the close up, image #6, the two valles are identified (ignore the numbered white boxes, as they are part of a scientific study of this region). In this false-color image elevation is indicated where the highest features are in white and brown, and the lowest features are pale green.

The next set of questions refer to Ares and Tiu Valles. On the wide scale image, the spot where the Mars Pathfinder *spacecraft landed is indicated. Can you guess why that particular spot was chosen?*

9. First, which way did the water flow that carved the Ares and Tiu Valles? Did water flow south-to-north, or north-to-south? How did you decide this? [Note that the latitude is indicated on the right hand side of image #6.] (**2 points**)

10. In our first close-up image (#7), there are two "teardrop islands". These two features can be found close to the "l" in the Pathfinder landing site label in image #6. There are other features with the same shape elsewhere in the channel. In image #8, we provide a wide field view of the "flood plains" of Tiu and Ares centered on the two teardrop islands of image #7. *Lay the transparency on this image and make a sketch of the pattern of these channels.* **Now add arrows to show the path and direction the flowing water took.** Look at the pattern of these channels. Are they dendritic or anastomosing? (**3 points**)

11. Now we want to get an idea of the volume of water required to form Ares Valles. Measure the length of the channel from the top end of the biggest "island" above the Pathfinder landing site (note there are two islands here, a smaller one with a deep crater, and a bigger one with a shallow crater. We want you to measure the channel that goes by this smaller island on the right side and to the left of the big island, and the channel that goes around the bigger island on the right to where they both join-up again at the top of this big island) to the bottom right corner of the image. In this image, 1 mm = 10 km. What is the total length of these channels? Show your work (**3 points**)

12. Measure the channel width in several places and find the average width. On average, how wide is the channel in km? Show your work (**2 points**)

13. The average depth is about 200 m. How much is that in km? (**1 point**)

14. Now multiply your answers (in units of km) to **find the volume of the channel in km^3.** Use the same ratio of water volume to channel

volume that we used in Question 3 to find the volume of water required to form the channel. Lake Michigan holds 5,000 km^3 of water, how does it compare to what you just calcualted? **Show your work** (**4 points**)

15. Obviously, the Ares and Tiu Valles formed in a different fashion than Warrego. We now want to examine the feature named "Hydaspis Chaos" in image #6. This feature "drains into" the Tiu Vallis. In image #9, we present a wide view image of this feature. In image #10, we show a close up of a small part of Hydaspis. Why do you think such features were given the name "Chaos" regions? (**2 points**)

16. Scientists believe that Chaos regions are formed by the sudden release of large amounts of groundwater (or, perhaps, the sudden melting of ice underneath the surface), causing massive, and rapid flooding. Does such an idea make sense to you? Why? What evidence for this hypothesis is present in these images to support this idea? (**4 points**)

17. In image #11 is a picture taken at the time of the disembarkation of the little Pathfinder rover (named "Sojourner") as it drove down the ramp from its lander. Is the surrounding terrain consistent with its location in the flood plain of Ares Vallis? Why/why not? (**3 points**)

18. Recent research into the age of the Ares and Tiu Valles suggest that, while they began to form around 3.6 billion years ago (like Warrego), water still flowed in these channels as recently as 2.5 billion years ago. Thus, the flood plains of Ares and Tiu are much younger than Warrego. Do you agree with this assessment? How did you arrive at this conclusion? (**4 points**)

19. You have now studied Warrego and Ares Valles up close. **Compare and contrast the two different varieties of fluvial (water-carved) landforms in as many ways as you can think of (at least three!).** Do you think they formed the same way? How does the volume of water required to form Ares Valles compare to the volume of water required to form Warrego Valles? (**5 points**)

3 The Global Perspective

In image #12 is a topographic map of Mars that is color-coded to show the altitude of the surface features where blue is low, and white is very high. Note that the northern half of Mars is lower than the southern half, and the North pole is several km lower than the South pole. The Ares and Tiu Valles eventually drain into the region labeled "Chryse Planitia" (longitude 330°, latitude 25°).

20. If there was an abundance of water on Mars, what would the planet look like? How might we prove if this was feasible? For example, scientists estimate the age of the northern plains as being formed between 3.6 and 2.5 billion years ago. How does this number compare with the ages of the Ares and Tiu Valles? Could they be one source of water for this ocean? (**5 points**)

One way to test the hypothesis that the northern region of Mars was once covered by an ocean is to look for similarities to Earth. Over the history of Earth, oceans have covered large parts of the current land masses/continents (as one once covered much of New Mexico). Thus, there could be ancient shoreline features from past Earth oceans that we can compare to the proposed "shoreline" areas of Mars. In image #13 is a comparison of the Ebro river basin (in Spain) to various regions found on Mars that border the northern plains. The Ebro river basin shown in the upper left panel was once below sea level, and a river drained into an ancient ocean. The sediment laid down by the river eventually became sedimentary rock, and once the area was uplifted, the softer material eroded away, leaving ridges of rock that trace the ancient river bed. The other three panels show similar features on Mars.

If the northern part of Mars was covered by an ocean, where did the water go? It might have evaporated away into space, or it could still be present frozen below the surface. In 2006, NASA sent a spacecraft named Phoenix that landed above the "arctic circle" of Mars (a latitude of 68° North). This lander had a shovel to dig below the surface as well as a laboratory to analyze the material that the shovel dug up. Image #14 shows a trench that Phoenix dug, showing sub-surface ice and how chunks of ice (in the trench shadow) evaporated (technically "sublimated") over time. The slow sublimation meant this was water ice, not carbon dioxide ice. This was confirmed when water was detected in the samples delivered to the onboard laboratory.

21. Given all of this evidence presented in the lab today, Mars certainly once had abundant surface water. We still do not know how much there was, how long it was present on the surface, or where it all went. But explain why discovery of large amounts of subsurface water ice might be important for astronauts that could one day visit Mars (**5 points**)

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3.1 Take Home Exercise (35 points total)

Answer the following questions on a separate sheet of paper, and turn it in with the rest of your lab.

1. What happened to all of the water that carved these valley systems? We do not see any water on the surface of Mars when we look at present-day images of the planet, but if our interpretation of these features is correct, and your calculated water volumes are correct (which they probably are), then where has all of the water gone? Discuss two possible (probable?) fates that the water might have experienced. Think about discussions we have had in class about the atmospheres of the various planets and what their fates have been. Also think about how Earth compares to Mars and how the water abundances on the two planets now differ. (**20 points**)

2. Scientists believe that life (the first, primitive, single cell creatures) on Earth began about 1 billion years after its formation, or 3.5 billion years ago. Scientists also believe that liquid water is essential for life to exist. Looking at the ages and lifetimes of the Warrego, Ares and Tiu Valles, what do you think about the possibility that life started on the planet Mars at the same time as Earth? What must have Mars been like at that time? What would have happened to this life? (**15 points**)

3.2 Possible Quiz Questions

1. Is water an important erosion process on Mars?

2. What does "dendritic" mean?

3. What does "anastomosing" mean?

3.3 Extra Credit (ask your TA for permission before attempting, 5 points)

In this lab you have found that dendritic and anastomosing "river" patterns are found on Mars, suggesting there was free flowing water at some time in Mars' history. Use web-based resources to investigate our current ideas about the history of water on Mars. Then find images of both dendritic and anastomosing features on the Earth (include them in your report). Describe where on our planet those particular patterns were found, and what type of climate exists in that part of the world. What does this suggest about the formation of similar features on Mars?