MSIP FINAL REPORT

Martian Lava Tubes

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Introduction

Since the introduction of modern astronomical technology, scientists have theorized that the existence of life on our neighboring planet Mars is possible, due to arguably two main factors: the similarities in the physical characteristics of Mars and Earth, as well as simply the general hype for the discovery of extraterrestrial life. Some physical similarities include topographical features, mineral composition, and many theories suggesting vast atmospheric and terrestrial similarities in the planets' early stages. One question to further investigate their physical similarities is: what is the size range, including factors such as average width and visible length, of lava tubes on Mars in comparison to those of Earth? This relationship may be significant, as it could demonstrate resemblances and differences between Earth and Martian volcanoes and possibly restructure current knowledge about both planets' similarities. In addition to this purpose, the study of lava tubes that arise from volcanoes and lava flow can be useful in planning future human operations on Mars, since such natural structures will protect bases from harmful dust, wind, and solar radiation, while providing a sturdy location and stable temperature. The question mentioned above raises several hypotheses, including the ideas that size ranges will be similar based on Earth/Mars similarities; there will be longer lava tubes on Mars because the volcanoes are larger, older, and more likely to be preserved; and there will be little or no difference between the two planets' lava tubes' widths because of topographical similarities.

Background

In addition to the multitude of present similarities between Mars and Earth, these two planets also contain volcanoes, indicating that tectonic activity is or was present on both planets at some time in their histories. It is known that Earth volcanoes are still active; therefore tectonic activity is still active as well. However, since previous studies have revealed that Martian volcanoes have been dormant for many thousands of years, it was concluded that tectonic activity on Mars is also currently nonexistent.

Volcanic eruptions on both Mars and Earth yield lava tubes. Although Martian volcanoes are currently classified as dormant, lava tubes were formed in its ancient history as a result of lava flow from active volcanoes. The appearances of such lava tubes can be described as "caves formed by flows of high viscous lava—a river of molten rock flowing from a particular eruption source—a volcano or a fissure for instance" (Frederick) whose tops and sides harden as lava continues to flow inside the newly-made tunnel. Lava flow begins after a volcano eruption, and it then flows sometimes as long as many kilometers. Lava tubes typically run several meters below the surface and can leave long, empty tunnels that almost appear to be man-made (Cain). For example, a known tube in Mauna Loa, Hawaii, starts from the eruption point and then continues for

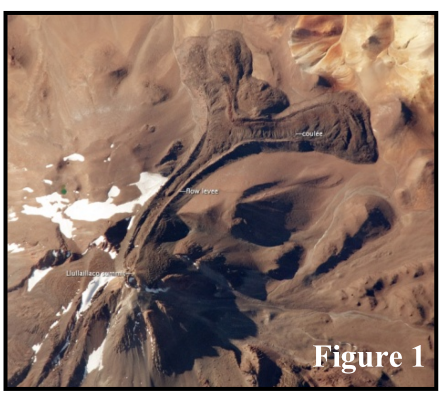


Figure 1

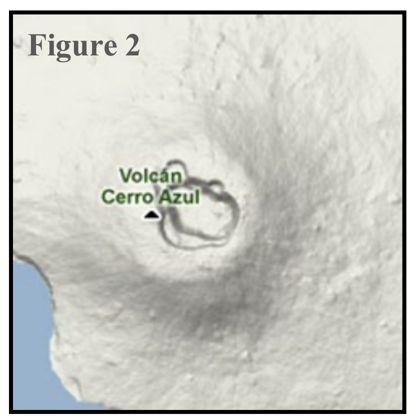


Figure 2

50 kilometers until it meets with the ocean. Figure 1 shows an example of volcanic lava flow on Earth, from the volcano Llullaillaco along the Argentinean-Chilean border in South America (Stefanov). Additionally, Figure 2 depicts the Earth volcano Cerro Azul, located on the Galapagos Islands (Google Maps). The visible faint lines extending out from the volcano likely represent lava tubes.

Although Mars is at least half of the size of Earth, the volcanoes on Mars' surface surpass any of the volcanoes that are present on Earth. The parallel sides of Earth's lava tubes cause any flowing lava to erode the outside as curves instead of the inside. Similarly, most of the channels on the Martian volcano Ascraeus Mons maintain a constant width. However, Mars and Earth's lava tubes differ in the sense that volcanic lava flow on Earth joins together to produce a wider flow, whereas the joining of channels on Mars has no impact on flow size ("The Strange Lava Tubes Of Mars").

The various volcanoes on the surface of Mars have been divided into three main classifications of volcanoes. These three types are *montes* (mountains), *tholi* (domes), and *paterae* (complex, collapsed shields) (Caplinger). The *montes* variety are very large and could be basaltic. Examples of montes on Mars are Ascraeus Mons, Pavonis Mons, and Arsia Mons. *Tholi* are generally smaller in size than the mountains, but they are also steeper. Tholi that exist on Mars include Tharsis Tholis, Ceraunius Tholis, and Uranius Tholis. The last type, *paterae*, can be varied in form but all have the same general characteristics such as shallow slopes, complex edges, and channels. Many types of paterae are present on Mars, including the Apollinaris Patera, Biblis Patera, Tyrrhena Patera, Ulysses Patera, and Uranius Patera (Caplinger). The various features associated with each type of volcano could be tied into the features of the lava tubes emitting from each volcano due to factors such as size and elevation.

The volcano type that was used in this investigation was the *mons*, which means that all of the observed volcanoes were assumed to be shield volcanoes. Shield volcanoes are formed at a hot spot where the crust is weak; on the other hand, composite volcanoes are formed at plate boundaries found at the edge of the crust. Several theories exist regarding the differences between the two types of volcanoes, including ideas that the volcanoes are comprised of different materials, or specific details regarding the nature of eruptions, stating the idea that the eruptions of tholi were smaller when active, therefore resulting in a smaller area of the actual volcano (Caplinger).

With regard to lava tubes on Earth, their formation appears to be quite similar to those of Mars: fast-moving lava (during eruptions) forming streams and hardening around the sides and tops to create "caves" in which lava continues to flow. Figure 3 shows this phenomenon of continuing lava flow, captured through a crack in a developing lava tube. The viscosity of lava impact tube size and shape, as lava with high viscosity (more tension and therefore does not spread out) tends to form long, narrow lava streams while low-viscosity lava generally


Figure 3

forms short, wide streams. A great example of a place on Earth to find lava tubes is Hawaii, due to the geography, tectonic activity, and abundance of volcanoes. In contrast to Martian lava tubes, which appear to be mostly smooth according to THEMIS images, Earth lava tubes often are have collapsed sections scattered along the length of the lava tubes, which frequently turn into simple caves. This is believed to be a result of atmospheric conditions such as winds, storms, gravity, etc. acting on the lava tubes (Tokinka), whereas Mars' thin atmosphere and relatively little meteorological activity may be the reason that most Martian lava tubes appear to be smooth without many cracks or collapsed sections. Figure 4 displays a falsely-colored image of these apparently smooth lava tubes on Mars ("The Strange Lava Tubes of Mars").

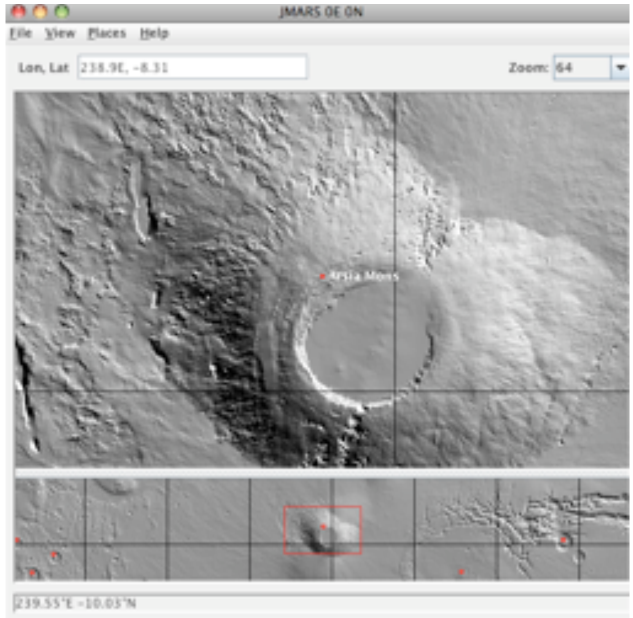

Figure 4

Lava tubes on Mars are a topic of great interest for scientists, due to many reasons including the fact that their inside environments may protect from the harsh external environment of Mars, as well as the fact that the enclosed environment of lava tubes may be able to sustain moderate temperatures from the heat of the lava that once flowed. Scientists' belief regarding this expectation is that this stable temperature might provide a significant opportunity for water formation and possibly primitive life forms (Daga). Human interest in Martian lava tubes also continues to strengthen due to the possibility that the favorable internal environments of lava tubes may provide reasonable locations for future human explorers to set up observation bases inside the lava tubes. As a result of such compelling beliefs about the possible uses of lava tubes on Mars, there is strong reason to believe that the relationship between lava tubes of both planets can provide insight to the formation or general nature of lava tubes.

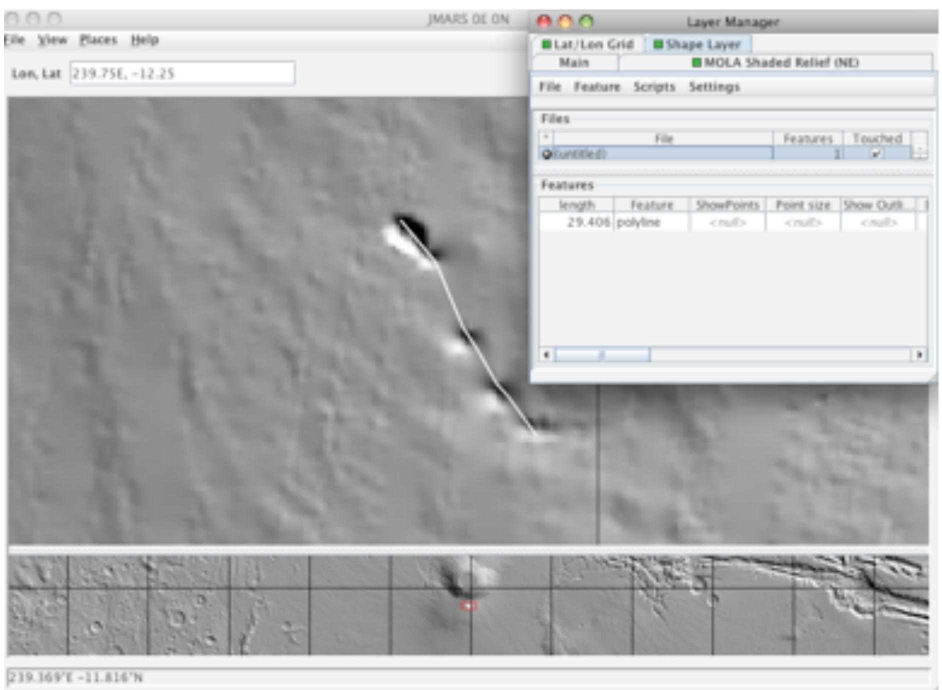
Methods

In the interest of expanding current knowledge of Martian lava tubes, the THEMIS camera, on-board NASA's Mars Odyssey spacecraft, was used in this investigation. This camera allowed the capture of images showing the different types of lava tubes found on Mars. Using the camera and corresponding computer software, the surface of Mars was scanned on a computer screen, and when the desired location was detected, instructions were sent to the camera to capture the image. Another significant material used in this investigation was the computer program JMARS developed by Arizona State University, in which specific tools such as the Nomenclature Map, the Shape Layer, the MOLA 128 ppd Elevation Map, and the THEMIS Night-over-Day Map were used.

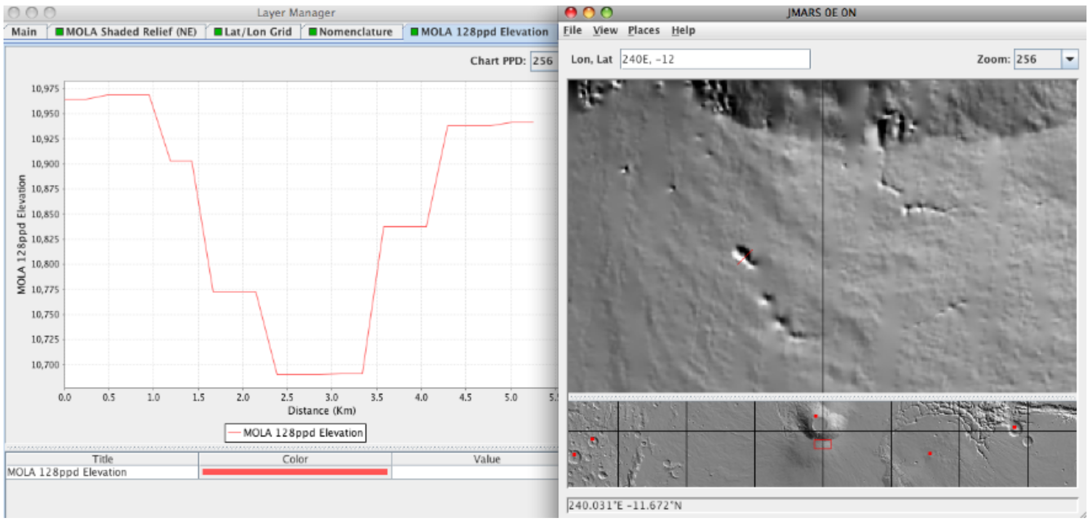
The Nomenclature Map helped to identify Martian volcanoes by scrolling through a list of surface features; this allowed easier detection of the lava tubes.



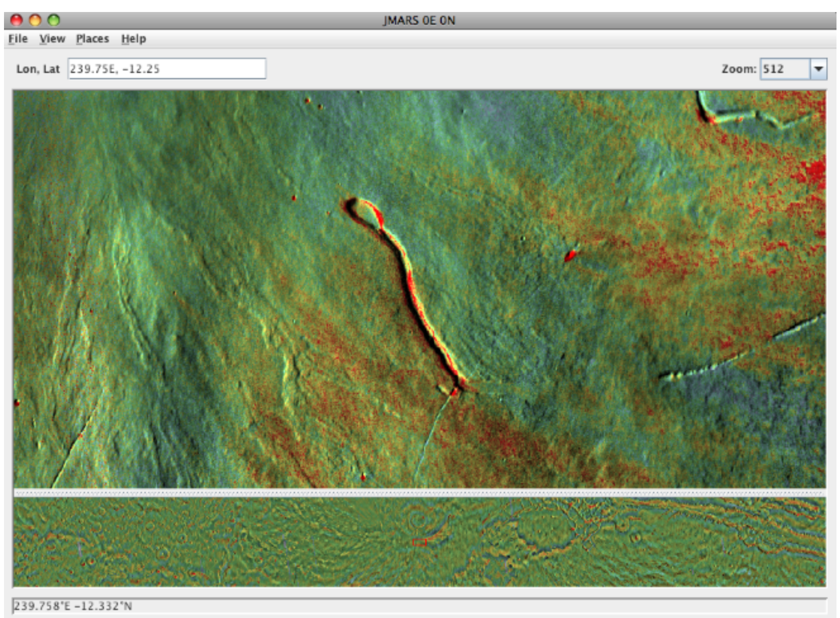
The Shape Layer was used to measure the lengths of lava tubes accurately.



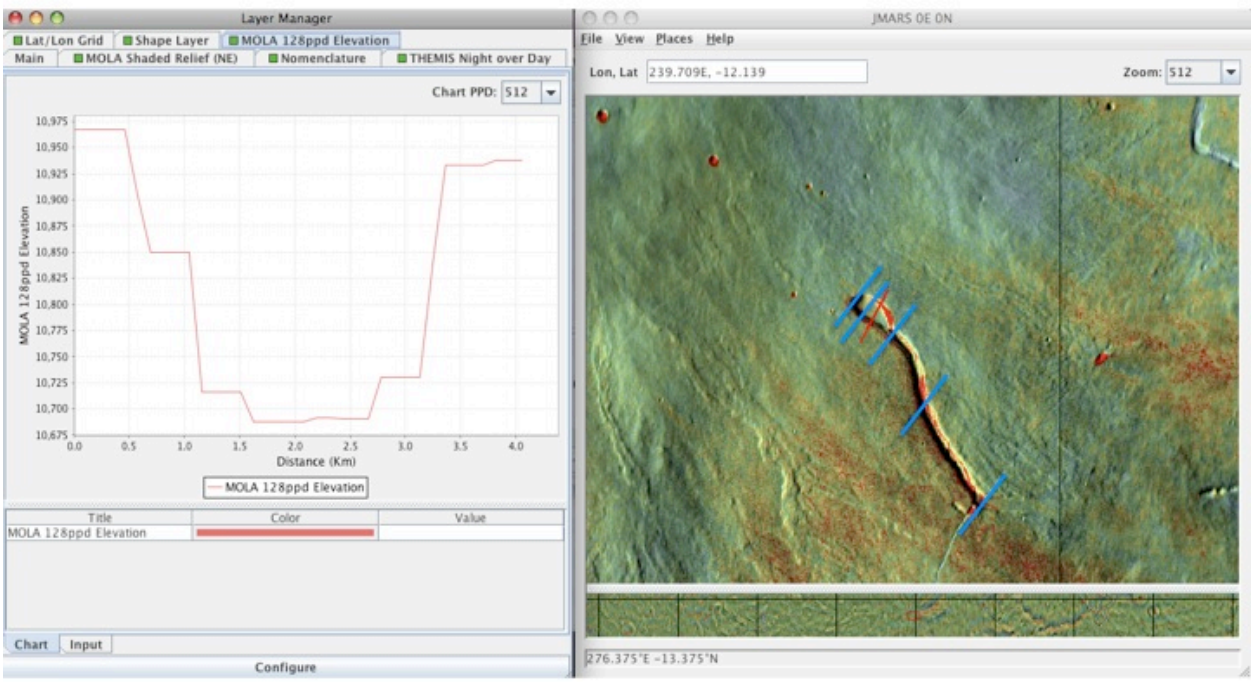
The MOLA 128 ppd Elevation Map was used to view and plot graphic data and find the measurements of lava tubes. The widths were measured using the MOLA Map by drawing a virtual line across the particular lava tube on the computer screen, which revealed the width measurements. A feature in the JMARS program helped determine relationships in lava tube size by inputting the widths and consequently showing a chart that provided the elevation in kilometers.



The THEMIS Night-over-Day Map was used occasionally to ease the process of finding lava tubes, as they were difficult to locate sometimes without its aid.

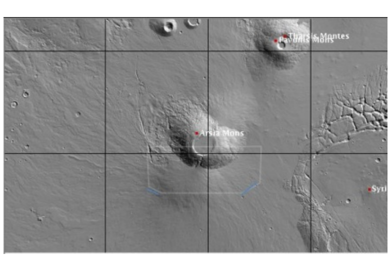


The following image portrays the typical procedure of finding the dimensions of the lava tubes on Mars using the JMARS program. The various colors in the image show that this lava tube was found using the Night-over-Day feature. Additionally, the blue lines shown in the image were drawn across the lava tube within the program at various locations in order to find the average width of that particular tube. A particular feature in the JMARS program plotted a graph representing the changes in elevation across a line; this graph is pictured below along with the image of the lava tube itself.

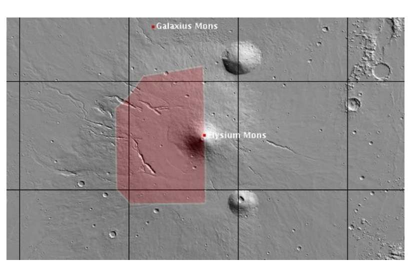


Data collection was limited only to specific regions of three major volcanoes on the Martian surface, from which the lava tubes were found, observed, and measured. The volcanoes and the regions were as follows:

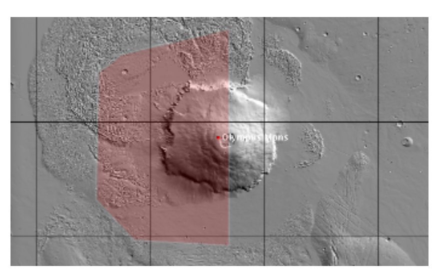
(south side of) Arsia Mons



(west side of) Elysium Mons



(west side of) Olympus Mons



Volcano	Longitude	Latitude	Type
Arsia Mons	240° 30′ 0″ E	-9° 30′ 0″ N	shield volcano
Elysium Mons	146° 54′ 0″ E	24° 48′ 0″ N	pyroclastic shield volcano
Olympus Mons	226° 0′ 0″ E	18° 24′ 0″ N	shield volcano

The specific regions that were observed were: the south side of Arsia Mons, the west side of Elysium Mons, and the west side of Olympus Mons. These locations were chosen because of their general isolation in the sense that they did not point in the direction of any other immediate volcanoes, ensuring that the results will only apply to the particular volcano and not accidentally belong to the proximate volcano. To further avoid any other complications, the decision of which data to keep and which to disregard was also carefully considered. This was achieved by observing the images and isolating those that showed clear, distinct lava tubes, and by avoiding images showing overlapping lava tubes in order to gain precise and accurate results.

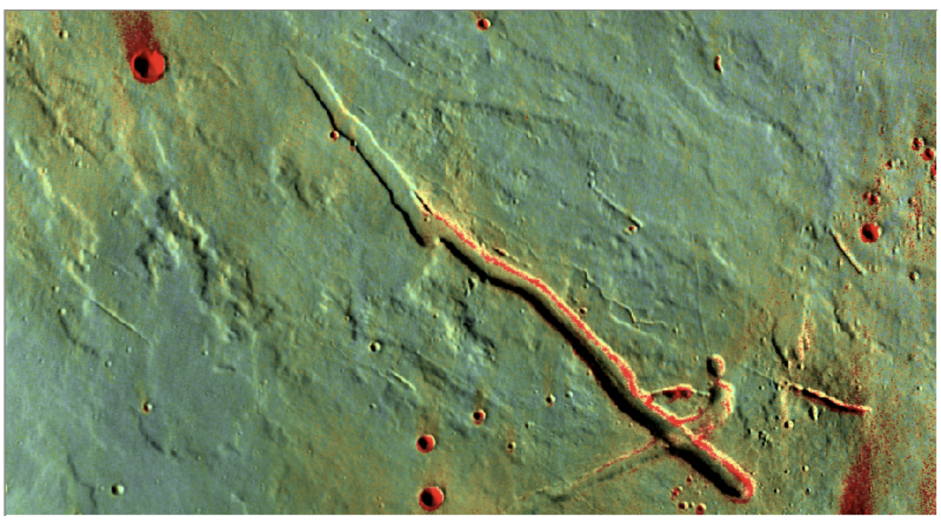
To ensure that data was collected in a universally same manner among all of the members of the group while answering the question of the investigation, several significant factors were controlled by all group members, including the means of data measurement, locations of data, and which data will be disregarded due to complications as discussed earlier.

Data

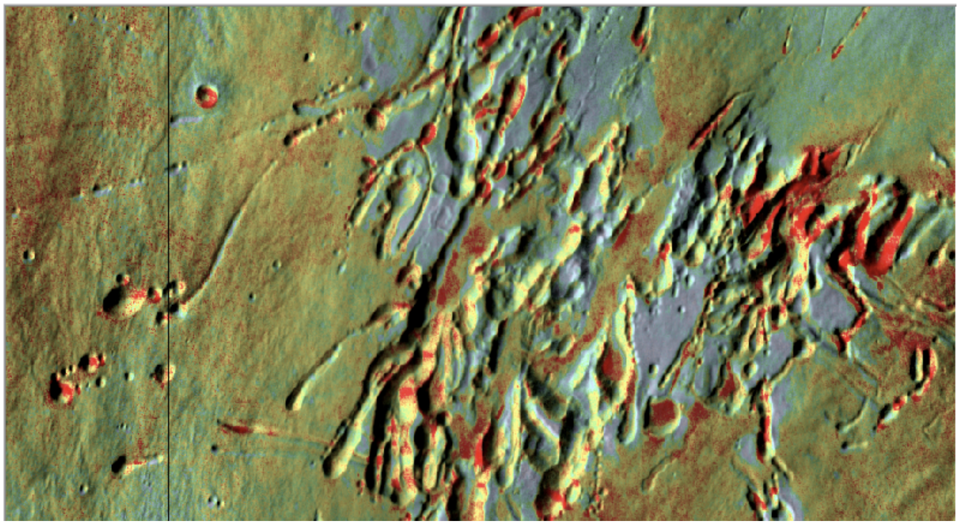
The data taken during this MSIP project consisted mainly of images of lava tubes from both Earth and Mars, using specific instruments. Throughout the project, 11 images from Earth and 10 lava tube images from Mars were collected. Because lava tubes are relatively not as prominent on Earth as on Mars, a limited number of locations was chosen to collect data for the lava tubes on Earth. These locations were the Galapagos Islands (8 images), New Mexico (2 images), and California (1 image). Lava tube data collection was not as successful on Mars as on Earth; therefore in this project more lava tube images were collected from Earth than from Mars. Martian lava tube images were taken from Arsia Mons (3 images), Elysium Mons (6 images), and Olympus Mons (1 image). With regard to the specific instruments, the THEMIS camera on-board the NASA Mars Odyssey Spacecraft was used as the mechanism to capture and render images from Mars for observation, with the help of the computer program JMARS developed by Arizona State University. Images of Earth lava tubes were taken using the online program Google Earth.

Below is an example of an image of lava tubes taken via the program JMARS, with the help of the Night-Over-Day Map in the specified region of Arsia Mons.

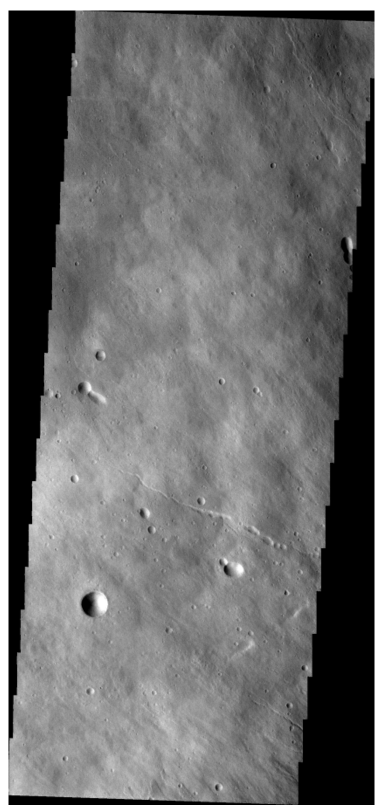
Another example of an image from JMARS suitable for data collection is shown below. The fact that the lava tube in this image is by itself and is well-defined made it a prime example of the types of data that were considered in the investigation.



The following image is an example of the many clusters of lava tubes found during the course of the observations. These were often disregarded from the data due to their complexity in finding their measurements, in which easily-made mistakes might have greatly skewed the results.

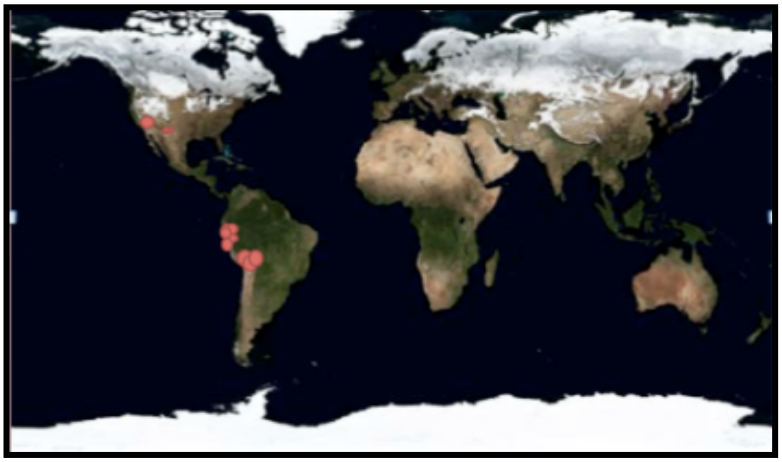


The images of the actual surface of Mars that were taken using the THEMIS camera on-board the NASA Mars Odyssey Spacecraft are pictured below. They are classified using the names “V44032009” and “V44011005” respectively. These images were never-before-captured until this observation and will not be officially released until several months’ time.

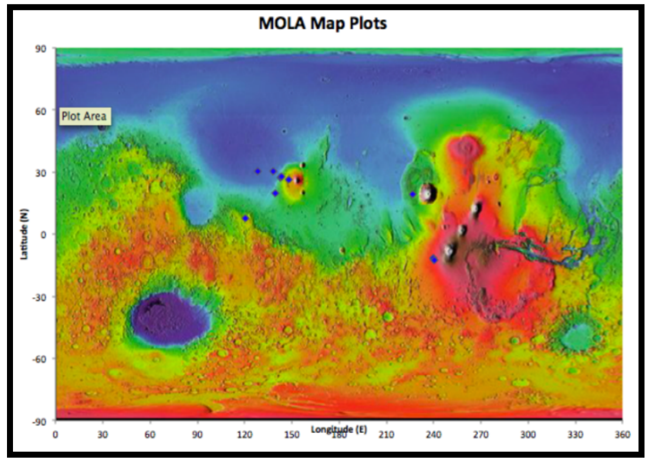


After all appropriate lava tubes were located and measured, two maps were made in order to show the general locations of lava tubes found on both Earth and Mars during the investigation. The map of the Earth is marked with small, salmon-colored circles that mark the areas where lava tubes were observed, which was mostly the southwestern United States and along the west coast of South America. The MOLA Map Plots shows the general location of most large Martian volcanoes to be in the region from about 240-270° E, to approximately 0-30° N. Several other volcanoes seem to puncture the surface of Mars at various other locations in the same general vicinity as the major volcanoes. These maps can be seen in the images that follow.

Locations of Volcanoes & Lava Tubes on Earth

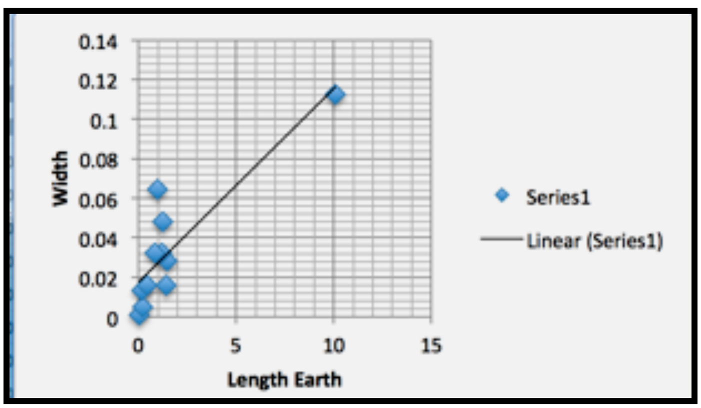


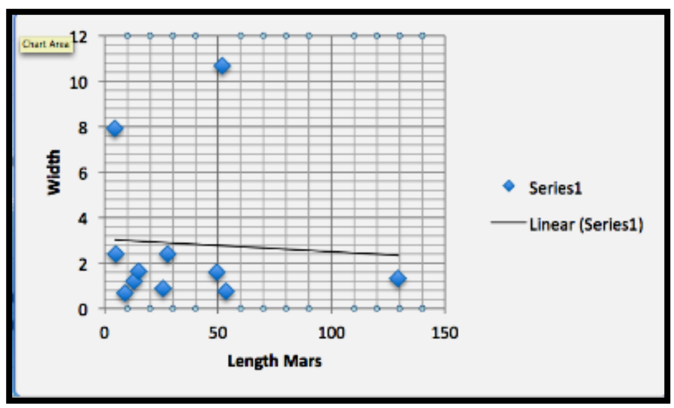
Locations of Lava Tubes on Mars: MOLA Map Plots



Two graphs were prepared that demonstrate the relationship between the independent variable of length and the dependent variable of width of both Earth and Martian lava tubes. The points for each lava tube observed are plotted, and the line represents the line of best fit to describe the pattern of length and widths.

The following graphs demonstrate the length-to-width relationship of Earth lava tubes and Martian lava tubes, respectively.





In comparing lava tubes on Earth and Mars, several significant conclusions can be made about the obvious differences seen in the measurements and the graphs. For example, Earth's lava tubes were relatively short and thin, where as Mars had long and wide lava tubes. This major difference can be seen in the axes of the graphs, which show a maximum length of 15 km and width of 0.14 km for Earth's lava tubes, whereas the graph showing Martian lava tubes has a much larger range with the maximum length of 150 km on the axis and a maximum width of 12 km according to the lava tubes that were observed. Therefore, it can safely be said that Martian lava tubes and Earth lava tubes differ greatly from one another with regard to size, by a scale of about 10:1 regarding the lengths, and a much greater scale of about 100:1 respectively regarding the widths.

Earth's lava tubes were found from composite volcanoes which have less lava flow and more debris/ash; and Mars' lava tube data was found from shield volcanoes that had slow, steady, and continuous lava flow when the volcanoes were active long ago. Mars' lava tubes are generally longer because Mars has a thin atmosphere which causes the lava to be cooled by radiation, which is a slower process than Earth's convection because of its thick atmosphere cooling the lava faster making the tubes shorter. Also, the speed of cooling affects their physical appearance in factors other than size, since a slower speed of cooling generally brings about smoother well-formed tubes rather than the relatively rough and possibly collapsed sections that result from rapid cooling. These differences between Mars and Earth are shown by the data plotted in the graphs, which again show a tremendous difference in the values in which the lava tubes are plotted.

In addition to the differences in simply the range of lengths and widths among the lava tubes of the two planets, the lines of best fit of both graphs also display varying trends. As seen by the graphs, the trend-line of Earth lava tubes is increasing at a considerable rate, whereas the trend-line of Martian lava tubes is seen to be slightly decreasing at a much slighter rate compared to the Earth lava tubes. This demonstrates yet another difference between the lava tubes. However, it is very possible that these results are due solely to the data taken, and if different lava tubes and data had been taken, there could have been a much different trend-line for both graphs. Other factors to test regarding these changes in trend-lines in future investigations include, say, the distance of the particular lava tubes from their parent volcanoes, or to consider the types and abundances of various topographical features surrounding the lava tubes.

Errors and Biases

Any inaccuracies, misinterpretations, and biases that may have occurred during this experiment are acknowledged. Some examples of the inaccuracies included surrounding environmental factors such as vegetation as well as the distorted views of the lava tubes. On Earth, vegetation and other surface features caused the amount of lava tubes found to be significantly smaller than the actual number of lava tubes on Earth. There may be more lava tubes than observed in this project, but they were not visible. It also hindered the accuracy of length measurements because portions of the lava tube may have been blocked from visibility. On Mars, there is the possibility that channels and craters could have been mistaken for lava tubes due to their similar, long, tube/line-like appearances. There is a certain percent of error when identifying the features of Mars; the identification of features is not definitive. Biases include differences in data collection, human activity and weather, and the differences of volcanoes. Only one width was recorded for the lava tubes on Earth but the average width was recorded for the lava tubes on Mars. Erosion and human development (i.e. roads, cities) might have eliminated collapsed lava tubes that might at one time have been visible. Another bias is the difference of the types of volcanoes found. On Earth, data was taken from lava tubes found near composite volcanoes. On Mars, data was taken from the lava tubes of shield volcanoes. Perhaps if more similar types of volcanoes were located on both planets, the results may have shown greater similarities than was the case according to this investigation.

Hypotheses

Based on the results of this investigation, the initial three hypotheses made by the group can be supported and/or disproved. The foundational question for this experiment questioned the relationship of size ranges including average width and visible length between the lava tubes of both Earth and Mars. The first hypothesis developed by the group stated that the size ranges will be similar due to the various instances of topographical similarities between Earth and Mars. However, as was clearly seen by the data taken at ASU and from the JMARS program, the graphs, and their interpretations, this hypothesis was refuted because there is in fact a monumental difference in their size ranges. The second hypothesis consisted of the idea that the lava tubes on Mars will show greater lengths than Earth lava tubes due to the fact that the Martian volcanoes are larger, older, and more likely to be preserved. The results of this project supported this hypothesis. The third and final hypothesis stated that there will be little or no difference between the two planets' lava tube widths due to topographical similarities. Similar to the case with the first hypothesis, the data and interpretations show that this hypothesis was incorrect. Although two out of three of the hypotheses were proven false, this entire project still provided tremendous insight on the nature of Martian and Earth lava tubes and their comparisons to each other and enriched the group's knowledge about the truth of the claims made by some people that Mars and Earth are very similar. Continued research such as this investigation will likely impact future decisions to possibly employ bases within Martian lava tubes and advance the knowledge of the entire human race regarding planets and the universe.

Special acknowledgement and gratitude are extended to the supervisors of the investigation who allowed the group to receive the honor of working with such scientific tools. The group would like to thank especially Mrs. Hestenes, Mr. Hill, and Mrs. Swann.

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'New Mexico, USA' 34°56'49.27"N and 108°06'09.05''W. Google Earth. November 15, 2003. October 4, 2005.

'New Mexico, USA' 34°56'39.23"N and 108°06'58.38''W. Google Earth. July 1, 2005. October 4, 2005.