Preliminary Syrtis Major Slope Maps and Lava Parameters Based on Elevation Data

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GEOG 5055 - Geospatial Programming

https://github.com/geog3050/khottendorf.git

Background

Mars is the fourth planet from the Sun, and is also known as the red planet due to its reddish hue that blankets the surface (Platt, 2024b). It is about half the size of Earth (figure 1) with a diameter of 6790 km, and has a very thin atmosphere that creates pressures of 101,000 pascals at the surface, which is 0.6 percent of Earth's atmospheric pressure at the surface. The atmosphere is composed of 96% carbon dioxide with minor amounts of nitrogen and argon. Due to its thin atmosphere that does not thermally insulate the planet, the surface temperature of Mars is on average -60℃. What we mainly know about the geology of Mars comes from missions to Mars that have spanned from 1964 to present day, but also from Martian meteorites that have landed on Earth. Despite the large amounts of data we have about Mars, we still know very little about the planet, right down to its very basic chemistry and geologic history. The pursuit of understanding Mars stems from the need to understand our home planet. Everything that humanity knows about the universe only comes from an Earth perspective. All of our thoughts and theories about life, laws of physics, and more all come from tests that have been conducted and worked on Earth, which only provides a very precise set of parameters for us to test our theories. Therefore being able to untangle the history of Mars will enable us to have another place to test everything we think we know.

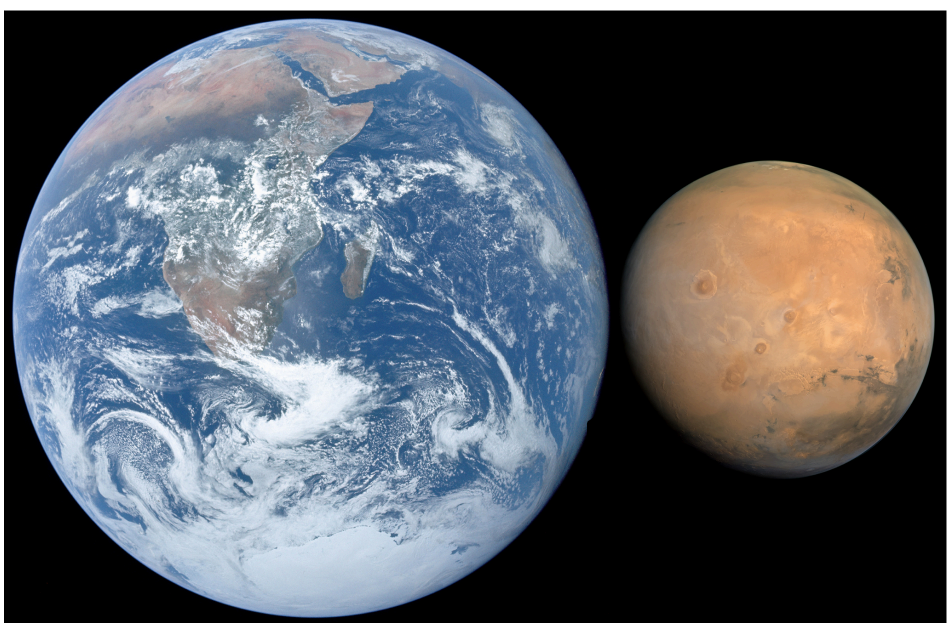

Figure 1: Size comparison of Earth and Mars. Earth is on the left and Mars is on the right. The size of Mars in comparison to Earth is usually unknown and often overestimated. In actuality the total area of land above sea level on Earth is equal to the total surface area of Mars. Image adapted from NASA.

Mars is especially valuable because of its lack of plate tectonics. It is thought that plate tectonics on Earth began between 2-3 billion years ago, which has destroyed or altered all of the crust that existed or was generated at the beginning of our planet's history. On the other hand, Mars currently shows no evidence of having plate tectonics like we do on Earth. This is thought to be due to the fact that since Mars is a smaller planet it will have cooled more quickly than Earth, which caused the crust to become very thick and brittle and not allow for the formation of plates that move on a ductile lower crust and upper mantle. Therefore, with the use of crater counting and preliminary geochronology of Martian crust, we can date surfaces on Mars to be older than 3 billion years old. Having access to these very old rocks that are minimally deformed allows us to study what Earth may have been like before plate tectonics, and help constrain when plate tectonics may have initiated on Earth as it is still unknown. It is thought that the initiation of plate tectonics is connected to the long lasting life that Earth has experienced, which makes this mystery one of great importance to people all over the world (Payre at al., 2023).

The task of understanding all of Mars is a big one, so it has been broken down into little pieces that people across the globe are trying to solve. One of these pieces is known as Syrtis Major Planum, as seen in Figure 2, which is a large volcanic province on Mars that is Hesparian in age (1.8 to 3.5 Ga). It has long been thought that, due to an assumed lack of water in the Martian mantle, that the first crust to solidify on Mars would be basaltic (less than 55 weight percent silica) and that lava flows on Mars could not be as diverse as they are on Earth in any point in Mars' geologic history. This is because in order to form magmas that have a higher silica content, you need a volatile, like water, to change the geochemistry in the upper crust and allow for melting to occur. This melting that occurs when water is introduced, usually through processes like subduction, causes the magma that forms to be higher in silica than the rocks it comes from. This process was thought to be largely absent from Mars, but that hypothesis has recently been challenged with findings from rovers which found compositions that ranged from basaltic to dioritic (67 weight percent silica) and with findings from NASA's recent *Insight* mission (Payre et al., 2023). *Insight*; Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport; is a lander on Mars that measured seismic activity and heat flow from 2018 to 2022 (NASA, 2023). The data gathered from this lander allowed scientists to place further constraints on the character of the Martian crust, mantle, and core. When reviewing the data received, it was found that the density of the crust of Mars could only lie between 2800 kg/m^3 to 3100 kg/m^3, which is lower than previously thought. The crustal density predicted from the seismicity of the planet is lower than that of basalt, which suggests that there is more diversity in the martian crust than previously thought. As seen in figure 1, Syrtis Major Planum is seen to be very dark from orbit, and is therefore thought to be more basaltic, however this assumption has never been proven. The volcanism that created this volcanic region is thought to have occurred for about 2 billion years from 3.6 to 1.6 billion years ago. This time period transects both when plate tectonics began on Earth and the beginning of Mar's geologic history. Therefore understanding the volcanic diversity of Syrtis Major will allow us to understand more about the beginning of Mars, Earth, and possibly life in our solar system

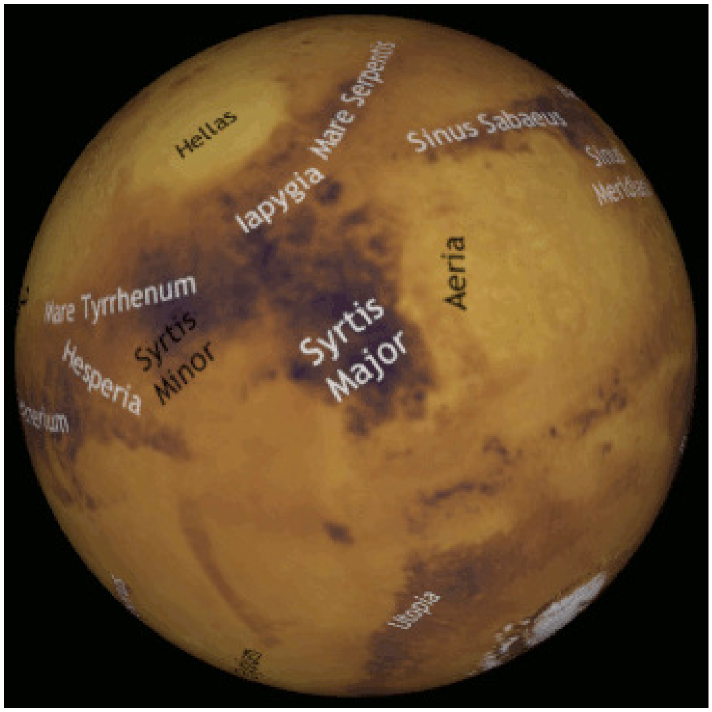

Figure 2: Syrtis Major Planum is labeled as the large dark spot in the center of the image of Mars. The white on the bottom is the south pole, and Hellas Impact Basin is labeled just north of Syrtis Major Planum. Image adapted from NASA.

Goals and Specific Objectives

One way to check the composition of Syrtis major would be to try and characterize the region with the current information we have on it. Due to previous missions we have detailed topographic data that can be used to constrain the rheology of the lavas that once flowed across the surface. Lavas that contain more silica (diorite, rhyolite, and others) tend to behave more viscously and make topographically high landforms with steep slopes (volcanic domes, stratovolcanoes, etc.) as seen in figure 3. Whereas lavas that have less silica (basalt, andesite, and others) tend to behave less viciously and create topographically low landforms with gentle slopes (shield volcanoes, lava tubes, and more) as seen in figure 3. Therefore, in a very simplified case, we can generalize that lavas high in silica will create features with high slopes and lavas low in silica will make low slopes. Therefore elevation data of Mars can be used to create a slope map of Syrtis Major Planum to identify areas of different slopes, and therefore possible different lava chemistry. This can then be checked against available mineralogical data from CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) in order to constrain volcanic diversity on Mars from 1.8 to 3.5 Ga ago (Platt, 2024a). This type of analysis is commonly done for lava flows on Earth (Kolzenburg et al., 2018) and other planets (Glaze et al., 2003).

Specific objectives with this work are to:

1. Derive a slope map with ArcPro from continuous elevation data of Syrtis Major.

2. To isolate areas of the mapping area that are above the mean slope and below the mean slope.

3. Compare the areas that are classified as having a higher than average slope with available mineralogical data for Syrtis Major and see if they overlap with areas thought to be more rich in silica.

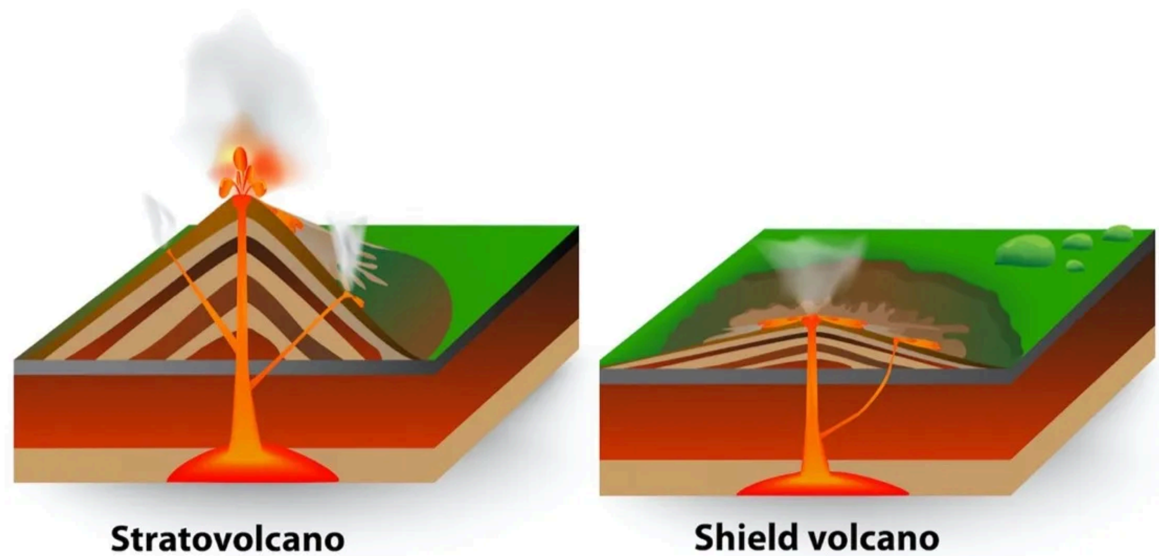

Figure 3: On the left is a stratovolcano and the right is a shield volcano. Stratovolcanoes are usually composed of lavas and pyroclasts that are of intermediate silica content (52-63 weight percent silica). The larger amount of silica makes the lava more viscous and creates landforms with steeper slopes. Shield volcanoes are typically composed of lavas with lower levels of silica (less than 55 weight percent). The lower levels of silica make the lava less viscous and so it forms landforms with more gentle slopes. These differences in topographic profiles that result from compositional differences allow one to make assumptions on the parameters of the lavas that make up a volcanic construct. Image from Science Friday's Explosion Math.

Data Collection and Descriptive Statistics

The data used in this project was published by the United States Geological Survey (USGS) Astrogeology Science Center, and is an infrared mosaic generated using Thermal Emission Imaging System (THEMIS) images from the 2001 Mars Odyssey orbiter mission (Fergason, 2014). The resolution of the data is 100 meters per pixel, but THEMIS data can have a resolution of up to 20 meters per pixel in 5 wavelength bands. The properties of the THEMIS data used can be seen in figure 4.

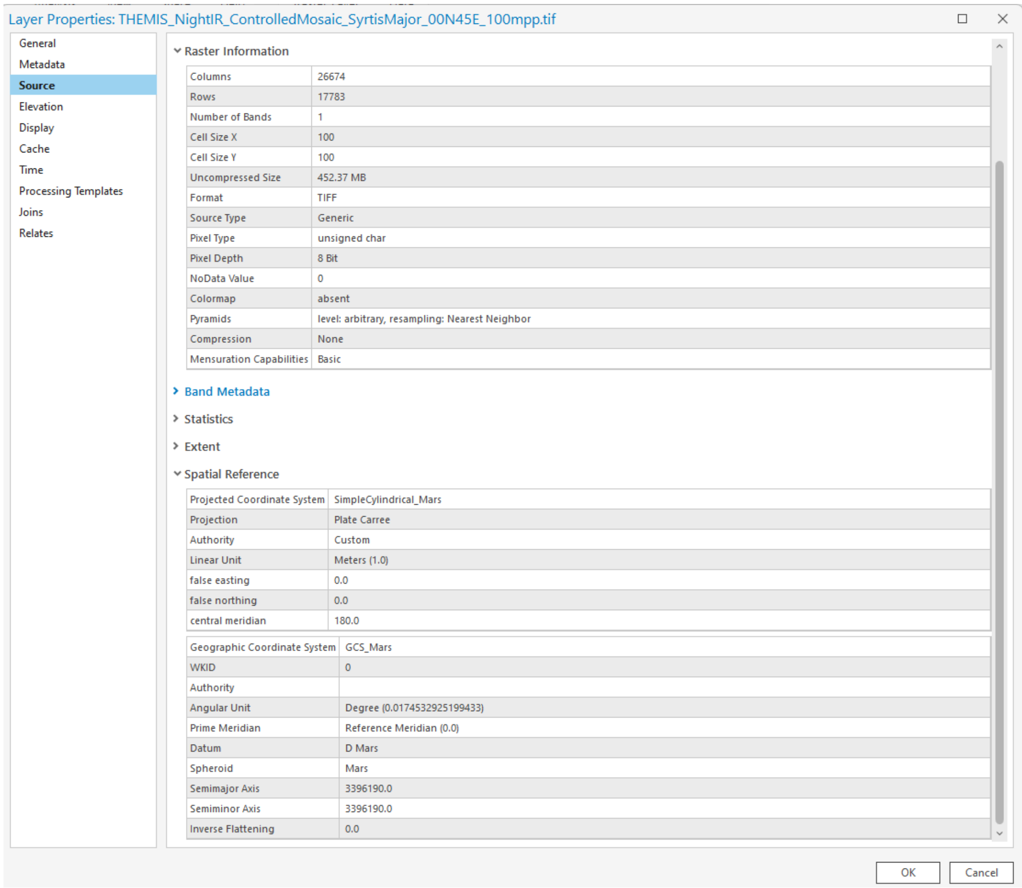

Figure 4: Layer properties of the THEMIS data of SMP used. The raster information and spatial reference are emphasized.

Methodology and Workflow Model

The slope map was generated by using ArcPy's arcpy.sa.Slope() function.Then ArcPy was used to determine the minimum and maximum slopes values, and then arcpy.sa.ReClassify() was used to create classes that contain the slopes that were higher and lower than average. Code and ArcGIS Project file for this work can be seen on https://github.com/geog3050/khottendorf.git.

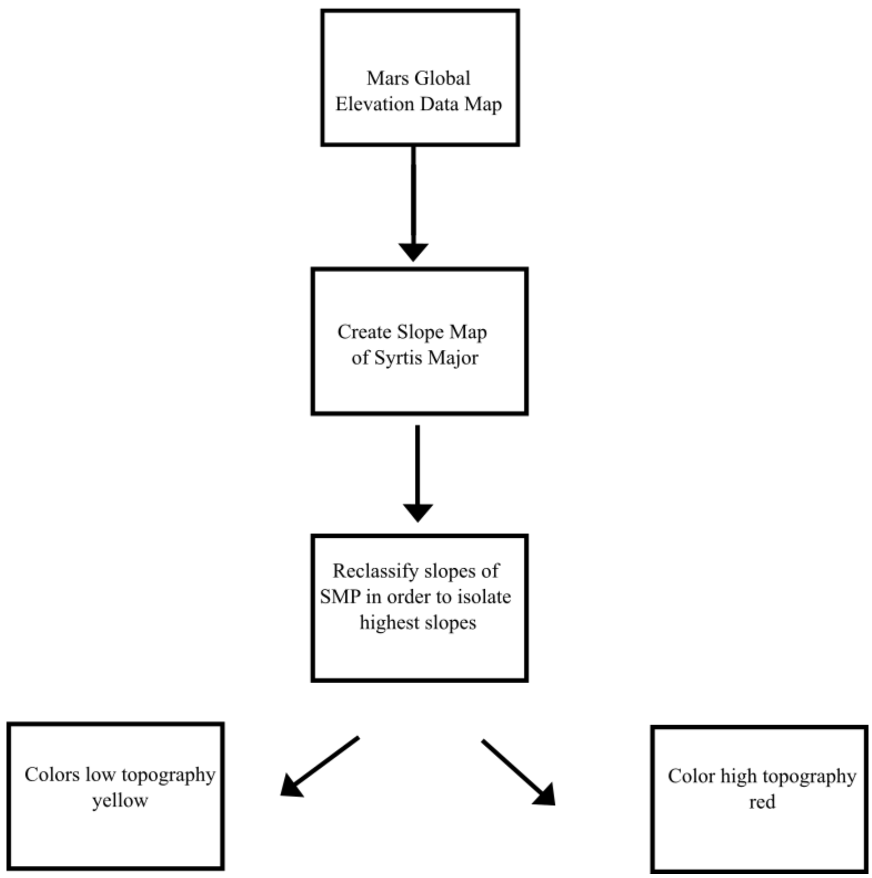

Figure 5: Workflow model of code used to make reclassified maps of Syrtis Major Planum.

Results

First a slope map of SMP was generated in order to create values that will later be classified. The original data from THEMIS is seen in figure 6, and the slope map is viewable in figure 7. It can be immediately seen that on average SMP has higher slopes than the immediate east and west. In order to better identify locations within SMP that have higher than average slopes, I classified the slope map in order to color the areas of the map red that have a higher than average slope. The result of this can be seen in figure 8.

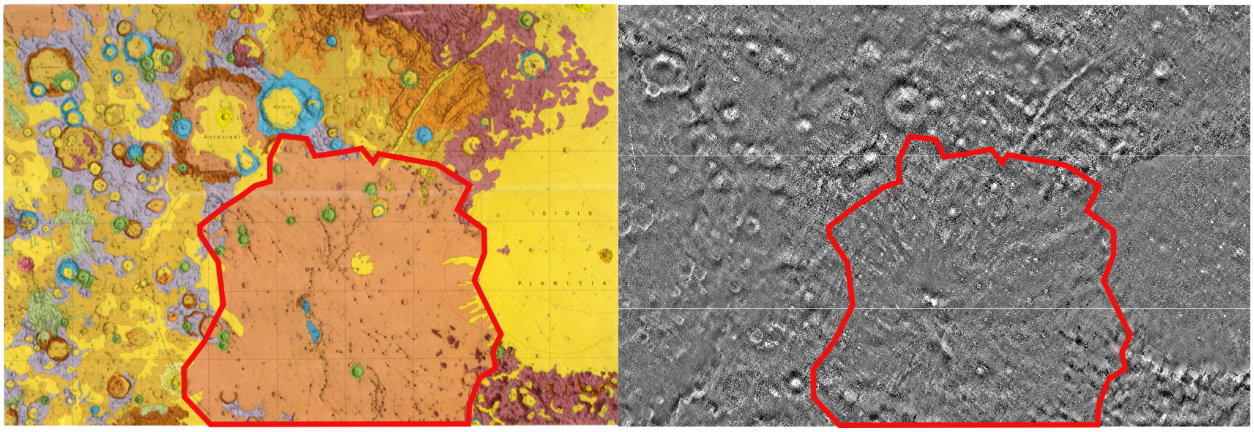

Figure 6: On the left is the geologic map of the Syrtis major Quadrangle of Mars (Meyer and Grolier, 1977). SMP is outlined in red and different geomorphological units are outlined in different colors. On the right is the THEMIS data with Syrtis major outlined in red. Both images are the same scale of 1:5,000,000 with north towards the top of the image.

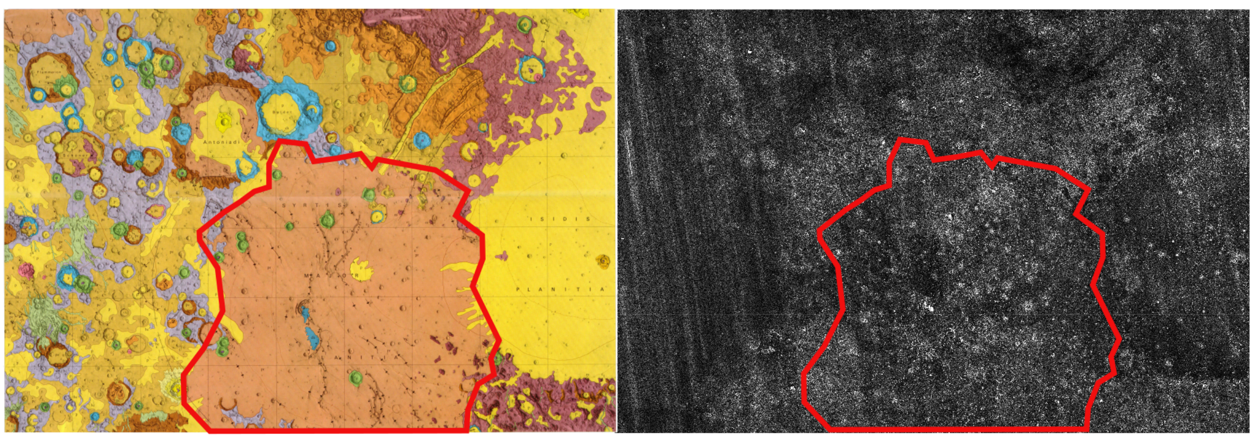

Figure 7: On the left is the geologic map of the Syrtis major Quadrangle of Mars (Meyer and Grolier, 1977). SMP is outlined in red and different geomorphological units are outlined in different colors. On the right is the slope map generated from the THEMIS data seen in figure 5 with Syrtis Major outlined in red. Gentle slopes are black and higher slopes are white. The scale of both images is 1:5,000,000 with north towards the top of the image.

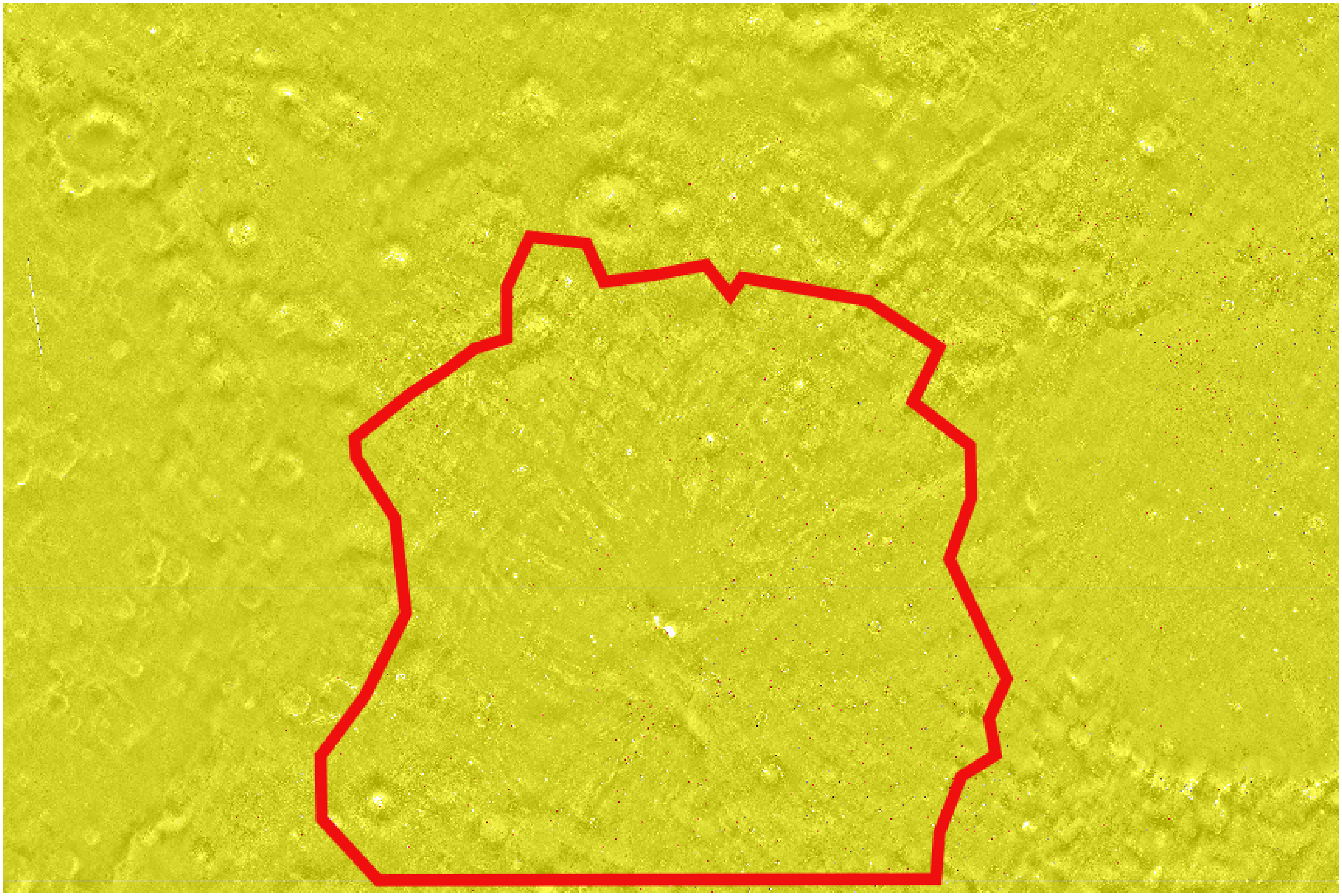

Figure 7: A layered image of the THEMIS data shown in figure 5 overlain by the classified highest sloped areas of the SMP. SMP is outlined in red. Yellow areas are the bottom 50% of slope values and the red dots show the areas that are the top 50% of the sloped areas. White areas signify no data. The scale is 1:5,000,000 and north is towards the top of the image.

Discussion and Conclusion

When looking at the slope classification, a few areas in SMP stand out. The most prominent is Nili Patera, which can be seen in figure 8. In Nili Patera there has been evidence of both basaltic and dacitic lavas (Eggers et al., 2021). This makes sense because Nili Patera is a caldera. A caldera is a landform that forms when a large amount of magma is evacuated from underground and erupted. The now empty magma chamber will collapse in on itself and form a depression, called a caldera. On Earth calderas are typically associated with large long lasting volcanic systems that are very compositionally diverse (Cole et al., 2005), but are especially known for their higher silica eruptibles that produce their most explosive eruptions. However, it is possible for volcanoes that only erupt lower silica lavas like basalt to make calderas, such as the Kilauea Caldera in Hawaii. A lot of the other areas that are red are associated with impact carters that aren't related to the volcanism that occurred in SMP, but some of them are smaller volcanoes that could also exhibit large amounts of igneous diversity only recently thought possible on Mars. Nili Planum and SMP overall exhibit evidence that suggests a large amount of igneous diversity in its 2 billion year life span at the beginning of Mar's geologic history. I will further investigate the diversity of the area in my PhD dissertation with crystallization experiments and remote sensing surveys.

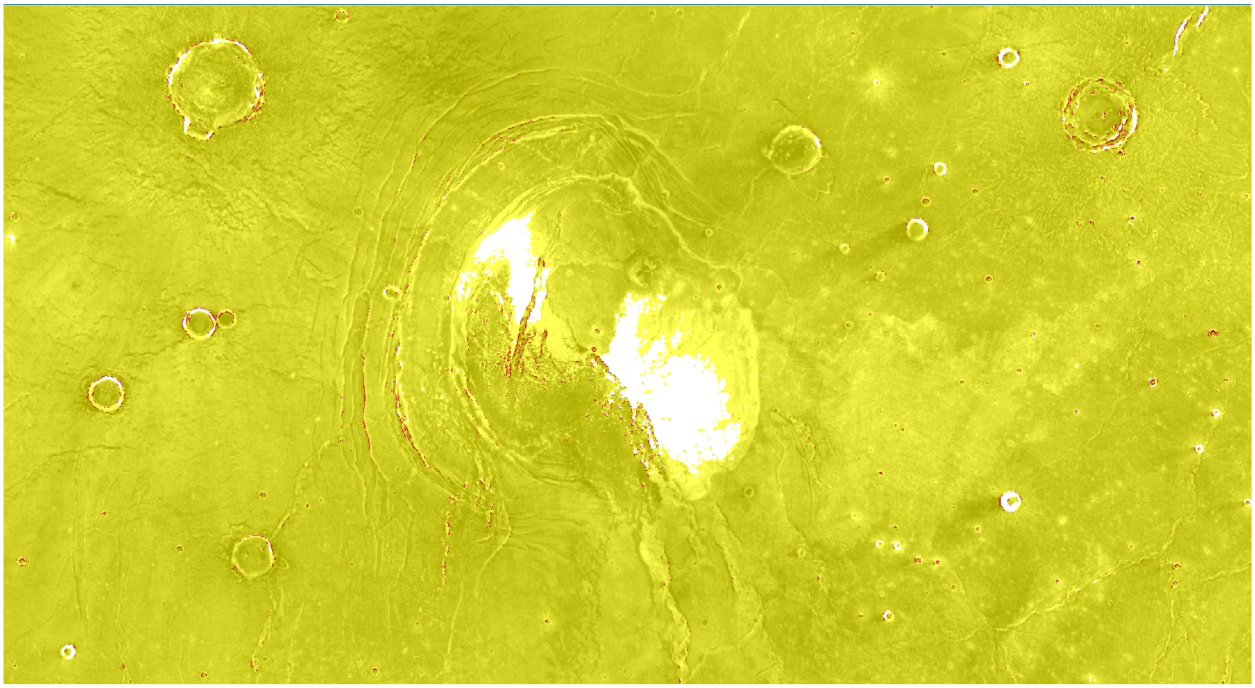

Figure 8: Close up image of Nili Patera. Which is the large rounded feature in the center of the figure. The other smaller circular objects are a mixture of other smaller volcanoes and impact craters. Yellow signifies lower than average slope and red signifies higher than average slopes. There is a high abundance of red in the caldera and on the southwest rim. in Scale is 1:500,000 and north is the top of the image.

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