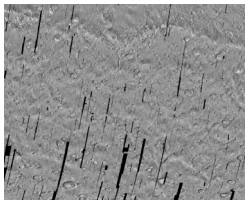
Geological Survey of Terra Cimmeria. Lindsey H. Williams[1], Zac Allison[1], Pier Bynum[1], Blair Dawkins[1], Tyler Evans[1], Evan Field[1], Dillon Flynn[1], Kathryn Peters[1], Ted Russo[1], Clark Witzleben[1], Sophia Tsang[1] [1] 3601 Ridge Rd, Durham NC

Introduction: Terra Cimmeria contains one of the most researched craters on the surface of Mars, Gusev Crater. It is an area of great interest to many researchers. The features in this region have been formed by various events in Mars' history possibly by the presence of water and extensive faulting as well as impacts. It is also possible that the features here are a result of volcanic activity or have been modified by volcanic activity.

Background: The Terra Cimmeria area examined was a highly cratered region in the southern highlands. Most of the large, older craters have been modified. The region also contains water-eroded canyon and valleys. There also exist many features called wrinkle ridges. The area is also cut by very long graben structures. In the northern most section of this area there is a volcano called Apollonaris Patera. Also in the north is Gusev Crater, one of the more studied features on Mars. It has a (water) channel (Ma'adim Valles) going into its southern portion. Recent study by the Spirit Rover confirms that the crater that has been filled in with basaltic ash and lava flows long ago. Terra Cimmeria also contains several areas of chaotic terrain (see left). This terrain has been interpreted to be formed by massive outpourings of underground fluids.

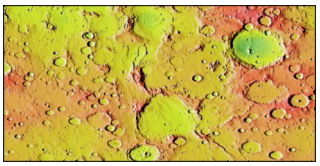
A graben is defined as a relatively low-standing fault block bounded by opposing normal faults. Graben (used as both singular and plural) can form in areas of rifting or extension, where normal faults are the most common type of fault. Between graben are relatively high-standing blocks called horsts.

Method: The data, as previously stated, is taken from the region of Mars known as Terra Cimmeria. The images used to compile the mosaic of this region were taken by THEMIS onboard the spacecraft known as Mars Odyssey. In order to retrieve this data and to properly analyze said data it was necessary to travel to Arizona State University. Based on interest in the relationship between graben and chaotic terrain in the region, a regional study of all features seen in Terra Cimmeria based on their morphology was made. Consequently, a regional mosaic (of daytime IR images) was put together by Dr, Josh Bandfield who helped guide this project. The mosaic spanned a region of Mars from about 0^0 to -60^0 N latitude and from about 150^0W to 200^0W longitude. From this mosaic and from THEMIS images of the area, it is possible to identify topographical features and use their cross-cutting relationships to define a relative timeline for the geological history of Terra Cimmeria. Below is the mosaic that served as the main focus of the study.



In addition, a search of the THEMIS archive available at http://themis-data.asu.edu/ was conducted. This website allows researcher to get close up images of features and to accommodate a better interpretation of the region.

Data: It is widely accepted that the Martian crust is largely volcanic in origin. The most ancient rocks on Mars have been pounded by meteor bombardment, and the Terra Cimmeria area is filled by many large, now modified impact features.



From http://themis-.asu.edu/ showing landscape dominated by large, modified impact features.

Features formed by water: It appears that water has played a role in the development of Terra Cimmeria topography, Ma'adim Valles, is a long, deep canyon that leads into Gusev Crater. It was presumably formed by a catastrophic flood of water.

Additionally, the ancient highlands of Terra Cimmeria show smaller scale valley systems that also have been presumably carved by liquid water, as shown below.

THEMIS Image V15559005
Note the presence of water eroded valleys. These are fairly common in the Terra Cimmeria Highlands
From http://themis.asu.edu/

Chaotic Terrain: It may be that the chaotic areas that trend generally west-southwest across Terra Cimmeria just south of the head of Ma'adim Vallis. These areas may have been sources of the water that formed the great canyon, although we found no geological evidence to support this claim. The connection between chaotic terrain and large-scale water erosion is shown better elsewhere on Mars. It has also been proposed that the area that roughly corresponds with where the chaotic terrain is in Terra Cimmeria once contained a water-filled lake [1]. Close inspection of the chaotic terrain shows it to be modified by later volcanic activity (see below) and to be cut by graben formation. It appears that the chaotic terrain predates both the event that produced the flood basalts and the forces which produced the graben.

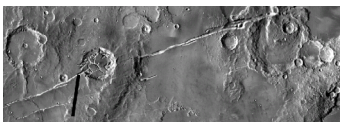
In addition, close inspection of chaotic terrain show that the blocky mountains that make up the terrain conspicuously resemble horns and arêtes that form on earth by the action of glaciers. Could it be that flowing ice has also played a part in the evolution of at least part of the Terra Cimmeria Terrain?

Flood Basalts: Older impact features, including Gusev Crater, has since been modified by volcanic activity. In Gusev Crater, the Spirit Rover is currently studying pyroclastic rocks that were altered in a water-rich environment. Basaltic lavas, which have been interpreted to overlie these pyroclastic rocks [2].

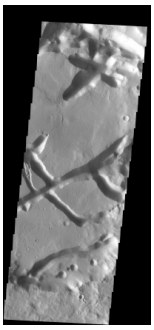
Though no morphological evidence of the pyroclastic rocks was observed by us, the modification of the ancient impact craters most likely was caused by a large-scale flood basalt event. The material in the older craters often contains lava tubes and wrinkle ridges on the surfaces of this basalt seem to be part of the lava emplacement process.

The formation of these flood basalts affected a huge area on Mars and exemplifies the planetary impact that Martian volcanism could accomplish. Since the surfaces of these flood basalts have relatively fewer impacts (mostly small and preserved cratering), we feel that they are relatively young. In addition the proximity of the Tharsis complex to the east of the area suggests that this event may well be a Tharsis volcanic event. On a smaller scale, it appears that younger lava flows were also produced by Apollonaris Patera.

Graben formation: After this study it is felt that graben structures that cross the Terra Cimmria region modify every other topraphic feature of the region. Thus, it is interpreted that the graben were actively forming after all other events mentioned above ceased (with the exception of preserved cratering). It is inferred that, like other large-scale rifts that radiate from the Tharsis complex (such as Valles Marineris), tensional forces that formed these graben were the result of the huge mass of Tharsis stressing the crust of Mars. It is also believed that there is evidence that the graben may have facilitated the distribution of flood basalts that originated in Tharsis. Many modified craters that were crossed by graben show lava tube formation.



Modified crater lying along a graben structure. Note lava tubes within the crater.



THEMIS image V15009002
Close up of collapsed lava tubes within crater crossed by graben

Conclusions: The Terra Cimmeria region of Mars contains major morphological features that possibly represent five groupings of crustal formation and modification events. We propose the following relative framework: 1.) Emplacement of an original surface, probably by volcanic activity, 2.) modification of this original crust by a hydrological cycle (water erosion) accompanied by frequent, large meteor impacts, 3.) Catastrophic release of water (from chaotic terrain area?) forming Ma'adim Valles (although we do not see morphological evidence for this and believe that the "chaotic" terrain of Terra Cimmeria may actually represent a late phase of our stage two when water (lakes?) retreated to smaller areas and froze into glaciers), 4.) rifting and widespread volcanism related to the development of the Tharsis Complex to the east, and 5.) subsequent modification of surface features under present day Martian conditions accompanied by less frequent, smaller meteor impacts.

Future Work: Our study took place over just three days. More time will allow a much more detailed study of this interesting area. We do feel that this report is just a general framework for a geological history and that we could make many additional observations using more THEMIS images and MOC images. In addition, we will watch as new data is sent back to earth by the Mars Reconnaissance Orbiter's HiRise Camera.

Acknowledgements: We would like to thank the MSIP staff at ASU, Ms. Wendy Taylor, Ms.Laurie Rogers, Ms. Melissa Bunton, and Dr. Josh Bandfield.

Sources: [1] Rossman Irwin III, Alan Howard, Ted Maxwell: *Geomorphology of Ma'adim Vallis, Mars, and Associated Paleolake Basins. Journal of Geophysical Research, 2004.*[2] Martinez-Alonso, Sara, Bruce Jakosky, Michael T. Mellon, Nathaniel Putzig: *A volcanic interpretation of Gusev Crater surface materials from thermophysical, spectral, and morphological evidence. Journal of Geophysical Research 2004.*