Geomorphology of a Crater Region within the Eridania Basin, Mars: Construction of a Geologic Map

by

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Abstract

The mapped crater region of Mars is located in the Southern Highlands specifically in the Eridania basin between the latitudes 179ºW - 176ºW and the longitudes 37ºS - 40ºS. The striking features within the mapping region are the two large, main craters, the east to west crosscutting Sirenum Fossae complex, the enigmatic chaotic terrain, and the north to south oriented wrinkle ridges. This study describes the geologic units of the region based on their unique morphological differences. Analysis of the units generated a geologic map of the area and an accompanying stratigraphic column placing the units into a relative age relationship. The resulting geologic map was produced using MOLA, CTX, THEMIS, and HiRISE images. By comparing the results to previous studies of the Martian surface, an interpretation of the geologic units and the processes that dominated their unique morphologies is determined. The final step of this study created a geologic history documenting the changing climate, depositional sequences, and structural influences that occurred within the mapping area. This analysis documents heavy tectonism, volcanism, eolian activity, fluvial activity, and lacustrine effects on the area. Also documented is a changing Martian climate from one that was warm and wet in the early history to one of a colder and dryer nature as time progressed.
I. Introduction

Our understanding of the processes that shaped the surface of Mars is continually growing with each study conducted. Interpreting the evidence preserved in the ever changing surface morphology has shown that throughout Martian history, there has been a suite of dominant forces that left their mark on the surface. The key forces controlling surface modification are volcanism, tectonism, meteoric impacts, eolian activity, lacustrine, and fluvial. Because many of these morphological features have remained well preserved on the present-day surface, stratigraphic relationships between the geologic units can be determined. Using the stratigraphic relationships as relative time markers, a geologic history of when the depositional events occurred and an understanding of their accompanying Martian climate can be constructed.

The purpose of this study is to construct a geologic map of a crater region within the Eridania basin located in the Southern Highlands. By looking at surface modification and unique morphological differences, the local geologic units of the region can be separately defined. Using this information to locate and identify unit contacts, a stratigraphic column can be created. This stratigraphic column provides relative ages of the units and the region as a whole which helps to determine how the surface evolved over time. By using previous studies of the Martian surface and climate as a reference, interpretations of these geologic units can be constructed. A geologic history can be synthesized by analyzing and comparing relative ages of the units, processes of deformation, and climate reconstruction.

The process of obtaining a geologic map of the crater region is as follows. The first step is to identify unit areas with unique morphological differences and describe
these different units. By doing so, the second step of creating a geologic map can be accomplished by identifying the points of contact between the different morphological units. The third step is to study the unit contacts to determine a regional stratigraphy thus placing each unit onto a relative time scale according to their depositional event. After identifying the units, the fourth step is to determine the main depositional processes of each unit and compare the findings to those of previous studies in the literature. The fifth and final step consists of combining all the previous steps to construct a relative geologic history of the Martian crater region putting into context the major geologic events and the major climate changes that occurred.
II. Methodology

2.1 Image Mosaic Construction

Images previously georeferenced by graduate student Lisa Korn from numerous satellites were imported into ArcMap and used to construct an image mosaic of the crater region within the Eridania basin. The images used were generated from the Mars Orbiter Laser Altimeter, the Context Camera, the Thermal Emission Imaging System, and the High Resolution Imaging System Experiment. These images combined provided the tools needed to make an appropriate and accurate geologic map of the crater region.

2.1.1 Mars Orbiter Laser Altimeter (MOLA)

The Mars Global Surveyor (MGS) launched by NASA in 1996 is in route to Mars. This MGS spacecraft is equipped with the MOLA instrumentation. MOLA’s laser emits a wavelength of 1.064 microns and has a maximum range of 787 km. Its range resolution is 37.5 cm and it has a vertical accuracy of 1 m (Smith et al., 2001). One of the primary objectives of the MGS MOLA instrumentation is to globally map the Martian topography (Smith et al., 2001). The information provided as a result of this objective helped to determine the structural differences between the geologic units present in the mapping area.

2.1.2 Context Camera (CTX)

The Mars Reconnaisance Orbiter (MRO) was launched in 2005, reaching Martian orbit in 2006. One of the instruments carried aboard this ship is the Context
Camera (CTX). The images captured by the CTX VIS imager instrumentation are high-resolution images of approximately 6 m/pixel. These images are taken in the 500-700 micron wavelength. The main objective of this imager is to document the geologic outcrops on Mars and the processes that shape them (Malin et al., 2007). Images from this instrument were heavily utilized in this project. They played a key role in mapping the geologic units within the defined mapping area, including the various contacts between them, and their stratigraphic relationships to each other.

2.1.3 Thermal Emission Imaging System (THEMIS)

The THEMIS instrumentation was carried to Mars by the NASA spacecraft, the Mars Odyssey. This instrument uses thermal-infrared, near-infrared, and visible image bands to provide images for analysis. It acquires global coverage of Mars at 100 m/pixel resolution. These bands allow for the global study of physical properties and mineral composition of the geologic suites found on the Martian surface (Christensen et al., 2004). For this project, only the thermal-infrared information was used. This provided an almost complete day and night time image array for the mapping area. This array was used to differentiate between the numerous geologic units based on their varying thermal inertial qualities.

2.1.4 High Resolution Imaging System Experiment (HiRISE)

The High Resolution Imaging System Experiment (HiRISE) accompanied the CTX instrumentation aboard the Mars Reconnaissance Orbiter (MRO) launched in 2005 (Malin et al., 2007). The images captured by HiRISE are in the VIS spectrum
and have a spatial resolution of approximately 25 cm. These images; however, will provide coverage of approximately 1% of the Martian surface. The main objective of this instrumentation is to study the existing geologic units, and to better understand the processes that shaped the landscape of the Martian surface (McEwen et al., 2007). Because of its high spatial resolution, the HiRISE images were used (where available) to compliment the CTX images. Their main purpose in this project was to assist with the identification of the geologic units and the stratigraphic relationships of the units present in the image boundaries.

2.2 ArcMap Software

Version 10.1 of the ArcMap software was used as the primary tool in constructing the geologic map of the crater region within the basin. By utilizing ArcMap software, unit delineations, unit contacts, and structural units and features were identified and drawn. The layout view in ArcMap was used to create the images seen in this study.

2.2.1 Mapping Region

The mapping region is located between the latitudes 179ºW - 176 ºW and the longitudes 37 ºS - 40 ºS. This crater region is located within the Eridania basin. The main features of this region are the two large craters in the center and the large crosscutting fossae complex from east to west across the region. The primary geologic units and structural units and features were mapped within this region.
utilizing the ArcMap software. Geologic units and structural units were delineated by colorful polygons while the structural features were identified with outline accents.

III. Results

3.1 Description of Geologic Units Present in the Mapping Area

The geologic units found in the Mars mapping region were determined through observations made from the various satellite images mentioned in the methodology section. These various units and their contacts were ascertained by mainly focusing on their morphological, textural, and color differences. Comparing and contrasting these criteria helped to define the most accurate mapping of the crater region. The geologic units described in this section are broken into two categories. The geologic units located inside the two large craters are referred to as the crater units and the geologic units found in the plains surrounding these craters are known as the plains units. All units fall into one of the two categories except for the mountainous terrain unit, which is present in both the crater and the plains regions. In addition to categorizing units based on their location within the Mars mapping region, there are some units that are better defined by their structural morphology. These structurally defined units are included at the end of the description of geologic units.

3.1.1 Mountainous Terrain Unit (Pmt)

The mountainous terrain unit is located in two specific places in the mapping region. It is exclusively found as the crater ejecta of the two largest craters in the center and southern area of the mapping region. In total, the mountainous terrain unit
covers approximately 5,000 km². This unit is composed of two distinct morphological features. The first and most distinct feature is the high relief areas relative to the surrounding terrain. These high relief areas consist of a mountainous morphology alternating with intermountain valleys. The highest relief areas are found closest to the rim of each large crater with their elevation decreasing as the distance from the rim increases. This mountainous morphology type exists at a maximum distance of 24 km from the crater rim. Between the high relief mountain structures, are valleys filled with talus from the surrounding mountain slopes (Figure 1a). The crater-facing slopes of the mountains appear to have a sharp dip while the plains-facing slopes have a more gradual dip. However, it is possible that this visual dip assessment is affected by the orientation and angle of the sun thus creating an illusion. The texture of the high-relief mountains and associated low relief valleys vary depending on their location relative to the crater. The largest, main crater in the center of the mapping area displays mountain regions with a smooth texture and valley regions with a knobby, hilly texture that is irregular (Figure 1a). These textures are both associated with a tonal range from medium to light. The second largest crater located south of the main crater, exhibit a mountain and valley complex demonstrating a similar rough, pocke
texture with a larger concentration of river channels incising the mountain slopes (Figure 1b). The texture observed with this mountain and valley complex is associated with a tonal range from dark to light.

The second distinct feature defining the mountainous terrain unit is the plateau morphology that has a more consistent relief than its mountainous counterpart. This feature is noted at a distance that is farther away from the crater rim than the higher,
irregular relief terrain as it was found extending a maximum distance of 33 km from the crater’s edge. These plateaus seem to be a representation of the crater ejecta that has been covered by surrounding units as a result of their depositional event (Figure 1c). The texture of the plateau’s surface is dependent on the plains material specific to the units in which they are located. A bright to medium toned, wavy plains material is associated with the main center crater’s ejecta plateau, and a dark to light toned, rougher and hummocky texture is associated with the smaller southern crater.

These two morphological features were identified and combined to distinguish the mountainous terrain unit as a distinct entity. This methodology was chosen because both features are part of the larger craters’ ejecta blanket. The mountain and valley complexes fading in elevation and irregularity into the flat plateaus are two distinct intertwined morphological features that help define the mountainous terrain unit.

Figure 1: A. Type section for the large, main crater mountainous terrain characterized by smooth, irregular high relief terrain and talus filled valleys. B. Type section for the southern, large crater mountainous terrain. It is characterized by the same irregular terrain in A but has a rougher texture. C. Type section for consistent relief topography of mountainous terrain found farther from crater rim than the irregular relief of mountainous terrain in A and B.
3.1.2 Crater Units

3.1.2.1 Bright Crater Deposit Unit (Cbd)

The bright crater deposit unit is exclusively found inside the two largest craters in the mapping region. More specifically this unit exists on the crater floors, crater walls, and the more resistant outcrops exposed on steep slopes in specific areas. The total size of this unit covers approximately 245 km$^2$ of the mapping area. This unit is characterized by two unique geologic morphologies. The first morphology consists of outcrops that have a higher relief than the surrounding units and that are heavily scarped. This morphology also includes large fractures running through the outcrop (Figure 2a). The second morphology identified is characterized by a rough blocky texture that is marked by a high density of polygonal fractures (Figure 2b). The overall tone of this unit, including both types of morphologies, is light to bright with a very bright signature on the nighttime THEMIS infrared images. Based on the unit description, the bright crater deposit unit is interpreted as an evaporate deposit.

![Figure 2: Type sections for the bright crater deposit unit (Cbd). A. Unit morphology characterized as having high relief, heavily scarped areas, and large fractures. B. Unit morphology characterized as having rough, blocky texture that has a high density of polygonal fractures. This figure is on a much smaller scale and was taken from a HiRISE image.](image-url)
3.1.2.2 Light Crater Terrain Unit (Clt)

The light crater terrain unit is located inside both of the two largest craters of the mapping region. Together, these two sites cover an area of approximately 340 km$^2$. This unit makes up the majority of both the central and southern crater floors. It is characterized by a flat expansive surface that has a slight upward slope in the areas adjacent to the crater wall (Figure 3). In the region of the large, central crater there is a profound fracture on the west side as illustrated in Figure 3. The texture of the light crater terrain is smooth with a light tone. This unit comes into contact with the bright deposits, chaotic terrain, rocky crater terrain, gully deposits, valley fill deposits, and lava flows. Because the light crater terrain unit covers such an expansive area within the crater, which contacts several regions mentioned above, this is an important unit in relation to the stratigraphy of the craters. This unit could be interpreted as a fluvial sedimentary unit, an eolian unit, or a lava flow.

Figure 3: Type section for the light crater terrain unit (Clt) characterized by a vast, flat terrain with a smooth texture and light tone. Also in the type section are the large fractures seen in the western section of the large, main crater.
3.1.2.3 Lava Flow Unit (Clf)

The crater lava flow unit is one of the smaller units in both the large, main crater and the southern crater. This unit is characterized by a rough texture and terrain that is characterized by a higher relief than the surrounding light crater terrain unit. A distinct feature of the crater lava flow is its lobate edges (Figure 4). Also characterizing this unit is its light tone and bright signature on the night time THEMIS infrared images.

3.1.2.4 Rocky Crater Terrain Unit (Crt)

The rocky crater terrain unit is present exclusively on the western crater wall of the main, large crater. This unit covers a very minimal area of the mapping region. It is characterized by a very rough, blocky texture that is located in the valleys of the crater wall while extending onto the crater floor (Figure 5). This unit is identified by a medium to light tone. The rocky crater terrain unit is interpreted as a mass-wasting event.

3.1.2.5 Valley Fill Deposit Unit (Cvf)

Valley fill deposits are found in the north and north-west areas of the large, main crater. This unit occupies the lower elevations and the relatively flat areas of the crater floor. It is characterized by a semi-rough pock marked terrain (Figure 6). The tone of this unit ranges from medium to light. The valley fill deposits unit is interpreted as fluvial deposits.
3.1.2.6 Gully Deposit Unit (Cgd)

The gully deposits unit is located exclusively within the crater walls and floor of the two large craters in the mapping region. In total, this unit covers an area of approximately 310 km$^2$. It is comprised of three major morphological features; old and young river channels, alluvial fans, and glacial tongues (Figure 7). The old river channels are characterized as channels that have undergone moderate to severe erosion exhibiting blunted edges with flattened angles. While the young river channels have experienced very little erosion and tend to have steeper angles and sharper edges. These river channels represent the beginning of the gully deposits and are located on the crater walls. Extending from the rivers and spreading out onto the crater floor are the alluvial fans. These fans vary in length and range from smooth to
rough textures. Protruding from the alluvial fans are the glacial tongues characterized by lobate depressions with a smooth texture. Not all of the gully deposits exhibit all three distinct morphological features. Some of the gully deposits have both river channels and alluvial fans, while others have river channels and glacial tongues.

3.1.3 Plains Units

3.1.3.1 Smooth Plains Terrain Unit (Pst)

The smooth plains terrain unit occurs throughout the entire mapping region but exhibits the highest frequency to the west of the large, main crater. This unit is found exclusively outside of the two largest craters in the surrounding plains and inside the valley created by the large fosse present on the eastern portion of the area. Covering approximately 3,460 km$^2$ of the mapping area, the smooth plains terrain is a
relatively large unit. It is characterized by its low relief and fairly consistent elevation. It tends to be defined by areas of lower elevation filled in with the surrounding material. With very few distinct morphological features, the texture of this unit is a key distinguishing element. The texture consists of very smooth deposits with a medium tone that seem to be fine grained (Figure 8). This unit is also heavily marked by craters with impact points varying from well defined crater ejecta blankets, to very eroded, almost completely filled in impact sites. The smooth plains unit contains multiple wrinkle ridges cutting through it and has few if any river channels incising its surface. Overall, this unit comes into contact with electric terrain, mountainous terrain, dark, rough terrain, terrain of high river channel densities, and stream deposits. Because the smooth terrain unit comes into contact with many other varying types of terrain, it is an integral unit in determining the stratigraphy of the crater region. Characterized by its flat morphology, smooth texture, and its occurrence in locally lower elevation sites, this unit is interpreted as a manteling deposit.
3.1.3.2 Electris Deposit Unit (Ped)

The vast electris deposits occupy the greatest amount of the mapping area. This unit covers approximately 9,600 km$^2$ of the crater region. It is composed of several different morphological features such as high relief mesas, smooth, shallow sloping deposits and a large valley (Figure 9a). The most distinguishing feature of the electris deposits unit is the massive, high relief, mesas. These mesas are distinct because of their high relief compared to the surrounding electris deposits. They characteristically have very sharp edges with little to no talus accumulation at the base of the mesa edge. The mesas occur in irregular shapes but usually have sharp, straight edges with very little rounding (Figure 9b). Dotting the electris deposits, the mesas in the region range from 2km to 7km in length. The material atop the deposits

Figure 8: Type section for the smooth plains terrain unit (Pst), characterized by very smooth, medium toned deposits. This unit has low relief and is noted to fill in depressed areas.
can range from smooth to rough. The smooth material resembles that of the surrounding plains and is medium in tone. Rougher mesa material is less common and has a characteristically bright tone. The landscape of the mesas transition to a continuous vast swath of lower relief plains deposit.

Having a gentle slope, the plains deposits are smooth to undulatory and have a dark-medium to medium tone (Figure 9c). The plains deposit feature of the electris deposits unit make up the majority of the electris unit and therefore, cover the largest area of the crater region. This section of the unit exhibits a large number of crater impacts ranging from craters with well preserved ejecta blankets to filled in, heavily eroded craters. There are also numerous wrinkle ridges that cut through the electris plains feature.

The last unique morphological feature of the electris deposits unit is noted in the north-eastern sector of the mapping region. In this area, the plains electris feature is incised by an immensley large fluvial like channel creating a deep valley (Figure 9a). The valley feature has sharp, steep walls surrounded by plains material and is filled in with a very smooth textured, medium toned material.

The numerous morphological features that make up this unit have been interpreted as electris deposits. This unit comes into contact with the mountainous terrain, the smooth plains terrain, the dark, rough terrain, stream deposits, and lava flows. Because it comes into contact with numerous other units, and has been the focus of many other studies of the Martian surface, the electris deposits play a key role in determining the stratigraphy and dating of the region.
3.1.3.3 Dark, Rough Terrain Unit (Pdr)

The dark, rough terrain is the second most expansive unit in the crater region. It primarily occurs south of the main crater and south of the large fossae running east to west through the mapping region. This unit covers approximately 8,430 km$^2$. It is characterized by a rough, pocked texture that has a dark-medium to dark tone (Figure 10). The terrain is relatively low relief with a consistent flat, plains morphology. The
wrinkle ridge structural unit runs along a north-south trajectory through this unit. Also present are numerous old, broad river channels that cover a large portion of this unit. Upon considering places of contact with other units, this unit is continually embayed. Characterized by its dark, rough texture, and its lobate embayments, the dark, rough terrain unit has been interpreted as a large lava flow.

![Type section for the dark, rough terrain unit (Pdr) that is characterized by a rough, pocked texture that has a dark tone.](image)

**Figure 10**: Type section for the dark, rough terrain unit (Pdr) that is characterized by a rough, pocked texture that has a dark tone.

### 3.1.3.4 High Channel Density Terrain Unit (Phcd)

The high channel density terrain unit is located south of the main large crater just outside of the crater rim. This unit encompasses approximately 555 km² of the mapping area. The main morphological feature of this unit is its high density of old river channels that have experienced erosion since their incision (Figure 11). These river channels are present in patches across the unit. A rough texture with a medium
to light tone help to define this unit. The high channel density terrain unit is being interpreted as primarily a sedimentary unit.

![Image](image.png)

**Figure 11:** Type section for the high channel density terrain unit (Phcd) characterized by its rough terrain that has a medium to light tone. The most distinct feature is the high density of river channels.

### 3.1.3.5 Low Channel Density Terrain Unit (Plcd)

The low channel density terrain unit is also found exclusively south of the main, large crater adjacent to the outside of the rim. This unit occupies an area that is approximately 390 km² in the mapping region. The texture of this unit is usually smoother than that of the surrounding high channel density terrain unit, although in some areas a rough texture is noted (Figure 12). This unit is represented by a tone that ranges from light to medium. The low channel density terrain occurs in the high river channel density terrain in distinct areas of depression. Most of the deposits present in the low channel density terrain unit are identified as fluvial deposits at the end of the
old river channels. However, some outcrops of this unit are noted in depressions located in high elevation areas of the low channel density terrain. The features of this unit support the interpretation of a fluvial deposit.

![Type section for the low channel density terrain unit (Plcd) characterized by a smoother texture than its surrounding terrain with a light to medium tone. Typically found in areas of depression.](image)

**Figure 12:** Type section for the low channel density terrain unit (Plcd) characterized by a smoother texture than its surrounding terrain with a light to medium tone. Typically found in areas of depression.

### 3.1.3.6 Plains Lava Flow Unit (Plf)

The plains lava flow unit is identified in the north-west section of the mapping region. This unit is characterized by a rough, wavy texture (Figure 13). The lava flow has a very characteristic dark tone and a bright signature on the night time THEMIS infrared images. Also distinctly characteristic of the lava flow are the lobate morphological forms found at the edges of the flow.
3.1.3.7 Stream Deposit Unit (Psd)

The stream deposits unit is observed irregularly throughout the mapping region. This unit is characterized by very smooth, flat deposits. The stream deposits form in a large, pool like morphology that is located in between, or at the end of, old river channels (Figure 14). This unit is noted to be superimposed upon other units that encompass them. The stream deposit unit is interpreted as fluvial deposits.

Figure 13: Type section for the plains lava flow unit (Plf) characterized by rough, wavy texture that has a very dark tone.
3.1.4 Structural Units and Features

3.1.4.1 Chaotic Terrain Unit (Cct), (Pct)

The chaotic terrain structural unit occupies an area of approximately 2040 km². It has two specific morphologies occurring within the main, center crater, and in the north-eastern part of the mapping region. The chaotic terrain associated with the main crater is characterized by a negative relief in relation to the surrounding unit, and the chaotic terrain in the north-eastern sector of the mapping area is identified by a positive relief compared to its surrounding unit. In the region of the main crater, this chaotic terrain unit exclusively incises the light crater terrain unit. The sunken, negative relief, terrain is dominated by two features consisting of a complex of irregular plateaus and surrounding valley fill areas (Figure 15a). The positive relief

Figure 14: Type section for the stream deposit unit (Psd) characterized by a smooth texture filling in a basin like depression. River channels are always found terminating at the edge of this unit.
plateaus of this sector range in size from 5.5 km to .5 km at their widest point. The sediment found on top of the plateaus has the same color and texture of the surrounding light crater terrain unit, possibly representing remnants predating the chaotic event. The valleys between the plateaus have a fluvial morphology suggesting water flow at one time. In some areas, the crater valley fill unit can be seen flowing into the chaotic structural unit along the valley floors. Both the plateaus and valley fill are medium in tone. The second type of chaotic terrain in the north-eastern sector is characterized by a positive relief. Here, the plateaus are protruding from the surrounding electris deposit unit (Figure 15b). These plateaus range in size from 2 km to less than a kilometer wide with a very bright to light tone.

3.1.4.2 Fossae and Wrinkle Ridge Features

There is a complex of graben features in the mapping region which are associated with the large fossae running across the entire mapping region. These graben features all run east to west varying in length and width. Also in the mapping region are numerous wrinkle ridges. These structural features run from north to south.

Figure 15: A. Type section for the crater chaotic structural unit (Cct) characterized by a negative relief complex of plateaus and filled valleys. B. Type section for the plains chaotic structural unit (Pct) characterized by a complex of positive relief plateaus protruding from the surrounding unit.
and also vary in length and width. Both of these structural units, their orientation, and geologic units they breach can be observed on the main geologic map of the region.

3.1.4.3 Crater Ejecta Feature (Pce)

The crater ejecta unit consists of the material deposited around a crater as a result of impact. It typically is characterized by a lobate form with a higher relief than the surrounding landscape. This structural unit typically has a rough texture and a medium tone. Crater ejecta in the mapping area are predominantly found on newer, medium sized craters. Examples of these ejecta can be found on the main geologic map of the region.

3.2 Stratigraphy of the Geologic Units Present in the Mapping Area

The stratigraphy of the geologic units present in the mapped crater region was created based on the relationships between contacting units. A geologic history which primarily consists of the relative time of deposition for the geologic units is best understood through the construction of the stratigraphic column. The following is an attempt to create a relative geologic history of the Mars mapping area.
The oldest geologic unit in the mapping region is the mountainous terrain unit.

As mentioned in section 3.1, this unit is present in both the crater and plains region of the mapping area making it important for both the crater stratigraphy and the plains stratigraphy. Because it is part of the crater ejecta, the mountainous terrain is older than all of the units found in the two large craters. Outside of the craters, in the plains area of the crater region, the mountainous terrain comes into contact with the electris deposits, the smooth plains terrain, the high channel density terrain, the low channel density terrain, and the dark, rough terrain. The electris terrain flows over and onto the higher elevation mountainous terrain making the mountainous terrain older than the electris terrain (Figure 16a). This same relationship also makes the mountainous material older than the smooth plains terrain (Figure 16a). To the south of the large crater, the high channel density terrain can be seen covering what was once the mountainous terrain indicating that the mountainous terrain is older than the high channel density terrain (Figure 16b). The mountainous terrain also pre-dates the low
channel density terrain. This relationship is highlighted to the south of the main crater where the low channel density terrain is observed embaying the mountainous terrain (Figure 16c). The last unit that contacts the mountainous terrain, also indicating its older geologic age, is the dark, rough terrain unit. This dark, rough terrain can be noted embaying the mountainous terrain, again revealing the relative younger age of the dark, rough terrain (Figure 16d).

**Figure 16:** A. Type section showing the contact of the mountain terrain (Pmt) with the electris deposit unit (Ped) and the smooth plains terrain unit (Pst). The younger Ped unit is seen flowing over and covering what was once Pmt material. The younger Pst unit is seen filling in depressed areas of the Pmt unit. B. Type section showing the contact between the older Pmt and younger high channel density unit (Phcd). The Phcd unit is completely covering what was once Pmt material. C. Type section showing the contact between the older Pmt and younger low density terrain unit (Plcd). The Plcd unit is seen embaying the Pmt unit. D. Type section showing the contact between the older Pmt and the younger dark, rough terrain unit (Pdr). The Pdr unit is seen flowing over and into a large depression of the Pmt unit.
3.2.1 Crater Stratigraphy

The second oldest unit present in the craters is the bright crater deposits. These deposits come into contact with only the light crater terrain. The relationship between these two units reveals their relative age. The light crater terrain embays the bright crater deposits and it fills in depressions among the bright crater deposits such as the polygonal fractures (Figure 17). Because of the nature of the contact, the bright crater deposits are considered older than the light crater terrain.

The next oldest unit present in the main crater is the remnant lava flow. As with the bright crater deposits, this unit also only comes into contact with the light crater terrain. Similar to the contact between the light crater terrain and the bright crater deposit, the lava flow is embayed by the light crater terrain. There is also a fault incising the lava flow which is filled in with the light crater terrain (Figure 18). These contact relationships indicate that the lava flow is older than the light crater material.

Figure 17: Type section for the contact between the older, bright crater deposit unit (Cbd) and the younger light crater terrain unit (Clt). The Clt unit can be seen flowing up to and embaying the Cbd unit. The arrows extending from 1 show the fractures that incise the Cbd unit and are filled in with the Clt unit.

Figure 18: Type section for the contact between the older crater lava flow unit (Clf) and the younger Clt unit. The Clt unit can be seen embaying and filling in the large fault that cuts through the Clf unit.

After the lava flow, the next oldest unit in the main crater is the light crater material. This unit is the most predominant unit, covering most of the crater floor.
Because of this large coverage area, it contacts a great number of the units in the crater. The light crater material is younger than the bright crater deposit and the lava flow. The reason for inferring this age relationship was discussed above and is illustrated in Figure 17 and 18. This unit is older than the other units it contacts, which are the valley fill unit, the structural chaotic terrain unit, and finally the gully deposits. The light crater material is older than the valley fill unit because the valley fill can be seen embaying the light crater material (Figure 19a). Since the chaotic event incises the light crater material, the light crater material must be older than the chaotic terrain (Figure 19b). Finally, the light crater material is considered older than the gully deposits because in multiple places, the gully deposits can be seen flowing onto the light crater material (Figure 19c).

**Figure 19:** A. Type section of the contact between the older light crater terrain unit (Clt) and the younger crater valley fill unit (Cvf). The Cvf unit can be seen embaying the Clt unit. B. Type section of the contact between the older Clt unit and the younger structural crater chaotic terrain unit (Cct). The Cct unit can be seen incising the Clt unit. C. Type section of the contact between the older Clt unit and the younger gully deposit unit (Cgd). The Cgd unit can be seen flowing onto and over the Clt unit.
Following the light crater terrain in age, is the rocky crater terrain unit. This unit comes into contact with the valley fill unit and the gully deposit unit. Both of these units are younger than the rocky crater terrain. There is an embayment relationship between the rocky crater terrain and the valley fill unit, where the valley fill unit is embaying the rocky crater terrain suggesting that the rocky crater terrain is older than the valley fill (Figure 20). The gully deposits can be seen flowing over the rocky crater terrain. This superimposition of gully deposits onto the rocky crater terrain suggests the rocky crater terrain was present before the gully deposits and is thus older than the gully deposits (Figure 20).

The second to youngest unit present in the large crater is the valley fill unit. This unit comes into contact with the light crater terrain, rocky crater terrain, chaotic terrain, and the gully deposits. As stated above, the valley fill is younger than both the light crater terrain and the rocky crater terrain (Figure 19a and Figure 20). The valley fill is also younger than the structural chaotic terrain unit as it is seen filling in the low elevation valleys between the chaotic plateaus (Figure 21). Lastly, the valley fill unit is older than the gully deposits. This age relationship is illustrated where the glacial tongues come into contact with the valley fill unit (Figure 20). The tongues of the gully deposits unit are noted to flow onto the valley fill and compile the valley fill unit into a terminal moraine.
The youngest geologic unit found in the two main craters is the gully deposits. As described above, the gully deposits are younger than the light crater material (Figure 19c), rocky crater terrain (Figure 20), and the valley fill unit (Figure 20).

### 3.2.2 Plains Stratigraphy

As mentioned above, the oldest geologic unit of all the plains units is the mountainous terrain unit. The next oldest plains unit is the high channel density terrain unit located to the south, just outside of the large, main crater rim. As described above, this unit is younger than the mountainous terrain (Figure 16b). Of the other contacted units, the high channel density terrain is oldest. The younger contacted units consist of the low channel density terrain, the dark, rough terrain, and the smooth plains terrain. The high channel density terrain is older than the low channel density terrain because the river channels observed in the high channel density terrain are not present in the low channel density terrain as they terminate at
the low channel density terrain contact. The low channel density terrain also fills in areas of depression present in the high channel density terrain (Figure 22a). The low channel density terrain is a product of the high channel density terrain during a time of precipitation as the run-off filled in the depressions of the high channel density terrain. With regards to the dark, rough terrain unit, the high channel density unit is determined to be older for two reasons. The first reason is that the dark, rough terrain embays the high channel density terrain. The second reason is that there are old-river channels present in the high channel density terrain that are not present in the dark, rough terrain (Figure 22b). This suggests that the high channel density unit was present during a time of precipitation when the dark, rough unit was not present, indicating that the dark, rough terrain was deposited after this time of precipitation. Next in order of oldest to more recent, the high channel density terrain is determined to be older than the smooth plains terrain because the smooth plains terrain flows onto and embays the high channel density terrain (Figure 22c).
Following in descending chronological order, the high channel density terrain is older than the low channel density terrain. This unit is found in the same area as the high channel density terrain, just south of the large crater rim. Of the units it contacts, the low channel density terrain unit is younger than the mountainous terrain and the high channel density terrain. These relationships are described above and depicted in Figures 16c and 22a. The low channel density terrain is older than the last unit it comes into contact with, which is the dark, rough terrain unit. This relationship was determined by noting that the dark, rough terrain unit embays the low channel density terrain, and it fills in some impact craters within the low channel density terrain (Figure 23).
The next geologic unit to form after the low channel density terrain is the electris deposit terrain. This unit comes into contact with the mountainous terrain unit, the plains chaotic terrain structural unit, the lava flow unit, the smooth plains terrain unit, the dark, rough terrain unit, and the stream deposit unit. The electris deposit unit is older than all of these contacted units except for the mountainous terrain unit and the plains chaotic terrain structural unit. The relationship with the mountainous terrain unit is described above and is illustrated in Figure 16a. In the north-east section of the mapping region, the chaotic event can be seen in the electris deposit. The chaotic terrain is older than the electris deposit because the remnant plateaus of the chaotic event can be seen protruding from the electris deposit. The

**Figure 23:** Type section of the contact between the older low channel density terrain unit (Plcd) and the younger dark, rough terrain unit (Pdr). The Pdr unit can be seen embaying the Plcd unit and filling in depressed areas in the Plcd unit. The arrows extending from 1 and 2 show specific impact crater areas of depression in the Plcd unit that have been filled in with the younger Pdr unit.
valleys crated by the chaotic event have been filled in by the electris deposit unit suggesting that the electris unit was deposited after the structural chaotic event (Figure 24a). In the north-west area of the mapping region, the relationship between the electris deposit unit, the lava flow unit, and the smooth plains terrain unit is demonstrated (Figure 24b). Here the lava flow unit is flowing over the electris deposit and filling in the lower elevation areas, especially some craters in the electris deposit suggesting that the electris deposit existed before the lava flow (Figure 24c). The smooth plains terrain also fills in larger depression areas of the electris deposits and it also embays the electris deposits (Figure 24d). This relationship indicates that the electris deposits are older than the smooth plains terrain. Finally, the relationship between the electris deposits and the dark, rough terrain can be evaluated in a very similar way. The dark, rough terrain fills in larger digressional areas of the electris deposit and it also fills in old river channels incising the electris deposit (Figure 24e). The electris deposit unit is also older than the stream deposit unit, because once again, the stream deposit unit is seen flowing over the electris deposit unit filling in a small depressed basin (Figure 24f).
Figure 24: A. Type section of the contact between the younger electris deposit unit (Ped) and the older chaotic terrain structural unit (Pct). The Ped unit can be seen between the remnant plateaus of the Pct crater event. B. Type section of the contacts between the Ped unit, the Plains lava flow unit (Plf) and the smooth plains terrain unit (Pst). C. Type section of the contact between the older Ped unit and the younger Plf unit. This picture is within the Ped unit where the darker Plf unit can be seen filling in areas of depression in the Ped unit. The arrows point to specific craters surrounded by Ped that have later been filled in with Plf. D. Type section of the contact between the older Ped unit and the younger Pst unit. Here the Pst unit is noted to embay the Ped unit and the Pst unit has completely filled in an area of depression within the Ped unit. E. Type section of the contact between the older Ped unit and the younger dark, rough terrain unit (Pdr). The Pdr unit is also seen filling is depressed areas of the Ped unit. The arrows coming from 1 show specific river channels incising the Ped unit that have been filled in with the Pdr unit. F. Type section of the contact between the older Ped unit and the younger stream deposit unit (Psd). The Psd unit is seen filling in a depressed basin of the Ped unit. The river channel feeding the Psd unit travels west out of the type section.
Following the the electris deposits unit in order of age is the plains lava flow unit. This unit is predominately observed in the north-west section of the mapping region. It comes into contact with the electris deposit unit and the smooth plains terrain unit (Figure 25a). As mentioned above, the lava flow is younger than the electris deposit unit (Figure 24c). In relation to the smooth plains terrain, the lava flow is older. This is determined by the smooth plains terrain embaying the lava flow unit and filling in areas of depression in the lava flow such as the impact craters (Figure 25b).

One of the youngest units in the plains section of the mapping region is the dark, rough terrain unit. This unit is the dominant unit in the southern region of the mapping area. Of the units it contacts, the dark rough terrain is younger than the mountainous terrain, the high channel density terrain, the low channel density terrain, and the electris deposit units. The determination of the younger age of the dark, rough terrain is explained above and is depicted in Figures 16d, 22b, 23, and 24e. The dark, rough terrain unit is older than the rest of the units it contacts, which includes the
smooth plains terrain and the stream deposit units. The dark, rough terrain unit is older than the smooth plains terrain unit because the smooth plains terrain completely encompasses and embays the dark, rough terrain in some areas, and it is seen flowing on top of the dark, rough terrain unit (Figure 26a, b). The smooth plains terrain can also be seen filling in areas of depression in the dark, rough terrain unit (Figure 26b). The dark, rough terrain unit is older than the last unit it contacts which is the stream deposit unit. This unit can be seen overlapping and pooling on top of the dark, rough terrain (Figure 26c).

**Figure 26:** A. Type section of the contact between the older dark, rough terrain unit (Pdr) and the younger smooth plains terrain unit (Pst). The Pdr unit is embayed, encompassed, and overlapped by the Pst unit. The arrows extending from 1 point to specific areas where the Pst unit fill in a depression and overlap the Pdr unit. B. Inset of image A. The arrow from 1 shows an impact crater depression in the Pdr unit filled in by the Pst unit. The arrow extending from 2 is an example of where the Pst unit overlaps the Pdr Unit. C. Type section of the contact between the older Pdr unit and younger stream deposit unit (Psd). The Psd unit is seen flowing onto the Pdr unit.
Following the dark, rough terrain in age, is the younger smooth plains terrain unit. This unit comes into contact with the mountainous terrain, the electris deposit, the plains lava flow, the dark, rough terrain, and the stream deposit units. Of the contacted units, the smooth plains terrain is younger than the mountainous terrain, the electris deposit, the plains lava flow, and the dark, rough terrain units. The determination of these age relationships has been discussed previously and is depicted in Figures 16a, 24d, 25b, and 26a. In regards to the stream deposit unit, the smooth plains terrain unit is older. The stream deposit unit can be seen flowing and pooling on top of the smooth plains terrain making the smooth plains terrain older than the stream deposit unit (Figure 26c).

The youngest unit present in the plains of the mapping region is the stream deposit unit. This unit comes into contact with the electris deposit, the dark, rough terrain, and the smooth plains terrain units. These age relationships have been discussed above and can be viewed in Figures 24f and 26c.
IV. Discussion

The units observed and described in the mapping region of Mars differ in time of formation, morphological features, and mechanisms of formation and alteration. These differences can be attributed to the continually changing Martian surface and atmosphere, which gave rise to different depositional environments and varying external forces that produced the units in existence today. All of the present units have unique features, which allow a geologic history of the mapping region to be constructed. This timeline is created from the current morphological features displayed on the varying unit surfaces. The main forces responsible for the modification and sediment redistribution of the units subsequent to their initial depositional event are volcanic, tectonic, eolian, fluvial, and lacustrine processes. Creating a geologic map of the crater region, with distinct unit contacts and their relationship to the structural features in the area, provided the tools to construct a geologic history of the area.

4.1 Relative Unit Dating Based on Crater Region Stratigraphy

Relative unit ages were determined by studying the stratigraphic relationships between the units in the mapping area. Based on other mapping studies conducted on the region surrounding the crater, the mapping area consists of units from the Noachian, Hesperian and extending into the early Amazonian Period. (Scott and Tonaka, 1986, Tanka et al., 2014, Greeley and Guest, 1987). Geologic ages of the units determined in this study are noted to correspond with the ages established in the previous investigations. The fossae complex traveling in an east, west trajectory
across the mapping region provided the most reliable age reference. These fossae and accompanying smaller grabens are part of the Sirenum Fossae graben network. Other studies have ascertained the age of this structural feature to have occurred around the Late Noachian to the Early Hisperian periods (Anderson et al., 2001). The Sirenum Fossae complex was mapped as crosscutting all crater and plains units except for the crater valley fill unit, the rocky crater terrain unit, and the plains stream deposit unit. This suggests that all units crosscut by the Sirenum Fossae graben complex are older than the Late Noachian or Early Hesperian time periods. Those units that are not disturbed by the grabens are younger than the Late Noachian to Early Hesperian periods. A discussion of the studied crater region’s history follows.

4.2 Geologic History of the Crater Mapping Region

4.2.1 Relative Ages of the Plains Units

The most dominant feature present in the entire mapped region is the large, main crater. The impact event that formed this crater occurred sometime before the Late Noachian to Early Hesperian period, which created the oldest identifiable structural feature present in the area. At the time of impact, the Martian surface was violently redistributed into a large crater ejecta blanket. This redistribution of the Martian surface created the oldest unit of the area, the mountainous terrain unit. Overlying the mountainous terrain unit are the high channel density and low channel density units. They were formed after the mountainous terrain unit. These units have been interpreted as heavily altered sedimentary units. Because of the numerous channel incisions found traversing the mountainous terrain and their subsequent

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catchment basins, these sedimentary units suggest that there was a period of precipitation following the crater impact. The study by Irwin et al. (2005) suggests that there was a time during the Noachian period where substantial erosion from fluvial degradation occurred. The idea of an early wet Mars with abundant fluvial degradation is also supported by the findings of Craddock and Howard (2002). The primary mechanism perpetuating the fluvial degradation is episodic, localized precipitation (Irwin et al., 2005). The runoff from the fluvial degradation of the high channel density sedimentary unit collected in catchment basins subsequently creating the low channel density unit which is also interpreted as a sedimentary deposit.

Following the deposition of the highly morphologically altered sedimentary units, the electris deposit unit was formed in the northern region of the mapping area. This was chronologically the next depositional event. The electris deposits are interpreted and labeled in accordance with the study by Grant et al., (2010) which investigated electris deposits in the Sirenum Fossae region. His morphological interpretation of the electris deposits in this region are consistent with the observations of this study discussed above in the unit descriptions. Irwin classifies electris deposits into four categories. Types 1-3 are distinguishable by their morphology and gradually range from mantled to unmantled and frequently have mesas that are flat on top with sharp, steep edges (Grant et al., 2010). The fourth morphological type of the electris deposits consists of a unique complex of buttes and mesas that create a morphology resembling chaotic material (Grant et al., 2010). In this study, types 1-3 were mapped as the electris deposit unit (Figure 9 a-c) and type 4 was labeled as chaotic material (Figure 15b). Consistent with Figure 9c, extensive
areas of the electris can be found covered by eolian deposited mantle debris (Grant et al, 2010). The electris deposit unit in this study’s mapping area was labeled such because of the similarities to the findings in the study by Grant et al. (2010). The electris deposits are believed to be most likely eolian deposited volcanic ash or tuffs (Grant et al, 2010, Grant and Schultz, 1990 and Schultz, 2002).

Post-dating the electris depositional events was the formation of the dark, rough terrain unit and the plains lava flow unit. The relative age relationship between the dark, rough terrain unit and the plains lava flow unit cannot be obtained through the stratigraphic construction of the mapped area. Based on the appearance and morphology of these two units; however, they are both interpreted as lava flows. These units were interpreted and identified as such based on the findings of Tanaka et al, (2014) and Greeley and Guest (1987). The presence of these lava flow type units as well as the volcanic electis deposits suggests that heavy volcanism occurred during this time of deposition.

The last plains unit deposited before the Late Noachian – Early Hesperian Sirenum Fossae complex was formed was the smooth plains terrain unit. This unit has been interpreted as mantle debris according to the conclusions of Tanaka and Scott (1986, 1987). Recognizing these findings that the smooth plains terrain unit consists of mantle debris suggests that eolian processes may have been the main depositional driver that resulted in the creation of this unit. Today, dust deposits are active at the polar regions. These polar regions can act as a template to study possible remnant eolian dust deposits scattered across the surface that formed in Mars’ past (Tanaka 1999). These deposits are preserved by induration resulting in soil formation. Past
changes in Mars’ orbit caused these eolian units to undergo a cyclical change of deposition, bonding and erosion, followed by redeposition. This repetitive cycle can cause these deposits to be moved and preserved (Tanaka, 1999).

Following the extensional tectonic event that created the Sirenum Fossae complex, dating around the Noachian-Hesperian boundary (Anderson et al, 2001), the stream deposit unit was formed. The relationship of the stream deposits superimposed upon the Sirenum Fossae complex suggests that the stream deposits are from a time period that is later than the Noachian-Hesperian boundary era. The interpretation of this unit is synonymous with its name and is a result of fluvial processes. These deposits and accompanying river channels are a morphological feature of the electriss deposit unit, the dark, rough terrain unit, and the smooth plains terrain unit. As stated before, the stream channels that terminate at the pooled stream deposit seem to have no specific place of origin. This suggests that during this depositional time period, the release of groundwater, possibly from subsurface ice melting, was likely the main cause of the fluvial process (Andrews-Hanna and Phillips, 2007).

Another structural feature observed in the mapping region, which can help identify what forces were present during the formation of various units is wrinkle ridges. These ridges appear in the electriss deposit unit, the plains lava flow unit, the dark, rough terrain unit, and the smooth plains terrain unit. Wrinkle ridges form as a result of compressional stresses from surrounding tectonism (Tanaka, 2014). This suggests that compressional tectonism was either present throughout the separate formation of each of these four units, or that compressional tectonism occurred during
the deposition of the overlying smooth plains terrain, the youngest of the wrinkle
ridge units.

4.2.2 Relative Ages of the Crater Units

As mentioned above, the Sirenum Fossae complex is observed crosscutting all
crater and plains units except for the valley fill unit, the rocky crater terrain unit, and
the plains stream deposit unit. As far as the crater units are concerned these fossae
specifically traverse the mountainous terrain unit, the bright crater deposit unit, the
light crater terrain unit, and the chaotic terrain structural unit. The units mapped
within the large craters of the mapping area cannot be dated relative to the plains
units because they cannot be compared in a stratigraphic context. As discussed above
the mountainous terrain unit, which makes up a portion of the crater walls is also the
oldest unit of the crater units. The next oldest units in the crater are the bright crater
deposit unit and the crater lava flow unit although their chronological age is not
distinguishable. Consistent with the unit description of the bright crater deposit unit,
they were both interpreted as an evaporate deposit (3.1.2.1). The main reasoning for
this interpretation was the presence of polygonal fracturing noted among the bright
crater deposit outcrops (Figure 2b). These polygonal fractures represent desiccation
features that occur at the onset of drying of previously water-saturated sediments (El-
Maarry et al., 2014 and Wray et al., 2011). Because polygonal fractures are present in
both large craters this suggests there was once water-saturated sediments deposited in
each crater that eventually evaporated. There was very likely either one paleolake that
encompassed both craters or each crater facilitated the formation of a paleolake (El-
Maarry et al., 2014). Present in the southern crater of the mapping region, is a deltaic structure (Figure 27). This fluvial structure supports the hypothesis that the standing water of the period was isolated to the crater alone meaning a paleolake was formed within each crater. If the area, which includes both large craters, was completely incorporated as part of a single larger paleolake, it is unlikely that this deltaic structure would have been able to form in the southern crater. These paleolakes were most likely created by the seepage of groundwater in to the crater from the Tharsis rise (El-Maarry et al., 2014).

The crater lava flow unit, found on the floor of the large main crater, is younger relative to the mountainous terrain unit but whose age cannot be stratigraphically distinguished from the bright crater terrain unit. This unit was named

Figure 27: Deltaic fan structural feature located in the southern, large crater. The presence of this structural feature provides evidence to support the hypothesis that there was once a paleolake local to this crater.
and identified as a lava flow because of its lobate edges, dark tone, and rough texture. These observations are consistent with the findings of Scott and Tanaka (1986). This unit is indicative of more volcanic activity within the region of the main crater however, an origin of this flow cannot be determined.

Next in chronological age as determined by stratigraphic context is the light crater terrain unit. As discussed in the results section, this unit covers the majority of the two large crater floors in the region (3.1.2.2). Because of its vast, homogenous cover, this unit was either interpreted as a fluvial sedimentary unit, an eolian unit, or a lava flow (Scott and Tanaka, 1986). Each of these interpretations has greatly varying outcomes in terms of the geologic history of the area. This unit could have either been the result of another standing water event, mass transportation of erosional sediment, or another volcanic event, which occurred prior to the formation of the deposits that created the crater lava flow unit. An accurate determination of the events responsible for the formation of this unit is not possible at this time.

Following the light crater terrain unit in relative age is the structural chaotic terrain unit. This unit is interpreted as chaotic terrain because of its irregular complex of plateaus and valleys. There are two popular explanations for the formation of the chaos structures; large outflow events resulting from water trapped underneath the surface, or the melting of ice in the crustal pore space. Based on the study conducted by Zegers et al. (2010) formation of the chaotic terrain structural unit in the crater is consistent with the second formation process. This suggests a geologic history of a climate warm enough to melt subsurface ice or mantle inclusions due to tectonism that could possibly melt the subsurface ice (Zerger et al., 2010).
The first crater unit to not be crosscut by the Sirenum Fossae complex is the rocky crater terrain unit. This relationship of the rocky crater unit superimposed over the Sirenum Fossae complex provides this unit an age younger than the Noachian-Hesperian boundary. This blocky, rough terrain is interpreted as mass wasting deposits. These deposits formed from eroded debris and were moved by geliflction and ice creep (Tanaka and Scott, 1987).

The valley fill unit that is noted to embay the rocky crater terrain is the next youngest unit in the crater. This unit has been interpreted as a fluvial deposit or an ice sublimation deposit. Given that this unit is stratigraphically between the rocky crater unit and the gully deposit unit, whose depositional processes are ice driven, the valley fill unit is more likely a product of ice sublimation than a fluvial process. In the study conducted by Head et al. (2003) they observed relatively young units at latitudes higher than 30º that have a similar mottled texture to the valley fill unit occurring at latitude of 38ºS. They interpreted this unit as being caused by ice sublimation occurring over multiple glaciation cycles due to obliquity (Head et al. 2003). This interpretation suggests a continuation of a cold climate during the deposition of the valley fill unit.

Finally, the gully deposit unit is the youngest crater unit. The incised river channels and alluvial fans found in this unit are formed by fluvial processes. The glacial tongues present in some gully deposits are created by standing glaciers extending from the mountainous terrain. These deposits suggest a colder climate allowing for surface ice formation with possible, occasional aqueous precipitation events. The majority of the units in the Mars mapping region are old deposits.
occurring before the Noachian-Hesperian boundary with only a few units being deposited after this time period.

4.2.3 Synthesis of the Geologic History

By comparing the morphologies of the units observed in the mapped crater region with Martian literature, possible interpretations and depositional processes were inferred. This information derived from this study enabled the creation of the geologic history of the mapped crater region. Using the Sirenum Fossae complex as a reference point, formed near the Late Noachian to Early Hesperian boundary, combined with the stratigraphy of the area allowed for the deduction of relative geologic ages of the units. Most of the units in the mapping area have a relatively older age than the Noachian-Hesperian boundary. Incorporating the processes of the numerous depositional events tells the geologic history of the area.

Referencing the impact of the large main crater which resulted in the formation of the mountainous terrain unit as a starting point, the Martian climate progressed to a warmer, wet climate. The warmer climate produced high amounts of precipitation creating the high channel density terrain unit and the low channel density terrain unit, and their fluvial morphologies (Irwin et al., 2005). There was subsequently a decrease in the presence of channels in younger units suggesting a drier Martian climate. After this time, the area was affected by heavy volcanic activity, which favored an environment that allowed the formation of units occurring in the plains and craters that have been interpreted as lava flows. The smooth plains terrain, eolian unit also
suggests that the Martian climate had become very dry and cooled following the earlier warm and wet climate (Tanaka, 1999).

A major feature of the region’s history was the existence of two paleolakes. The sites of these lakes were within the two large craters. The presence of a deltaic fan in the southern crater (Figure 27) and the bright crater deposits in both craters that are evaporites exhibiting polygonal fracturing are evidence of the pre-existing paleolakes. These lakes, like others in the area, were most likely formed from the seepage of ground water due to the rise of the Tharsis complex (El-Maarry et al., 2014). Since these lakes were probably fed by groundwater and not atmospheric precipitation, this suggests the Martian climate during this time was relatively dry compared to the climate present previously during the formation of the high channel density unit and low channel density unit. The presence of polygonally fractured evaporite deposits in both craters suggests that the climate remained dry or became progressively drier over time.

The units forming after the Sirenum Fossae crosscut the mapping region all suggest they were created in a dry, cold Martian climate. The rocky crater terrain unit, valley fill unit, gully deposit unit, and stream deposit unit represent transitional units that were formed during a climate that was cold enough to have standing surface ice and glaciers, but that also exhibited periods with temperatures warm enough for ice sublimation and melting. These warmer periods did not resemble the warm, wet older period. This climate cycle was irregular and depended on the obliquity of the planet (Head et al., 2003).
V. Conclusion

This study of a crater region in the Eridania basin of Mars resulted in a geologic map illustrating the geologic units present in the area and their contacts. An important result of this study was the detailed descriptions of these mapped units along with the morphological features unique to each unit. Due to the relatively small range of the mapping area, this study was able to have a more detailed focus on the units present when compared to larger studies of the Eridania basin or other areas of the Martian surface. The description and interpretation of the units provided the means to compare them to the results from previously conducted studies. This comparison of data supports a stronger hypothesis concerning the forces responsible for creating the morphologies. It is hypothesized that the processes of morphological change within the region varied from volcanic and tectonically driven, to eolian and fluvial morphologies, and lastly to features created from ice formation and sublimation. Understanding these processes provide the platform for the synthesis of the geologic history of the region.

A stratigraphic column was also created to establish the relative age of the area and the units therein. Interpretation of the described units facilitated a comparison to units discussed in previous studies and helped to understand the processes that shaped the units. Understanding the depositional forces responsible for the creation of the regional units was integral in constructing the region’s geologic history and accompanying climate changes. Using the Sirenum Fossae as an accurate date marker, the majority of the crater region units were older than the Late Noachian.
to Early Hesperian boundary suggesting that the most geologically active time periods of the crater region were prior to the formation of the Sirenum Fossae.

The end goal of this project was to construct a relative geological history of the units present in the mapped region. Historical climate changes of the mapped crater region were documented based on the changing processes and the environments required for the formation of the unique morphologies of the units. The crater region’s early history was defined by a warmer, wetter climate producing ample amounts of atmospheric precipitation and creating many of the old river channels present in the area. As time progressed, the climate began to cool and became drier. Eventually, the climate was cold enough to have standing ice in the form of glaciers in the youngest unit of the region. Throughout the region’s history, many volcanic events made their mark upon its surface. Perhaps one of the most intriguing features of the area’s history is the presence of two paleolakes located in each of the large craters. Features and depositional units consistent with standing water in both craters provided the evidence for the existence of a paleolake at one time. As the climate continued to cool and dry, the lakes evaporated and the Martian climate moved into an ice dominated era. Tectonic activity was also present in the region evidenced by the east to west oriented Sirenum Fossae complex and the north to south oriented wrinkle ridges.

Further study of the region in an attempt to create definitive quantitative dates, instead of relative depositional dates of the units, will help to refine the geologic history of the planet. Remote sensing of the polygonally fractured evaporate units could lead to a better understanding of the paleolake environment.
VI. References


VII. Appendices

Legend

Lines Type
Graben Old River Channel Wrinkle Ridge Young River Channel

Units
Chaotic Terrain (Cct), (Pct)
Crater Ejecta (Pce)
Stream Deposit (Psd)
Smooth Plains Terrain (Pst)
Dark, Rough Terrain (Pdr)
Electris Deposit (Ped)
Low Channel Density Terrain (Plcd)
High Channel Density Terrain (Phcd)
Gully Deposit (Cgd)
Valley Fill Deposit (Cvf)
Rocky Crater Terrain (Crt)
Light Crater Terrain (Clt)
Lava Flows (clf), (Plf)
Bright Crater Deposit (Cbd)
Mountainous Terrain (Pmt)

Appendix Image 1: The entire extent of the mapped crater region.
Appendix Image 2: Zoomed in image of the main, large crater found in the center of the mapping region.