SUMMER RESEARCH FELLOWSHIP REPORT

ON

IMPACT CRATERS ON VALLES MARINERIS AND THEIR EJECTA STRUCTURES

SUBMITTED BY:

Ms. HARSHITHA M.P

III YEAR B.Sc

The national degree college

Basavanagudi

Bangalore-04

WORK CARRIED OUT UNDER THE GUIDANCE OF

Dr. P. SENTHIL KUMAR

Senior Scientist,

Planetary Geosciences,

CSIR-NGRI, Hyderabad, India

JUNE-JULY 2016

DECLARATION

I, Harshitha M.P, student of III YEAR B.Sc, The National Degree College, Basavanagudi, Bangalore-04 have completed my Summer Research Fellowship work on the topic “Impact craters on valles marineris and their ejecta structures” under the guidance of Dr. P. Senthil Kumar, Senior Scientist, Planetary Geoscience, CSIR-National Geophysical Research Institute, Hyderabad.

Place: Hyderabad   Ms. Harshitha M.P

Date: 22 July, 2016

सी एस आई आर - राष्ट्रीय भूभौतिकीय अनुसंधान संस्थान
(वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद्)
पो.ब.सं. 724 उप्पल रोड, हैदराबाद - 500 007, आँ.प्र. भारत
CSIR - NATIONAL GEOPHYSICAL RESEARCH INSTITUTE
(Council of Scientific & Industrial Research)
Post Bag # 724, Uppal Road, Hyderabad - 500 007, A.P., INDIA

Dr. P. Senthil Kumar

Senior Scientist

Planetary Geosciences

22 July, 2016

CERTIFICATE

This is to certify that, Ms. Harshitha M.P, student of The National Degree College, Basavanagudi, Banglore - 04 has been successfully completed her summer research fellowship work during the period of 30 May, 2016 to 24 July, 2016 under my guidance on the project entitled "Impact craters on Valles Marineris and their ejecta structures".

Dr. P. Senthil Kumar

Dr. P. Senthil Kumar
Senior Scientist
National Geophysical Research Institute
Council of Scientific and Industrial Research
Uppal Road, Hyderabad-500 606. India

ABSTRACT

Impact Craters on Mars are not much different than the impact craters found on other solid surfaces. However, most impact craters on Mars are rampart (craters having a fluidized ejecta blanket) which indicates the presence of water on the Mars surface. And hence, determining the aspects of such craters and their ejecta structures which is the main aim of my project helps us to understand the evolution of the planet. The fluidized ejecta blankets of Martian craters appear to have been emplaced as thin ground-hugging flows. This peculiar form of Martian ejecta blankets is generally attributed to the presence of liquid water or ice in the substrate.

ArcMap 10.4.1 of the ArcGIS software is used to map the terrain features accurately. The different parts of a crater, its floor, wall, ejecta blanket and in case of complex crater, its central and central pit all can be distinctly mapped. The basemaps that are being used are CTX, THEMIS and HSRC_DTM(central Valles Marineris).

ACKNOWLEDGEMENT

I am greatly indebted to the following personnel for the role they played in making this report and my summer research fellowship period at National Geophysical Research Institute, Hyderabad during May 30 - July 24, 2016.

I am grateful to my guide Dr. P. Senthil Kumar, Senior Scientist, Planetary Geosciences, CSIR- National Geophysical Research Institute, Hyderabad, for his exemplary guidance, monitoring and constant encouragement and for providing me invaluable time and information which added value and quality to the project.

I also express my sincere gratitude to Indian Science Academy for selecting me for this prestigious summer research fellowship. I thank the Director, CSIR-National Geophysical Research Institute, Hyderabad for granting the approval to carry out Summer Research Fellowship work at CSIR-NGRI. I express my sincere gratitude to Dr. Ajay Mangalik, Chairman, SAC, CSIR - NGRI for his kind permission to be inducted at NGRI and all valuable administrative support. I sincerely thank Mr.N.Krishna, Ms.U.Sruthi and Mr. Aravind Bharathvaj S, Project Assistants in the Planetary Geosciences Division for their kind and sincere support and help during the entire project.

I express my thanks to Dr. Y.C.Kamala, department of physics, the national degree college, Bangalore-04 and the entire physics department of the national degree college for the moral and constant support. And last but not the least, I would thank my parents for the constant support they provide me to explore and experience new aspects. Also, I would like to thank the Indian Academy of Sciences, Bangalore for the providing the opportunity under the summer training programme.

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INTRODUCTION

Mars being the fourth planet from the sun in our solar system is also called as “Ares”, the Greek mythical god of war because of its association to the colour red with blood. This unusual red colour is attributed to relatively large quantities of rust, Fe_2O_3. Mars is almost 1.5237 AU (1AU= 1.4960×10^{08} Km) away from the sun and has only about one-tenth of that of Earth’s mass and 37.6% of Earth’s gravitational force. Mars has a fairly eccentric orbit and its day is almost the same as Earth-24 hours and 40 minutes. Its equator tilts 25.2 degrees with respect to its orbital plane and this tilt causes opposite seasons in the planet’s two hemispheres.

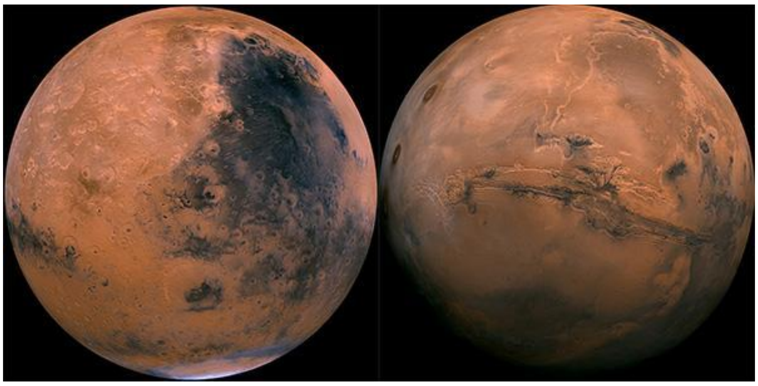


Figure 01.Image of Mars

The global appearance of Mars reveals long straight linear features that were referred to as ‘canals’ or ‘channels’ and also the seasonal polar caps and other surface features such as impact craters, dunes and volcanoes. A geological division between the northern and southern hemispheres is referred to as the crustal dichotomy, characterized by complex geology and prominent scraps. This crustal dichotomy is a striking asymmetry between the two hemispheres. One half of the planet, mostly in the southern hemisphere, is heavily cratered and elevated 1-4 Km above the nominal surface level, the Martian geoid, at a mean equatorial radius of 3396.0+/-0.3 km. The other hemisphere is relatively smooth and lies at or below this level. Mars’s appearance is characterized by four giant shield volcanoes in the Tharsis region, including Olympus Mons (largest volcano in our solar system) and a massive canyon system, Valles Marineris. The reason behind this is the relatively low surface gravity and cold, thick lithosphere enabling the existence of such high mountains. The interior of the planet is considered to have a liquid core with a radius between 1520 and 1840 km, due to the lack of internal magnetic field and its low density. Mars climate is one of extreme changes. Its thin atmosphere is the main reason for its extreme difference in temperature. Mars atmosphere is 95% carbon dioxide, but the low atmospheric pressure at its surface gives not much to moderate the temperature.

Mars has two moons orbiting it, Phobos ("fear" in greek) and Deimos("terror"). They orbit Mars in nearly circular orbits close to the planet's equatorial plane. Both satellites are in synchronous rotation. Phobos being close to Mars, is heavily cratered, close to saturation. And Deimos's surface is rather smooth. These moons are considered to be captured asteroids, given its small size and irregular shape.

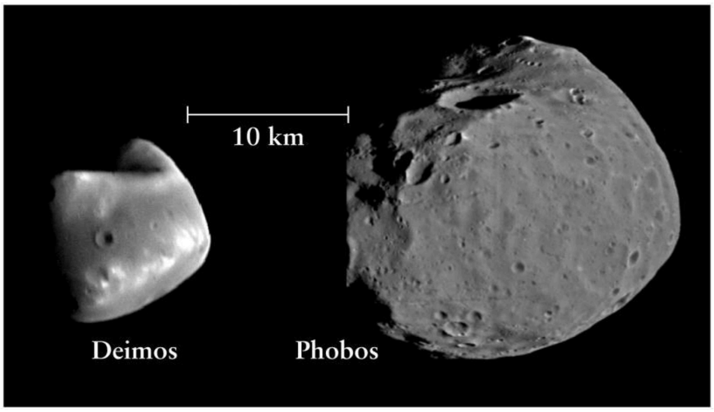


Figure 02: Moons of Mars

MARS ATMOSPHERE

As mentioned earlier, Mars has very extreme changes in its atmosphere. The primary atmospheric constituent is CO_2 (~95%) with ~3% N_2 gas. The mean temperature is ~215 K (-58.15°C) , and the average surface pressure on Mars is 6 mbar. The low surface pressure on Mars is below the saturated vapour pressure curve for liquid water, so water is either present as ice or water vapour. The small amount of water vapour in the Martian air forms water-ice clouds at altitudes of ~10 km above the equatorial regions. Mars has substantial condensation flows, where CO_2 freezes out over the winter pole and sublimates above the summer pole. Because Mars' atmosphere is tenous, it responds rapidly to the solar heating, leading to large latitudinal, diurnal and seasonal variations in surface emperature. The temperature is as low as ~130 K at the winter pole and peaks at ~300 K at the subsolar point during the day.

The Martian atmosphere is said to start dissipate to its current thin sate toward the end of Noachian period. Three factors likely contributed to the to the loss of the Martian atmosphere: Jean's escape, solar wind erosion and impact erosion. Also, the magnetometer experiment on Mars global surveyor revealed that Mars does not have an active magnetic field at the present time, but Noachian-aged rocks in some areas of the planet retain a remnant magnetization, indicating a paleomagnetic field. Planetary magnetic fields repel charged particles from the solar wind, and the loss of this protective magnetic field results in striping of a planetary atmosphere by the impact of energetic solar wind particles.

GEOLOGICAL TIME SCALE ON MARS

A stratigraphic principle used to calculate the age on planets where impact craters are well preserved is that of crater number density. The number of craters greater than a given size per unit surface area (usually million km^2) provides a relative age for that surface. Heavily cratered surfaces are old, and sparsely cratered surfaces are young. Old surfaces have a lot of big craters, and young surfaces have mostly small craters or none at all.

Studies of impact crater densities on the Martian surface have delineated three broad periods in the planet's geologic history. The periods were named after places on Mars that have large-scale surface features, such as large craters or widespread lava flows,that date back to these time periods. The absolute ages given here are only approximate. From oldest to youngest, the time periods are:

- **Pre-Noachian** Represents the interval from the accretion and differentiation of the planet about 4.5 billion years ago (Gya) to the formation of the Hellas impact basin, between 4.1 and 3.8 Gya] Most of the geologic record of this interval has been erased by subsequent erosion and high impact rates. The crustal dichotomy is thought to have formed during this time, along with the Argyre and Isidis basins.
- **Noachian Period** (named after Noachis Terra): Formation of the oldest extant surfaces of Mars between 4.1 and about 3.7 billion years ago (Gya). Noachian-aged surfaces are scarred by many large impact craters. The Tharsis bulge is thought to have formed during the Noachian, along with extensive erosion by liquid water producing river valley networks. Large lakes or oceans may have been present.
- **Hesperian Period** (named after Hesperia Planum): 3.7 to approximately 3.0 Gya. Marked by the formation of extensive lava plains. The formation of Olympus Mons probably began during this period. Catastrophic releases of water carved extensive outflow channels around Chryse Planitia and elsewhere. Ephemeral lakes or seas formed in the northern lowlands.

- **Amazonian Period** (named after Amazonis Planitia): 3.0 Gya to present. Amazonian regions have few meteorite impact craters but are otherwise quite varied. Lava flows, glacial/periglacial activity, and minor releases of liquid water continued during this period.

WATER ON MARS

Under the current climatic conditions, liquid water cannot exist on Mars. The low surface pressure on Mars, ~6 mbar, is below the saturated vapour pressure curve for liquid water, so water is present as a vapour or as ice. The total amount of water vapour present in the atmosphere of Mars would barely fill a small pond and the water volume in the ice on the north polar cap is about 4% of the Earth's south polar ice sheet. Due to the thin atmosphere on Mars, rainfall is not possible.

The *Viking* orbiting modules and *Mariner 9* found evidence to support the hypothesis that running water was once common on Mars. The observed polygon structures on Mars, are typical of ice-wedge polygons on Earth that form via seasonal melting and freezing of water in and on the surface. The channels, gullies, and layers of sedimentary rock discovered on Mars clearly suggest that the planet was very different 3.5 billion years ago. Liquid water seems to have played an important role in shaping the planet's surface along other features such as volcanoes, tectonic shifts, ice and strong winds.

1. IMPACT CRATERS

Most of the impact craters on Mars has an ejecta blanket that looks like they have 'flowed' to their current positions rather than traveled through space along ballistic trajectories. This suggests that the surface was fluidized by the impacts. Craters with fluidized eject blankets are referred to as rampart craters. Hence, Mars must have significant fraction of water-ice in its crust or at least have had subsurface ice during early bombardment era. *Mars Global Surveyor* (MGS) images revealed evidence of seepage at the edge of some crater walls and of 'ponding', the accumulation of water in ponds on some crater floors.

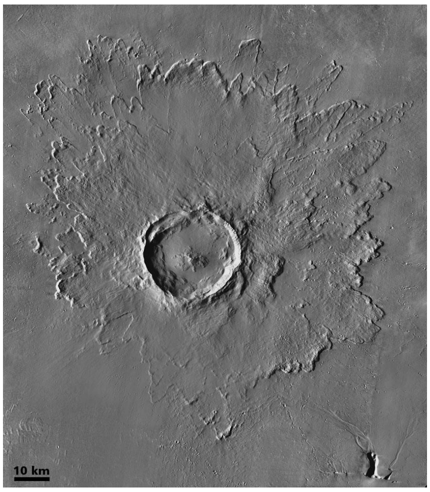


Figure03.rampart Martian crater

2. VALLEYS AND CHANNELS

The oldest Martian terrain contains numerous fluvial features, similar in appearance to dendritic river systems on Earth. Along with such dendritic river systems, there are also immense channel systems or outflow channels, starting in the highlands and draining into the low northern plains. The presence of teardrop-shaped 'islands' in the outflow channels suggests that vast flows of water have flooded the plains.

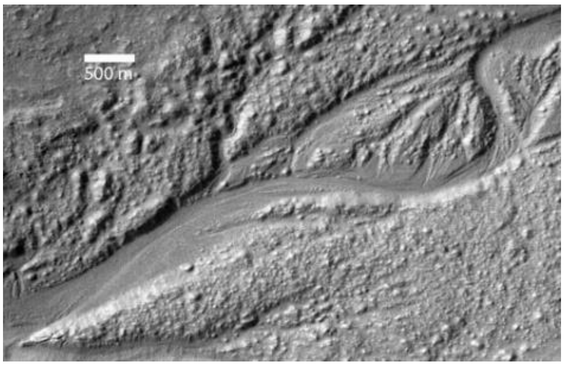


Figure 04.A channel on Mars

3. GULLIES

A gully is a landform created by running water, eroding sharply into soil, typically on a hillside. Gullies resemble large ditches or small valleys, but are meters to tens of meters in depth and width. When the gully formation is in process, the water flow rate can be substantial, causing a significant deep cutting action into soil. .The formation of such gullies likely involves a low-viscosity fluid, such as water, moving down hill. The intriguing observation is that most gullies are very young and there are no impact craters superposed on these features.

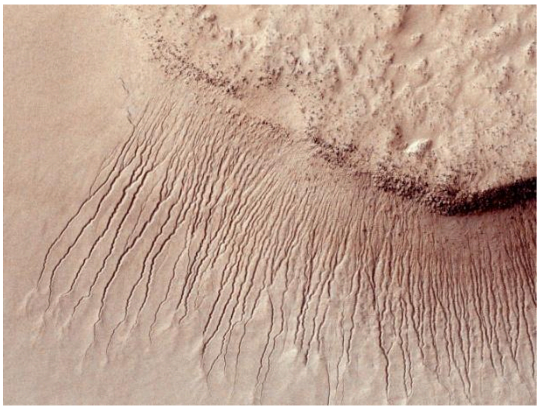


Figure05. Mars’ gullies

IMPACT CRATERS: INTRODUCTION

Collisions are frequent events within (and outside) our solar system, considering the geological timescales and the large sizes and distances between the celestial bodies. These collision speeds are typically hypersonic and cause violent impacts with ejecta thrown outwards from the location of the impact and by leaving long-lasting depressions on the surface. Impact craters are produced on every body in the solar system that has a solid surface.

An impact crater is an approximately circular depression in the surface of a planet, moon, or other solid body in the Solar System or elsewhere, formed by the hypervelocity impact of a smaller body with the surface. In contrast to volcanic craters, which result from explosion or internal collapse, impact craters typically have raised rims and floors that are lower in elevation than the surrounding terrain. Impact craters range from small, simple, bowl-shaped depressions to large, complex, multi-ringed impact basins. Meteor Crater is perhaps the best-known example of a small impact crater on Earth. Impact cratering involves the nearly instantaneous transfer of energy from the impactor to the target. If the target has a environment, as Earth, the impactor is seen as a fireball or bolide, before impact.

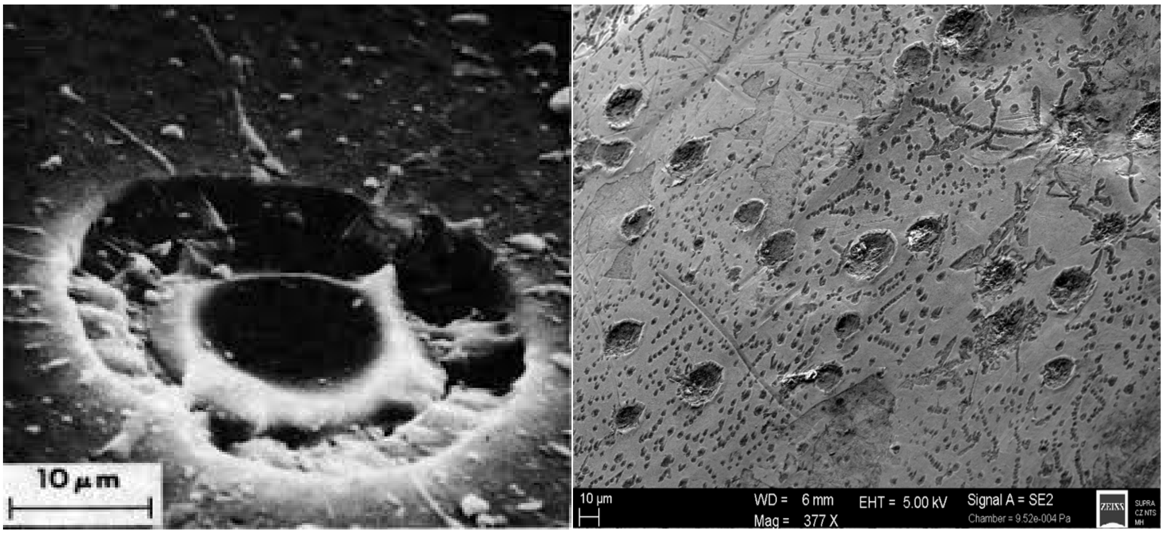
CRATER MORPHOLOGY

Impact craters are classified into a size-morphology sequence, although alll impact craters are described as ”circular rimmed depressions”, the details vary not only with the size, but also with substrate material, planet and age.

MICROCRATERS

Microcrtaers are often referred to as ‘pits’, their size ranges from 0.1 micrometres to sub-centimetres. These tiny craters are caused by impacts of micrometeorites or high velocity cosmic dust grains on airless bodies. Microcraters are central bowl shaped pits, often thickly lined with glass. A pit is frequently surrounded by a light halo of pervasively shattered rock materials.

Figure 06: Microcraters



SIMPLE CRATERS

Simple craters are typically up to several kilometres across, are bowl shaped with a bright ejecta deposit and a circular raised rim. The interior slope is steepest near rim and smoothly decreases toward the crater’s centre. Simple craters also known as small craters do not have a central flat floor. Crater’s interior is nearly parabolic (in some cases). The rim to floor depth in such craters is equal to one-fifth of the rim to rim diameter. Generally, the rim height above the surface will be equal to 4% of the crater’s diameter.

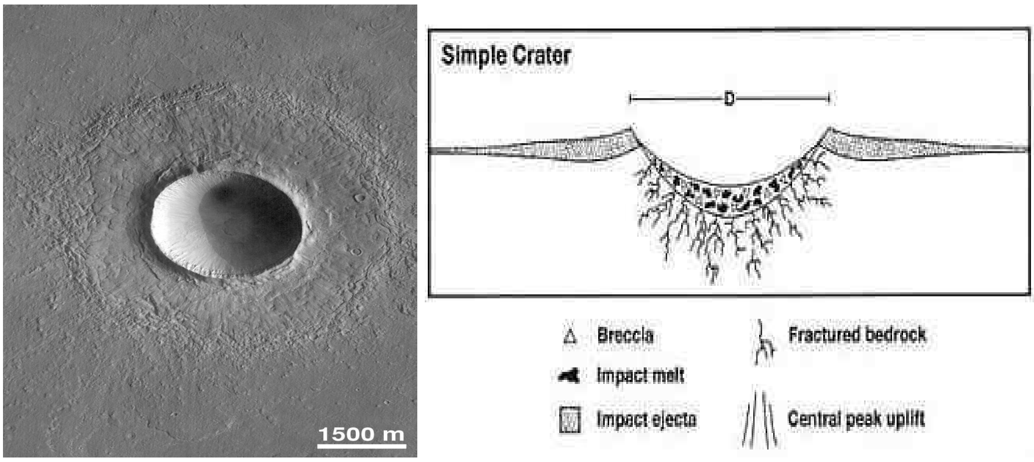


Figure 07: Simple crater

COMPLEX CRATERS

Complex craters usually have flat floor and a central peak and the inside of the ring is characterised by terraces. They have diameters of a few tens up to a few hundred kilometres. The minimum frequency size for a crater to acquire a complex morphology also depends on the strength of the target's surface material. The central peak is composed of rocks that originated below the floor and were uplifted during the impact. Sometimes, the central peak is replaced by an inner concentric ring of irregular peaks, forming a pit in the middle.

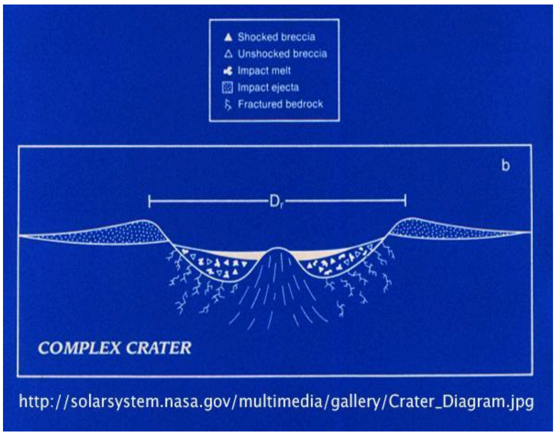


Figure 08: complex crater

MULTIRING CRATERS

Multiring basins are systems of concentric rings, which cover larger areas than the complex craters. The inner ring often consists of hills in a rough circle and the crater floor may be partly flooded by lava. Multiring basins are most common in lunar craters. The best example is the Orientale basin on the moon.

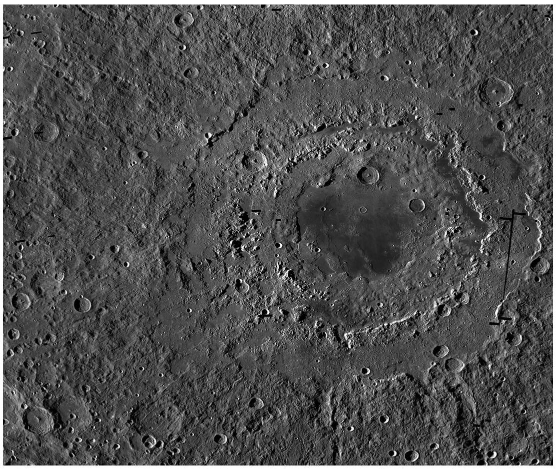


Figure 09: Lunar multiring crater, Orientale basin

ABERRANT CRATER TYPES

Most elliptical craters are due to highly oblique impact and they form ‘butterfly’ like structures. Layers of different strength in the target produce concentric craters, strong regional joint trends may result in square or polygonal craters and pre-existing topography may produce extra wide terraces in the walls of complex craters adjacent to topographic highs. Also, many Martian craters have peculiar fluidized ejecta blankets with petal like lobes and terminal ramparts.

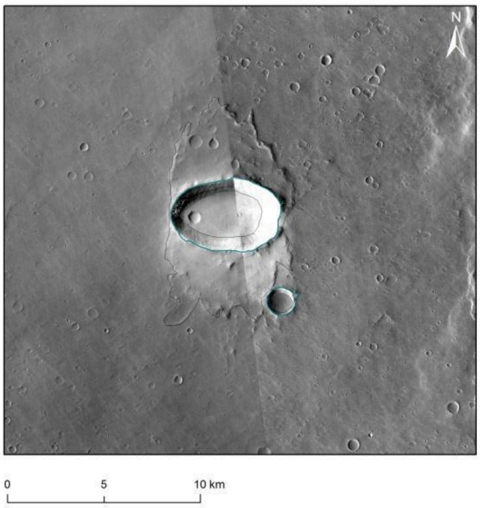


Figure 10: An elliptical (“butterfly”) crater

FORMATION OF CRATERS

The formation of a crater consists of a rapid sequence of phenomena, which starts when the impactor first hits the target and ends when the last debris around the crater has fallen down. This process is easily understood by identifying three stages: an impact begins with the ***contact and compression stage***, which is followed by an ***excavation stage*** and ends with a ***collapse and modification stage.*** This three stages was first proposed by Gault et al.(1968).

CONTACT AND COMPRESSION STAGE

The first stage of impact cratering begins when the projectile contacts the target surface. The swiftly moving projectile then pushes target material out of its path, compressing it and accelerating it to a larger fraction of the impact velocity. At the same time, the target's resistance to penetration decelerates the projectile. These velocity changes are mediated by shock waves: material in the contact zone between the projectile and target is strongly compressed, creating shock waves at the boundary between the compressed and uncompressed material. These shock waves originate at the point where the projectile first touches the target's surface. As the projectile, continues its plunge into the surface, the shock fronts spread and propagate into both projectile and target. Both materials may either melt or vaporize upon unloading from such pressures. Most of the projectile's initial kinetic energy is transferred to the target: the underlying rocks are compressed, heated, and accelerated to high speed.

The principal result of this stage is the transfer of most of the projectile's kinetic energy to the target. This stage ends after the projectile has unloaded from high pressure.

EXCAVATION STAGE

During this stage, a more or less hemispherical shock wave propagates into the target, weakening as it expands and engulfs more material. This shock wave and the following rarefaction set target material in motion, initiating a subsonic excavation flow that eventually opens the crater. The resulting crater's diameter is many times larger than the projectile that produced it. The ejecta curtain forms and begins to blanket the terrain adjacent to the final crater during this stage. The target's material strength and gravity become important near the end of excavation.

MODIFICATION STAGE

Excavation produces a bowl-shaped "transient crater" that generally collapses under gravity. During modification, loose debris slides down the steep interior walls of small craters, pooling on the floor of the final bowl-shaped depression. Large craters collapse more spectacularly: slump terraces form on the walls and central peaks rise in the interior.

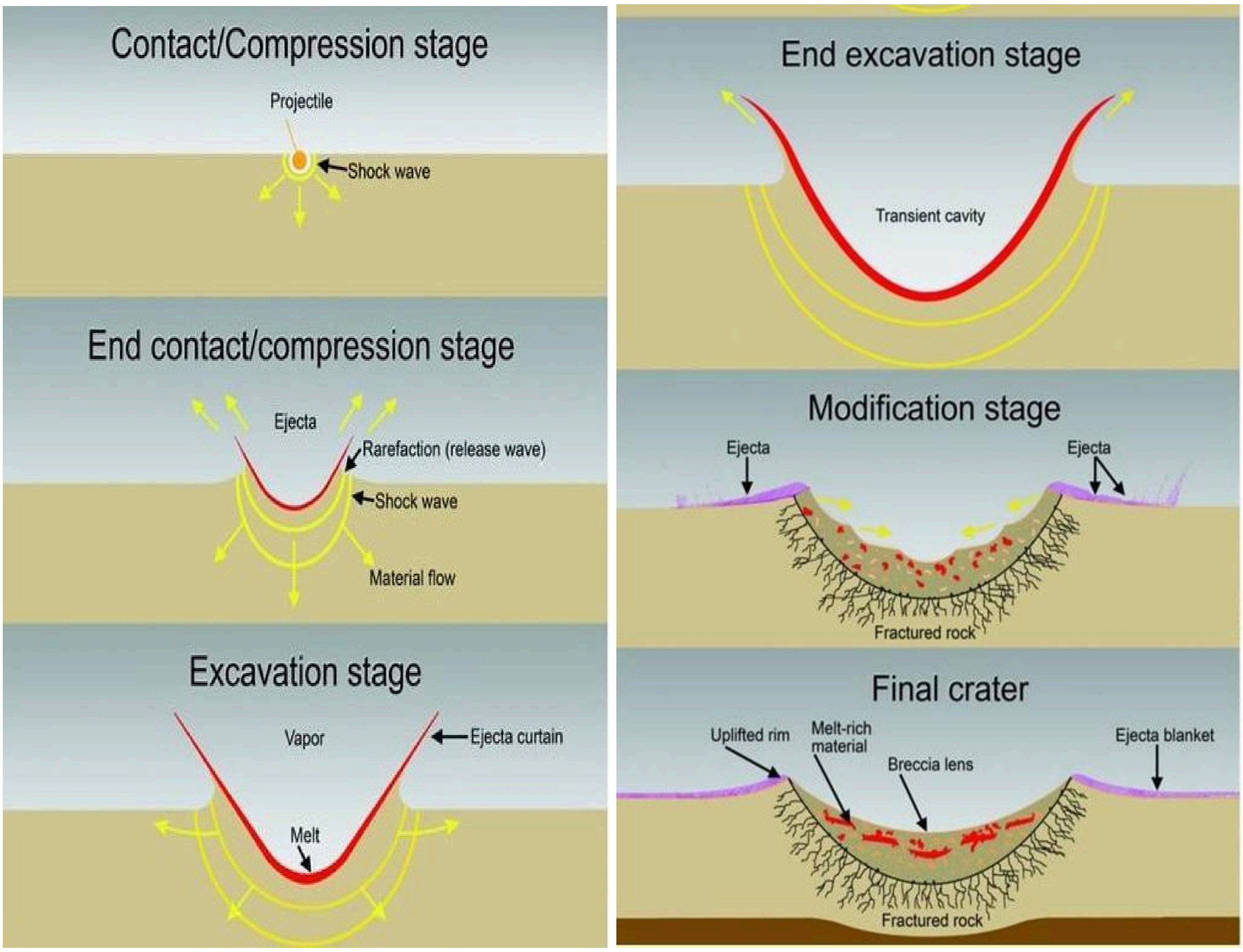
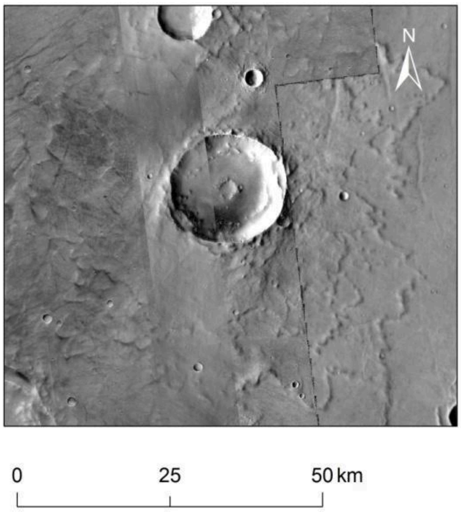


Figure 11. 3 stages of the formation of an impact crater

MARTIAN CRATERS

Impact craters are seen on most solid surfaces and Mars is no exception. However, Martian impact craters are different than the craters seen on moon and mercury. The thin atmosphere and low gravity and the presence of subsurface volatiles are all factors for the different features of Martian impact craters. The two major differences between the Moon and Mars that contributes to dissimilar morphologies are the presence of a thin atmosphere and the distribution of subsurface ice on Mars. Martian impact craters provide insights into formation ages of terrain units, near-surface properties, and the planet's degradational history.

Large, complex craters (≥7 km) display more complicated interior structures, including central rises (central peaks), central rings of peaks (peak rings), central depressions (central pits), and gravity induced wall collapse (wall terraces).



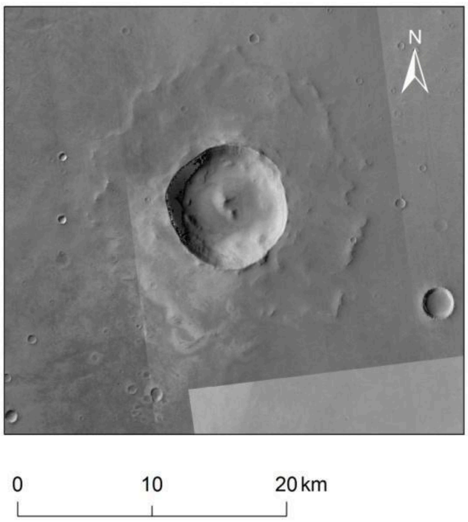


Figure11 Figure12

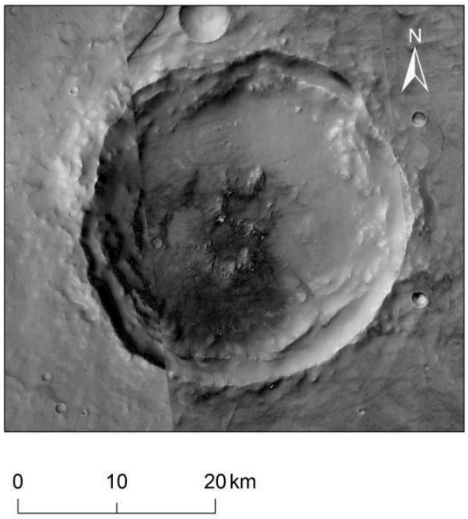


Figure13

Figure 11: NASA's MRO CTX image showing a Martian crater with a central pit

Figure 12: NASA's MRO CTX image showing a Martian crater with a central peak

Figure 13: NASA's MRO CTX image showing a Martian crater with terraced wall

Central pits are circular to elliptical depressions in the centre of many Martian impact craters, located directly on the crater floor ("floor pit") or atop a central rise or peak ("summit peak"). Central pits are also found in abundance in the impact craters on Jupiter's ice rich moons of Callisto and Ganymede. This results in a model for the formation of central pits, vaporization of subsurface volatiles and explosive release of the resulting gases during crater formation.

MARTIAN IMPACT CRATER'S EJECTA STRUCTURES

Martian craters have peculiar fluidized ejecta blankets with petal like lobes and terminal ramparts. The ejecta blanket of an impact crater is divided into two sections: an inner continuous ejecta blanket and an outer discontinuous blanket. Continuous ejecta blankets surrounding fresh craters on volatile-poor bodies like moon and mercury are thick deposits of fragmented material ejected from the crater along ballistic trajectories. However, continuous ejecta deposits surrounding fresh Martian craters display a fluidized appearance, suggesting emplacement by flow processes. The layered morphologies in the structure of the ejecta deposits revealed by the *Mars Global Surveyor* (MGS) Mars Orbiter Camera (MOC), Viking Orbiter cameras, and *Mars Odyssey* Thermal Emission Imaging System (THEMIS) are subdivided into single layer ejecta (SLE), double layer ejecta (DLE) and multiple layer ejecta (MLE) classes, based on the number of ejecta layers surrounding the crater. The layered ejecta morphologies exhibit strong dependencies on crater diameter and geographic location. The morphologic features associated with the layered ejecta structures suggest that the ejected material is emplaced by some type of fluidization mechanism. One formation model proposes that impact into and vaporization of subsurface volatiles produces a vapour cloud which emplaces the entrained ejecta as a flow deposit around the crater (subsurface volatile model). The other major formation model says that the thin atmosphere serves as the medium in which the ejecta are entrained (atmospheric model).

The distance from the crater rim to the most distant rampart of the continuous ejecta blanket ("runout distance") depends on latitude, terrain, and type of morphology. It is believed to provide information about the viscosity of the ejecta flow. This runout distance can be normalized to the crater radius using a parameter called the ejecta mobility (EM) ratio. EM = average extent of continuous ejecta layer / crater radius. Ejecta mobility varies with latitude but shows little variation among different terrain units. However, ejecta mobility value may vary from time to time due to the degradation of the crater and its ejecta blanket. Various geologic processes resulted in high erosion rates, which can be observed by the missing rims, eroded walls and deposit filled flat floors of impact craters. The resulting degradation rates are estimated at ~1000nm/yr during this period, comparable to some of the slowest erosion rates on earth.

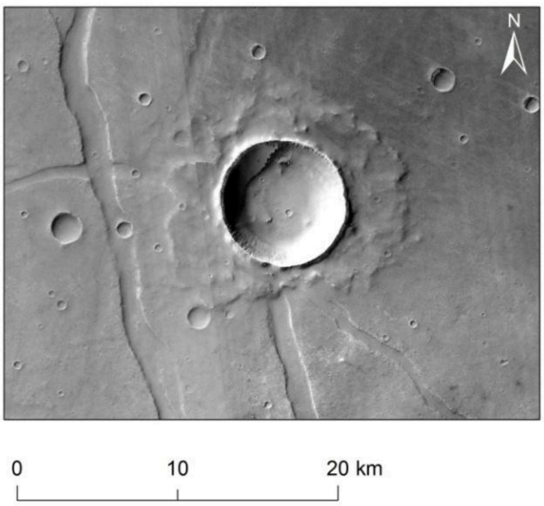


Figure 14: NASA's MRO CTX image showing a SLE

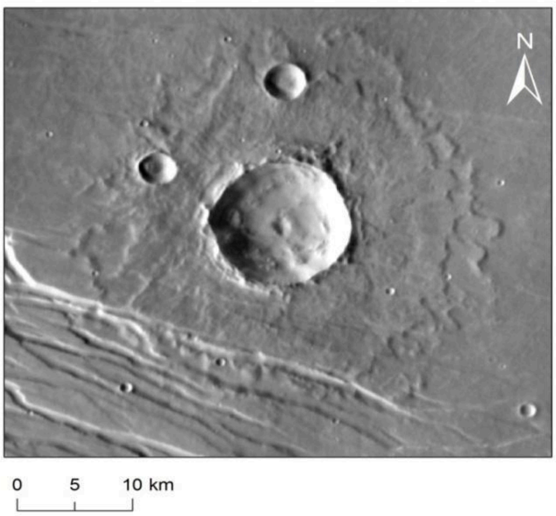


Figure 15: NASA's MRO CTX image showing a DLE

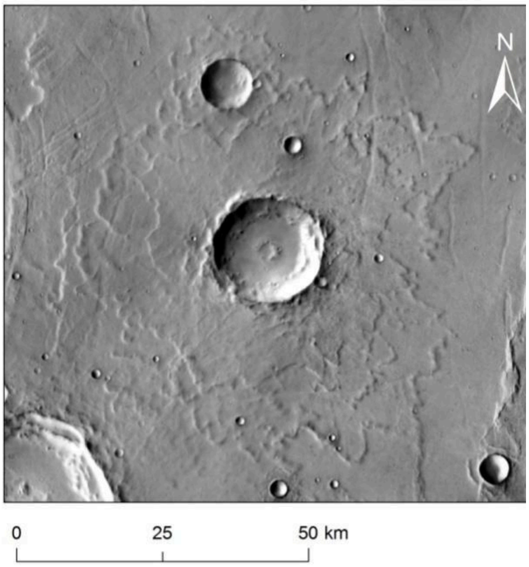


Figure 16: NASA's MRO CTX image showing a MLE

CENTRAL VALLES MARINERIS

Valles marineris is the largest canyon system in the solar system that cuts a wide swath across the face of Mars. It is located along the equator of Mars, on the east side of the Tharsis Bulge, and stretches for nearly a quarter of the planet's circumference. The grand valley extends over 3,000 kilometers long, spans as much as 600 kilometers across, and delves as much as 8 kilometers deep. By comparison, the Earth's Grand Canyon in Arizona, USA is 800 kilometers long, 30 kilometers across, and 1.8 kilometers deep. The origin of the Valles Marineris remains unknown, although a leading hypothesis holds that it started as a crack billions of years ago as the planet cooled. It has been recently suggested that Valles Marineris is a large tectonic "crack" in the Martian crust. Most researchers agree that this formed as the crust thickened in the Tharsis region to the west, and was subsequently widened by erosion. Near the eastern flanks of the rift, there appear to be channels that may have been formed by water or carbon dioxide. It has also been proposed that Valles Marineris is a large channel formed by the erosion of lava flowing from the flank of Pavonis Mons.

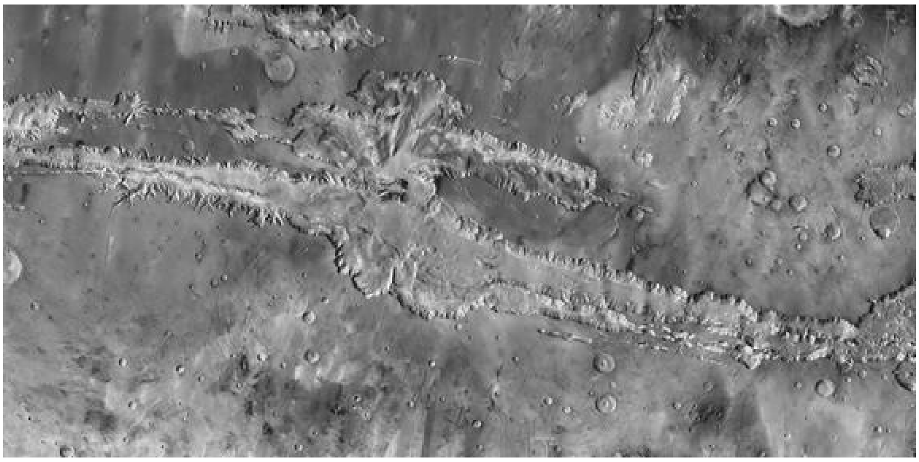


Figure 17: Image of Central Valles Marineris

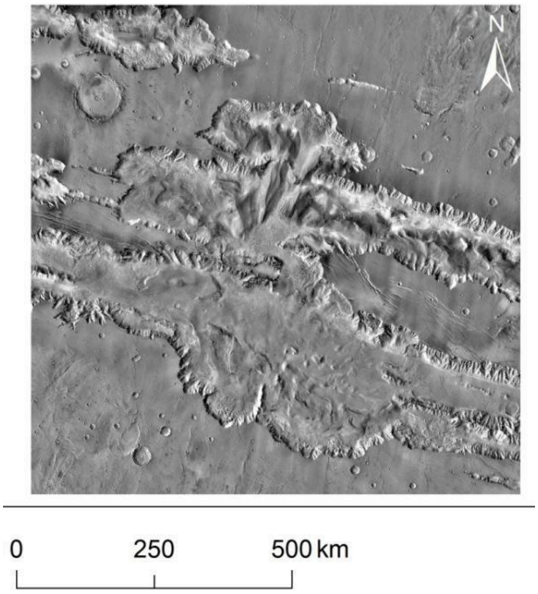


Figure 18: NASA's MRO CTX image showing Valles Marineris (image used in my mapping)

The total number of craters that were studied in this region is 1026, where 978 were simple craters ranging from 219.599813 to 14,662.407746 metres in crater radius and 48 complex craters with various features, such as central peaks, central pits and terraced walls and fluidized ejecta blanket with different morphologies and lobe structures. The range of the complex craters' radius was seen to be 508.465018 to 45,403.6913 metres (figure 20).

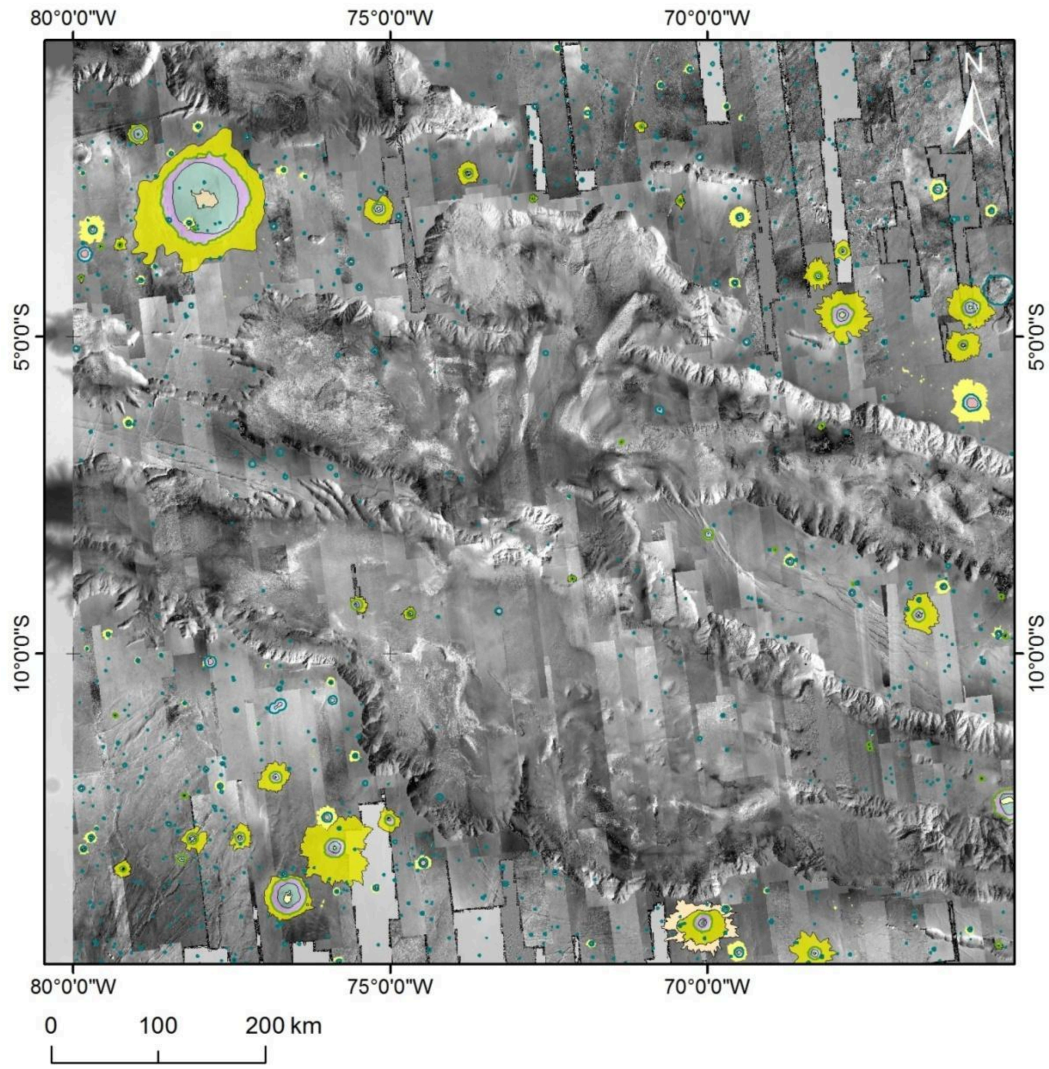


Figure19: NASA's MRO CTX image showing the impact craters in the Central Valles Marineris region of Mars.

CRATERS ON EARTH AND MARS

Meteriote falls on Earth are not rare and many impact craters have been identified, however due to the dense atmosphere, many meteors burn off before they hit the surface. One calculation suggests that ~7000 meteorites greater than 100 g in mass (≥2 cm) make it to the ground each year, which translates into one fall per square kilometre every 100,000 years. The main difference between Earth's impact craters and Mars' is the presence of an atmosphere. Earth's impact craters are very quickly eroded due to the tectonic activity and the water flow. Because the Earth's crust is continuously renewed, impact craters are relatively rare and difficult to find and to recognize. The smallest meteoroids to hit the Earth's atmosphere are slowed to benign speeds by gas drag or vaporized before they hit the ground. Extremely large impactors can melt a planet's crust and eliminate life entirely. Also the different erosion rates on Earth and Mars play a vital role between the planet's impact craters.

MAPPING

Since 1960, many satellites have been launched to capture the planet Mars and to learn more about the red planet. The first successive mission was Mariner 4, sent by the U.S, it sent a total of 21 images of Mars. Mars Reconnaissance Orbiter (MRO) is a Mars Orbiter launched by NASA on 12 August 2005. It has since then returned more than 26 terabytes (TB) of information – the largest by any Orbiter. This Orbiter contains many instruments which are valuable for our understanding of the planet. It contains devices for: HiRISE images, CTX images, CRISM images.

The dataset which was used for the project is CTX (Context Camera) imagery. The CTX image has a resolution of 6 metre/pixel. It is lower than the high resolution HiRISE images having a resolution of 25cm/pixel. The CTX images from the USGS dataset is downloaded and processed in ISIS software that works on Linux platform for error corrections. The study area of the project is Central Valles Marineris region of Mars. The image is opened using the software ArcGIS that interpret the image in Raster format and the mapping is thus done. ArcGIS contains tools for mapping the structures. The CTX image forms the geodatabase that is used to work on. A dataset is created by adding a layer on top of each other making it possible to select the required features alone. A specific feature in the image can be added as the Feature dataset. The subcategories of which can be designated as Feature class.

In this data the CTX image forms the geodatabase. A Feature dataset is Geology and in it contains many Feature classes like: wall, floor, ejecta blanket and rim of an impact crater.

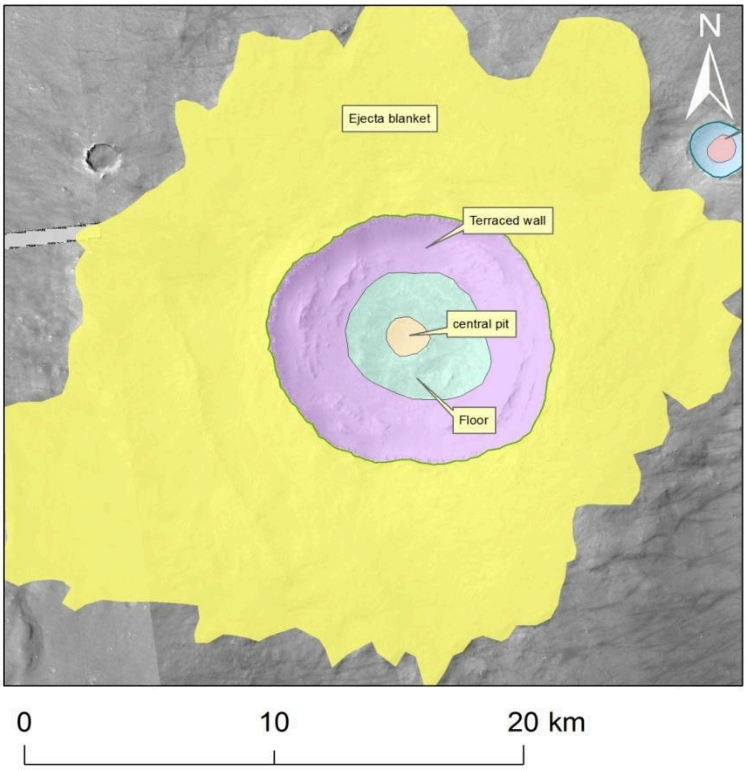


Figure 20: A labelled complex Martian crater

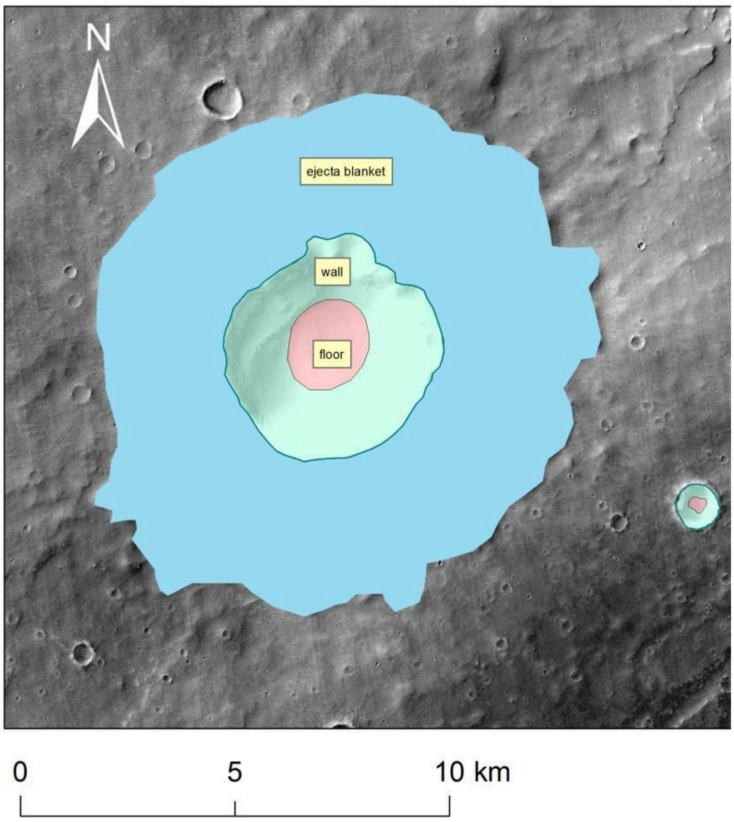


Figure 21 : A labelled simple Martian crater

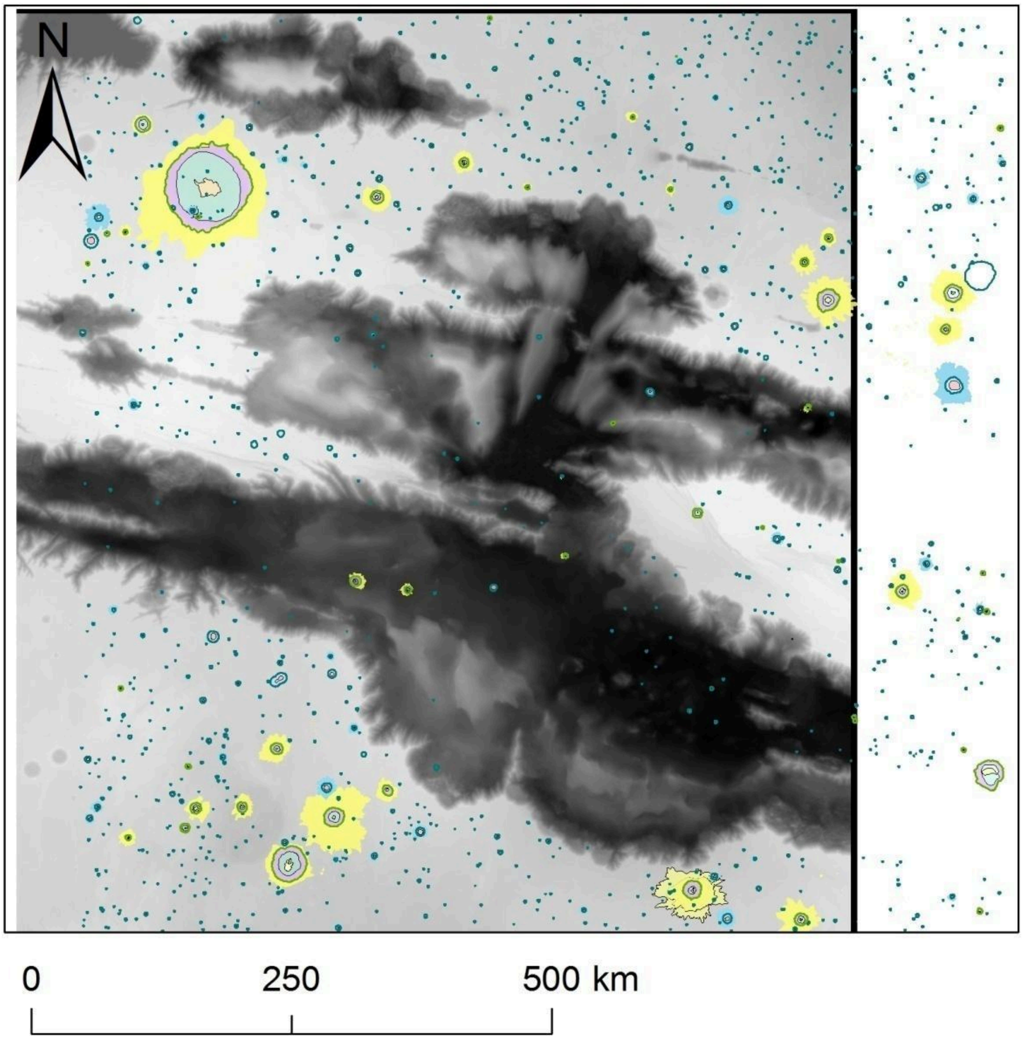


Figure 22: CentralVallesMarineris image showing the plotted craters and its dense population around the canyon

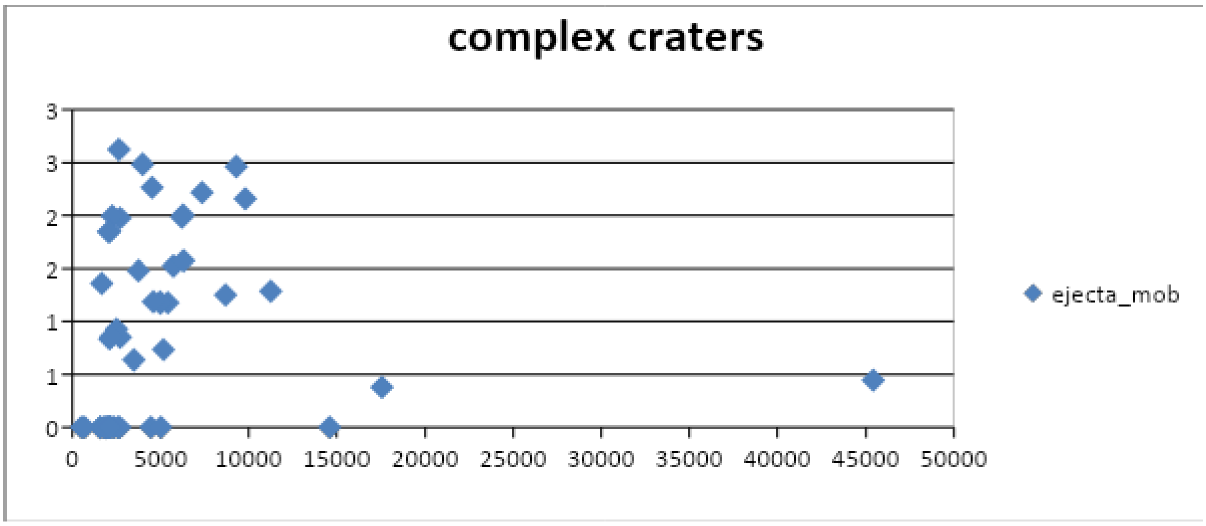
DISCUSSIONS

Impact craters provide insights into the geologic evolution and near surface structure of Mars. The planet's crustal dichotomy in the hemisphere may be the result of numerous impacts. Layered ejecta morphologies, central pits and terrain softening all indicate the presence of substantial quantities of ice within the upper few kilometres of the Martian substrate. The three types of layered ejecta morphologies show differences in EM values (Table 01 and 02), and it also varies with latitude ranging from an average value of 1.43 near the equator to over 2.0 at between 40ºN and 50ºN. The distribution of the layered morphologies, shows the wide spread distribution of subsurface volatiles. Also, other charecters such as lobatness, a quantified parameter for the sinuosity of their ramparts can be calculated to understand the craters and the surface and the geologic evolution of the planet. The graph plotted against the crater radius and the ejecta mobility (EM) shows that as the radius of the crater increases, the EM values decreases, this is due to the mathematical formula (EM= average extent of continuous ejecta layer / crater radius).

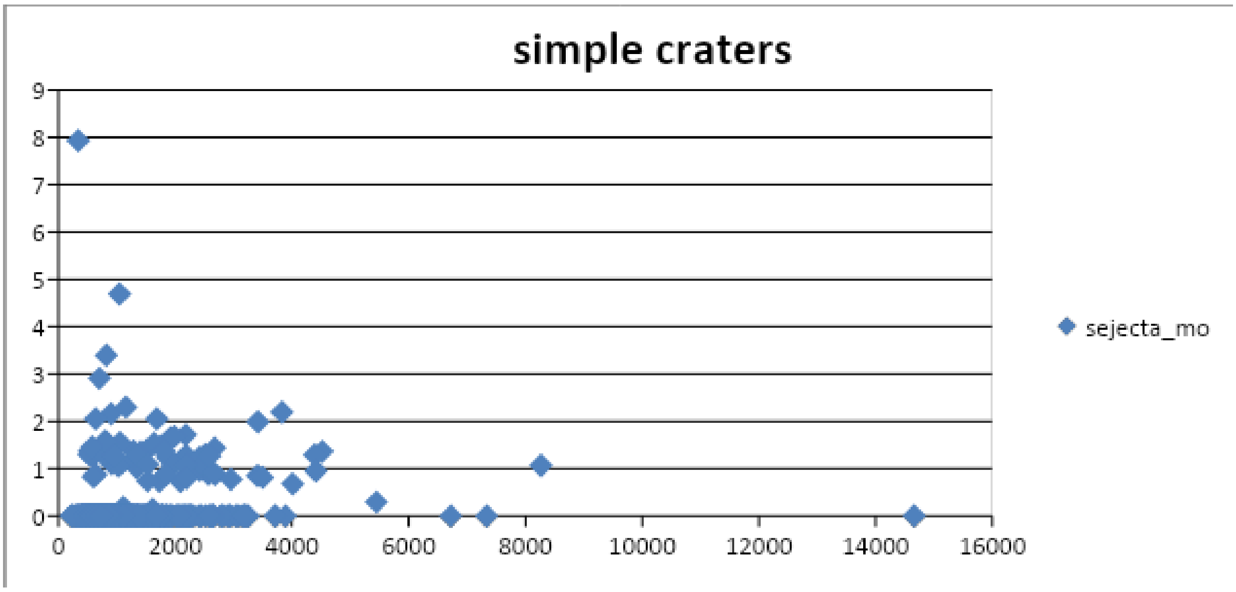
	SLE	DLE	MLE
AVE. EM	1.32	1.52	1.75
MAX. EM	4.69	2.00	2.46
MIN. EM	0.18	0.92	1.25
	SLE	DLE	MLE
AVE. EM	1.53	1.49	2.17
MAX. EM	6.60	3.30	4.70
MIN. EM	0.20	1.04	0.30

Table01. EM values from the data studied

Table02. EM values from N.G. Barlow's paper.



Graph 1 showing EM values plotted against crater radius in complex Martian craters



Graph 2 showing EM values plotted against crater radius in simple Martian craters

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