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Keck Geology Consortium: Projects 2013-2014
Short Contributions— Martian Pāhoehoe Lava Project

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SUSAN KONKOL, University of Nevada, Reno
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INTRODUCTION

The flows in El Malpais National Monument in New Mexico are quaternary and include the McCartys flow and the Bandera flow. The McCartys lava flow is approximately 2500-3,000 years old, and is mainly composed of pāhoehoe lava. The Bandera eruption occurred 9,500-10,000 years ago near the Jemez fault. These lava flows are basalt. Mars may have had volcanism much like Earth. Most of Mar's geologic past has experienced volcanism. The Elysium region has the youngest eruptions (Hamilton, 2013). Lava flows range in age from 3.4 Ga to 60 Ma but volcanism may still be active today (Platz and Michael., 2011) Depressions on Mars and structures created by lava flows are visible on the planet. A comparison of the surface depressions of the McCartys flow with depressions on Mars in the Elysium Mons region was studied to show structural similarities of depressions and lava flows. Remote sensing data from the Viking Lander in the 1970s which used X ray fluorescence, reflection spectroscopy, and photochemical weathering models have shown that Mars may have iron-rich, mafic and ultra-mafic lavas of very low viscosity which is very similar to the lava and flow regime of the McCartys flow in New Mexico (Greeley and Spudis, 1981). Channels have been formed northwest of Elysium Mons, a large

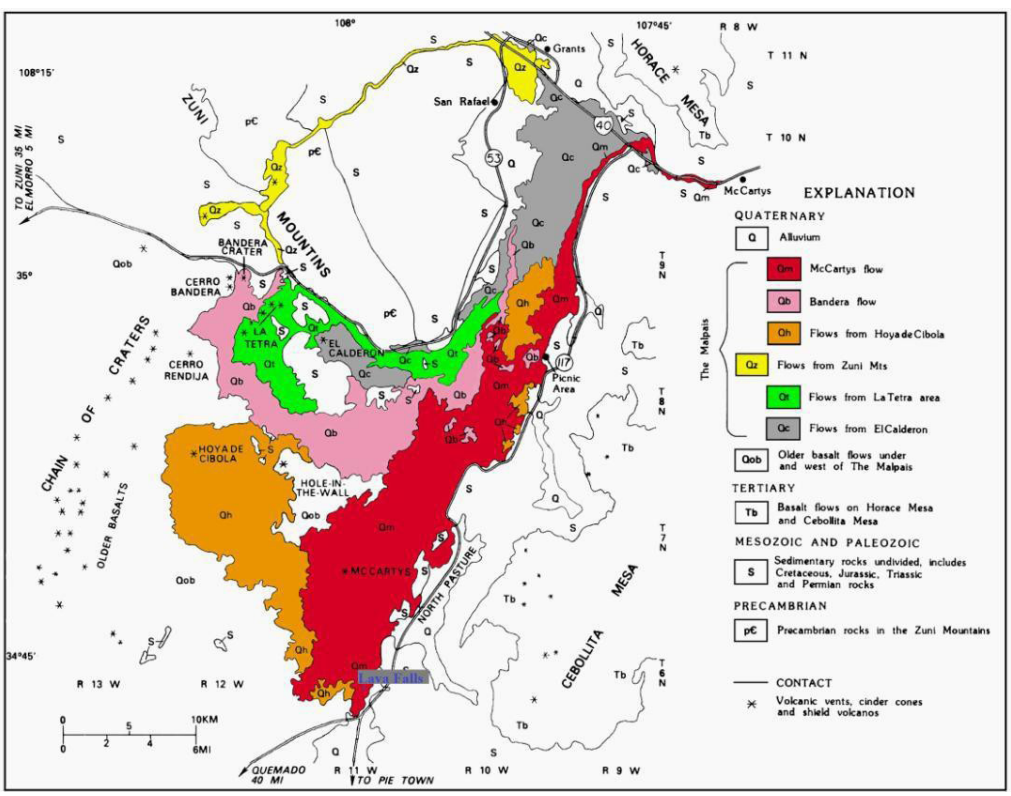


Figure 1. Geologic Map of El Malpais National Monument: McCartys and Bandera Flow (New Mexico Bureau of Geology and Mineral Resources).

volcano (Kestay, 2007). Scientists have questioned whether the channels contained water or lava. Water may be a sign that there was life on Mars. However, these channels on Mars may be collapsed lava tubes. Whether the flow was water or lava is the question. Figure 1 shows the flow pattern of the McCartys lava flow in New Mexico. From space, it appears very similar to the Martian pattern (Google Earth, 2012). This may indicate lava on Mars with similar fluid properties.

Viking data in the 1980's showed that volcanism has been one of the important geologic processes on Mars. Photos revealed widespread basaltic volcanism on the planet along with satellite images which have also shown widespread basalt on Mars (Greeley and Spudis,1981). The volcanic depressions and flows developed by continued and prolonged eruptions may have come from a point source vent, Elysium Mons, a shield volcano (Greeley and Spudis, 1981). The McCarty's flow also had a point source similar to the Martian flows. A shield volcano, approximately 40 km south of the flow in the area that was studied, spewed the lava (New Mexico Bureau of Geology and Mineral Resources, 2012).

The volcanism on Mars has been compared to volcanism on the Moon (Greeley and Spudis, 1981) and finally volcanism on Earth. Understanding the type of the depressions in the Elysium region on Mars will allow scientists to understand the types of flows that have occurred in Martian geological history. This may help discern between hydrologic flows and lava flows that will reveal the Martian geologic past.

METHODS

Depressions

Three pits were analyzed for flow direction. Figure 2 shows the pits in the McCarty's flow which were studied. A transect was taken of the pits. The slopes and cracks were measured for width and depth.

In Pit 1, wedges give a direction to the lava flow in this pit. Lineations are on the top of the lava of Pits 1, 3, and 4 and continue throughout the area and surround the pits. They show the direction of flow which is in the same direction as the lines in the rock.

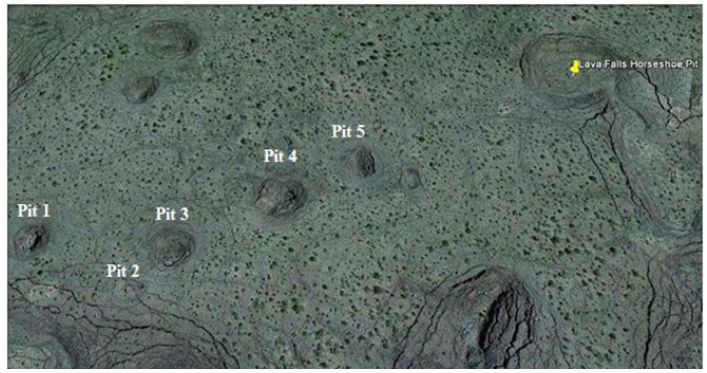


Figure 2. Map of the Pits 1, 2, 3, 4, 5 and Lava Falls Horseshoe Pit in El Malpais National Monument, created by the McCartys flow 2500- 3900 years ago. The lava flowed around mounds that produced boulders on the west side. It eventually built a wall around each mound which became the pit. Cracks developed from the pressure of the magma underneath the surface. The (Google Earth, 2012).

In Pit 3, spiral rings were observed. Lineations covered the top of the east side. Bulbous lava and flat rocks covered the top of the north side. The top of the south side had flat lobes lying on the surface.

Pāhoehoe lava flow creates ropes and lobes. Observations were made of these lava ropes that formed concave semicircles. A rope with a concave structure was observed on the top of the north side of Pit 4. Other observations were striations on large boulders on the top of the west side of Pit 4 that pointed in the direction where the partially cooled lava had flowed over them. Boulders on the west side of Pit 4 were deposited in concave semicircles. On the south side and east side surfaces of Pit 4, lineations covered the ground.

Data Analysis

All data were collected from the lava flows in El Malpais National Monument. In the lab, a slope map (fig. 3) was created from the profile pit data. Remote sensing was viewed of the lava flows in El Malpais National Monument and compared with the remote sensing on Mars. Images were used from NASA's Mars Odyssey THEMIS (Thermal Emission Imaging System) infrared camera system, which is part of NASA's High Resolution Imaging Science Experiment (HiRISE) (Christensen, et. al., 2007).

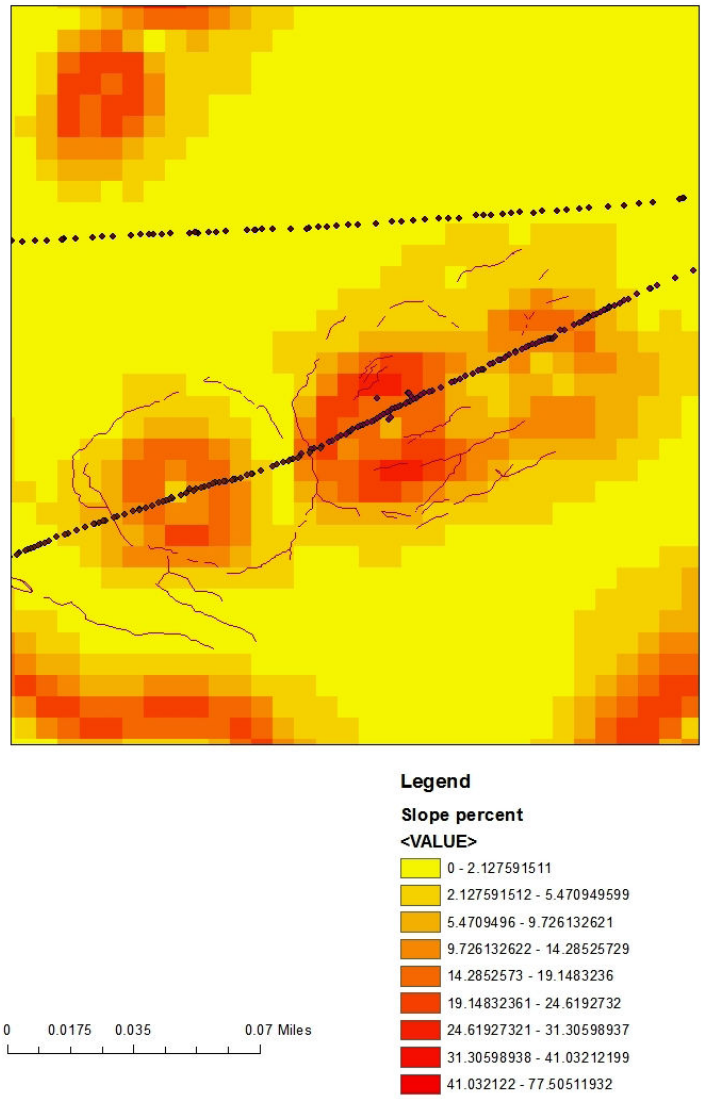
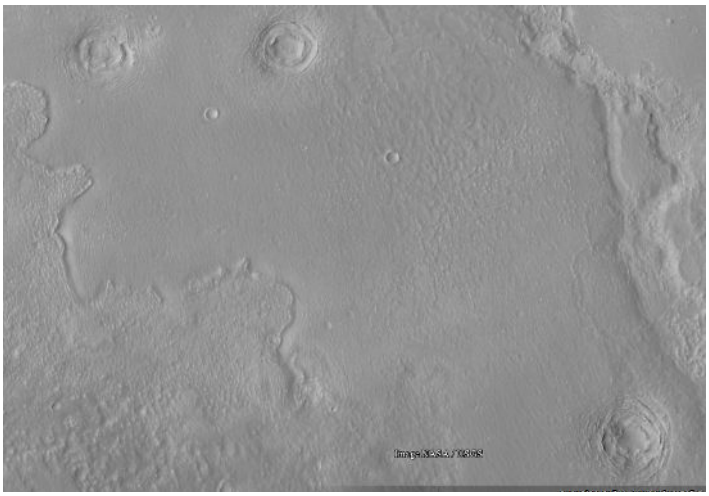


Figure 3. The slope of Pit 3, Pit 4 and Pit 5 in the McCarty's flow in El Malpais National Monument, NM. The graph shows the percent of slope on the walls of the depressions and the surrounding morphology. The steepest walls are in Pit 4. Pit 4 has two pits inside a larger pit structure.

DISCUSSION

Morphology of flow

A pāhoehoe flow is characterized by a horizontal upper surface which can be hundreds of meters wide (Hon et al., 1994). Lava rise pits form in lava rises. Lava rises form when lava flows under the surface and uplifts the crust. Lava pits near Kalapana in Hawaii were filmed while the lava flowed and showed how the structures were formed. As the lava flows on the surface, it surrounds uplifted areas or mounds (Walker, 1991). An uplifted area eventually becomes surrounded by a circular or elongated wall of lava which exceeds the height of the uplifted area creating a pit with a mound inside. The surface of the areas where the original hills and mounds were, are now pits surrounded by walls of flatten lava lobes, lava ropes, or broken lava. The McCartys flow is pāhoehoe lava and was formed by the cooled, flowing surface being dragged, and deformed by hotter, flowing lava. The McCartys flow has many lava rise pits. The subsurface inflates contributing to the rising of the surrounding plateau and the depth of the pits. Similar depression structures can be seen on



Three depressions in the Hrad Vallis region of Mars. The depressions appear to have inflated features which are present in depressions formed by of a lava flow.

Mars from remote sensing in the Hrad Vallis region (Greeley and Spudis, 1981).

Another characteristic of the McCartys flow is the inflated lava flows from high pressure and temperature under the surface. Inflated pāhoehoe lava can have large breakouts in the front of the lava flow. Lava from these breakouts spreads rapidly at first, but diminishes as the lava supply decreases (Hon, et al, 2003). In El Malpais National Monument, inflated surfaces surround the pits. The pits are very similar to the pits in the McCartys flow in El Malpais National Monument (fig.4). They are depressions with an uplift in or near the center inside the pit. Rim depressions on Mars have been grouped into three main classifications. Hydrovolcanic structures have lava-water interactions. An example is a basaltic ring. Sedimentary types are much like mud volcanoes where the sediments become over pressurized. Depressions can also be caused by

ice-related actions where the ground water freezes which increases the pressure and causes inflation (Burr, 2009). The surface then collapses when the ice thaws. Hrad Vallis is a channel from a hydrovolcanic flow with many pits that may have formed when the Elysium Mons complex flowed below the surface (Christiansen, 2007). Channels in the Elysium region show flow structures that are similar to flow structure on Earth (fig. 5).

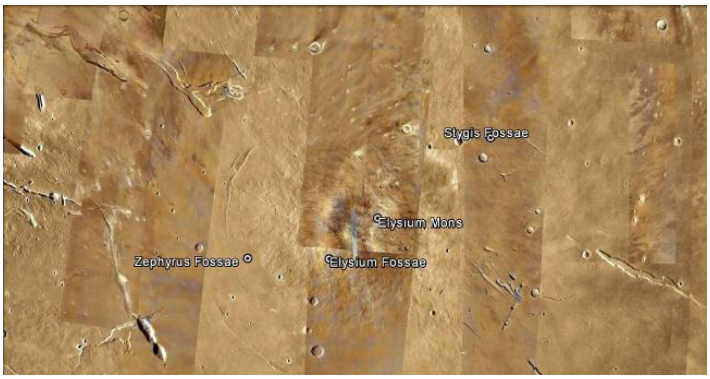


Figure 5. The Elysium Mons Region of Mars. The Elysium Mons is a large volcano in the bottom left of the figure. Channels surround the volcano where lava flowed away from the volcano (Google Earth, 2012).

The slopes in the Pits 3,4, and 5 where analyzed. The slopes tend to be the steepest on the east and west walls of the pits in the direction of lava flow. Pit 4 had the steepest slope.

Pāhoehoe lava flows form lava tubes. The Bandera flow and flows in Hawaii have produced lava tubes. Lava tubes in Hawaii have produced tubes up to 12 km in length (Kauahikaua, et al., 1998). They are created when lava flows in a river-like manner. A roof of solid rock forms over the flow allowing the hotter lava inside to continue to flow. These types of formations appear on Mars in channels. Remote sensing has shown tube-like rock structures on Mars (Greeley and Spudis, 1981).

Volcanism on Mars has been compared to maria lava flows on the Moon. This has allowed scientists to hypothesize about the type of volcanism and volcanic material on Mars. Pāhoehoe lava tends to be smoother than ‘a’ā, but broken Pāhoehoe lava may resemble a’a. It has a low viscosity making it a very fluid lava (Hon et. al., 2003). Ropy lava tends to create arcs of rope-like formations. The velocity is greatest in the middle of the ropes. This causes the ropes to stretch on the sides while extending in the middle. A rope structure was observed on the top of the east side of Pit 4 which shows the ropes stretched in the middle. The concavity of the structure points in the direction of flow. The limitations of viewing Mars has not allowed viewing these type of structures on the planet.

The McCartys flow shows an accumulation of flows. Lava flows have three distinct parts: the magma, the viscous layer, and the crust. Magma is formed by a change in pressure in the mantle (Pinkerton et.al. 2002). Magma is aggregated into large magma chambers. Inflation occurs when the subsurface pressure in the magma rises. The McCartys flow created a an inflated landscape that surrounded the Horseshoe Pit. Two or more inflated landscapes can combine to form a pit between them. A pit may have lava that is piled up in boulders on one surface on one side above the pit with a smooth flow on the top of the other wall on the other side (Hon et. al., 1994). A good example of this is Pit 4. This pit is actually a twin pit with two pits surrounded by one large pit.

Viscosity is an important factor in a lava flow. A Newtonian fluid will deform with an applied critical stress in a flow. In a Brigham fluid, viscosity adds yield strength to a fluid to make it flow. The viscous layer is in the middle of the flow. A basalt flow has a lower viscosity than a silica rich flow. The more viscous a flow the more stress is applied to it. It has a greater opportunity to fracture. Mars has had lava flows with low viscosity (Greeley and Spudis, 1981), similar to the lava flows observed in El Malpais National Monument.

Direction of Flow

The flow direction is a characteristic of the flow regime which can then be compared to the flow regime in the Elysium Mons region on Mars. Elysium Mons appears to have channels flowing away from it. Low rates for viscosity of this type of flow on earth are 10^3 Pas. This rate has been implied for the flows on Mars because of the flow structures that have been seen that pertain to low velocity (Vaucher, 2009).

In Pit 3, spiral rings show flow direction. Flow is opposite the direction of the rings. As the lava flow

moves forward, lava on the sides of the flow is rolled up into a ring in the opposite direction.

The morphology of the lava flow observed can either give direction of the flow or establish what portion of the lava flowed into an area first. The Lava Falls Horseshoe pit shows direction from ropy lava arcs and lobes on large sections of the pit floor. Most of the directions indicate a southeast to northwest flow within the floor of the pit. The structure of this pit can be compared to the vast number of pits which appear similar on Mars in the Elysium region. If the structures are very similar, it can then be implied that Mars has had the same type of volcanism as Earth.

A large u-shaped formation of large boulders stands on the west wall of Pit 4. These rocks infer a pile-up of lava on the western wall of Pit 4 during a lava flow. Since the pile-up of broken rock is on the west side, there is an indication of an eastward flow direction. The direction of flow determines the type structures around the pits. A pile of boulders is on the side of the pit where the lava entered the area. Striations in the rock are on the opposite side of the pit. This distinction along with the concavity of ropy lava on the north side and the lineations on the south side indicate an west-east flow. Knowledge of the direction of flow around these pits can prove to be very helpful when determining the type of structures and flow direction on Mars along with the type of the lava which produced the structures.

CONCLUSION

The pits and depressions on Mars are compared with the pits and depressions from the Bandera and McCartys flows. Elysium Mons is a large shield volcano. There are three large sinuous channels seen on the surface of Mars. They have been compared to the moon where these channels are carved out by lava. Extrapolating that knowledge to the Elysium Mons area, lava appears to be the type of flow in that area on Mars (Greeley and Spudis, 1981). Lava flows covers the Elysium Region. It is very fluid lava which appears to be pāhoehoe lava as in the McCartys flow. Where the three channels meet, there are large depressions and faults (Kestay, 2007). A stack of basalt can be seen in the channels which indicates that lava, not water, was the last fluid that flowed there. This may solve the question of whether the channels were used to transport water or lava. The depressions in the Hrad Vallis region show inflated features which agree with a subsurface lava flow.

More analyses of the morphology of the pits and depressions on Mars should be performed. Since ground-truthing is not possible at this time, only comparisons of remote sensing can be used. However, since knowledge of the type of lava and its flow regime is known on Earth, it may be inferred that similar lava flows, have formed many of these channels. This may answer many questions about channels and structures created from fluid flow on Mars and distinguish among the different types of surface depressions. Using this research, scientists may learn more about the geologic past on Mars

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