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Short Contributions— Martian Pāhoehoe Lava Project

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CHRIS HAMILTON, University of Maryland and NASA-GSFC
JAKE BLEACHER, NASA-GSFC
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BASALT PLATEAU ESCARPMENT CRACK PATTERNS-FIELD, GIS & ANALOG MODELING OF THE MCCARTYS FLOW AND IMPLICATIONS FOR MARS

JESSICA MCHALE, Mount Holyoke College
Research Advisor: Michelle Markley

INTRODUCTION

The 3900 years old McCartys flow, part of the Zuni Bandera Volcanic field in New Mexico, is a basaltic flow with predominantly pahoehoe textures (Nichols 1946; Dunbar and Phillips 2004.). The source of the flow is a low shield in the southern part of the El Malpais National Monument. The flow extends over 40 km northwards downslope towards Interstate 40 and 10km southwards (upslope) where the flow is an inflation plateau, a relatively flat-topped plateau that was uplifted by the injection of lava underneath its crust. The crust is the brittle, solid top layer of a flow that contains the highest percentage of vesicles. The core of the flow is almost devoid of vesicles and does not have the flow textures visible on the crust. The edge of the plateau has steep escarpments, several meters high, marked by either a sub-horizontal cleft or tilted crust.

A prominent feature of the McCartys flow is the pits that dot the distal parts of the flow towards the south and north of the source vent. Nichols (1946), who surveyed the flow from 1933 to 1935 and again in 1938, believed these pits to have formed by the partial collapse of the roof of large lava tubes. Walker (1991) calls these pits lava-rise pits or subsidence pits. Citing a previous paper by Champion and Greeley (1977), who were unable to find evidence of lava tubes, Walker proposes his own theory of how subsidence pits form. The pits form when the lava inflates due to lava injection and then part of it collapses. Alternatively, an object blocks the lava flow and the lava flow inflates around the obstruction leaving a pit. Most workers accept both explanation as equally valid because no one has identified what factors would be useful to discriminate between the two explanations.

According to Nichols (1946), cracks come in two types on the McCartys flow. He identified long, wide and deep wedge-shaped cracks, all on the scales of meters and also smaller cracks that are roughly parallel to the escarpments, or edges, of the flow. The parallel escarpment cracks are saw-toothed in places, which Nichols (1946) attributes to breaking along columnar joints. Nichols (1946) claims the large wedge-shaped cracks were mainly caused by the uplift of the crust during inflation, while the smaller escarpment cracks were caused by thermal contraction. I believe the cracks appearance is slightly more complex than that; I have identified three crack pattern types along the inflation plateau's escarpments. The purpose of this study is to classify and understand the origin of various crack geometries on the escarpments.

The identification and classification of crack geometries on Earth inflation plateau escarpments can be translated onto similar features on Mars. These crack type patterns could give hints about the inflation process of a particular plateau, which is valuable because the Mars data is primary satellite imagery.

METHODS

Field Surveying, DGPS and GIS

All of my field work took place on the escarpment of the southeastern branch of the McCartys flow. In three locations, I measured changes in slope dip and shape using a compass and differential GPS. With a measuring tape as a guide we marked a straight line using tin foil covered rocks. We completed also several traverses across a horseshoe shaped inflation pit and across parts of the inflation plateau using the differential GPS. On satellite photos of the McCartys flow, I used ArcGIS to digitize the cracks along the escarpments of the flow.

Peg Wax Modeling

Polyethylene glycol 600, here after referred to as PEG wax, is a wax that when cooled from a liquid to a solid state displays rheology similar to a lava flow. For this reason the wax has been used to model lava flow behavior. I plan to use the wax to model lava behavior and crack formation on the edge of an inflation plateau. Inflation plateaus are impossible to accurately model by including all aspects (Glaze and Baloga 2013), therefore this model will only focus on lava, or wax, inflating and cracking on the edges. The model was adapted from a PEG wax model presented in a paper by Fink and Griffiths (1990).

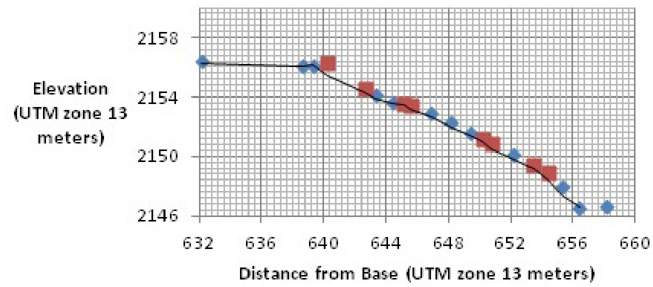
I cut a 2cm hole into the bottom of a fish tank and the hole was fit with a valve. The fish tank is 9 inches tall, 14.5 inches long and 8 inches wide. Four notched wooden blocks elevate the tank above the lab bench. I fitted a 40cm long pipe with a diameter of 3/4cm to the valve at one end and to the peristalsis pump at the other. Another identical pipe connects the other end of the peristalsis pump up to a 300ml capacity vial. A rod suspends a glass vial 45cm about the level of the bottom of the tank. I filled the tank with 10 liters of sucrose solution that had been kept at a temperature of about 5ºC in a refrigerator; this temperature is well below the solidifying point of the PEG wax. The sucrose solution had a density of 111 g/ml. The PEG wax is melted in a microwave for 20 seconds and then I mixed the blue food dye in. The wax was then left to cool to room temperature in its liquid state. The wax is poured into the glass vial. The wax traveled through the pipes, pumped into the cold sucrose solution in the tank and flowed along the bottom of the tank before solidifying. While the wax flowed a camera videoed the wax's flowing and appearance from the side. I used a second camera to take photographs of the flow from above. I used a Taylor meat thermometer to measure the temperature of the wax, sucrose solution and room before each experiment began.

RESULTS

Field Surveying and GPS

Type A

Traverse J is an excellent example of the Type A morphology of the escarpment (Fig. 1). The graph of the DGPS points for Traverse J shows an overall linear slope of the edge of the escarpment. Traverse J has four cracks, the one at the top of the slope is 2.5 meters wide, and none of the other cracks is wider than a meter. In summary, Type A escarpment morphology is characterized by a linear slope, linear base and one large, wide, crack near the rim, other cracks are smaller and parallel to the larger crack.



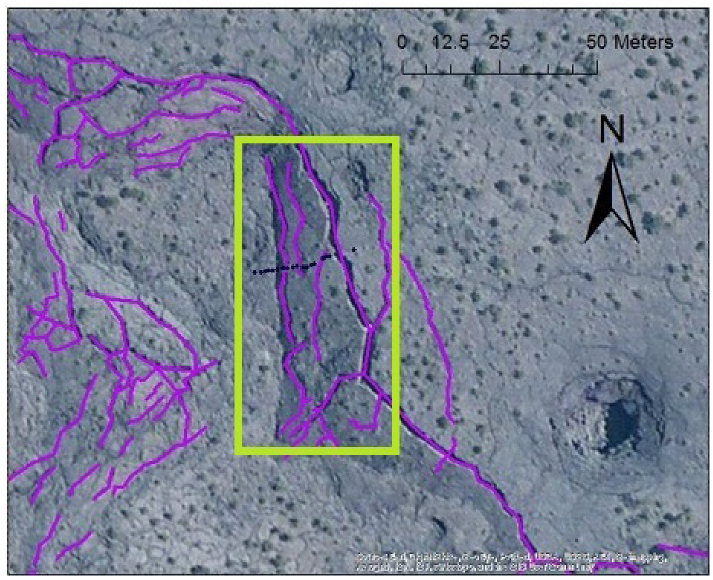
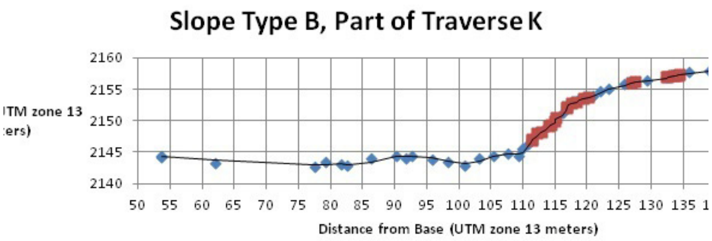


Figure 1. The graph contains the DGPS points for Traverse J, an example of a Type A crack pattern escarpment. In the graph, the blue diamonds are DGPS points and the red squares are crack markers (usually on either side of a crack, but occasionally only one point per crack). The lower picture is a satellite image of the escarpment that Traverse J crossed. The green box highlights the slope, the magenta lines denote the largest, and most visible cracks. The dark blue dots on the slope are the Traverse J DGPS points.

Type B

Traverse K is a pretty good example of the Type B morphology of the escarpment (Fig. 2). The graph of the DGPS points for Traverse K demonstrates the letter 'S' appearance of the slope, which is create by local variation in plate positions. The slope of Traverse K is concave near the base of the slope, the linear in the middle and convex near the top before connecting with the horizontal top of the plateau. These slopes have the largest amounts of cracks of all three types. Traverse K has 10 cracks, these cracks are rarely, if ever, are wider than one meter, and are subparallel to each other. In summary, Type B escarpment morphology is characterized by an 'S'-shaped slope, concave base and lots of similarly sized small, thin, cracks subparallel to each other.



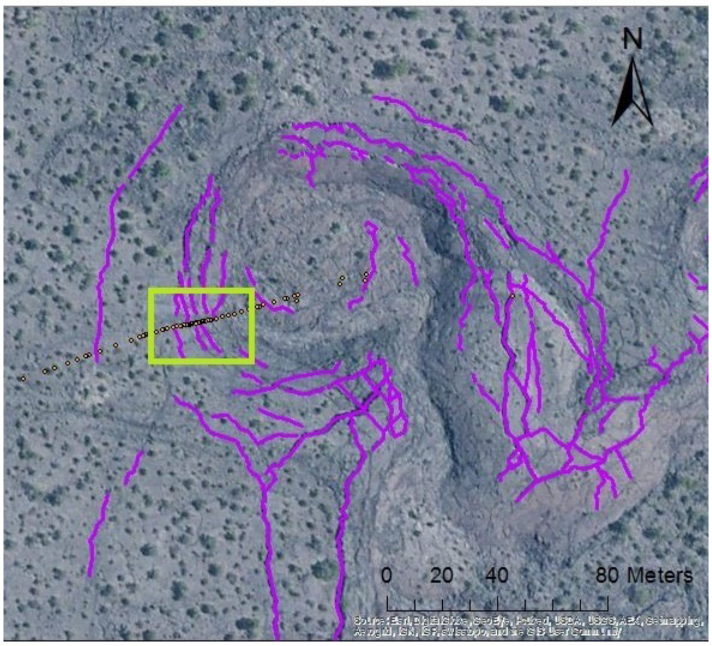
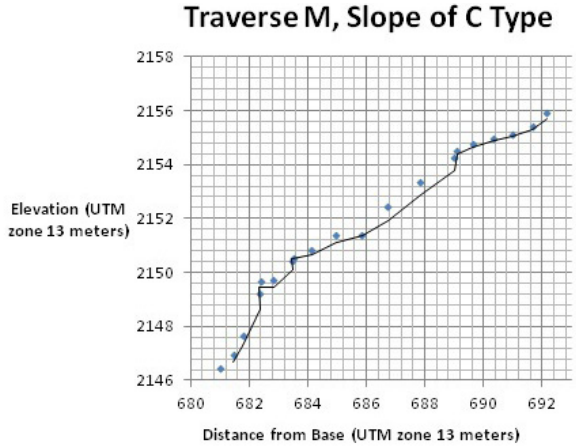


Figure 2. The graph contains the DGPS points for Traverse K, an example of a Type B crack pattern escarpment. In the graph, the blue diamonds are DGPS points and the red squares are crack markers (usually on either side of a crack, but occasionally only one point per crack). The lower picture is a satellite image of the escarpment that Traverse K crossed. The green box highlights the slope, the magenta lines denote the largest, and most visible cracks. The dark blue dots on the slope are the Traverse K DGPS points.



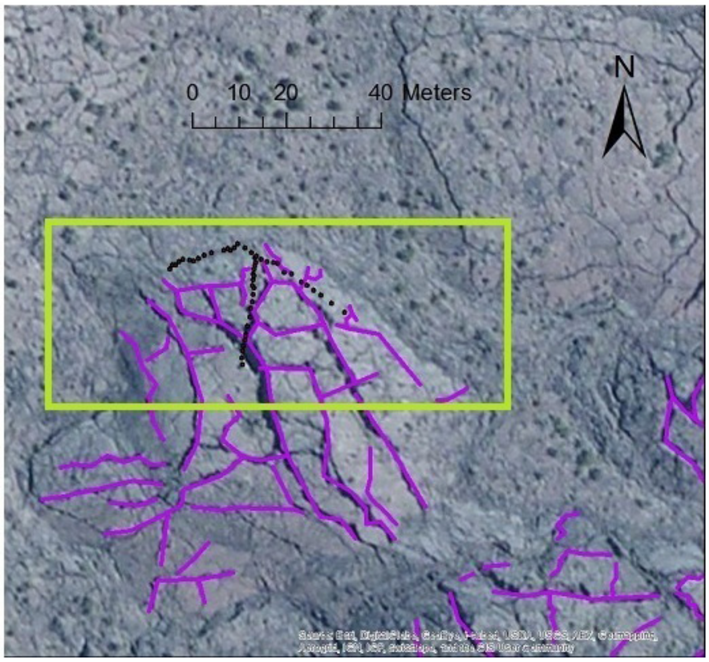


Figure 3. The graph contains the DGPS points for Traverse M, an example of a Type C crack pattern escarpment. In the graph, the blue diamonds are DGPS points. No cracks are marked in the graph for this slope because traverses are not accurate measurement the polygonal crack pattern seen on Type C escarpments. The lower picture is a satellite image of the escarpment that Traverse M crossed. The green box highlights the slope, the magenta lines denote the largest, and most visible cracks. The red dots mark the Traverse M DGPS points around the base and up the measured slope.

Type C

Traverse M is on excellent example of the Type C morphology of the escarpment (Fig. 3). The graph of the DGPS points for Traverse M shows an overall convex slope of the edge of the escarpment. The three cracks crossed by Traverse M vary in width from .3 meters to 1.1 meters wide. In summary, Type C escarpment morphology is characterized by a convex slope, convex base and many polygonal, intersecting cracks of various widths.

Peg Wax Modeling

I conducted five runs of my analog model, the process evolved over the course of the trial runs. The fourth trial run was the most successful run, in terms of material preparation. The fifth run was the same as the fourth trial.

The fourth trial took place on February 18th; the wax flows from 1:16 to 2:15pm. I maintained the slope added during runs two and three. To create the 1.98° slope I inserted a 1.4cm thick book between the tank and two of the supporting blocks on the side closest to the suspended vial; the slope was small, but created a significant flow direction away from the vent. I heated 280mL of PEG wax in the microwave and mixed three drops of blue food dye into the liquid. The wax was then allowed to sit and cool to room temperature overnight. I mixed 6L of water with 1320g of sucrose, half the amount of sucrose of the previous mixes. It has a density of 111g/ml. The sucrose solution was left in the refrigerator. At the start of the trial run the wax was 21.2°C, the room was 22.0°C and the sucrose solution was 5.2°C. At 1:30pm the sucrose in the tank was 7.2°C. At 1:32pm there was a sudden explosion on the side of the vent that was facing down slope. The wax flowed and grew until 2:13pm when a final stage of wax and air was pumped up into the tank. At 2:15pm I switched the pump off and the wax stopped flowing. At this point the sucrose solution was 9.8°C. This trial had the wax hardening at a much more consistent rate that any of the previous runs.

DISCUSSION

Escarpment Type Crack Implications

Crack pattern types A, B and C represent different local geometries of the escarpment. Type A crack pattern escarpments look like a hinge because of the characteristic wide crack. I believe this crack pattern type if formed when an inflation plateau inflates, results when the edge failed to hold together under the pressure of inflation. Type B crack pattern escarpments have lots of narrow subparallel cracks that I believe are created when the rounded edge of a lobe that has inflated collapses when the lava drains away. Type B cracks look like the cracks that appear on a cake when it deflates after being taken out of the oven. Type C crack pattern escarpments are characterized by convex and polygonal cracks that I believe are formed by the upward movement of inflation. Type C escarpments are similar in appearance to tumuli.

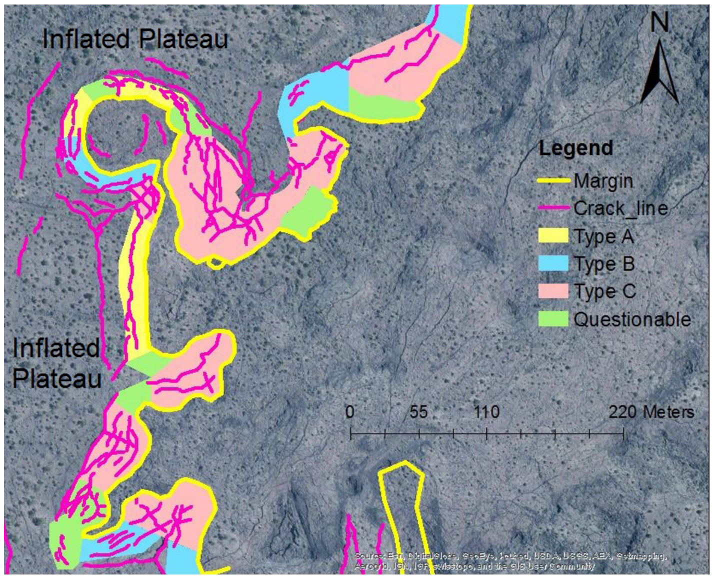


Figure 4. This figure is an image of part of the mapped and identified crack type slopes. Magenta lines are cracks visible in the satellite imagery. Yellow indicates an escarpment section of crack Type A; blue indicates an escarpment section of crack Type B; pink indicates an escarpment section of crack Type C; green indicates questionable/non-crack type section. Only the escarpments of the inflation plateau are mapped. The yellow lines mark the edges of the margins, the bottom of the escarpments.

These crack pattern types can be applied to the escarpments of the rest of the inflation plateau (Fig. 4). Slopes with a Type C crack pattern bulge outward, which supports the idea of the cracks being formed by inflation. Slopes with a Type B crack pattern have a concave base, which means the slope does not bulge out from the plateau and this therefore supports the idea that the cracks on those slopes are primary formed by deflation. Slopes with a Type A crack pattern are the rarest of the three, but when they do appear they are long and straight in planar view, which supports the idea that they were formed by when a horizontal slab was over flexed and broke, or failed, resulting in a hinge-like appearance. Not all escarpments or lava features along the escarpment of an inflation plateau match a crack pattern type. These areas are most often transition or suture zones between crack types. They can also be secondary lava flows over the top of already inflated slopes or through cracks on the inflation plateau escarpments, these features have smooth relatively crack free surfaces. In Figure 4, this last, non-crack type slope, designation also covers sections of escarpment that are too hard to identify with the air photos available, possibly due to lighting, angle or resolution.

Problems with Traverses

A major problem with traverse mapping of Type C crack pattern escarpments is the inherent polygon pattern of the cracks causes a straight line to be an incomplete map of the cracks on the escarpment. Depending on where the traverse is placed the slope can seem to have several narrower cracks or one wider crack. Traverse M was on a part of an escarpment with one of the widest and deepest cracks I saw in the field, but because of the angle of the traverse that was not accurately captured in the data. In the case of Type C escarpments GIS mapping gives a more accurate picture.

Peg Wax Analog Modeling

PEG wax never becomes hard enough to be brittle and form cracks. It appears to flow a bit like lava and can appear to inflate itself, but the peg wax is always elastic enough to stretch without breaking.

Implications for Mars

The crack type patterns that I mapped using aerial and satellite imagery of the McCartys flow could also be mapped on Mars. If these crack pattern types were found along the escarpments of a flow this occurrence could be used as evidence that the volcanic feature is an inflation plateau. The crack pattern types would give hints about the local emplacement history of potential inflation plateaus.

Figure 5 is an image of Mars on which I highlighted the cracks. I identified a section of escarpment that is most likely a Type B crack pattern; this section has a concave base and many subparallel cracks. The section marked as a possible Type C has many small features, which although I was unable to trace them, I believe they are thin and intersecting cracks. The section marked as a possible Type A has long wide cracks and a relatively linear base; I believe

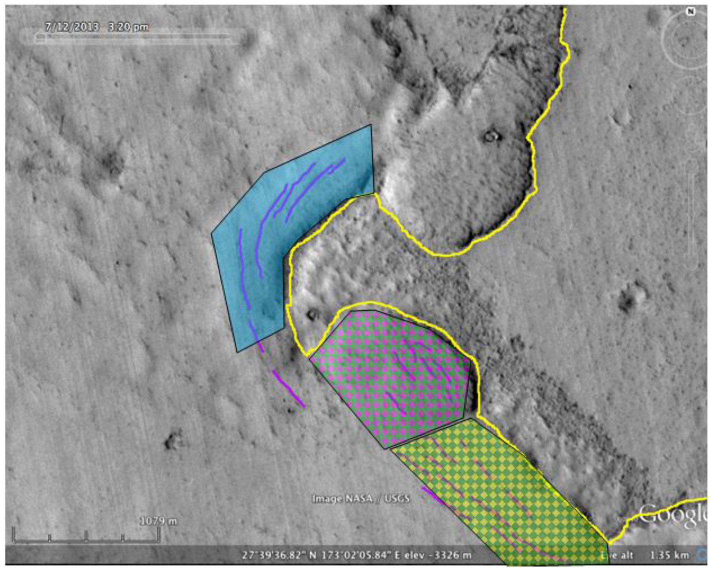


Figure 5. This figure is an image of crack on the surface of Mars 200km north-east of the Phlegra Dorsa area near Elysium. Magenta lines denote the cracks; the yellow line denotes what I believe to be the margin of the inflated feature. The blue shape is the outline of a section I believe to have a Type B crack pattern, the pink and green checkered shape marks what I tentatively believe to be a Type C crack pattern, and the yellow and green checkered shape marks what I tentatively believe to be a Type A crack pattern section. Cracks are much harder to discern in this image from GoogleMars than images of Earth.

most of the cracks in this section are actually on top of the plateau and not part of the escarpment. A series of clearer, closer photos from different angles is necessary for me to be more definitive when identifying crack type patterns on Mars.

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