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2013-2014 PROJECTS

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Faculty: *ROB STERNBERG*, Franklin & Marshall College, *JOSHUA FEINBERG*, Univ. Minnesota, *STEVEN SHACKLEY,* Univ. California, Berkeley, *ANASTASIA STEFFEN*, Valles Caldera Trust, and Dept. of Anthropology, University of New Mexico
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Faculty: *JOHN GARVER*, Union College, *CAMERON DAVIDSON*, Carleton College
Students: *BRIAN FRETT*, Carleton College, *KATE KAMINSKI*, Union College, *BRIANNA RICK*, Carleton College, *MEGHAN RIEHL*, Union College, *CLAUDIA ROIG*, Univ. of Puerto Rico, Mayagüez Campus, *ADRIAN WACKETT*, Trinity University,

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Faculty: *ROBERT NEWTON*, Smith College, *ANNA MARTINI*, Amherst College, *JON WOODRUFF*, Univ. Massachusetts, Amherst, BRIAN YELLEN, University of Massachusetts
Students: *LUCY ANDREWS*, Macalester College, *AMY DELBECQ*, Beloit College, *SAMANTHA DOW*, Univ. Connecticut, *CATHERINE DUNN*, Oberlin College, *WESLEY JOHNSON*, Univ. Massachusetts, *RACHEL JOHNSON,* Carleton College, *SCOTT KUGEL*, The College of Wooster, *AIDA OROZCO*, Amherst College, *JULIA SEIDENSTEIN,* Lafayette College

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Students: *KYRA BRISSON*, Hampshire College, *KYLE METCALFE*, Pomona College, *MICHELLE PARDIS*, Williams College, *CECILIA PESSOA*, Amherst College, *HANNAH PLON*, Wesleyan Univ., *KERRY STREIFF*, Whitman College

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Students: *SUSAN KONKOL*, Univ. Nevada-Reno, *JESSICA MCHALE*, Mt. Holyoke College, *RYAN SAMUELS,* Franklin & Marshall College, *MEGAN SWITZER*, Colgate University, *HESTER VON MEERSCHEIDT*, Boise State University, *CHARLES WISE*, Vassar College

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

LAVA ON MARS AND THE EARTH: A COMPARATIVE STUDY OF INFLATED AND DISRUPTED FLOWS
Faculty: ANDREW DE WET, Franklin & Marshall College
CHRIS HAMILTON, University of Maryland and NASA-GSFC
JAKE BLEACHER, NASA-GSFC
BRENT GARRY, NASA-GSFC

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LAVA ON MARS AND THE EARTH: A COMPARATIVE STUDY OF INFLATED AND DISRUPTED FLOWS

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JAKE BLEACHER, NASA-GSFC
BRENT GARRY, NASA-GSFC

ABSTRACT

Both fluvial and volcanic processes have been invoked to explain various channel and flow morphologies in martian locations such as on the flanks of Ascraeus Mons and in the Elysium Planitia region (Mouganis-Mark and Christensen, 2005; Bleacher et al., 2008; Trumble et al., 2008, Murray et al., 2010; Bleacher et al., 2010; Hamilton et al., 2010), but in many cases the precise determinations of their origin remain enigmatic. Unraveling the details of the role of water and volcanism on Mars is extremely important, especially in the context of the search of extinct or extant life on Mars. Knowing how these channel and flow features formed will provide us with a better understanding of the role of volcanic and fluvial processes in the geological evolution of Mars. The development of better criteria to distinguish fluvial from volcanic processes is crucial in this endeavour.

Developing robust Earth analogs is one way to define morphological criteria and the Zuni Bandera Volcanic Field (ZBVF) in New Mexico is a location where basaltic lava flows are very well preserved (KellerLynn, 2012). This Keck project studied the morphology of two flows in the ZBVF to understand their emplacement mechanisms and the associated features such as channels, shatter complexes, break-outs, pits, and plateaus or terraces. The morphologies of lava flows generated by effusive basaltic eruptions can provide a record of paleo-eruption conditions and details about the emplacement mechanisms. Many of the morphologies preserved in the ZBVF are similar to features observed on Mars and may shed new light on the Martian features origin.

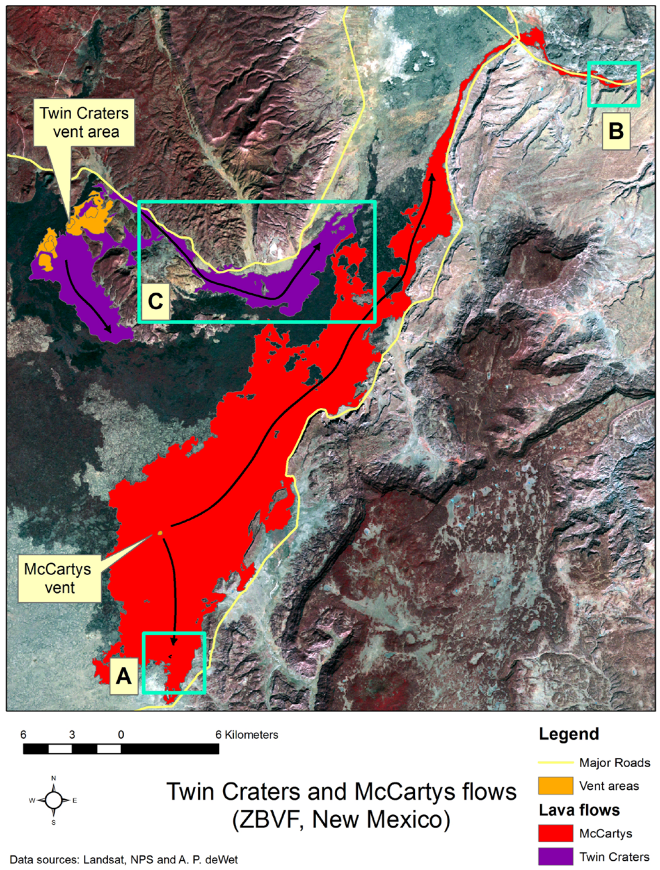

Figure 1 Map showing the locations of the Twin Craters and McCartys basaltic lava flows within the Zuni Bandera Volcanic Field (ZBVF) in New Mexico. The 3.9 kyr McCartys flow extends from the vent northwards for over 50 km and southwards for over 8 km. The 18 kyrs old Twin Craters flow originated from a complex field of vents and flowed south-east and eastwards for over 18 km. Charles Wise, Jess McHale and Sue Konkol focused on the Lava Falls (Horseshoe) area (area A). Megan Switzer studied part of the extreme distal part of the north-east flow of the McCartys flow (area B) and Hester von Meerscheidt and Ryan Samuels focused on the Twin Craters flow (area C). Source: Landsat, National Park Service (KellerLynn, 2012), and A. P. de Wet.

* now at the University of Arizona

INTRODUCTION

In this study, we focused on characterization of the basaltic lava flows in the ZBVF (Figure 1) to establish a context for interpreting analogous flows on Mars. The ZBVF is composed of >100 monogenetic vents (low shields and cinder cones) with associated lava flows that coalesce and merge (Luedke and Smith, 1978; Luedke, 1993, KellerLynn, 2012) to produce a "plains-style" (Greeley, 1982) volcanic province. The ZBVF is associated with the Jemez lineament a zone of crustal weakness associated with numerous volcanic fields of Late Cenozoic age, extending from central Arizona to northeastern New Mexico (KellerLynn, 2012). Within the ZBVF, numerous basaltic volcanic features are well preserved (Nichols, 1946). We conducted field work on the McCartys and Twin Craters flows which are ~3.9 kyrs and ~18 kyrs old respectively (Dunbar and Phillips, 2004; KellerLynn, 2012).

MCCARTYS FLOW

The relatively young McCartys flow exhibits some of the best basaltic lava flow features in the USA outside of Hawaii. From the vent, the main flow extends almost 50 km north towards Grants and then east down the Rio San Jose valley. The flow also extends south for about 10 km (Figure 1). The flow includes pahoehoe and a'a type flows and probable inflation features occur widely, but are particularly well developed in the southern area where pahoehoe flows dominate (Mabery et al., 1999). Regional topography suggests that the southern flow was emplaced on a gentle upward slope. This likely affected sheet flow and lobe emplacement, and aided in the formation of plateaus/terraces and inflation features which are prominent in this area. At least 4 distinct plateaus or terraces were mapped and individual plateaus are frequently separated and surrounded by numerous generations of smaller break-out lobes and flows (Figure 2, 3).

Detailed field observations of cross-cutting relationships can be used to determine the relative timing of many of these events (de Wet et al., 2014). Cracks or clefts likely formed through inflation can constrain the timing and emplacement of individual flows and plateaus. Slab thickness as measured by the crack or cleft depth can be related to the cooling history of the flow by the equation:

$$t = 164.8C^2$$

(Hon et al., 1994) where t is time in hours and C the crust thickness in meters. However individual plateau cooling ages cannot definitively determine the timing of emplacement of the whole flow complex because the relationship between the plateaus has not been resolved. Numerous circular and semi-circular pits occur in this area. These features could have formed through collapse over thick flows or through inflation processes similar to inflation processes described from Hawaii (Hon et al., 1994). Understanding the details of how the McCartys flow was emplaced will be important in determining effusion rates, and thus

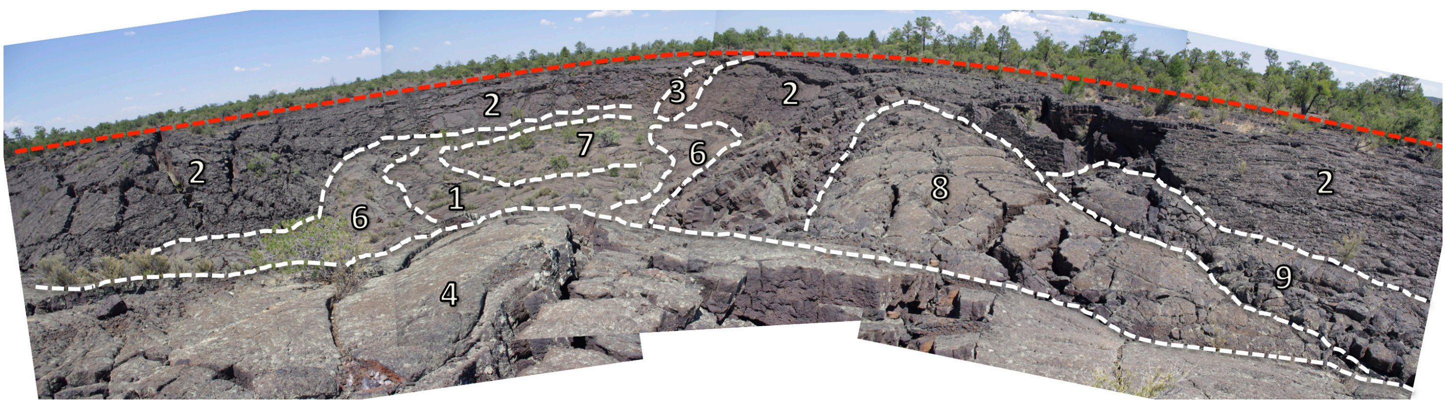

Figure 2 View westwards of the Lava Falls ("Horseshoe") area of the McCartys flow (ZBVF), New Mexico showing the inflated plateau (red dotted line) and most of the 10 different generations of flows in the area. The lava flows are numbered from oldest (1) to youngest (10). See figure 3 for a map view of this area.

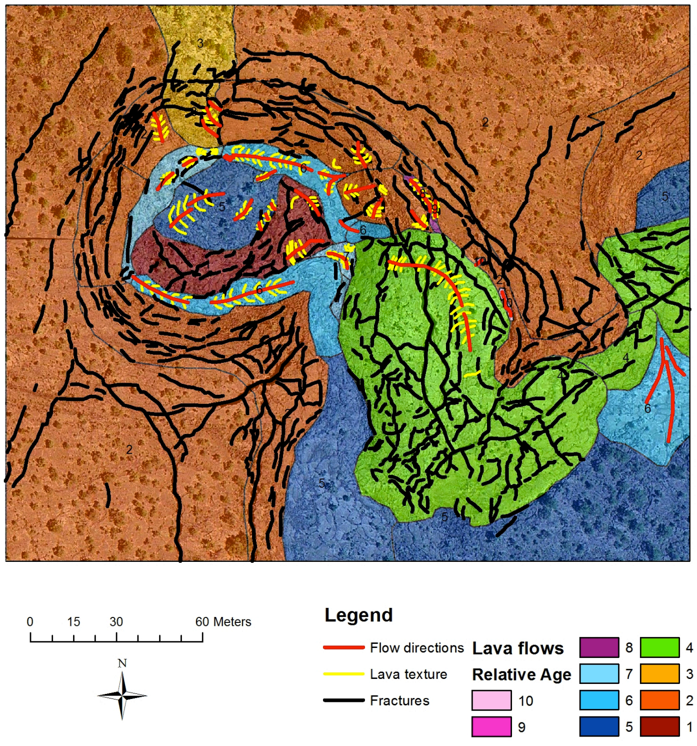

Figure 3 Relative ages of the lava plateau and associated break-out lobes and flows in the Lava Falls (Horseshoe) area of the McCartys flow (ZBVF), New Mexico. The lava flows are numbered from oldest (1) to youngest (10). Relative ages relationships were determined from field observations. Lava textures (ropes) in yellow. Flow orientations are marked in red with the flow direction towards the convex side of the textures. Inflation cracks or clefts are marked in black. Figure 2 shows a view west across the semi-circular feature ("Horseshoe") in the upper-center of the map.

be helpful in understanding the formation of similar features in the Hrad Vallis, Phlegra Dorsa and other locations on Mars (Scheidt et al., 2014).

TWIN CRATERS FLOW

The Twin Craters flow is probably composed of several overlapping flows from different vents which traveled at least 26 km eastward and then northeastward (KellerLynn, 2012) (Figure 1). The multiple eruptions likely occurred over a short (less than 1,000 years) time period. A well developed channel fed the medial and distal parts of the flow and includes lava tube and collapsed sections, as well as possible shatter complexes. The flow field includes a'a, transitional, and pahoehoe textures. Two prominent limestone ridges in the path of the flow appear to have influenced the distribution of these textures by impeding flow and causing changes in flow slope, velocity and thickness. Understanding the distribution of these textures is important because similar features are common on Mars.

The development of the Tharsis Montes on Mars includes main flank formation followed by rift zone activity (Crumpler & Aubele, 1978) but the relationship between the two is not entirely clear. It is suggested that these two episodes represent a magmatic continuum (Wilson et al., 2001), two temporally unique but spatially overlapping magmatic events (Bleacher et al., 2007), and a magmatic event (main flanks) followed by hydrothermal and fluvial activity (rift aprons) (Murray et al., 2009).

While most channels exposed on Ascraeus have been ascribe to volcanic processes some well developed sinuous and anastomosing channels have been ascribed to either fluvial erosion (Bleacher et al., 2007; Trumble et al., 2008, Murray et al., 2009; Mouganis-Mark and Christensen, 2005) or to volcanic processes (Garry et al., 2007; Bleacher et al., 2010). In order to resolve this debate, better criteria are needed to definitively distinguish between these processes. Earth analog studies of morhologically similar features such as the Twin Craters flow may generate better distinguishing criteria.

METHODS

Over the summer of 2013 the student projects comprised two components – a field component consisted of lava flow morphology study in the Zuni-Bandera Volcanic Field in New Mexico, followed by a lab component involving processing the field observations and GPS data, combined with computer mapping and analysis using GIS, and sample preparation at F&M College in Lancaster. After several days of general field observations including a visit to the Bandera caldera and flow field, the whole group spent several days collecting GPS data, mapping and making field observations in the Lava Falls area (the "Horseshoe") of the McCartys flow. Ryan Samuels and Hester von Meerschidt used this experience as a springboard to focus on the flow morphologies in the Twin Craters flow while the remainder of the group continued to focus on the McCartys flow. Megan Switzer concentrated on the geochemistry and petrology of one lobe of the north-east distal part of the McCartys flow. The samples were collected at a road cut and partly processed for thin-sections and whole-rock geochemistry at F&M College. Geochemical analyses were completed at Colgate University.

Once the field work was completed the group traveled to F&M College to process the field data and observations, and began the digital mapping component of the project. GPS data was combined with high resolution aerial photography, 10m DEM data and other datasets to generate maps, cross-sections and other outputs.

The research group presented their preliminary results at the end of the summer at NASA-GSFC. Hester von Meerscheidt and Ryan Samuels presented posters at AGU in Fall 2013; Ryan Samuels gave an oral presentation and Jessica McHale and Charles Wise gave poster presentations at the regional NEGSA meeting in Lancaster in March 2014.

STUDENT PROJECTS

Inflation processes associated with the McCartys flow

Charles Wise, Jessica McHale and Sue Konkol focused on understanding the emplacement mechanisms for the Lava Falls area of the McCartys lava flow. This area is located in the southern part of the McCartys flow, approximately 8 km from the main vent (Figure 1, 2).

Charles Wise (Vassar College) analysed the inflation crack systems within the McCartys lava flow and considered possible applications to understanding similar Mars features. A key question is whether the depth and distribution of the crack system can definitively support inflation as the dominant emplacement mechanism of the lava plateaus. The cracks may also serve to distinguish between competing explanations for the formation of the multiple plateaus developed in the area and differential inflation of a single sheet-like lava flow or multiple individual stacked flows, or complexly emplaced and inflated flows (Figure 4). Understanding these processes is important in determining the effusion rates and history of the McCartys flow and may help in interpreting possible similar features on Mars.

Jessica McHale (Mount Holyoke College) examined inflation crack patterns along the margins of the plateau that includes the Lava Falls area and attempted to physically model in the lab the formation of cracks using PEG wax analog modeling. Three patterns of cracks were recognized based on the crack frequency and geometry – Type "A" (linear), Type "B" (convex), and Type "C" (concave). The question is whether these crack patterns are consistent with inflation processes and whether their geometries can exclude other processes such as collapse or shrinkage due to cooling.

Sue Konkol's (University of Nevada, Reno) study concentrated on the formation of circular and semi-circular features or pits in the plateau area around the Lava Falls area and compared them to similar features on Mars. The Lava Falls features range in size from a few meters to over 50 meters in diameter and up to 10 meters in depth. Concentric cracks up to several meters wide and over 6 meters deep surround these features. The bottom of the features is usually partially filled with rubble and sometimes have *in situ* lava flows and break-out lobes. At least two alternative processes could have formed these features, either inflation of sheet-like lava flows that differentially inflated around small variations in the original surface over which the sheet flowed, or collapse into an existing thick flow during emplacement – perhaps along lava tubes. Inflation is the preferred mechanism for a variety of reasons including the presence of lateral 'squeeze-outs' in the side walls of these pits, the concentric crack features, and the lack of alignment of the features along preferred pathways or tubes.

Geochemistry and Petrology of the McCartys flow

Megan Switzer (Colgate University) focused on examining the geochemical and petrographic variations within one inflated lava lobe located ~50 km from the vent, near extreme distal extent of the north-east part of the McCartys flow (figure 1). Here an excellent fresh vertical roadcut along State Road 124 exposed the complete thickness of a 6.5

m thick inflated lobe of the McCartys flow. Megan described the textural and mineralogical variations in the flow observable in the field and collected a suite of 27 samples from the base to the top of the flow. Petrographic and geochemical studies revealed minor but important vertical variations in texture and composition. This study was partly motivated by the possibility that variations in geochemistry might be helpful in unraveling the emplacement mechanisms of the McCartys flow, particularly in the southern part of the flow where spectacular plateau features exist. These plateaus likely formed through inflation processes but the details of the emplacement of the main plateaus and the numerous smaller flows and break-out lobes is unclear (Figures 3, 4). Of particular interest is whether the McCartys flow was essentially one event occurring over several months or numerous events spread over several years or even decades or millenia. Geochemical variations might provide clues about this history and Megan's study provides important constraints on the variations in the geochemisty that we might expect from individual flows that can be compared to samples taken from other parts of the flow field.

Flow morphology of the Twin Craters flow

Hester Von Meerscheidt (Boise State University) examined the influence of topographic obstacles on basaltic lava flow morphologies associated with the Twin Craters flow. Hester was able to distinguish four major surface textural facies and several subfacies based on field observations and remote sensing mapping using high resolution aerial photography. A critical question is the relationship between the flows and several major bluffs or hills blocking the flow on the valley floor. This study suggests that lava was backing up behind the bluffs beneath the pāhoehoe crust and pressurization beneath the crust resulted in numerous breakouts of low-viscosity lava upstream and around the large bluff. These results indicate that topography can have a significant influence on lava flow dynamics and the ultimate textures produced.

Ryan Samuels (Franklin & Marshall College) focused on the variations within the flow channel of the Twin Craters flow. Much of the flow occurred within a well preserved lava tube but Ryan identified and mapped several features including possible shatter complexes, channel bifurcations and collapses along the channel. It appears that bifurcations occur in association with

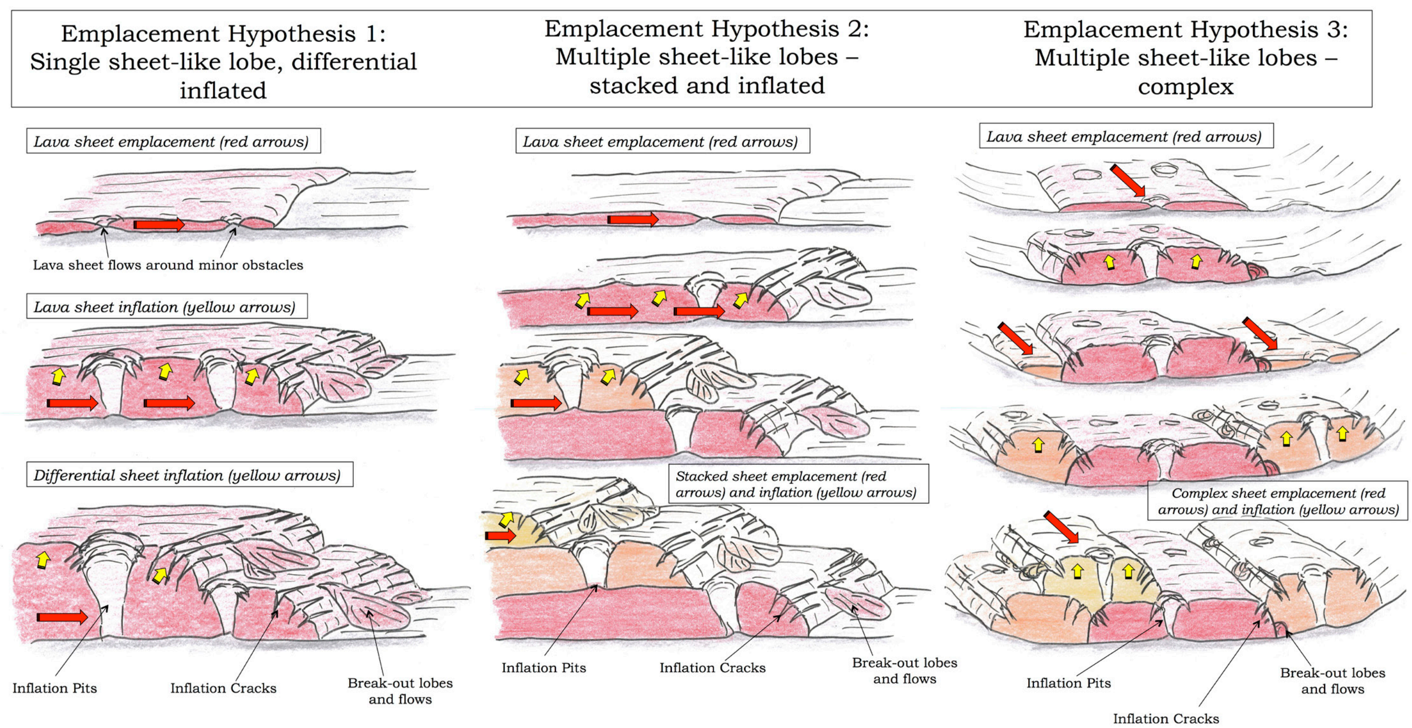

Figure 4 Alternative emplacement mechanisms for the Lava Falls area of the McCartys flow.

Figure 5 Shatter feature associated with the Twin Craters flow. Arrows indicate the flow direction (eastwards). Dotted line marks the shattered and partially welded margins of the feature. Hummocky late flows occur in the central parts of the feature. Feature is approximately 60m wide and 200m long.

steep slopes while shatter complexes occur where slopes are much shallower (Figure 5). The formation of these features is probably related to a complex interaction of mechanisms including the effects of the slope. Steep slopes may lead to high flow velocities and the development of channel bifucations while low slopes lead to variations in flow and the formation of shatter complexes, as documented from Hawaii (Orr, 2010). Very similar features are observed on the north-east flanks of the Mars volcano Ascraeus leading to the suggestion that similar volcanic processes formed the features there as well.

CONCLUSIONS

Spectacular plateaus or terraces, break-out lobes and flows, cracks/clefts, and pits were observed and mapped in 3.9 kyr McCartys flow. The cracks were assigned to three different types based on their geometry and are likely consistent with formation through inflation processes. While we cannot definitely prove that the pits formed through inflation rather than collapse, this seems to be the most plausible mechanism of formation. The relative timing of over 10 distinct break-out lobes and flows was determined in the Lava Falls area. Analysis of the crack depths indicates that individual plateaus required many months to form but until the relationships between the multiple plateaus is resolved, the overall duration of the emplacement of the McCartys flow can only be estimated. The features observed in the McCartys flow seem to be very similar to features on Mars and would be consistent with a volcanic origin for these features.

The geochemistry of one individual flow lobe in the McCartys flow suggests that individual flows have very little geochemical variation vertically and this implies that sampling of exposed (upper) parts of flows in the Lava Falls area will accurately represent the overall composition of the individual flows, and thus might be helpful in resolving the emplacement details of the whole flow field. These results will inform our sampling strategy entering the next phase of the study in this area.

It is clear that the morphology of the Twin Craters flow was influenced by a variety of factors. Channel bifurcations, shatter complexes and break-outs are related to a complex interaction between factors such as major obstacles in the flow field, variations in channel slope and shape, and perhaps effusion rates. Channel collapses and bifurcations are common and result in morphologies that, when viewed *in isolation,* could be confused with channels formed by fluvial processes. On the other hand, features such as tumuli, break-outs and shatter complexes are morphologically unique and are associated with volcanic processes. Morphologically similar features on the flanks of Ascraeus Mons, Mars likely formed by similar volcanic processes.

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