# PROCEEDINGS OF THE TWENTY-SEVENTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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# KECK GEOLOGY CONSORTIUM
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# CHANNEL BIFURCATION AND SHATTER RING FEATURES ASSOCIATED WITH THE TWIN CRATERS LAVA FLOW, ZUNI-BANDERA VOLCANIC FIELD, NM: INSIGHTS INTO SIMILAR FEATURES ON MARS

**RYAN C. SAMUELS,** Franklin & Marshall College
**Research Advisor:** Andrew de Wet

## INTRODUCTION

The origin of channel features in the Tharsis Region of Mars has been interpreted as lava flows (Bleacher et al, 2010; Garry et al, 2007; Hiesinger et al, 2007), however others have suggested that the channel features could also be either mud-flows or rivers systems (Trumble et al, 2008; Murray et al. 2010). Evidence provided by remote sensing and rovers seem to have made a convincing argument in favor of large quantities of frozen water existing below the surface of Mars (for example: Boynton et al., 2002), however recently HiRISE and CTX imagery and MOLA data have revealed channel features that suggest a more volcanic origin; ultimately, leaving the problem of how the Tharsis region formed unresolved.

Clearly, careful examination of flow features in the Tharsis region is important for distinguishing between volcanic and fluvial/mudflow processes. These processes may be distinguished by identifying features that are unique to either volcanic or fluvial processes. Two features in particular, shatter ring features and lava tubes, are well-preserved channel related features that are typical of lava flows, but not of aqueous flows. Because the Twin Craters lava flow, NM contains these features and another common channel feature- points of bifurcation- it can be used as an analog. Therefore, developing field experience to confidently identify these channel features formed by volcanic processes in remote sensing data from the Earth is vital to determining the origin of flow units in the Tharsis region and other similar locations on Mars.

## TWIN CRATERS LAVA FLOW

El Malpais National Monument is located approximately 7 miles east of Grants, NM. Bordered by Jurassic-aged sandstones that comprise the Cebollita Mesa to the south and limestones of The Zuni Mountains to the north, the Zuni-Bandera Volcanic Field (ZBVF), located within the monument, is famous for its numerous generations of well-preserved basaltic lava flows and cinder cones (Keller, 2012). The ZBVF occurs along the Jemez linament, a zone of apparent crustal weakness defined by a concentration of late-Cenozoic volcanism (Laughlin et al., 1982). The ZBVF also occurs in a “transition zone” between the Colorado Plateau, with crustal thicknesses of over 40 km to the Rio Grande Rift where the crust is much thinner. The Jemez linament trends north-northeast, and includes the ZBVF, the Mt. Taylor volcanic field, and the Jemez volcanic field. The Jemez linament has been a long-lasting tectonic feature that penetrates the lithosphere to great depth, and the basaltic lavas of the ZBVF appear to be mantle-derived melts (Laughlin et al., 1982).

The flows in the ZBVF range in age from 120,000 to 3000 years, however the broader region has been volcanically active for approximately 1 million years. The Twin Craters, is 18,000 years old and is heavily weathered (Keller, 2012). This flow is sometimes referred to as the La Tetra flow, however for this paper all names are based off of the National Park Service Map (Fig. 1). Easily accessible via the Zuni-Acoma Trailhead from Rt. 53 the Twin Craters basaltic flow

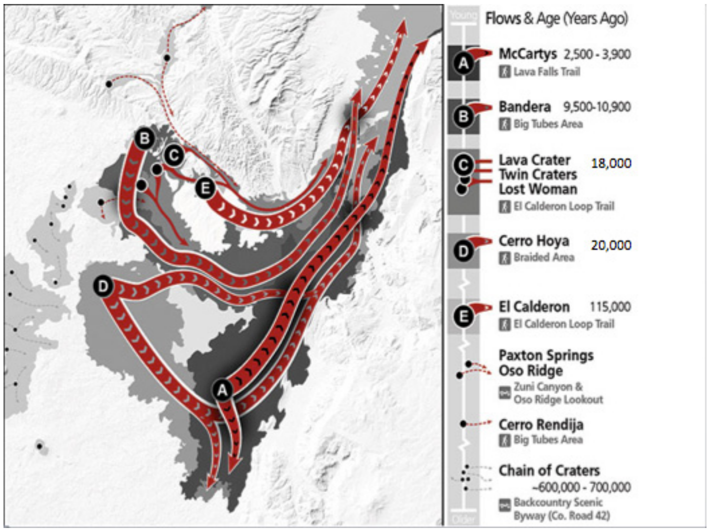



*Figure 1. Geologic Map of El Malpais National Monument. Red arrows indicate flow directions from the sources (from NPS, 2014).*

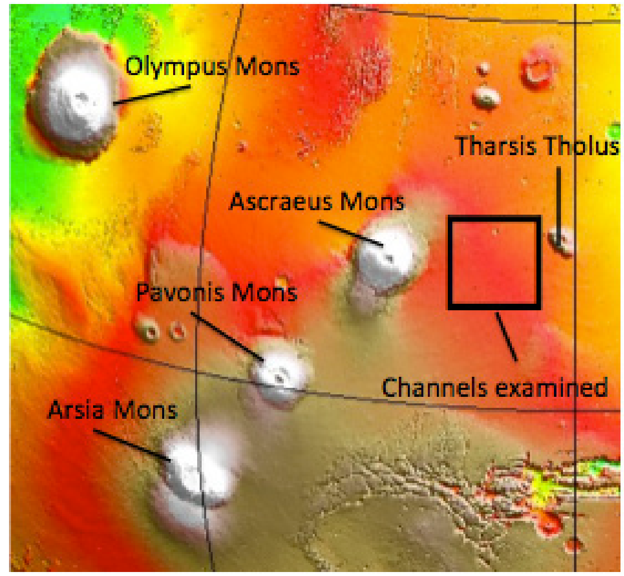



*Figure 2. Detailed DEM data map of the Tharsis region of Mars.*

has not been studied extensively, is highly eroded, and contains a network of well-preserved collapsed tubes and channels.

## Lava Tubes and Channels

In many places along the Twin Craters flow the only indication of a tube is a gentle linear swell meandering across grasslands or lava fields. Collapse tubes, however, indicate the presence of underlying tubes. Collapse tubes are formed by catastrophic cave-roof failure. Observations in Hawaii have revealed that most of the collapse takes place either during the latter stages of tube formation or immediately after tube cooling (Rogers and Mosch, 1997). The trench may take on several forms depending on the plasticity of the basalt, the stresses involved in the roofed over part of the tube, and size and roof thickness of the tube itself. If the lava is still relatively plastic, the roof may sag to form a shallow trough. If the lava is more rigid, the roof may totally fail, and result in a sharp-edged collapse trench (Rogers and Mosch, 1997).

Lava tubes occur in lavas composed of basalt and the primary physical factors affecting tube formation are silica content, temperature, duration and rate of flow, ground gradient, and channel sinuosity. In order for a lava tube to form, an eruption must continue for a relatively long period of time and emanate from discrete vents, not long fissures. Many initial lava flows form sheet flows, but if the flow continues for even a few tens of minutes, channels begin to form within the flow. If the flow continues for at least several hours, significant lava tubes will begin to form (Rogers and Mosch, 1997).

## Shatter Rings

Shatter rings are circular volcanic features, typically tens of meters in diameter that form over active lava tubes and are typified by an upraised rim of welded breccia and a central depression. It was previously unknown what exactly caused them to form in a particular location, however it has been observed in Hawaii that the welded breccia rim was formed via repeated episodic inflation and deflation periods, that are directly proportional to the fluctuations in the level of lava in the tube, that force layers of lava outward (Orr, 2009). The blocky rubble is then cemented together via small pahoehoe breakouts along the base. It has been suggested that shatter rings form in areas where there is an abrupt decrease in the flow velocity, perhaps resulting from a large increase in tube width, an abrupt decrease in tube slope, or a sudden change in tube direction (Orr, 2009).

## THARSIS REGION- MARS

The Tharsis region extends from the northern lowland plains southward to Solis Planum, and from Arcadia Planitia eastward to Lunae Planum (Schaber et al, 1978). Physiographically, the Tharsis region is a somewhat elongate and irregular regional dome with three large volcanoes (Ascraeus Mons, Pavonis Mons, and Arsia Mons) aligned alongs its crest to form Tharsis Montes (Fig. 2).

More than 20 geologic units have been mapped, mostly lava flows whose eruptive sequences have been established by overlap, embayment, and transection relations (Schaber et al., 1978). Broad relatively flat sheet flows with smooth-appearing surfaces are common on the extensive plains surrounding the Tharsis volcanoes and on their gentle lower slopes. Channel and tube-fed flows are more common on the steeper slopes higher up the sides of the volcanoes and have rougher textures (Carr et al., 1977). The flows and channels examined for this project are located on the extensive, flat plains between Ascraeus Mons (~250 km east from the base) and Tharsis Tholus and contain well-preserved channel features, easily recognizable via remotely sensed imagery and MOLA data.

## METHODS

The study of lava tubes at the Twin Craters flow was done via a combination of field observations and remote sensing. First, the tubes, collapsed channels, and shatter ring features were recorded, photographed, and geo-referenced using a Garmin 062 GPS. Depth, width, and heights of each feature were measured using a Nikon Laser Forestry Pro laser rangefinder. We hiked out from the Zuni-Acoma Trailhead and worked our way westward, being careful to note any collapse features and changes in morphology.

Second, ArcGIS software was used to map the flows, channels, and shatter ring features observed within the Twin Craters flow. Channel width and depth measurements were made every 500 meters along the channel and cross-sections were composed at features of interest. Additionally, DEM data was used to map slope and topographic profiles along the length of the channel.

Finally, the aforementioned mapping techniques of the Twin Craters Flow were applied to various flows in the Tharsis Region of Mars.

## RESULTS AND OBSERVATIONS

As the Twin Craters Flow advanced, preferred pathways developed in the older portions of the flow, sometimes evolving into lava-tube systems. The channel observed at the Twin Craters flow (easily identifiable from its levees on both sides) is variable in width and depth along its length, however individual channel features have consistent channel widths. The Twin Craters Flow has two distinctive sections: an east section and west section that are divided by a northward facing limestone ridge. Toward the west the channel has a typical width of 14 meters, reaching a maximum width of 60 meters and a depth of 3 meters. As one progresses eastward toward the limestone ridge, the channel steadily becomes narrower and deeper, having an average width of 10 meters and reaching a maximum width and depth of 20 meters and 8 meters respectively.

The eastern portion, in comparison to the generally narrower and deeper western section, is much wider and shallower, having an average width of 30 meters and reaching a maximum width of 190 meters and minimum depth of 1 meter. The limestone ridge appears to have blocked the flow, forcing the flow to bypass the ridge to the north and south and thereby limit the passage of lava into the eastern channel.

Three shatter ring features formed along the length of the Twin Craters flow. They are marked by a sudden increase in channel width and have a wide (2-5 meter) rim. The western-most shatter ring feature has a bowling-pin-like shape (Fig. 3 A) with a total length of 200 meters and a diameter of 60 meters; significantly wider than the tube it is connected to. This feature can be divided into a smaller northwestern (30 meters wide by 80 meters long) portion and larger southeastern section (60 meters wide by 120 meters long). Within the welded breccia rim there is a "multigenerational" flow scheme in which there is a sequence of three pahoehoe breakouts. The youngest of these breakouts directly drains into the departing channel, which flows confined to within the channel toward the southeast. This same multigenerational flow characteristic is observed at the other shatter ring features. Additionally, based on DEM slope analysis (5 m pixel resolution), shatter ring features appear to form in localities of low slope immediately preceded

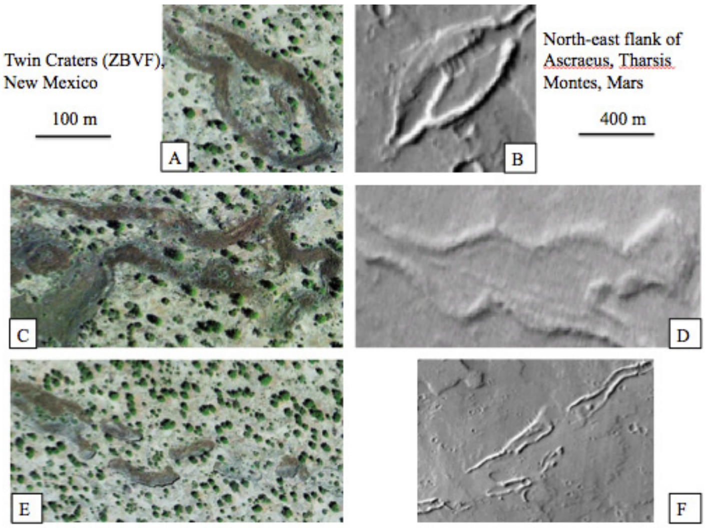



*Figure 3. Comparison of channel features on both Twin Craters (left column) and Mars (right column). The scale bars are associated with each corresponding column. All features, channel widths, and lava flows on Mars appear to be approximately 4x larger than those on Earth. A,B. Circular shatter ring features. C,D. Elongate shatter ring features. E,F. Channel bifurcation zones*

by a locally high slope (Fig. 4). Shatter features and these changes in slopes are also observable in DEM topographic cross-sections.

Two types of channels exist in the area studied on Mars- the northeastern flank of Ascraeus Mons: a very narrow and deep channel and a much wider and shallower channel with internal flow ridges that are perpendicular to flow direction. The transition between these two types is very sharp and the exact reasons for this rapid transition are unknown. Each channel type maintains a relatively consistent width throughout the length of the flow. Easily identifiable by what appears to be levees on both sides, the rims of the channels are narrow. In the very narrow and deep channels tubes form occasionally. In some cases, catastrophic roof failure leads to collapsed tubes, which when taken out of context, could be misinterpreted as isolated vents. No tubes are associated with the larger and shallower channels.

Channel features, closely resembling shatter ring features seen in the Twin Craters flow (Fig. 3), are also present on Mars, but are much larger. They are

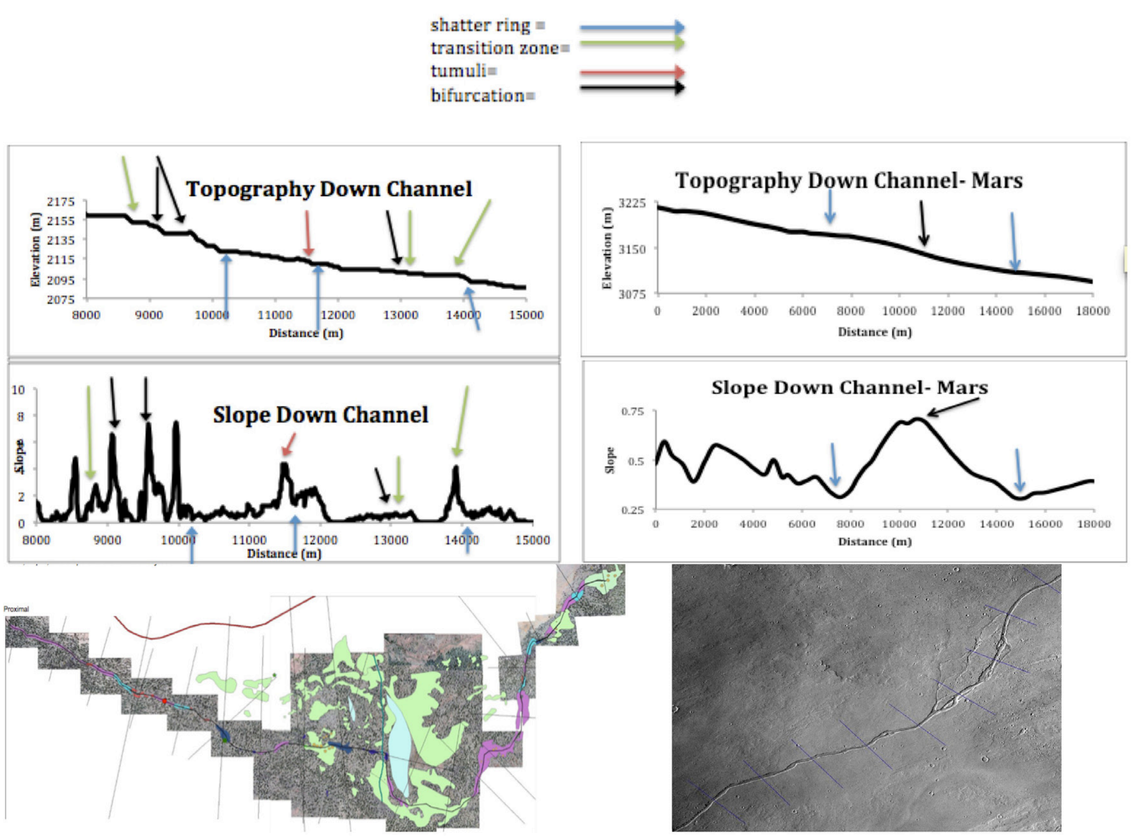



*Figure 4. Labeled channel features along topographic and slope channel profiles for Twin Craters (left column) and Mars (right column). The lines across the channel represent cross-sections taken at 500 meter and 2000 meter intervals respectively.*

circular to elongate and form over active lava channels or tubes, range in size from 100- 500 m in diameter, are relatively abundant, appear as a sudden or abrupt increases in channel width and in some cases still have an internal channel within them, and have a much thicker rim. Due to the very low resolution of the MOLA topographic data (490 meter pixel resolution) detailed slope and topographic characteristics of these features could not be determined.

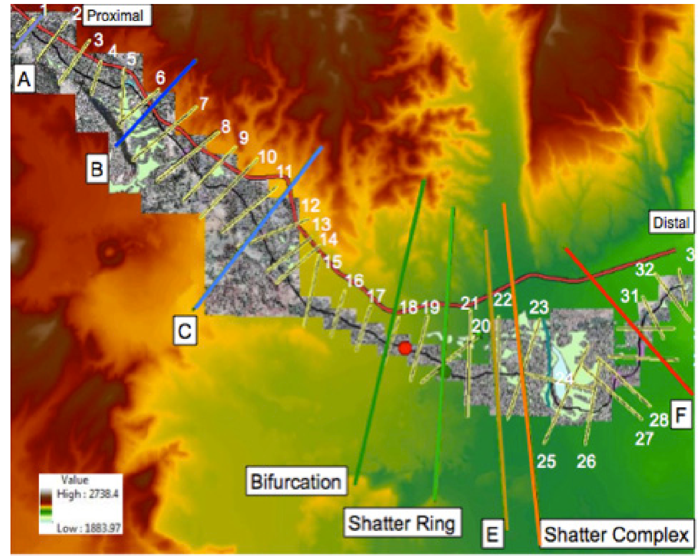
On both Mars and Earth bifurcation of the channel is frequent. In some cases the bifurcated channels flow back into the main channel, whereas in other instances they create new preferred pathways. Based on DEM slope analysis bifurcation zones occur in areas of locally high slope (Fig. 4).

## DISCUSSION

Based on the DEM results for each associated feature, there appears to be a relationship between the channel variations and slope along the Twin Craters Flow. Shatter ring features occur where there is a transition from steep to flat while bifurcation occurs in association with sleeper slopes. These relationships suggest that rapid slope increases cause bifurcation to occur, possibly due to a localized reduction in pressure, while sudden decreases result in shatter ring features due to pressure increases or fluctuations.

On a broader scale (Map 1), as the flow traveled southeast away from its vent, it ultimately interacted with two limestone ridges that blocked its path and caused a backing up of pressure throughout the system. This pressure buildup therefore likely resulted in the observed a'a breakouts coming from the pahoehoe flow as the system was trying to bypass the ridge.

Because no apparent ridges or sharp elevation features are observed on Mars, local slope/pressure relationships may be the primary mechanism causing the observed channel features. Additionally, since the observed channel features on Mars appear similar to those in the Twin Craters flow based on remote sensing imagery, it is plausible that the observed channel features on Mars are also shatter ring-related features.




*Map 1. ArcGIS map of the Twin Craters flow transposed on top of DEM data. Yellow cross sections represent 500 meter intervals.*

Despite the limitations of the MOLA topographic data, Martian bifurcation zones appeared to exhibit similar local high slope characteristics as those observed at the Twin Craters Flow. Additionally, since some of the shatter features on Mars appear to occur in bends in the channel, this could account for several instances of localized pressure backup that leads to the development of these shatter ring features and add some validity to Orr's (2009) hypothesis.

## CONLUSION

The following observations enable me to conclude that the Tharsis Region of Mars is most likely volcanic in origin:

1. Detailed field observations, remote sensing imagery, and GIS mapping of the volcanic Twin Craters Flow and Tharsis Region suggests a complex slope/pressure relationship is primarily responsible for the localities of bifurcation and shatter ring features.

2. Shatter ring features, bifurcation, and channels appear to exhibit similar geomorphic characteristics on both Mars and Earth.

3. Shatter ring features only form from slope/pressure relationships; therefore their presence on Mars suggests that a fluvial origin is doubtful.

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