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PROCEEDINGS OF THE TWENTY-FIFTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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Research Advisor: Patrick Spencer

VOLCANIC OR FLUVIAL CHANNELS ON THE SOUTH-EAST RIFT APRON OF ASCREAUS MONS
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ORIGIN OF SINUOUS CHANNELS ON THE SW APRON OF ASCRAEUS MONS AND THE SURROUNDING PLAINS, MARS

ZACHARY SCHIERL, Whitman College
Research Advisor: Patrick Spencer

INTRODUCTION

Ascraeus Mons is one of three large shield volcanoes, collectively known as the Tharsis Montes, located along a NE-SW trending lineament atop the Tharsis Bulge on Mars. Ascraeus is the northernmost, largest, and presumably the youngest of the Tharsis Montes, with an edifice that measures 375 x 870 km and rises nearly 15 km above the surrounding plains (Plescia 2004). The main flank has been active throughout much of Mars' geologic history yet some of the summit calderas show signs of activity as recently as 60 Ma (Robbins et al., 2011).

Ascraeus Mons is bounded to the NE and SW by fan shaped rift aprons consisting primarily of lava flows whose source in not immediately apparent (Plescia 2004, Murray et al. 2010). These aprons appear to be the source of lava flows that extend for hundreds of kilometers out onto the surrounding plains. Spacecraft images, beginning with Viking in the 1970's, revealed that the SW rift apron of Ascraeus Mons is cut by numerous sinuous channels, many of which originate from large, linear, and bowl shaped depressions known as the Ascraeus Chasmata. The length of these channels varies widely but some extend for several hundred kilometers onto the flatter plains east of the rift apron.

The sinuous channels often display a very complex morphology. Features such as braided channels, streamlined islands, and anastomosing channel patterns have led to debate over the origin of the channels. Some studies have supported a fluvial origin (Murray et al. 2010) while others have proposed a volcanic origin (Bleacher et al. 2010). Recently, it has been shown that one of the longest sinuous channels on the Ascraeus rift apron transitions into what is interpreted as a roofed-over lava channel or lava tube at its distal end, thus supporting the idea that the entire feature is volcanic (Bleacher et al. 2010). In addition, field observations of recent lava flows on Hawai'i have shown that lava flows are capable of producing features that are normally associated with fluvial processes, such as the complex braided and anastomosing channels and streamlined islands that are observed in the Ascraeus sinuous channels (Bleacher et al. 2010). Arguments against a volcanic origin include the fact that the amount of lava needed to erode channels of the size observed is much larger than the observed volume of Martian lava flows (Murray et al. 2010). However, this objection fails to consider the fact that the sinuous channels could be constructional features, as are the similar channels observed in Hawai'i.

METHODOLOGY

In order to make a more broad and definitive statement about the origin of the Ascraeus sinuous channels, we have mapped out all the sinuous channels in the NE quadrant of the Ascraeus rift apron (collaborating authors have similarly mapped the SE, NW, and SE quadrants) as well as a number of channels on the surrounding plains in the vicinity of Tharsis Tholus. In addition to mapping out the sinuous channels, we also identify and map a variety of associated features on the Ascraeus apron based on geomorphologic characteristics. Raised vents, impact craters, collapse pits, elongated depressions, sinuous chains of collapse pits, and shallow channels within lobate flow features are mapped along with the sinuous channels in an attempt to identify significant spatial and temporal relationships between these features and the sinuous channels.

We use a mosaic of daytime thermal infrared images from Mars Global Surveyor's Thermal Emission Imaging System (THEMIS) instrument as our basemap. This data set has a resolution of 230m/pixel

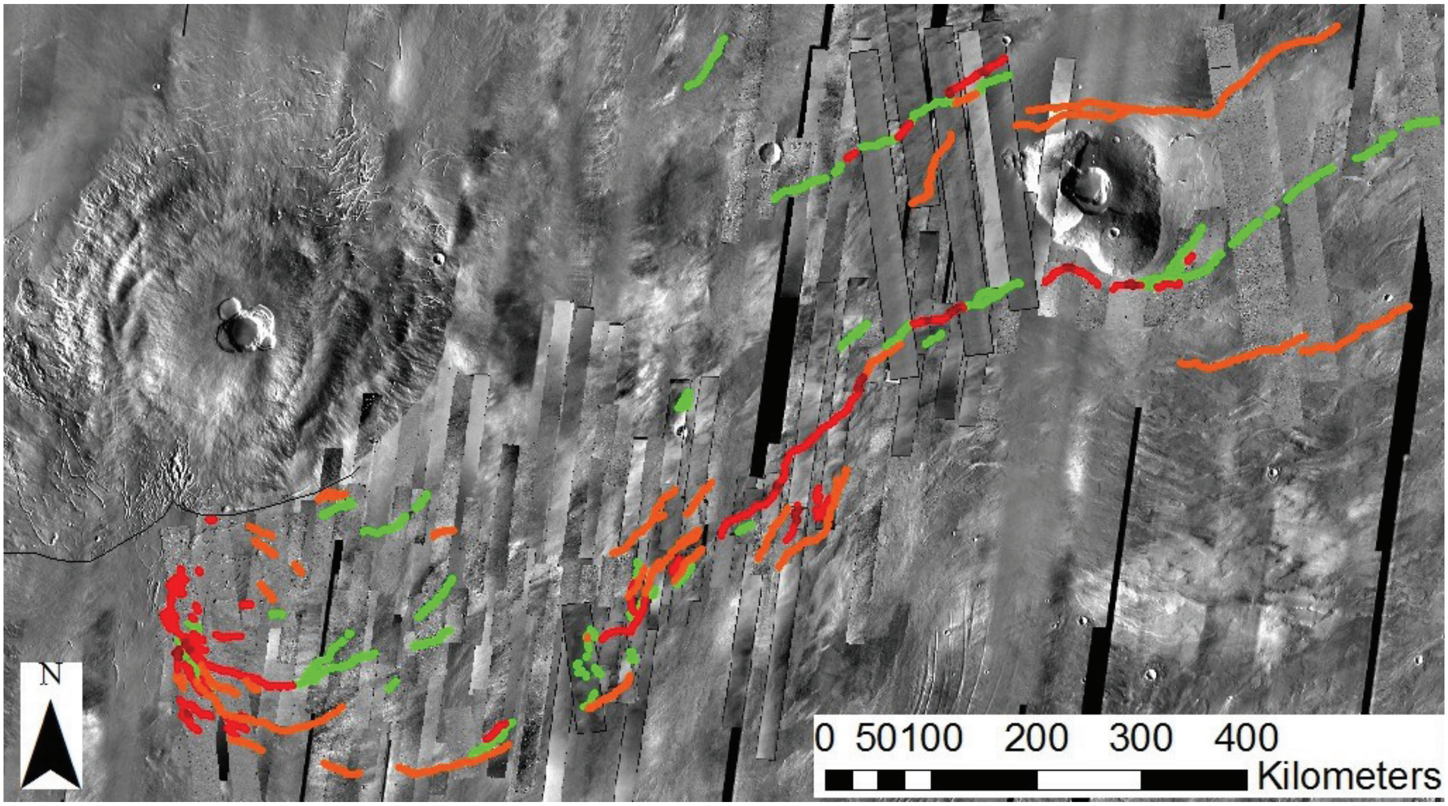

Figure 1-Distribution of sinuous channels (red), collapsed lava tubes (green), and lava flow channels (orange) on the Ascraeus Mons rift apron and surrounding plains extending east to Tharsis Tholus (shield at upper right).

and is used to identify larger features and serve as a reference for georeferencing higher resolution data sets. Most mapping was completed using THEMIS visible light images which have a resolution of 19m/pixel. Higher resolution data sets from Mars Orbital Camera (MOC) (1.5-12m/pixel), Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) (6m/pixel), the High Resolution Imaging Science Experiment (HiRISE) onboard MRO (0.3-1m/pixel), and the High Resolution Stereo Camera (HRSC) on board the Mars Express orbiter (2-30m/pixel) were also used in places to examine features in greater detail. Gridded elevation data from Mars Orbiter Laser Altimeter (MOLA) is used to produce topographical profiles along the channels and to create contour maps from which we infer the direction of flow. All data is projected using the Mars2000 Equidistant Cylindrical coordinate system.

We also observe features in the Pōhue Bay Flow and 1907 Mauna Loa flow on the island of Hawai'i that appear to be analogous to some of the channel and tube features observed on Ascraeus.

RESULTS

We map out all distinct sinuous channels on the apron down to a resolution of about 12m; the approximate resolution of the visible THEMIS images which provide the most complete, high resolution coverage of the study area. We define a sinuous channel to be any non-linear, continuous, negative relief feature that is topographically controlled (i.e. proceeds in a direction consistent with the downhill flow of a fluid). Our mapping leads to two important observations: first, that the morphology of the sinuous channels is variable depending on their location relative to the rift apron, and secondly, the sinuous channels are frequently associated with sinuous chains of elongated collapse pits, which, as will be described shortly, we interpret as collapsed lava tubes.

Morphology

Mapping reveals that the sinuous channels in the study area can be divided into two broad categories based on geomorphologic characteristics (Fig 2). In general, more complex channels are located on the

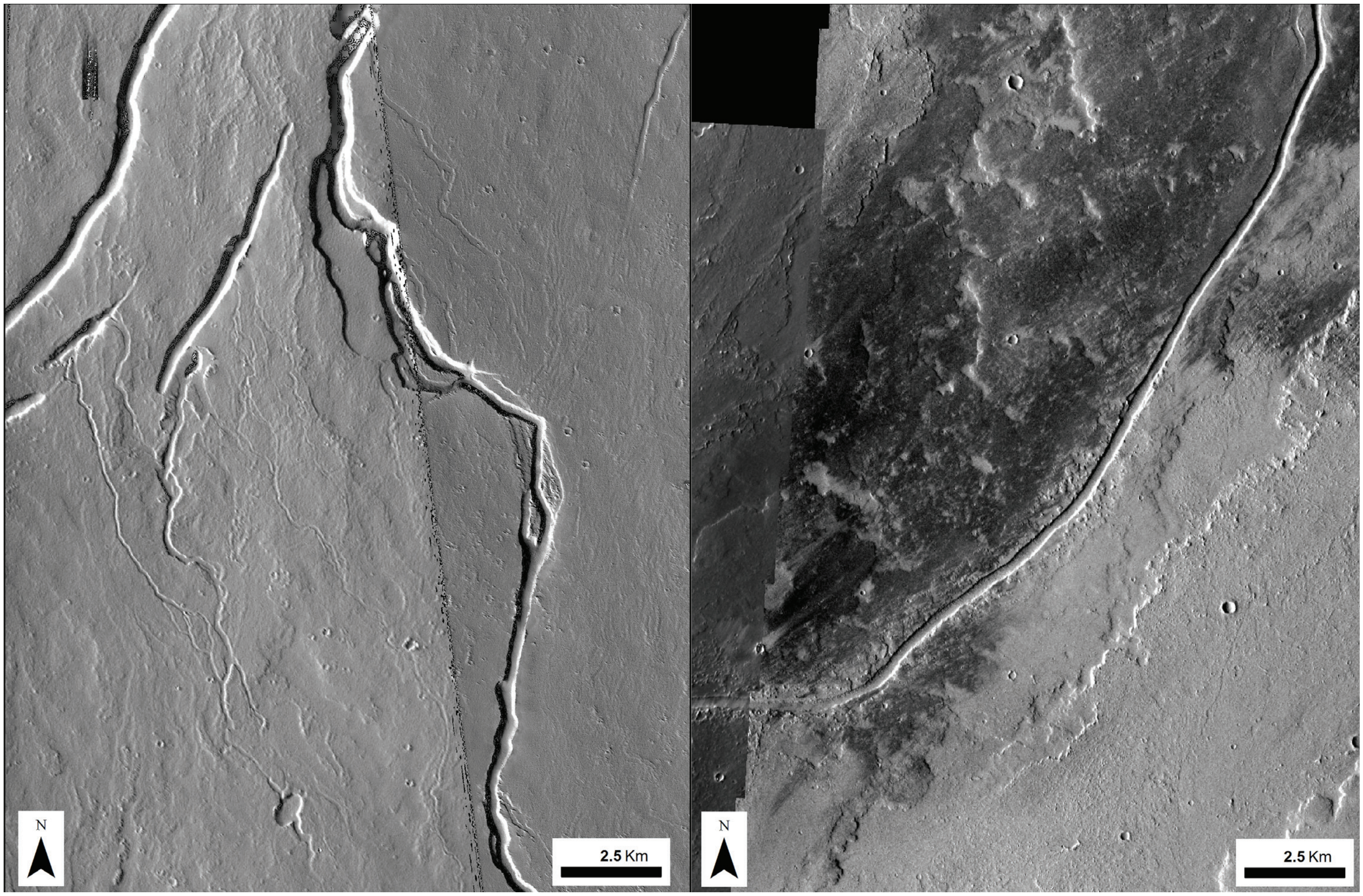

Figure 2-Comparison of the two different types of sinuous channel observed on the Ascraeus Mons rift apron and plains. (LEFT)-typical sinuous channel observed on the proximal apron, with nested channels, channel islands, and anastomosing channel pattern. Downhill direction is to the lower right. Such channels generally originate from the linear depression features at upper left. (RIGHT)-typical sinuous channel observed on the distal apron and plains, displaying a simpler morphology, a straighter channel, levees, and a general lack of features such as islands or tributary channels. Downhill direction is to the upper right.

proximal apron, closest to the main flank of Ascraeus Mons while the simpler channels are located on the distal apron or on the surrounding plains. The complex, proximal channels generally have an intricate network of nested, braided, and anastomosing channels, often with multiple distinct channels originating from the same source. The distal portions of these channels are often indistinct and they do not appear to be associated with any discrete lava flow. The proximal channels also appear to be the youngest features in the study area as there are no instances of them being cross-cut by any other type of feature save for other sinuous channels.

The second type of channel displays a comparatively simple morphology and are found predominantly on the distal apron and surrounding plains. The simple, distal channels are generally straighter and rarely have branching tributaries. Streamlined islands are still sometimes found within the channel but braided and nested channels are rare. This category of channels also appears older as the source of the channels is often buried by more recent flows. The channels are also observed to be cross-cut by linear scarp or fault like features in several areas. Finally, the distal channels often are often bordered by lobes which appear to be the result of material overflowing the channel walls and building up levees on either side.

Distribution and Slope

An analysis of the geographic distribution of the sinu-

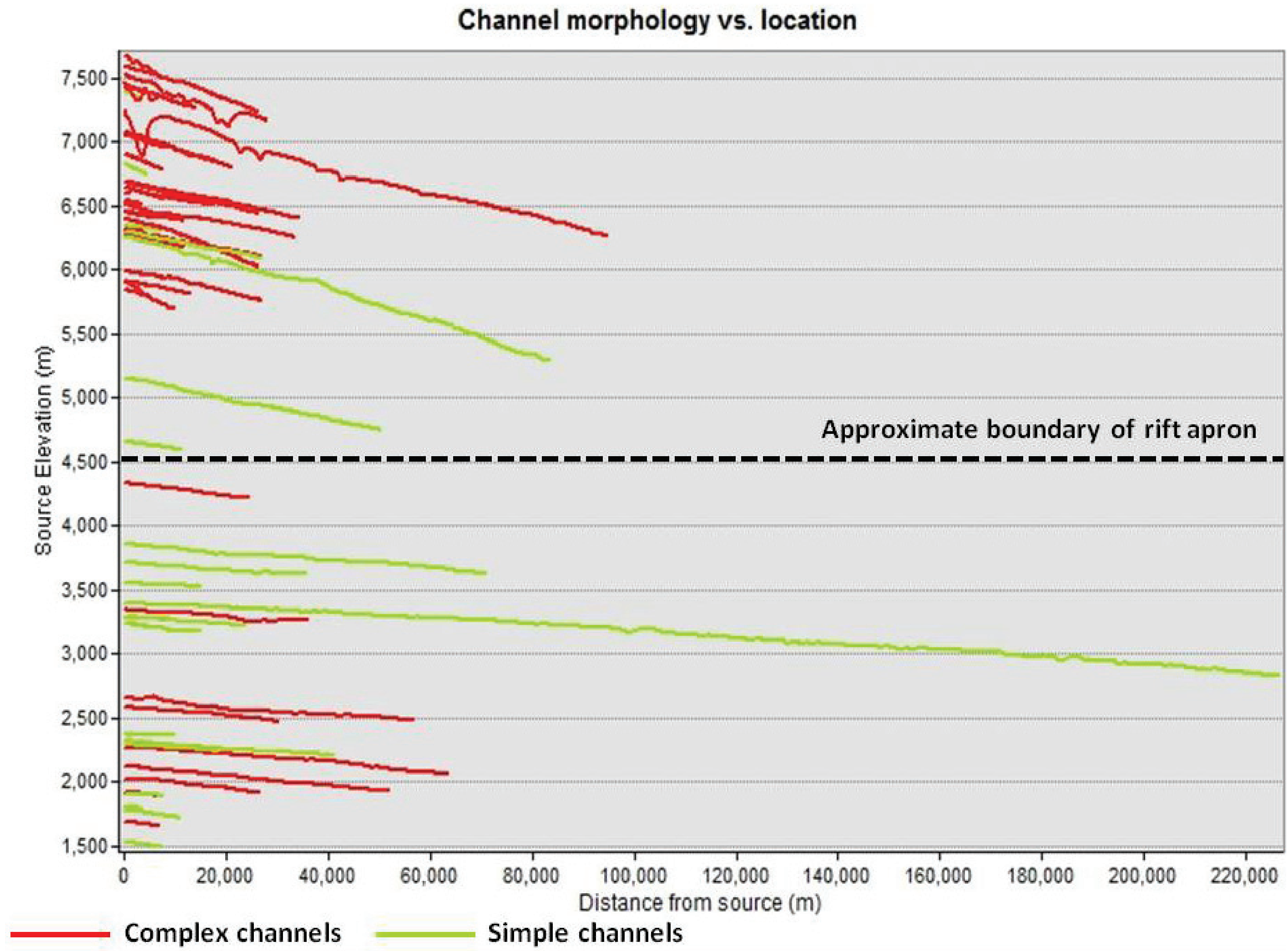

Figure 3-Topographic profiles for all mapped sinuous channels sorted by morphology and location. Red lines represent channels with a complex morphology which are found predominantly on the proximal apron. Green profiles represent simple channels which become more common with increasing distance from the rift apron.

ous channels shows that the simple channels increase in abundance with increasing distance from the rift apron although there are still a few extremely complex channels found at these distances (Fig 3). Using elevation data from MOLA, we create topographic profiles along each of the 65 mapped channels using ArcGIS. From these profiles, we are able to derive the average gradient of the channels. While slopes across the study area are generally low (less than 2˚), these profiles reveal that the average gradient of the complex channels is 0.92% while the average gradient of the simple channels is 0.56%. The average slope of the sinuous collapse pit features is 0.55%.

DISCUSSION

Mapping other features in addition to the sinuous channels allows us to see that the channels are not isolated features, but instead are often connected to other types of features. Most notably, the sinuous channels frequently transition into sinuous chains of elongate collapse pits (and vice-versa). In other places the channels transition into wide, shallow channels that clearly represent flow with a lobate lava flow.

Terrestrial Analog: Hawai'i

The sinuous chains of collapse pits observed in the study area are inferred to be collapsed lava tubes on the basis of morphological similarities with collapsed lava tubes in Hawai'ian lava flows. Recent basaltic lava flows on Hawai'i offer a potential earth analog for the Ascraeus Mons rift apron and lava flows from both a compositional and weathering standpoint.

Since the rate of weathering on Mars is drastically lower on Mars than it is on Earth (due to its thin atmosphere and lack of sustained liquid water on the surface), only very recent lava flows on Earth will be as pristine as Martian flows.

Aerial photographs of the Pōhue Bay lava flow on the SW flank of Mauna Loa and the 1801 Hualalai Flow show sinuous chains of collapse pits that are similar to the collapse features that are ubiquitous on the plains surrounding the Ascraeus rift apron (Fig 4). From the ground, the collapse features are observed to be associated with an underlying lava tube (Fig 5). In both cases, the length of the collapse features varies while the width remains nearly constant over the areal extent of the feature. If indeed the sinuous chains of collapse pits on Ascraeus are analogous to the Hawai'ian features, then the consistency of the relationship between lava tubes and sinuous channels across the Ascraeus rift apron and plains provides a strong link between the sinuous channels and a feature of known volcanic origin. Furthering this link is the fact that the Pōhue Bay Flow transitions into a broad, constructional lava channel upstream of the collapse structures in Figure 5, which provides supporting evidence that lava channels can alternate between a channel and tube morphology, just as is observed on Ascraeus (Jurado-Chichay & Rowland 1995).

Figure 4-Aerial (TOP) and field (BOTTOM) photos of collapsed lave tube structures in the Pōhue Bay Lava Flow, Hawai'i. Note the lava tube associated with collapse pit in bottom photo. Collapse structure in bottom photo measures approximately 50x20m and is roughly 25m deep.

We also observe several teardrop shaped islands within an overflow channel near the upstream end of the Pōhue Bay collapse pit section. These islands are generally about 10m in length with a tapered downstream end. They, rise, on average, about 1 m above the base of the channel. Although the scale of these features is much smaller than the streamlined islands observed in the Ascraeus sinuous channels, it is nevertheless another demonstration that lava flows are capable of producing features that are normally associated with fluvial processes. Other studies have also shown that larger scale islands can be produced in lava channels as the result of surges of lava down the channel (Garry 2007). In addition, eruptive volumes on Mars are significantly larger than volumes for Hawai'ian lava flows. Estimates of effusion rates for the Tharsis volcanoes range from 19,000-29,000 m3/s for some of the largest flows compared to 80-890 m3/s for the channels in the Pōhue Bay Flow, and 35-100 m3/s for the overflow channels in which the islands were observed (Garry 2007; Jurado-Chichay & Rowland 1994). Larger eruption rates would be expected to produce similar features on a much larger scale.

Spatial Relationships

Mapping out a sinuous channel/tube system across large distances is difficult, especially on the distal apron and plains where the channels are frequently buried by more recent activity. Nevertheless, it is possible in a few locations to trace a single feature across several hundred kilometers. We have accomplished this for four features in the vicinity of Tharsis Tholus, where there have been fewer subsequent flows to cover the channel. All four of these features clearly

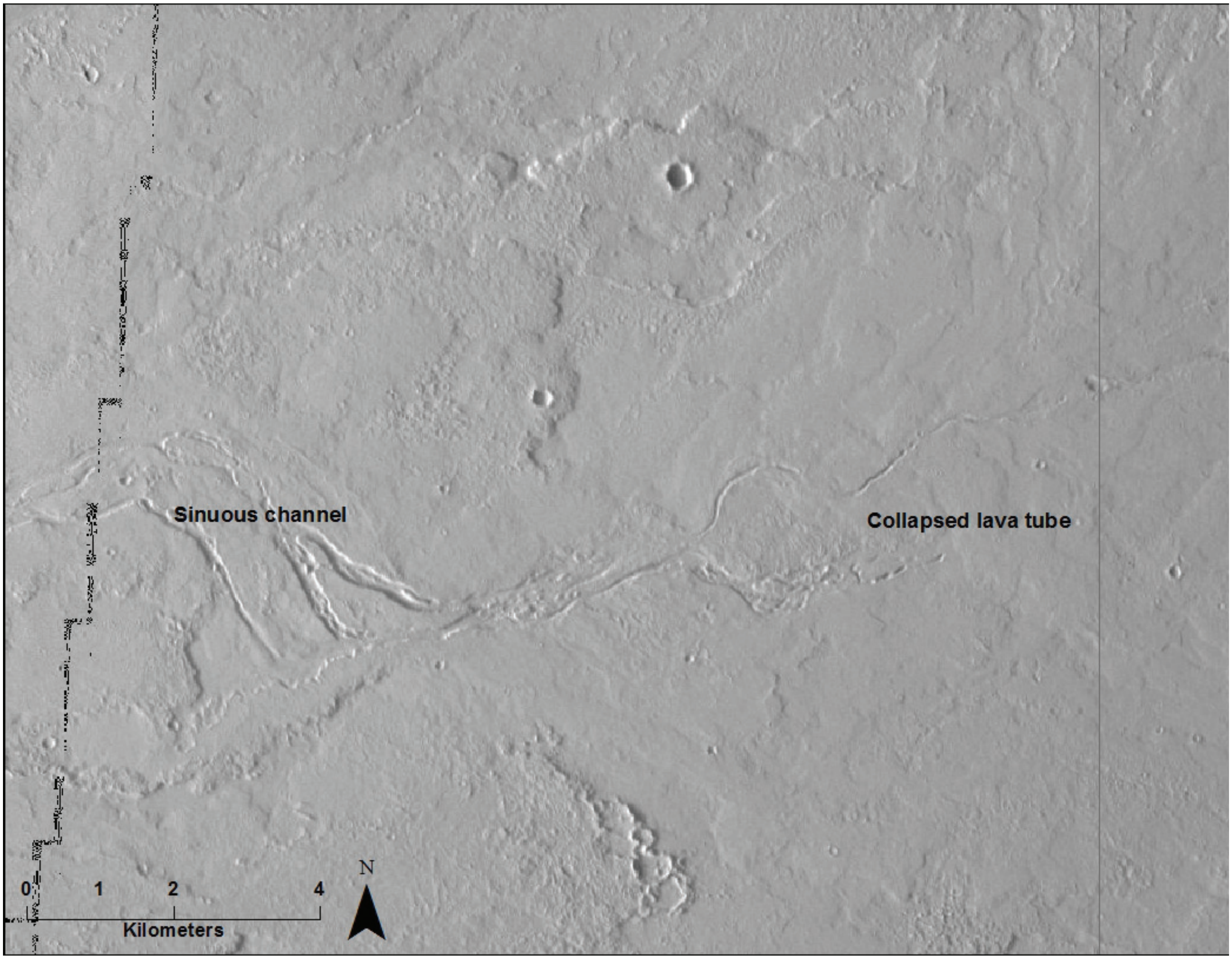

Figure 5-A sinuous channel with multiple branches transitions into a collapsed lava tube section near Tharsis Tholus. The collapse structures here are 80-100m wide. Downhill direction is to the right. (THEMIS V063070181)

display a mixed sinuous channel/collapsed lava tube/lobate lava flow morphology, establishing that the relationship between a sinuous channel and lava tube on the proximal apron noted by Bleacher et al. 2010 is consistent across the study area (see Fig 5 for example).

We also observe a number of other spatial relationships that are consistent with a volcanic origin for the sinuous channels. Individual sinuous channels extend across much greater distances than do lobate lava flows in the same area. This relationship is due to the fact that lava flowing along a channel or tube is insulated, allowing it to travel further than a lobate flow which would have a much greater surface area and therefore cool faster (Jurado-Chichay & Rowland 1994). The collapsed tube features also become more numerous with increasing distance from Ascraeus Mons while sinuous channels become less numerous. Because lava tubes provide an even greater level of insulation than lava channels, we would therefore expect to see tubes extending to greater distances before the lava cooled to the point of solidification (Bleacher et al. 2007). Bleacher et al. 2007 also noted that long-lived, stable eruptions tend to produce tubes while sporadic and transient eruptions form channels. A qualitative analysis of impact crater densities in the study area indicate that the distal plains (where the tubes are most common) are indeed significantly older than the proximal apron which is consistent with the types of volcanic features we observe in this area.

CONCLUSIONS

The fact that a large number of the sinuous channels, both on the apron and on the surrounding plain, transition into lava tubes or channels that are clearly associated with a discrete lava flow makes a strong case that the entirety of the sinuous channel features were produced by volcanic processes. The difference in morphology between the simple and complex channels is likely tied to the observed difference in slope rather than the mode of formation. The preponderance of lava tubes versus channels on the surfaces with shallower slopes is likely the result of lava tubes being more likely to form on shallower slopes where the flow velocity is lower (Sakimoto et al. 1996).

However, this interpretation does not exclude the possibility of subsequent fluvial alteration of the channels, a phenomenon that could also help explain the increased complexity of the proximal channels (Bleacher et al. 2010). Another possibility is that magma was erupted onto a surface that had been previous dissected by fluvial processes in which case we would expect lava to preferentially flow along any pre-existing channels. However, without information about subsurface geology, this is a very difficult theory to test. If indeed the sinuous channel features on the Ascraeus apron are the result of volcanic processes, this could have implications for other areas of Mars as well. Sinuous channels that are similar morphologically to the Ascraeus features are found across Mars on a variety of scales, with most having traditionally been attributed to some form of fluvial activity. Our conclusions suggest that additional study into the origin of such features in volcanic regions may be merited.

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