The origin and modification of a trough in the Nili Fossae, Mars

Martin Wong
Department of Geosciences, Williams College, 947 Main St, Williamstown, MA 01267
Faculty sponsor: Reinhard A. Wobus, Williams College

Erin R. Kraal
Department of Geology, Washington and Lee University, Lexington, VA 24450
Faculty sponsor: Sam Kozak, Washington and Lee University; .Martha Gilmore, Washington and Lee University

INTRODUCTION

The Nili Fossae, centered at 23° N and 282° W, is a series of curved troughs located to the northeast of the Syrtis Major shield volcano and to the northwest of the Isidis impact basin (Figure 1). The largest trough in the Nili Fossae measures 550 km in length and varies between 10 and 30 km in width. It begins to the south in Hesperian age volcanic flows from Syrtis Major, extends through Noachian aged cratered units, and ends near the North-South dichotomy, a division between the older cratered highlands in the southern hemisphere and the younger, smoother lowlands to the north. The trough has scarp-like walls, a smooth floor, and curves gently, approximately concentric to the Isidis Basin. The trough has been interpreted by various authors in large scale regional maps as a trough, a fracture, and a graben (Greenley and Guest, 1987; Spitzer, 1980; Craddock, 1994). However, its smooth, flat floor, the development of tributaries along the edge of the trough, and its large size in relation to other tectonic features in the area suggest at least a more complex history, if not a different origin. Craddock (1994) suggested that the Nili Fossae may be related to the impact event which created the Isidis Basin during the late Noachian (~4.2 Ga). The purpose of this study was to examine in detail this largest trough in the Nili Fossae region to determine its origin and subsequent modification.

METHODS

To determine the processes which had created and modified the trough, we mapped the area with Viking 1 and 2 images. We used images with a resolution of 0.087 - 0.140 km/pixel. Images were viewed using Photoshop and NIH Image software. Mapping allowed us to identify geomorphological features which may indicate which processes had been involved in the formation and modification of the trough. To further test for a tectonic origin, we measured the height of the western wall of the trough to compare it to the expected displacement pattern of a graben. The height of the wall was measured at regular intervals along the trough using a shadow method (Yingst and Head, 1997). We also compared the orientations of the trough and the tributaries to other tectonic features in the region.

RESULTS

Mapping. During mapping, we observed a number of features in the trough. The trough itself has scarp-like walls and a smooth, flat floor relative to the surrounding cratered highlands. The floor of the trough is not featureless however. Some channels and lineaments are present in the floor of the trough. The channels on the floor of the trough typically run sub-parallel to the direction of the trough. Lineaments are typically found parallel or perpendicular to the trough walls. Lineaments sometimes appear to define the boundaries of lobate flows within the floor of the trough.

Wall height. Although wall height is variable along the length of the trough, measurements of the wall height seem to suggest a pattern. The wall height generally seems to increase from the northern end of the trough to the southern end. Wall height is 0 at either end because this is where it merges with the surrounding terrain. Due to the shadow measurement method we used, the measured heights of the wall are not precise as absolute values, but are relevant in relation to each other.

Regional tectonics. The fractures near the trough provide a basis for establishing a regional tectonic pattern. We measured the orientation of 14 fractures around the trough and plotted them on a rose diagram. The fractures occur in two distinct sets. The primary set is oriented at 30°-40° and the secondary set is oriented at 320°-330°. The orientation of the trough was measured at 50 km intervals to compare it with this regional tectonic pattern. The trough has an orientation similar to the primary set of fractures, 30°-50° (Figure 2). The orientation of

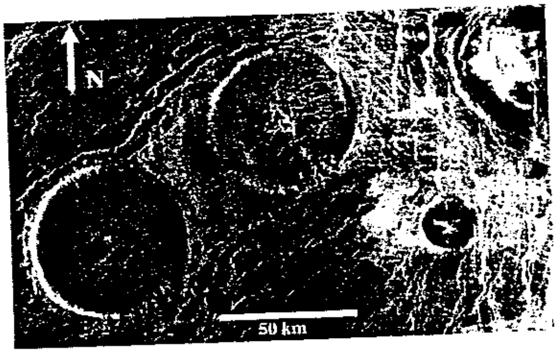

Figure 1. A steep-sided dome, located at (12°N, 8°E).

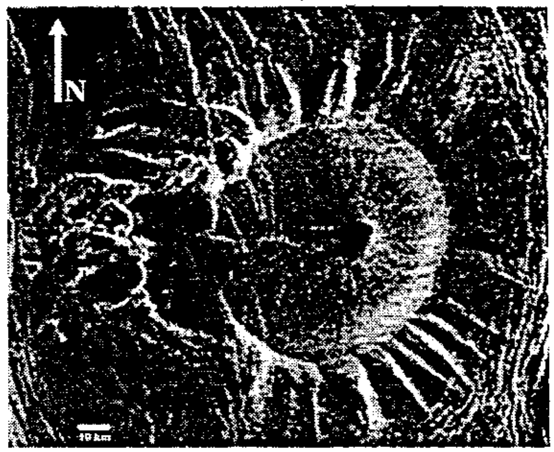

Figure 2. A tick, located at (18°N, 6°E).

Figure 3. An anemone, located at (15°S, 197°E).

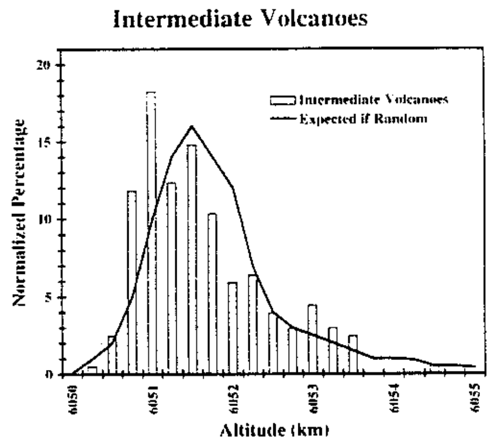

Figure 4. Graph of the distribution of the intermediate volcanoes as a function of altitude. The mean is 6051.6 km.

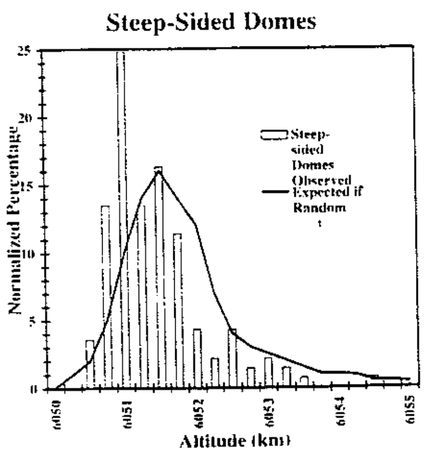

Figure 5. Graph of the distribution of steep-side domes as a function of altitude. The mean is 6051.8 km.

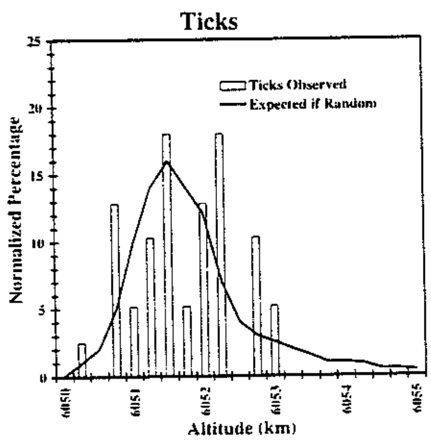

Figure 6. Graph of the distribution of ticks as a function of altitude. The mean is 6051.7 km.

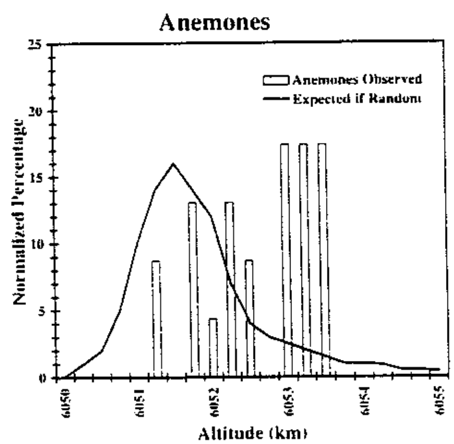

Figure 7. Graph of the distribution of anemones as a function of altitude. The mean is 6052.6 km.

the tributaries along the side of the trough were also measured. The tributaries also have a similar orientation to the fractures. The tributaries are oriented primarily at 320°-330°, the same orientation as the secondary set of fractures (Figure 3).

DISCUSSION

Origin. The steep scarp-like walls, rectangular cross section, and flat floor suggests that the trough is a graben. A fluvial origin, either through catastrophic outflow or by more gradual processes, was ruled out due to the lack of streamlining of features, scour marks, v-shaped cross section, and other characteristic fluvial features.

The wall height data also supports a tectonic origin. Ideally, a graben displays maximum displacement in its center and minimum displacement near its ends (Burgmann et al, 1994). The trough has a minimum wall height near its northern end and increasing wall height towards the southern end where it meets the Syrtis Major shield volcano. This would suggest a graben with volcanic flows from Syrtis Major covering the southern half. The increase in wall height towards the southern end of the trough represents increased displacement towards its original center.

The orientations of trough and surrounding fractures further suggest a tectonic origin. We interpret the two main sets of fractures around the trough as defining a regional tectonic pattern. The orientation of the trough is very similar to the primary set of fractures and thus were probably created by similar processes.

Modification. While fluvial processes were not involved in the formation of the trough, we believe that they have played a significant role in its subsequent modification. The tributaries which have formed along the edges of the trough have a number of unusual characteristics such as theater-shaped heads of first order tributaries, a relatively constant width from source to outlet, high and steep valley walls, and frequent hanging valleys. In addition, the orientation data show that tributaries are structurally controlled by the regional tectonic pattern. Using the criteria established by Laity and Matlin (1985), we interpret these tributaries to be sapping channels fed by the seepage of ground water. The water released from this seepage may have created the small channels on the floor of the trough. We also believe that mass wasting processes such as slumping and debris flows have played an important role in the modification of the trough. Mass wasting processes could have created the lobate flows and the relatively smooth floor of the graben. The seepage of ground water may have facilitated mass wasting processes by reducing pore pressure in the sediment.

Regional Setting. One interesting aspect of the trough is its proximity and apparent geometric relationship to the Isidis impact basin. The primary set of fractures and the trough are concentric with the Isidis Basin while the secondary set of fractures is radial to the basin. This suggests that the formation of the trough and the regional tectonic pattern are related to the impact event which created the Isidis Basin. Melosh and McKinnon (1980) proposed the Ring Tectonics theory which suggests that tectonic features, including extensional features such as graben, may be generated through an impact event. They suggested that these features would form both radial to and concentric with the impact basin. The one requirement for the theory is that the impactor must be large enough to penetrate the lithosphere. The Nili Fossae has this radial and concentric pattern of tectonic features. In addition, the Isidis Basin is one of the largest recognized impact basins on Mars. The impactor may have been large enough to generate such a tectonic pattern.

SUMMARY

The largest trough in the Nili Fossae is interpreted to be a graben that has been subsequently modified through sapping channels and mass wasting processes. The orientation of the trough and the sapping channels corresponds to a regional tectonic pattern of fractures which is both concentric with and radial to the Isidis Basin. The formation of the trough may be related to the impact event which created the Isidis Basin. The Ring Tectonics theory provides a possible mechanism for the formation of such a tectonic pattern due to an impact event.

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Regional Map of the Nili Fossae

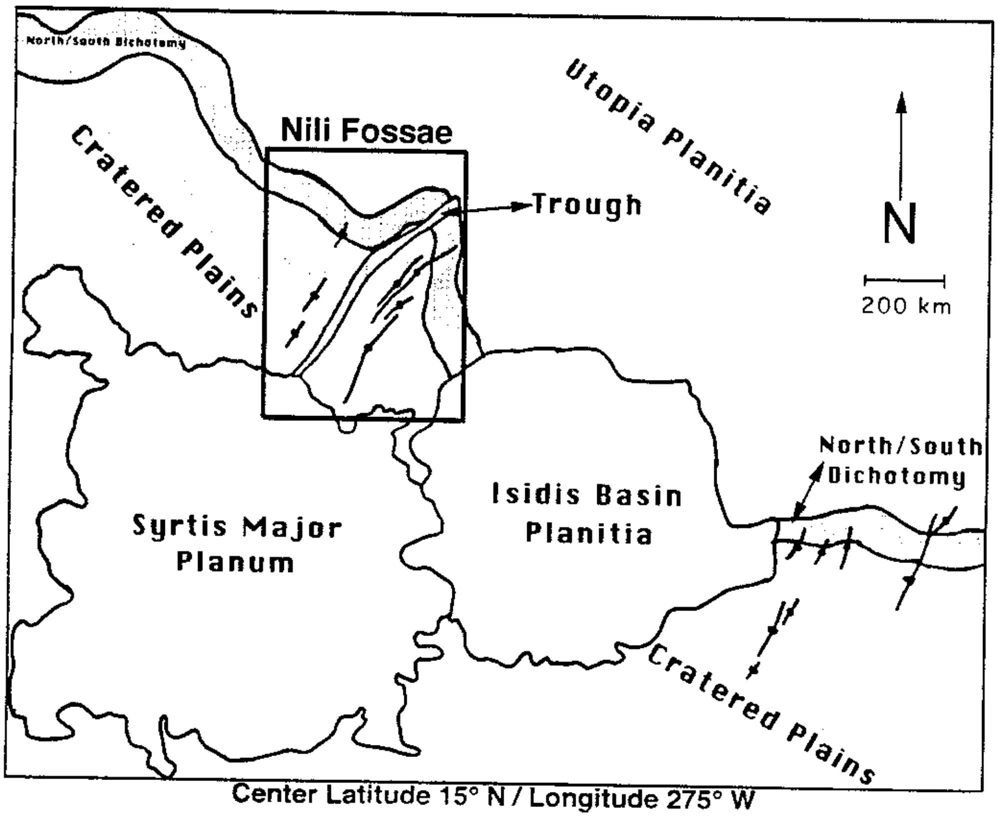

Figure 1 – The area of major geological providences surrounding the Nili Fossae, including the shield volcano, Syrtis Major, and the Isidis impact basin. The Nili Fossae is indicated with a box.

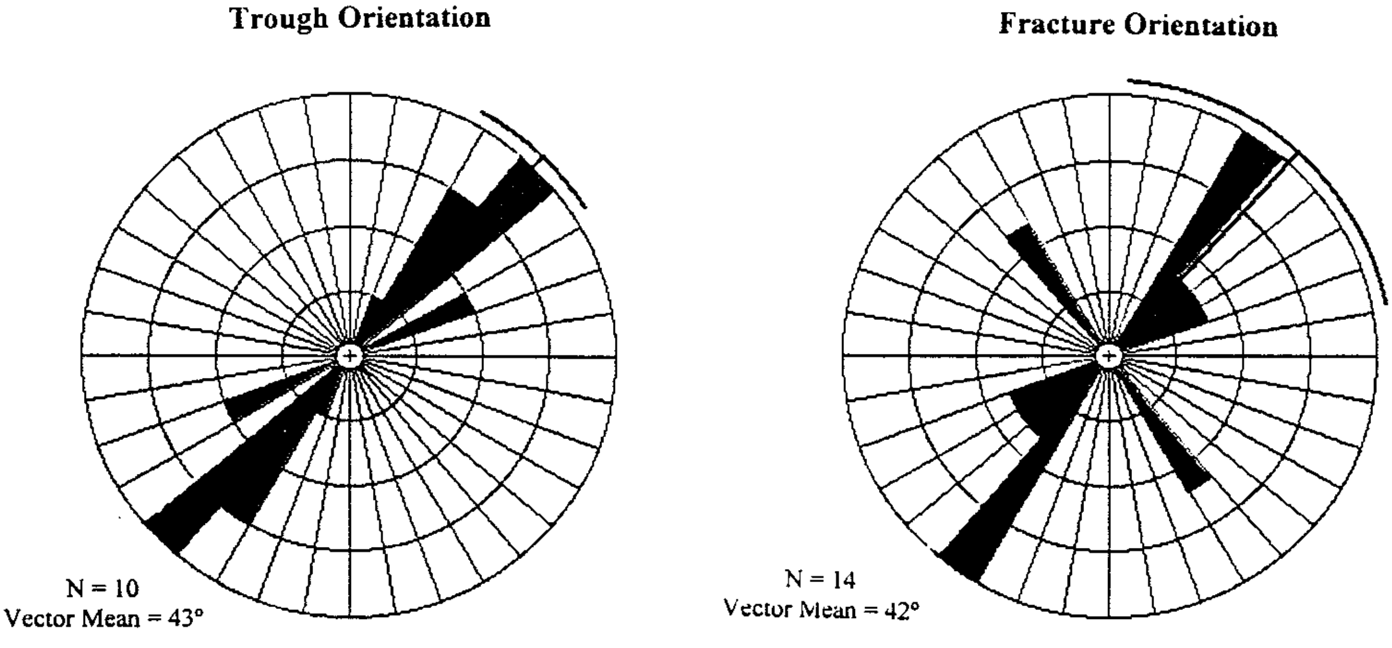

Figure 2 – The trough (left) has a dominant orientation of 30°-50°. The regional fractures have 2 main orientations. The dominant orientation of the fractures (right) is very similar to the orientation of the trough, 30°-40°. The fractures have a secondary orientation of 320°-330°.

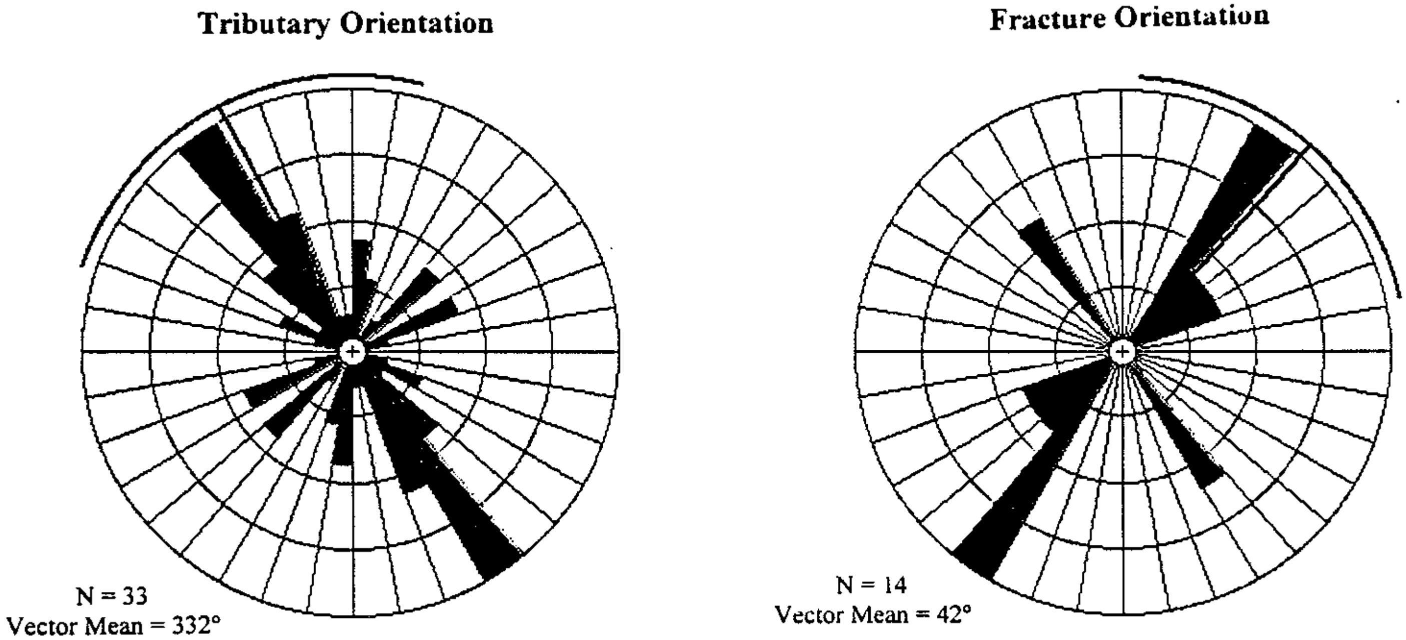

Figure 3 – The tributaries along the side of the trough (left) have a similar orientation to the secondary set of regional fractures. The tributaries are oriented primarily at 320°-330°. For comparison, the orientation of the fractures is shown on the right.

A possible third festoon flow in Atalanta Planitia, Venus

Heather M. Wright
Department of Geology, Whitman College, Walla Walla, WA 99362
Faculty Sponsor: Pat Spencer, Whitman College

Lena S. Fletcher
Department of Geology, Smith College, 98 Green St., Northampton, MA 01063-0100
Faculty Sponsor: Robert Newton, Smith College

INTRODUCTION

The majority of volcanic features on Venus are thought to be of basaltic composition [*Head et al.*, 1992]. One exception to the uniformity of this composition may be the unusual festoon-type flow. Festoons, as defined by *Head et al.* [1992], are "radar-bright flows that show organized patterns of internal streamlines (looped or curved components) analogous to the ridge and flow bands typical of viscous terrestrial lava flows known as coulees." Two festoon flows have been identified and studied in detail [*Moore et al.*, 1992; *Schenk and Moore*, 1992; *Permenter and Nusbaum*, 1994; *Head and Hess*, 1996], one in a lowland plains and one in a highland area. However, a third possible flow, located in the plains region Atalanta Planitia, in the northern hemisphere (latitude 69.8° to 70.8°N, longitude 200.9° to 203.1°E) has not yet been studied in detail [*Head et al.*, 1992]. In Brown University's tabulated catalog of volcanic features on Venus this festoon is cited with a question mark. This indicates that authors are unsure about whether or not it qualifies as a festoon [*Crumpler et al.*, 1997]. Through comparison with the other two festoon flows and terrestrial analogs, we will evaluate whether or not this third flow should in fact be formally classified as a festoon. See Figure 1.

METHODS

Using Magellan data and several computer programs which allow us to interpret the data, we acquired measurements of altitude, reflectivity, emissivity and root-mean-square (RMS) slope and determine the flow area of the third possible festoon. The data measurements were used in the interpretations section to compare the flows and determine whether or not the third flow is a festoon. We also used terrestrial analogs to support these types of conclusions.

In order to identify the characteristic features of festoon flows, we tabulated specific quantitative attributes of the first two festoons. Then, to facilitate comparison, we took the same measurements for the Atalanta flow. The tabulated characteristics of the festoons include data acquired during the Magellan mission, such as emissivity, reflectivity and RMS slope. We used Magellan altimetry data to determine the altitude, topography, and thickness of the flow. We also calculated north-south and east-west dimensions, the area, and the ridge spacing of the ogive-looking features (the alternating light and dark bands on a glacier concave in the direction of flow). Using the thickness and the area values we calculated the volume of the flow. Finally we determined bulk density, yield strength and viscosity using a combination of previous measurements. See Table.

Root-Mean-Square Slope. The RMS slope is a measure of the roughness of the surface due to undulations larger than the wavelength of the radar (12.6 cm) [*Ford et al.*, 1992].

Density. Measurements of reflectivity can be used as indicators of surface density [*Tyler et al.*, 1976]. To make the correlation between density and reflectivity, first we used the Fresnel coefficient formula which relates the reflectivity to the dielectric constant of a material [*Ford et al*, 1993]. The equation is:

$$p = \left(\frac{1-\sqrt{e}}{1+\sqrt{e}} \right)^2 \qquad [1]$$

where *p* is the Fresnel reflection coefficient (reflectivity) of the flow and *e* is the dielectric constant. Fresnel reflectivity measures how well a material can reflect electromagnetic radiation. Therefore, the dielectric constant, which is an indicator of a material's electromagnetic properties, can be related to reflectivity. However, the assumption must be made that the material does not contain any conducting particles [*Pettengill* et al., 1991]. In addition, the equation assumes that the surface is free of sharp discontinuities and is homogeneous [*Tyler et al.*, 1976]. Using Maple software we solved equation 1 for dielectric constant using both the high and low bounds of reflectivity measurements for the Atalanta flow. We then solved for the bulk density of the flow material using a relationship determined by *Olhoeft and Strangway* [1975] for lunar rocks and soils using the equation: