GULLIES ON MARS: THE DEBATE ABOUT FORMATIVE PROCESSES
(Keynote)

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1. Introduction

The discovery of very young gully systems on Mars has occasioned a lively debate about the processes and materials involved in their formation (Malin and Edgett, 2000). The strong interest in these features results because the majority of studies have concluded that flowing liquid water has been involved in their formation and the possible implications for past or present microbiotic life on Mars. This paper reviews the occurrence and morphology of the gullies and the range of hypotheses about their formation.

2. Present and past Martian environments

Early in martian history an active hydrological cycle eroded extensive valley networks and infilled craters with eroded sediment. This period of intensive fluvial activity stopped about 3.7 billion years ago due to the loss of the most of the atmospheric gasses, possibly as a result of the loss of the magnetic field. Since that time the atmospheric pressure has been only a few tens of millibars and average surface temperatures have been well below freezing. Subsequent fluvial activity has generally been limited to occasional floods from subsurface sources (outflow channels) and possibly to melting of snow accumulations on major volcanoes and gully formation elsewhere.

3. Morphology and occurrence of gullies

The gullies that have been the focus of intensive recent study are noteworthy because of their youthfulness, indicated by the lack of superimposed impact craters. The density of impact craters is the primary means of relative age dating on planetary surfaces. Features of appreciable size that lack craters are estimated to be no older than tens of millions of years.

The arrival of the Mars Observer Camera (MOC) high resolution camera into orbit in 1997 permited recognition of features on the surface as small as a few meters in size, resulting in the first definitive recognition of the gully features. The gullies occur primarily on steep slopes in the mid to polar latitudes, generally on the walls of relatively young impact craters or tectonic scarps. A typical setting for gullies is a scarp or interior crater wall that is 200-500 m tall and averages 20° in steepness. The gullies typically display an upper *alcove* incised into the slope, often with crudely dendritic channels merging downslope to a well-defined throat below which is a conical *apron* on the lower part of the host slope (Fig. 1). The apron often displays well-defined distributary channels that have a straight to modestly sinuous planform and often narrow gradually downslope. Although quantitative measurements have not been possible to date, the volume of the apron seems commensurate with the size of the alcove. The close association and similar size of alcove and apron indicate that erosion of the alcoves and downslope transport and deposition of the erosional debris has created the aprons.

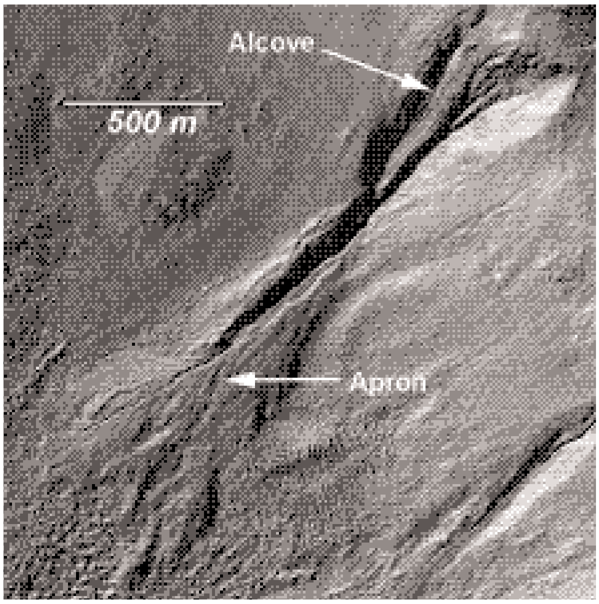

Fig. 1. Part of HiRISE image PSP_001368_ 1400 showing a typical gully system on a Martian Crater wall.

Although there is a wide range of gully morphologies, a few generalizations are possible:

1). The gullies are most common at mid-latitudes, with a preferance toward occurrence on pole-facing slopes, at higher latitudes the orientation bias is less strong (Berman et al., 2005).

2). Gully alcoves generally originate at a consistent elevation on crater or scarp walls, sometimes exposing layered or bouldery rocks (Fig. 2). (Malin and Edgett, 2000; Gilmore and Phillips, 2002). In a few cases gullies occur at multiple elevations. Smaller gullies are often incised solely into thick, fine grained, and possibly volatile rich "pasted-on" terrain on crater walls and scarps, as in the gully at the lower right of Fig. 1 (Mustard et al., 2001; Bleamaster and Crown, 2005).

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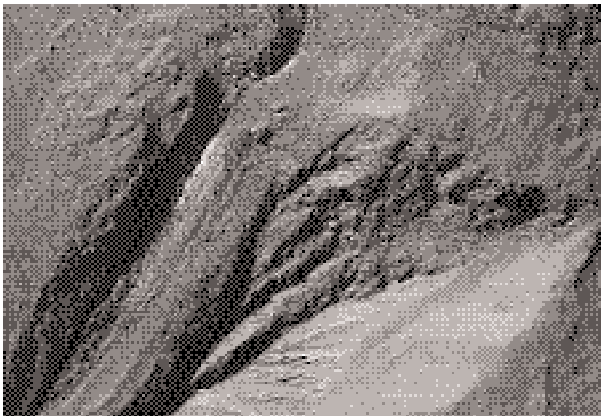

Fig 2. Inset of Fig. 1 showing alcove.

3). Aprons are surprisingly free of coarse debris (>1 m in size) (Fig. 3). Most aprons appear to be steeper than 10°, and many are probably steeper than 20°. Aprons often have sinuous feeder channels and multiple distributaries, and hints of depositional lobes (although levees are rare).

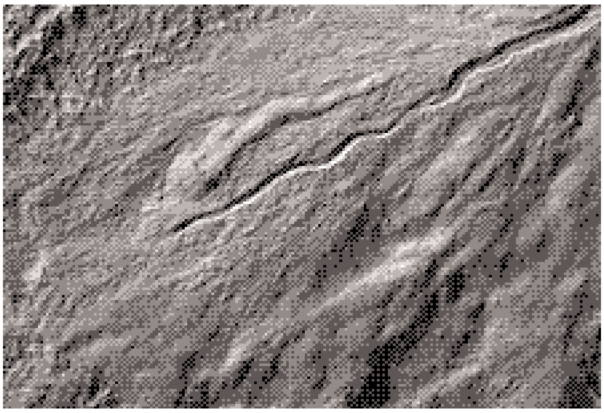

Fig. 3. Inset of Fig. 1 showing apron.

4). Aprons almost always terminate abruptly downslope. Channels extending beyond the apron are rare.

5). Gully systems often show a complex history. For example, in Fig. 1 the apron apex has been deeply entrenched, and multiple ages of debris emplacement are shown in Fig. 3. In some cases alcoves show recent entrenchment into larger, older alcoves that appear to have "healed" by deposition or mass wasting (Fig. 2).

6. Patchy albedo brightening during the past few years on two aprons suggests recent gully activity (Malin et al., 2006).

3. Formation mechanisms

A wide range of formation mechanisms have been proposed. These include:

- Flow from groundwater (Malin and Edgett, 2000; Gilmore and Phillips, 2002; Heldmann and Mellon, 2004; Márquez et al., 2005). Observations supporting this are the common elevation of alcoves on crater walls or cliffs, exposure of layered rocks in alcoves, and difficulties mobilizing liquid water in the modern surface environment.
- Explosive eruptions of water or CO_2 (Mellon and Phillips, 2001; Musselwhite et al., 2001).
- Melting of water from seasonal or epochal accumulations of frost, or from melting of "pasted-on" mantles (Costard et al., 2002; Hecht, 2002; Christensen, 2003; Mangold et al., 2003).
- Formation by dry mass wasting or by CO_2 gasses from seasonal sublimation (Treiman, 2003; Shinbrot et al., 2004; Ishii et al., 2006; Bart, 2007).

Distinguishing between these hypothesis is difficult because the steepness of the features means only slight stresses in excess of gravity are required to initiate and maintain flows. The limited mobility of the flows is also indicated by the steepness of the aprons and lack flows beyond the aprons. Examples of possible terrestrial analogs will be presented.

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