EPHEMERAL DARK SPOTS ASSOCIATED WITH MARTIAN GULLIES N.T. Bridges[1], K.E. Herkenhoff[2], T.N. Titus[2], and H.H. Kieffer[2] [1]Jet Propulsion Laboratory (4800 Oak Grove Dr., MS 183-501, Pasadena, CA 91109; nathan.bridges@jpl.nasa.gov), [2]U.S. Geological Survey (Astrogeology Team, 2255 N. Gemini Drive, Flagstaff, AZ 86001-1698; kherkenhoff@usgs.gov, ttitus@flagmail.wr.usgs.gov, hkieffer@usgs.gov)

Introduction: The recent finding of abundant, apparently young, Martian gullies with morphologies indicative of groundwater seepage and surface runoff processes (1) was surprising in that volumes of near-surface liquid water of sufficient quantity to modify the surface geology were not thought possible under current conditions (2,3). This discovery has therefore called into question our current understanding of the stability, transport processes, and geologic role of water on Mars. Reported here are observations of dark spots in the seasonal frost cap confined to Martian gully channels that indicate a surface with distinct thermophysical properties.

Methods: This study grew out of a survey by the first author of gullies in released (as of July, 2000) Mars Orbiter Camera (MOC) narrow angle (NA) camera images within ±65° of the equator. Sixty-two regions on forty-seven images containing one or more gullies were found. Of these, one gully assemblage, located within the northwestern wall of a depression in an unnamed crater in the seasonal frost cap, was found that exhibited dark spots within its channels. These features were identified in a MOC image taken in southern spring (L_s = 185) at a latitude of 63°S (Figure 1a). Following the most recent public release of MOC data (October, 2000), a search was made to find other images of the same area. One image, taken later in the same spring (L_s = 243), was found (Figure 1b) and shows no evidence for any spots. To determine relative brightnesses within images, the MOC frames are currently being radiometrically calibrated to radiance factor (I/F) over the NA bandpass of 0.50-0.90 µm.

Thermal Emission Spectrometer (TES) brightness temperatures acquired at the same time and location as the MOC images were examined to confirm the presence of solid CO_2 and infer regional (3 x 6 km) thermophysical properties. Brightness temperatures at 18 µm (T_{18}) and 25 µm (T_{25}) were compared to CO_2 sublimation temperatures expected for the surface atmospheric pressures at the given season and location (4). TES Lambert albedos (0.3-3 µm bandpass) were also used to infer the presence of frost because the albedo of frost covered regions (4) are generally greater than those in areas lacking frost, which have phase-angle-corrected albedos less than 0.35 (5,6). TES values reported here represent several adjacent TES pixels (efforts to accurately overlay the positions of TES and MOC are ongoing, the results of which will be given at LPSC).

Observations: *Early Spring* The early spring image shows that the spots are located almost exclusively within the gully major and secondary channels and are lacking on the gully alcoves, gully aprons, and the surrounding terrain (Figure 1). The spots are most heavily concentrated within the upper regions of the channels, where shadowing from the nearby wall is strongest, and encompass 0.065 km^2. Their shapes are generally oval, although round, teardrop, and amorphous forms are also present. The long axes of non-rounded spots are generally oriented parallel to local dip and mirror the trends of the channels. They seem to decrease in concentration and elongation with downslope distance. The spots occur both individually and as assemblages. The assemblages are arranged like a string of pearls, with the long axes oriented downslope, and are generally located in the higher portions of the channels. Individual spots vary in size from the limit of resolution (4.4 m pixel^{-1}) to 30 x 100 m, with spot assemblages having lengths up to 250 m. The calibrated MOC brightness of the illuminated spots is lower than anywhere else in the non-shadowed portion of the image and is in marked contrast to higher brightnesses in the non-spot channel material and surrounding terrain. Regional T_{18} and T_{25} brightness temperatures are 143-147 and 141 K, respectively. The TES-derived regional Lambert albedo is 0.34.

Late Spring In the late spring the same gully channels lack spots and instead contain dark material (Figure 1b). Regional TES T_{18}, T_{25}, and Lambert albedo values are 263-266 K, 263-268 K and 0.16-0.17, respectively.

Interpretations

Ambient Conditions Associated With Gully Spots

Geomorphology, albedo, and brightness temperatures of the gully spot region as a function of time of year provides some insight into spot origin and the composition of the gully channel material. The early springtime image showing the spots (Figure 1a) was acquired during the retreat of the southern seasonal cap. At this time of year, the surface atmospheric pressure is 4.5±0.5 mb (7), giving a CO_2 sublimation temperature of 145-146K (4). Therefore, the brightness temperatures are indicative of solid CO_2 on the surface, with the albedo indicating that it is predominantly in the form of frost.

The higher brightness temperatures, lower regional albedos, and greater degree of image contrast between the gully channels and surrounding terrain in the late springtime image is indicative of an absence of solid CO_2. It is therefore likely that the gully spots represent some process associated with surface CO_2 frost or ice and its springtime behavior within the gully channels.

Martian Analogs to the Gully Spots and Possible Origins

The gully spots bear a resemblance to spots seen on polar dunes and the south polar layered deposits (SPLD) at the same time of year. The dune and SPLD spots have similar appearances and regional thermal/albedo properties. The north polar erg and SPLD have thermal inertias of 25-150 and 50-100 J m^{-2} s$^{-0.5}$ K^{-1} (8,9), respectively, indicating that spots in these regions are on fine grained or porous material. Two origins have been proposed for these spots, origins which also may apply to the gully spots:

Hypothesis 1: Defrosting Features Previous analyses of MOC images shows that polar dunes are the first surfaces to brighten in the autumn or winter and the first features to exhibit spots in the spring or summer, an observation that has been interpreted as due to frosting and defrosting, respectively, that occurs earlier than in surrounding terrain (10). These dune dark spots grow and coalesce as the season progresses. During this time, temperatures are above, but close to, the CO_2 sublimation temperature (11). Defrosting in the gullies may be assisted by the low albedo of the channel fill (Figure 1b), which should radiatively heat CO_2 frost that is optically-thin for some solar wavelengths and illumination geometries.

Hypothesis 2: CO_2 Slab Ice Another possibility for such spots on Mars is that they represent coarse-grained CO_2 slab ice, which has been proposed to occur during defrosting of the southern seasonal cap (12). This "cryptic" material has a low and fairly constant albedo, low brightness temperature, and seems virtually transparent to solar radiation (12). Because of these properties, cryptic material may have an albedo similar to its substrate and therefore should be considerably darker than surrounding frosted terrain.

Inferred Properties of Gully Channel Material Based on Presence of Ephemeral Spots

Defrosting Origin

A porous material invoked for the defrosting mechanism is consistent with an erosional origin for the gullies, although a low thermal inertia material is not. Any material mobilized by a fluid or deposited by dry mass wasting will largely be particulate in nature. Based on terrestrial gully analogs, coarse/high thermal inertia debris should be the most common material in the gully channels, with low inertia fines being a sub-component. So, the presence of loosely aggregated, particulate material in the gullies is similar, in this sense, to dunes (although with a larger particle size) and, by some uncertain process, may cause defrosting earlier than in other regions.

Slab Ice Origin

If the spots represent CO_2 slab ice, then a mechanism for producing CO_2 grains that are larger than in adjacent regions and an explanation as to why this occurs in the channels are needed. Although the mechanisms for formation of CO_2 slab ice are presently a mystery, the localized dark areas that persist at regional CO_2 temperatures indicates that some subtlety of local surface and atmospheric conditions at the time of initial seasonal frost formation may yield relatively coarse grains, which then become the stable form for continued growth (13). Why this would occur preferentially in gully channels, however, is as much a mystery as is the mechanism for forming CO_2 slab ice elsewhere on Mars

A Paradox: Gully Spots Exist on Material That Probably Has a High Thermal Inertia

We are presently perplexed why the morphologic Martian analogs for the gully spots, namely dark spots on polar dunes and the SPLD, occur on low thermal inertia materials. This is because, as based on terrestrial gully analogs, gully channel material is likely to have a high thermal inertia. This is further supported by the confinement of dark albedo material to the gully channels as seen in the late springtime image (Figure 1-right)

Association With Water Ice?

Perhaps gully spots have an origin very different from seasonal spots elsewhere on Mars, despite their similar morphology. One speculative explanation is that near-surface lenses of H_2O ice deposited from seepage of water into the ground following gully formation somehow influences the formation of seasonal spots. This would both explain the confinement of spots to the gully channels and the apparent absence of spots in other high inertia areas of Mars. Under present orbital parameters and temperature/pressure conditions, water ice with an albedo of 0.4-0.6 at temperate to polar latitudes will sublimate at a rate of 0.1-1.5 cm yr^{-1}, so that ice originally 10 m thick will take 10^3-10^5 years to get completely removed (2,14,15). Therefore, given that the gullies may be younger than 10^6 years (1), near-surface ice in a disequilibrium thermal state within the channel materials is possible.

Whatever the causes of these seasonal splotches, they point to some interesting processes presently occurring in the gully channels that should be further studied.

Note

This represents a work in progress and is paced by our evolving, and still poor, understanding of the complex Martian surface as revealed by MGS.

Acknowledgements

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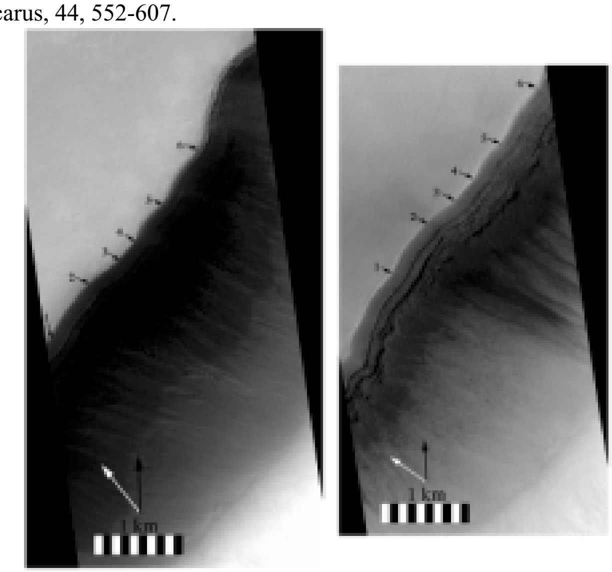

a b

Figure 1 Gully channels in early and late spring Large black arrow is north direction , white arrow is azimuth to Sun, and arrows with integers are tie points between images. a) Portion of MOC image M03-07645 in sinusoidal projection showing dark splotches within gully channels at L_s = 185 (early spring). Note the lack of brightness variations independent of relief, save for the splotches themselves, indicating that the surface is covered with frost. b) Portion of MOC image M09-02965 in sinusoidal projection showing the same gullies as at left, but at L_s = 255 (late spring). Albedo variations are apparent, indicating a lack of frost. Dark material is generally confined to the gully channels.