GULLY-POLYGON INTERACTION AND STRATIGRAPHY ON EARTH AND MARS: SAND-WEDGE POLYGONS AS PART OF COLD-DEESERT, NEAR-SURFACE FLUVIAL SYSTEMS. J.S. Levy1, J.W. Head1, D.R. Marchant1, G.A. Morgan1, and J.L. Dickson1, 1Dept. of Geol. Sci., Brown Univ., Providence, RI, 02912, USA (joseph levy@brown.edu), 2Dept. of Earth Sci., Boston Univ., Boston, MA 02215 USA.

Introduction: Gullies on Mars are a class of young features initially interpreted to have formed by flow of liquid water through groundwater discharge from underground aquifers [1, 2], and are possibly still active [3]. Numerous alternative explanations have been proposed (see summary in [4]), and recent terrestrial analog work in the Antarctic Dry Valleys (ADV) has reported on the primacy of top-down melting of snow as a source for water flowing through the active layer and hyporheic zones of these terrestrial gullies [5-8]. Although gullies are found in periglacial terrains on Earth and Mars [9-11], the effects of polygonal patterning on the generation and modification of gullies has not been broadly discussed. We present field measurements and observations that suggest polygonally patterned ground (sand wedge and composite polygons) contributes to the production, transport, and storage of liquid water in gullies located in Wright Valley, Antarctica. Further, stratigraphic and morphological relationships between gully and polygon features in the ADV provide a sequence of feature formation. Analogous features on Mars suggest that similar processes may be forming and modifying gullies in both environments.

Sand-wedge and Composite Polygons: Background. Sand- and composite-wedge polygons form in Wright Valley when thermal contraction stresses overcome the tensile strength of the ice-cemented soil (meters thick continuous permafrost), resulting in thermal contraction cracks, which re-expand on annual timescales [12-14]. Sand grains from the overlying 20-40 cm thick, seasonally moist active layer are winnowed into the cracks, producing the sand wedge and a surface trough [12-14]. If sufficient melt water is available, the sands may be interbedded with vertical lenses of ice, thus producing composite-wedge polygons. Sand wedge- and composite-wedge polygons in Wright Valley are broadly characterized by a flat ice cement table beneath the polygon interior, which deepens along a smooth slope towards the ice cement table.

Production of Meltwater. Water flowing through ADV gully systems is produced largely through the melting of perennial snowbanks in the gully alcove and the melting of wind-blown snow trapped in the gully channel [5-8]. Polygon troughs also act as accumulation sites for wind-blown snow (Fig. 1a); troughs that intersect gully channels provide an alternative down-slope path for meltwater to distal portions of the gully and marginal hyporheic zone (Figs. 1e, 2a) [7, 10]. Analogous relationships are present on Mars (Fig. 1b); frost is present in polygon troughs within and surrounding gullies.

Water Transport. Polygonally patterned ground promotes surface and shallow subsurface flow of water in ADV gullies.

Trough Annexation. Where gully channels intersect polygon troughs oriented down-slope, gully channels follow the polygon trough (Fig. 1c). Gully channels follow troughs for tens of meters until the trough ceases to trend down-slope. Annexed portions of polygon troughs are widened and sinuous on ~1 m wavelengths; channel-annexed trough intersections with adjoining polygon troughs are commonly rounded rather than angular. Analogous channel-polygon relationships are present on Mars (Fig. 1d).

Water Storage. Water flowing through ADV gully systems accumulates in distal hyporheic zones [6, 7], which are patterned by polygons. “Wet-topped polygons” (WTP) have dark polygon centers surrounded by light polygon troughs (Fig. 2e). The albedo difference between WTP centers and troughs is due largely to a difference in soil moisture (~4-5 wt.% in the dark interior surfaces, <0.5 wt.% in the light trough surfaces), with a secondary darkening occurring due to the presence of dark dolerite cobbles in the polygon centers. WTP troughs are filled with coarse sand and pebbles: a well-drained environment which holds little water (<1.5 wt.%), even at depth. In contrast WTP centers are underlain by a mixture of clay and cobbles which can hold significant amounts of water at depth (5-9 wt.% in unfrozen soils, and up to 12 wt.% in ice-cemented sediments). Water stored in distal hyporheic zones in Wright Valley is strongly partitioned into polygon interiors over polygon troughs. Despite the seasonal generation of meltwater, no ice-wedge polygons have been observed.

Stratigraphic Relationships. Overprinting. Gully fan deposits overprint polygonally patterned desert pavement surfaces in Wright Valley (Fig. 2c). Gully fans consist of bedded and cross-bedded pebbles and sands, which have been locally deflated. Contacts between fan material and patterned surfaces with well-developed pavements are gradational. Meter-scale outcrops of polygonally patterned colluvium with well-developed desert pavements are present within the fans, evidence of embayment of locally high patterned ground areas by fan deposits. Subdued polygonal patterns is present within fan deposits, and is interpreted as continued expansion of thermal contraction crack
(sand wedge) polygon troughs during and subsequent to fan deposition. Analogous features are present on Mars (Figure 2d).

**Truncated Polygon Troughs.** Several polygon troughs are cross-cut by gully channels in Wright Valley (Fig. 2a). Polygon troughs intersect gully channels at near-orthogonal and oblique angles. Troughs present on one bank of the gully channel can commonly be matched to troughs present on the opposite bank. Taken together, these two lines of evidence suggest that the polygon troughs were cut by the gully channel, rather than forming subsequent to gully channel formation. Analogous relationships between polygonally patterned surfaces and gully channels/alcoves are observed on Mars (Fig. 2b).

**Discussion and Implications.** Observations of relationships between polygonally patterned ground and gullies in the Antarctic Dry Valleys suggest that the presence of sand- and composite-wedge polygons: 1) enhances the accumulation and transport of gully meltwater, 2) affects the partitioning of gully water in distal hyporheic zones, and 3) can locally affect the course of gully channels by trough annexation. Accordingly, polygons are an important part of the water transport system in cold desert environments, and warrant continued investigation.

Stratigraphic relationships between polygonally patterned terrain and gully features provides insight into the sequence of processes modifying the ground surface in Wright Valley. Trough annexation by gully channels implies that some polygons pre-date the formation of the gullies. Local depressions and furrows in the ice cement table produced by thermal contraction cracks channelize and direct water flowing along the ice cement table surface. When concentrated water flow associated with gully channel formation encounters a thermal contraction crack with an appropriate down-slope orientation, annexation occurs, enhancing water flow through the polygon trough, resulting in the widening of the trough and the rounding of angular intersections with other troughs. Annexed troughs are abandoned when the troughs turn away from the local ice table slope, and gully channel formation proceeds as normal. Overprinting of polygonally patterned ground by fan deposits and cross-cutting of polygon troughs by gully channels further suggest that gully formation occurred subsequent to the initial formation of patterned ground in Wright Valley. We interpret the presence of subdued polygonal features within the fans as evidence that polygon evolution has continued subsequent to burial by fan deposits, suggesting that climate conditions have remained suitable for sand- and composite-wedge polygon evolution during the entire process of gully formation.

The presence of polygonally patterned ground in Wright Valley subsequent to the formation of shallow permafrost prior to gully formation. The continuing evolution of polygons in Wright Valley during gully formation implies the continued existence of the permafrost layer for the duration of gully processes, as the presence of a thick permafrost layer acts as an impermeable layer at depth over which snowmelt-derived water flows [5-8]. The presence of similar morphological features on Mars, with similar relationships between gullies and polygons suggests that analogous processes may have occurred in recent geological time on Mars.

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Figure 1. a) Snowbank in polygon trough in ADV. Snowbank is 60-80 cm wide across the short axis and < 10 cm thick. b) Frost-filled polygon troughs in Terra Sirenum gully (PSP_001816_1410). Scale bar is 10 m. c) Polygon trough annexation in ADV. d) Vertical arrow, expanded polygons; horizontal arrow, sinuous depression. Possible trough annexation in Terra Sirenum (PSP_002291_1335). Scale bar is 10 m. e) Polygon trough cross-cut by gully channel in ADV. Arrow indicates expansion of hyporheic zone by melting snow drainage.
Figure 2. a) Polygon trough cross-cut by gully channel in ADV. Snowbank is present in gully. b) Upper arrow, polygon troughs cross-cut by recent gully alcove expansion on Mars. Lower arrow, older, non-cross-cut polygon troughs. Arrow ~30 m across (PSP_001816_1410). c) Gully fan overprinting patterned ground in ADV. Fan is ~100 m wide. d) Gully fan overprinting patterned ground in Terra Sirenum. Scale bar is 50 m (PSP_002291_1335). e) WTP in ADV. Polygons are 10-20 m wide. Gully systems in background.