DILUVIAL DUNES IN ATHABASCA VALLES, MARS: MORPHOLOGY, MODELING AND IMPLICATIONS. D. M. Burr[1], P. A. Carling[2], R. A. Beyer[3], and N. Lancaster[4], [1]USGS Astrogeology Program (2255 N Gemini Dr. Flagstaff AZ 86001, dmburr@usgs.gov), [2]School of Geography, Southhampton University (Highfield, Southampton, SO17 1BJ, UK) [3]Department of Planetary Sciences, University of Arizona (Tucson AZ 85721) [4]USGS Earth Surfaces Dynamics Program (National Center, 12201 Sunrise Valley Dr., Reston VA 20192).

Introduction: A set of linear, flow-transverse periodic bedforms (Fig. 1) lies on the floor of the main channel of Athabasca Valles, Mars, near 9N 156E [1,2]. The channel appears very young [2,3,4] and originates at one of the Cerberus Fossae volcanotectonic fissures [5]. Investigations into the surface channel flow should therefore provide information on recent subsurface groundwater flow. We analyzed the transverse periodic bedforms to determine the flow regime and estimate the discharge that formed them.

Morphologic investigations:

Dunes vs. antidunes: The forms have previously been classified as diluvial dunes [2]. Dunes are transverse bedforms with steeper lee slopes than stoss slopes. They form under subcritical flow, i.e. flow for which the Froude number, $Fr = U/\sqrt{(dg)}$, is less than 1, where U is the flow velocity, d is the flow depth and g is the gravitational acceleration. With sufficient sediment supply, dunes form under the condition that $\sim 0.5 < Fr < \sim 0.84$ [6]. Conversely, the forms have also previously been classified as diluvial antidunes [1]. Antidunes are ephemeral bedforms having either along-strike symmetry or steeper stoss slopes than lee slopes. They develop under high subcritical or supercritical flow (i.e. flow for which the Fr>1) [6]. Flows between ~0.84 and 1 are termed transitional flows, and are generally characterized by an "upper stage" plane bed.

Photoclinometry measurements: In order to determine the bedforms' slope morphology—whether dune-like or antidune-like—, we used a profiling photoclinometry technique. The technique measures slopes in the downsun direction, which was perpendicular to the strike of the bedforms. Thus we could measure dune lee and stoss slopes, and did so at 72 different locations on almost all of the distinguishable individual dunes. From these slope measurements, we derived topographic profiles by multiplying the image resolution (3.1m/px) by the tangent of the slope for each pixel and integrating along each pixel.

Forms as dunes: The topographic profiles indicate the bedforms are dunes, not antidunes (Fig 2). The profiles are almost all asymmetric with the lee slopes being steeper than the stoss slopes. Supportive evidence for the classification of the features as dunes includes their preservation, which is unusual for antidunes, and their location in a channel with a very gentle slope (0.0006 m/m or 0.032°), which is not conducive to supercritical flow.

Discharge estimate:

Based on the determination that the forms were dunes, we undertook to use them to estimate the discharge that formed them.

Previous estimates: The discharge down Athabasca Valles has been previously estimates two ways: 1) using Manning's equation modified by [7] for Martian gravity [5], which provides a discharge estimate at a point from slope and water depth; and 2) using a hydraulic step-backwater model (HEC-RAS) modified for Martian gravity [8]. Step-backwater models use multiple channel cross-sections and a user-specified discharge to produce a model water height, which is matched to geological indicators of water height. Both these methods gave discharge estimates of ~1-2 x 10^6 m^3/s.

Both these methods depend explicitly on flow cross-sectional area, i.e. on correct interpretation of geologic indicators of floodwater height, which is more uncertain with remote sensing than in terrestrial applications of the models. These methods also depend implicitly on the assumption that current channel topography as used in the model is the same as the channel topography at the time of the flood. The very shallow slope of the main channel of Athabasca Valles and indications of post-flooding embayment by lavas [4, 9] call this assumption into question. Therefore, a method that uses morphological indicators of discharge independent of cross-sectional area or channel topography is desirable.

Dune flow model: A model that derives discharge from channel bedforms is such a method. The dune flow model of Carling [10] derives hydraulic parameters based on a) the shape of dunes and b) the sediment size. This model has been applied to diluvial dunes during flooding in the Toutle River, WA, USA, with reasonable agreement with measured values. It has also been applied to paleodunes formed during catastrophic flooding in Kuray, Siberia, with resultant peak discharge estimates of 7.5 x 10^5 m^3/s [10].

a) The shape of the dunes is used as an indication of the dunes' stage of evolution. The dune flow model can provides results for 3 different stages of evolution: 1) incipient dune growth, 2) near transition to an upper stage plane bed, and 3) stabilization on the waning limb of the flood [10]. The flattened crestal platforms of many of the Athabascan dunes suggests imminent transition to an upper stage plane bed, and thus stage 2 likely best reflects the conditions at the time of the dunes' formation.

b) Sediment size constrains the velocity profile of the flow. Sediment sizes could not be measured from MGS or MO data, although a few possible meter-scale (2-3 px) boulders are visible on the dunes. Therefore, we deduced minimum likely sediment sizes from the calculations of Komar [11] in conjunction with flow velocities of HEC-RAS model. The material that comprises dunes is deposited bedload (not suspended or wash load). For the HEC-RAS model velocities of ~3-5 m/s, [11] shows that material coarser than 2 mm would have been transported as bedload. Thus, we ran the model for a mean sediment size of 3 mm as a minimum possible value, and for an order of magnitude increase of 30 mm.

We applied this dune flow model to the Athabasca Valles dunes for all three stages of dune growth and both sediment sizes. The lower sediment size estimate is a minimum value [11], and, because of the possible meter-scale boulders, we think the order of magnitude increase is more likely the actual grain size. We also think the most likely stage of evolution reflected by the present dune morphology is that of incipient transition to an upper stage plane bed. For these two conditions—30 mm average grain size and dune formation stage 2—, the resultant dune flow model discharge is $\sim 2 \times 10^6$ m^3/s. Other permutations of these 2 conditions produced significantly lower flows.

The significance of the dune morphology: Because the dune flow model was initiated with HEC-RAS model velocities, errors in the HEC-RAS modeling would result in errors in the dune flow model. Two geological indicators constrain the HEC-RAS model velocities: the presence of the dunes, and the indications of floodwater height. Dunes constrain the relationship between flow velocity and water depth such that $\sim 0.5 < U/\sqrt{(dg)} < \sim 0.84$. The HEC-RAS model results give $Fr = U/\sqrt{(dg)} = \sim 0.5$, consistent with the bedforms being dunes. If the HEC-RAS velocity were much lower for the same water depth, the water depth also would have to be lower for Fr to remain within the appropriate range of values for dunes. However, geological evidence indicates that the peak water depth model values were not much lower. The extent of longitudinal lineations, which are interpreted as being formed by the floodwater [e.g. 2,3], indicates a minimum peak water depth; likewise, the dunes must have been submerged. The peak water heights we derive with the dune flow model agree with these geologic indications of peak water depth. These indications, along with the constraint imposed by the dunes, indicate that the HEC-RAS model velocities with which we initiated the dune flow model are approximately correct.

Implications:

The discharge estimate derived from the dune flow model is very similar to previous surface discharge estimates that were difficult to match with subsurface flow through a porous medium. This may indicate that the Martian subsurface is at least locally or periodically significantly more permeable than aquifers on Earth. Alternatively, it may indicate that the aquifer material was extruded with the water [12].

References:

[1] Rice et al. (2002) *LPS XXXIII*, Abstract #2026. [2] Burr et al. (2002) *Icarus*, *159*, p53. [3] Berman and Hartmann (2002) *Icarus, 159*, p1. [4] Werner et al. (2003) *JGR 108*, p22-1. [5]Burr et al. (2002) *GRL 29* p13-1. [6] Simons et al. (1965) "Sedimentary structures generated by flow in alluvial channels" *in* Primary Sedimentary Structures and their Hydrodynamic Interpretation. [7] Carr (1979) *JGR* 84 p2995. [8] Burr (2003) *Hydro. Sci. J.* 48, p655. [9] Lanagan and McEwen, *Icarus*, submitted. [10] Carling (1996) "A preliminary palaeohydraulic model applied to Late-Glacial gravel dunes: Altai Mountains, Siberia" *in* Global and Continental Changes: the Context of Palaeohydrology. [11] Komar (1980) *Icarus* 42, p317. [12] Carr M.H. (1996) Water on Mars.

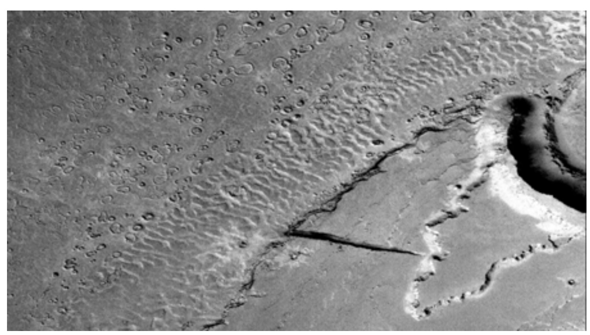

Figure 1: Subset of E10-01384, showing transverse bedforms on Athabasca Vallis floor.

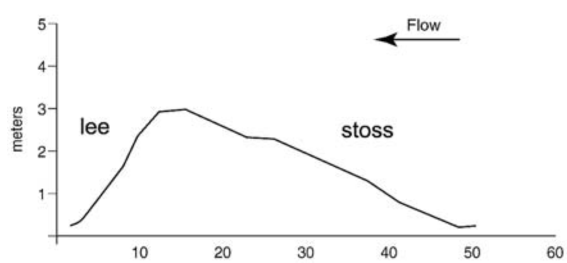

Figure 2: photoclinometry profile of an Athabascan dune bedform.