REGIONALLY COMPARTMENTED GROUNDWATER FLOW ON MARS.
K. P. Harrison[1] and R. E. Grimm[1], [1]Southwest Research Institute, 1050 Walnut St, Ste 300, Boulder, CO 80302, harrison@boulder.swri.edu.

Introduction: Groundwater likely influenced the erosion or weathering of large Martian fluvial features, including outflow channels [1, 2] and valley networks [3, 4]. Groundwater may also have contributed to the formation of widespread sulfate and phyllosilicate deposits [5, 6], and a variety of bedrock outcrop features observed by the Mars Exploration Rover Opportunity [7]. The spatial distribution of these phenomena suggests that groundwater flow might once have been widespread on Mars. Groundwater simulations to date have assumed laterally uniform permeabilities capable of supporting global-scale flows [e.g., 8, 9]. It has been argued [10] that in terrestrial crust, the pervasive presence of fracturing prevents any large-scale geologic formation from being considered impermeable, implying (for both the earth and Mars) that lateral hydraulic connectivity is essentially unlimited.

Global-scale groundwater flows are not, however, observed terrestrially because high precipitation rates shape the water table to a subdued replica of the topography, limiting hydraulic gradients to small spatial scales. Arid climates allow at most regional-scale groundwater flows. If the terrestrial and Martian crusts are hydrologically similar, the globally arid nature of Mars may have allowed truly global flows. However, the wide distribution of Martian groundwater-related features does not explicitly require global-scale flow: it is possible that groundwater circulated in isolated local- to regional-scale aquifers.

We suggest a means of constraining the viability of global-scale flow on Mars using chaotic terrains (CT). CTs are groups of large (10s km) randomly arranged mesas resulting from the collapse of an ice-filled permafrost layer (cryosphere) due to high aquifer pore pressures exerted from below [1]. Cryosphere disruption allows pore pressures to be released through the discharge of large volumes of groundwater to the surface. CTs thus serve as markers for high pore pressures in the Martian aquifer. A groundwater simulation that responds to high pore pressures with a cryosphere disruption mechanism can thus be used to search for global-scale groundwater flow patterns consistent with observed chaotic terrain locations.

Model: We implement the above approach with a groundwater model that employs aquifer recharge as a means of generating high pore pressures [11]. Downward infiltration of recharged water locally raises the water table, producing lateral hydraulic gradients that drive groundwater radially outwards to other parts of the aquifer. Pore pressures rise regionally (and eventually globally) and, at some location determined by elevation and proximity to the recharge zone, groundwater "breakout" occurs, i.e. pressures reach a value high enough to open fractures in the cryosphere through which groundwater then issues. This breakout mechanism causes a local- to regional drop in pore pressures and so influences the location of subsequent breakouts.

Of particular importance to the spatial scale of groundwater flow is the lateral variation of permeability k. In lieu of observational constraints we adopt a stochastic approach. Depth-averaged $\log_{10}k$ (model depth is 19 km) is made to vary laterally about a mean value of -12.7 (with k in units of m^2) with a standard deviation of 0.5. We impose a lateral length scale of 15° (about 900 km, based on average geologic unit dimensions). We generate 100 stochastic realizations, each of which is implemented in an independent model. We also consider the following model variations: 1) south polar recharge (nominally, recharge is over Tharsis), 2) alternative topography reflecting the assumption that significant cryosphere disruption occurred just prior to large-scale collapse of CTs, incision of outflow channels, and the widening of the Valles Marineris canyons, 3) breakout when pore pressures reach hydrostatic values (nominally, lithostatic values are required), 4) k length scale is increased to 75° to introduce more chaos-to-channel variability, 5) standard deviation of $\log_{10}k$ is increased to 1.0. For each unique combination of the above variations, we ran 100 models, resulting in a total of 3200.

Results: Results from the first three model variations are shown in Fig. 1. Eight unique combinations arise, each with 100 models covering the same set of independent permeability realizations. For each combination, we plot on a single map the breakout locations from all 100 models. Circles indicate breakout sites, with circle diameter proportional to the number of models from the suite of 100 that produced a breakout at the circle center. Thus, for example, the single large circle over Hellas in Fig. 1a indicates that most models in the suite (97) produced a breakout at the same location. We omit breakouts that are initiated later than 1 Ga: we regard this as a suitable upper limit to the period of outflow channel initiation from approximately the end of the Noachian to the early Amazonian.

Results from model suites with the last two variations (permeability statistics) show a somewhat greater number and spatial diversity of breakouts, but the general distribution seen in Fig. 1 is conserved.

Discussion: Our results indicate that cryosphere disruption is not widely predicted for the circum-Chryse and eastern Hellas CTs, the traditionally accepted sources of groundwater discharge for outflow channel flooding. Even in the model suite with the most favorable initial conditions (hydrostatic breakout pressure and long *k* path length), only 16% of models produce cryosphere disruption at the circum-Chryse CTs, and these were limited largely to Hydraotes Chaos, the deepest CT. Furthermore, many models produced cryosphere disruption in Amazonis and western Hellas Planitae where no evidence of disruption is observed. We conclude that global-scale groundwater flow, even when limited to tortuous flow paths connecting regional-scale high permeability zones, cannot produce a cryosphere disruption pattern commensurate with observations. It is thus likely that Martian groundwater flow was locally or regionally isolated. Isolation may be due to limited hydraulic connectivity imposed by geologic formations not included in our model, or by the limited distribution of groundwater.

A further conclusion is that cryosphere disruption in the Valles Marineris canyon system (driven by aquifer recharge over Tharsis) is highly probable, even if groundwater flow is assumed to be regional. The position of the canyon system upstream of chaotic terrains suggests that groundwater discharge through Valles Marineris faults may have been a significant, if not dominant, source of water for outflow channel flooding. This mechanism already constitutes the standard formation model of outflow channels elsewhere on Mars, including Athabasca and Mangala Valles. Our results therefore suggest that the role of CTs in circum-Chryse outflow channel formation must be carefully revisited and, if necessary, modified. If the formation of CTs can be shown to be unrelated to high aquifer pore pressures, then global-scale groundwater flow remains a possibility.

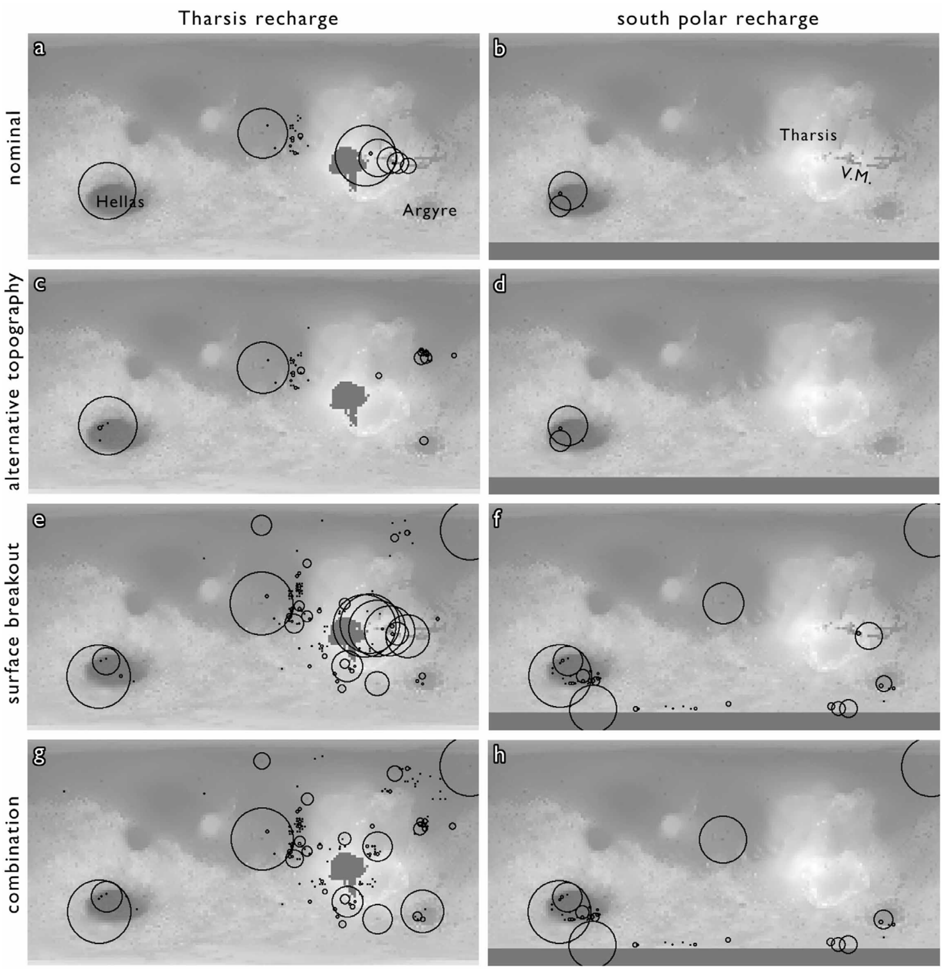

Figure 1. Compilation of breakout locations for nominal stochastic permeability models. Each frame superimposes breakouts from 100 independent simulations. Circle diameter is explained in the text. As indicated by uniformly grey areas, left column frames have Tharsis recharge, right column frames have south polar recharge. Each row indicates the affect of a model variation delineated in the text.

References: [1] Carr, M. H. (1979) *JGR, 84*, 2995–3007. [2] Baker, V. R. (1982) *The Channels of Mars*, Univ. Tx. Press. [3] Craddock, R. A., Howard, A. D. (2002) *JGR*, *107*, doi: 10.1029/2001JE001505. [4] Luo, W., Howard, A. D. (2008) *JGR*, *113*, doi: 10.1029/2007JE002981. [5] Gendrin, A. N., *et al*. (2005) *Science*, *307*, 1587-1591. [6] Poulet, F., *et al*. (2005) *Nature*, *438*, 623-627. [7] Grotzinger J. P. *et al*. (2005) *Earth Plan. Sci. Lett.*, *240*, 11-72. [8] Harrison, K. P., Grimm, R. E. (2004) *GRL*, *31*, doi: 10.1029/2004GL020502. [9] Andrews-Hanna, J. C., Phillips, R. J. (2007) *JGR*, *112*, doi: 10.1029/2005JE002881. [10] Clifford, S. M. (1993) *JGR*, *98*, 10973-11016. [11] Harrison, K. P., Grimm, R. E. (2009) *JGR*, *114*, doi: 10.1029/2008JE003300.