OCCURRENCE OF PALEOLAKES ON EARLY MARS AND EMPIRICAL CONSTRAINTS ON WATER BUDGETS. T. A. Maxwell[1], R. P. Irwin III[1], A. D. Howard[2], and M. Higbie[2], [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, MRC 315, 6th St. at Independence Ave. SW, Washington DC 20013-7012, maxwellt@si.edu, irwinr@si.edu; [2]Department of Environmental Sciences, P.O. Box 400123, University of Virginia, Charlottesville, VA 22904-4123, ah6p@virginia.edu, higbie@virginia.edu.

Prior estimates of water volumes and discharges from martian channels have been based primarily on channel morphometry and to some extent on the amount of water available under various conditions from a defined watershed [1,2]. The occurrence of breached craters (those with either an entrance channel through the rim or exit breach or both) allow another constraint to be used to determine the volume of water involved in carving channels under reasonable assumptions. Here we use measurements of breached impact craters and their contributing watersheds to constrain the average annual water budget to an order of magnitude.

Recent studies of Martian valley networks using higher-resolution imaging and topography have provided the first imprecise constraints on watershed hydrology around the Noachian/Hesperian transition. Published estimates include the runoff production rate in individual events, the total amount of water required to form certain landforms, and the duration of a more Earthlike paleoclimate on early Mars. Meander development by lateral accretion on a delta surface in Eberswalde crater requires persistent flow and relative stability of the lake level over hundreds to thousands of years [1,2]. The sizes of alluvial fans and deltas suggest that Earthlike (perhaps arid to semiarid) conditions prevailed for 10^4–10^6 years [1-4], and low drainage densities on the order of ~0.01–0.1 [e.g., 5] likely constrain the latest episode of more intense fluvial activity to <~10^6yr duration. Measurements of the width and bend wavelength of locally exposed interior channels suggest formative discharges comparable to the two-year flood that typically controls channel morphometry in terrestrial humid regions [6]. These data constrain only the dominant discharge, however, which occurs less than ~5% of the time in most terrestrial rivers. The recurrence interval of the channel-forming Martian floods has not been constrained, however, and the annual water budget is more relevant to paleoclimate than is the magnitude of any individual flood.

Earlier studies established that aquifer recharge was required to carve the valleys [7,8], and fully dissected surfaces in local areas, origin of some tributaries near sharp drainage divides, and patterns of crater modification imply an areally distributed, atmospheric water source [e.g., 9-11]. The equatorial highland landscape preserves no evidence for widespread glaciation, although creep has dominated the modification of impact craters at middle to high latitudes [12]. Aside from observations that valley networks are better developed in some areas [7,8], we still have no quantitative constraint on whether the climate varied significantly around Mars at the equator. A basic assumption of the present work, predicated on these earlier results, is that the discharge in valley networks and standing water in lakes is derived from precipitation and/or meteoric groundwater discharge from the contributing watersheds.

Several craters in the Terra Cimmeria and eastern Margaritifer Sinus regions have entrance and exit breaches that we use as an indicator of temporary lakes that controlled runoff. The local topography around some of these craters funneled water across the upslope rim, forming an entrance breach (Fig. 1). Presumably the lake level would be controlled by a long-term balance between input and evaporation. Assuming an evaporation rate of 1 m/yr and acknowledging the range of terrestrial data (0 to > 3m/yr) allows us to constrain the water budget in Martian valley networks. Basins that filled with water and

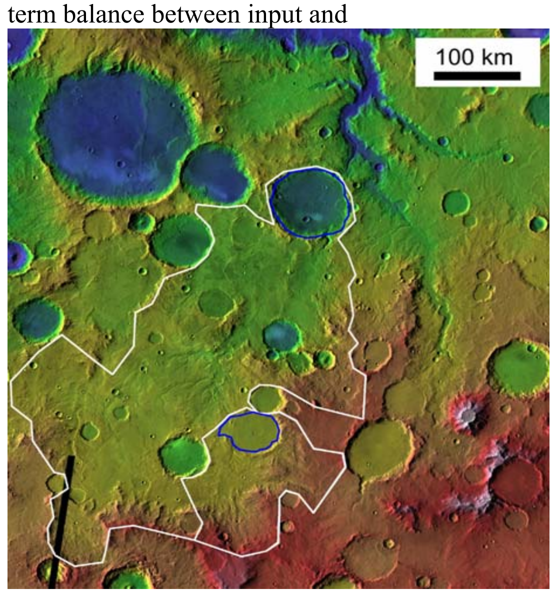

Figure 1. Water from a valley network in eastern Terra Cimmeria was routed through a crater by preexisting topography.

overflowed received a long-term input that exceeded evaporation, whereas terminal basins did not.

We mapped breached impact craters in the Terra Cimmeria/Terra Sirenum region (0–30°S, 120–190°E) and Margaritifer Sinus (0–30°S, 320–360°E) using the 231 m/pixel THEMIS daytime infrared global mosaic and 463 m/pixel MOLA topographic grid. We recognized 16 basins with both a contributing and an outlet valley.

Several issues complicate the interpretation of contributing areas. 1) Some watersheds contain a large fresh crater or its ejecta that complicate mapping the older contributing valley network. 2) Although some drainage divides are sharp-crested, many occur on undissected or poorly dissected interfluve areas. The total area that contributed direct runoff or infiltrated groundwater was estimated and may contain errors of ~20%. 3) Some impact craters with outlet valleys are highly degraded and/or have deeply gullied exterior slopes, and it is unclear to what extent overflow or piracy from outside the rim were responsible for breaching the low divide. For these reasons, the data are limited to basins with intact rims, relatively deep outlet breaches, and contributing watersheds that contained no large fresh impact craters.

Craters with deep outlet valleys are interpreted to be paleolake basins, because alternative explanations fail to explain the suite of characteristics observed at each site. The outlet valley is always larger and more deeply incised than other valleys in the area, although it would not have a larger water supply unless the breached crater and its contributing watershed were included. The floors of these breached craters are typically slightly concave and not dissected by a through-flowing stream, so we find no evidence that the basin was ever completely filled with sediment. In three basins observed in Margaritifer Sinus, the crater floor contains a wind-eroded, knobby surface layer that is topographically confined below the level of the contributing and outlet valley thalwegs. These basin floors have high thermal inertias relative to the surrounding uplands, likely related to exposure of a rocky material that underlies the wind-eroded fines. These features are consistent with deposition of the friable unit in standing water but not with impact, airfall, or volcanic deposits. In Terra Cimmeria, several breached craters have floor material with an intact small crater population and wrinkle ridges that are identical to interpreted volcanic plains surfaces elsewhere on Mars. Heavily wind-eroded crater floor deposits are found in several areas of the equatorial highlands alongside craters with the more typical resistant floors and well-preserved small craters. The nature of floor material thus varies with location and geologic setting, and there is not one unique material type for breached (or intact) crater floors.

The water budget varies with assumed lake evaporation rate as follows. For the Eastern Hemisphere basins, the evaporation range of 0.2–2 m/yr and a critical watershed/basin area ratio of ~15:1 implies runoff production of 1–10 cm/yr, comparable to the Basin and Range province of the southwestern U.S. Filling Eberswalde crater in western Margaritifer Sinus to the –1400 m elevation of the delta front yields a lake of ~400 km^2, relative to a watershed area of ~4800 km^2, a ratio of 12:1 or a runoff production of 2– 20 cm/yr. In eastern Margaritifer Sinus, where valley networks are well developed, overflow of two large basins with a ratio of ~4:1 implies runoff of 5–50 cm/yr, similar to terrestrial semiarid regions. Actual precipitation rates were likely higher as some water would have evaporated from the upland surface.

Other topographic factors secondary to contributing area are being examined, as well as the characteristics of floor materials relative to geologic events subsequent to channel forming. Such factors as the elevation, relief, and slope of the watershed (as well as the relative areas of dissected slopes and undissected plateaus in each one), and the volume of the basin below its spill point will influence the runoff production rate that must be maintained to yield an overflow.

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