HAVE THERE BEEN LARGE, RECENT (MID-LATE AMAZONIAN) WATER FLOODS ON MARS? A.S. McEwen[1], L.P. Keszthelyi[2], and J.A. Grant[3] [1]Lunar and Planetary Lab, University of Arizona, Tucson AZ 85721 (mcewen@lpl.arizona.edu), [2]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001 (laz@usgs.gov), [3]Center for Earth and Planetary Studies, Smithsonian Ins., 6th St. at Independence Ave, Washington DC 20560 (grantj@si.edu).

Introduction: A key question for astrobiology and future exploration is whether groundwater is currently abundant within Mars [1]. Unfortunately, direct detection of deep groundwater seems unlikely with the ground-penetrating radars on Mars Express and MRO [2]. While there are multiple convincing lines of evidence for water on Mars, it will nearly all be in the form of ice unless the volume of water exceeds the accessible pore volume of the cryosphere [3]. Global water estimates based on outflow channel erosion suggest that there was probably far more water than likely pore space through the Hesperian [4]. Recent reanalysis by Clifford et al. [5] concludes that extant deep groundwater is less likely but still possible. An alternate model [6] predicts that high loss rates during times of low obliquity should have entirely dessicated equatorial Mars.

There are several reports (discussed below) of outflow-channel activity in the Middle to Late Amazonian (≤1.5 Gyr [7]). If sufficient groundwater existed to create outflow channels in the past Gyr, especially in the equatorial region, it probably persists today. How robust is the evidence for large floods of water in the Middle or Late Amazonian? While there are large unmistakable erosional channels on Mars, the young ages reported for some are debatable. In the course of planning and analyzing MRO/HiRISE images of Mars, we have concluded that all or most of the young crater retention ages (CRAs) attributed to outflow channels actually date lavas that postdate the channels (or perhaps carved the channels in some cases). Although there is much published literature supporting recent water floods on Mars, we believe this question is not yet answered.

Did water or lava carve outflow channels? Most Mars scientists accept that outflow channels were carved by water [e.g., 8], but alternate hypotheses persist, especially that lava carved the outflow channels [9]. However, we doubt the hypothesis that all or most Martian outflow channels were carved by lava. Instead, we propose that most outflow channels are ancient and have been flooded by lava in more recent times. This sequence of events would explain why young flood deposits of the sort indicated by terrestrial analogs are difficult to find in spite of searches with HiRISE [10].

We cannot rule out a volcanic origin for some Martian channels. Lava flows on Mars, even in recent times, appear to have involved fully turbulent flow similar to the water floods postulated to have carved the outflow channels [11]. If channel erosion is primarily by suspension and traction of sediment, a turbulent bubble-laden lava flow may be similar in erosive potential to sediment-rich water (or mud). However, if erosion depends on mechanisms such as hydraulic plucking or cavitation [12], lava may be relatively ineffective compared with water.

There have been few descriptions of definitive water flood deposits on Mars, although such deposits are common along the floors of terrestrial flood channels [e.g., 13]. Nevertheless, we favor the hypothesis that most of the large channels were carved by water based on (1) abundant evidence for water on Mars, (2) the few examples of outflow channels which do retain flood deposits (e.g., Uzboi Vallis discussed below), and (3) the fact that bedrock erosion by water is well documented and better understood [12-14].

Athabasca and other channels in Elysium Planitia: Prior to MRO's arrival at Mars, Athabasca Valles was considered the youngest outflow channel on Mars [15, 16]; there even appeared to be well-preserved subaqueous dunes [17]. Remarkably, HiRISE images showed the channels, including the putative dunes, to be entirely coated by lava [18]. Young (<10 Ma) CRAs for Athabasca Valles [15, 19] apply to the lava, not the channels, unless lava carved the channels. Somewhat older CRAs (but still Late Amazonian) for surfaces in Grota, Rahway, and Marte Valles also correspond to channel-filling lava flows. The simplest explanation is for the lava to have carved these channels, but we do not have a strong understanding of erosion by lava, and it cannot explain outflow channels such as Uzboi Valles. The next simplest explanation is that the channels are water-carved features and lava flows often erupted from the same tectonic source regions and followed the pre-existing topographic lows.

Because of the lava coating we have poor constraints on the age of the channels, if they were originally carved by water. Geologic mapping [20] shows Marte, Rahway, and Grota Valles cutting Cerberus Fossae Unit 2 (AEc_2, Late to Middle Amazonian), which implies channel activity in the Late Amazonian. However, this unit (probably lava) could postdate, but not completely fill, the older fluvially-carved channels. The youngest lavas then followed the already lavacovered channels, leaving sharp banks when the lava drained, as in Athabasca Valles. The age ambiguity could be resolved if there were a section of channel with no lava and enough superposed craters to get a CRA, but we have not found such an area anywhere in this region. Although [21] interpreted Athabasca Vallis as extremely young because it cut young lava flows, we now realize that the lava filled and overflowed the channel in places, then drained away.

Mangala Valles: Water flooding episodes at ~3.5 Gyr, ~1 Gyr, ~0.5 Gyr, and ~0.2 Gyr have been reported [22]. In contrast, [23] interpreted Mangala Valles as a lava-carved system. Not analyzed by these workers are the many Context Camera (CTX) images over this region, which provide extensive coverage at near ideal illumination angles and scale (~6 m/pixel), and show a suite of landform, common on Martian lava flows, over the most sparsely-cratered surfaces within the channels [Fig. 7 of ref. 9]. A meters-thick mantle of dust or pyroclastics obscures much of the surface at HiRISE scales [24]. We suggest that the ~3.5 Gyr surfaces correspond to the fluvial activity here, and the later dates correspond to episodes of volcanism.

Kasei Valles and Echus Chasmata: Young CRAs (0-1 Gyr) have been reported for these channels, but were not confirmed in a more detailed study [25]. The floors of the Amazonian-age interior channels in Kasei Valles [26] are seen to be lava-coated in HiRISE images, so the young ages apply to the most recent lava flows, not the major channel carving episodes. Some of these lava flows can be traced to sources in the Tharsis rise rather than from the chaos terrains where the channels originated.

High-altitude channels: Young channels high on the Tharsis bulge have been described and interpreted as water-carved [27]. However, they are relatively small compared to most outflow channels and require local recharge [28] rather than sourcing from a global or large-scale groundwater table [3, 5]. Also, we have found nothing in the HiRISE images to rule out the idea that these are volcanic channels, since there appears to be a morphologic continuum with features essentially identical to lunar sinuous rilles.

Uzboi Vallis: Uzboi Vallis, while not Amazonian, is one of the best examples of an outflow channel with preserved water-flood erosional morphology and deposits while also lacking evidence for lava infilling. Uzboi is the proximal section of the Uzboi-Ladon-Morova (ULM) system and lacks a significant chaos source region, thereby distinguishing it from many Martian outflow systems [29]. The system emerges full width from the northern margin of Argyre basin and traverses as a series of incised segments separated by depositional basins created by impact. Initial incision of the ULM likely occurred in the Noachian [29, 30], though late activity persisted well into the Hesperian.

The interior of Uzboi preserves local layered alluvial deposits, likely associated with discharge from tributary valleys, and a series of longitudinal grooves and ridges interpreted to have formed during rapid drainage of water from the vallis [31, 32]. At the downstream end of Uzboi, a series of broad, boulder-laden fans and capping by subaqueous dunes occur in Holden crater and are associated with late Uzboi floods [32]. In addition, there are widespread sedimentary layers of varying expression within the fill in Ladon Basin and downstream of Ladon Valles, though rocks capping portions of the sequence in Ladon basin may be volcanic [29, 30]. Given the assemblage of fluvial and alluvial landforms associated with the ULM and the paucity of volcanic landforms near the system, incision of the system by water appears required.

Conclusions: Water carved the large outflow channels, but many have been flooded by more recent lava and there is no conclusive evidence in the published literature for water floods in the past Gyr.

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