SECONDARY CHAOS ON MARS PRODUCED SUBSTANTIAL FLOODING. Neil Coleman, Univ. of Pittsburgh at Johnstown (Dept. of Energy & Earth Resources, Johnstown, PA 15904; ncoleman@pitt.edu).

Introduction: Understanding the origin of chaos on Mars is key to resolving links between the groundwater flow system and surface flooding. Some outflow channels have chaos that formed on their floors at locations of deep channel incision. These have been called *secondary chaos* [1], and they resemble the "primary" chaos found at some channel heads but are smaller in scale. They are theorized to have spawned via deep channel incision that thinned the crust and cryosphere, permitting breakthrough of pressurized groundwater from beneath. Examples of secondary chaos are found in Maja, Shalbatana, and Elaver Valles and on the floors of channels that issued from Hydaspis Chaos. I previously described the secondary chaos in Ravi Vallis [1], and included a simple mathematical model for these fluid pressure outbreaks. Large groundwater discharges erupted at Aromatum Chaos, eroding Ravi Vallis (Fig. 1) and triggering secondary chaos to form downstream inside the channel, including the two largest, Iamuna and Oxia Chaos.

Rodríguez et al. [2] examined 34 secondary chaos and concluded that 33 of them were collapsed zones that apparently did not produce floods. Their rationale for no flooding has 2 main points: (a) all secondary chaos occur in scarp-bounded depressions; and (b) they have downstream margins that do not show more deeply incised scour marks than their upstream margins. They conclude that episodes of chaos collapse "likely involved the release of relatively low volumes of ground volatiles in the form of…sedimentary volcanism and/or sublimation vapors…"

Discussion: It is extraordinary to claim little or no flooding from secondary chaos, when the primary chaos they resemble generated floods that eroded enormous channels. In this limited space I reexamine some of the chaos studied by *Rodríguez et al.* [2], who accept that Oxia Chaos (Fig. 1) produced substantial outflow flooding. This secondary chaos is scarp-bounded on its downstream margin. Therefore this single characteristic should not preclude a flood interpretation for any chaos. Contrary to [2], topographic data confirm that Iamuna Chaos was also a significant flooding source – its downstream margin is not scarp bounded and the channel downstream from Iamuna was *substantially deepened and widened* by groundwater outflow erosion, the enhanced width being ⅔ that of the entire chaos. These features are clear in Fig. 2 and also in Fig. 5a of [2]. This evidence continues to support the model of incision-generated outflow for Ravi Vallis and its secondary chaos [1]. Similarly, Shalbatana Vallis has a larger cross-section at the downstream end of Xanthe Chaos, a secondary chaos not studied by [2].

There should be no expectation that secondary chaos would generate floods of similar magnitude to those from upstream primary chaos at channel heads. Based on the theory that groundwater breakout was triggered by incision and cryosphere thinning [1], it follows that the pressure release at a primary chaos would have reduced the confined aquifer pressure *before* the downstream secondary chaos formed.

Key points not considered by *Rodríguez et al.* [2] relate to the source and duration of channel flow and

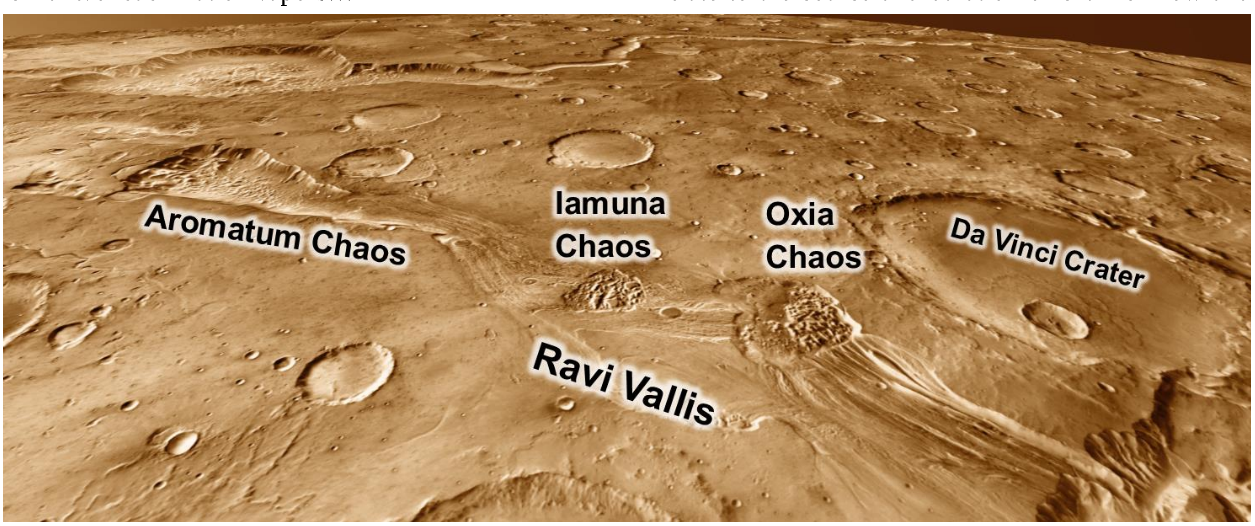

Fig. 1. Slant view of the Ravi Vallis channel system (eye height 180 km). Flow was from upper left to lower right. Aromatum is a "primary" chaos. Iamuna Chaos is at 319.39 °E, 0.28 °S. Da Vinci is 100 km wide.

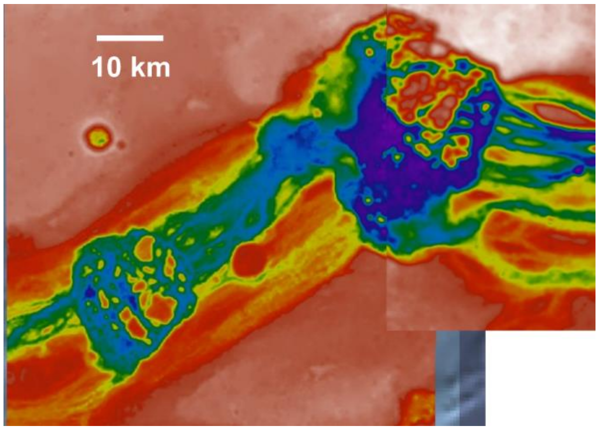

Fig. 2. HRSC topography [3] of Iamuna (left) & Oxia Chaos (right). Deepest features are purple.

the strong influence these had on the *preservation* of secondary chaos. This is neatly illustrated by secondary chaos in Elaver Vallis (Fig. 3). There is no chaos at the head of Elaver V. These channels were carved by the breach of a deep lake in Morella Crater [4]. This source of Elaver V. was not discussed by [2], and flood scoured terrain was incorrectly identified as a primary chaos (white outline, left side of their Fig. 12). Two Elaver channels were formed, a deeper northern one that eventually captured all the flow, and a shallower southern channel left high and dry with hanging valleys at both ends. Chaos formed on both channel floors, but *sustained flow* in the northern channel scoured and eroded chaos B and C producing relatively smoother chaos floors. Flow in the southern channel ended quickly, allowing the discharging chaos A with its mesas and mounds to be better preserved (blue circle, Fig. 3). The channel downstream from chaos A is 75+ m deeper than the upstream channel, providing evidence of outflow from this secondary chaos. This illustrates the importance of a regional view, showing how each chaos relates to its channel and source. A regional view of Elaver Vallis explains the morphology of its chaos, and shows why many secondary chaos may retain little evidence of outflow flooding – *they were deeply scoured by sustained flow* from upstream.

Conclusions: Like primary chaos at the heads of some channels, the secondary chaos that formed on channel floors likely produced significant outflows of groundwater, albeit with lower discharge rates. This is illustrated at Ravi Vallis, where the initiation of outflow at secondary chaos would have further depressurized the aquifer and halted flow from the upstream source, Aromatum chaos. If discharge from a secondary chaos occurred at the same time as continuing flow from upstream, the evidence of outflow at the secondary chaos would likely be eroded away or degraded, as occurred in the northern channel of Elaver Vallis. In fact *chaos may have formed on many other channel floors* and been entirely stripped away if the channel was deeply incised. It would therefore be improper to conclude no outflow had occurred. It is also reasonable to presume that cryosphere breach and groundwater outflow would promote mobilization and loss of subsurface material (ice, ash, salts) during or after the outflow, causing more subsidence at a secondary chaos.

In summary, a regional perspective is essential to properly interpret the genesis and *preservation* of secondary chaos and associated erosional features. A similar regional perspective was needed to properly interpret Missoula megaflood landforms on Earth, including recognition of Pleistocene Lake Missoula as the source of repetitive floods. Many landforms were obliterated by successive megafloods, while some others (e.g., giant current ripples and pendant bars) were formed by the last big flood and therefore preserved.

References: [1] *Coleman N.* (2005) *JGR Planets*, http://onlinelibrary.wiley.com/doi/10.1029/2005JE002419/pdf. [2] *Rodríguez J. et al.* (2011) doi: http://dx.doi.org/10.1016/j.icarus.2010.09.027. [3] *Heipke et al.* (2007) *Planet. & Space Sci.* doi:10.1016/j.pss.2007.07.006. [4] *Coleman N.* (2013) *JGR*, doi: http://dx.doi.org/10.1029/2012JE004193.

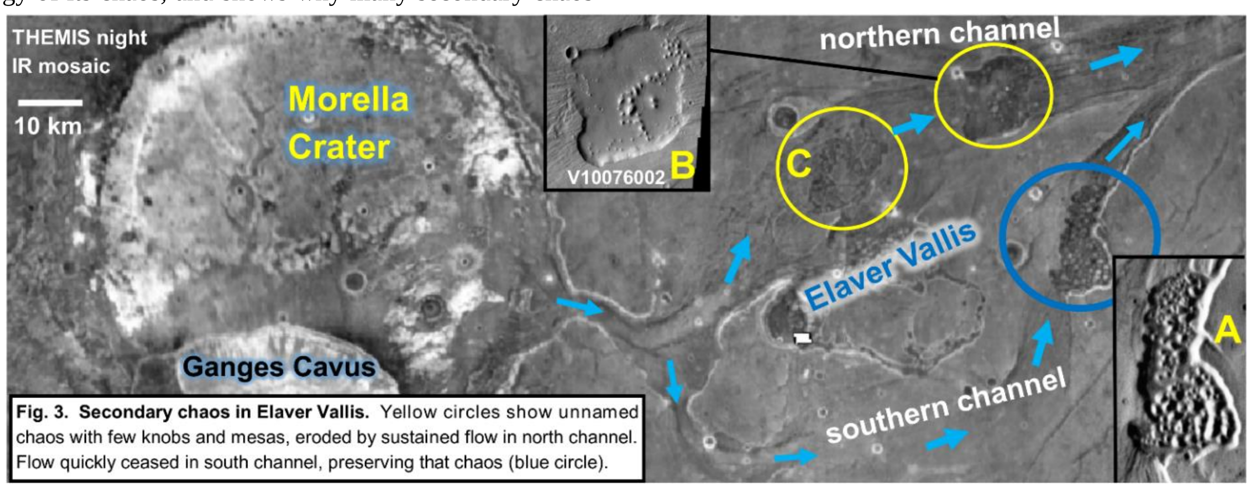

Fig. 3. Secondary chaos in Elaver Vallis. Yellow circles show unnamed chaos with few knobs and mesas, eroded by sustained flow in north channel. Flow quickly ceased in south channel, preserving that chaos (blue circle).