GLACIATION AND VOLCANIC INTERACTION TO FORM THE MODERN NORTHEAST SYRTIS REGION OF MARS. J. R. Skok[1] and J. F. Mustard[2], [1]Louisiana State University, Baton Rouge, LA, 70803, jskok@lsu.edu. [2]Brown University, Providence, RI, 02912

Introduction: The Northeast scarp of the Syrtis Major volcano encompasses a range of Martian geologic history in stratigraphic section and an associated diverse mineralogy [1,2,3]. The region is well characterized spectrally with identified minerals ranging from crystalline igneous (olivine and pyroxene) [4] to diverse minerals indicative of aqueous alteration (smectites, kaolinite, serpentine, carbonate and sulfates) [1,5]. The region contains well-developed fluvial and deltaic systems including the open basin lake in Jezero crater [6,7]. West of the scarp are Hesperian volcanics from the Syrtis Major volcanic complex [8]. Here we detail a small channel and basin system that bridges the important and well-exposed Hesperian-Noachian stratigraphic boundary. The system has several diagnostic properties that indicate the climatic history of the region. The specific morphology of the channel-basin system is best explained as forming and evolving in the presence of multiple periods of glaciation in the region. This is consistent with observations of the eastern Syrtis Major scarp [9].

Upland Channels: The northern most volcanic flows of the Syrtis Major structure fill in the topographic lows of a rough knobbed terrain that makes up the southern border of NE Syrtis. These lavas form a generally flat surface with a slight slope down toward the east. On these volcanics, a subtle channel system branches and meanders [Figure 1, blue], following the slope to the East. Before leaving the volcanics, the channels branch to the North, South and East, all eroding the volcanics back where they exit, but only the east channel leads to the basin described below. The other channels lead to Noachian plains but have no further evidence of flow morphology. A key observation is that the channels have no clearly defined origin. In a nearby mapped fluvial system [10] channels on the volcanics seem to be sourced by impacts into the volcanic releasing trapped fluids. This does not seem to be the case for these channels, as they have no clear origin. The eastern channel leads east through an eroded notch in the volcanics and a sulfate rich boxwork terrain and into a topographic basin in the neighboring Noachian plains.

Basin: The system's main depression [Figure 1, red outline] formed an open basin lake as signified by the outlet channel described below. The basin has a depth of ~500 m compared to the plains to the North and ~300 m compared to the volcanic to the south. It is currently floored by a dark mafic mantling material common in the topographic lows in the area, particularly the Nili Fossae region to the NE. An impact crater in the mantling material exposes an underlying layer of magnesium carbonate-bearing strata. The basin has two possible outlets, one based on current topography would have drained to the southeast at an elevation of -2450 m and one based on the outlet channel morphology would have drained to the east with a -2350 m meter elevation. The latter would have had to be active at some point to develop that morphology described below. There is no geomorphic evidence for fluvial activity to the southwest, which means that either the general topography would have been different when the system was active or that the southeast outlet was blocked at the time.

Outlet: The main outlet channel [Figure 1, green] begins at the basin's eastern edge and can be traced for 48 km over which it loses ~750 m of elevation. It terminates at -3100 m of elevation in the Isidis Basin in a potential but ill-defined fan structure. This could mean that Isidis was filled to a depth of ~700 m at this time where the fan for formed, that the flow was blocked or slowed by ice or snow, or that the stream lost its water and sediment load through ground infiltration or sublimation. The outlet channel has segments of braided channels that could be formed from heavy discharge or multiple flow episodes.

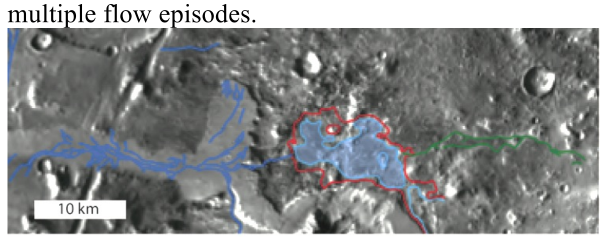

Figure 1: Channel-Basin system highlighted. Blue lines map the upland source channels. The blue shaded region marks a fully enclosed topographic basin, while red is a hypothetical basin needed to activate the eastern outlet channel marked in green.

Establishing ages of surface units through crater counting: The geologic timeline has been further developed with crater counting of some of the relevant units [Figure 2]. The volcanics underlying the upland source channels were dated near 3.4 Ga, toward the youngest range of the early Hesperian basalts erupted as part of the Syrtis Major complex [6]. The altered plain to the north of the basin has a crater retention age of 3.71 Ga while the mantling material in the basin has a young age of 1.29 Ga. While the volcanics provide a strong unit that should have preserved impacts, the plains and basin fill units are likely to be softer and the ages should be seen as minimums.

Questions: These integrated observations of fluvial channels, volcanic deposits, and topography present challenges to developing a unified local volcanic and hydrologic history. The main inconsistencies are: (1) the volcanics flow ~500 km from the caldera source but stop abruptly and form a cliff at the edge of this basin depression instead of filling it in. (2) The source channels are etched in the basalt and have no clear point of origin. Are they of volcanic origin in inherent to emplacement or fluvial with a dispersed origin? (3) Current topography would have lead to basin outflow to the southeast despite no evidence of flow and a clear outlet channel to the east.

Hypotheses: Each of the listed questions can be explained in multiple ways. For (1) the lavas could have originally filled in the basin, and have been eroded back. However, the crater counting of this plain is older than the volcanics meaning that the lower terrain has been collecting crater since before volcanic emplacement. We propose that a cold-based glacier covered the plains during the volcanic emplacement. This would allow the retention of large craters without eroding or modifying the surface. This would explain the cliff forming nature of the volcanics, the failure to fill in the nearby topographic lows and the older crater age of the plains.

The lack of source origin in (2) could be the result of the channels forming from lava flows inherent to the volcanic emplacement or the erosion of a source crater or morphology. A volcanic origin of the channels would not explain the deep erosion of the volcanic cliff edge or the meandering nature as the surface levels out. Instead, we propose a channel origin by melting of snow or ice. A distributed fluvial source from a snow pack or latitude dependent layer would leave no clear source origin but eventually accumulate enough to begin incision.

The outlet channel problem (3) could be explained in several ways. The first is that the regional topographic was different during period when the basin and its outlet were active. This should be expressed in faulting in the volcanics but is not observed. Alternatively, the southeastern outlet could have been blocked by an extension of the volcanic plateau that has since eroded away. This option is difficult to support or refute with current observations. However, the erosion would likely require a significant fluid flow to break down and remove the volcanics and no evidence of fluvial morphology is observed here. An alternative hypothesis is that the southeast outlet was blocked by a glacial damn forcing the basin outflow to the eastern outlet.

Implications: While multiple hypotheses have been considered for each of the inconsistencies listed above, the simplest single solution seems to be that the volcanics were emplaced and the channel and basin system were active in a time of repeated mid-latitude glaciation [11] in the early Hesperian. This would account for the cliff forming volcanics not covering older and lower terrain, the distributed source channels and the basin's outlet to the East.

The geologic diversity of NE Syrtis make understanding the timing of the key events here, critical to understanding the overall history of Mars. One key aspect of this area is the clear contact between the phyllosilicate bearing Noachian material and the Hesperian sulfates at the base of the Syrtis volcanics. This compositional contact is critical to understanding the evolution of the Martian environment. If this contact developed in the presence of ice and volatiles as well as the overlying volcanics, it could effect the interpretation of the chemical nature of this transition.

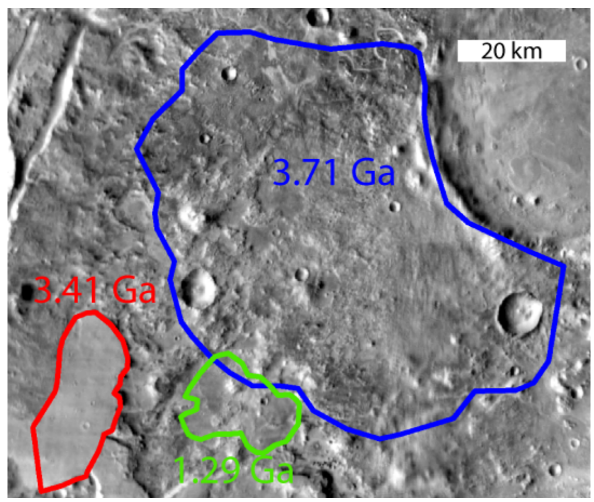

Figure 2: Crater counts of key areas. Red (3.41 Ga) is an edge section of the Syrtis Major Volcanics. Green (1.29 Ga) is the basin mentioned throughout this work. Its young age indicated late fill or soft deposits. Blue (3.41 Ga) is the Noachian Plains that would have been covered with ice deposits to stop fill from southern basalts.

References: [1] Ehlmann and Mustard (2012) *GRL*, 39, L11202. [2] Mustard et al., (2008) *JGR*, 114, E00D12. [3] Mangold et al., (2007) *JGR*, 177, E08S04. [4] Mustard et al., (2005) *Science,* 307, 1594-1597. [5] Ehlmann et al., (2009) *JGR*, 114, E00D08. [6] Fassett and Head (2005) *GRL*, 32, L14201. [7] Ehlmann et al., (2008) *Nat. Geo.*, 1, 355-358. [8] Hiesinger and Head (2004) *JGR* 109, E01004. [9] Ivanov and Head (2003) *JGR*, 108, E6. 5063. [10] Mangold et al., (2008) *Planet. & Space Sci.* 56, 1030-1042. [11] Head et al., (2003) *Nature,* 426, 797-802.