PATTERNS OF MARTIAN DEGLACIATION: ASSESSING THE DISTRIBUTION OF PARAGLACIAL FEATURES IN MID-LATITUDE CRATERS. Erica R. Jawin[1] and James W. Head[1], [1]Department of Earth, Environmental, and Planetary Sciences, Brown University, Providence, RI 02912 USA (Erica_Jawin@brown.edu).

Introduction: Extensive evidence of non-polar ice exists on Mars, predominantly in the form of debris-covered glaciers in the mid-latitudes including lobate debris aprons (LDA), lineated valley fill (LVF), and concentric crater fill (CCF) [*1–3*]. These deposits are believed to have accumulated in periods of higher obliquity (~35°) in the last few hundred million years [*4–7*]. Stratigraphically younger latitude-dependent mantle (LDM) suggests that ice ages have continued to occur in the geologically recent past [*8*, *9*]. Integral to the discussion of glaciation and ice ages on Mars is the role of deglaciation. In terrestrial glacial regions, the period directly following deglaciation is referred to as the paraglacial period, in which the environment returns to "equilibrium" or interglacial conditions [*10*,*11*]. Recently, a paraglacial period has been identified in martian mid-latitude crater glacial deposits [*12*]. This paraglacial period is expected to have initiated within the past 5 Ma based on modeled obliquity variations [*13*], and the current climate setting in these craters is either in the waning stages of a paraglacial period, or fully in an interglacial period [*14*].

This work builds upon previous paraglacial analyses of martian glaciated craters [*12*,*14*], and seeks to determine the degree of variability in paraglacial reworking within the martian mid-latitudes. On Earth, paraglacial modification often exhibits a specific suite of geomorphic features [*11*], a subset of which are also seen on Mars [*12*]. It is therefore expected that this suite of geomorphic units will be present in the glaciated craters in the martian mid-latitudes. The variations seen in this analysis will aid in assessing patterns of accumulation and ablation during recent glacial periods on Mars.

Methods: The analysis of paraglacial features was carried out by assessing the population of CCF-bearing craters in the mid-latitudes as described by [*15*], and documenting the paraglacial features present in each crater. Specific paraglacial features include spatulate depressions, gullies, washboard terrain, crater wall polygons, and broad pits [*12*]. Observations were made using a combination of visual images: 6 m/pixel Context Camera (CTX) and 30 cm/pixel High Resolution Imaging Science Experiment (HiRISE) [*16*,*17*]. The fine-scale nature of these features are most accurately resolved in HiRISE data; however, extensive CTX coverage allowed at least initial observations to be made in all craters.

Observations: The analysis of mid-latitude glaciated craters showed that the degree of paraglacial reworking is variable across the planet (Fig. 1, Table 1). This analysis yielded several observations: **(1)** ~70% of mid-latitude glaciated craters contain some evidence of paraglacial reworking (one or more paraglacial features is present inside the crater). **(2)** Many more paraglaciated craters are present in the southern hemisphere than in the northern; this is predominantly due to the older average age of the southern highlands relative to the northern lowlands, and therefore a larger crater population which can be glaciated; however, proportionally there are more paraglaciated craters in the south than in the north: 89% and 44% respectively contain at least 1 feature (Table 1). **(3)** The distribution of features is not ubiquitous across all craters. Many craters contain multiple paraglacial features (Fig. 2A, Table 1), while some craters contain CCF,

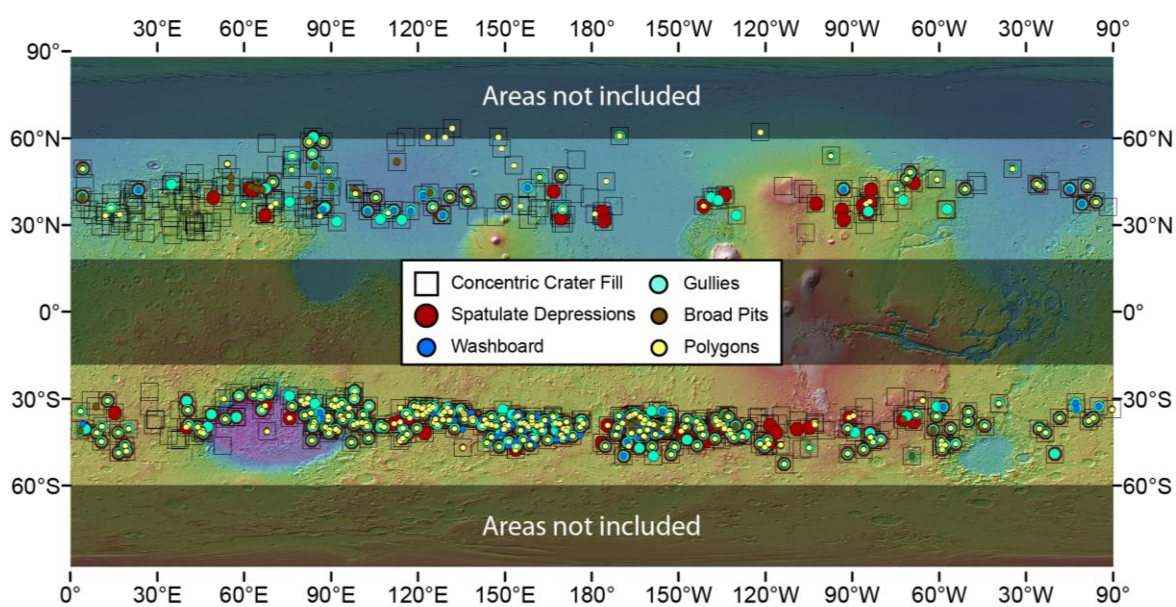

Figure 1. Distribution of paraglacial features in glaciated craters across the mid-latitudes. CCF crater database from [15].

but no paraglacial features (Figure 2B). Features are generally present on pole-facing slopes, as has been reported in previous studies assessing gully orientation and CCF flow orientation [*15,18*]. **(4)** Northern hemisphere craters are often more completely filled with CCF than southern hemisphere craters, inhibiting the formation of paraglacial features in the crater wall (such as crater wall polygons and washboard terrain). **(5)** The highest concentrations of paraglacial features in the southern hemisphere are located in regions that have been predicted to experience melting conditions at higher obliquities in the last few hundred million years [*19*], including Newton crater, the eastern rim of Hellas, and Terra Cimmeria. The region west of Hellas (~30°E) is distinct in the southern hemisphere for its lack of paraglacial features. In the northern hemisphere, the highest concentration of glaciated craters exists in the Deuteronilus-Protonilus Mensae region, although almost all of these craters do not exhibit paraglacial reworking. The highest concentration of craters with multiple paraglacial features in the northern hemisphere is in Utopia Planitia, although on average the concentration of paraglacial features in this area (and the hemisphere on the whole) is lower than in the southern hemisphere (Table 1).

Discussion: The variations in paraglacial reworking suggest that accumulation and ablation are not completely dependent on latitude; primarily, regional circulation patterns will affect the distribution precipitation throughout the md-latitudes. The highest concentrations of glaciated craters in the northern hemisphere are broadly located in regions predicted to be areas of enhanced winter precipitation in periods of higher obliquity by general circulation models [5]. This prediction is confirmed by the higher degree of fill in northern hemisphere craters. The relative paucity of paraglacial features in much of the northern hemisphere, specifically in the Deuteronilus-Protonilus Mensae region which is noted for its concentration of glacial features, may be attributed to differences in many factors including circulation patterns, elevation, atmospheric pressure, and temperature, which led to lower rates of ablation, and less paraglacial reworking.

Another potential source of variability in the paraglacial features is the presence of latitude-dependent mantle (LDM) [9]. In many craters, particularly in the northern hemisphere, deposits of CCF are mantled by LDM, obscuring the presence of paraglacial features on the crater wall and floor (see the "mantled" class in [*25*]). In some craters, the LDM has been modified by subsequent gully formation [*26*], but this deposit complicates the identification of paraglacial features. Subsequent analyses of the detailed nature and distribution of LDM and its relation to larger glacial cycles will aid in interpreting the paraglacial response in glaciated craters.

References: **1.** Levy et al. (2007), *JGR,* 112. **2.** Levy et al. (2010), *Icarus,* 209. **3.** Head et al. (2010), *EPSL,* 294. **4.** Mangold et al. (2003), *JGR,* 108. **5.** Madeleine et al. (2009), *Icarus,* 203. **6.** Morgan et al. (2009), *Icarus,* 202. **7.** Fassett et al. (2014), *Geology,* 42. **8.** Mustard et al. (2001), *Nature,* 412. **9.** Head et al. (2003), *Nature,* 426. **10.** Church & Ryder (1972), *GSA,* 83. **11.** Ballantyne (2002), *Quat. Sci. Rev.,* 21. **12.** Jawin et al. (2014), LPSC 45th, #2241. **13.** Laskar et al. (2004), *Icarus,* 170. **14.** Jawin et al. (2015), LPSC 46th, #2016. **15.** Dickson et al. (2012), *Icarus,* 219. **16.** Malin et al. (2007), *JGR,* 112. **17.** McEwen et al. (2007), *JGR,* 112. **18.** Dickson et al. (2007), *Icarus,* 188. **19.** Dickson et al. (2015), LPSC 46th, #1035. **20.** Costard et al. (2002), *Science,* 295. **21.** Williams et al. (2009), *Icarus,* 200. **22.** Lachenbruch (1962), *GSA,* 70. **23.** Marchant et al., *GSA,* 114 (2002). **24.** Marchant & Head (2007), *Icarus,* 192. **25.** Harrison et al. (2015), LPSC 46th, #1625. **26.** Dickson et al. (2015), *Icarus,* 252.

	Total (n=631)	North (n=246)	South (n=385)
1 Feature	71	44	89
2 Features	55	23	76
3 Features	44	15	62
4 Features	31	9	44
5 Features	17	5	24

Table 1. Percent of glaciated craters with evidence of paraglaciation. Paraglacial features include spatulate depressions, gullies, washboard terrain, crater wall polygons, and broad pits. For example, 24% of glaciated craters in the southern hemisphere contain all 5 paraglacial features.

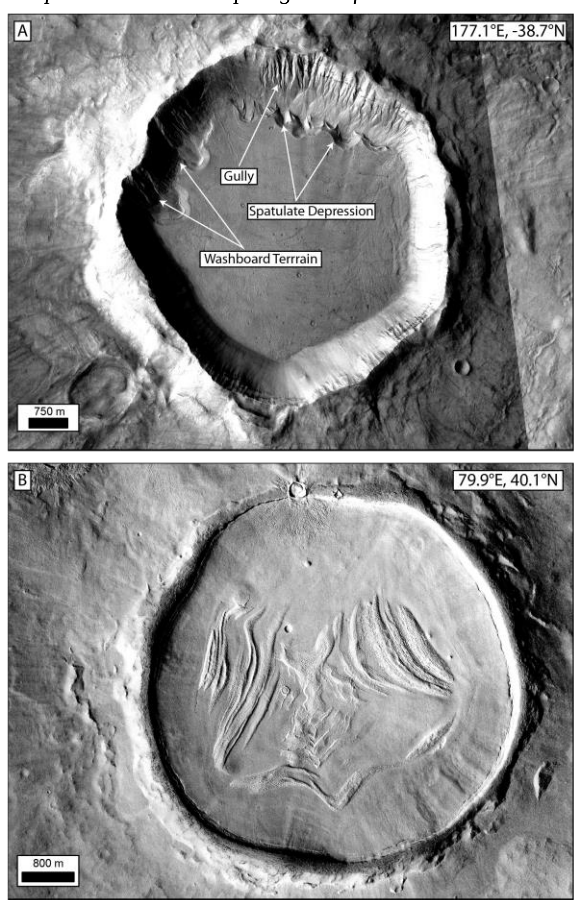

Figure 2. Variation in morphology and distribution of paraglacial features in glaciated craters. (A) Crater with evidence of paraglacial modification. CTX image G09_021635_1405. (B) Crater containing no paraglacial features. CTX image P16_007437_2220.