SPATIAL DISTRIBUTION OF MARTIAN IMPACT CRATERS MODERATED BY GEOLOGIC UNIT AND AGE. P. C. Boan[1] and E. B. Hughes[2], [1]Department of Earth and Planetary Sciences, University of California, Riverside; Riverside, CA, 92512. [2]Department of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, Georgia, 30332

Introduction: Crater populations on planetary bodies are key to constraining the age, geologic history and surface processes of the planet. While extensive surveys of craters on Mars have been undertaken (e.g., [1]), statistical approaches to constraining the spatial distribution of crater populations, particularly testing for aggregation, regularity (non-randomness), or randomness, remain underexplored. In particular, there is an absence of studies investigating crater aggregation based on geologic unit. This kind of analysis is key to analytically investigating the extent of the secondary crater population of Mars, which in turn can help fine-tune age constraints of Martian surfaces [2]. It can also aid in determining how crater distributions change after surface modification (i.e., surface weathering leading to apparent aggregation of craters, or lava flows obscuring crater presence). Here, we analyze the spatial distribution of crater populations on Mars as moderated by the geologic units, and determine the extent of variation in aggregation regularity, and randomness.

Methods: A population of 12,123 craters were examined from the northern Terra Sirenum, Medusa Fossae, and southern Amazonis Planitia regions to determine their spatial distribution using SPPA methods. We chose this region (Fig. 1.; 20°S, 180°W; 20°S, 140°W; 17°N, 180°W; 17°N, 140°W) to cover a broad range of Martian surfaces and ages, including the hemispheric dichotomy.

Standard methods for examining spatial distributions, such as nearest neighbor analysis, are often hindered by edge effect and irregularly shaped study areas. In order to account for this, craters were examined using Spatial Point Pattern Analysis (SPPA), a method widely used in ecological studies and approaches spatial patterns more holistically. Tests were performed in *Programita* and the R package *Spatstat* [3,4].

Crater patterns were tested against a null hypothesis of randomness (the colored envelopes in Fig. 2), and specifically a Heterogeneous Poisson distribution [3]. In these plots the solid line indicates the examined populations spatial pattern using a pair correlation function (PCF) [3]. If the line is above the simulation envelopes, patterns were determined to be aggregated, and if below the pattern was determined to be regular. If the pattern was plotted within the colored simulation envelopes it was determined to be completely spatially random (Fig. 2).
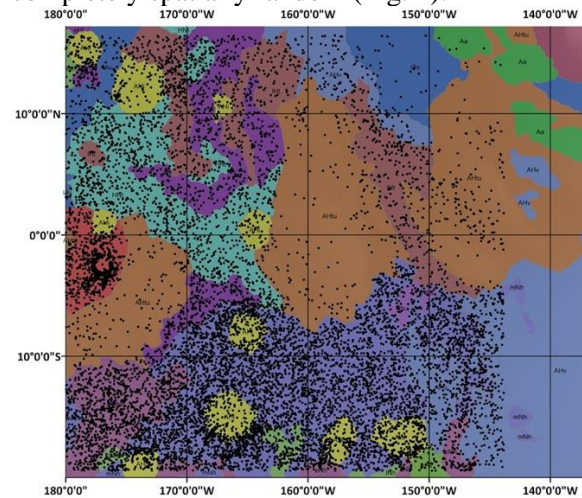

Fig. 1 *Study area for the spatial analysis, showing the crater population distribution (black dots) overlaying the geologic units from [4].*

Results: The total crater population within the study area had an aggregated distribution (Fig. 2A). This population was then divided into primaries and secondaries using the preexisting classifications [1]. The primaries displayed a regular distribution, while secondaries in the region had an aggregated distribution. Further examination of the crater distributions in relation to geology were varied [5]. Most units have a random distribution, with one unit regularly distributed (The Amazonian and Hesperian transition undivided unit) and three others (The Amazonian and Hesperian impact unit; the Hesperian transition undivided unit and the Middle Noachian highland unit) showing aggregation (Table 1).

Discussion: Craters may be clustered due to several different processes. The first is secondary cratering, a process in which an initial impact will

produce a radius of secondary craters. A population of secondary craters should register as a clustered population [6, 7]. Surface weathering, such as fluvial, lacustrine, or aeolian weathering, may also produce clustered results, with heavily modified surfaces obscuring the presence of crater populations, while relatively unmodified surfaces may show more random distributions. Volcanic resurfacing may also lead to clustered crater populations (obscuring smaller craters on regional scales) [7].
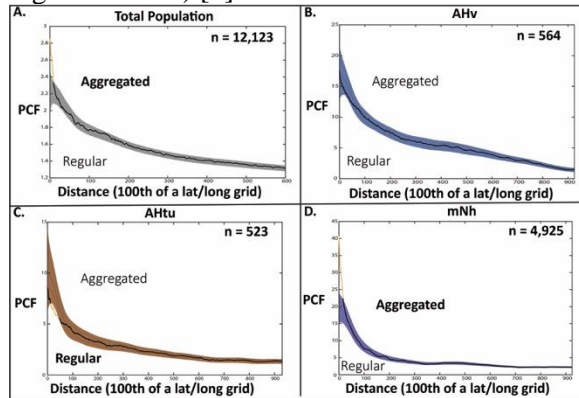

***Fig. 2** Results from the PFC tests for aggregation, regularity and randomness. The examined pattern is displayed as a solid black line, unless it is outside of a simulation envelope, in which case it is gold. Here we display two results indicating aggregation (TP and mNh), one demonstrating regularity (AHtu), and one demonstrating randomness (AHv). Note that any exit from the simulation envelope is statistically viable.*

While an aggregated distribution in some units is logical—specifically AHi unit which consists of 10 large impact zones—others are more intriguing. Clustering in the Middle Noachian highland unit (mNh) indicates craters are aggregating within the Terra Sirenum region. This region may have undergone extensive lacustrine surface weathering in the late Noachian [8], and therefore surface modification may have led to apparent crater clustering. We also may be identifying the presence of regional secondary crater populations.

Regular distribution of craters in the Amazonian and Hesperian transition undivided unit is also an intriguing result. This unit covers the Medusa Fossae region, which is interpreted to be relatively young and extensively redistributed aeolian material [9]. A regular distribution of

craters may be due to the relatively sparser crater population owing to the young age of the surface. However, the Late Amazonian volcanic unit (lAv) does not show regularity in spite of its age, indicating another enigmatic process may be at play. It is possible that regular population distributions may be a proxy for extensive aeolian surficial materials, or for relatively young surfaces.

Unit	Name	Crater N	CSR - PCF	HP - PCF
Aa	Amazonian Apron	6	N/A	N/A
AHi	Amazonian and Hesperian impact unit	1167	Clustering	Clustering
AHtu	Amazonian and Hesperian transition undivided unit	523	Clustering	Regular
AHv	Amazonian and Hesperian volcanic	564	Clustering	Random
eHt	Early Hesperian transition unit	772	Clustering	Random
eHv	Early Hesperian volcanic unit	26	Clustering	Random
eNh	Early Noachian highland unit	1176	Clustering	Random
HNt	Hesperian and Noachian transition unit	1100	Clustering	Random
Htu	Hesperian transition undivided unit	741	Clustering	Clustering
lAv	Late Amazonian volcanic unit	141	Clustering	Random
lHt	Late Hesperian transition unit	715	Clustering	Random
lNh	Late Noachian highland unit	191	Clustering	Random
mNh	Middle Noachian highland unit	4952	Clustering	Clustering
Nhu	Noachian highland undivided unit	50	Clustering	Random
TP	Total Regional Population	600	Clustering	Clustering

***Table 1.** PCF test results. The Heterogeneous Poisson (HP) null model, which corrects for the spatial variability between geologic polygons of like units, demonstrates variability in clustering moderated by geologic unit.*

Future Work: The work presented herein shows that SPPA is an applicable method for analyzing Martian impact craters spatial distributions, both as a whole population and within geologic units. This lays the foundation for future work examining the entire population of Martian impact craters spatial distributions in relation to geology, while continuing to investigate methods to isolate and test for aggregation in secondary crater populations on Mars.

References: [1] Robbins and Hynek (2012). *J. Geophys. Res.,* 115, E05004. [2] Robbins and Hynek (2014) *EPSL,* 400, 66-76. [3] Wiegand and Moloney (2014) *HB. of SPPA in Eco.* [4] Baddeley at al. (2015) *SPP Method. & App R* [5] Tanka et al. (2014) *P&SS,* 95, 11-24. [6] Bierhaus et al. (2005) *Nature,* 437, 1125-1127. [7] McEwen and Bierhaus (2006) *Annu Rev Earth Planet Sci*, 34, 535-67. [8] Wray et al. (2011). *JGR* 116, E01001. [9] Harrison et al. (2010). *Icarus* 209, 405-415.