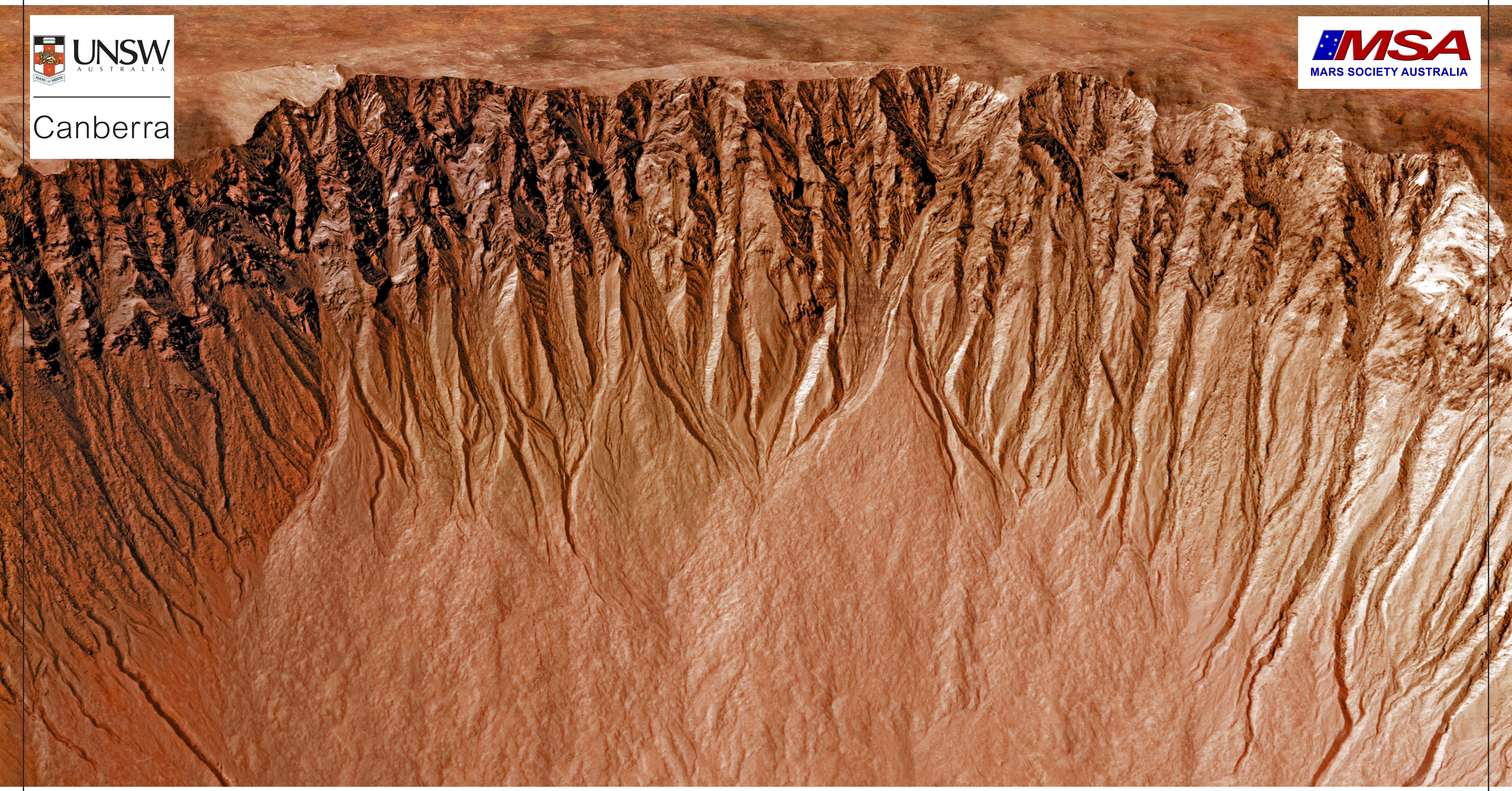
Using point pattern and thermal inertia analyses to test self-organisation in Martian mid-latitude gullies

S. W. Hobbs[1,2], D.J. Paull[1], J. D. A. Clarke[2], E.G. Jones[3], A. Wheeler[2,4], [1] School of Science, University of New South Wales, Australian Defence Force Academy, Northcott Drive, Canberra, Australian Capital Territory. [2] Mars Society Australia, P.O. Box 327, Clifton Hill, VIC 3068. [3] Computational Learning Systems Laboratory, School of ITMS, University of South Australia, Adelaide, SA. [4] QGESS Pty Ltd.



Introduction

Self-organisation in geomorphology has been observed to occur in landform evolution. Analysis of spatial distribution of such landforms provide insight into interpretation of their history where active process and erosion affect geometry, relief and identity of these features. Previous point pattern analysis has been applied to rootless cones, and sand dunes on Mars and Earth. In this work we conducted nearest-neighbour analysis (NNA) on Martian crater gullies to determine whether these features exhibited some form of self organisation.

Method

In order to conduct NNA on Martian gullies it was important to obtain cratered sites possessing at least 25 gullies within each crater wall. This minimum figure was chosen to help mitigate against statistical edge effects and skewed data resulting from sampling from too small a population size. We found seven gullied crater sites residing the Martian mid-latitudes suitable for NNA. These sites included Triolet, Galap Kaiser and Palikir Craters. Gasa Crater and its larger host crater, and a fresh, gullied crater west of Hellas Basin were also selected. The mid-latitude sites were chosen as climate and pole-facing aspect of gullies in this region are comparable across Martian gully sites, providing consistency in climatic regimes. Additionally, previous research using quantitative morphological analysis has indicated these gully sites may have been influenced by erosion by liquid water. We then compared these with similar NNA analysis conducted on Meteor Crater, a ~1 km diameter impact crater residing in Arizona. Previous research has used Meteor Crater as terrestrial analogue for Martian gullies.

ESRI ArcGIS software was then used to capture gully heads and channel termini. From these points, the nearest neighbor statistic, R, was generated by calculating the ratio of observed average distance between nearest neighbours of a point distribution and the expected average distance between nearest neighbours, based on the area of, and number of points in the distribution. To determine the nearest neighbour, the distance from each point to every other point in the distribution is measured. This allows for a statistic to be computed for second to the n^{th} nearest neighbour. These higher order analyses allow a distribution to be examined at different scales despite the calculated R-statistic itself being without scale. Where the R-statistic for the nearest neighbour calculation indicates a patterned dispersal ($R > 1.0$); second, third, etc., to the n^{th} nearest neighbour could suggest a random dispersal ($R = 1.0$) or a clustered dispersal ($R < 1.0$).

Results and Discussion

Location	*R*-nearest	*R*-second order	*R*-third order
Primary Site	0.72	0.68	0.75
Triolet Crater	0.86	0.74	0.78
Kaiser Crater	0.55	0.54	0.60
Gasa-host Crater	0.52	0.55	0.57
Gasa Crater	0.80	0.73	0.82
Palikir Crater	0.59	0.55	0.56
Galap Crater	0.59	0.52	0.59
Meteor Crater	0.81	0.80	0.91

Table 1: R-statistic calculated to the third order for the distribution of hillside gullies in impact craters on Mars and Meteor Crater in Arizona, USA.

These results show values consistently below unity for nearest to third order neighbours across all studied sites. Interpretation of the NNA appears to suggest that there is a tendency towards clustering of hillside gullies in all instances examined and that it is unlikely that an organized, regular morphological pattern exists. At these locations, topography and lithology are likely to be the controlling mechanisms for the formation of these hillside gullies rather than the eroding media. Heterogeneities within the lithology, such as areas where the rock strength is lesser than other areas, can determine the initiation of gully formation and experience faster rates of erosion. Additionally, slope angle of the target lithology and attitude and direction of an impactor will also influence initiation. Previous research into the geomorphology of these sites seems to indicate this, where although definite trends in mid-latitude gully morphology are apparent, individual variations in local geology and slope significantly influence gully evolution. The tendency towards clustering also suggests temporal heterogeneity as differences in gully wall height and steepness may not only be explained by lithologic and topographic variation. Without dating information, a definitive conclusion cannot be made.

The Meteor Crater gullies also followed the self-organisation trend of the Martian gullies. Previous research into this site indicated that gullies preferentially eroded in fractures caused by the meteor impact, thus tending to be controlled by the local geology.

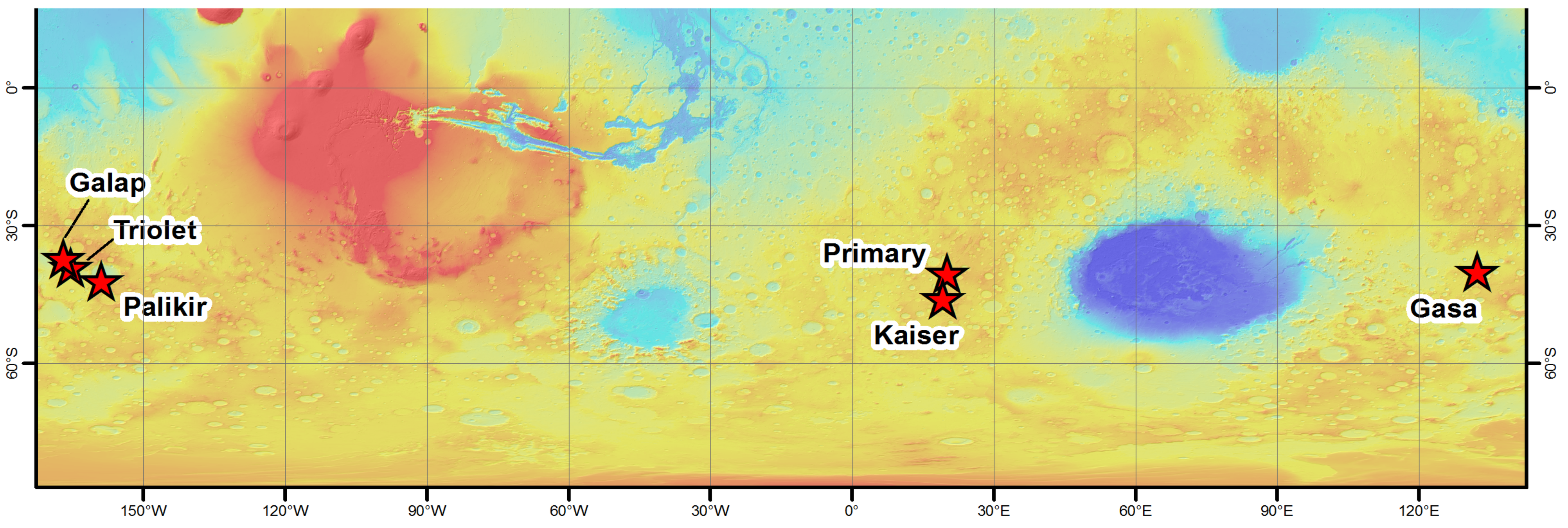
The higher order analyses are instructive in that departure from the clustering trend observed for the nearest neighbours is negligible. This is suggesting that, at local and regional scales, hillside gully formation is neither a random nor an organized pattern development and that, once initiated, their evolution continues being influenced by those initiation mechanisms. Previous research into formation of evenly-spaced drainage systems, at a scale of Martian gullies indicated that competition for drainage area and water flow eventually forced stunted the growth of smaller drainage pathways. This left remaining channels to enlarge and eventually cause their drainage-derived watersheds to adjoin with their neighbours and achieve equilibrium with a specified wavelength.

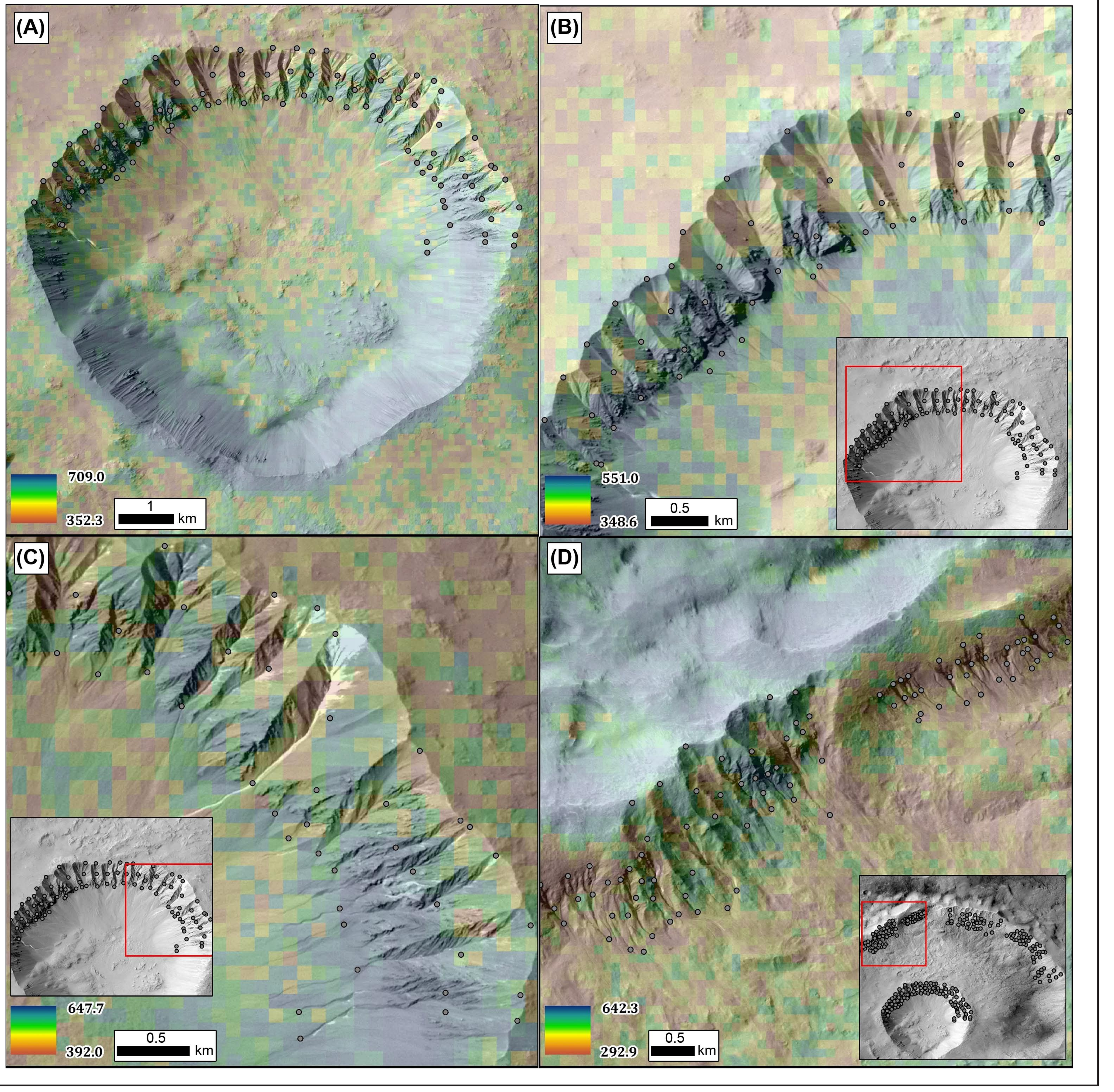
Thermal inertia analysis was able to provide a degree of insight into the material in which some of the studied gullies resided. For example, the location of gully alcoves in the higher thermal inertia region at the Kaiser Crater site indicates a region where coarser grains and larger fragments of materials were eroded from the crater walls. This is consistent with terrestrial gully erosion, where larger, coarse grained material is eroded out of the gully alcove, and transported downslope. Additionally, gullies overprinting ice-rich deposits at the Kaiser Crater site is consistent with gully activity occurring at different periods of Martian history. This is an important issue, and may help in identifying whether liquid water based or CO_2-based processes were involved in gully formation. Gullies may in fact have been eroded through either or both processes at different periods of time.

This complex nature of Martian gully evolution is consistent with our analysis of Martian gully self-organisation where we were unable to unambiguously identify an organized, regular morphological pattern. This was also the case with our analysis of Meteor Crater gullies, where channel emplacement was affected of fracturing of the underlying regolith from the initial meteor impact.

Conclusion

NNA on gully sites shows clustering at various scales. This clustering suggests that while global factors influence Martian gully evolution, an understanding of local geologic and environmental conditions are important in how these features develop over time. Future analysis will be conducted on gullies closer to the Martian pole, where colder climate regimes are likely to influence gully formation. Future analysis may also be conducted on equator facing crater wall ravines to determine whether these features possess a degree of self-organisation.





(Top) Perspective view of Martian gullies. (Top right) Location of analysed Martian gullies. (Right) Thermal inertia results of studied Martian gullied craters. Insets show the location of master images.