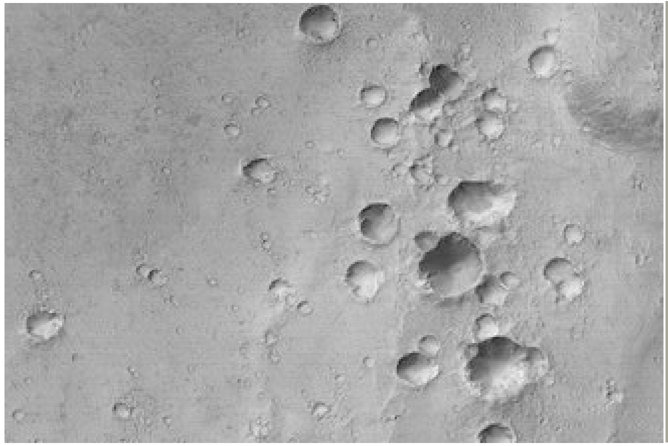

Planetary surface dating from crater size-frequency distribution measurements: spatial randomness and clustering

Greg Michael, Thomas Platz, Thomas Kneissl, Nico Schmedemann
Planetary Sciences and Remote Sensing
Department of Earth Sciences
Freie Universitaet Berlin

Purpose

- To draw conclusions about the impactor population – or about the age of a surface unit – using a crater count, you have to be certain that the crater population corresponds to an exposure to the impact flux in a known way
- In an ideal scenario, each impact produces a single crater, which is retained by the surface until the time of observation. This process produces a random spatial configuration of the craters
- Real surfaces are rarely so well behaved. One must be selective in choosing counting areas which are geologically homogeneous: not only in their formation, but also in their modification history. The quality of the conclusions depends strongly on making an adequate choice of area
- A randomness analysis can be used to verify the homogeneity of a measured population, and conversely to reject counts which are spatially non-random

Ingredients of a crater age measurement

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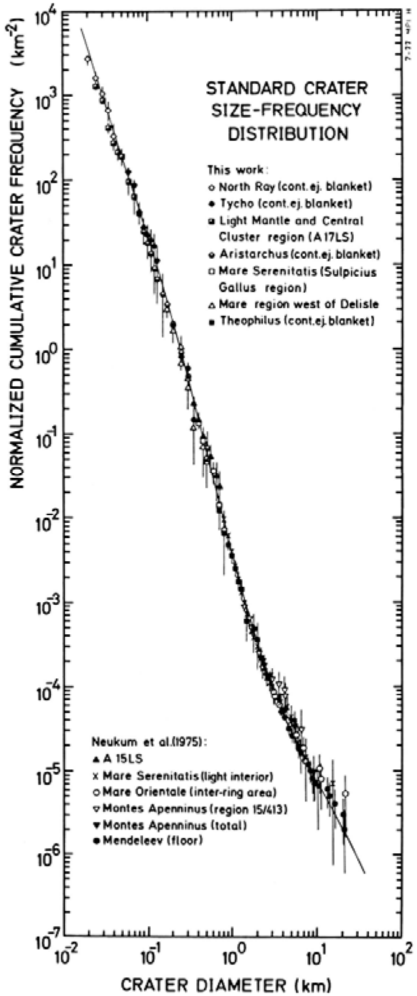
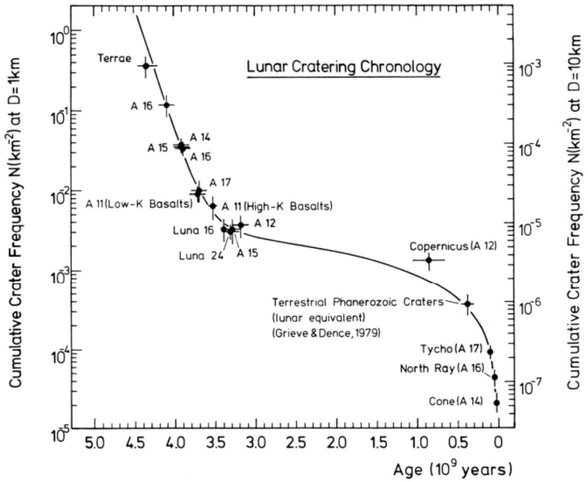




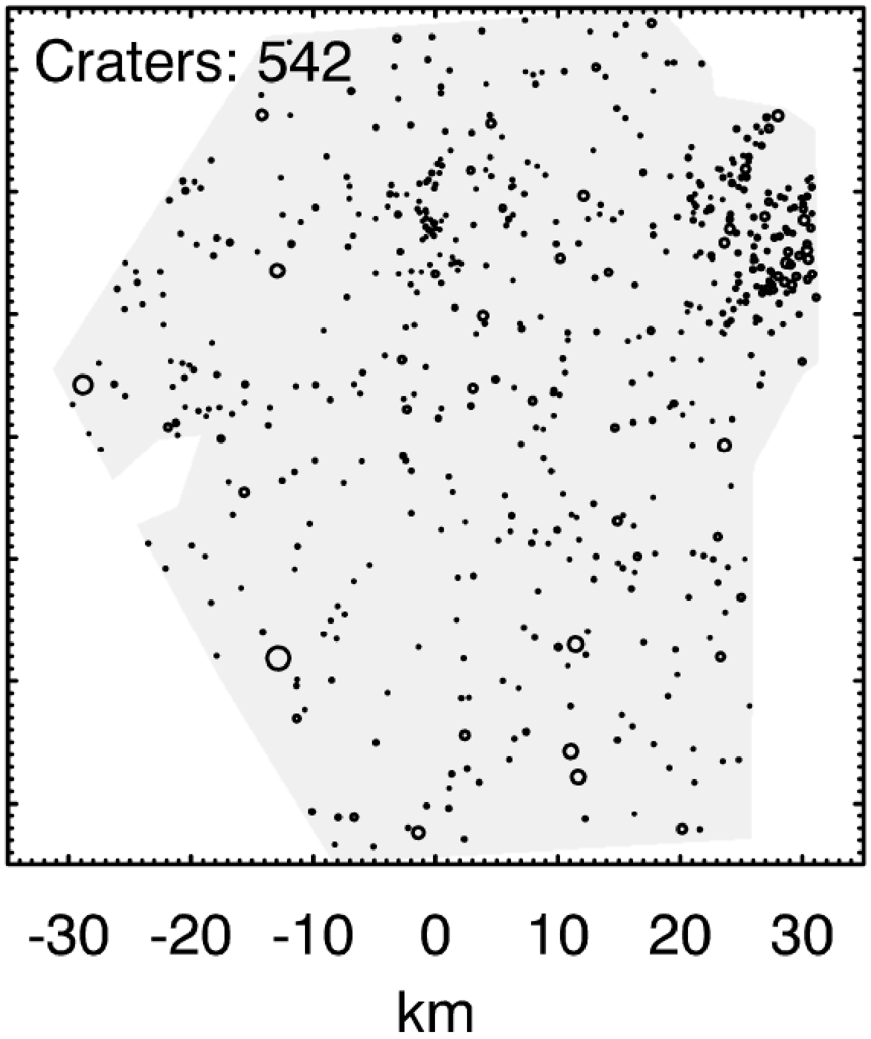
- Known size-frequency distribution of impacting bodies
- Some estimate of the variation of the impact rate as far back as the oldest observable surfaces

(a similar system can be devised for a two-population model)

- Impact craters form independently of each other
  - *be cautious of secondaries, fragmented impactors*
- Accumulating surface retains its crater population
  - Or, more weakly, *has a spatially uniform resurfacing history*

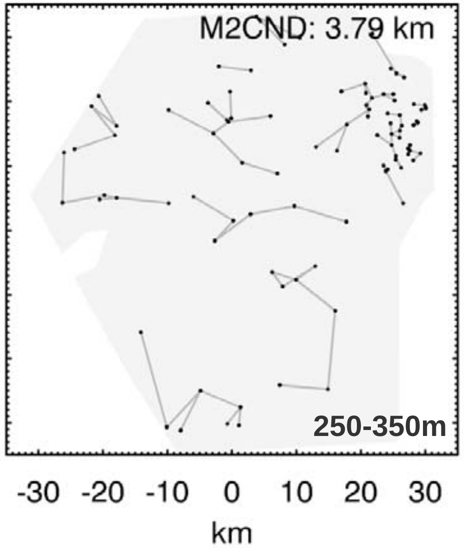
Violation of either condition yields a non-random population

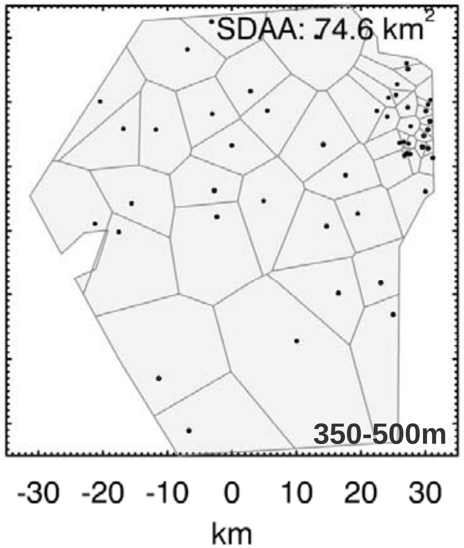
What does a non-random population look like?



- Clustered sub-unit near Elysium Mons, Mars
- Two obviously clustered regions, which normally would be excluded from a crater count for dating
- Possible to recognise this clustering with a visual inspection, but more objectively, how can we measure the degree of clustering?

How to measure spatial randomness?





- Split population into bins by diameter – wish to examine clustering only between comparably-sized craters. We use root-2 bin spacing

- Select measure sensitive to clustering; two shown here:
  - *Mean 2nd-closest neighbour distance (M2CND)*
  - *Standard deviation of adjacent area (SDAA)*

How to measure spatial randomness?

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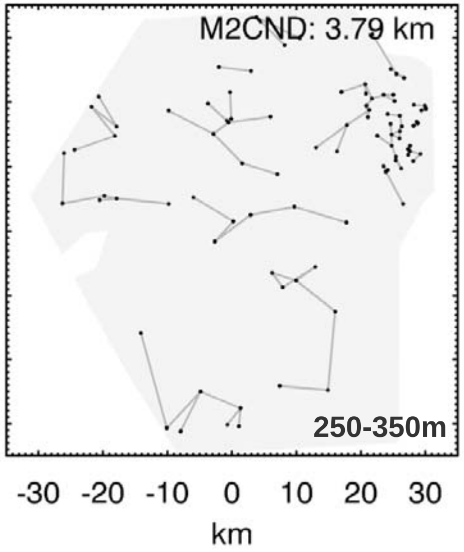
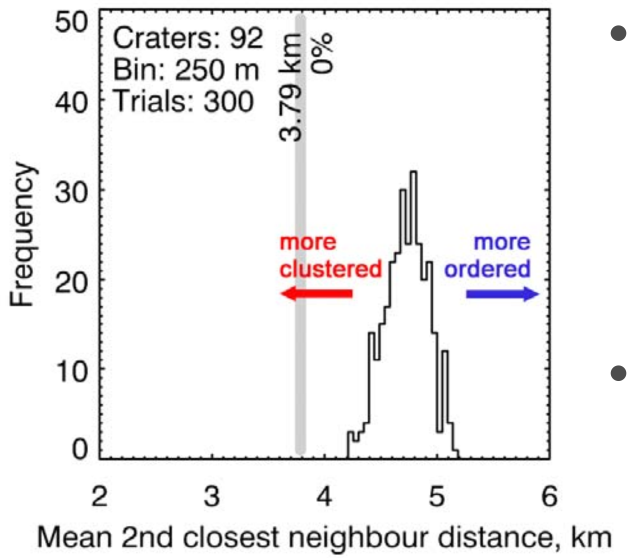
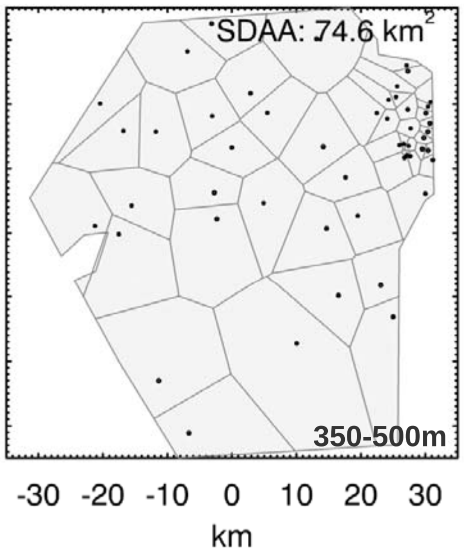
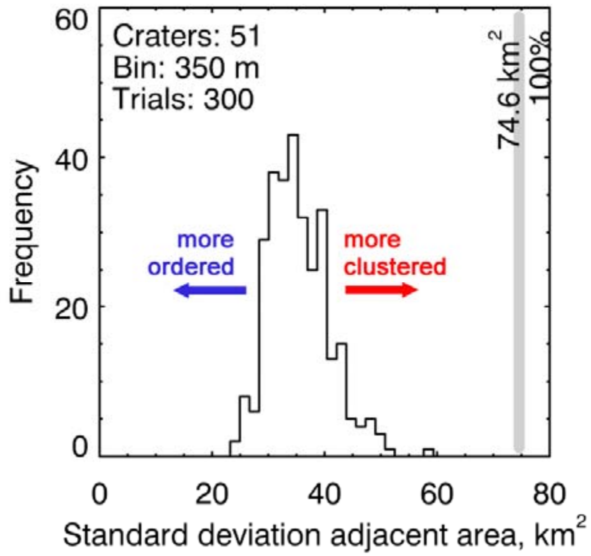


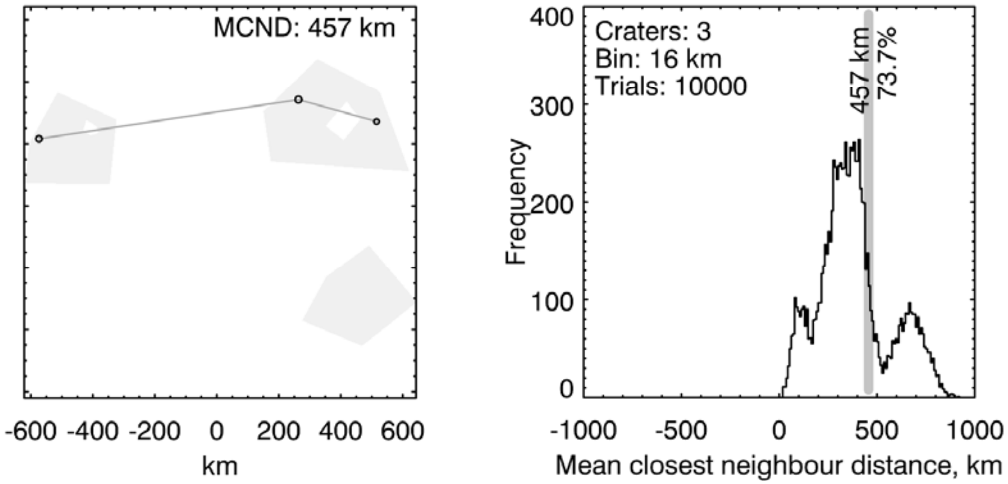






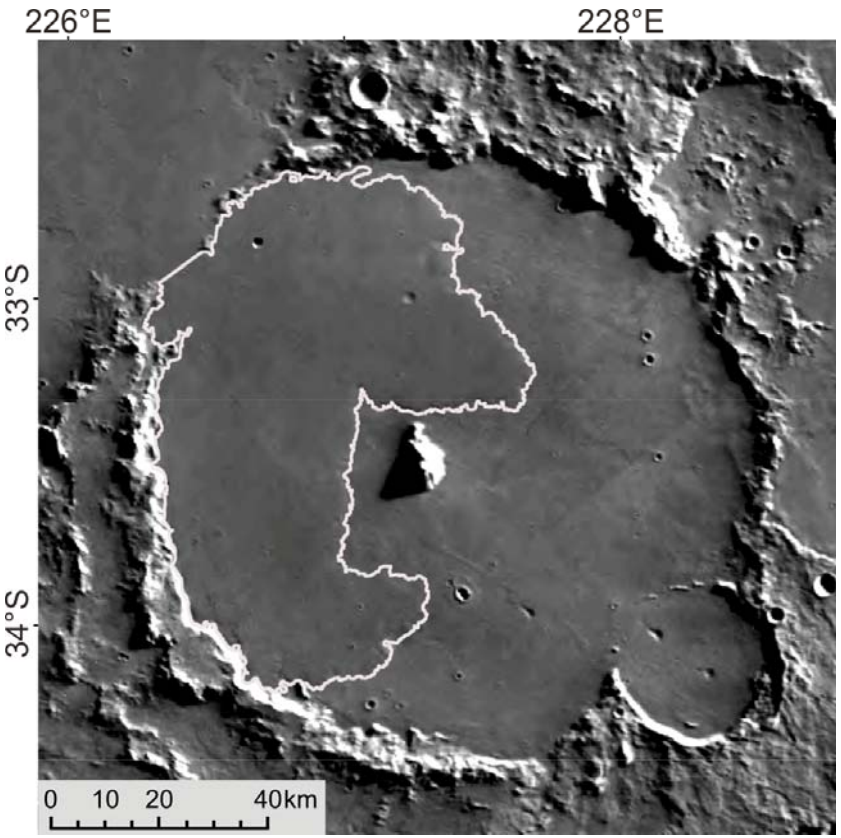
- Split population into bins by diameter – wish to examine clustering only between comparably-sized craters. We use root-2 bin spacing
- Select measure sensitive to clustering; two shown here:
  - *Mean 2nd-closest neighbour distance (M2CND)*
  - *Standard deviation of adjacent area (SDAA)*
- Compare clustering measure to histogram for series of random configurations of same population
- Assess degree of clustering: SDs above/below mean

Influence of boundary



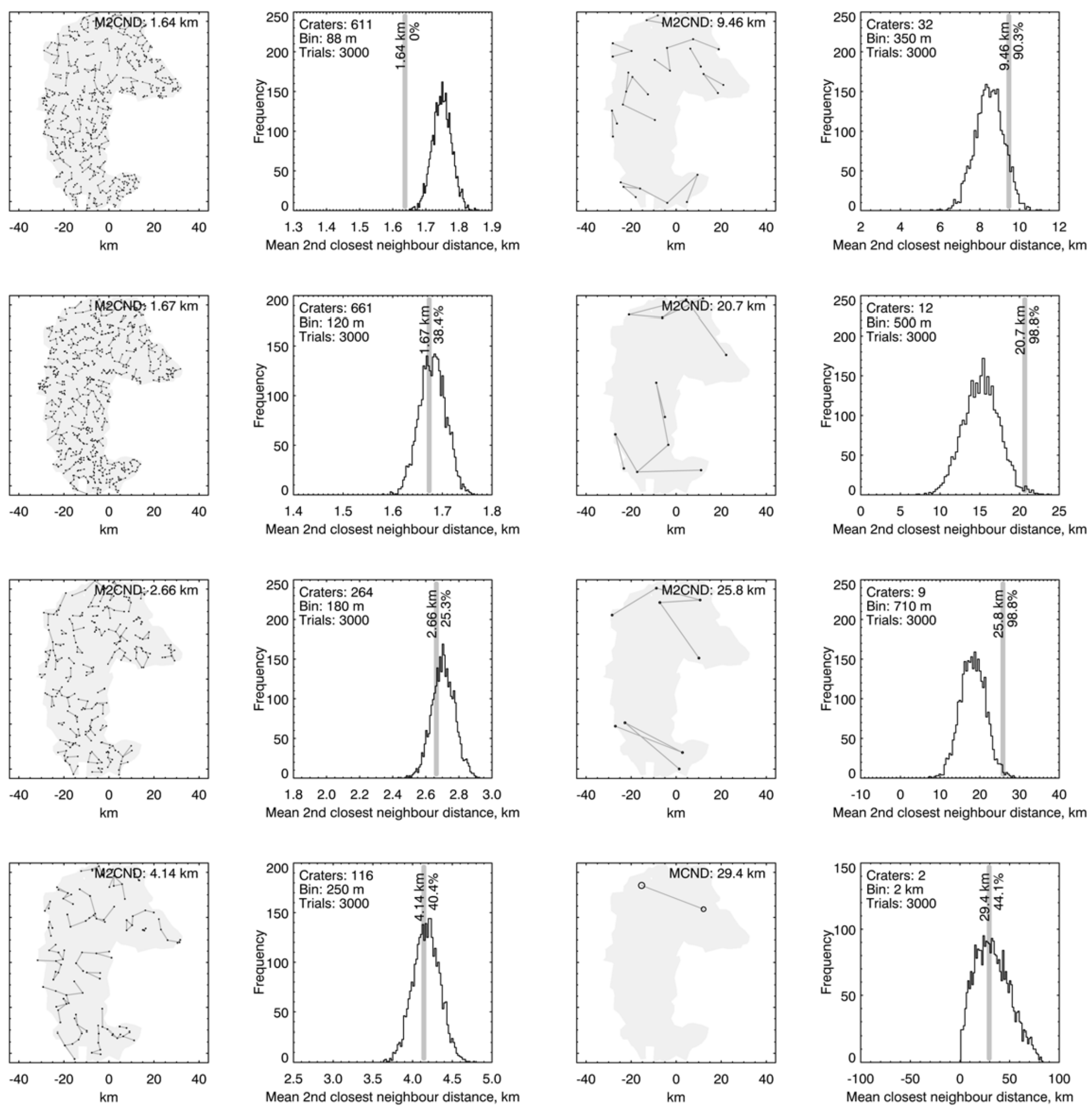
- The range of possible values for a clustering measure for random configurations is sensitive to the shape of the counting area boundary
- In this extreme example – a disjoint counting area – we see a trimodal variation of the *mean closest neighbour distance* measure
- In general, differently shaped areas will show different ranges for the expected variation of the clustering measure (e.g. a circular crater floor vs. an elongated lava flow of equivalent area)
- This is the reason to use a numerical approach to the problem

Example site: Pickering crater, Mars



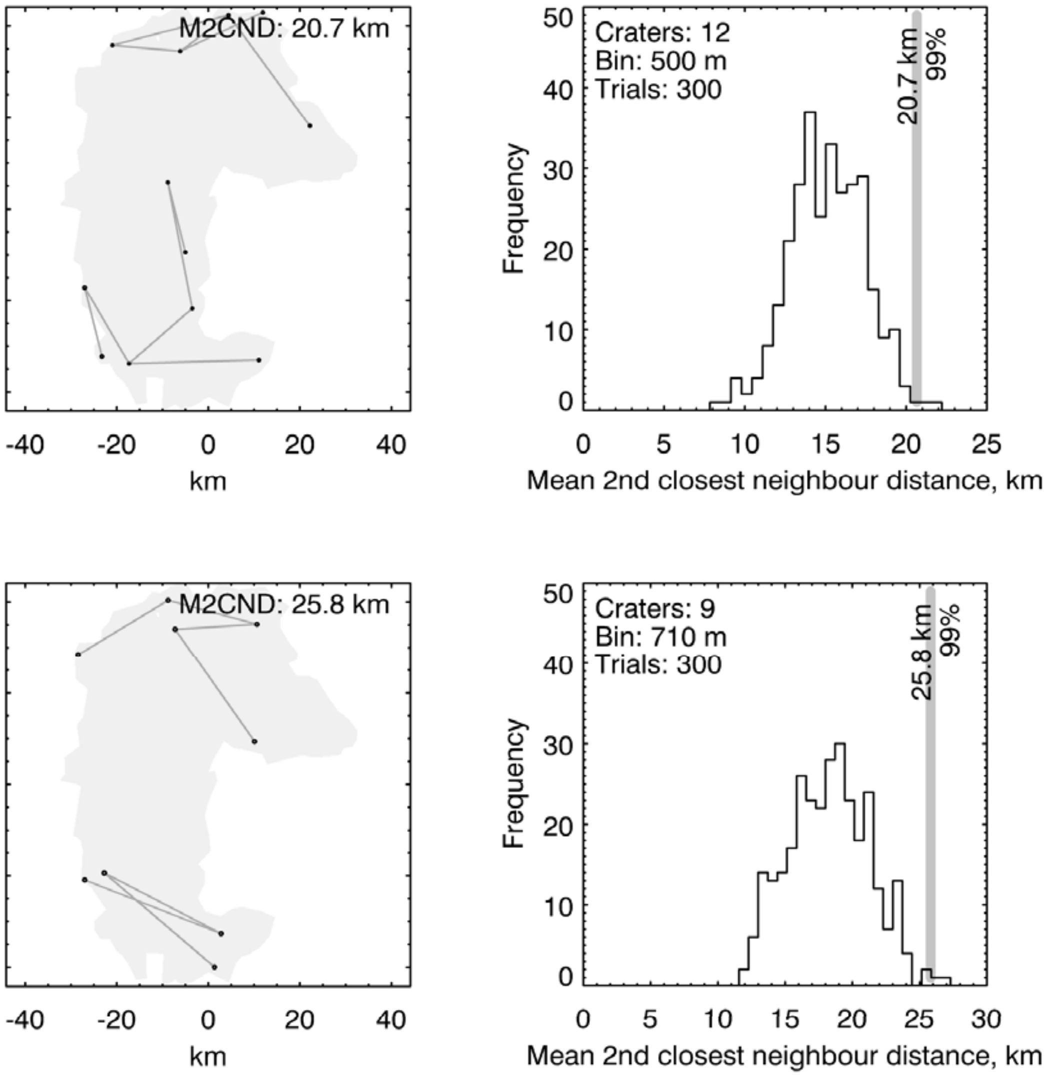
- 80 km lava-flooded crater with a younger flow entering from NW
- Boundary is unambiguous
- Expect unit and its underlying basement to have well-defined ages
- No obvious modification: expect a 'clean' crater count here
- Some larger craters protrude through the flow from the underlying surface (Platz et al. 2010)

Pickering crater: randomness analysis



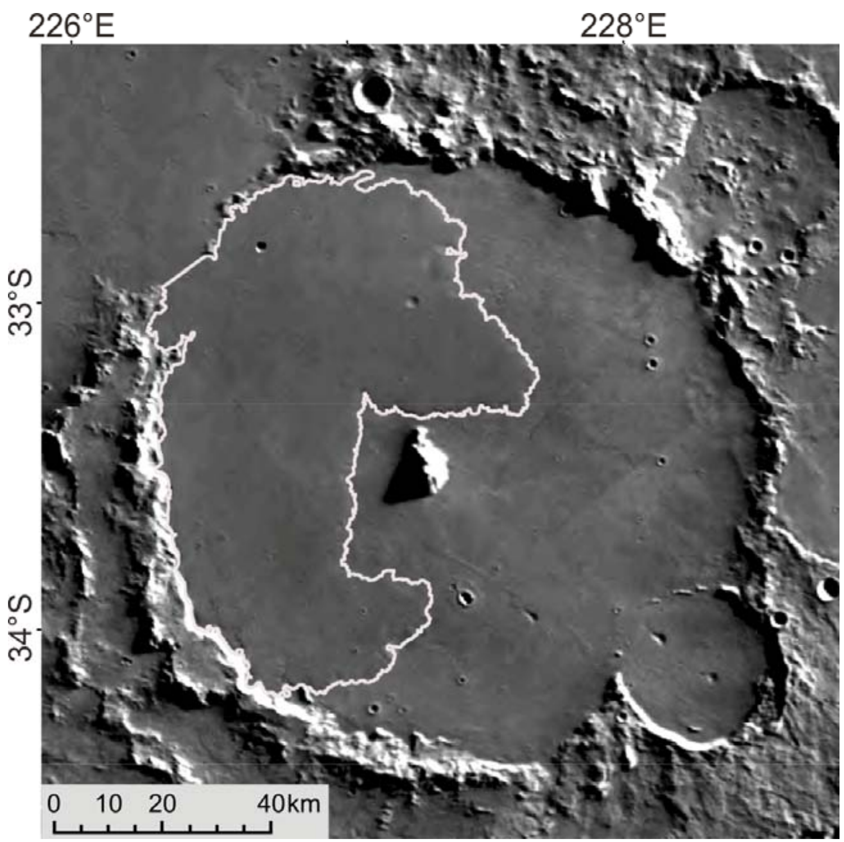
- Apparent clustering in smallest 88 m bin - measurement effect, cf. resolution fall-off
- ‘Well-behaved’ populations in 120, 180 and 250 m bins
- More separated than random populations in 350, 500 and 710 m bins
- ‘Well-behaved’ again in 2 km bin (1 and 1.4 km bins empty)

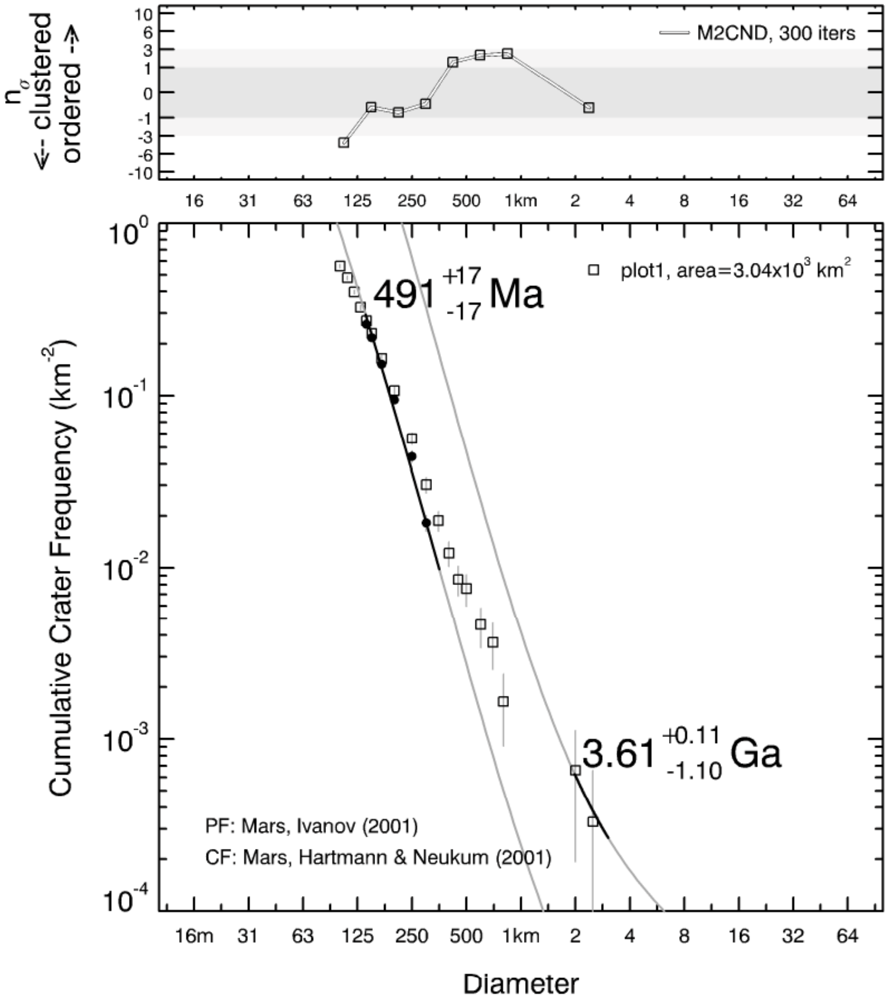
Pickering crater: non-random diameter range



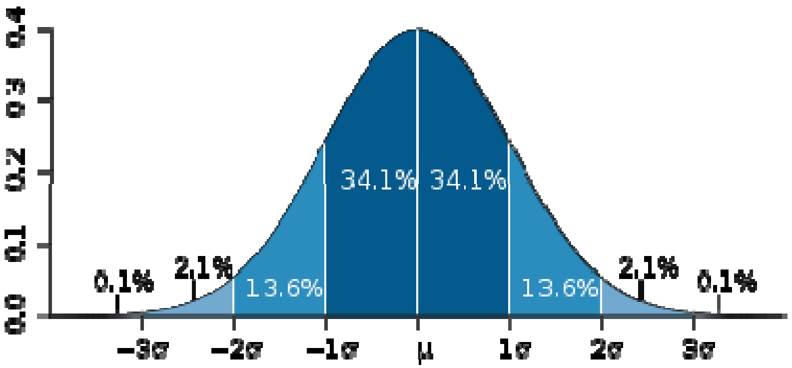
- More separated than random populations in 350, 500 and 710 m bins. Why?
- Many of the craters located close to unit boundary
- Not obvious from visual inspection
- Likely relates to lesser flow thickness near the boundary: some of these craters belong to the underlying unit
- Exclude these bins from diameter range used to determine age, since this population is non-random

Pickering crater: RA summary





What is random?



- From a random scattering, any configuration is *possible*, but some are less likely than others
- What is deemed likely or unlikely is determined by the clustering measure
- Roughly 2 of 100 random configurations will lie beyond the 2σ boundary; 1 in a 1000 beyond 3σ
- It's always possible to construct special configurations which any one measure will not identify
  - e.g. equidistant points around the edge of a circular unit would defeat the SDAA measure
- Judgement should be a combination of the analysis result and an examination of the configuration for possible geological influences

Conclusions

- A randomness analysis provides a deeper understanding of the spatial structure of a measured crater population
- Deviations in randomness measures can highlight the influence of geological modifications of the crater population
- Presentation of a randomness analysis can help others make an objective assessment of the quality of an age measurement
- The technique is of particular relevance to the study of early solar system impactor populations

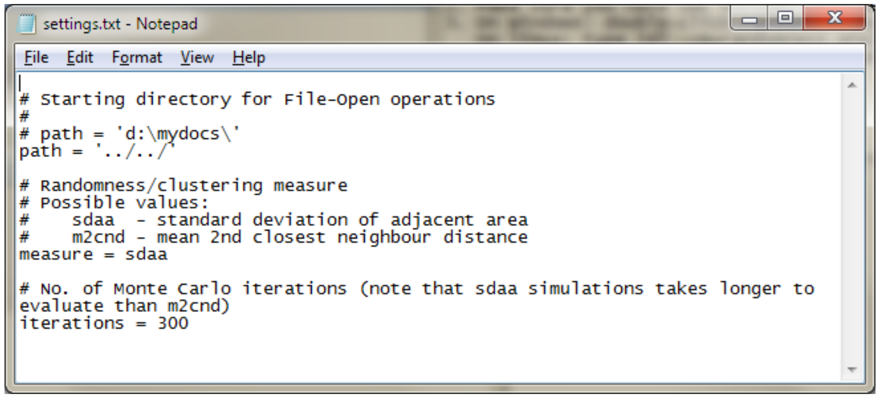
Planetary surface dating from crater size-frequency distribution measurements: spatial randomness and clustering. G. Michael, T. Platz, T. Kneissl, N. Schmedemann, Icarus, December 2011.

Randomness analysis software

- Runs in IDL virtual machine, as Craterstats
  - Start from Craterstats utilities menu, or by double-clicking randomness_analysis.sav

- Select an .scc crater-count file produced by CraterTools
  - this file contains the crater locations and the unit boundary polygon as well as the diameters
  - can select more than one file with ctrl-clicks

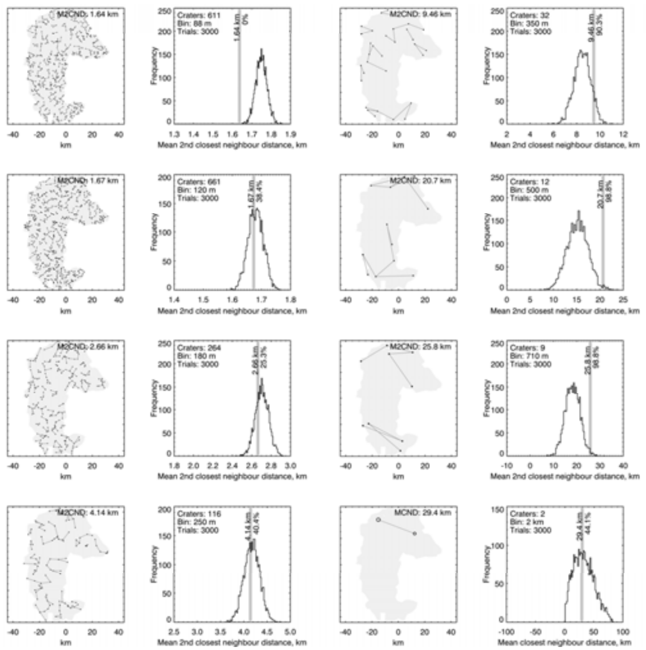
- Program settings can be changed by editing `randomness_analysis/settings.txt` inside the `craterstats` folder
  - clustering measure
  - iterations
  - starting path for file-open operations

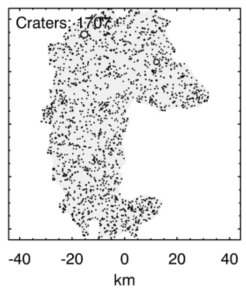


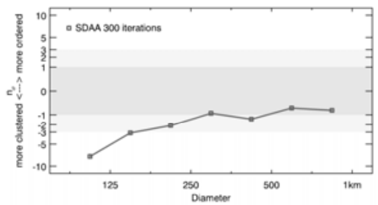

```
# Starting directory for File-Open operations
#
# path = 'd:\mydocs\'
path = '../../'

# Randomness/clustering measure
# Possible values:
#    sdaa  - standard deviation of adjacent area
#    m2cnd - mean 2nd closest neighbour distance
measure = sdaa

# No. of Monte Carlo iterations (note that sdaa simulations takes longer to
evaluate than m2cnd)
iterations = 300
```

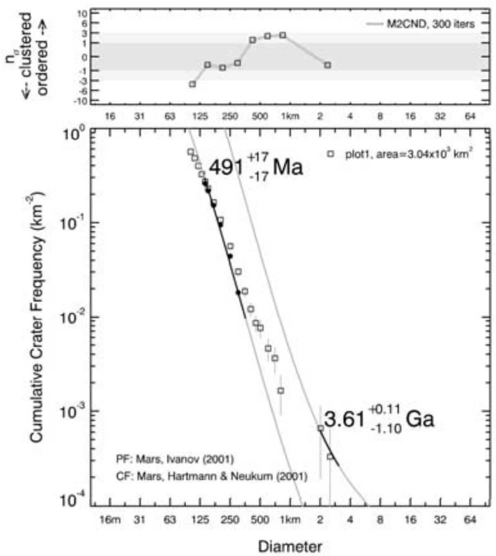
Randomness analysis software

- Results are placed in a sub-folder where the .scc file resides
  - composite results figure
  - crater map
  - n_sigma plot









- Additionally, a text file containing a table of the n_sigma values is placed together with the .scc file
  - used by Craterstats to recreate the n_sigma plot

Randomness analysis software - task

- Modify the file `randomness_analysis/settings.txt` to use the m2cnd clustering measure
- Start craterstats, and then the randomness analysis utility
- Select the crater-count `sample/Pickering.scc`
- Wait for the analysis to finish, then examine the results
- Create a crater-count plot in craterstats, displaying the n_sigma diagram
- Create two fits for the basement age and the resurfacing age using appropriate diameter ranges, taking account of the randomness analysis results