# Seismic expression of thermal degradation on the Moon

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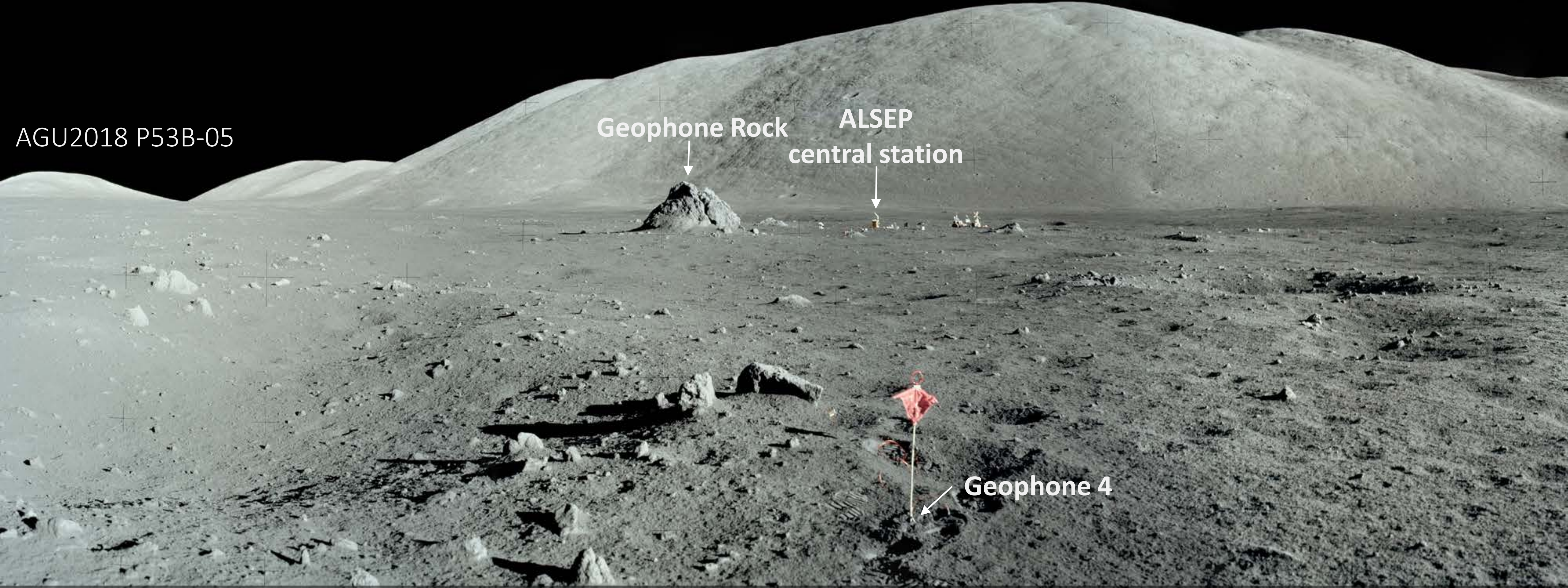


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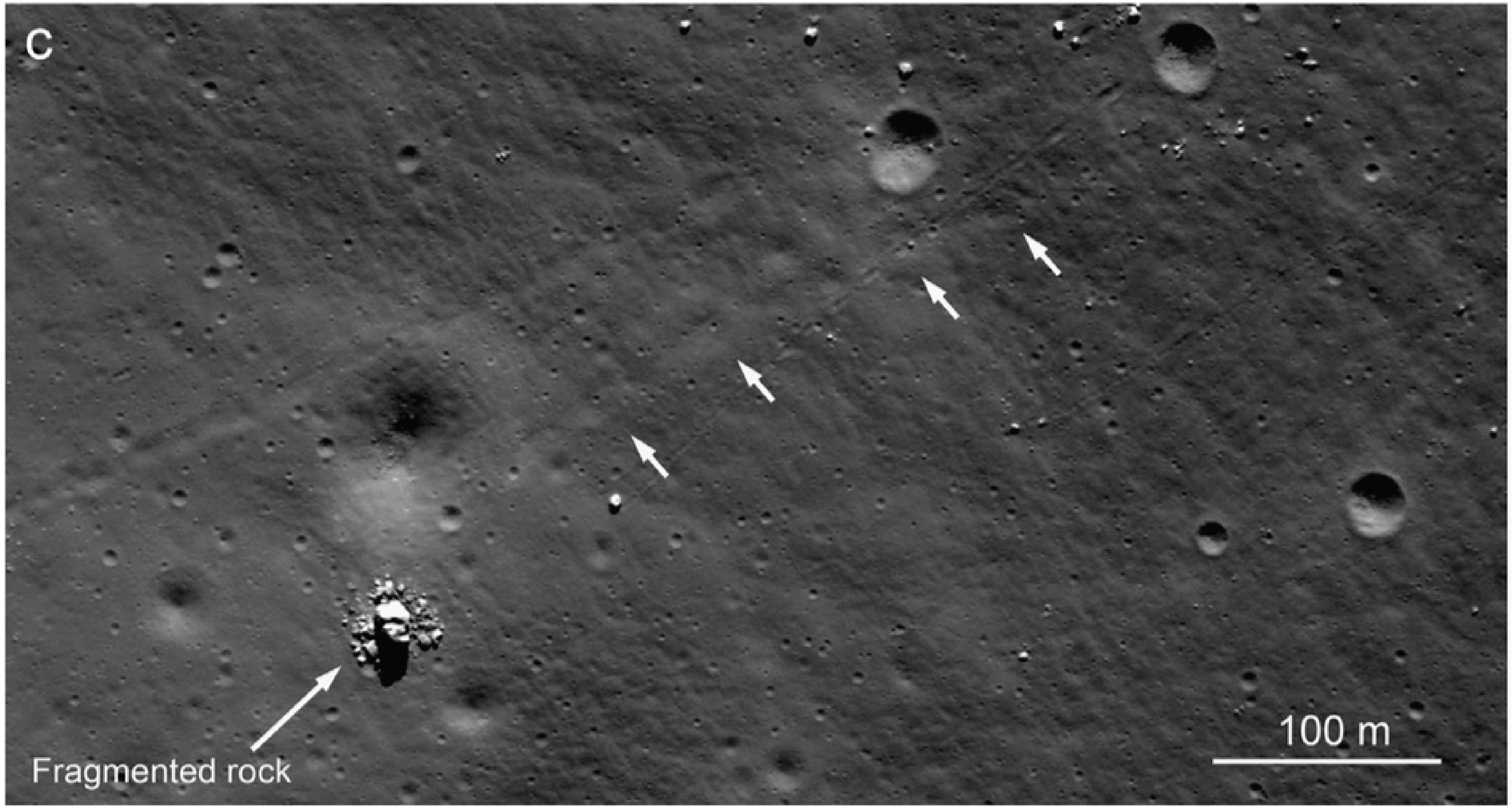
# Thermal degradation of rocks

Degraded rocks have been observed on the Moon & linked to impact processes, although "the role of thermal cycling is unknown and possibly contributes to the destruction of lunar surface rocks, especially of relatively large size" (Basilevsky et al., 2013)

Questions:

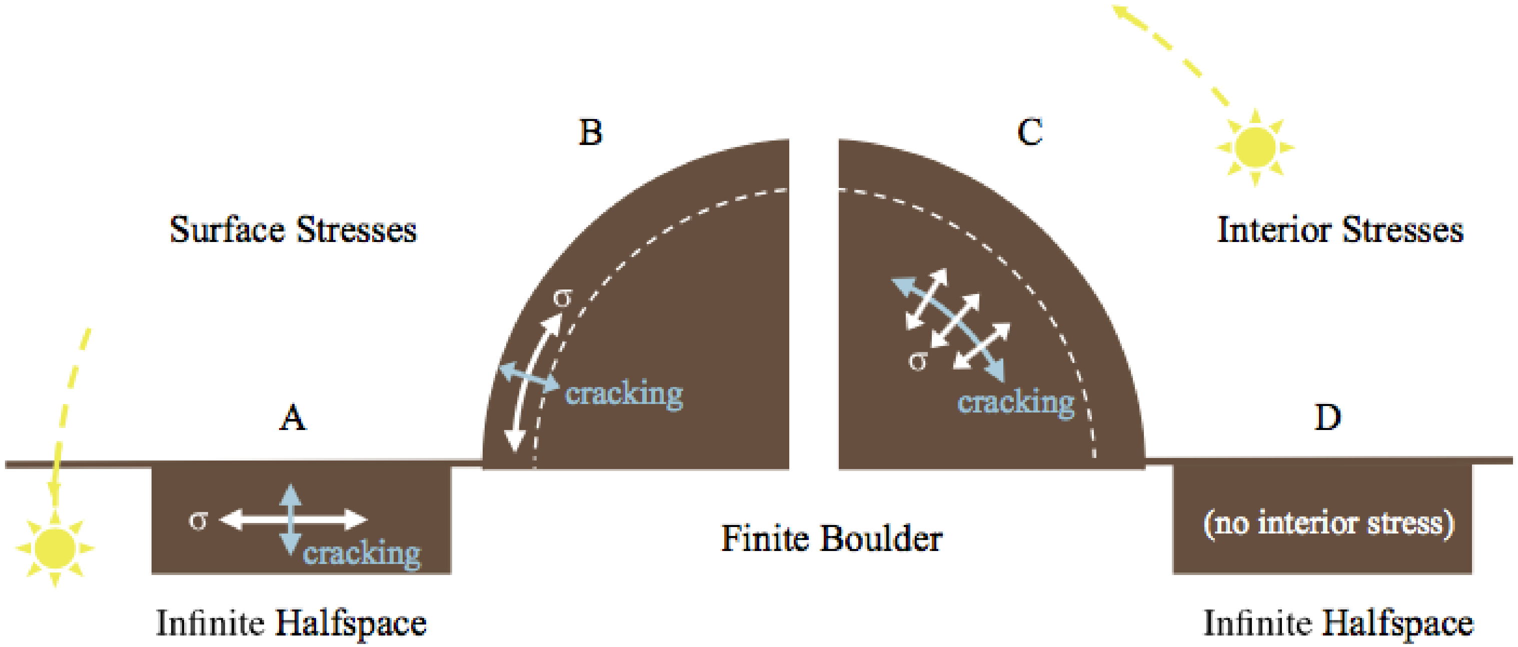
1) Are rocks thermally degrading in the present day?
2) If so, is this signal present in the Apollo seismic data?




20m boulder in the central peak complex of the lunar crater Schiller

# Thermal modeling

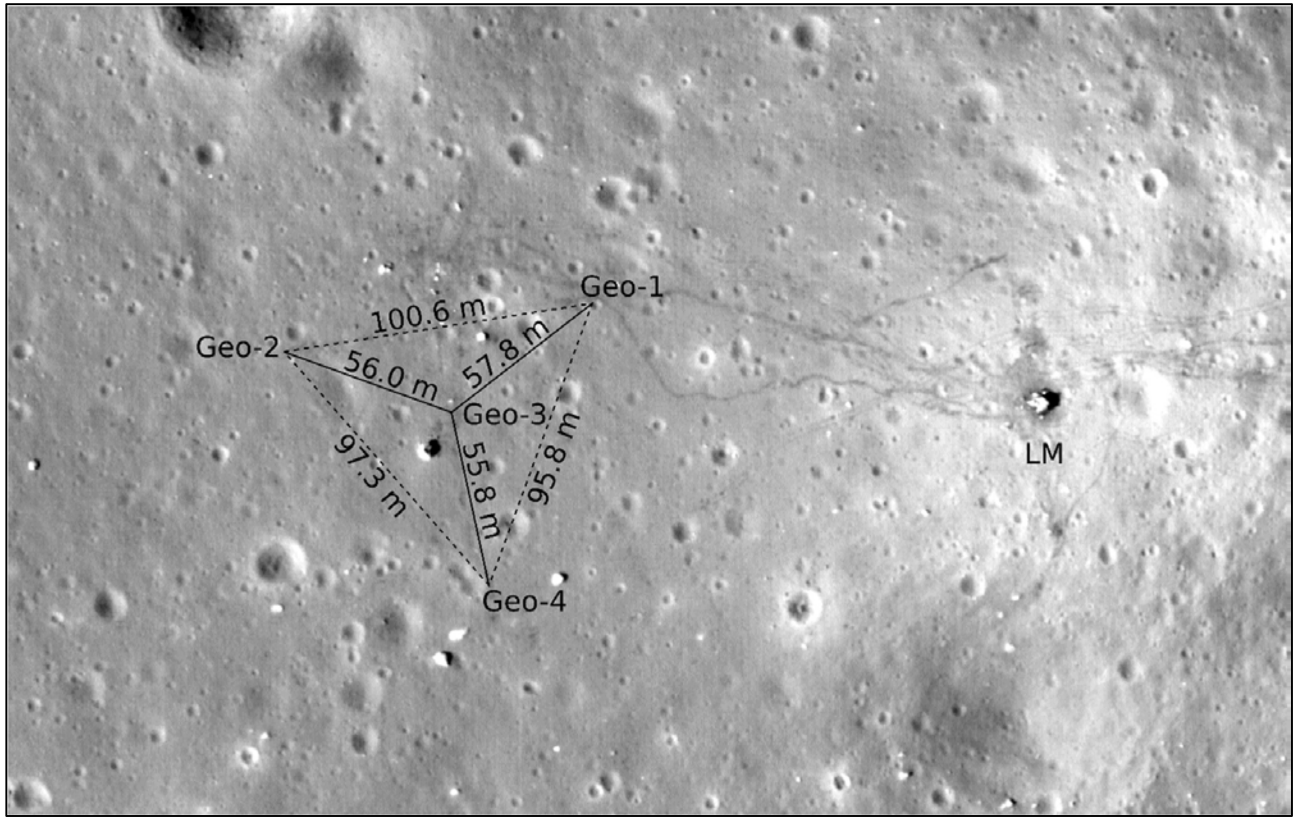
Thermal modeling of macroscopic thermomechanical behavior of lunar boulders in response to diurnal thermal forcing shows it can potentially contribute to breakdown (Molaro et al., 2017) (in lunar rocks down to 30cm)




surface and interior stresses in an infinite halfspace and a finite boulder. The white arrows denote the orientation of the maximum principal stress, and the blue arrows denote the resulting direction of crack propagation.

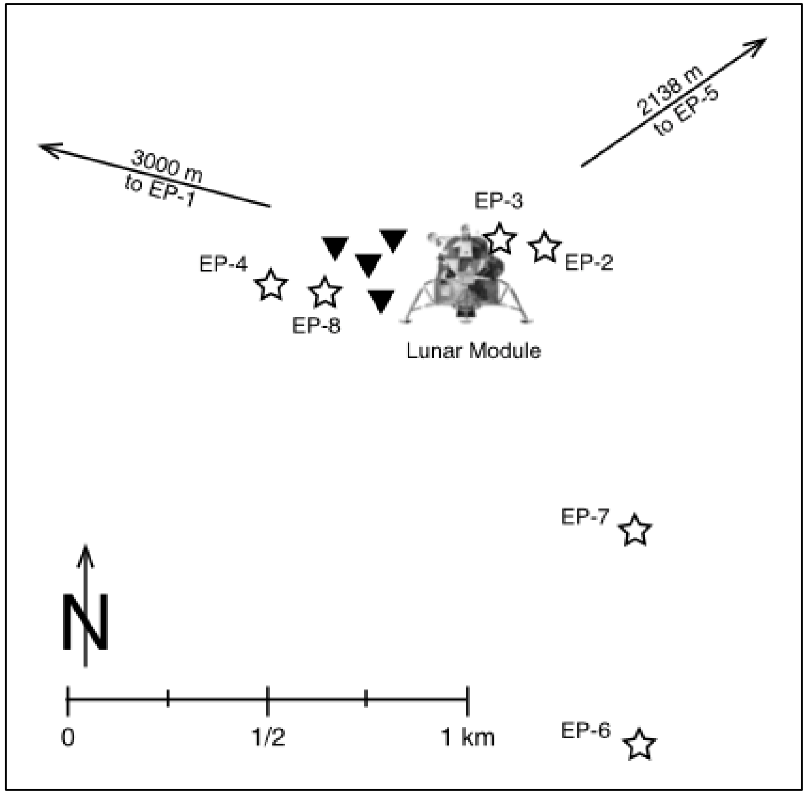
# Apollo seismic data

Lunar Seismic Profiling Experiment (LSPE)
was part of the
Apollo Lunar Surface Experiment Package (ALSEP)




Heffels et al., 2017 (PSS)

Sollberger et al., 2016 (GRL)

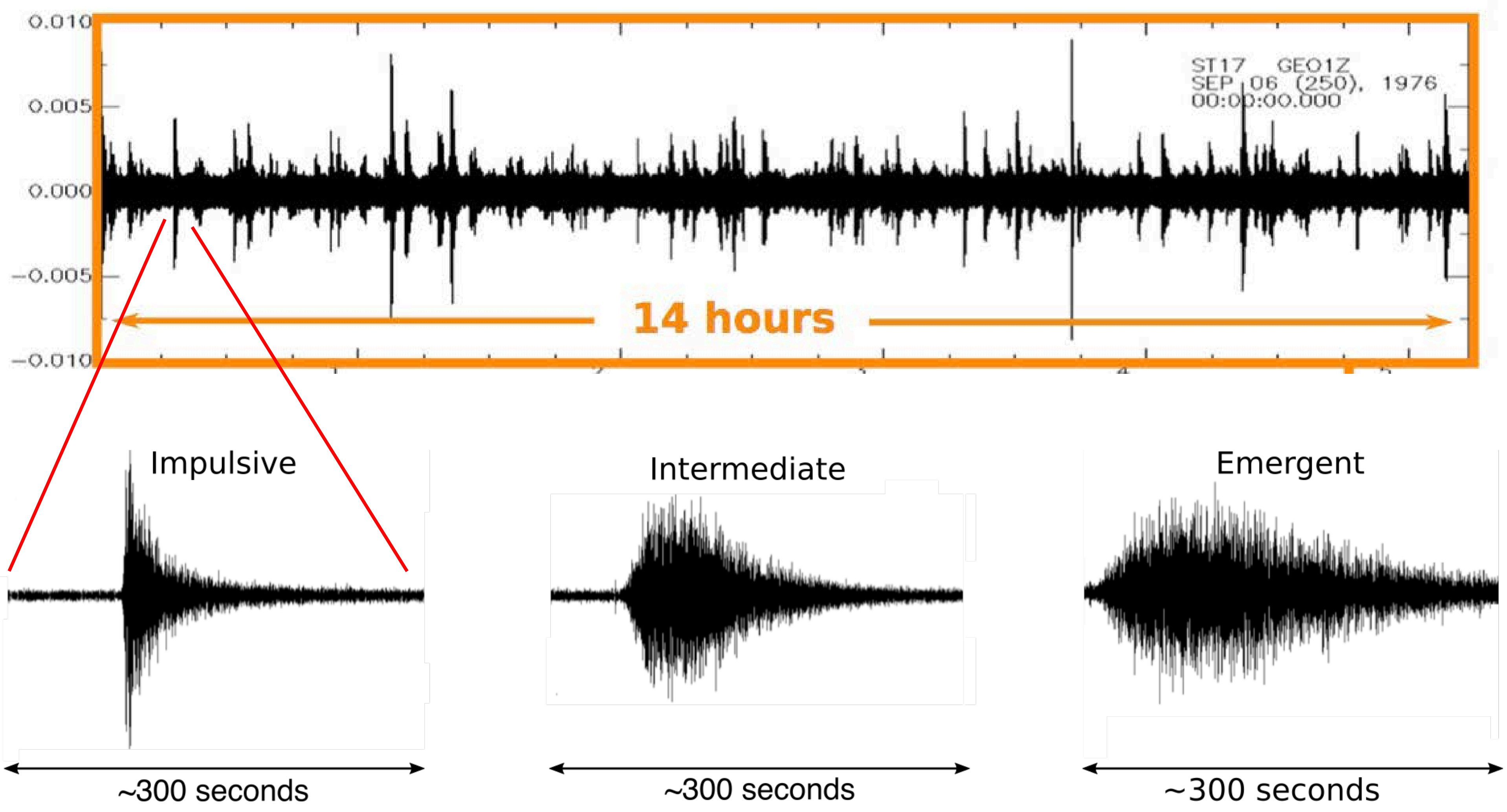



Primary modes of operation:

1. Active experiment
2. “Listening” mode

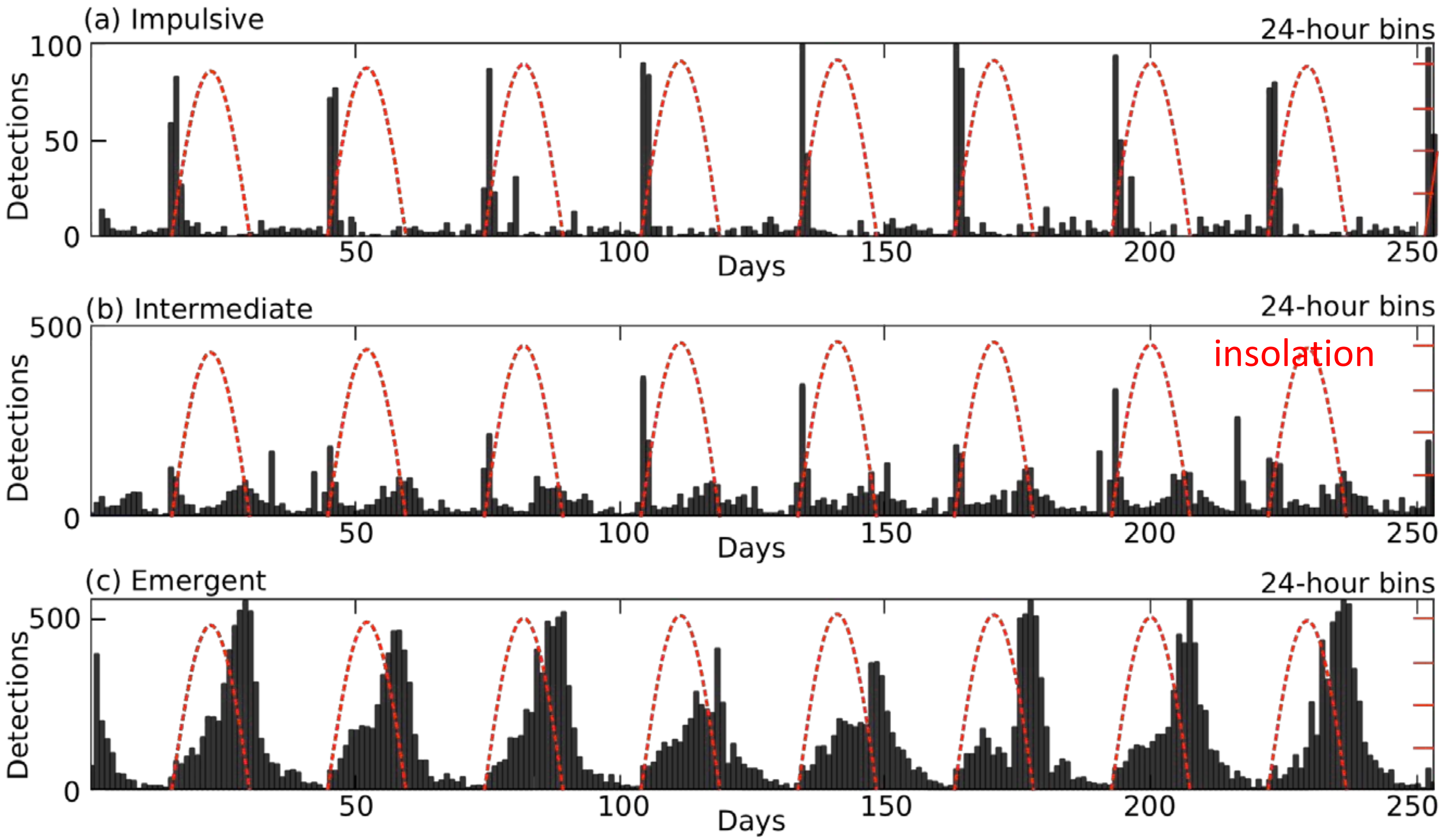
# Thermal Moonquakes

Continuous "listening mode" data contains many small "noise" events



# Thermal Moonquakes

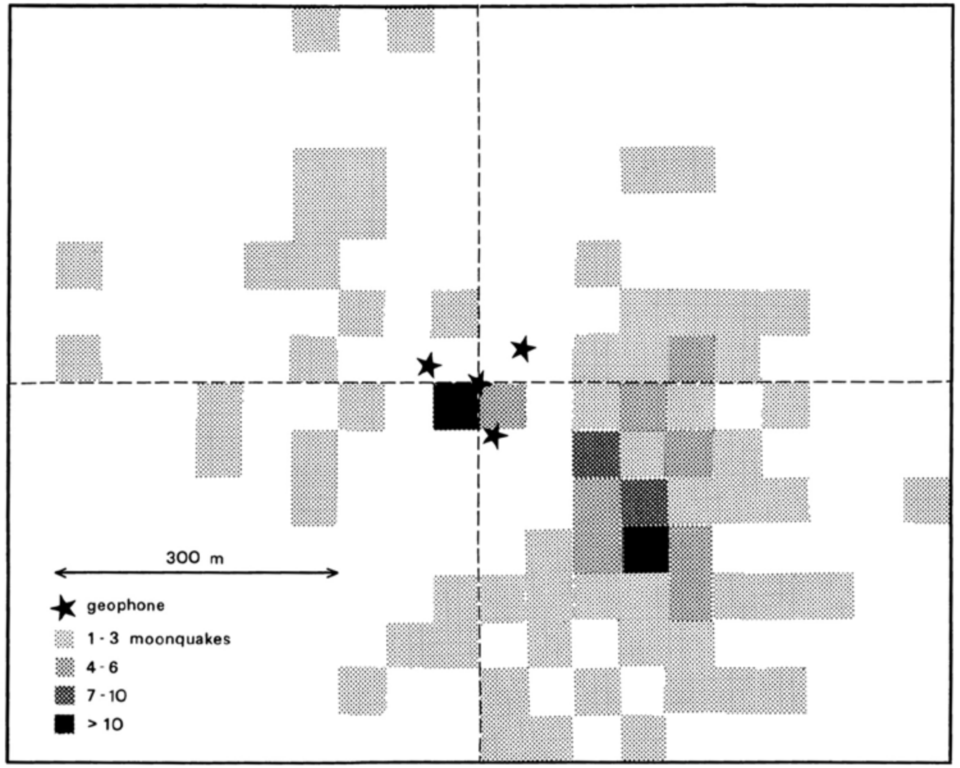
HMM event detection algorithm identified >50k detections showing strong diurnal occurrence patterns consistent with previous observations. Dimech et al., 2017 (Results in Physics). Approximately 1/3 of these represent distinct events.



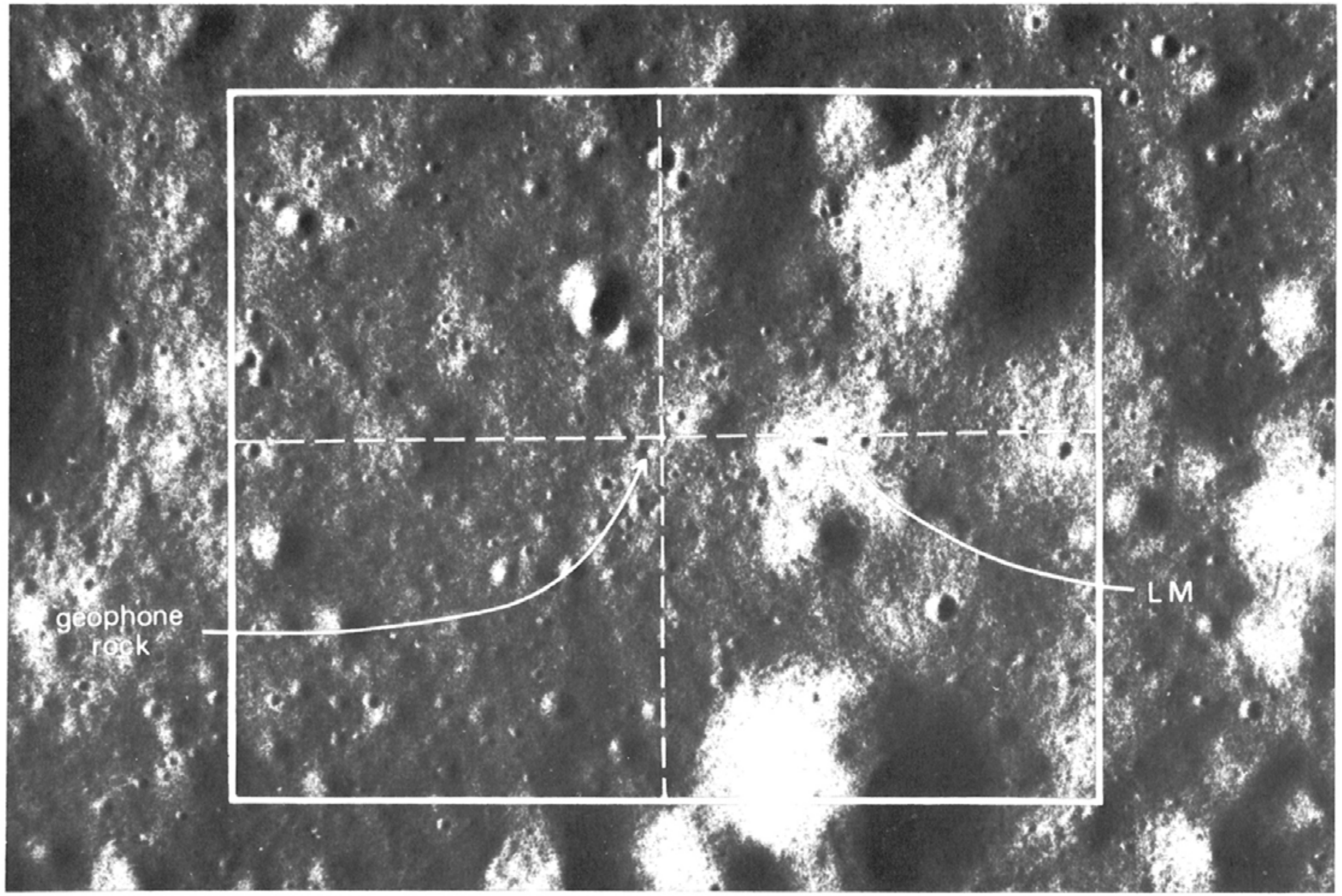
# Thermal Moonquakes

Early work located thermal moonquakes detected by LSPE & conclude signals possibly represented thermal movement of the regolith

- Used signal amplitudes
- Locations accurate to ~50m



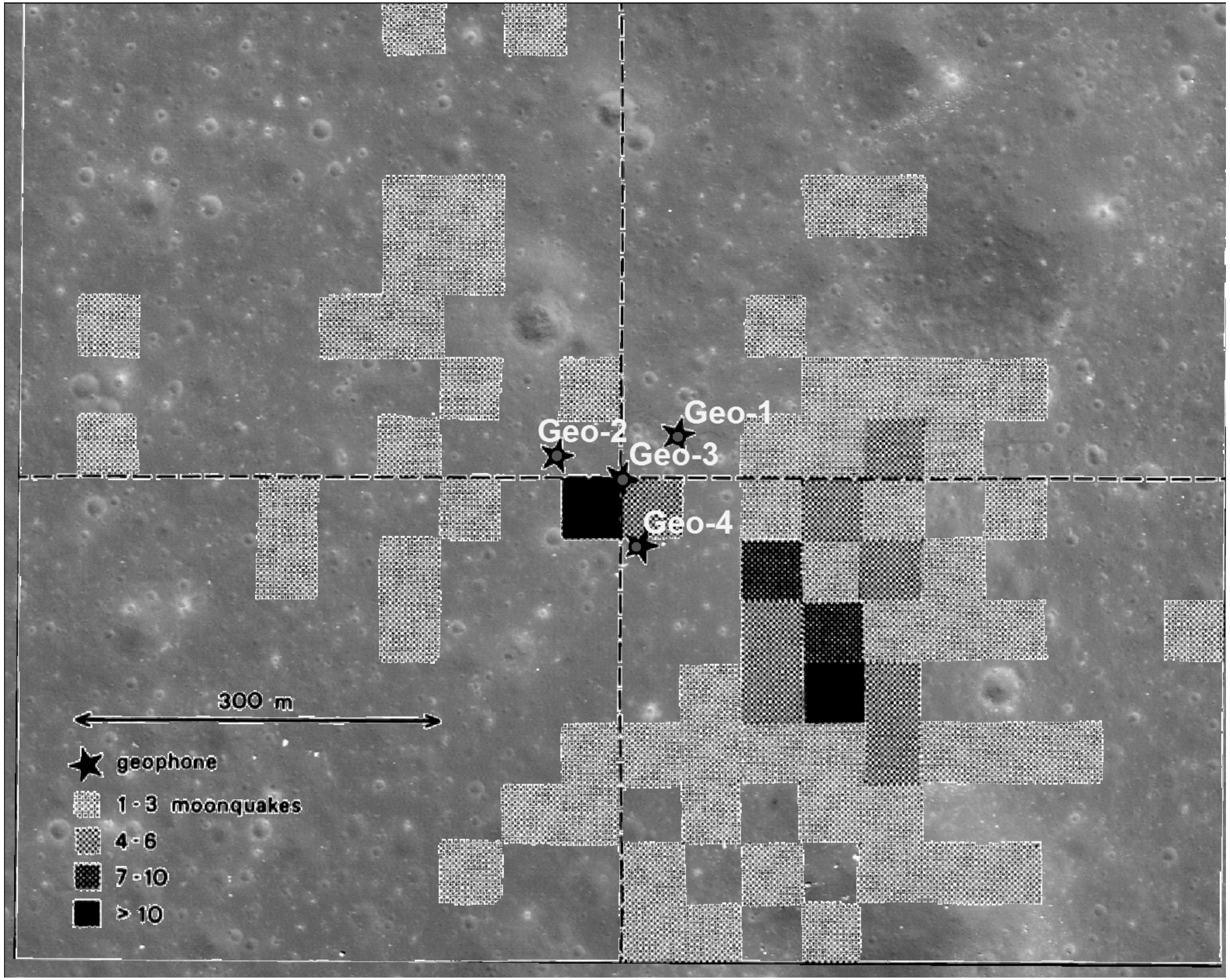

Duennebier 1976, Proc. Lunar Sci. Conf.



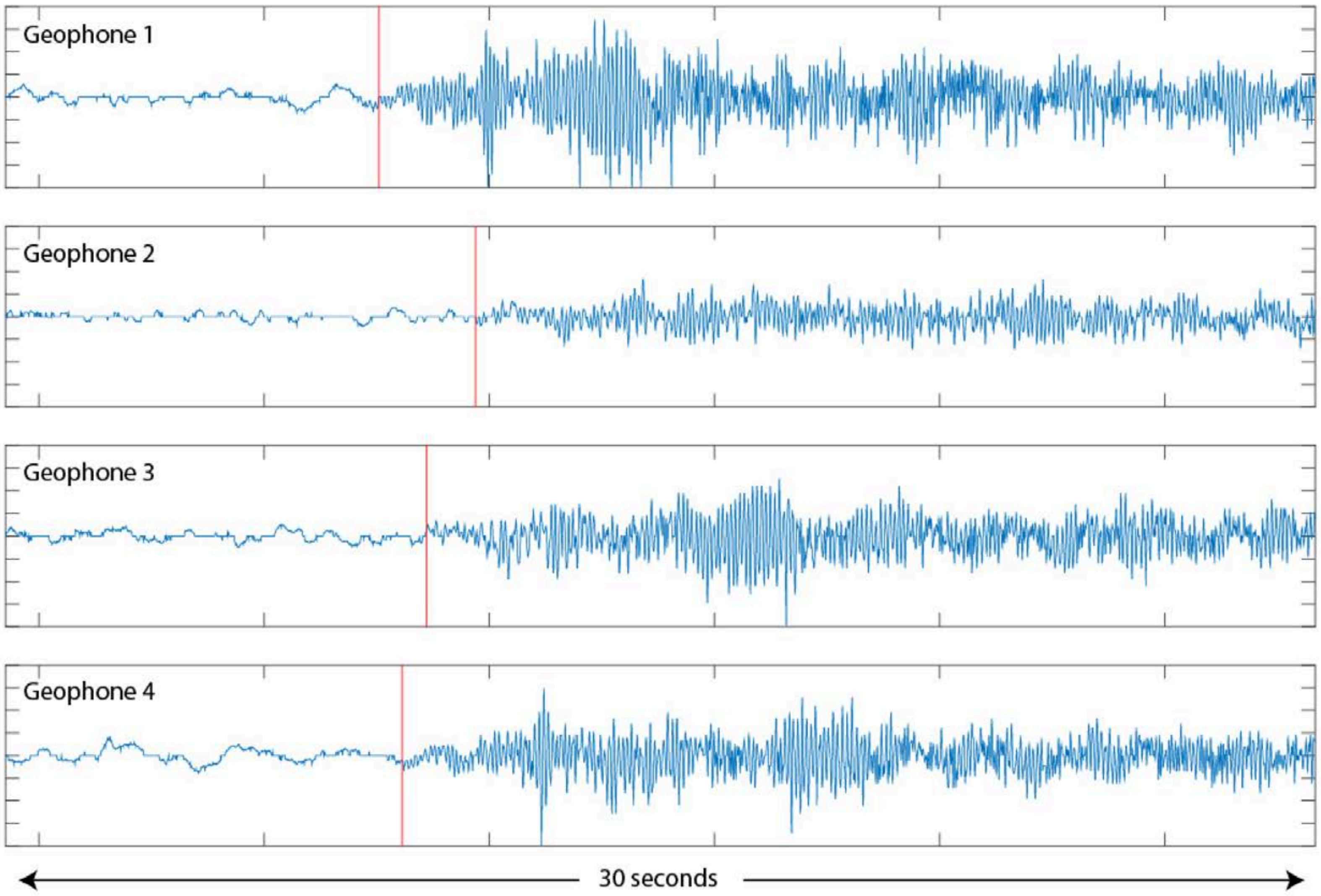

Apollo PanCam image

# Thermal Moonquakes

LROC image



# Event location

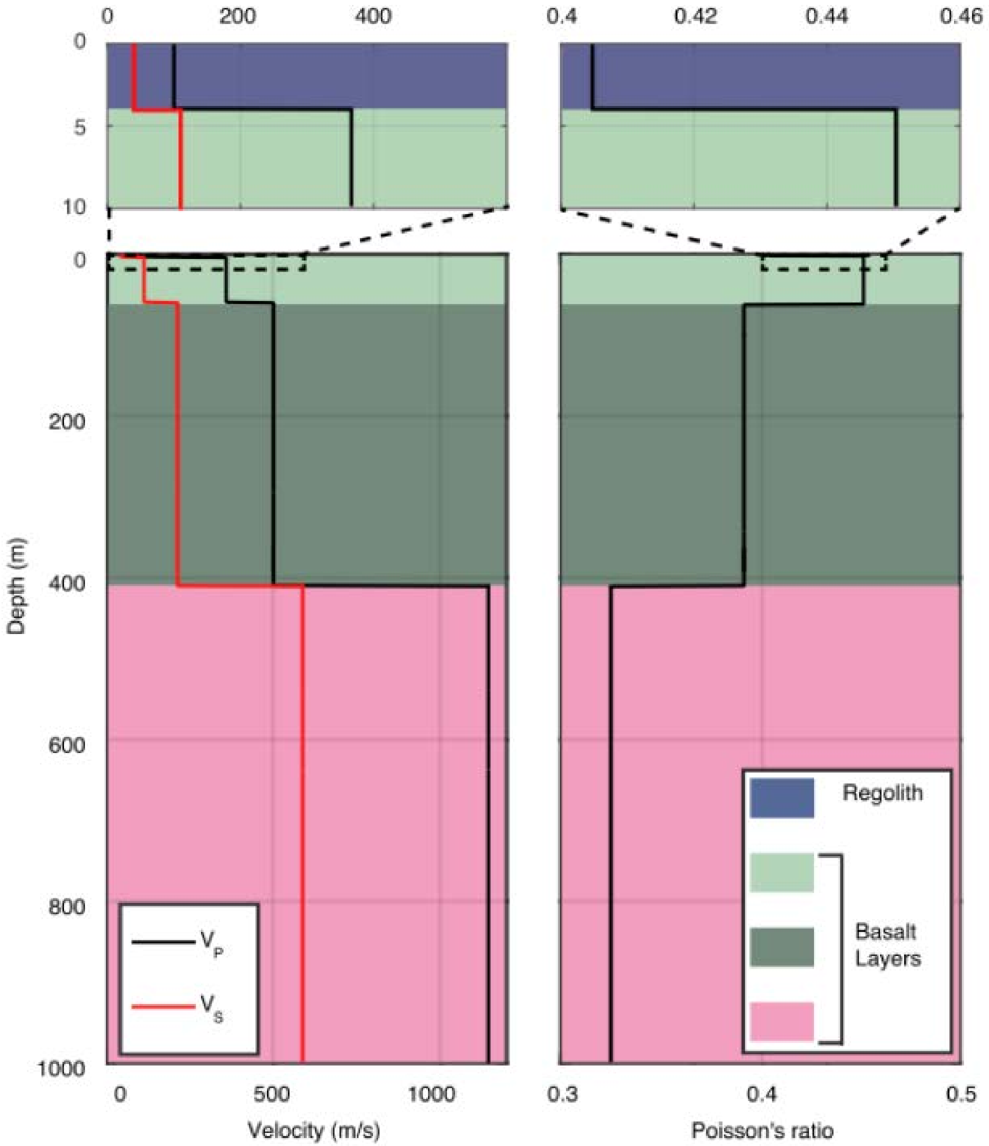


# Event location

Method by Schmerr:

1. Fit location and origin time to model + observations
2. Input arrival times at 4 geophones
3. Minimize misfit between observed and calculated arrivals on 1-km grid centered on array

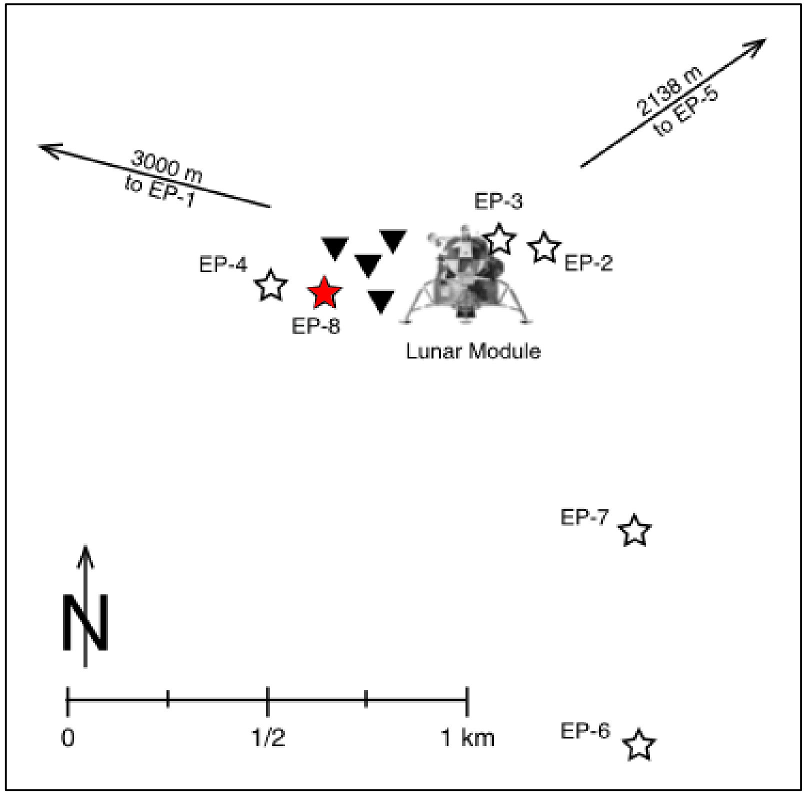
New velocity model produced from re-analysis of Apollo 17 active experiment data using seismic wavefield gradient approach: Sollberger et al., 2016 (GRL)

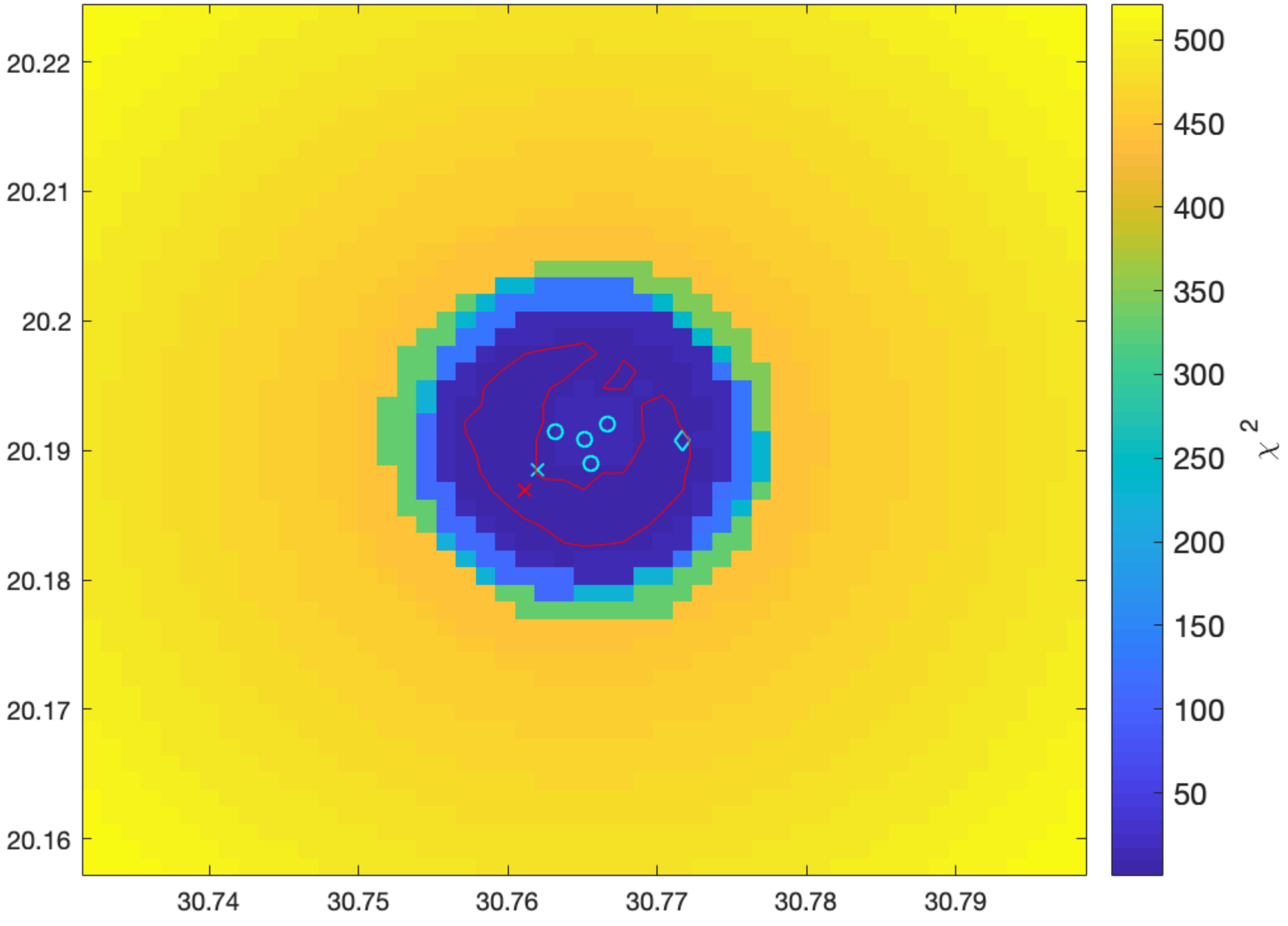


# Event location

Location results: testing with known locations of the active experiment explosive packages (EPs)

Sollberger et al., 2016 (GRL)



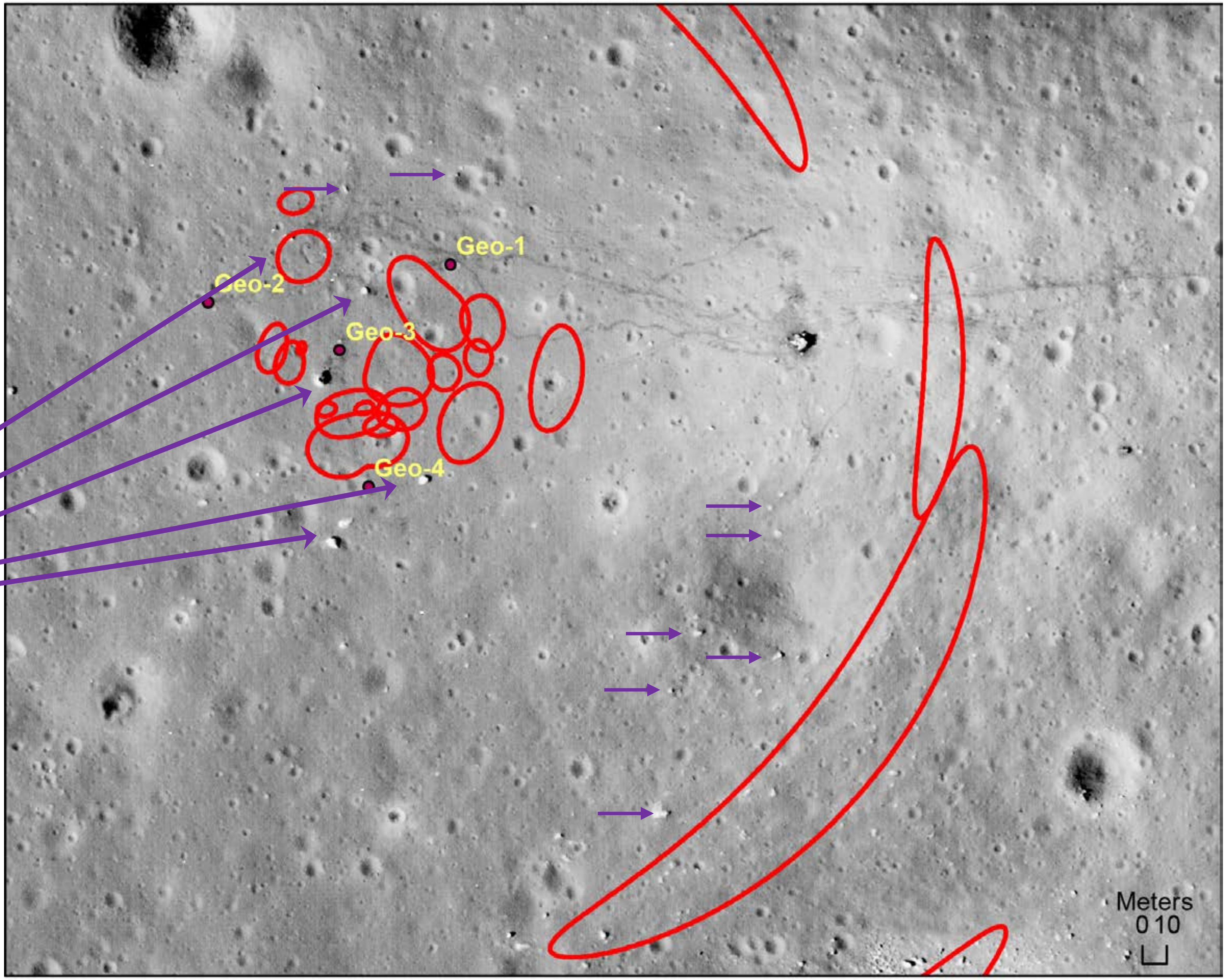



# Event location

Analysis 1:

What do we see inside those contours?

rocks mapped by Haase et al. 2012 (JGR)

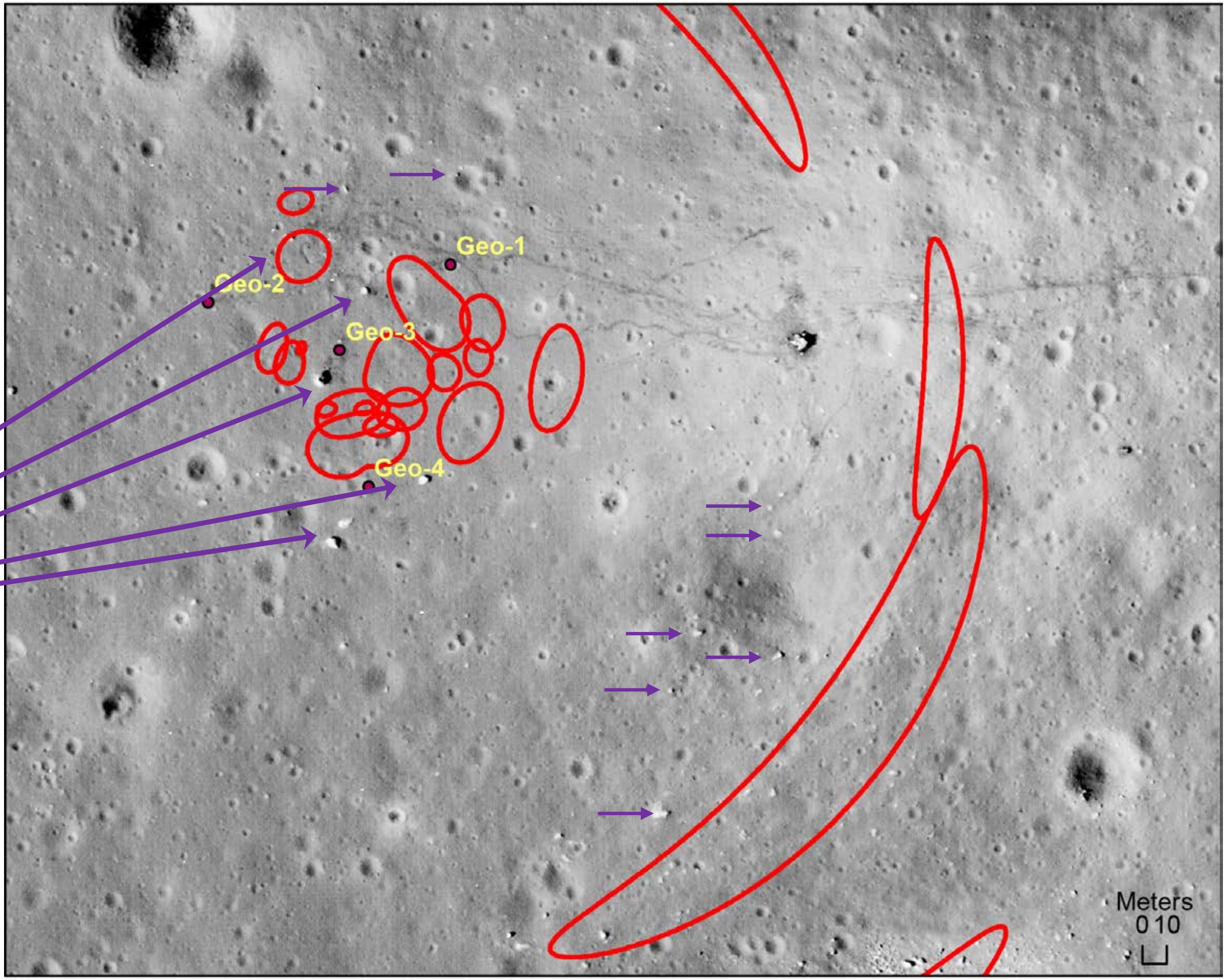


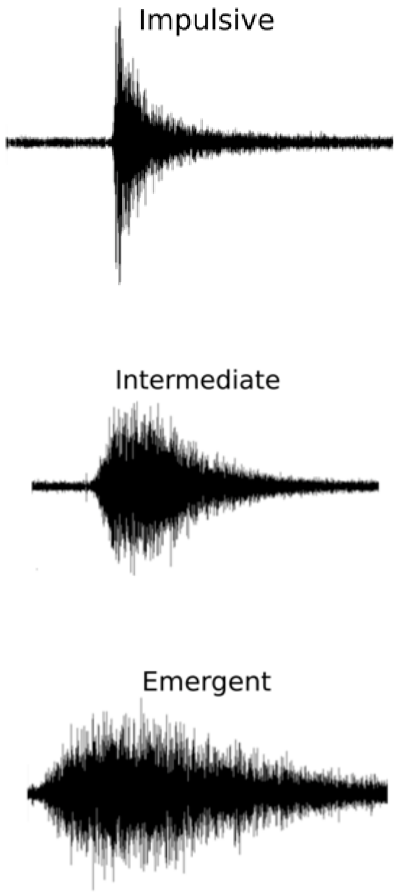
# Event location

Analysis 2:

Are there any obvious patterns based on waveform type?

rocks mapped by Haase et al. 2012 (JGR)

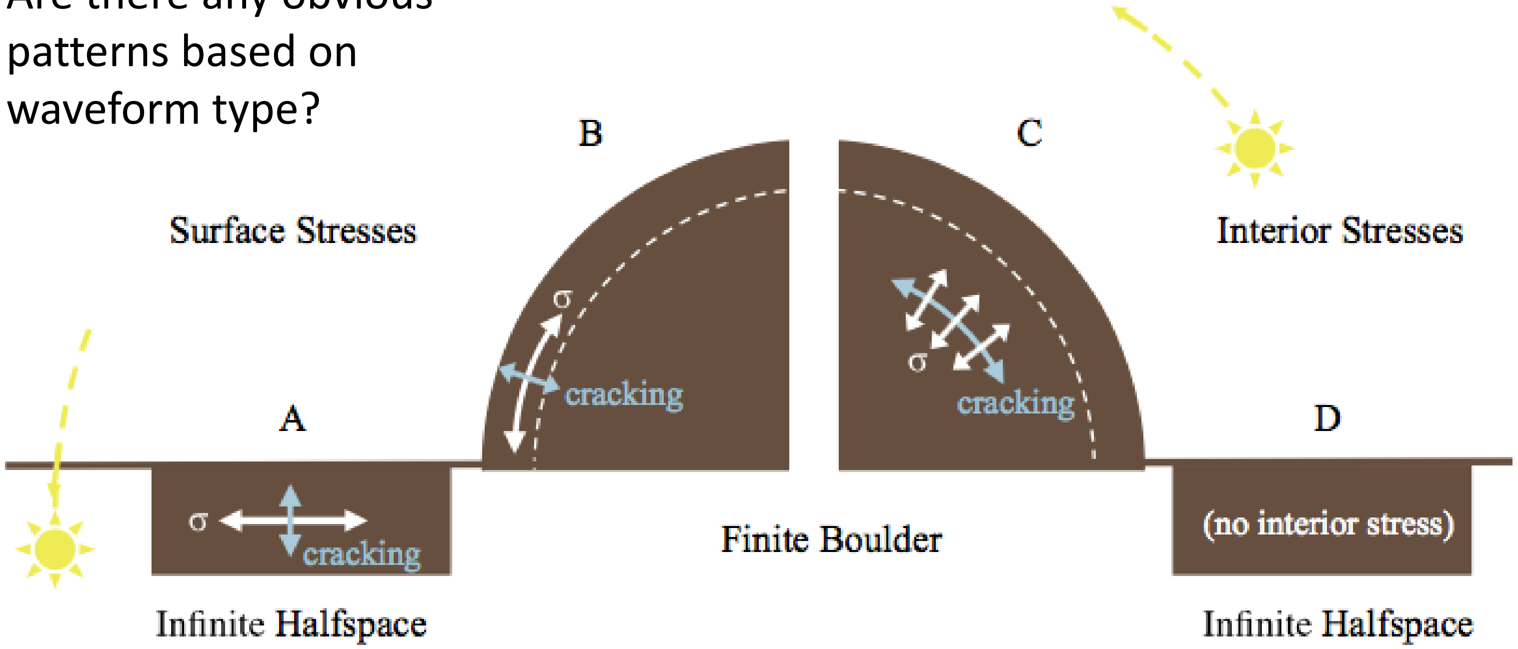


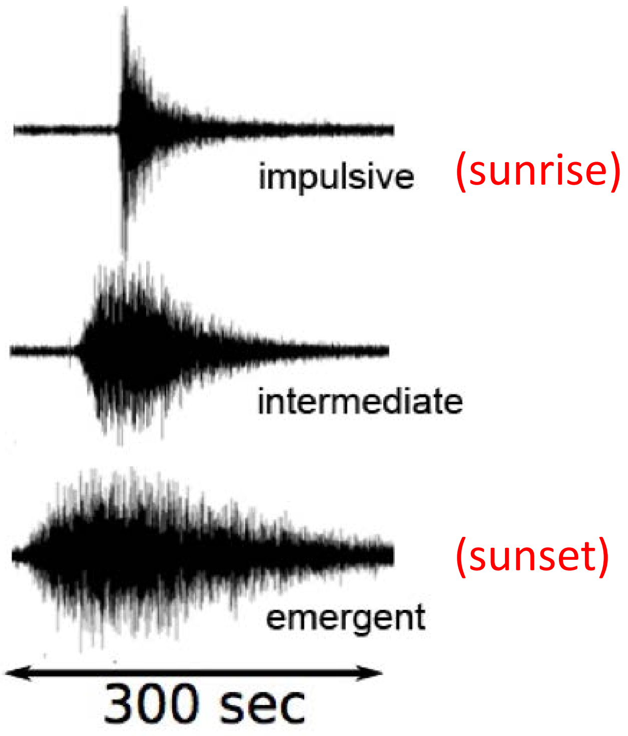
# Thermal modeling

Analysis 2:

Are there any obvious patterns based on waveform type?




Do waveform rise/decay times indicate type of cracking?



# Future work

Can thermal moonquakes be correlated with surface features?

→

Can we assess the extent to which thermally-induced rock breakdown contributes to regolith production?

→

Can such processes contribute to regional microseismic noise?

(test with terrestrial analog data)

Acoustic emission (AE) sensors have recorded diurnal micro-cracking associated with elastic wave generation within boulders in the field (Warren et al., 2013)

At the macro scale, thermally-triggered rock dome exfoliation has also been observed on Earth (Collins et al., 2018)