Thermal marsquakes

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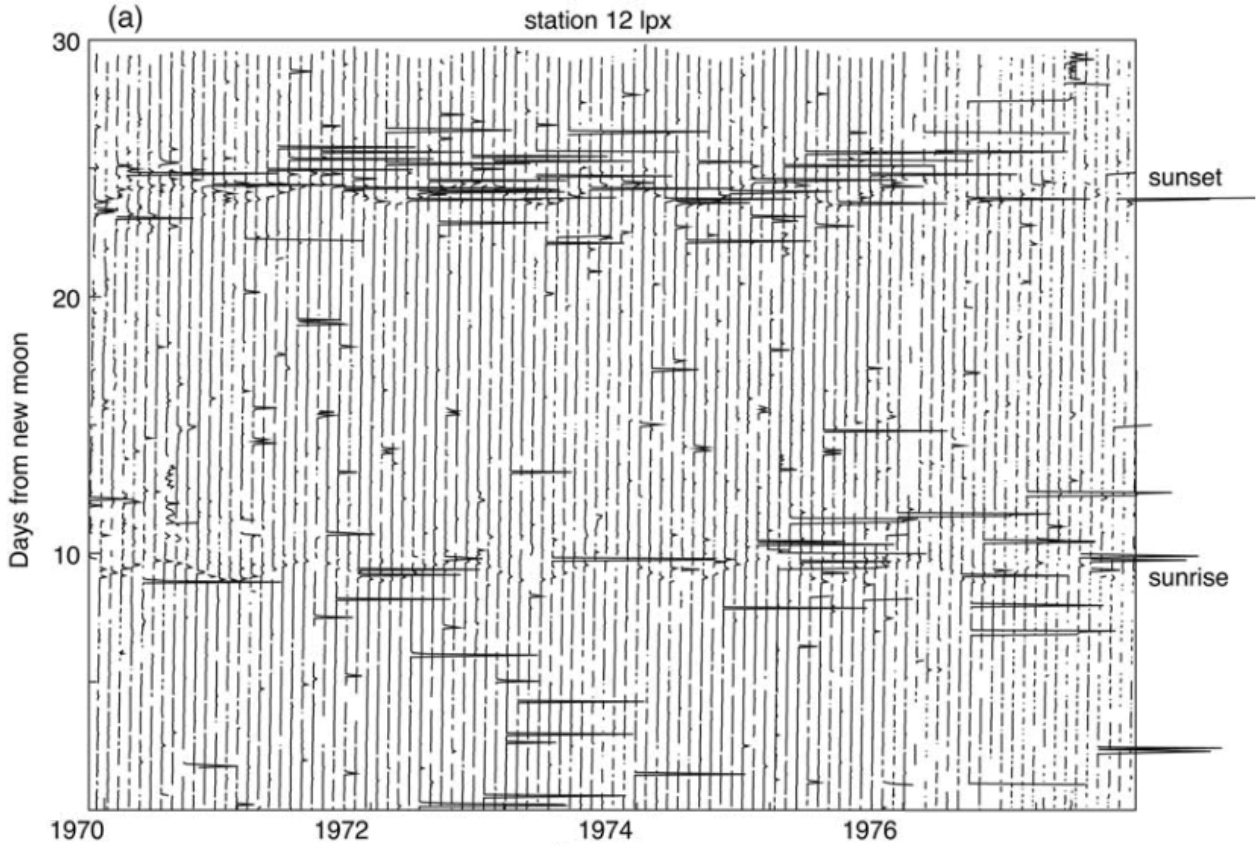
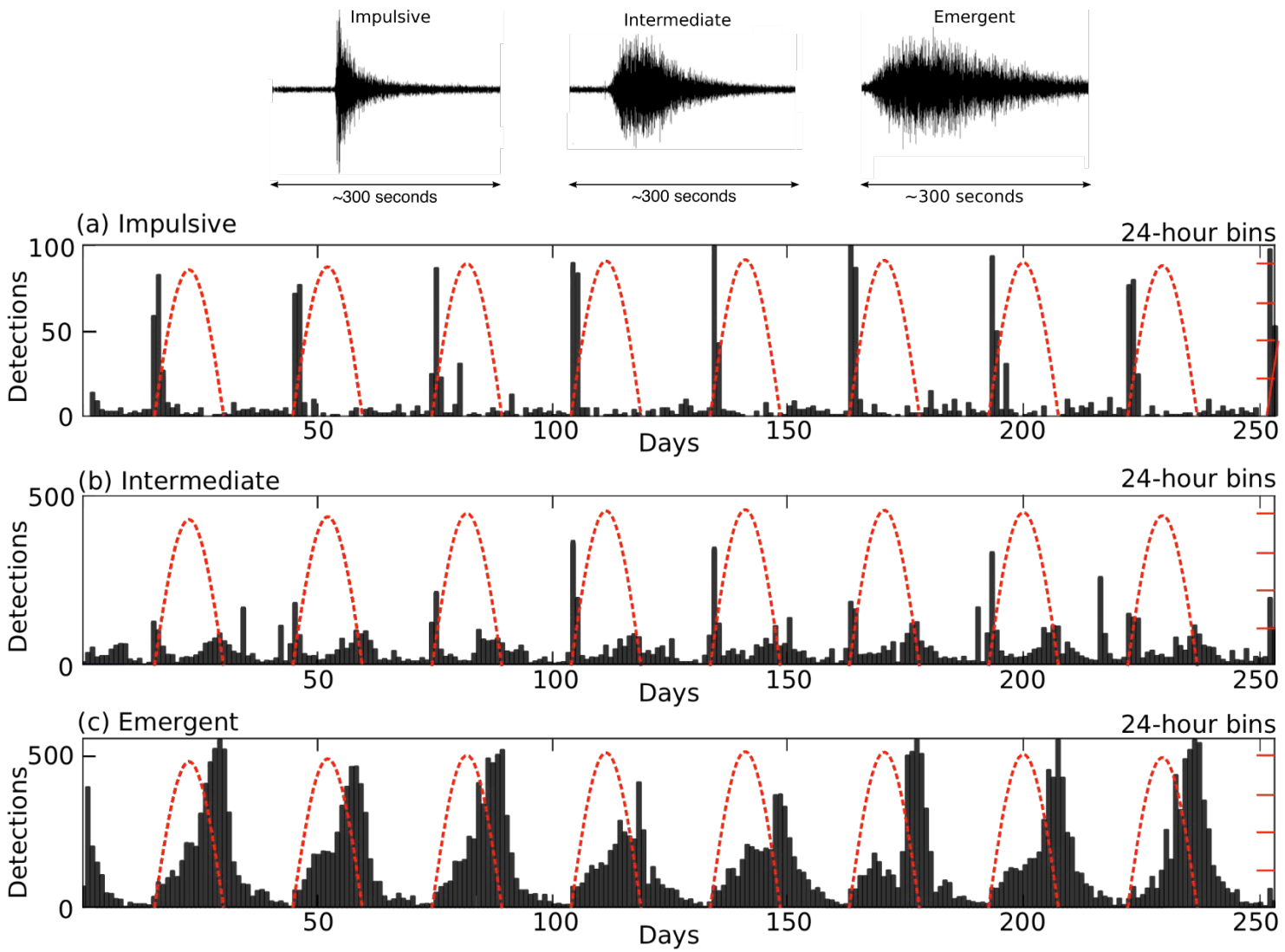
Thermal moonquakes

- What are thermal moonquakes?
  - Large-amplitude anomalies characterized by sharp onsets and exponential amplitude decay, observed on all Apollo stations in both LP and SP data at times of sunrise and sunset



Apollo 12 LP PSE continuous data maximum peak-to-peak amplitudes in 1-hour time windows as a function of time since the last new Moon (Bulow et al., 2005)

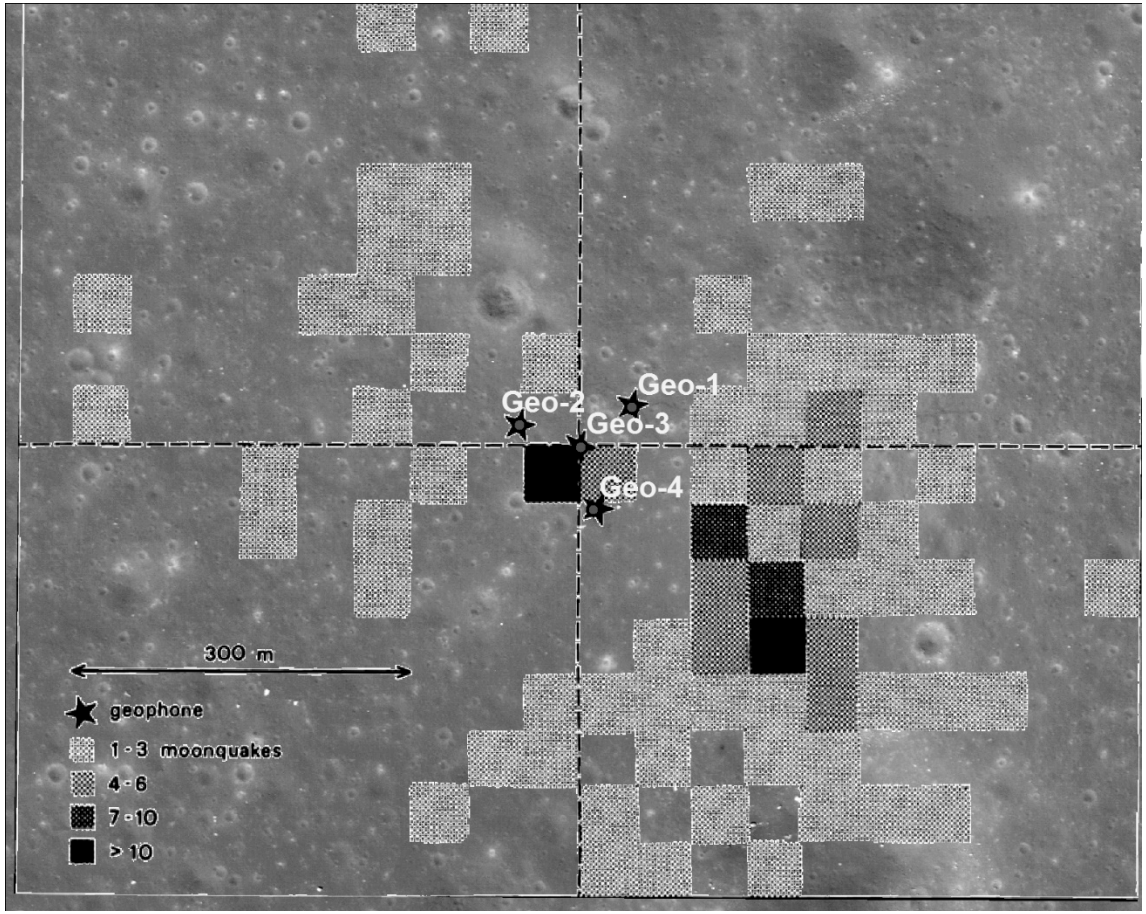
Thermal moonquakes



Histogram of the number of thermal events per day in Apollo 17 LSPE geophone data (Dimech et al., 2017)

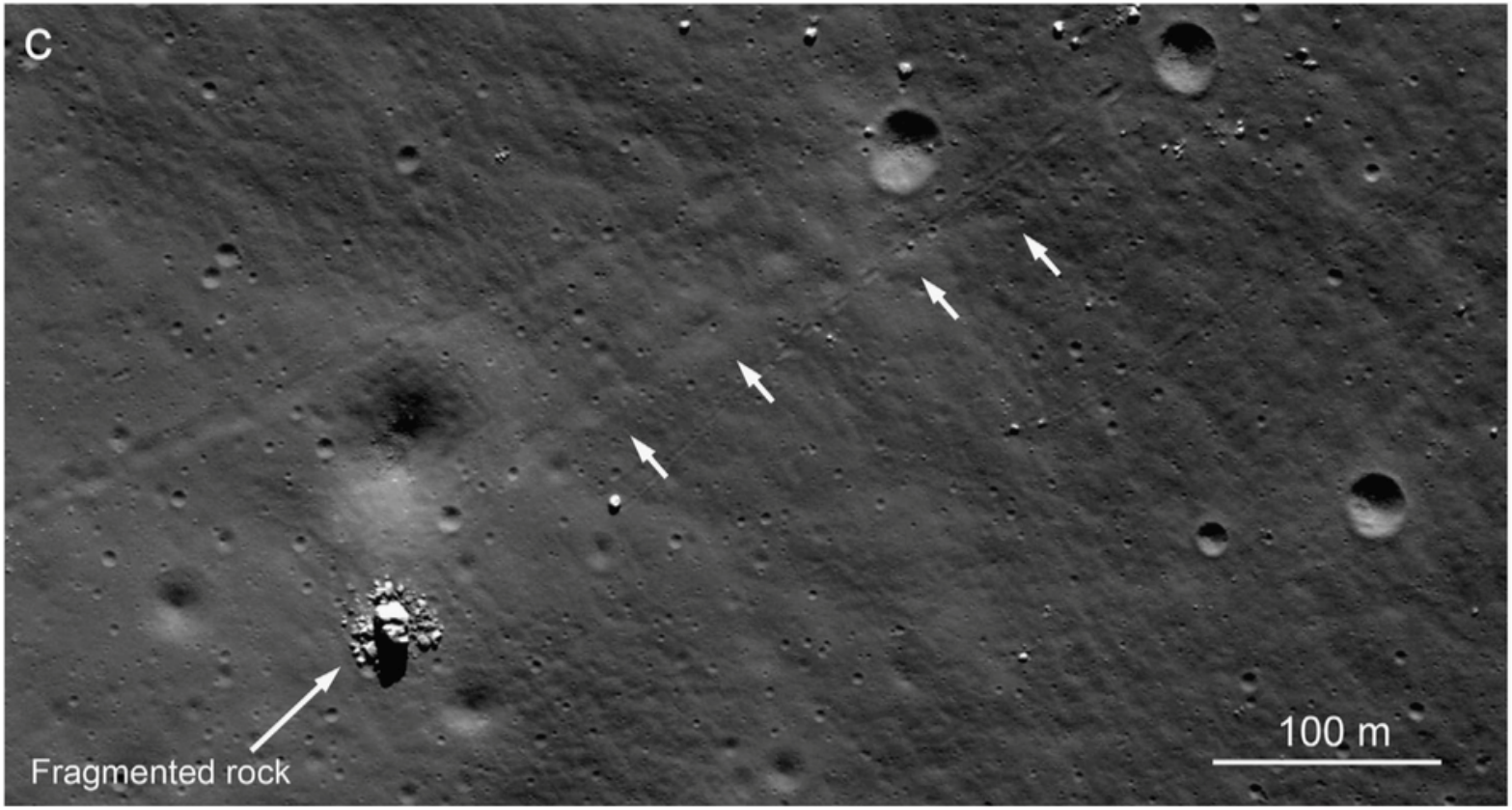
Thermal moonquakes

- Some evidence for correlation with rocks at Apollo 17 landing site
- Primarily posited to represent thermal movement of the regolith (Duennebier 1976), after accounting for lander-generated noise



Thermal moonquakes

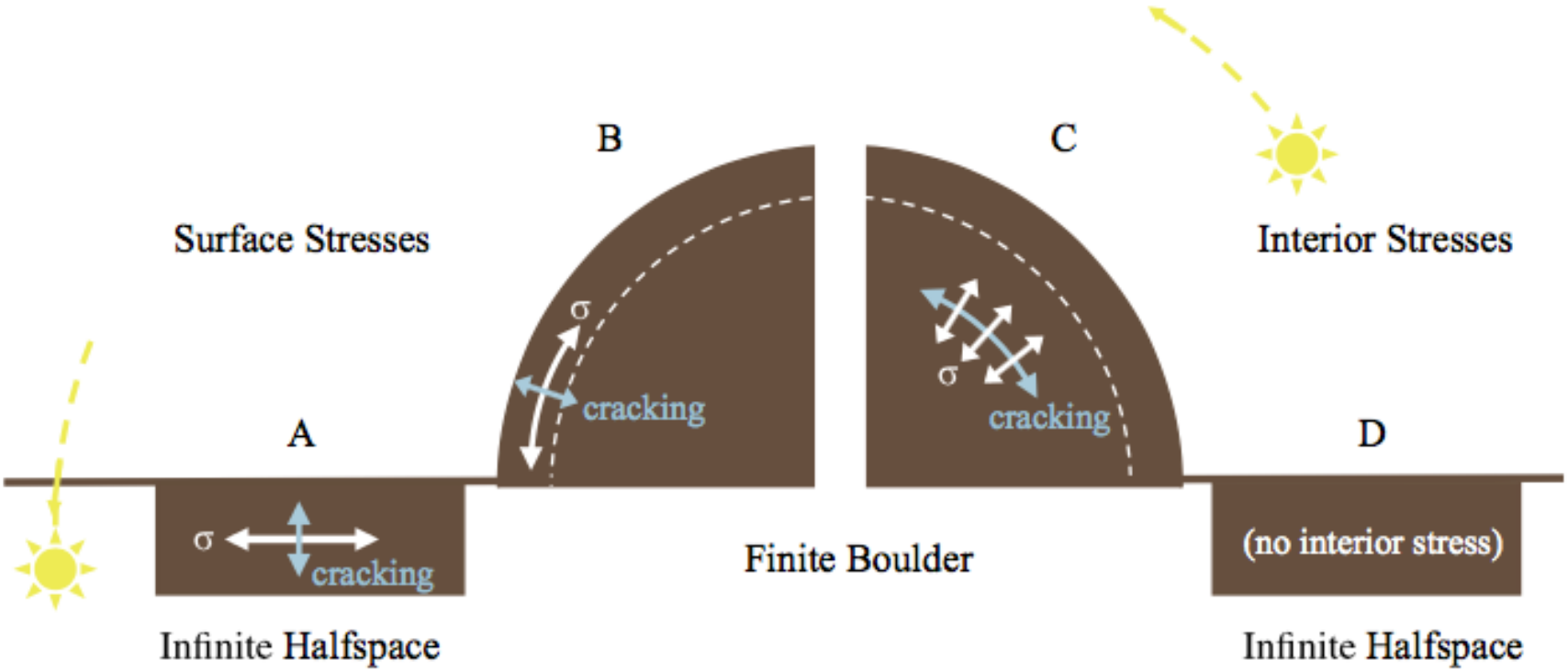
- Degraded rocks have been observed on the Moon & linked to impact processes, although “the role of thermal cycling is unknown and possibly contributes to the destruction of lunar surface rocks, especially of relatively large size” (Basilevsky et al., 2013)



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

Thermal moonquakes

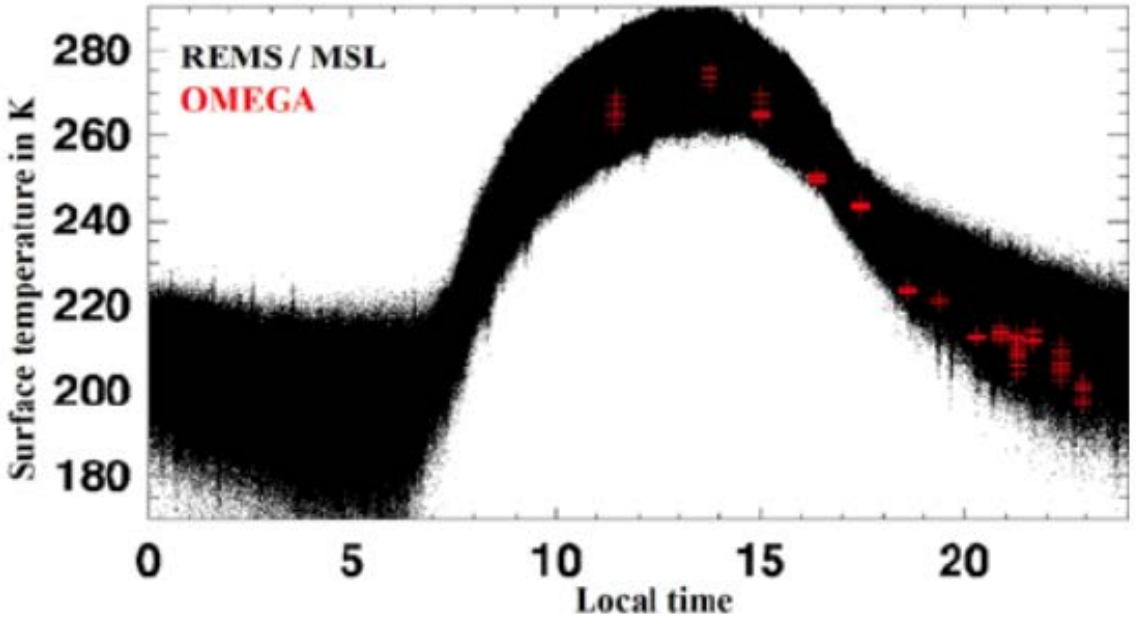
- Macroscopic thermomechanical behavior of lunar boulders in response to diurnal thermal forcing has been modeled & found to potentially contribute to breakdown (Molaro et al., 2017)



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.

Should we expect to see thermal marsquakes?

- Lunar diurnal temperature swing: ~300K
- Mars diurnal temperature swing: ~100K (still quite large)



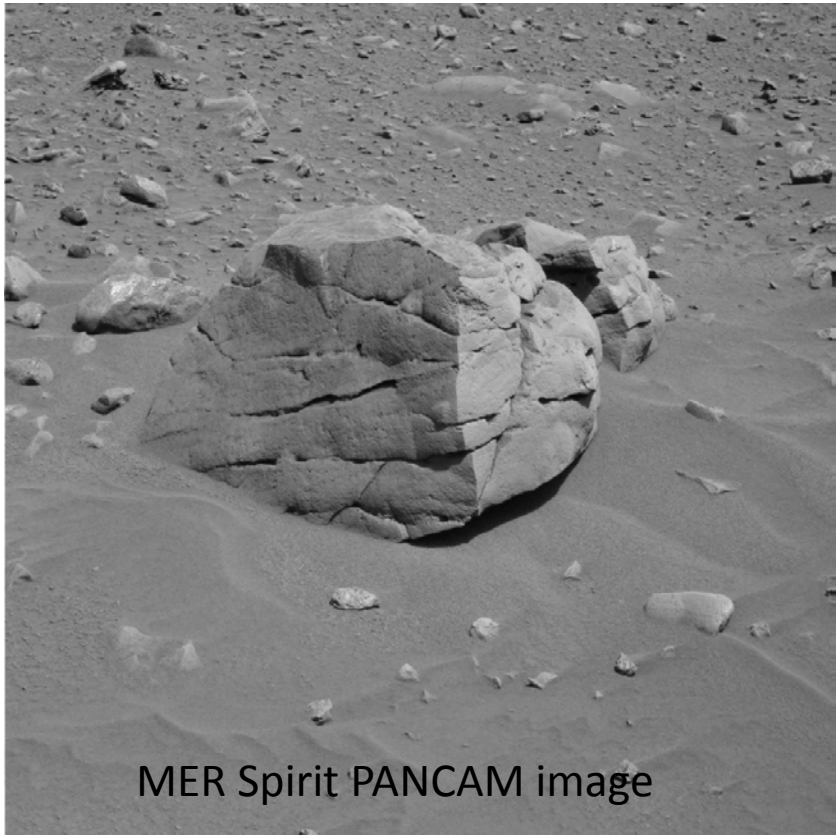
Surface temperatures at Gale Crater northern plains (Audouard et al., 2014)

Should we expect to see thermal marsquakes?

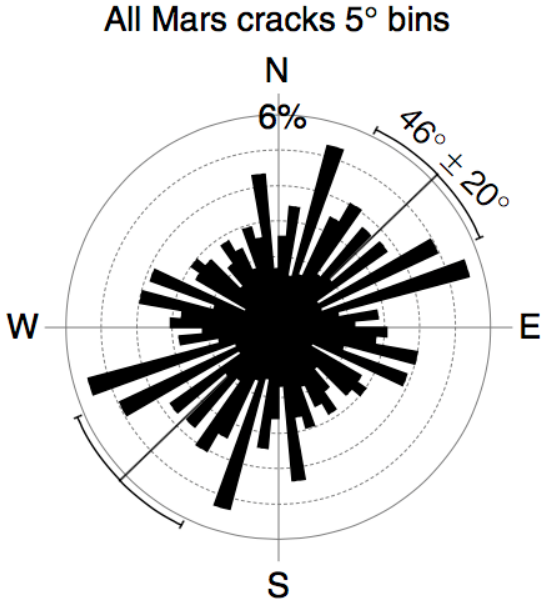
There is evidence for thermal fracturing on Mars (Eppes et al., 2014):

– Martian boulders (rocks >20cm) exhibit cracks with preferred orientations

– Calculated solar-induced thermal stresses for Martian rocks are consistent with solar-driven directional cracking.



MER Spirit PANCAM image

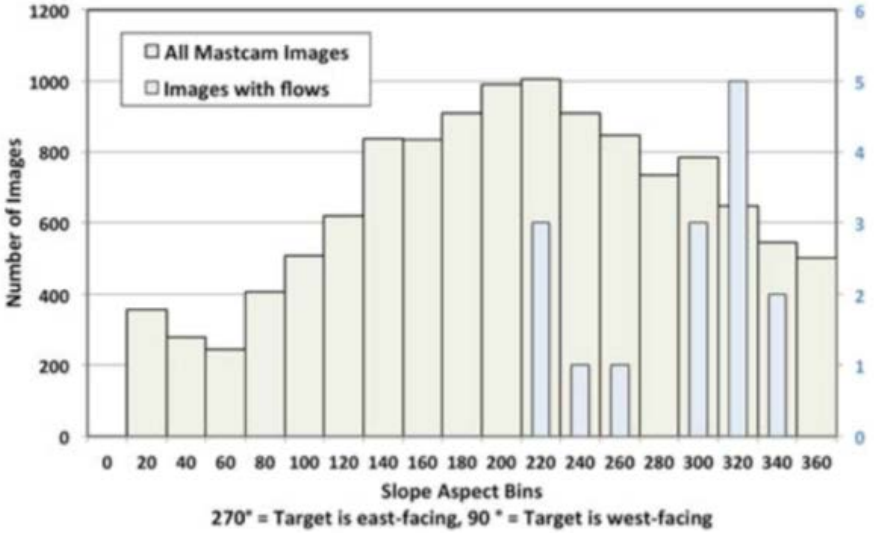


Crack strikes in 1,440 rocks

Should we expect to see thermal marsquakes?

There is evidence for other types of preferential “failure” on Mars (Dickson et al., 2016):

Brittle failures/slumping of “armoring” regolith layer beneath an outcrop in the Kimberly Formation (MSL mastcam mosaic)

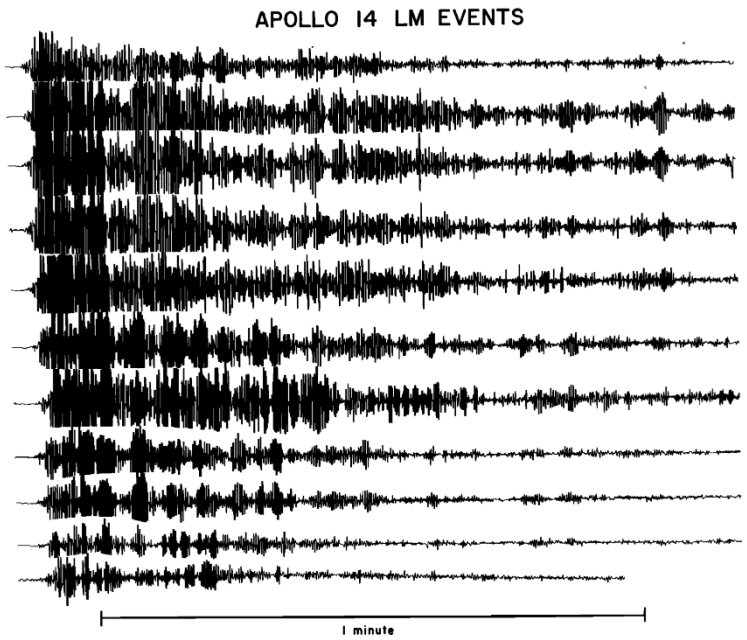


Histogram of aspect angle for all such observed features shows they predominantly occur on East-facing slopes (some observational bias), possibly diurnal brine evaporation? Hydration/dehydration?

Should we expect to see thermal marsquakes?

There will also be lander-generated diurnal thermal noise

- This was known to exist on Apollo (Duennebier & Sutton, 1974)
  - Characterized only by signal features: short rise-times, 4 & 8 Hz spectral peaks, identical waveforms

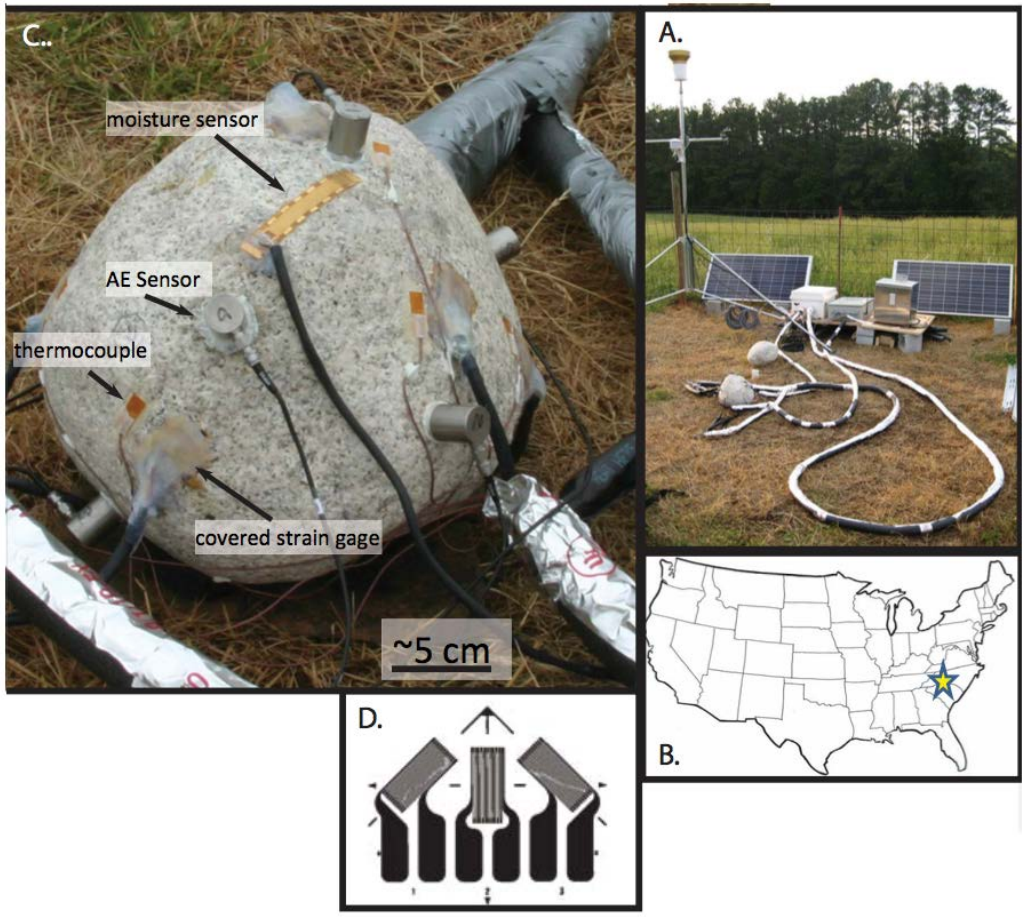


- This was known to exist on Viking (Anderson, 1977)
  - Seismometer had an “auto-trigger” mode for data storage, adjusted to reduce false triggering from lander thermal “pops”

Also predicted for Venus (Lorenz, 2012). Any indication from other Mars landers?

What about on Earth?

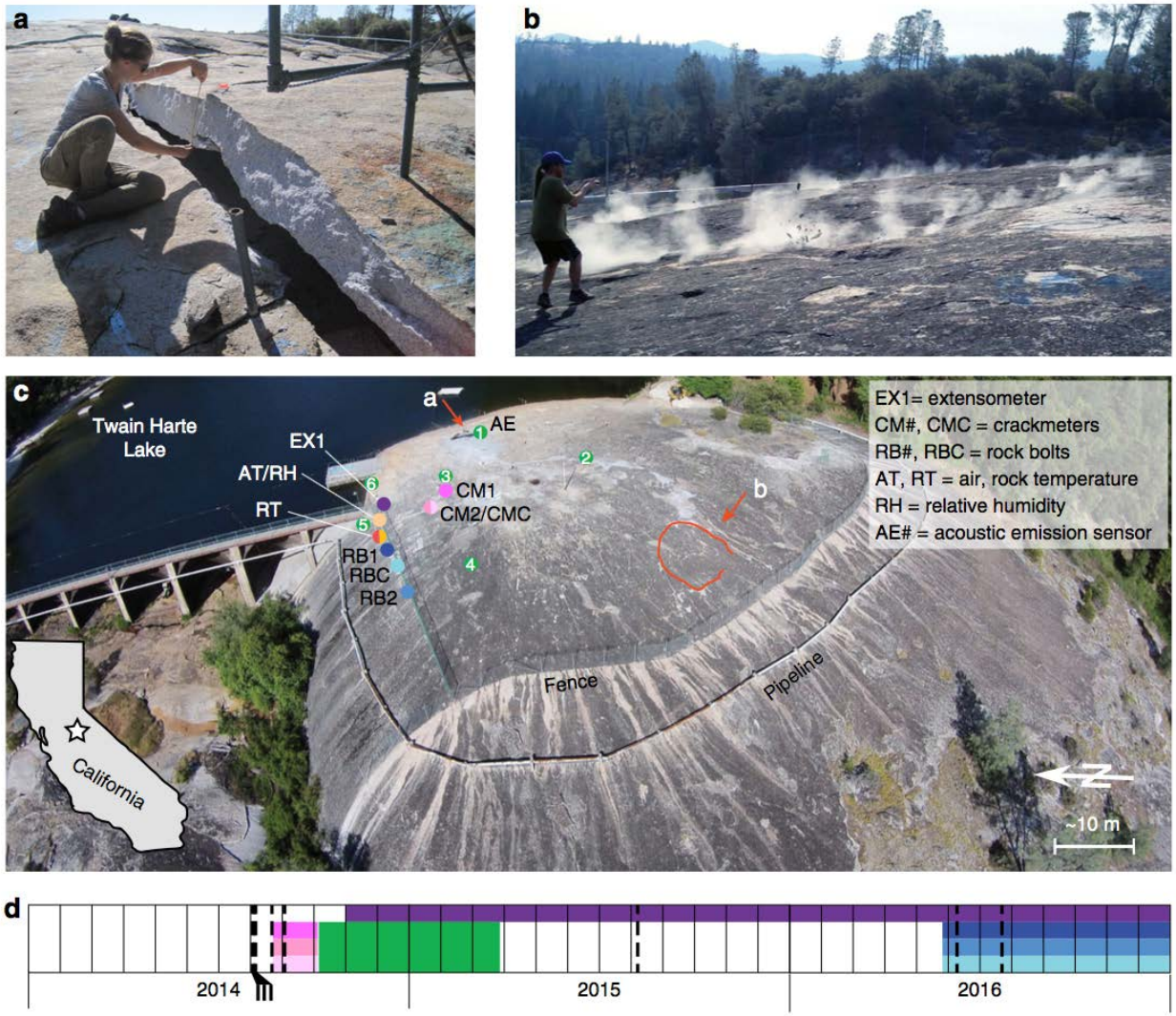
- Acoustic emission (AE) sensors have recorded diurnal micro-cracking associated with elastic wave generation within boulders in the field (Warren et al., 2013)
  - "During the first four months, the deployed boulder experienced almost 12 000 AE events, the majority of which occur in the afternoon when temperatures are decreasing."



Can this process contribute to regional microseismic noise?

What about on Earth?

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



"…thermally driven stress— combined with long-term thermally driven subcritical cracking— was the likely trigger for exfoliation"

(8 fractures over 3 summers)

What about in the terrestrial seismic data record?

- Do these types of events appear in terrestrial data?
  - Arid regions with low anthropogenic noise?
  - Instrument sensitivity?
  - Signal frequency content?
  - Transmission through regolith?

What next?

- **IF** rocks are responsible for thermal marsquakes, **AND** SEIS can record them… it's probable that at least some rocks are within general vicinity of InSight lander
  - Can diurnal thermal marsquakes be a source of seismic noise?
  - Can we do science with them?