EP41C-0942: Real-time Observations of Rock Cracking and Weather Provide Insights into Thermal Stress-Related Processes of Mechanical Weathering.

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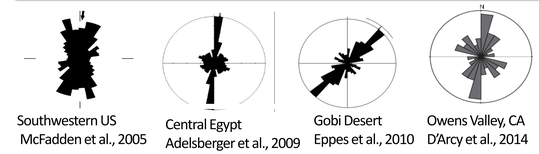
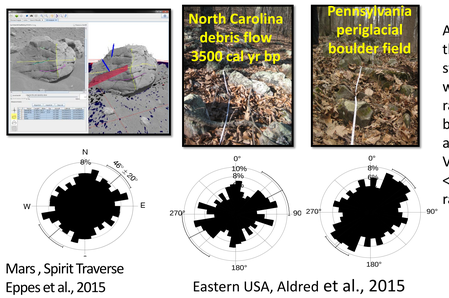
Motivating Field Observations

Cracks in mid-latitude desert rocks exhibit preferred orientations,



Southwestern US McFadden et al., 2005 | Central Egypt Adelsberger et al., 2009 | Gobi Desert Eppes et al., 2010 | Owens Valley, CA D'Arcy et al., 2014

as do cracks in rocks on Mars and in humid-temperate boulder fields,



Mars , Spirit Traverse Eppes et al., 2015 | Eastern USA, Aldred et al., 2015

All data presented in this panel are crack strike orientations that were measured on randomly chosen non-bedrock boulders. Rao and/or Raleigh P-Values for all plots are <0.05, indicating non-random orientations.

leading to the inference that insolation plays a key role in rock breakdown under a broad range of temperature and humidity conditions.

Research Question

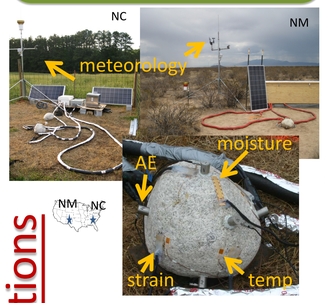
What is the role of those conditions in driving or limiting mechanical weathering?

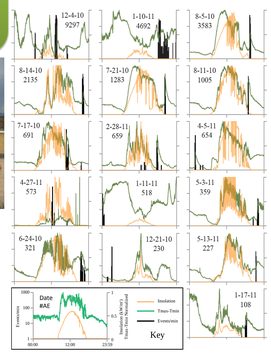
and

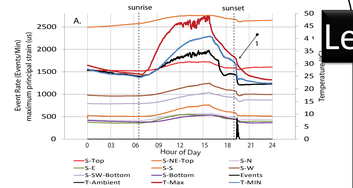
Motivating Instrumentation Observations

We directly monitored rock cracking using acoustic emission (AE) sensors, and rock-environmental conditions in two granite boulders (NC – 1 year; NM – 3years), and found that

→ **at both sites, the vast majority of observed cracking occurred during thermal events, and recorded strain shows evidence of thermal fatigue,**



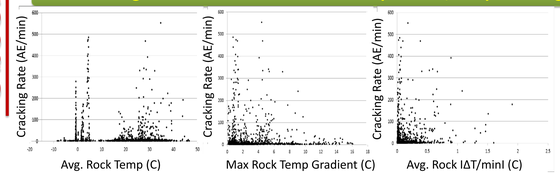




Data from Eppes et al., in review

Left: example days in which the highest numbers of AE occurred in the NC rock. Virtually all event clusters for NM & NC occur during relatively rapid and complex rock surface temperature changes that coincide with peak solar-induced thermal stresses at sunset or mid-day. **Above:** A typical day in which cracking occurred, where rock surface strain tracks with rock surface temperature, and cracking occurs during relatively rapid temperature and strain changes, in this case brought on by a sudden storm.

but cracking rates do not correlate with temperature, temperature gradient, or rate of temperature change.



Left: All three panels depict temperature conditions during individual minutes when AE were recorded in NC (n = 1201) versus the AE rate, a measure that is proportional to rock fracture. We observe no trends in these temperature metrics and rock cracking throughout the entire period of record for the NC rock. (Gradient = Max rock surface temp. – min. rock surface temp)

Led to

New Numerical Modeling Of Solar-Induced Crack Growth

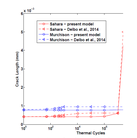
We developed a model for temp- & moisture-dependent subcritical crack growth to inform our interpretation of measured cracking and field data.

Model Parameters

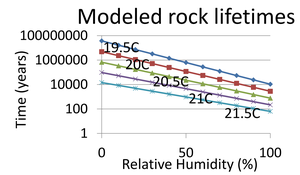
1) Solar-Induced Temperature Field
   --conductive heat transfer of a sinusoidal heating function (from Holzhousen, 1989)
1) Solar-induced thermal stress field (from Holzhousen, 1989)
   -- intergranular interactions only
   -- f(diurnal temp. range)
   --f(differences in Coefficient of thermal expansion of adjacent minerals.
3) Crack growth modeled as a novel combination of Paris's Law (fatigue) & Charles' Law

$$a(N) = \left[a_o^{\beta} + \beta C_1 N\right]^{1/\beta}$$

- $a(N)$=crack length at diurnal cycle, N
- $a_0 = a(0)$ = initial crack length
- β =1-m/2
- $C_1 = C\Delta\sigma_{max}\pi^{m/2}$, where C & m are material- and environment-dependent Paris law coefficients available in the literature, and $\Delta\sigma_{max}$=$\Delta\sigma_{max}(z)$ is the depth-dependent maximum thermal stress



Model validat



Preliminary model results show the strong dependence that both diurnal temperature range and relative humidity have on rock lifetimes (calculated as spalling of a 1 m boulder).Different lines represent different average annual diurnal temperature ranges.

Model results show that simple, insolation-induced crack growth rates are strongly dependent on 1) temperature range and 2) moisture

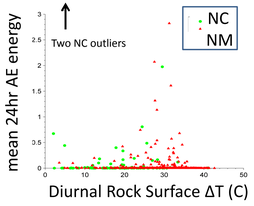
Eppes and Keanini, in preparation

which led to

New Analysis of AE-measured cracking Data

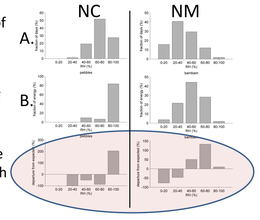
Diurnal temperature range by itself is not a strong predictor of AE-measured cracking rate s(left), but **cracking disproportionately occurs under relatively high ΔT and humidity conditions (bottom left).**

Cracking also disproportionately occurs on days with climatologically extreme temperatures (right).



cracking with respect to diurnal temp. range

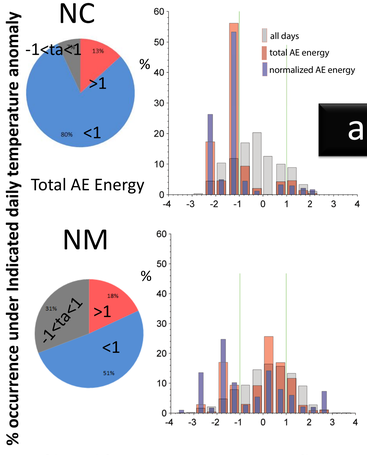
We examined the fraction of the entire period of record characterized by various humidity conditions (A), compared to the fraction of AE energy measured under those conditions (B). Generally, cracking rates are higher than expected at high humidity (circled data).



cracking with respect to daily relative humidity

We compared average daily temperatures for days in which AE occurred, to the average daily temperatures for those dates derived from 1951-1980 climate data from nearby weather stations in order to calculate the temperature anomaly of any given "cracking day" with respect to climate data. We then normalized the data to account for any over-or under-sampling of extreme temperature days in the year of observation.

As such, any absolute temperature anomaly values greater than one represent climatically extreme temperatures (> 1σ) for days when cracking occurred.



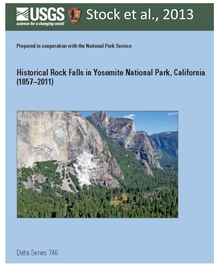
cracking with respect to temp. anomalies

and

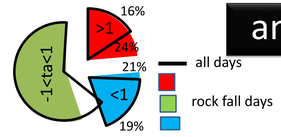
A Case Study of Rock Fall

Rock fall data from a complex field site where other stress loading is undoubtedly at play (e.g. topography, higher occurrence of freezing temperatures) are consistent with our AE observations:

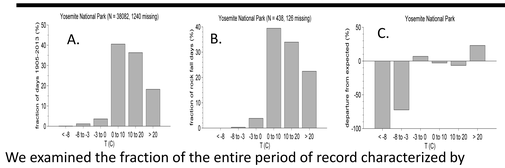
More than expected rock falls occur under extreme temperatures.



Using Stock et al.'s (2013) detailed ~100 year record of rock falls from Yosemite National Park, we examined the percentage of all falls occurring on days with anonymously high or low temperatures compared to climate data from Yosemite Valley. About 10% more rock falls than expected occur on these days overall.



Occurrences (%) of indicated temp anomaly



We examined the fraction of the entire period of record characterized by various temperature conditions (A), compared to the fraction of rock falls observed under those conditions (B). Generally, rock fall rates are higher than expected at high temperatures (C).

and

Conclusions and Implications

Model results show that crack growth rates in rock, regardless of loading mechanism, are strongly dependent on moisture.

Crack growth rates under solar-induced intergranular stresses are strongly dependent on the variance in rock surface temperature from far field temperature (ΔT) (approximated in the model by the diurnal temperature range).

Days with extreme temperatures represent the days when there is the highest likelihood of reaching maximums in ΔT , thus approaching critical stresses necessary to rapidly propagate cracks.

Therefore when other stress-inducing triggers occur (freezing conditions, weather-induced thermal stress), the rock is "primed" for failure.

Thus, when considering drivers or limits to all stress-loading mechanisms, both moisture and insolation-related stresses should be considered.