Biomarkers as a tool for measuring frictional heating in faults

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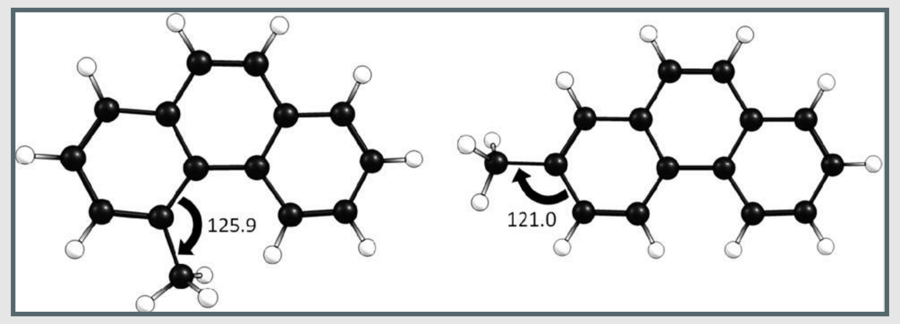
Introduction:

During earthquakes, frictional resistance along a fault plane can lead to the generation of dramatic increases in temperature. Investigating temperature rise within fault zones provides a promising tool for the detection of past earthquake events. Here we will explore the use of biomarkers as an alternative approach to identify and investigate temperature rise along the Muddy Mountain thrust, Nevada.

Biomarkers as a paleothermometer:

Biomarkers are biological molecules produces by living organisms that are preserved in the rock record. They have several advantages that make them a useful proxy for earthquake slip: they are abundant in sedimentary rocks, their structure is systematically altered with heating, and they are present over a wide range of time-temperature windows. We are interested in the biomarker methylphenanthrene (MP), a polycyclic aromatic hydrocarbon that is formed by the diagenesis of pre-existing organic material. It is found at moderate depths (~1-4 km) and has thermally stable and unstable isomers.



Szczerba, 2010

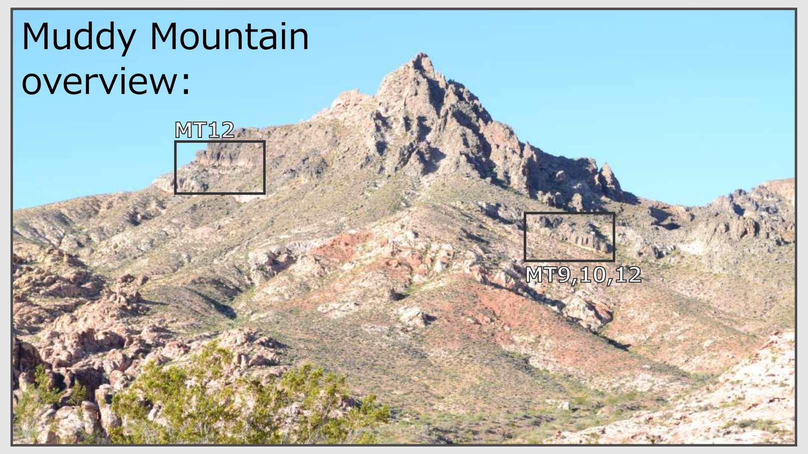
Muddy Mountain thrust:

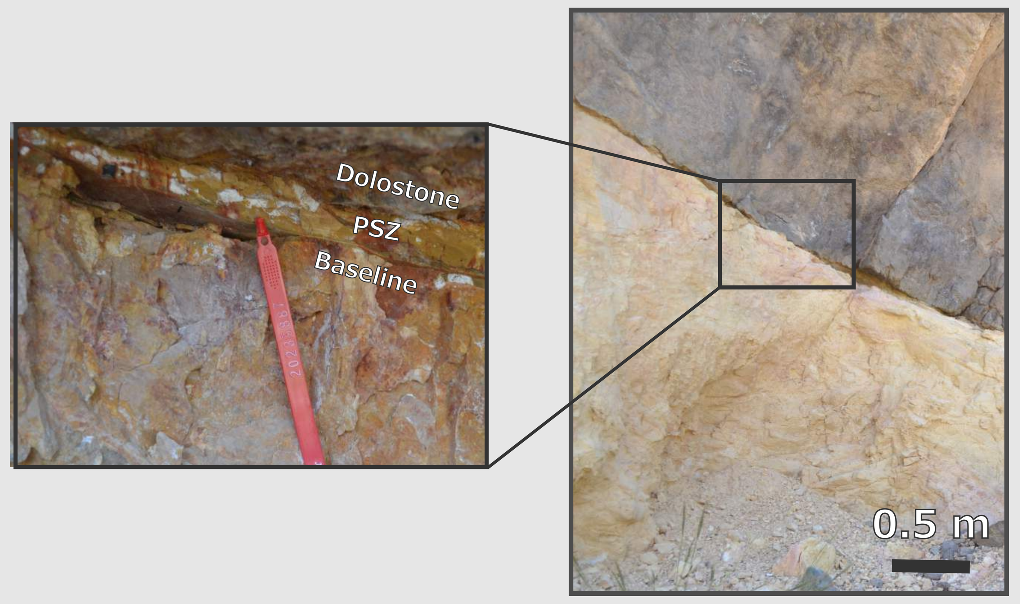
The Muddy Mountain thrust in southeast Nevada consists of brecciated Paleozoic dolostone thrusting over Jurassic Aztec Sandstone with a thick layer of molasse sandwiched between the two. It has a broad damage zone ~10-100 m thick that is associated with cataclasis, fracturing, and the incorporation of sheared slabs of dolomite from the hanging wall (*Brock and Engelder, 1977*). It is an ideal location for this study due to the extensive long-strike exposure of a localized fault zone.

As temperature increases, the abundance of thermally stable isomers of MP increase while the less stable isomers. This occurs in order as the methyl group changes position on the MP molecule in order to reduce steric hinderance. These changes occur systematically as thermal energy increases with increasing temperature and are quantified using the following indices:

$$\text{MPI-3} = \frac{\text{2MP + 3MP}}{\text{2MP + 3MP + 1MP + 9MP}} \qquad \text{PP-1} = \frac{\text{2MP + 3MP}}{\text{2MP + 3MP + 1MP}}$$

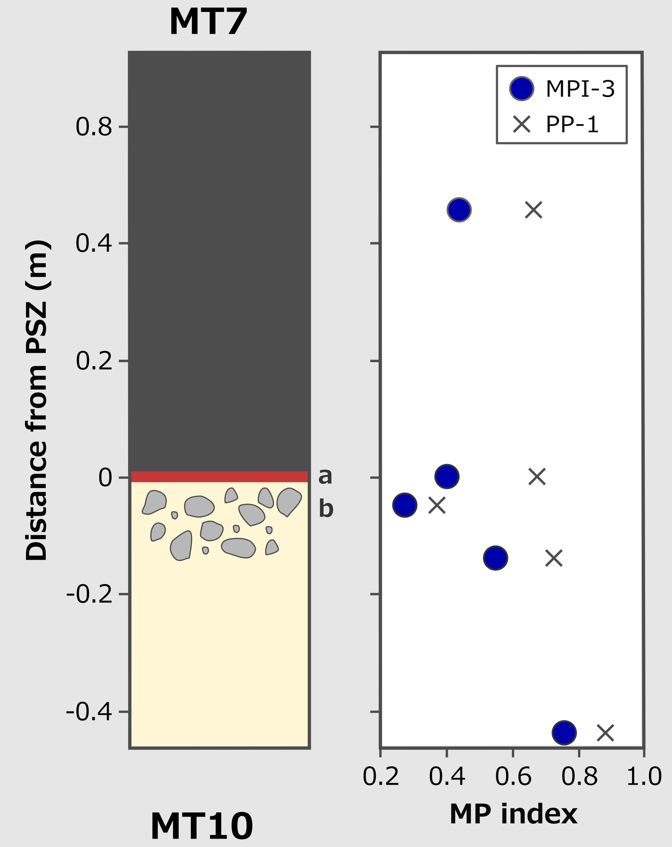
Preliminary results:

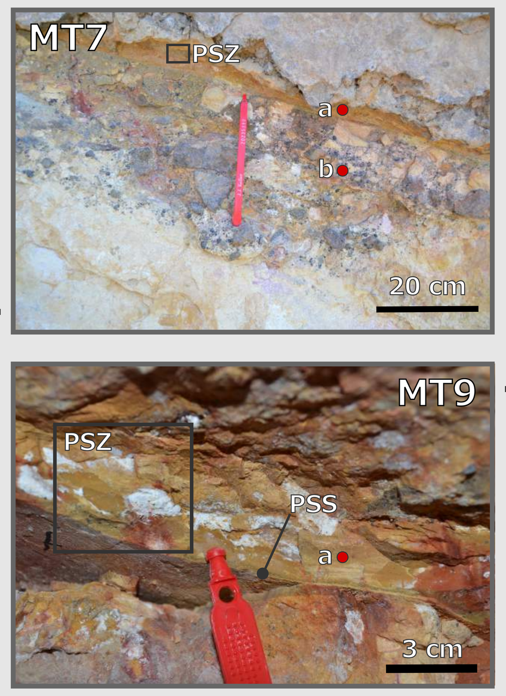


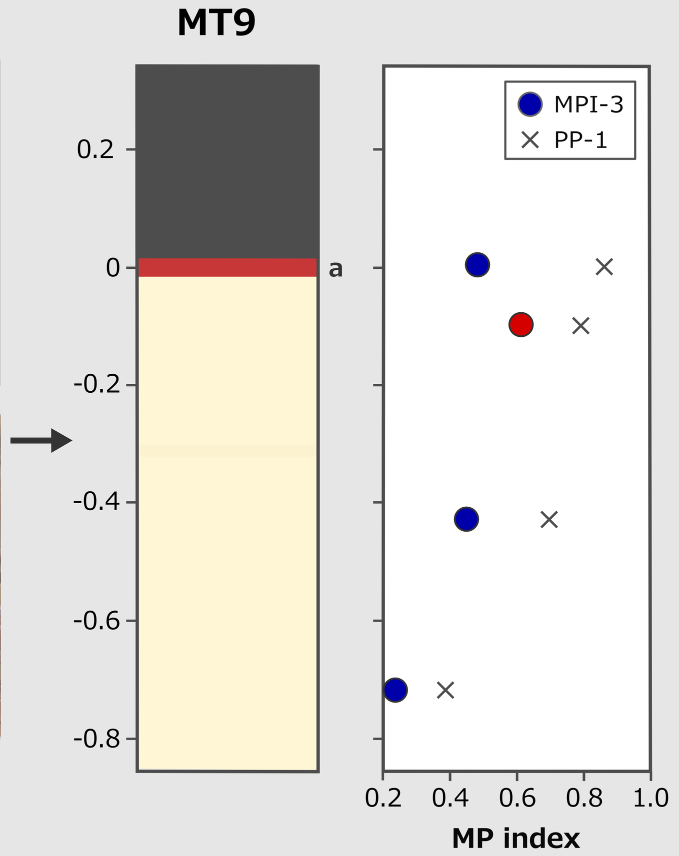


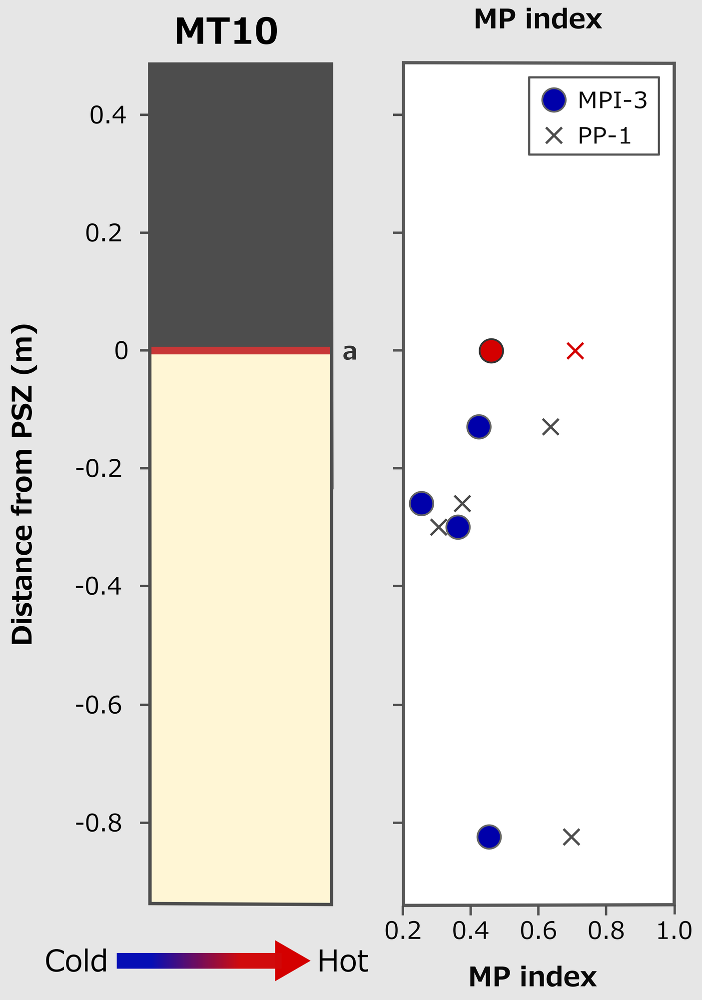
Lithologies:

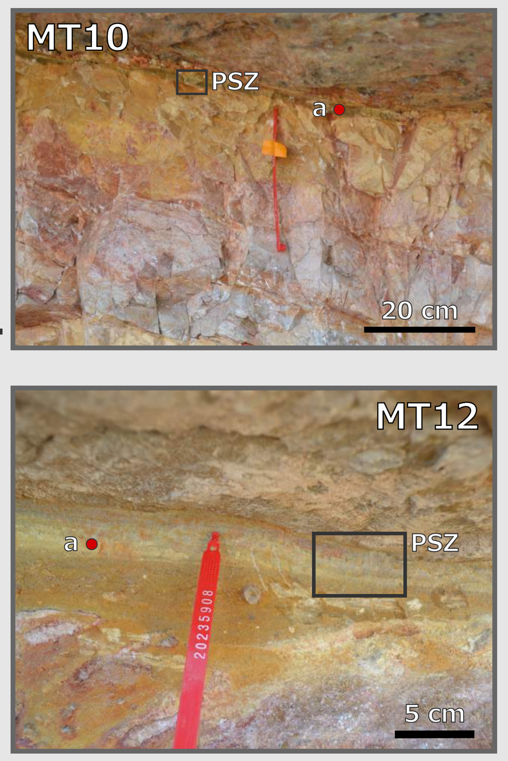
- Brecciated Paleozoic dolostone with overpressure chimneys
- Fractured and variably altered
- Indurated, baked dolostone
- Principal slip zone (PSZ) with possible principal slip surface (PSS) in some sites.
- Breccia with clasts of dolostone and baseline

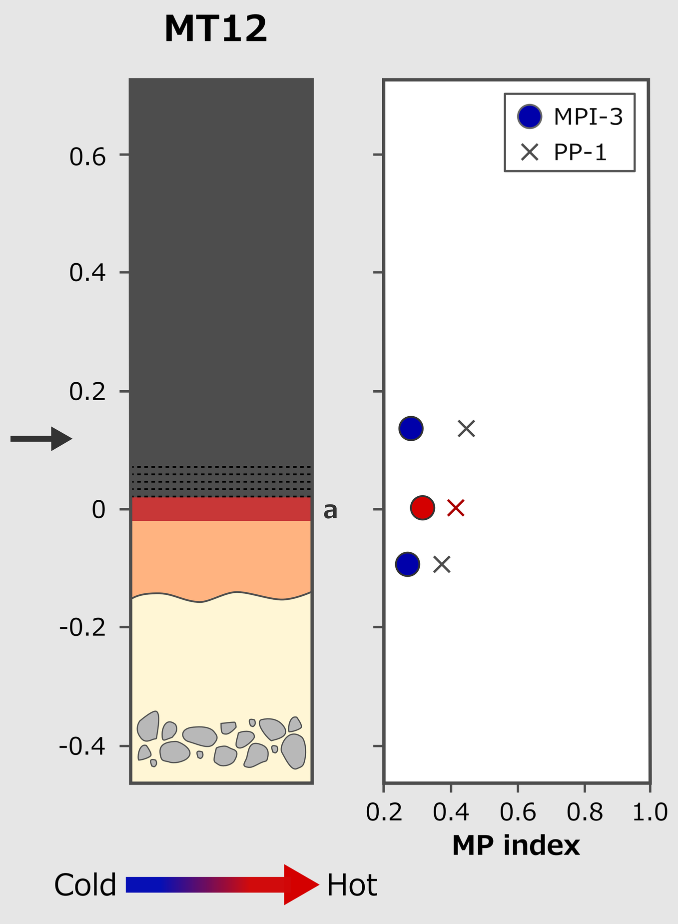








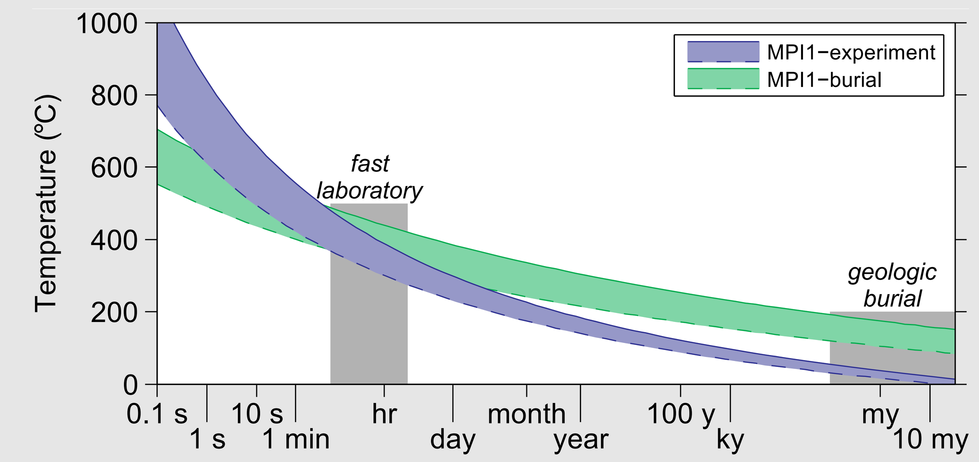




A clear heating signal is observed in transects MT10 and MT12. Transects 7 and 9 do not have a clear heating signal within the PSZ, but we see possible evidence of temperature rise just below the PSZ in MT9

Quantifying temperature along the fault:

The relationship between biomarker maturity and temperature was established from studies in the petroleum industry, where it was applied to long-duration, burial heating of biomarkers. The time and temperature dependence of MP reaction allows us to apply similar techniques on short duration, earthquake heating timescales.



Sheppard et al., 2015

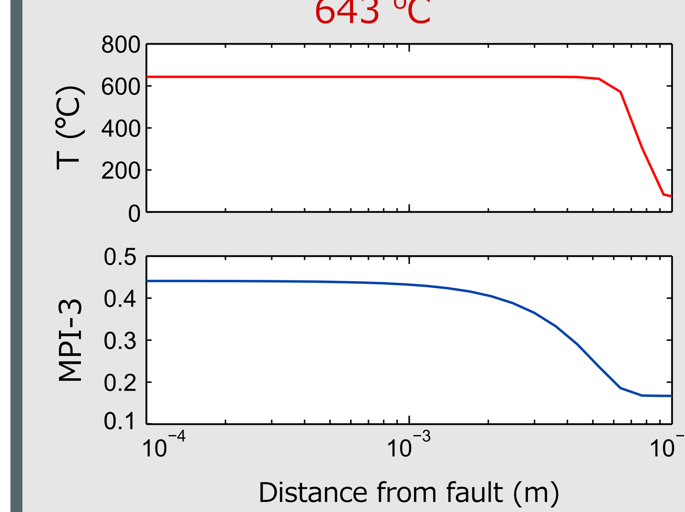
MP thermal maturity follows an Arrhenius relationship with temperature we use this in combination with the instantaneous temperature rise equation from *Lachenbruch (1986)* coupled with heat diffusion according to *Carlslaw and Jaegar (1959)* to create a forward model for temperature rise.

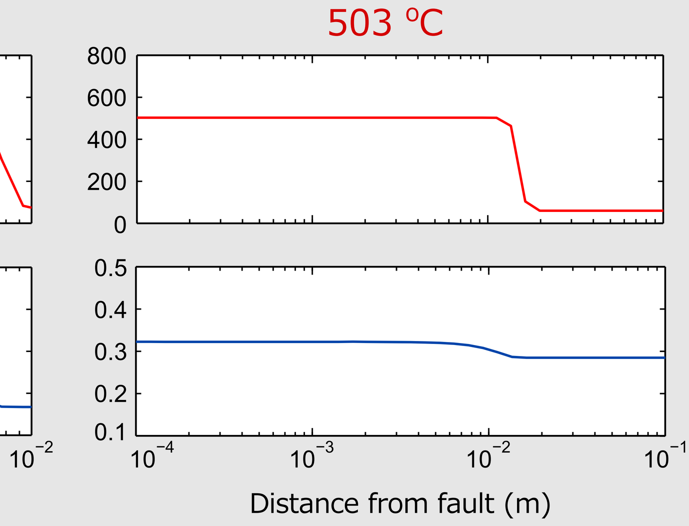
$$\theta = \frac{1}{2}\frac{\tau}{\rho c}\frac{u}{a}\left[1-4^{i}2\,\mathrm{erfc}\,\frac{a}{\sqrt{4\alpha t}}\right]$$

Lachenburch, 1986

Where θ is the temperature in space and time, τ is shear stress, ρ is density, **c** is heat capacity, **u** is slip distance and **a** is fault half-width. We assume a slip velocity of 1 ms^{-1} and a density of 2,000 kgm^{-3}, then vary shear stress to produce the observed MPI-3 values.

MT10	MT12
Fault width: 1.5 cm	Fault width: 3 cm
Max temperature rise: 643 °C	Max temperature rise: 503 °C





Conclusions:

- Half our transects show a clear temperature signal, while half do not
- This could reflect from stress heterogeneity on the meter scale, a lithological influence on MPI-3, or low methylphenanthrene concentrains
- Future work will explore the relationship between MPI-3 and lithology, as well as how mixing lithologies in the shear zone affects MPI-3

References: Sheppard, R. E., Polissar, P. J., & Savage, H. M. (2015). Organic thermal maturity as a proxy for frictional fault heating: Experimental constraints on methylphenanthrene kinetics at earthquake timescales. Geochimica et Cosmochimica Acta, 151, 103-116; Brock, W. G., & Engelder, T. (1977). Deformation associated with the movement of the Muddy Mountain overthrust in the Buffington window, southeastern Nevada. Geological Society of America Bulletin, 88(11), 1667-1677. Lachenbruch, A. H. (1986). Simple models for the estimation and measurement of frictional heating

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