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Frictional melting during seismic rupture? A new Raman Spectroscopy approach to detect short-lived heat pulses

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Whether seismic rupture propagates over large distances to generate earthquakes or on the contrary slows down quickly, is heavily dependent on the slip processes operating within the fault core. One possible scenario is that during seismic slip, the frictional work induces a local and transient release of heat up to reach the melting of the rock. This melt-lubrication of the fault plane results in resistance drop and promotes further propagation of the fault. Nonetheless, assessing the occurrence of flash melting has turned problematic, especially in the metasediments that constitute a large fraction of seismically active collision or subduction zones.

In this work, we explore the effects of short-lived intense heating on the crystallinity of the carbonaceous particles present in the fault core. For this purpose, we carried out flash-heating experiments on pellets of natural sediments. Using a pair of lasers, the sample temperature was raised to 1400°C for durations ranging from 0.5 to 60 seconds, resulting in partial to total melting. The carbonaceous particles were then analyzed by Raman Spectroscopy. The spectroscopic signal of particles intensely heated for a short period of time present an atypical shape, with a large D_3 band centered around 1500cm^{-1}. The $D_3/G_{sl.}$ ratio in Flash-heating experiments show an evolution from 0.2 for the starting material up to 0.7 after a couple of seconds of Flash-heating. Following this experimental work, we analyzed with Raman spectroscopy several independent examples of short-lived intense heating of carbon-bearing rocks: static heating, stick-slip, high-velocity-friction experiments, In all these cases, we observed the presence of a prominent D_3 band and a $D_3/G_{sl.}$ ratio larger than reference material. Based on these observations, we established a new parameter, the $D_3/G_{sl.}$ ratio, as sensitive to short-lived intense heating.

Finally, we applied this new Raman parameter in association with micro-structural observations to discriminate the formation process of five Black Fault Rocks (BFR) from the Shimanto and the Kodiak Accretionary Complex. Microstructures are in several cases ambiguous as to the occurrence of melting in the BFR. However, the $D_3/G_{sl.}$ ratio shows a large increase in the Kure and the Mugi BFR while the values are close to 0.2 in the host-rock. In contrast, Nobeoka, Okitsu and Kodiak BFR show similar values in comparing the BFR veins and the host-rocks. Accordingly, the Mugi and Kure BFR are associated with a molten origin when the three others BFR are the result of mechanical wear solely, without evidence for large temperature increase.

In summary, the $D_3/G_{sl.}$ ratio is a parameter that can be easily retrieved in most fault rocks cutting across sediments and that efficiently tracks the occurrence of short-lived intense heating. The use of this parameter appears as a promising approach to decipher the dynamics of faulting and to discriminate faults with intense frictional work from faults where temperature increase was much more limited, either because of slow creep or inhibiting processes (e.g. fluid vaporization during slip).