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A new fault-thermometer based on vitrinite maturation by frictional heat

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To detect frictional heating effects along faults provides key insight into the dynamics of earthquakes and faulting [e.g., Brodsky et al., 2010]. Evidence of substantial frictional heating along a fault is also a reliable indicator determining whether a fault has slipped at high velocity in the past, which is crucial for assessing earthquake and tsunami hazard. The vitrinite reflectance (R_o) measurement has been considered a possible thermometer of fault zones, especially in accretionary wedges where vitrinite fragments are common [e.g., Sakaguchi et al., 2011]. Under normal burial conditions, vitrinite reflectance (R_o) increases by irreversible maturation reaction as temperature is elevated and thus sensitively records the maximum temperature to which the vitrinite is subjected. However, the commonly used kinetic models of vitrinite maturation [e.g., Sweeney and Burnham, 1990] may not yield accurate estimates of the peak temperature in a fault zone resulting from fast frictional heating rates [Kitamura et al., 2012; Fulton and Harris, 2012]. Thus, we performed high-velocity friction experiments aimed at revealing coal maturation by frictional heat generated at slip velocities representative of natural earthquakes up to 1.3 m/s. Our previous results [Kitamura et al., 2012] show that coal can mature in typical earthquake rise time (e.g., ˜10 seconds), and herein we indicates R_o increases exponentially with peak temperature exponentially.

Using the correlation between R_o and temperature rises we estimate the dynamic friction during coseismic faulting in two natural fault zones : one is a fault in the Shimanto accretionary prism and another is a megasplay fault in the Nankai trough. The fault zone in the Shimanto accretionary prism has a very narrow shear localized zone with ˜8 mm thickness. An average R_o of vitrinite grains in host rocks is ˜1.2% which corresponds to a maximum burial temperature of about 180^{o}C using the geothermometer by Sweeney and Burnham (1990). In contrast, R_o values in the localized zone ranges between 1.7 to 5.6%. The high R_o corresponds to ˜630^{o}C using our new thermometer. We estimate the dynamic shear stress of 0.79 MPa (that corresponds to 0.01 in friction coefficient) from the observed heat anomaly, assuming the fault movement of displacement at maximum burial depth of ˜6 km (˜76 MPa effective normal stress). We also apply this way to the heat anomaly detected by vitrinite reflectance in the shallow portions of the megasplay fault [Sakaguchi et al., 2011]. R_o anomaly across the fault zone is about 0.6% that corresponds to temperature rise of 170^{o}C using our fault thermometer. This temperature anomaly can be explained by dynamic shear stress of 0.53 MPa (dynamic friction of ˜0.18), assuming fault displacement of 15 m at the current depth conditions. These results are consistent with the estimate of dynamic friction from temperature measurement across the fault zone after the 1999 Chi-Chi, Taiwan earthquake [e.g., Kano et al., 2006] and with the result of high-velocity friction experiments [e.g., Di Toro et al., 2011]. The fault-thermometer based on coal maturation can be a possible tool to estimate of fault parameters from natural fault zones.

Keywords: fault, frictional heating, vitrinite reflectance, carbonaceous matter, Earthquake