Importance of initial maturity and reaction kinetics on maturation of carbonaceous material and its implications for thermal maturity as a proxy for temperature in estimation of coseismic slip parameters

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Most of total seismic energy during earthquake slip is considered to convert into frictional heat, which activates many physicochemical reactions in faults. Various thermal indicators for detecting frictional heat recorded in fault rocks have been suggested, such as formation of pseudotachylyte and thermal transformation of fault-forming minerals. Among these reactions, thermal maturation of carbonaceous materials (CM) has been received a considerable attention, because CM changes its maturity in response to ambient temperature even with short-term heating duration.

On the basis of these backgrounds, CM maturity has been applied to estimate maximum temperature and coseismic slip parameters experienced by various faults during earthquakes (e.g., Hirono et al., 2015; Kaneki et a., 2016). These studies, however, may contain several concerns when evaluating amount of frictional heat from CM maturity: (1) mechanochemical effect, (2) kinetic effect of heating rate, (3) effect of initial maturity, and (4) cumulative effect of repeated earthquakes. Recently, Kaneki et al. (2018) and Kaneki and Hirono (2018) experimentally investigated the impacts of (1) and (2), and suggested that kinetic effects of both shear-induced mechanochemistry and heating rate can strongly dominate maturation process of CM, indicating that such kinetic effects should be considered to establish CM as a more rigorous fault geo-thermometer. However, the impacts of (3) and (4) on CM maturation process still remain unknown, leading to uncertainties in estimation of maximum temperatures from CM maturity.

In this study, we aim to understand the impact of (3) on CM maturation process and its implication for CM-based fault geo-thermometer. We adopted four grades of CM for our starting materials (lignite, bituminous coal, anthracite, and graphite), and performed low-velocity friction experiments with slip rate of 1 mm $s^{-1}$and normal stresses of 1 and 3 MPa under dry condition, to reproduce coseismic shear damage on CM samples without frictional heating. We then conducted heating experiments on both intact and sheared CM samples with targeted temperatures of 100, 200, 300, ..., 1300 °C (100 °C interval) and heating rates of approximately 1 and several hundreds of °C s^{-1}. We finally carried out infrared and Raman spectroscopies to evaluate maturity of both intact CM samples and products after friction and heating experiments. The results show that mechanochemical effect can enhance maturation process of lignite by ~100 °C whereas no significant difference between maturities of intact and sheared CM samples are present in bituminous coal, anthracite, and graphite. All CM samples, except for graphite that showed no significant change in maturity with heating, show higher reaction temperature by ~500 °C in heating experiments with higher heating rate. These results indicate that kinetic effects of both mechanochemistry and heating rate affect CM maturation process and the effects depends on initial maturity of CM. Thus, by taking consideration into initial maturity and kinetic effects, thermal maturation of CM could be an universal proxy for temperature in estimation of coseismic slip parameters.

Keywords: Earthquake, Carbonaceous material, Frictional heat, Initial maturity, Chemical kinetics

