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Slow and rapid response: The temperature memory of smectite in JFAST's Tohoku earthquake core samples (Japan)

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The ability of clay minerals to absorb and retain interlayer water during large slip events can be limited because of locally high frictional heating temperatures. Core samples from JFAST (Japan Trench Fast Drilling Project) Expedition 343 provide a unique opportunity to characterize smectitic clay minerals in fault rocks of an active plate-boundary fault that produced a displacement of ∼50 meters during the Tohoku earthquake of 2011.
Smectite is abundant in the fault zone identified at 820 mbsf. Chemical compositions analyzed by ICP-OES show a significant amount of Fe, and lesser Mg and K. In order to analyze the swelling capacity of smectite during slow and rapid temperature changes, we heated and cooled samples in steps of 25 °C from 25 to 225 °C at different rates, using a temperature stage and humidity chamber attached to an X-ray diffractometer. Rapid heating is represented by 5 min and slow heating by 5 hours for each sample. Cooling back to ∼25 °C was achieved within 15-40 min, depending on the maximum heating temperature.
X-ray analyses of randomly-oriented and oriented samples were conducted on air-dried and glycolated samples. Illite and smectite are the most abundant clay mineral types detected. Mineralogic characterization of illite shows 1Md and 2M1 polytypes, with authigenically formed 1Md slightly more abundant in the finer grained material. Clay size fractions 0.05 - 0.5 microns show pure smectite with a characteristic interlayer distance of 1.2 nm that increases to 1.7 nm after ethylene glycolization, indicating up to 3 water layers. Based on slow and rapid heating and cooling experiments of these samples, we observe that (i) both slow and fast heating causes similar reduction of water layers in smectite, (ii) smectite recovers faster to the original hydration state after quick heating than slow heating, and (iii) non-recoverable collapse of all smectite occurs at temperatures > 200 °C, regardless of the heating rate. Based on these results, we conclude that frictional heating cannot exceed a temperature of 200 °C when smectitic clays are present in these fault rocks, but that high frictional heating may be restricted to very thin and highly localized slip zones. With water available at depth and temperatures less than 200 °C, swelling properties of smectite-rich fault rock are preserved. The occurrence here indicates that broad shear heating at the sampled site of the Tohoku earthquake was relatively low.