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Natural and Experimental Seismic Slip on Clay Gouge: In the Case of the Taiwan Chelungpu Fault Drilling Project

Li-Wei Kuo[1,2], Thi Trinh Nguyen[1], Szu-Ting Kuo[1], and Wen-Jie Wu[3]

[1] Department of Earth Sciences, National Central University, Taiwan

[2] Earthquake-Disaster & Risk Evaluation and Management Center, National Central University, Taiwan

[3] Department of Geology, Chinese Culture University, Taiwan

Catastrophic events such as earthquakes, tsunamis, and landslides are often associated with large coseismic slip localized to relatively thin slip zones. During seismic slip, the accumulated frictional heat tends to drive thermally activated physical and chemical processes within the slip zone. At shallow crustal depths, water-saturated clay-rich gouges are common components of fault slip zones. Therefore, recognition of slip zone within clay-bearing fault zone and understanding its strength and frictional behavior, and the associated thermally triggering mechanisms, are critical to earthquake physics and seismic hazard assessment.

The Chelungpu fault ruptured northward along a segment of approximately 90 km due to the 1999 Mw 7.6 Chi-Chi earthquake. Subsequently, the Taiwan Chelungpu Fault Drilling Project (TCDP) was initiated to investigate and penetrate the active fault zone. Through the integration of mineralogical, microstructural, chemical, and magnetic evidence, the principal slip zones (PSZ) in the TCDP-A and TCDP-B boreholes were identified (Ma et al., 2006; Ishikawa et al., 2008; Boullier et al., 2009; Kuo et al, 2009; Chou et al., 2012). These zones exhibited evidence of both frictional melting (up to 1000˚C) and thermal pressurization (< 300˚C) of clay gouges from the 1999 Chi-Chi earthquake (Boullier t al., 2009; Kuo et al., 2011).

In order to understand the mechanisms that triggered these phenomena within the slip zone, rotary shear rock friction experiments were conducted on water-saturated TCDP fault gouges at depths corresponding to expected seismic slip depths. The experiments involved shearing the gouges at 1 m/s with a normal stress of 10 MPa under various conditions including fluid-drained, fluid-undrained, and pore-pressure controlled conditions. The results indicated dynamic weakening behaviors in all conditions, albeit with differing peaks and steady-state values of the friction coefficient.

Following the experimental seismic slip on the TCDP gouges, it was observed that frictional melting of gouges could occur after the cessation of thermal pressurization in fluid-drained experiments, similar to the characteristics of the PSZ in TCDP-A. This was attributed to the water's ability to absorb frictional heat, indicating that water deficiency in the PSZ caused an increase in temperature leading to gouge melting. Conversely, in fluid-undrained experiments, thermal pressurization was triggered and sustained until the end of the experiment, resulting in gouge fluidization resembling the PSZ of TCDP-B.

The study concluded that the dynamic weakening of fault gouges during the 1999 Chi-Chi earthquake was mainly caused by thermal pressurization. Furthermore, it suggested that spatial hydraulic variations along fault zones can contribute to different physical and chemical reactions and associated coseismic effects following a seismic event.

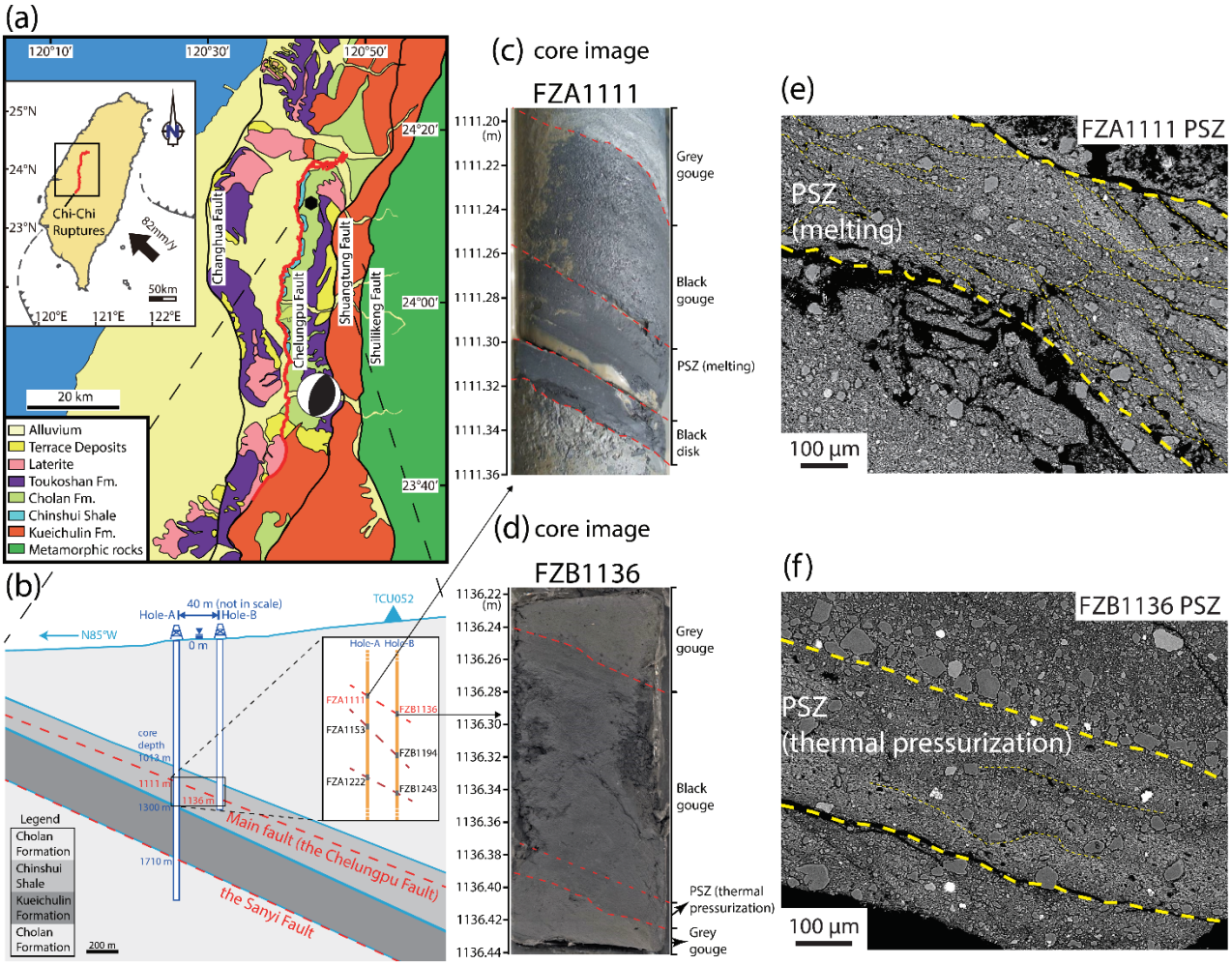

Figure 1. Geological setting, TCDP sites, PSZs recognized in two boreholes and the associated microstructures.

REFERENCES

Boullier, A.-M., Yeh, E.-C., Boutareaud, S., Song, S.-R., & Tsai, C.-H. (2009). Microscale anatomy of the 1999 Chi-Chi earthquake fault zone. *Geochemistry, Geophysics, Geosystems*, *10*(3), Q03016. https://doi.org/10.1029/2008gc002252

Chou, Y.-M., Song, S.-R., Aubourg, C., Lee, T.-Q., Boullier, A.-M., Song, Y.-F., Yeh, E.-C., Kuo, L.-W., & Wang, C.-Y. (2012). An earthquake slip zone is a magnetic recorder. *Geology*, *40*(6), 551–554. https://doi.org/10.1130/g32864.1

Ishikawa, T., Tanimizu, M., Nagaishi, K., Matsuoka, J., Tadai, O., Sakaguchi, M., Hirono, T., Mishima, T., Tanikawa, W., Lin, W., Kikuta, H., Soh, W., & Song, S.-R. (2008). Coseismic fluid–rock interactions at high temperatures in the Chelungpu fault. *Nature Geoscience*, *1*(10), 679–683.

https://doi.org/10.1038/ngeo308

Kuo, L.-W., Song, S.-R., Yeh, E.-C., & Chen, H.-F. (2009). Clay mineral anomalies in the fault zone of the Chelungpu Fault, Taiwan, and their implications. *Geophysical Research Letters*, *36*(18), L18306. https://doi.org/10.1029/2009gl039269

Kuo, L.-W., Song, S.-R., Huang, L., Yeh, E.-C., & Chen, H.-F. (2011). Temperature estimates of coseismic heating in clay-rich fault gouges, the Chelungpu fault zones, Taiwan. *Tectonophysics*, *502*(3–4), 315–327. https://doi.org/10.1016/j.tecto.2011.02.001

Ma, K.-F., Tanaka, H., Song, S.-R., Wang, C.-Y., Hung, J.-H., Tsai, Y.-B., Mori, J., Song, Y.-F., Yeh, E.-C., Soh, W., Sone, H., Kuo, L.-W., & Wu, H.-Y. (2006). Slip zone and energetics of a large earthquake from the Taiwan Chelungpu-fault Drilling Project. *Nature*, *444*(7118), 473–476. https://doi.org/10.1038/nature05253