What should we look for at Hikurangi in light of our findings in the Japan Trench?

Virginia Toy [1], Patrick Fulton[2], Matt Ikari[3], Expedition 343 Scientists[4]

[1] Dept. of Geology, Univ. Otago, Dunedin, New Zealand; [2] Dept. of Earth and Planetary Sciences, Univ. California Santa Cruz, CA, USA; [3]MARUM, Center for Marine Environmental Sciences, Univ. Bremen, Germany; [4] Please refer to Chester et al., 2012 for these affiliations.

virginia.toy@otago.ac.nz

IODP Expedition 343 (the Japan Trench Fast Drilling Project, JFAST) successfully sampled the Tohoku subduction thrust shear zone, as well as folded and faulted Miocene sediments of the hanging wall sediment prism, and underthrust sub-horizontally bedded, comparatively undeformed, Cretaceous siliceous muds and cherts of the Pacific Plate (Chester et al., 2012). Comprehensive downhole and 'logging while drilling' (LWD) geophysical data were also collected across the plate boundary interface (e.g. Lin et al., 2013). Associated geophysical surveys provided high quality seismic images of the subsurface (Nakamura et al., 2013) and bathymetric data both before and after the 2011 M_w9.0 rupture, confirming a larger than expected horizontal displacement of the seafloor (>50m) that contributed to the devastating tsunami (Fujiwara et al., 2011). A subsurface temperature observatory was installed to measure possible thermal anomalies resulting from frictional heating on the fault (Fulton et al., 2013).

Physical properties and fluid chemistry were measured aboard the ship (Chester et al., 2012), and the recovered material has since been subjected to studies of frictional and hydrologic properties (Ikari et al., 2013, Hirose et al., 2013, Tanikawa et al., 2013; Ujiie et al., in prep.), composition, thermal history (Savage et al., 2012), macro- and microscale fabric (Chester et al., submitted; Dresen et al., 2012; Kirkpatrick et al., 2013; Rowe et al., in prep; Toy et al., 2012), clay mineralogy (Kameda et al., 2013), and magnetic properties (Mishima et al., 2013)
The plate boundary interface comprises smectite-rich (Kameda et al., 2013) 'scaly' clays, likely derived from incoming Pacific Plate pelagic sediments (Chester et al., submitted). These clays have low frictional strength, velocity-weakening tendencies at low shearing velocities (Ikari et al., 2013), and particularly low peak (pre-yield) strength at intermediate to high shearing velocities (Hirose et al., 2013). Velocity-strengthening behavior is typical at intermediate and high shearing velocities, as is a tendency to thermally pressurize (Ujiie et al., in prep.).

Borehole breakouts (Lin et al., 2013) and changes of focal mechanisms of aftershocks along with a number of normal faulting events in the hanging wall accretionary prism (Hasegawa et al., 2011) suggest near total stress drop at shallow depths during the 2011 earthquake (i.e. seismic efficiency approaching 100%, as opposed to expected efficiency of typical earthquakes on the order of <10%; McGarr et al., 1999). Thus, the subduction thrust probably behaved as per models of Noda & Lapusta (2013), where a particularly energetic rupture that initiated at seismogenic depths on the subduction thrust propagated into the shallow region where, despite a tendency toward velocity-strengthening behavior, low frictional strength and dynamic weakening mechanisms facilitated very large slip to the trench. ***Could the Hikurangi subduction zone generate similar larger-than-expected tsunami?*** We suggest that large shallow slip resulting in large tsunami may be possible if the shallow fault zone materials have mineralogy, structure, and hydrologic properties comparable to Tohoku (ie. are smectite-rich, low permeability and prone to dynamic weakening), as then low frictional strength at seismic slip velocities (~1 m/s) is likely. Measurement of frictional properties, and examination of structural records would lend more certainty to any predictions regarding the zone's behaviour. Abundant smectites are particularly likely at Hikurangi because of volcanic sediment input from the adjacent Taupo Volcanic Zone. Analysis of geologic signatures of heating within fault zone cores may also provide insight into the potential for large slip at shallow depths (Sakaguchi et al., 2011; Fulton and Harris, 2012). Furthermore, it is important to record the subsurface structure and bathymetry in order to clearly document any changes during future events. Equally important are pre-failure records of the in situ stress state, and monitoring of thermal and hydrologic conditions. In order to obtain these data, we need to drill into the Hikurangi subduction interface and the incoming plate sedimentary sequence at the earliest opportunity. We should also be prepared to mobilize in a rapid-response project similar to JFAST to examine changes in these parameters (particularly the stress state) after any future event, providing both greater understanding of the Hikurangi Margin, and enhancing our ability to predict seismic behaviour of other circum-Pacific subduction thrusts.

References:

Chester, F., Rowe, C., Ujiie, K., Moore, J.C., Kirkpatrick, J., Regalla, C., Remitti, F., Toy, V.,Wolfson-Schwher, M., Bose, S., Kameda, J., Mori, J., Brodsky, E., Eguchi, N., Toczko, S., and Exp. 343 and 343T Scientists. Submitted. Highly localized plate boundary thrust in the region of 50 m coseismic slip, M9.1 Tohoku-oki earthquake, 2011. Nature.

Chester, F., Mori, J., Toczko, S., Eguchi, N., and Exp. 343/343T Scientists. 2012. Japan Trench Fast Drilling Project (JFAST). IODP Preliminary Report, 343/343T. doi: 10.2044/iodp.pr.343343T.2012.

Dresen, G.H., Janssen, C., Wirth, R., Naumann, R., Morales, L.F.G., Toy, V.G., and Exp. 343 Scientists, 2012. Micro- and nanostructures of J-FAST 343 core samples – first results. 2012 Fall Meeting, AGU, San Francisco, CA.

Fujiwara, T. et al. 2011. The 2011 Tohoku-Oki Earthquake: Displacement Reaching the Trench Axis. Science 334, 1240 .

Fulton, P., Brodsky, E., Kano, Y., Mori, J., Chester, F., Kyo, M., Namba, Y., Eguchi, N., Toczko, S., Ito, Y. and Exp. 343 Scientists. 2013. The JFAST Fault Zone Observatory: Monitoring the frictional heat from the 2011 Tohoku Earthquake. Japan Geoscience Union (JpGU) Meeting, May 19-24, Chiba, Japan.

Fulton, P.M. and R.N. Harris (2012), Thermal considerations in inferring frictional heating from vitrinite reflectance and implications for estimates of shallow coseismic slip within the Nankai Subduction Zone, Earth Planet. Sci. Lett., 335–336, 206–215, 10.1016/j.epsl.2012.04.012.

Hasegawa, A., K. Yoshida, T. Okada. 2011. Nearly complete stress drop in the 2011 Mw9.0 off the Pacific coast of Tohoku earthquake, Earth, Planets and Space, 63-67, doi:10.5047/eps.2011,06.007.

Hirose, T., Tanikawa, W., Mukoyoshi, H., Tadai, O., Lin, W., Exp. 343 Science Party. 2013. Extreme Low Friction of the Tohoku Plate Boundary as a possible factor for seismic slip propagation toward the trench. JpGU Meeting, May 19-24, Chiba, Japan.

Ikari, M., Kameda, J., Kopf, A., Saffer, D., Marone, C., Exp. 343 Science Party. 2013. Frictional behavior of the plate boundary décollement zone in the Japan Trench, sampled during the Japan Trench Fast Drilling Project (JFAST). EGU Meeting, 7-12 April, Vienna, Austria.

Kameda, J., Ujiie, K., Hirose, T., Ikari, M. Remitti, F., Shimizu, M., Hamada, Y., Kimura, G., Chester, F., Mori, J. Eguchi, N. Toczko, S. 343 Exp. Scientists. 2013. Clay mineral characteristics of the plate-boundary fault at the Japan Trench. JpGU Meeting, May 19-24, Chiba, Japan.

Kirkpatrick, J., Rowe, C., Ujiie, K., Regalla, C., Remitti, F., Toy, V., Wolfson-Schwehr, F., Bose, S., Kameda,J., Moore,J.C., Chester, F., Exp. 343 and 343T Scientists. 2013. Structure and composition of the plate boundary décollement in the area of maximum slip during the 2011 Tohoku-Oki earthquake. JpGU Meeting, May 19-24, Chiba, Japan.

Lin, W., Conin, M., Moore, J.C., Chester, F.M., Nakamura, Y., Mori, J.J., Anderson, L., Brodsky, E., Eguchi, N., Exp. 343 Scientists (2013), Stress state in the largest displacement area of the 2011 Tohoku-Oki earthquake. Science 339 (6120), 687-690. doi: 10.1126/science.1229397.

McGarr, A., 1999. On relating apparent stress to the stress causing earthquake fault slip. J. Geophys. Res. 104 (B2), 3003–3012. doi:10.1029/1998JB900083.

Mishima, T., Yang, T., Mori, J., Chester, F., Eguchi, N., Toczko, S., Exp.343 Scientists. 2013. Rock-magnetic properties of the plate-boundary thrust material drilled during IODP Exp. 343 (JFAST). JpGU Meeting, May 19-24, Chiba, Japan.

Nakamura, Y., Kodaira, S., Miura, S., Regalla, C., Takahashi, Y., Obana, K.,Fujie, K., Cook, B., Conin, M., Chester, F., Mori, J., Eguchi, N., Toczko, S., Exp. 343 Scientists. 2013. Seismic imaging in the Japan Trench axis area off Miyagi, northeastern Japan. JpGU Meeting, May 19-24, Chiba, Japan.

Noda, H., Lapusta, N. 2013. Stable creeping fault segments can become destructive as a result of dynamic weakening. Nature. doi: 10.1038/nature11703.

Rowe, C., Moores, J.C., Remitti, F., Exp. 343 Scientists, in prep. The thickness of subduction plate boundary faults from the seafloor into the seismogenic zone.

Sakaguchi, A., F. Chester, D. Curewitz, O. Fabbri, D. Goldsby, G. Kimura, C.-F. Li, Y. Masaki, E. J. Screaton, A. Tsutsumi, K. Ujiie, and A. Yamaguchi, 2011, Seismic slip propagation to the updip end of plate boundary subduction interface faults: Vitrinite reflectance geothermometry on Integrated Ocean Drilling Program NanTroSEIZE cores, Geology, 39, 395–398, doi:10.1130/G31642.1.

Savage, H. Polissar, P., Sheppard, R., Rowe, C., Kirkpatrick, J., Exp. 343 Scientists. 2012. Evidence for frictional heating of the decollement in drillcores from Exp. 343: JFAST. 2012 Fall Meeting, AGU, San Francisco, CA

Tanikawa,W.,Hirose,T., Lin,W. and IODP Exp. 343 Scientists. 2013. Fluid transport properties of sediments near the plate boundary fault at Japan Trench. JpGU Meeting, May 19-24, Chiba, Japan.

Toy, V.G., Boulton, C.J., Barth, N.C., Carpenter, B., IODP Exp. 343 Scientists and IODP-MI, Goldsby, D., Kopf, A., Mitchell, T., Marone, C., Sutherland, R., Townend, J., Tullis, T. What can microstructural observations of natural faults tell us about the dissipative mechanisms that operated at the earthquake source? ECGS Workshop: Earthquake Source Physics on Various Scales, Luxembourg, October 3-5.

Ujiie, K., Tanaka, H., Saito, T., Tsutsumi, A., Mori, J., Kameda, J., Chester, F., Eguchi, N., Toczko, S., and Exp. 343 scientists. In preparation. Large slip on a shallow plate-boundary thrust promoted by low co-seismic shear strength.