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Tohoku rupture reloaded?

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To the Editor

Tormann *et al*.[1] evaluate changes in the *b*-value, a measure of the relative abundance of small and large earthquakes, as a function of space and time in northeast Japan. Near the high-slip zone of the 2011 magnitude 9 Tohoku-oki rupture, they document a sudden increase in the *b*-value at the time of the earthquake and its return to about 77% of its average 1998–2003 value within about two years. Assuming that the *b*-value is negatively correlated with differential stress[2], they infer that the stress relieved by the earthquake has very rapidly recovered to levels found before the earthquake. Consequently, the authors propose that megathrust earthquake occurrences follow a Poisson process and are effectively random in time. However, we argue that the hazard of a great tsunami-producing earthquake in this section of the Japan megathrust zone is unlikely to already be almost as high as it was just before the 2011 event. Instead, many centuries of stress accumulation are required to rebuild stress and produce another great event.

Prior to the earthquake, the seismicity in northeast Japan was predominantly contractional and involved reverse faults (Fig. 1a, c). Since the Tohoku-oki earthquake, there have been few reverse events near the high-slip zone of the rupture (Fig. 1b, d) and aftershocks primarily occurred as extensional (normal faulting) events in both the overriding and down-going plates of the subduction zone. The dominance of normal faulting suggests that the stress drop during the mainshock was large enough, relative to the background stress, to reverse the style of faulting near the high-slip zone[3,4]. Because events with different faulting types in northeast Japan have different *b*-values (Supplementary Information), we suggest that the observed coseismic rise and postseismic decay of *b*-values (Fig. 1f) partly reflect the fact that Tormann and colleagues sampled event populations with different mechanisms and from different source volumes in the subduction zone (Fig. 1e).

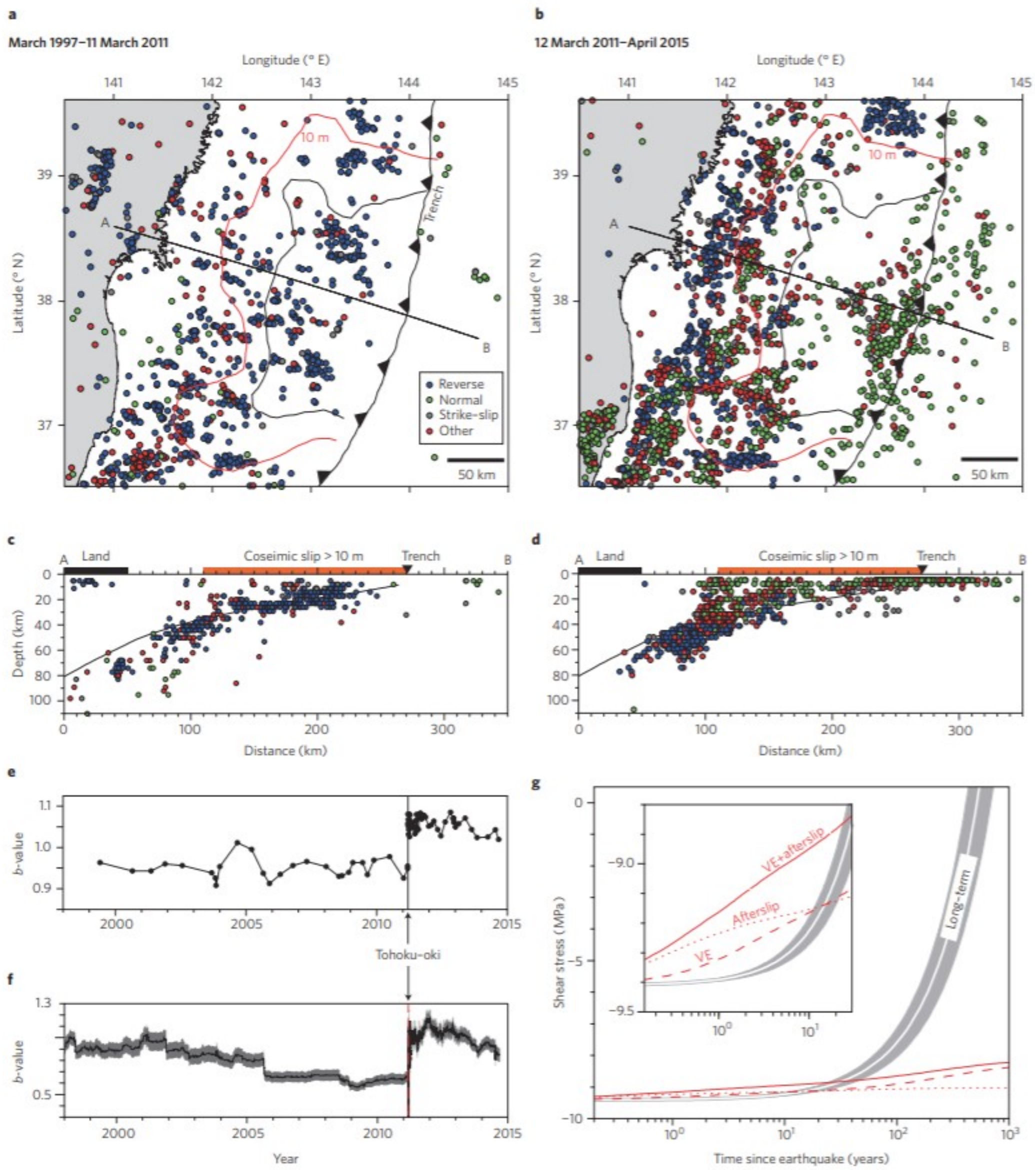

Figure 1: Distribution of focal mechanisms, time series of the *b*-value and modelled stress changes. a,b, The distribution of F-net seismic catalogue focal mechanisms from before (**a**) and after (**b**) the Tohoku-oki earthquake. The red line shows the 10 m slip contour6. **c,d**, Events shown along 200 km-wide cross-sections. Black lines indicate the top of the subducting plate. **e**, Time series of the *b*-value within the 10 m slip contour expected from the observed change in distribution of focal mechanisms (Supplementary Information). **f**, Observed time series of the *b*-value and its standard deviation (grey shading) within the 10 m slip contour. Image reproduced from ref. 1, NPG. **g**, Modelled time series of average coseismic, postseismic and interseismic shear stress within the high-slip zone. Inset shows the first thirty years. The modelled postseismic stress recovery (solid red line) includes contributions from viscoelastic relaxation (VE, dashed line) and afterslip (dotted line). Long-term stress increase (white line with grey shaded region reflecting range of assumed convergence rates) is due to steady plate convergence about the locked high-slip zone.

Tormann and colleagues argue that reloading of stress caused by rapid postseismic deformation processes, complemented by fault healing processes and stress-field homogenization, may quickly re-establish compressional stress levels to those found just before the earthquake.

However, although reloading of a megathrust rupture is indeed most rapid during the early period of postseismic relaxation, our models of stress recovery constrained by geodetic and seismicity data suggest that only a very small fraction of the approximately 10 MPa coseismic stress drop in the high-slip zone could have been recovered in the first three postseismic years. Even when considering the contributions from multiple sources of postseismic deformation[5], the average shear-stress changes near the high-slip zone only amount to less than 0.5 MPa within three years and approach 1 MPa after relaxation of coseismic stress perturbations more than two decades later (Fig. 1g). Completion of the transient relaxation together with loading from steady plate convergence allow for full shear-stress recovery within several hundred years (Supplementary Information).

In summary, we suggest that the temporal changes of *b*-values near the high-slip zone of the Tohoku-oki earthquake may reflect sampling of earthquakes from different volumes and fault populations in the subduction zone. Furthermore, postseismic relaxation processes are not capable of rapidly reloading the fault. Although the spatial and temporal variations of *b*-values are intriguing, it appears premature to assume *b*-values as a direct proxy for stress on the Japan subduction thrust and to argue for general randomness of megathrust earthquakes based on this observation.

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