

Evolution and progressive geomorphic manifestation of surface faulting: A comparison of the Wairau and Awatere faults, South Island, New Zealand

Brendan Duffy

School of Earth Sciences, The University of Melbourne, Parkville, Melbourne, Victoria 3010, Australia

Zinke et al. (2015) documented a flight of Saxton River terraces deformed by the Awatere fault, South Island, New Zealand. They concluded that the manifestation of off-fault deformation (OFD) is a cumulative effect, and therefore may not be immediately apparent on younger terraces, with implications for slip rate determinations. I argue that they did not adequately consider the detailed structural setting of elements of OFD within the Saxton River releasing bend on the Awatere fault. The surface deformation at Saxton River is probably controlled by the coincidence of terraces with structural zones within the bend, and I contest the authors' conclusion that off-plane deformation is simply hidden in younger terraces.

The influence of structural complexity on the width and geometry of OFD is well established (e.g., Milliner et al., 2015). Zinke et al.'s figure DR2 (in GSA Data Repository 2015341) shows that OFD along the Awatere fault occurs at bends or steps in the fault plane, including at Saxton River where the fault bends right relative to the main trace by 5–10°, ~50 m east of the T2-T3 riser. This gives rise to a graben (T1 tread) and two pressure ridges (T2 tread and bedrock spur) that define and bound an overall 150-m-wide releasing bend (Mason et al., 2006) (Figs. 1A and 1B). The paired pressure-ridge and graben geometry is predicted when the wall rocks on either side of a strike-slip fault approach and interact with a fault bend during an earthquake (Sibson, 1989), and has been reported on the Hope (Cowan, 1990) and Greendale (Duffy et al., 2013) faults in New Zealand, and the San Andreas fault in California (Ben-Zion et al., 2012), among others.

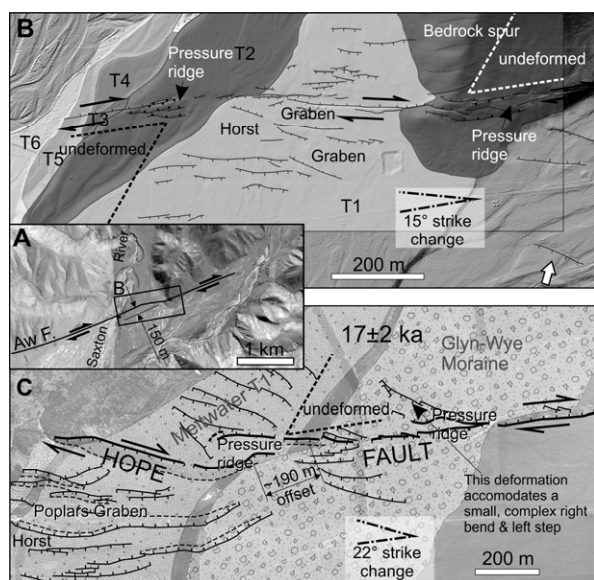


Figure 1. A: Setting of the Saxton River terraces, showing distinct releasing jog in the Awatere fault (Aw F). **B:** Terrace map after Zinke et al. (2015, their figures 2B and DR4). White arrow indicates OFD scarp not mentioned in paper. Ticks point in dip direction of scarp. Note apparently undeformed areas in the convex wall on either side of releasing bend. **C:** Poplars Graben on the Hope fault, redrawn from Cowan (1990). Note apparently undeformed zone in same structural position as on Awatere fault.

fault contracts as it moves west through a left bend (σ_3 vertical) at the T1-T2 riser. The fault crossing T4–6 is almost pure strike-slip (σ_2 vertical). Surface deformation in the 0- to 200-m-wide zone between all three local stress regimes is subtle/distributed because no single fault orientation is appropriate; pervasive fracturing probably occurs at depth (King and Nábělek, 1985) and manifests as distributed granular flow of gravels. The apparent lack of discrete deformation of the bedrock east of the spur on the north wall of the Awatere fault at the Saxton River site probably highlights a similar area, where the north wall of the fault approaches a left bend as it moves eastward out of the releasing bend.

An analogous situation occurs at Poplars Graben on the nearby Hope Fault (Fig. 1C), which deforms a 17 ka surface at a strike change of ~22° (Cowan, 1990). A similar, apparently undeformed, zone occurs in the same structural location on a 17 ka surface that has accumulated ~190 m of displacement. Given the exceptional preservation and expression of faulting at Poplars Graben, its marked similarity with the much younger Saxton River T2 suggests that subdued OFD at both sites relates to structural location relative to strike changes. This is supported by the >400 m width of OFD on young surfaces southeast of T1 (see trace [white arrow] in Fig. 1B).

The youngest Saxton River terraces have slipped further than the ~5 m of slip that produced spectacular OFD on an undeformed surface during rupture of the Greendale fault (Quigley et al., 2012). I suggest that structural control, rather than age, limits the manifestation of OFD at the Saxton River site. Slip rates on immature faults therefore need to be determined in cognizance of the detailed local structure and potential or otherwise for OFD arising from structural interaction between component secondary faults.

REFERENCES CITED

- Ben-Zion, Y., Rockwell, T. K., Shi, Z., and Xu, S., 2012, Reversed-polarity secondary deformation structures near fault stepovers: *Journal of Applied Mechanics*, v. 79, 031025, doi:10.1115/1.4006154.
- Cowan, H. A., 1990, Late Quaternary displacements on the Hope Fault at Glyn Wye, North Canterbury: *New Zealand Journal of Geology & Geophysics*, v. 33, p. 285–293.
- Duffy, B., Quigley, M.C., Barrell, D., Van Dissen, R., Stahl, T., Leprince, S., McInnes, C., and Bilderback, E., 2013, Fault kinematics and surface deformation across a releasing bend during the 2010 M_w 7.1 Darfield, New Zealand, earthquake revealed by differential LiDAR and cadastral surveying: *Geological Society of America Bulletin*, v. 125, p. 420–431, doi:10.1130/B30753.1.
- King, G., and Nábělek, J., 1985, Role of fault bends in the initiation and termination of earthquake rupture: *Science*, v. 228, p. 984–987, doi:10.1126/science.228.4702.984.
- Mason, D.P.M., Little, T.A., and Van Dissen, R.J., 2006, Rates of active faulting during late Quaternary fluvial terrace formation at Saxton River, Awatere fault, New Zealand: *Geological Society of America Bulletin*, v. 118, p. 1431–1446, doi:10.1130/B25961.1.
- Milliner, C.W.D., Dolan, J.F., Hollingsworth, J., Leprince, S., Ayoub, F., and Sammis, C.G., 2015, Quantifying near-field and off-fault deformation patterns of the 1992 M_w 7.3 Landers earthquake: *Geochemistry Geophysics Geosystems*, v. 16, p. 1577–1598, doi:10.1002/2014GC005693.
- Quigley, M.C., Van Dissen, R., Litchfield, N., Villamor, P., Duffy, B., Barrell, D., Furlong, K., Stahl, T., Bilderback, E., and Noble, D., 2012, Surface rupture during the 2010 M_w 7.1 Darfield (Canterbury) earthquake: Implications for fault rupture dynamics and seismic-hazard analysis: *Geology*, v. 40, p. 55–58, doi:10.1130/G32528.1.
- Sibson, R.H., 1989, Earthquake faulting as a structural process: *Journal of Structural Geology*, v. 11, p. 1–14, doi:10.1016/0191-8141(89)90032-1.
- Zinke, R., Dolan, J.F., Van Dissen, R., Grenader, J.R., Rhodes, E.J., McGuire, C.P., Langridge, R.M., Nicol, A., and Hatem, A.E., 2015, Evolution and progressive geomorphic manifestation of surface faulting: A comparison of the Wairau and Awatere Faults, South Island, New Zealand: *Geology*, v. 43, p. 1019–1022, doi:10.1130/G37065.1.