Geomorphic Deformation of a Small Glaciofluvial Basin by an Upstream-Facing Thrust Fault over Multiple Glacial Cycles

Rachel J. Comp[a,b]

[a] Skidmore College, Saratoga Springs, New York

[b] Frontiers Abroad, University of Canterbury, Christchurch, New Zealand

Abstract:

Geomorphic analysis of glaciofluvial basins containing thrust faults provides insight into the process of tectonic alteration of glaciofluvial sediment and terrace occupation, as observed in the Upper Hawkins Basin at Dalethorpe, Canterbury, New Zealand. Terraces created by glaciofluvial activity in the Upper Hawkins Basin as well as key geomorphic features such as landslides and fault scarps were mapped using DEM analysis. Relative heights and slopes of the terraces extracted from the DEM allowed for a moderate understanding of the relative displacement the terraces underwent during each stage of occupation. An inferred fault trace was mapped and the basin was divided into up-thrown and down-thrown sections. Three main sets of terraces were identified along with their corresponding subsets, as well as a potential fourth terrace. It was concluded that the Springfield Fault is no longer active even though a recurrence interval of roughly 6.36ka was obtained due to non-displaced radiocarbon sediments yielding an age of 25.44ka ± 0.175ka in a trench on Terrace A.

1- Introduction:

The behavior and slip rates of faults are important to know so that relatively accurate hazard assessments of the fault and its proximal area can be made. Land use planning and development also relies heavily on understanding fault behavior and what regions it may affect in certain ways. Many studies of faults have been undertaken in order to quantify slip rates by determining the age of geomorphic markers near the fault and the relative displacement of these markers. By knowing slip rates, interpretations can be made relating to the characteristics of active known and recently unknown faults so that precautionary actions can be taken in order to ensure the safety of those who may live in close proximity to the fault. The Canterbury Plains region is located in the central part of the South Island of New Zealand along the eastern side of the country. It is nestled amongst a plethora of active known and unknown faults, especially the major faults in the Porters Pass Fault Zone and the recently ruptured Greendale Fault. The immense M_w 7.1 Darfield Earthquake produced by the Greendale Fault relieved stress along the Greendale Fault and created a stress increase in the Porters Pass Fault Zone (Evans, 2000; Steacy et al., 2013). Knowing this, it is of utmost importance to understand how the faults in the Porters Pass Fault Zone will react to this distribution of increased stress.

The Springfield Fault is an ESE dipping thrust fault that is located within the Upper Hawkins glaciofluvial Basin located on a farm known as Dalethorpe. The fault lies within the increased stress region of the Canterbury Plains which was shown through Coulomb modeling (Evans, 2000; Duffy et al., 2007; Steacy et al., 2013). The fault is located in close proximity to the South Island's main city of Christchurch, and was recently classified as a seismic hazard with an estimated recurrence interval of 5,000 years (Stirling et al., 2007). Further research by Duffy (2008) produced a recurrence interval of $6{,}380 \pm 430$ years. Although the Springfield Fault was found to have a large recurrence interval it still is seen as an active hazard since it has been estimated to be active since the last glacial maximum, and is therefore an important fault to study and understand how it affects the surrounding area.

In this paper, we attempt to quantify slip rate over specific intervals for the Springfield Fault. Geomorphic markers are picked out, analyzed, and are given plausible ages. Displacement of the markers between their down-thrown and up-thrown counterparts are calculated, and their relatives slopes are derived, all using GIS analysis of an SRTM DEM of Dalethorpe. Using this data we estimate slip rates and a relative recurrence interval for the fault, and the potential seismic hazard of the Springfield Fault is reevaluated.

2- Geologic Setting:

The Upper Hawkins Basin is comprised of four main geologic deposits of varying compositions. The basement rock is known as the Rakaia Terrane torlesse rocks. These are overlain by the Broken River Formation, which lead to the discovery of the Springfield fault by Speight (1924) during the analysis of the coal beds in the formation. The View Hill Volcanics are emplaced on top of the Broken River Formation and are not very extensive. The glacial and fluvioglacial deposits are the Woodlands, Windwhistle, and Springston Formations. The Woodlands Formation was deposited after the Waimean Glaciation, the Windwhistle Formation after the Otiran Glaciation, and the Springston Formation was deposited during the reworking of the basin by the Hawkins River within the last 10,000 years. The oceanic isotope stages (OIS) for the Waimean Glaciation (OIS6) show a glacial period of 300,000-180,000 ya, and for the Otiran Glaciation (OIS1) it lasted from 70,000-18,000 ya (Turnbull, 2000). The Springfield Fault shows no surface rupture and therefore the fault trace has only been inferred based on the structure of geomorphic markers. The Springfield Fault is not the only fault located in close proximity to the town of Springfield. The Kowai Fault runs sub-parallel to the Springfield Fault, and is expected to intersect and even act in conjunction with the Springfield Fault, which is a noteworthy aspect when considering the increased stress in the area as modeled by Steacy (2013) (Evans, 2000).

3- Methods:

An SRTM DEM was derived using data retrieved from a quadcopter flown over the extent of the Upper Hawkins Basin at Dalethorpe. Once the DEM was processed to a working resolution a hill shade layer made at 10x amplification was made, as well as a half-meter aspect layer and slope layer. A Mylar map created by in-field analysis at Dalethorpe was then scanned and added as a layer on top of the base DEM. Using the Mylar, shape files were made in order to classify the different types of geomorphic markers seen such as terraces, swamps, and landslides. These features were color-coded and the terraces were named based on previous research and relative heights compared to one another. The use of Arcscene was especially helpful in this respect in order to analyze the terraces in 3D. Linear features were traced out and classified by color as well, such as major and minor terrace edges, major and minor streams/rivers, and syn/anti-clines. An inferred fault trace was drawn across the map based on previous data as well as the terrace distribution seen on the DEM. Height analysis of the terraces was done by drawing profiles across the DEM that ran approximately parallel to the fault trace. Heights were recorded and averaged for each terrace. Slope analysis was conducted by profiling the most well-preserved terraces and exporting the data to excel. Once this was graphed in a scatter plot, a trend line was added and the arctan of the slope of the trend line was found in order to get the degree of slope angle.

4- Results:

Radiocarbon dating of a clay layer within the strata of the down-thrown A Terrace recovered from a trench that was dug in conjunction with this research was found to be 25.44ka ± 0.175ka. Based on height data retrieved, average slip was estimated to be around 4m per event. According to the date retrieved from the radiocarbon samples in the clay on terrace A and the estimated number of events to have occurred during the occupation of terrace A, the recurrence interval for the trench was estimated to be ~6.36ka. Average heights of terraces, surface displacement as total uplift, and estimated number of events can be seen in Figure 1. The slope angles of the terraces are listed in Figure 2.

5- Discussion:

The number of events and the age of the clay layer for Terrace A suggest a recurrence interval of ~6.36ka, but it is a known fact that the fault has not ruptured within the last 25,000. A loess layer is seen on top of all of the terraces except for both A Terraces. This loess layer was dated by Duffy (2008) and showed an age of 22.7ka ± 3.23ka at the meeting point between the loess and a gravel layer. It was observed that the loess layer is not faulted or folded, and therefore shows that the fault has not moved in at least this amount of time. Since the fault has not ruptured since the LGM, the Springfield Fault can be classified as an inactive fault, and the recurrence interval calculated through this method of analysis is not valid. Based on slope analysis, a nice correlation of relatively equal slopes between each main and corresponding subset can be seen. This shows that the geomorphic alteration of the area caused by each tectonic event is in a vertical direction and no rotation or tilting of the terraces has occurred by fault activity.

It is important to note that the analysis of the glaciofluvial basin focused solely on how the fault may have altered the terrain, and did not include any analysis on how each glacial event may have contributed to the alteration of geomorphic markers. The heights and slopes calculated in this research were assumed to be created by fault activity alone. Terrace heights may be higher or lower than what they would be if the fault was the only source contributing to their alteration since glacial activity such as erosion or deposition could also have changed the terrace heights over time. This sort of glacial activity could be the reason why a recurrence interval suggesting an active fault may have been obtained. Further research needs to be executed to understand how the Waimean and Otiran glaciations have affected the Upper Hawkins Basin at Dalethorpe so more accurate assumptions and conclusions as to how the Springfield Fault has affected the Upper Hawkins Basin.

6- Conclusion:

The glaciofluvial terraces located within the Upper Hawkins Basin at Dalethorpe still have much that is unknown about them. More plausible recurrence intervals could be calculated by further analysis of the ages of the terraces, since the recurrence interval of ~6.36ka calculated for the Springfield Fault is inaccurate. The collection of sediment cores for the older terraces would be a potential project that could lead to the proper dating of the older terraces. Trenching of those terraces would be a highly recommended project in order to further understand how the fault has affected the glaciofluvial terraces of the basin. It would be expected that in the older terraces, there would be more activity shown within their strata, and would therefore show greater insight into behavior of the Springfield Fault, since Terrace A showed no large activity within 25.44ka ± 0.175ka. More likely recurrence intervals could be produced by analyzing the older terraces and by taking into account how glacial activity has altered the basin. Further analysis in this regard would aid in helping to determine whether or not the Springfield Fault actually poses any seismic hazard to the towns of Springfield and Christchurch, as well as the rest of the Canterbury Region.

7- Acknowledgements:

I’d like to thank the EQC Capability Fund for providing the money to make this research a possibility, as well as Christopher Gomez and Paul Bealing for retrieving the data and making the SRTM DEM needed for this research. I’d like to especially thank Brendan Duffy for the immense help and guidance throughout this whole process. He has been an excellent mentor in showing me how to conduct independent research and for supplying the confidence in me needed to motivate me in times of struggles and confusion. Without these people, I would not have been able to complete this research.

Figure 1. Terrace heights and number of estimated tectonic events based on total uplift.

Average Down-thrown Heights (m)	Average Up-thrown Heights (m)	Surface Displacement as Total Uplift (m)	Estimated # events
Terrace C = 457.4			
	Terrace C_1 = 469.6	12.2	3
	Terrace C_2 = 457.4	9.8	2
Terrace B = 459.6			
	Terrace B_0 = 456.4	3.2	1
	Terrace B_1 = 455.9	0.5	0
	Terrace B_{2e} = 450.1	5.8	1
	Terrace B_4 = 450.1	0	0
Terrace A = 451.7			
	Terrace A = 433.9	17.8	4

* Note: Terrace B_{2w} and B_3 have been exempt since their heights were skewed by tree cover.

Figure 2. Calculated slope angle for the terraces at Dalethorpe.

Terrace	Calculated Slope (º) Down-thrown Terraces	Calculated Slope (º) Up-Thrown Terraces
Terrace C	2.708072	
Terrace C_1		Degraded
Terrace C_2		Degraded
Terrace B	2.078924	
Terrace B_0		Degraded
Terrace B_1		Degraded
Terrace B_{2e}		1.752704
Terrace B_{2w}		1.74698
Terrace B_3		Obscured
Terrace B_4		Degraded and Obscured
Terrace A Down-thrown	1.266031	
Terrace A Up-thrown	0.956751	

References:

Duffy, B.G., 2008. Development of multi-channel analysis of surface wave (MASW) for characterising the internal structure of active fault zones as a predictive method of identifying the distribution of ground deformation. University of Canterbury Masters Thesis.

Duffy, B., Campbell, J., Finnemore, M., 2007. Defining fault avoidance zones and associated geotechnical properties using MASW: A case study on the Springfield Fault, New Zealand. University of Canterbury.

Evans, S.T., 2000. Paleoseismic analysis of the Springfield Fault, Central Canterbury. BSc (Hons) Thesis, University of Canterbury.

Speight, R., 1924. The Benmore Coal Area of the Malvern Hills. Transactions and Proceedings of the Royal Society of New Zealand, 1868-1961, 55, 619-626.

Steacy, S., Jiménez, A., Holden, C., 2013. Stress triggering and the Canterbury earthquake sequence. Geophysical Journal International 196, 473-480.

Stirling, M., Litchfield, N., Smith, W., Barnes, P., Gerstenberger, M., McVerry, G., Pettinga, J., 2007. Updated probabilistic Seismic Hazard Assessment for the Canterbury Region. Environment Canterbury Regional Council. U06/6.

Turnbull, I.M., 2000. Geology of the Southeastern Eyre Mountains relevant to tenure review. Conservation Advisory Science Notes No. 276. Department of Conservation, Wellington.