Paleoseismicity of a Near-Surface Blind Thrust: An Example from the Springfield Fault, Canterbury, New Zealand

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Abstract

The Springfield Fault provides insight into the possible methods that can be used to determine the paleoseismic history of a blind fault. The Canterbury region of South Island, New Zealand is an area that is riddled with faults, and with each successive earthquake, the stress fields shift. Since the advent of the Canterbury Earthquake Sequence (CES) in 2010, stress has shifted onto the Dalethorpe area, among others. In the Dalethorpe region lies the Springfield Fault, a blind thrust fault in an active glaciofluvial and tectonic setting. By trenching this fault, we were able to examine the overlying unfaulted and folded strata of a blind fault. Through the creation of a tectono-depositional model based on the dates and data gathered in the trench, as well as the geomorphological evidence in the surrounding area, it was determined that the fault last ruptured between 25-4ka. Using a recurrence interval of 6380±430yrs as determined by Duffy et al. (2008), the fault is categorized as being late in its seismic cycle. These results gain us further resources for methods to determine paleoseismicity of active faults, both blind and otherwise, and allow us to better understand the seismicity of the Canterbury region at large.

I. Introduction

The Springfield Fault, in the area of Dalethorpe, is located 65km WNW of Christchurch, New Zealand (Figure 1), and lies in an area of increased coulomb stress (Steacy et al. 2013). In the wake of the recent Canterbury Earthquake Sequence (CES), the Springfield Fault has been added to the Stirling hazard model (Stirling et al. 2007). Given the recent flurry of activity regarding the fault, it has become clear that it needed to be studied more fully, and thus a trench was dug. The aim of the trench was to better constrain the paleoseismicity, and to examine the nature of the Springfield Fault. Digging a trench has long been one of the best methods of conducting a paleoseismic study. A trench makes it possible to see the faulted strata as they appear naturally and underground. Occasionally, however, the evidence in the trench is not as clear as may be desired. This study addresses one such situation, and examines the interpretation of unfaulted strata that are nevertheless associated with an active fault.

Dalethorpe is an area of dynamic glaciofluvial and tectonic history, and what is presented in the trench and in the outcrop must be interpreted using established methods in new ways.

The Springfield Fault was first documented by Robert Speight in 1924 in a paper that was largely concerned with the Benmore area to the northwest of the fault. The fault was mentioned in passing as a possible member of a set of sub-parallel faults that were inferred through close examination of coal beds. Since Speight identified the fault, there has been a sparse amount of work completed on the area. Knowledge of the Springfield Fault increased when Evans (2000) used geomorphic analyses of river terrace offsets to poorly constrain the age of the youngest terrace at 1000-7500 years old. Three near vertical offsets of ~0.4m were discovered when the fault was imaged using an inverted resistivity model by Corboz in 2004. Duffy et al. (2008) also used seismic imaging of deformed straths and estimates of erosion to complete a partial paleoseismic analysis of the fault. According to Duffy et al. (2008), it has been roughly 1,300 years since the river abandoned the lowest terrace, shortly after the most recent seismic event, and the recurrence interval for the fault is 6380±430yrs. In addition, Tonkin has abundant unpublished data on loess cover through the Dalethorpe basin, which aided in the most recent efforts to constrain the age of the fault.

In this study, a more thorough paleoseismic investigation of the Springfield Fault is carried out. This paper reports a paleoseismic trench and the tectono-depositional model that is used to analyse and interpret it. Optically Stimulated Luminescence (OSL) and radiocarbon dating were carried out in efforts to improve date constraints on the last rupture of the fault, and to date the key horizons. The dates on these horizons – the surface, a clay layer, and silt layers – were used together to improve the date constraints. The Springfield Fault is a fault that is both well expressed in the landscape and has a good outcrop, yet it remains blind in the terrace in which the trench was dug. The interpretation of this fault, then, allows us the unique opportunity to draw upon the geomorphology of the outcrop of a blind fault. This affords the possibility to not only study the paleoseismicity of the Springfield Fault, but to examine the ways a blind fault expresses itself in a landscape using the geophysical control that is provided by the outcrop.

II. Study Site Settings

The Canterbury Region of South Island, New Zealand has been a location of great scientific interest in recent years, given the commencement of the CES. When looked at most simply, the Canterbury Plains are underlain by five main stratigraphic units, the torlesse basement Rakaia terrane, beneath Mount Somers Volcanics, beneath a late Cretaceous-Paleogene unit and a Miocene unit, beneath the Pliocene aged Kowai formation. The Kowai formation is superficially overlain by

Quaternary aged gravels. Beneath these strata to the south are two fault-bounded grabens whose bounding normal faults extend up into the overlying units (Jongens et al. 2012). To the northwest, east oriented folds and reactivated reverse faulting are abundant. The fault matrix that exists within the Canterbury Plains is dynamic, and the areas of increased stress have changed since the beginning of the CES (Steacy et al. 2013). The results of the few studies regarding the Springfield Fault since Speight (1924) have agreed on the established geology of the area as torlesse rocks beneath cretaceous and cenozoic rocks, and quaternary gravel deposits (Evans 2000).

III. Methods and Results

In February of 2014, a 34x3x4m trench was dug on the Dalethorpe farm in Springfield. Over the course of four days, the trench was logged, and samples were taken for OSL and radiocarbon dating. Once back in the lab, the samples were sent off, and the log was digitized (Figures 2 and 3) and the trench was interpreted in light of dates from previously collected samples. Tonkins' unpublished data on loess deposition was combined with dating done by Duffy et al. (2008) in order to calculate an age of abandonment for the youngest terrace (terrace A).

i. Trench Stratigraphy

Top Bench

The top bench of the trench along the Springfield Fault is 34m long and ~2m high. The eastern end of the north (swamp) side of the trench (Figure 2) has fairly even, horizontal layers. The top ~0.25m is a massive, dark brown, silt loam A horizon, followed by ~0.25m light olive brown silty clay loam with occasional clasts. The B horizon contains red mottling beginning at meter 5.5 and tapering out at meter 32. On the south (sunny) side (Figure 3), both the A and B horizon are ~0.5m thick. The A and B Horizons remain at these approximate thicknesses until meter 14.5 (meter 10 on the sunny side) when together they are between 0.75-1.25m thick. The two units then taper out to their original thicknesses at meter 31.5. Beneath the B Horizon is a unit of light yellow brown clayey sandy gravel. The clayey sandy gravel unit is consistently ~0.25m thick on the swamp side, on the sunny side it begins ~0.5m thick, tapers to ~0.125m thick at meter 9, thickens again to ~0.25m thick at meter 22, before ending abruptly at meter 27.5. Beneath the clayey sandy gravel unit is a unit of grey sandy gravel with visible horizontal preferred orientation parallel to bedding. The grey sandy gravel begins ~0.75m thick on the eastern end of the trench before thickening to ~1m thick at meter 6. An oxidation horizon appears occasionally throughout the unit, generally ~0.5m thick. On the western end of the trench (Figure 4), finer grained units appear. The lowermost of the silt and clay units begins at meter

25.5 (meter 26.6 on the sunny side). The bottom ~0.125m of this unit is a purple clay which is most visible on the sunny side. Atop the clay are three layers of silt (two units on the sunny side), each ~0.25m thick that coarsen upwards, and are separated by 1-10cm of grey sandy gravel.

Bottom Bench

The bottom bench is 6 meters shorter than the top bench, losing 2 meters on the western end and 4 meters on the eastern end (3 meters on the sunny side). The bench is 1.5m high. The main unit of the bottom bench is an orange sandy gravel. This gravel is the same composition of the grey sandy gravel in the top bench, but has been oxidized. The oxidation horizon is occasionally visible in the bottom ~0.5m of the top bench. The greywacke bedrock is visible on the eastern end of the trench (Figure 5), thrust into the gravels from meters 4-7 (meters 3-9 on the sunny side). The bedrock is a very poorly indurated dark blue grey, is very fractured, and composed of quartz and argellite. The bottom of the bottom bench was often obscured by ~1-10 cm of water.

ii. Geochronology

The Springfield Fault can be seen in outcrop just to the south of the dig site along a cut bank of the Hawkins river. Here, the greywacke bedrock is visible, along with a fault angle depression where the bedrock is being thrust over glaciofluvial gravels. This manifestation of the fault continues ~10m up to the trench, where <1m of bedrock is visible in the easternmost meter of the trench. The western end of the trench is characterized by finer grained clay and silt beds. Radiocarbon samples from the older purple clay beds came back with an age of 25ka. This age serves as a maximum age for the last event along the fault. Lying above the clay beds are silt beds interspersed with layers of gravel. Given their positioning relative to the clay beds, the upper layers of the silt beds are <25ka. The exact dates of the top layer of silt can provide an upper bracket for the minimum age of the last event along the Springfield Fault. The OSL samples that were taken in this top layer of silt are currently outstanding, and when they are returned can be used to better constrain the dates put forth in this paper.

In order to determine an absolute minimum age for the last event along the fault, one can look at the terrace surface. Despite there being multiple tactics for determining the age, this aspect of the terrace surface remains uncertain. Loess accumulation was used in this study to infer the age of the terrace. In the Dalethorpe basin, the surrounding area is overlain by ~1.2m of loess that has been dated to 25ka (Duffy et al. 2008). This data results in an accumulation rate of 0.048mm/yr. Terrace A, however, has little to no loess overlying it. It is possible that 10cm of loess could be missed or mistaken, but once 20cm (~4000 years worth) have accumulated, it is impossible. Given these loess age ranges, the minimum age for activity along the fault, and thus the abandonment of the A surface, was within the last 4000 years – during the mid-holocene.

IV. Interpretation

In order to best interpret what is visible in the trench, a tectono-depositional model was created. This model postulates that the Springfield Fault has progressively ruptured through the older gravels, but remained blind and thus only folded the younger gravels. Long term accumulation of slip along the fault caused the greywacke bedrock to thrust through the older gravels. After the initial thrusting, the area ponded and the clay layer was deposited. Dating from this clay layer gave the maximum age of the fault as 25ka. As the slip continued to accrue, the river continued to deposit gravels, such that a fault scarp never truly developed, and the clay layer was buried. The newer gravels that overlay the bedrock and clay were merely folded, which is made manifest by rotated clasts that were visible in the trench. Once folding occurred on the eastern side of the fault, further ponding occurred on the western, thus the silt layers were formed from which a minimum age of the fault will be determined.

This model incorporates what is visible in the outcrop with what was seen in the trench to provide an interpretation of a blind fault, and how that fault manifests itself in the overlying unfaulted strata. The dates that have been gathered from this study of the Springfield Fault, should also be viewed in light of the results of past research. By looking at the results for offset and recurrence interval calculated by Duffy et al. (2008), it can be determined where the fault is in its seismic cycle, as well as how the Springfield Fault fits into the network of faulting in the Canterbury plains. New data are consistently being acquired and interpreted about this network of faults, and the extent of the hazard that these faults pose to the city of Christchurch.

V. Discussion

The study and trenching of the Springfield Fault lead to further dating of the sediments, as well as a better understanding of the depositional environment into which the fault propagated and formed. The dating and tectono-depositional model combined show a last rupture of the Springfield Fault at no greater than 25ka, and no younger than ~4ka. When examined in conjunction with the recurrence interval of 6380±430yrs as calculated from incision rates of the Hawkins river on terrace risers by Duffy et al. (2008), a seismic cycle begins to take shape. The radiocarbon age of 25ka provides a maximum age for the last event along the fault, an age which is well outside of the calculated recurrence interval. It can be hypothesized, thus, that the fault is no longer active. However, given the gravel layers in between this bottommost clay layer, and the silt layer which will provide a more accurate age, it can be assumed that the true age of the fault is closer to that of the terrace than that of the clay. The absence of loess on the surface of Terrace A leads to the conclusion that the last event occurred at an absolute minimum of 4ka. Thus it can be established that the Springfield Fault is fairly late in tis seismic cycle. OSL dates from the silt layers will provide a more exact constraint.

Since the advent of the CES which triggered ≥ 6 different faults, Steacy et al. (2013) have conducted extensive research on modelling the stress fields in the Canterbury region. Previous Coulomb stress maps created by Steacy et al. (2013) resulted in 100 percent of the following Mw≥5.5 earthquakes occurring in positive stress areas. The Springfield Fault extends across the Waimakariri river, and the bulk of it lies well inside a zone of increased stress, as shown by Steacy et al. (2013) (Figure 6). Given the probability that the fault is late in its seismic cycle, and that it has experienced increased amounts of stress in recent years, it is feasible that the fault is currently gathering slip and will soon rupture. The Springfield Fault is in close proximity to the Kowai and Porter's Pass faults, and thus, a rupture along the Springfield Fault may result in the onset of another earthquake sequence which could impact the city of Christchurch once again.

VI. Conclusion

By looking at the outcrop of the Springfield Fault at the Hawkins river in conjunction with the trench, a tectono-depositional model was created which proposed that the fault accrued sufficient long term slip to thrust through older gravels, but to merely fold the overlying gravels. This folding resulted in ponding on the western side of the fault which caused deposition of fine grained clays and silts. Radiocarbon dating of the bottommost clay resulted in a maximum age for the most recent event along the Springfield Fault at 25ka. Outstanding OSL dating of the silt layers will provide a minimum age for the most recent event. Until those dates are returned, an approximate age derived from loess deposition of 4ka on the surface of the terrace serves as an absolute minimum age. These constraints, combined with a recurrence interval of 6380±430yrs (Duffy et al. 2008), lead to the conclusion that the fault is late in its seismic cycle. A fault late in its seismic cycle is hazardous, especially since the Springfield Fault lies in an area of increased coulomb stress (Steacy et al. 2013).

Suggested further work in the area includes trenching the location of the third offset imaged by Corboz (2004). Additionally, determining the amount of offset that has accumulated along the Springfield Fault, and thus beginning to estimate how large of an earthquake to expect in order to enhance our knowledge about the hazard of the fault. Further and more extensive hazard analysis may also prove beneficial, as the Springfield Fault lies in close proximity to the town of Springfield, and crosses state highway 73, one of the main east/west highways on the South Island.

VII. Acknowledgements

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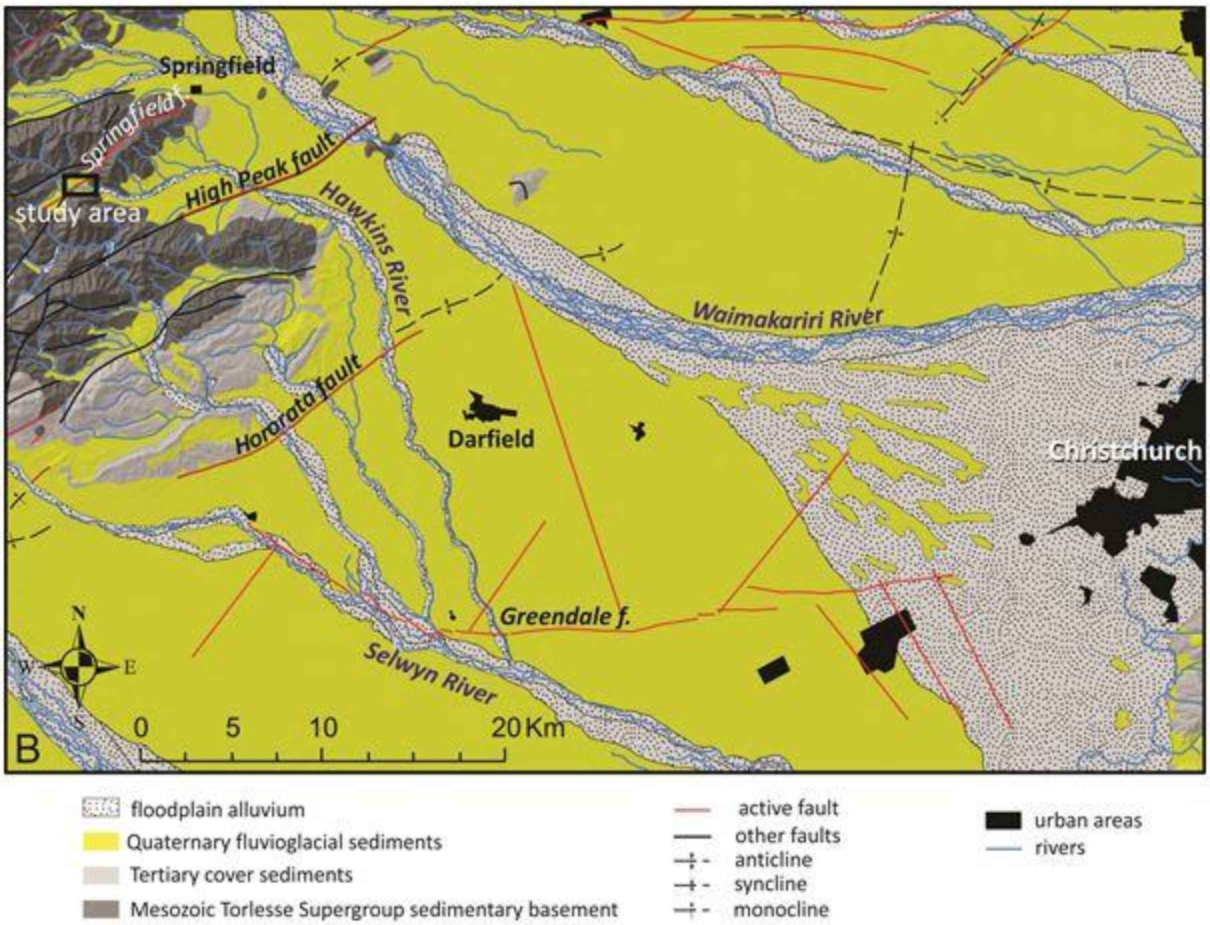
Springfield
Springfield f.
High Peak fault
study area
Hawkins River
Waimakariri River
Hororata fault
Darfield
Christchurch
Greendale f.
Selwyn River
N
E
S
W
B
0
5
10
20 Km
floodplain alluvium
Quaternary fluvioglacial sediments
Tertiary cover sediments
Mesozoic Torlesse Supergroup sedimentary basement
active fault
other faults
anticline
syncline
monocline
urban areas
rivers

Figure 1

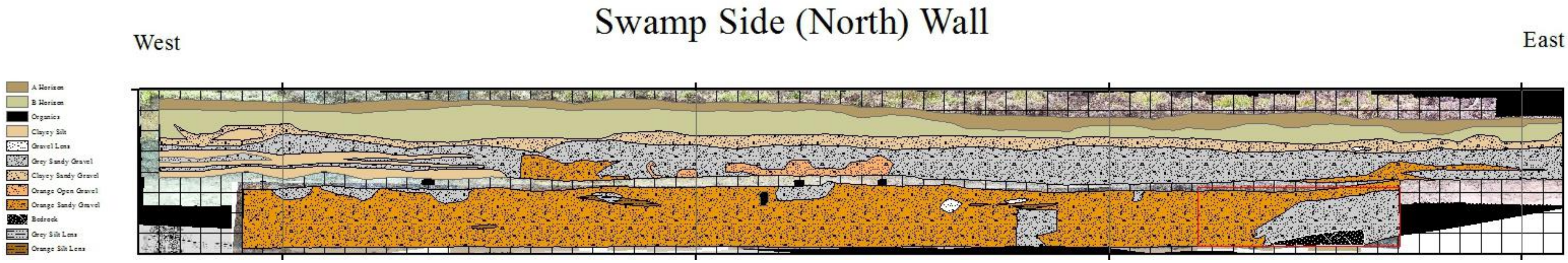

Figure 2

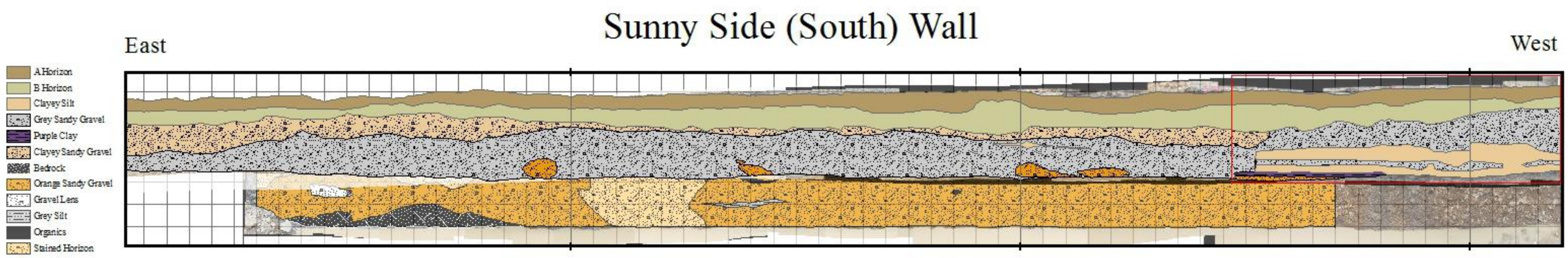

Figure 3

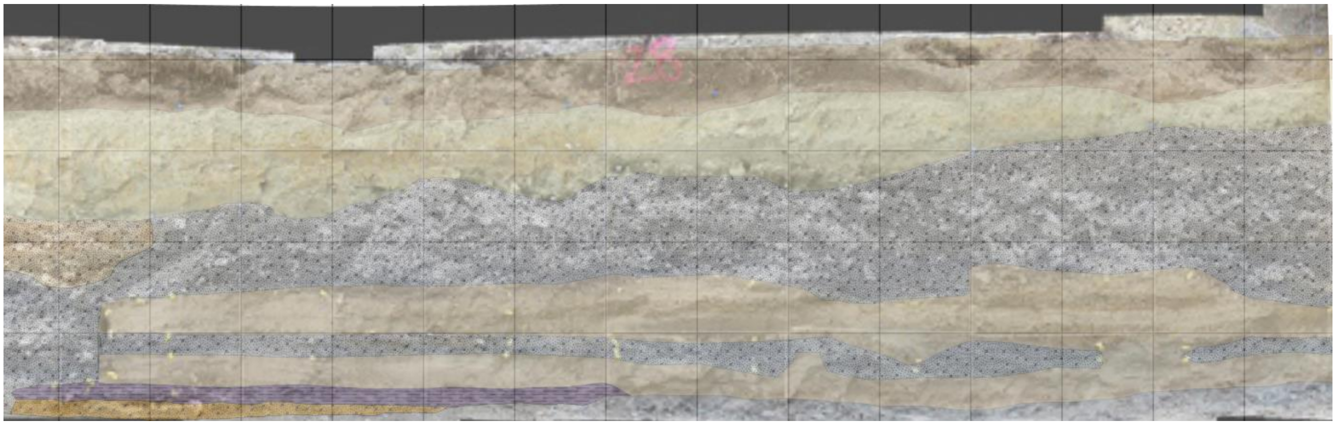

Figure 4

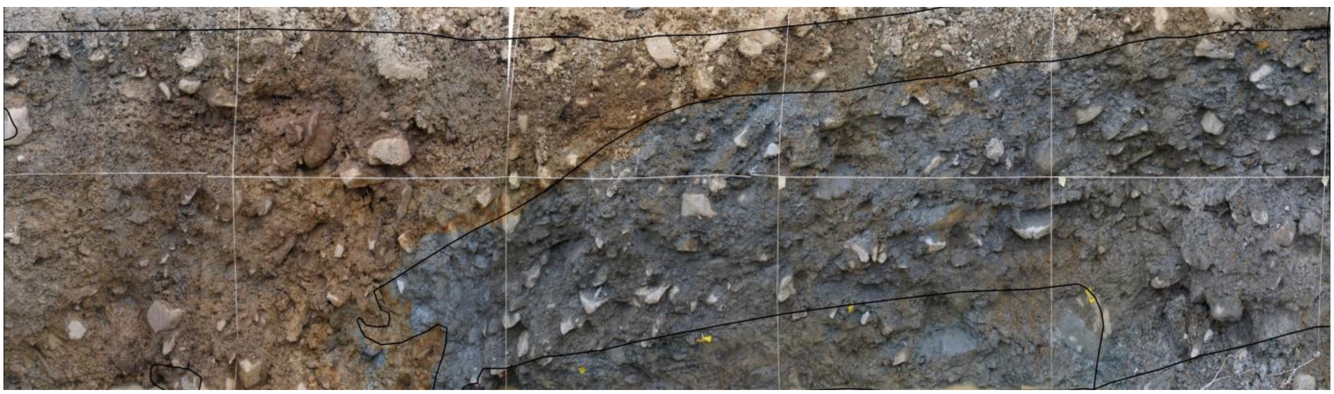

Figure 5

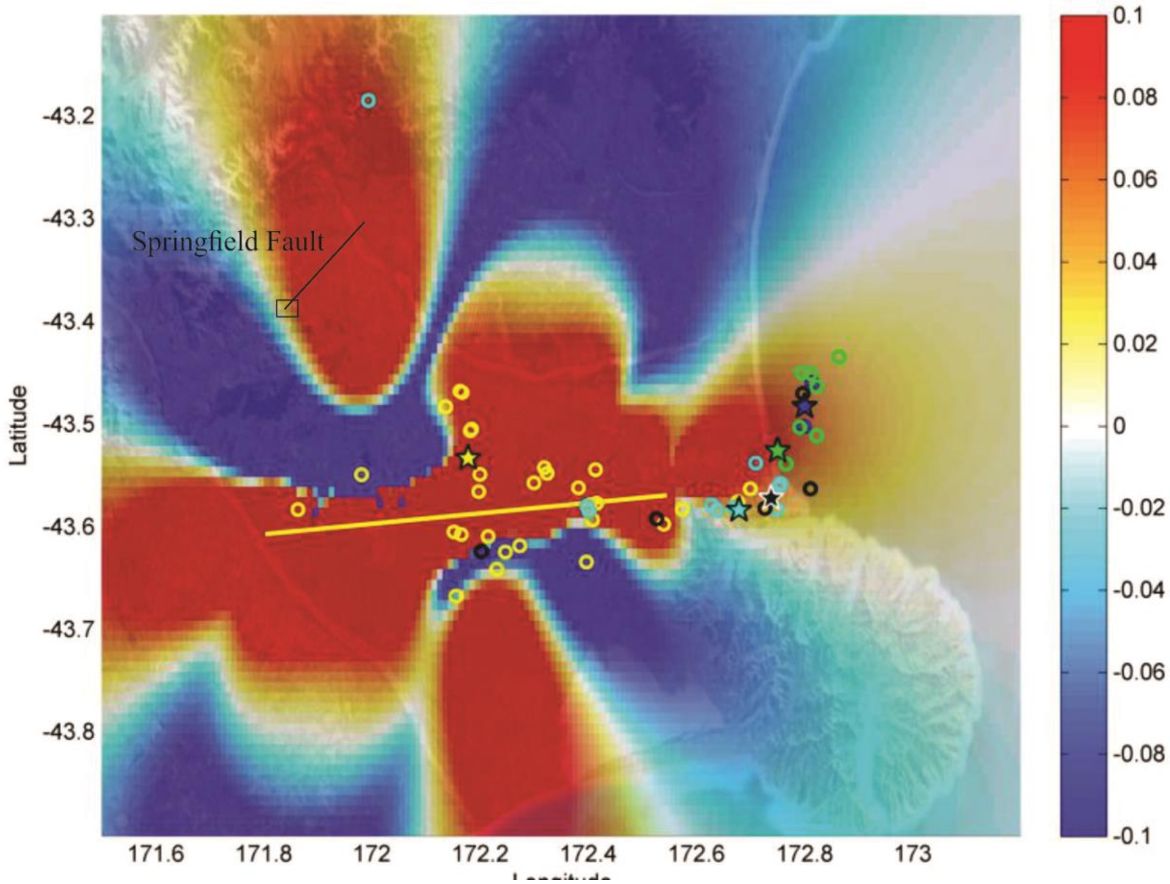

Figure 6

Figure Captions

Figure 1: Taken from Duffy et al. (2008). "Faults and folds are based on GNS Science QMAP data sets" (Duffy et al. 2008). The Springfield Fault and the study area can be seen in the northwestern corner of the map.

Figure 2: The north wall of the trench log. The extent window on the east end of the trench log corresponds to figure 5.

Figure 3: The south wall of the trench log. The extent window on the west end of the trench log corresponds to figure 4.

Figure 4: The eastern end of the bottom bench of the north wall of the trench. The very lowest unit shows the greywacke bedrock.

Figure 5: The western end of the top bench of the south wall of the trench. The purple outlines the bottom layer of clay from which the radiocarbon samples were taken. Overlying the purple clay are the silt layers from which OSL dating will provide a minimum age for the Springfield Fault.

Figure 6: Coulomb stress change map modified from Steacy et al. (2013). The areas in read are areas of increased stress, whereas the areas in blue are areas of decreased stress. The approximate location of

the Springfield Fault has been added in the northwest corner of the map with a small box around the study area.