ABSTRACT
Earthquakes and tsunamis pose a serious threat to much of New Zealand’s coastal community, but so far there has been no historic or geologic evidence for these events having occurred. At Conway Flats, 30km south of Kaikoura, are estuary deposits containing numerous paleo-trees left in growth position that resemble a paleo-tsunami deposit. Field observations, map data, and stratigraphic data were collected and interpreted in conjunction with microfossil analyses of sediment samples to determine what caused the preservation of these trees. There was insufficient evidence of tsunami inundation or seismic activity, and it was concluded that the Conway trees most likely died due to sudden sea level rise and were preserved in a low-energy estuarine environment.

INTRODUCTION
Earthquake and tsunami hazards are a serious concern for much of New Zealand’s coastal community, and in many cases the most readily available way to learn about these hazards in more localized settings is to examine the effects of past events. The Kaikoura area in particular lies in a tectonically complex region within the Marlborough Fault System, putting it at risk for submarine earthquakes and tsunamis (Walters et al. 2006). Unfortunately, only a small amount of historic evidence for tsunamis exists in this region (DuBois unpublished PhD), leaving little to apply to modern hazards. Terrace deposits just 30km south of Kaikoura on the Conway Coast, however, may represent paleo-seismic or tsunami deposits.

Conway Flats (figure 1) is, like Kaikoura, directly adjacent to numerous active faults, and it is made up of a series of unusually well preserved alluvial fan and estuary delta deposits that have recorded local coastal activity for the last several hundred thousand years (McConnico and Bassett 2005). Just offshore are a series of large strike-slip faults, putting the area at risk for seismic activity and tsunamis (McConnico and Bassett 2005). Just inland are four terraces, the youngest of which is approximately 8,000 years old and contains numerous standing tree trunks that may represent a single paleo-forest (McConnico and Bassett 2005; figure 2). The top of this youngest terrace slopes landward before meeting the base of the next terrace, possibly indicating an additional thrust fault offshore as in Kaikoura, increasing the likelihood of submarine earthquakes and tsunamis.

Previous work
Conway Flats has been thoroughly studied over the last several decades (Suggate 1965; Ota et al. 1984; McConnico and Bassett 2005; McConnico and Bassett 2007). The Conway Flats paleo-trees have been carbon dated by Suggate (1965), Ota et al. (1984), and McConnico (PhD thesis 2012), revealing ages between 8400 and 6437 years with uncertainties of up to 200 years. Ota et al. (1984) documented the morphology of the Conway coast terraces and calculated approximate uplift rates of the area, finding an average of 2 meters per thousand years. McConnico and Bassett (2005 and 2007) documented the terrace facies, noting many instances
of imbricated clasts and concluding the terraces represent gravity-induced slumps in marine foreset beds.

McConnico (2012) built upon this work, carrying out a PhD thesis on the geologic evolution of Conway Flats. This involved: 1) geomorphic mapping of the Hawkswood Range as the structural boundary to the Conway terraces, 2) sedimentary analysis of terrace deposits, 3) recreation of paleo-environment using geomorphic and sedimentary data, 4) refining of age constraints of terrace surfaces, 5) identification of sediment source for fan deltas, and 6) use of sequence stratigraphy to synthesize and merge geomorphic, sedimentologic, and tectonic data (McConnico 2012). McConnico (2012) concluded the delta deposits are of Quaternary origin and formed in a compressional tectonic setting, calculating an uplift rate for the youngest terrace of 1.35 m/ka. A high percentage of slump deposits were noted, containing many characteristics of seismic and coseismic events (McConnico 2012). Together, these studies provide the backdrop for analysis of the preservation of the buried forest and preliminarily identification of past hazard deposits of the Conway and Kaikoura coast.

Study Objectives

The goal of this study is to determine if the Conway trees represent a paleo-forest that died in a single event, and if they did whether that event was a tsunami, flood, earthquake, or large storm. Previous data revealed tree ages between 8400 and 6437 years with uncertainties up to 200 years (Suggate 1965; Ota 1984; McConnico 2012), implying a gradual die-back. However, preliminary fieldwork showed trees to be rooted along the same elevation and sediment horizon. The surrounding tectonics of the area strongly indicate the potential for tsunami and seismic hazards, but the coastal setting could also have put the forest at risk of a large storm or flood. To pave the way for a more comprehensive analysis of the past and current hazards in the Conway and Kaikoura region, this study will combine field mapping techniques with microfossil analysis to determine which scenario is the most likely for the preservation of this environment.

GEOLOGIC CONTEXT

Local Hazards

The Kaikoura area lies in a tectonically complex region within the Marlborough Fault System, putting it at risk for submarine earthquakes and tsunamis (Rattenbury et al. 2006). Approximately 40 km offshore, a large submarine trench marks the edge of the plate boundary and represents the potential for submarine landslides and subsequent tsunamis (Walters et al. 2006b). While there is little geologic evidence of these events having occurred, archaeological evidence of marine sediments overlaying a Maori occupation site suggests that there have been events in the past several hundred years of marine inundation (Duckmanton 1974). Investigation of the submarine canyon by Lewis and Barnes (1999) indicates that sediments along the canyon rim are likely unstable and may show evidence of past slope failures. This evidence combined with the area’s complex geologic setting indicates the need to study potential hazards of the Kaikoura coast in preparation should an event occur.

Walters et al. (2006a and 2006b) used numerical modeling to calculate the possible effects of a tsunami on the Kaikoura coast, caused by either a local fault rupture or submarine landslide respectively. Walters et al. (2006a) determined that the northern coast would be highly exposed to damage and that the highest waves would be delayed by up to 1.5 hours after an event. Walters et al. (2006b) concluded that a submarine landslide generated tsunami represents a major potential hazard to the south of the Kaikoura Peninsula with waves arriving within 1-3 minutes at several locations. This type of event may or may not include an earthquake pre-
cursor, and the most likely case would involve multiple tsunami waves occurring in close succession (Walters et al. 2006b).

Some historical and geochemical evidence tentatively suggests previous episodes of tsunami inundation on the Kaikoura coast (DuBois unpublished PhD). Analysis of oral histories suggests that Kaikoura has been subject to tsunamis 11 times in the recent past, though none of these events appear in the published record (DuBois unpublished PhD), and geologic analysis indicated that deposits in Goose Bay, Kaikoura may be derived from a locally sourced tsunami (DuBois unpublished PhD). These data indicate the need to search further for contemporaneous deposits, to confirm whether these deposits represent paleo-tsunamis and what extent of damage can be expected from such an event.

While only a small amount of historic evidence for tsunamis exists in this region, there is ample contextual evidence to conclude that earthquake and tsunami hazards pose a serious threat to the South Island’s eastern coastal community. The terrace deposits of the Conway Coast show extremely similar conditions to that of Kaikoura, and they could provide a baseline for hazard study of the greater east coast. Because of the excellent preservation and exposure of the Conway Flats paleo-trees, this area represent an ideal starting place in the search for geologic evidence of past hazard events.

METHODS

Field notes and stratigraphic data were compiled and compared against published studies that delineate diagnostic features of storm and tsunami deposits (e.g. Morton et al. 2007; Goff et al. 2011). These are summarized in figure 3.

Map and Stratigraphic Data

Tree coordinates along the beach at Conway Flats were collected, mapped, and correlated with $^{14}$C ages from Ota et al (1984) and McConnico (2012) in order to reveal any patterns in tree ages. Stratigraphic columns were drafted to determine whether the same depositional environment was responsible for the burial of all the trees and what that environment could be.

Microfossil Analysis

Four samples were collected from the sediment layer directly overlying the base of the trees. These were subsampled (fist-sized chunks), and subsamples were sieved, separated via heavy liquids, split, and searched for microfossils. No more than 3 hours was spent with each sample searching for microfossils. Diatom and foraminifera specimens collected within this timeframe were identified to the genus or species level and used as proxies for water depth.

Analysis of sea-level curves

A previous sea level curve from Clement et al. (2009) was compared to the calculated uplift rates of the region (2 m/ka and 1.35 m/ka; Ota et al 1984 and McConnico 2012, respectively) to correlate terrace levels to paleo- sea levels and determine if any significant change in local sea level had occurred. If the uplift rate exceeds sea level rise, this would imply that coseismic subsidence had at some point occurred. If the rate of sea level rise exceeds that of the uplifting region, this would imply the trees died due to sea level rise.

Paleocurrent data

Paleocurrent data was collected in the field in order to determine whether the sediment source was derived from the land or sea. A seaward paleocurrent would serve as for a flood
event, whereas a landward paleocurrent would indicate a large coastal storm event (Morton et al. 2007). Multiple directions of paleocurrent would be evidence of tsunami inundation and backwash (Goff et al. 2011).

RESULTS (Summarized in figure 3)

Map Data
Age data did not reveal a pattern in ages laterally along the beach, as ages fluctuated from north to south (figure 1). There was not enough resolution in age data to distinguish a pattern in ages between near shore and far shore, however McConnico (2012) concluded that there was a pattern of trees younging away from the coast.

Stratigraphic Analysis
Field observations and stratigraphic columns indicated that trees were all located along the same conglomerate horizon (figure 4). Above this horizon was primarily silt and clays with one or two more conglomerate layers, indicating primarily low energy conditions during burial (figure 4).

Microfossils
One single foraminifera was found in sample CF03 (figure 5a). It was identified as Cibicides temperatus, a deep marine species found from 80 to 1500 m (Hayward et al. 2012). The diatom Campylodiscus spp. was found in high abundance in all four sediment samples, but as it is found from shallow to deep sea no further information can be inferred (figure 5b).

Sea Level Curve
Ota et al. (1984) and McConnico (2012) calculated regional uplift rates of 2 m/ka and 1.35 m/ka, whereas the sea level curve by Clement et al. (2009) indicates a sea level rise of about 10 m/ka. This means that sea level was rising about 5-7 times faster than the region was uplifting. Sea level ceased rising approximately when the trees were buried (figure 6).

Paleocurrent
One paleocurrent indicator was found, yielding a seaward sediment flow (figure 7).

DISCUSSION
The Conway Flats trees are all located along the same sediment horizon, indicating they died in a single catastrophic event. There is insufficient evidence, however, to indicate that they died in a tsunami (figure 3). There are few geologic proxies to indicate tsunami inundation, and microfossil evidence was inconclusive. Only one foraminifera was found, though it was a deep marine species, and the diatoms found are not indicative of a specific aquatic environment. The one paleocurrent indicator found could represent evidence of a tsunami, flood, or remobilization of upper terrace material, and thus is inconclusive without further data.

The most likely cause of death for the Conway Flats trees is sea level rise. Sea level data from Clement et al. (2009) indicates that sea level rose rapidly, about 10 m/ka, from about 15 ka until about 7 ka, approximately when the Conway Flats trees were buried. Ota et al. (1984) and McConnico (2012) calculated uplift rates for the region to be about 1.35-2 m/ka, much slower than sea level rise. This indicates that the trees were most likely drowned by the rising sea.

The fact that sea level plateaued to its current position at about the time of the trees’ death likely explains why the trees were preserved in growth position. The silts and clays that overlay the trees are indicative of a low energy, estuarine environment, implying that sea level rose only
enough to inundate the trees with more salt than they were adapted to. This would kill the trees, but still leave them standing. There are modern examples of this phenomenon on the Conway coast (figure 8). This would explain why only a single continuous line of trees along the coast now exists, and trees further seaward would have been knocked over by beach waves and trees further inland would have been in environments with low preservation ability.

CONCLUSIONS

- The Conway Flats trees all belong to the same sediment horizon and, therefore, represent a single paleo-forest.
- There is insufficient geologic, biologic, and geomorphic evidence to support the hypothesis of tsunami inundation.
- Instead, rapid sea level rise followed by prolonged sea level stability likely caused death and preservation of the Conway trees.
- Sea level likely rose just enough to inundate the tree roots with enough salt water to kill them but leave them in a low energy estuary where they were preserved in growth position.

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REFERENCES


Figure 1. Location of study site, paleotrees, and age data. Data labels correspond to sediment locations. Numbers indicate generalized age data locations.

Figure 2. Field photo of the subfossil podocarp trees (Conway Flats, New Zealand), with terrace deposits visible behind. Field notebook for scale.
**Proxy Toolkit for Paleotsunami Deposits**

*Modified from Goff et al. (2011)*

The following data derives from field and laboratory analysis carried out in the fall of 2015.

### Geological

- Deposit very poorly sorted
- Sediments fine upwards and inland
- Deposit contains repeating units from individual waves
- Distinct lower and upper sub-units representing runup and backwash
- Lower contact usually unconformable or erosional
- Loading structures at base of deposit
- Liquifaction features on the ground surface
- Contains intraclasts of reworked material

### Biological

- Contains individual shells / shell-rich units
- Shell, wood and less dense debris "rafted" near top of sequence
- Contains buried vascular plant material / soil / skeletal remains
- Increase in abundance of marine to brackish diatoms, often broken
- Deeper water foraminifera species introduced, often broken
- Pollen concentrations often diluted in the deposit

### Geomorphological

- Uplift or subsidence/compaction of site/locality
- Scour/erosion/reworking of sediments at site/locality
- Sand sheet or gravel deposition/gravel pavements
- Low likelihood of storm inundation

### Contextual

- Known tsunamigenic sources
- Low likelihood of storm inundation
- Similar coastal deposits found regionally *(unpublished PhD Jen Dubois)*
- Known contemporaneous tsunami deposits

### Alternatives

- Trees rooted in distinct horizons: Multiple events
- Age pattern in plant material: Gradual die-back
- Sea level rise exceeded uplift rates: Gradual die-back
- Paleocurrents point landward: Large storm
- Paleocurrents point seaward: Flood

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**Figure 3.** Proxy toolkit for paleotsunami deposits, modified from Goff et al. (2011). Data derives primarily from field and laboratory analyses carried out in the fall of 2015. Data derived from other sources is cited within the table.
Figure 4. Stratigraphic columns of three locations containing paleo-trees. The trees appear to all be rooted within the same conglomerate horizon and are buried primarily by silts and clays, indicating a low energy estuarine environment.

Figure 5. Microfossils found in sample CF03. (a) Scanning electron microscope (SEM) image of foraminifera species *Cibicides temperatus* (taken from Hayward et al. 2010). *C. temperatus* is commonly found off the east coast of New Zealand from 80-1500m. One individual was found in one sediment sample (CF03). (b) SEM image of diatom *Campylodiscus* spp. (taken from Spaulding and Edlund 2009), which can be found from brackish to deep marine settings. All four sediment samples contained numerous individuals.
Figure 6. Sea level curve of the Southwest Pacific region surrounding New Zealand, modified from Clement et al. (2009). Sea level rose about 66 meters between 15ka and 7ka, giving a rate of about 10 m/ka. This is an order of magnitude larger than the calculated uplift rate of the region (1.35 m/ka; McConnico 2012). The range of age dates for the Conway Flats paleo-trees is highlighted in red.
Figure 7. Paleocurrent indicator. Pictured are sediment packages ramped up against a paleotree, indicating a seaward paleocurrent direction. Photo on the right is a close-up of the boxed region in the left. Field notebook and pencil for scale.
Figure 8. Field photograph of modern standing dead trees in the current estuary.