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A plate boundary earthquake record from a wetland adjacent to the Alpine fault in New Zealand refines hazard estimates

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ABSTRACT

Discovery and investigation of millennial-scale geological records of past large earthquakes improve understanding of earthquake frequency, recurrence behaviour, and likelihood of future rupture of major active faults. Here we present a ∼2000 year-long, seven-event earthquake record from John O'Groats wetland adjacent to the Alpine fault in New Zealand, one of the most active strike-slip faults in the world. We linked this record with the 7000 year-long, 22-event earthquake record from Hokuri Creek (20 km along strike to the north) to refine estimates of earthquake frequency and recurrence behaviour for the South Westland section of the plate boundary fault. Eight cores from John O'Groats wetland revealed a sequence that alternated between organic-dominated and clastic-dominated sediment packages. Transitions from a thick organic unit to a thick clastic unit that were sharp, involved a significant change in depositional environment, and were basin-wide, were interpreted as evidence of past surface-rupturing earthquakes. Radiocarbon dates of short-lived organic fractions either side of these transitions were modelled to provide estimates for earthquake ages. Of the seven events recognised at the John O'Groats site, three post-date the most recent event at Hokuri Creek, two match events at Hokuri Creek, and two events at John O'Groats occurred in a long interval during which the Hokuri Creek site may not have been recording earthquakes clearly. The preferred John O'Groats–Hokuri Creek earthquake record consists of 27 events since ∼6000 BC for which we calculate a mean recurrence interval of 291 ± 23 years, shorter than previously estimated for the South Westland section of the fault and shorter than the current interseismic period. The revised 50-year conditional probability of a surface-rupturing earthquake on this fault section is 29%. The coefficient of variation is estimated at 0.41. We suggest the low recurrence variability is likely to be a feature of other strike-slip plate boundary faults similar to the Alpine fault.

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1. Introduction

Plate boundary faults are the longest, most active faults in the world because they accommodate a high proportion of relative movement between two tectonic plates. Therefore, they are prone to rupturing in larger earthquakes than shorter faults within plates. Geological evidence of multiple major earthquakes on these faults provides insights into earthquake recurrence over many seismic cycles and is imperative for improving our understanding of fault behaviour and seismic hazard (Berryman et al., 2012a; Biasi et al., 2015; Kozaci et al., 2011; Marco et al., 1996; Scharer et al., 2010; Wechsler et al., 2014). However, direct methods of determining past earthquake occurrence, such as trenching across faults and dating offset stratigraphy, rarely reveal evidence for more than the last few earthquakes, especially in high sedimentation-rate regimes such as New Zealand (Langridge et al., 2011; Little et al., 2009). Indirect methods, such as dating of marine and lacustrine turbidites caused by seismic shaking, provide longer earthquake records but are not uniquely tied to a single fault unless correlation between multiple sites enables fault source determination (Goldfinger et al., 2007; Howarth et al., 2014).

On the strike-slip section of the plate boundary through New Zealand (the Alpine fault; Fig. 1A) there are opportunities to derive long earthquake records from sediments that, although not offset by fault rupture, are uniquely tied to Alpine fault earthquakes.

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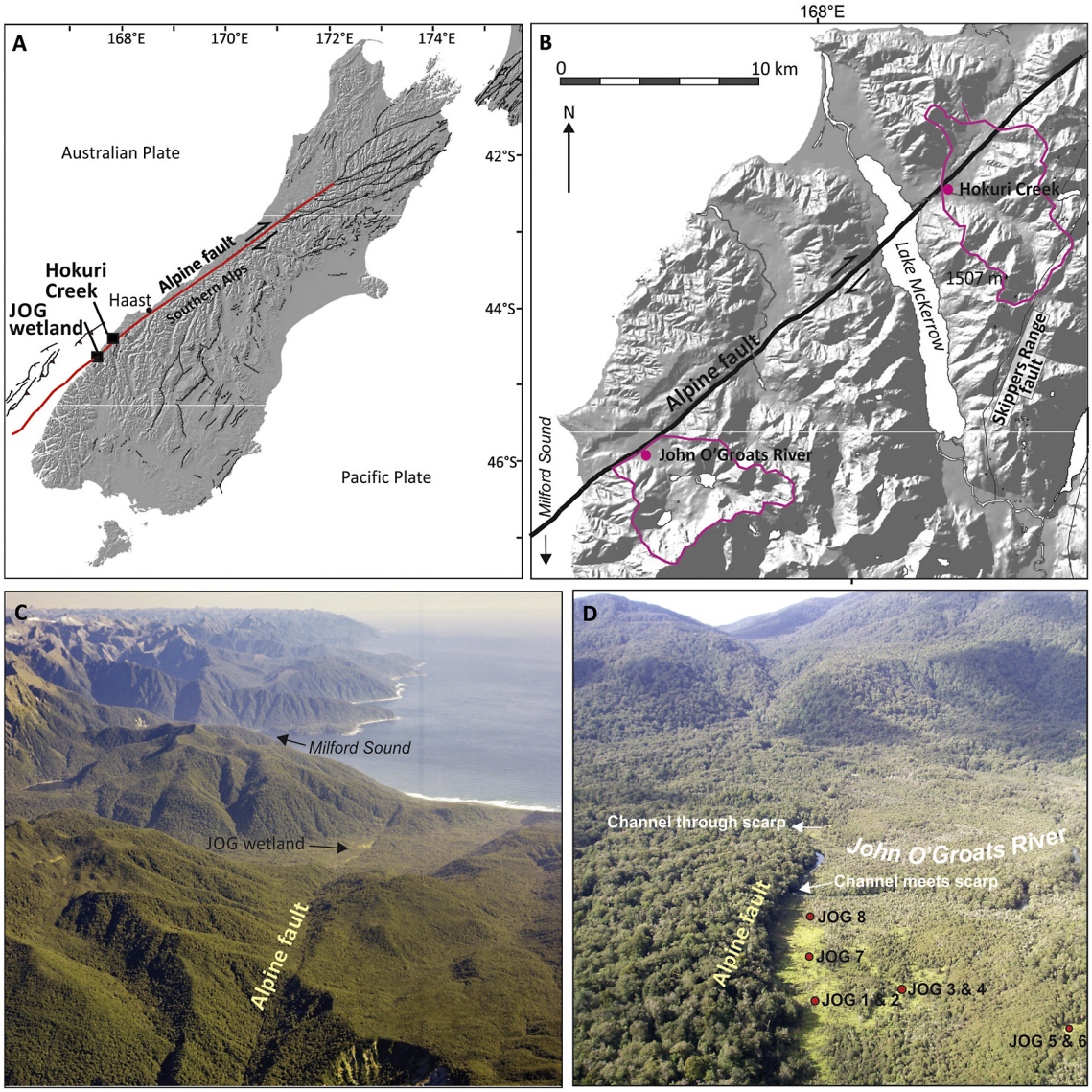

Fig. 1. [Colour online; black and white in hardcopy.] Location maps and photos for the John O'Groats wetland study area. A: The South Island of New Zealand showing major active onshore faults (black lines) and the Alpine fault which is the boundary between the Australian and Pacific plates in this location (red). John O'Groats (JOG) wetland is near the southern onshore extent of this fault. B: Location of the Alpine fault in northern Fiordland/southern South Westland showing the John O'Groats and Hokuri Creek study sites (dots) and their catchments (outlined). C: Oblique aerial photo looking southwest along the Alpine fault towards John O'Groats wetland beyond which the fault extends offshore near the mouth of Milford Sound. D: Oblique aerial photo looking northeast along the Alpine fault showing John O'Groats wetland in the foreground (centre and right) with core locations (dots and labels). The densely forested foreground to the left of the core sites is on the up-thrown side of the fault. The river channel is visible in the middle ground. The distance between where it meets the fault scarp and where it flows through the scarp is about 190 m. Photos by Lloyd Homer, courtesy GNS Science.

At Hokuri Creek (Fig. 1B) an 18-metre-thick natural exposure provided evidence for 22 earthquakes from ∼6000 BC to ∼1000 AD (Berryman et al., 2012a). Adding the most recent 1000 years of earthquakes from the Haast trench sites (Berryman et al., 2012b) led to a 24-event, 8000-year long record of earthquakes on the South Westland section (southern-most onshore part) of the Alpine fault (Clark et al., 2013). This record demonstrates quasi-periodic (regular) recurrence of large (≥M7) to great (≥M8) earthquakes, an observation that may be applicable to other long strike-slip faults that accommodate plate motion in relative isolation from other faults (Berryman et al., 2012a). The record also enables refinement of seismic hazard estimates such as providing a 27% probability that the next surface-rupturing earthquake on this section of the fault will occur in the next 50 years (Biasi et al., 2015). In these ways, the long earthquake record contributes to knowledge of global plate boundary fault behaviour and to local seismic hazard considerations. However, the research so far has two weaknesses: all but two earthquakes are derived from a single site, providing little indication of how applicable the observations are along the length of the fault, and the most recent earthquakes are not preserved at the site and are instead assumed to have the same ages as the two most recent surface-rupturing earthquakes recorded at Haast, 100 km northeast along the fault.

We investigated a site at John O'Groats River, 20 km southwest along the Alpine fault from the Hokuri Creek site, to test the lateral extent and completeness of the longest earthquake record for this fault and to improve it if possible. Here we provide a 2000-year-long record with evidence for seven surface-rupturing earthquakes. We use this dataset to augment the long earthquake record from Hokuri Creek, and provide new estimates for the regularity of occurrence and frequency of large to great earthquakes on the southern onshore part of the plate boundary. This work has implications for the discovery of new long earthquake records, models of earthquake recurrence, and seismic hazard.

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