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Contest 2012

Great megathrust earthquake hazard in New Zealand

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Key message for media: Why are these findings important?
The world's largest earthquakes are produced by rupture on the sloping boundary between tectonic plates (Mw >9) (e.g. 1960 Chile, 1964 Alaska, 2004 Sumatra–Andaman, 2011 Tohoku earthquakes). New Zealand has just such a sloping plate boundary running beneath the east coast of the North Island but there have been no such large earthquakes generated along it in historic times. We provide the strongest evidence so far assembled that there have been at least eight such major subduction earthquakes on the plate boundary beneath Hawkes Bay in the last 7500 years, with the four most recent within the last 2000 years. The most recent, just 500 years ago, likely resulted in rupture along 350 km of the plate boundary with subsidence recorded at both southern Hawkes Bay and Blenheim, Marlborough.

Abstract: Our research has shown that the last two co-seismic subsidence events in Hawkes Bay and Marlborough have similar dates (500 and 900 cal years BP) and could quite possibly have been the result of ~350 km-long rupture on the Hikurangi Margin subducting plate boundary. A total of eight potentially subduction earthquake-related subsidence events are recorded from Ahuriri Inlet sediments over the past 7500 yrs with an average recurrence time of 900 yrs, but being more frequent (average recurrence time 400 yrs) for the four most recent subsidence events. The youngest uplifted terrace on the South Wairarapa coast (635 cal yrs BP) is shown to be older than, and unrelated to, the ~500 cal yr BP subsidence event at Hawkes Bay and Marlborough. In the last 3500 yrs southern Poverty Bay has experienced gradual, possibly aseismic subsidence with no evidence of any co-seismic vertical displacement events. Prior to this we recognise two events in southern Poverty Bay – 1 m uplift event 4500 cal yrs BP and 1.2 m of subsidence 5700 cal yrs BP. These two Poverty Bay events correlate in time to coastal deformation recorded within 50 km to the north and south and are inferred to have been generated by an offshore upper plate fault (4500 yr event) and possibly a subduction interface rupture (5700 yr event) that is not recognised further south.

Keywords: Great earthquakes hazard; subduction interface ruptures; Hikurangi Subduction Margin; Poverty Bay; Hawkes Bay; coastal Wairarapa; Marlborough

Introduction / Background:

A great megathrust earthquake at the Hikurangi Margin has the potential to be New Zealand's worst natural hazard scenario and yet it is currently unknown **if they happen, how big** they might be, and **how often** they are likely to occur. Our aim has been to address this crucial gap in natural hazard knowledge by better constraining geological evidence of past large earthquakes on New Zealand's east coast. We hoped to identify and quantify the magnitude and frequency of Hikurangi megathrust earthquakes – fundamental, underpinning research into New Zealand's geological hazards. The need for such information was demonstrated by the 2010 revision of the New Zealand National Seismic Hazard model which stated "*The lack of historical or paleoseismic data constraining the recurrence behaviour of Hikurangi subduction zone earthquakes makes the calibration of our Hikurangi source model difficult at the present time".* To account for the Hikurangi Margin hazard the

National Seismic Hazard Model relies on estimated rupture lengths, displacements, and derived earthquake magnitudes and frequencies.

Greater clarity of the potential risk of megathrust earthquakes is expected to give local and national civil defence organisations more certainty in the preparations for such an event and their planned response to the resulting damage and casualties.

A great earthquake of M >8 is likely to cause a substantial tsunami along much of the eastern and southern coasts of the North Island. Our results will be valuable for New Zealand tsunami hazard assessment and will feed into more realistic tsunami models, which in turn determine coastal evacuation zones and influence land use planning.

Objectives or Research Aims

Research aim 1.1

Title Are the last two major subsidence events at Ahuriri, southern Hawkes Bay, accurately documented and dated at 600 and 1600 yrs ago (By end 2013) and are there equivalent subsidence events recorded at southern Poverty Bay (by end 2014)?

Text We will obtain numerous new short cores from interbedded peat and intertidal marine sediment in former embayments at Ahuriri and southern Poverty Bay, undertake microfossil analyses, determine the Late Holocene history of relative sea level, and obtain a number of radiocarbon and tephra ages to precisely date the two youngest abrupt subsidence events, which at present are only constrained by radiocarbon dating at one location.

Achievement Measure

Submission of a manuscript to a peer-reviewed journal for publication (by 30 June 2014).

Objective Achieved? Yes

Research Results

- 45 short reconnaissance and vibracores have been sunk in the Poraiti Lane, Poraiti Rd end and Ohingaora embayments of the former Ahuriri Inlet, southern Hawkes Bay. All cores have been logged, sampled and 295 samples studied for foraminifera and 50 radiocarbon and 9 tephra dates obtained.
- The 600 yr event previously identified and dated in one small area by Alan Hull (1986) has been difficult to identify but is now recognised in 4 locations as about 0.8 m of subsidence occurring between 571 and 406 cal yrs BP.
- The 1600 yr event previously identified in a paddock beyond the end of Poraiti Lane by Alan Hull (1986) is now recognised as comprising three separate subsidence events in three former embayments of Ahuriri Inlet. These are dated at 1739-1686 cal yrs BP (~1 m), 1496-1256 cal yrs BP (~0.6 m), and 1024-865 cal yrs BP (~1.2 m).
- 29 short reconnaissance and vibracores were taken in the Orongo, Te Hau, Wherowhero Lagoon and Taurau Valley areas of southern Poverty Bay. Results from lithologic logs, 162 foraminiferal fossil faunal samples and their MAT paleoelevation estimates, 23 radiocarbon dates and tephrostratigraphy were used to identify sudden earthquake displacement events and periods of gradual subsidence.
- In southern Poverty Bay, we document gradual subsidence over the past 3500 yrs at rates of 0.5-1.0 m per 1000 yrs, with rates decreasing southwestwards. We have no evidence of any sudden, possibly co-seismic events in southern Poverty Bay in the last 4000 yrs. Contemporary GPS measurements suggest that the subduction interface in this region is currently dominated by steady aseismic creep and slow slip events. Our results are consistent with the possibility that plate motion at this part of the subduction margin has been accommodated largely aseismically for at least the last 4000 yrs.

- In southern Poverty Bay there is evidence for one sudden subsidence event (~1.2 m) at 5700±400 cal yrs BP, which may have been generated by a subduction interface earthquake centred offshore and recorded in other published studies in northern Hawkes Bay, c. 35 km to the south.
- In southern Poverty Bay there is also evidence for one sudden uplift event (~1 m) at 4500±300 cal yrs BP, which might have been generated by rupture on an offshore upper plate fault that also uplifted coastal terraces at Pakarae and Mahia, 40 km to the north and south of the study area, or by rupture on the subduction interface penetrating beneath Poverty Bay.

Output

Hayward, B.W., Sabaa, A.T., Grenfell, H.R., Cochran, U.A., Clark, K.J., Litchfield, N.J., Wallace, L.M., Marden, M., Palmer, A.S., in press. Foraminiferal record of Holocene paleo-earthquakes on the subsiding south-western Poverty Bay coastline, New Zealand. New Zealand Journal of Geology and Geophysics. [see appendix 1]

Research aim 1.2

Title How much uplift occurred in the earthquake that raised the ~600 yr BP Wairarapa terrace and what is its precise age?

Research aim The Wairarapa raised terraces are considered to be the result of coseismic uplift on upper plate reverse faults. However, at other subduction margins (e.g., Alaska megathrust earthquake in 1964, and at the Nankai Trough in Japan) upper plate reverse faults rupture synchronously with the subduction interface. We aim to test whether the c. 600 yrs BP marine terrace along the Wairarapa coast uplifted synchronously with a subsidence event at Big Lagoon and Ahuriri. We will map the extent of the terrace, determine the amount of uplift and precisely date the terrace, which at present is only constrained by two radiocarbon ages.

Achievement Measure

Presentation of results and interpretation to a relevant NZ geoscience conference (by 31 Dec 2014).

Objective Achieved? Yes

Research results

- Our new work indicates uplift of ~1 m (not adjusted for NZ Holocene sea-level curve) during this most recent event on the Wairarapa coast.
- Our new work combined with previous dating indicates that the best estimate for timing of the terrace uplift on the Wairarapa coast is 635±20 cal. yrs BP.
- This age does not correlate with ages determined for inferred subduction paleoearthquakes, manifest as subsidence events at Marlborough (our research aim 1.3) and southern Hawkes Bay (our research aims 1.1 and 1.4).
- This event is considered to be the result of a rupture on a nearby upper plate fault and not on the subduction interface.

Results transfer to users

- One oral paper on Wairarapa terraces study and its interpretation was presented to the NZ scientific earthquake hazards and geological community at the 2014 Geoscience Society of NZ Conference in New Plymouth.
- One GNS Science Report has been produced and disseminated to those likely to have some interest in the results.

Output

Litchfield, N.C., Cochran, U.A., Berryman, K.R., Ansell, B., Clark, K.J. 2013. Timing and amount of uplift of the youngest Holocene marine terrace along the Honeycomb Rock – Riversdale Beach coast, eastern Wairarapa. GNS Science Report 2013/54, 45 p. [see appendix 2]

Research aim 1.3

Title Are there sufficient well-dated subsidence/uplift events along the East Coast to persuasively conclude that there was a great megathrust earthquake ~600 yrs ago and if so, what was its extent and likely magnitude?

Text

The ages of vertical deformation events at Big Lagoon, Wairarapa coast, Ahuriri and Poverty Bay will be constrained using multiple radiocarbon ages, and possibly tephrachronology for the northern sites. The programme, OxCal, will be used to produce probability distributions of the event ages at each site and we will assess these for correlation or non-correlation to one another. If all or some of the vertical deformation events correlate (within the uncertainty bounds of radiocarbon dating) we will use forward elastic dislocation models to estimate the extent and magnitude of the subduction interface earthquake that caused the upper plate deformation.

The elastic dislocation models will be tuned to match the amount of vertical displacement observed at each site.

Achievement Measure

Submission of a manuscript to a high-profile, peer-reviewed journal (by 31 Dec 2014).

Objective Achieved? Yes

Research results

- The previously determined “600 yr paleoearthquake” has been restudied and redated to have occurred at 518-472 cal yrs BP at Big Lagoon (Marlborough), 655-615 cal yrs BP on the Wairarapa coast and 571-406 cal yrs BP (2 sigma) at Ahuriri Inlet, southern Hawkes Bay. There is no record of a sudden vertical displacement event in southern Poverty Bay at about this time. The dating shows that the Wairarapa terrace uplift event was earlier and separate from the subsidence events recorded at Marlborough and Hawkes Bay.
- The subsidence events recorded at Marlborough and Hawkes Bay are quite possibly the same event and, if so, they were most likely generated by rupture of the subduction interface along a substantial length of the Hikurangi Margin.
- Our studies also show that there were significant subsidence events at Big Lagoon at 879-798 cal yrs BP and at Ahuriri Inlet at 1016-865 cal yrs that could also be the same subduction interface rupture or two separate ruptures close in time.
- The 879-798 cal yrs BP subsidence event at Marlborough was accompanied by a tsunami.

Output

Clark, K.J., Hayward, B.W., Cochran, U.A., Wallace, L.M., Grenfell, H.R., Power, W.L., Sabaa, A.T., Submitted. Subduction earthquakes at the southern Hikurangi margin, New Zealand, over the past 1000 years. [see appendix 3]

Hayward, B.W., Clark, K.J., Sabaa, A.T., Cochran, U.A., Submitted. Taphonomically-and infaunally-adjusted salt marsh foraminiferal record of late Holocene earthquake displacements and a tsunami sand, New Zealand. [see appendix 4]

Research aim 1.4

Title What is the likely recurrence time of earthquakes similar to the 600 yr event based on comparison with the previously published subsidence events at Ahuriri?

Research aim If the c. 600 yr BP subsidence event at Ahuriri is shown to relate to a likely megathrust earthquake we will compare the characteristics of that event horizon with subsidence events known to be recorded in the older Ahuriri sedimentary record. If the event horizons share similar characteristics in terms of spatial extent, amount of displacement and suddenness of change then they likely relate to the same earthquake source. We will attempt to attain a recurrence on subduction earthquakes by dating older subsidence events at Ahuriri. We will radiocarbon date existing core material or, if feasible, attain new vibracores.

Achievement Measure

Presentation of results of all Research aims to relevant Regional Council and Civil Defence staff. Publication in manuscript associated with Research Aim 1.3 or a separate manuscript depending on results obtained. During this contract these results will be progressively reported to the New Zealand earthquake hazards community through reports, and oral presentations (by 31 Dec 2014).

Objective Achieved? Yes

Research Results

- Our new research at Ahuriri recognises eight (six previously recognised) large subsidence events in the last 7200 yrs dated at: 7323-6988 cal yrs BP, 5228-4873 cal yrs BP, 4375-3736 cal yrs BP, 2814-2405 cal yrs BP, 1739-1686 cal yrs BP, 1496-1256 cal yrs BP, 1024-865 cal yrs BP, 571-406 cal yrs BP.
- Each of these events resulted in 0.6-1.2 m of subsidence at Ahuriri and is likely to have been generated by rupture on the same fault which we infer was most probably the subduction interface.
- Based on the above dated events, we conclude that the time interval between these inferred subduction interface earthquakes was highly variable. Over the past 7200 years the recurrence time averages 900 yrs. The average recurrence time between the last four events however was only 410 yrs.
- The 1931 Hawkes Bay Earthquake produced about 1.5 m uplift at Ahuriri and was therefore quite different from the more common large subsidence events in southern Hawkes Bay. An uplift event has been identified at Ahuriri and dated at 5520-5203 cal yrs BP. Like the 1931 earthquake it was probably generated by rupture on a local upper plate thrust fault.

Results transfer to users

In 2013 and 2014 members of our team have presented four conference papers (3 oral, 1 poster) and attended two workshops with local authority officials.

- Bruce Hayward and Kate Clark presented one oral and one poster paper on the Big Lagoon Marlborough results to the NZ earthquake hazards and scientific and geological community at the 2013 Geoscience Society of NZ Conference in Christchurch.
- Bruce Hayward presented one oral paper on Poverty Bay results to the NZ scientific earthquake hazards and geological community at the 2014 Geoscience Society of NZ Conference in New Plymouth.
- Kate Clark presented an oral paper on Big Lagoon, Marlborough results and their interpretation in terms of subduction interface earthquakes to a global earthquake hazard community at the Geological Society of America Conference in Vancouver in 2014.

- Ursula Cochran presented recent results and answered questions on our Hikurangi subduction zone earthquake research to the Hawke's Bay and Gisborne Civil Defence and Emergency Management Groups at the Hawke's Bay CDEM Group's Hazard Research Review workshop on 29th May 2014.
- Kate Clark (Big Lagoon, Wairarapa terraces) and Laura Wallace (Subduction interface) gave presentations and answered questions on our subduction earthquake studies at a Cook Strait tsunami workshop for officers of Wellington Regional Council, Marlborough District Council, Tasman District Council and Environment Canterbury on 26th June 2014.

Output

Manuscripts

Hayward, B.W., Grenfell, H.R., Sabaa, A.T., Clark, K.J., Cochran, U.A., Palmer, A.S., Submitted. Drivers of environmental change in three Holocene embayments on the western edge of Ahuriri Inlet, Hawkes Bay, New Zealand. [see appendix 5]

Hayward, B.W., Grenfell, H.R., Sabaa, A.T., Clark, K.J., Cochran, U.A., Wallace, L.M., Palmer, A.S. Final draft ready for submission in Jan 2015. Salt-marsh foraminiferal record of ten large Holocene (last 7500 yrs) earthquakes on a subducting plate margin, Hawkes Bay, New Zealand.

Conference abstracts

Clark, K., Cochran, U., Litchfield, N., Wallace, L., Hayward, B.W., 2013. Comparison of prehistoric and contemporary coastal deformation along the Hikurangi margin and implications for subduction earthquake studies. Abstracts, Geosciences 2013 Conference, Christchurch. Geoscience Society of New Zealand Miscellaneous Publication 136A, 17.

Hayward, B.W., Sabaa, A.T., Clark, K.J., Cochran, U.A., 2013. Taphonomically-adjusted foraminiferal paleoelevation estimates provide improve Holocene earthquake records from New Zealand salt marshes. Abstracts, Geosciences 2013 Conference, Christchurch. Geoscience Society of New Zealand Miscellaneous Publication 136A, 40.

Clark, K.J., Hayward, B.W., Cochran, U.A., Wallace, L.M., Grenfell, H.R., Power, W.L., Sabaa, A.T., 2014. Evidence for paleo-subduction earthquakes and tsunami at a margin with pervasive active upper plate faulting: southern Hikurangi Margin, New Zealand. Abstracts, Geological Society of America Conference, Vancouver, 46(6), 32.

Hayward, B.W., Sabaa, A.T., Grenfell, H.R., Cochran, U.A., Clark, K.J., Litchfield, N.J., Wallace, L.M., Marden, M., Palmer, A.S., 2014. Foraminiferal record of Holocene paleo-earthquakes on the subsiding south-western Poverty Bay coastline, New Zealand. Abstracts, Geosciences 2014 Conference, Christchurch. Geoscience Society of New Zealand Miscellaneous Publication, 47.

Litchfield, N., Cochran, U.A., Berryman, K., Clark, K.J., 2014. Age and altitude of a young marine terrace on the Wairarapa coast: implications for Hikurangi Margin tectonics. Abstracts, Geosciences 2014 Conference, Christchurch. Geoscience Society of New Zealand Miscellaneous Publication, 66.

Conclusions & Recommendations:

- Our research dates the youngest subsidence events at both Hawkes Bay and Marlborough at approx. 500 yrs ago and suggests that they were possibly the same event. If so, then this event was most likely produced by rupture on the subduction interface along at least 350 km of the Hikurangi Margin (southern half of the east coast of the North Island).

- We date the second youngest subsidence event at both Hawkes Bay and Marlborough at approx. 900 yrs ago and this too could have been a single subduction earthquake, similar to that ~500 yrs ago.
- We record and date a further six earlier subsidence events at southern Hawkes Bay since 7200 yrs ago and these likely had similar subduction earthquake origins to the two most recent.
- The average recurrence times in Hawkes Bay for inferred subduction earthquakes over the past 7500 yrs has been 900 yrs, but has been closer to 400 yrs over the last 2000 yrs.
- We conclude that New Zealand's Hikurangi plate margin along the east side of the North Island does have a Holocene record of subduction earthquakes and it is highly probable that another will occur in the future.
- Future work could be directed towards:
    a. Improving the precision of dating of the youngest subsidence event in Hawkes Bay, possibly in other embayments of Ahuriri Inlet (such as around Park Island).
    b. Coring deeper in the Poraiti Rd end and Ohingaora embayments of Ahuriri Inlet to find more complete and higher resolution records of displacement events between 7500 and 3500 yrs ago, to improve our understanding of recurrence times and their possible variability through time.
    c. Searching for pre-1000 yr old records of subsidence events elsewhere in the lower Wairau Valley, Marlborough, or in other coastal areas nearby such as at Lake Grassmere.
    d. Finding a record of discrete subsidence events in the Holocene sediments at Porangahau by locating paleo salt marsh deposits.
    e. Finding and better dating of paleotsunami deposits that may be related to subduction earthquake along the east coast of the North Island.
    f. Recording and dating turbidite deposits, possibly generated by these major earthquake events, in deep-sea sedimentary records east of the southern North Island,– to test the hypothesis that these events involved rupture and significant shaking along 300 km+ of the plate boundary.
    g. Our research results need to be built into any updating of the *New Zealand National Seismic Hazard model* and the increased likelihood of such a major event promulgated to organisations involved with hazard awareness.
    h. The Hawkes Bay TLAs and Civil Defence need to be further informed about the increased risk and likely much shorter recurrence time to the next major subsidence event and its impact on the low-lying land currently being developed for subdivision west of Napier.

Appendices: List them here or include as attachment(s).

Appendix 1. Hayward, B.W., Sabaa, A.T., Grenfell, H.R., Cochran, U.A., Clark, K.J., Litchfield, N.J., Wallace, L.M., Marden, M., Palmer, A.S., in press. Foraminiferal record of Holocene paleo-earthquakes on the subsiding south-western Poverty Bay coastline, New Zealand. New Zealand Journal of Geology and Geophysics. MS accepted.

Appendix 2. Litchfield, N.C., Cochran, U.A., Berryman, K.R., Ansell, B., Clark, K.J. 2013. Timing and amount of uplift of the youngest Holocene marine terrace along the Honeycomb Rock – Riversdale Beach coast, eastern Wairarapa. GNS Science Report 2013/54, 45 p.

Appendix 3. Clark, K.J., Hayward, B.W., Cochran, U.A., Wallace, L.M., Grenfell, H.R., Power, W.L., Sabaa, A.T., Submitted. Subduction earthquakes at the southern Hikurangi margin, New Zealand, over the past 1000 years.

Appendix 4. Hayward, B.W., Clark, K.J., Sabaa, A.T., Cochran, U.A., Submitted. Taphonomically-and infaunally-adjusted salt marsh foraminiferal record of late Holocene earthquake displacements and a tsunami sand, New Zealand.

Appendix 5. Hayward, B.W., Grenfell, H.R., Sabaa, A.T., Clark, K.J., Cochran, U.A., Palmer, A.S., Submitted. Drivers of environmental change in three Holocene embayments on the western edge of Ahuriri Inlet, Hawkes Bay, New Zealand.