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Coastal Environmental Change
During Sea-Level Highstands:
A Global Synthesis with implications
for management of future coastal change

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Is there a precursor to great subduction zone earthquakes?

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Abstract

Veiled behind the scientific justification of studying past environmental processes such as sea-level change (indeed within the proposal documents for more than one IGCP project) in order to better understand a complex interaction of processes lies a difficult question, but one totally justified by the needs of society. At what point can our investigations emerge to produce results, interpretations or models that identify a hazard and potentially reduce risk?

Early on in our investigations of great subduction zone earthquakes in south-central Alaska we identified a phase of relative sea-level (RSL) rise that preceded the 1964 earthquake. This differed from a consensus view described by the earthquake deformation cycle model at that time. Microfossil and ^{137}Cs analyses (Hamilton 1998; Shennan et al., 1999) demonstrated that this pre-seismic RSL rise commenced about a decade before the earthquake. Karlstom (1964) provides observational evidence, of marsh sedimentation at Girdwood, to support this. In contrast, seismological models, themselves very contentious, suggested that if such a phase existed it was in the order of days to months.

We evaluate the stratigraphic evidence for the 1964 event and other great earthquakes over the last 5000 years, at four sites around the Cook Inlet: Kenai, Girdwood, Kasilof and Ocean View, Anchorage. At all sites there is evidence for a rise in RSL prior to the 1964 earthquake (where it is recorded) and the preceding events. Most pre-seismic signals occur in 3 – 5cm of sediment below the earthquake horizon and have their own diatom assemblage rather than a mixture of diatoms found in the underlying peat together with those from the overlying silt. Quantitative reconstructions from diatom transfer functions suggest pre-seismic RSL rise ranges from +0.07 ± 0.10 m to +0.21 ± 0.10 m.

Other possible explanations for pre-seismic RSL rise include a temporary change in sea level due to the El Nino Southern Oscillation (ENSO).

ENSO can cause higher water levels along the west coast of the USA and Alaska, for example, the 1997-1998 El Nino caused a short-lived sea-level rise during the winter of approximately 0.20 m at Seldovia and Seward, Alaska (data from http://pmel.noaa.gov).

Any effect before the 1964 event would be as short lived and the magnitude would be even smaller as the only El Nino as large as the 1997-1998 occurred in 1940-1942.

Observations at Girdwood by Karlstrom (1964) suggest that the relative sea-level rise started in 1953 corresponds to an El Nino peak but it could not account for continued flooding of the marsh surface between 1954 and 1957 when El Nino was weak.

The short-term effect could not account for a relative sea-level rise over the period of several years to a decade and it is hard to envisage how such a process could occur before every peat-silt boundary. Other possibilities include sediment mixing around boundaries due to the flow or percolation of water, diatoms burrowing through the sediment column, tidal inundation and effects of ice.

Mulholland (2002) took an experimental approach to investigate any pre-seismic relative sea-level rise.

Blocks of salt marsh sediment were extracted and transplanted into the tidal flat at Kenai, Alaska and Cowpen Marsh, UK, and sediment allowed to accumulate for up to nine months.

This simulated co-seismic submergence and investigated whether mixing from any cause, including bioturbation and effects of ice, could account for the pre-seismic signal using computer modelling. Mulholland (2002) found that bioturbation is limited to a few millimetres and so it cannot account for a pre-seismic signal over a few centimetres.

If it does form part of the EDC model and occurs over several years to a decade, possible mechanisms of pre-seismic RSL rise include aseismic slip (e.g. Dragert et al., 2001; Miller et al., 2002). For example, tide gauge data in Japan (Katsumata et al., 2002) record several centimetres of aseismic subsidence during a five year period before the 1994 Hokkaido-Toho-Oki earthquake (magnitude 8.3). Other possible mechanisms include certain seismic quiescence models (e.g. Kato et al., 1997; Wyss et al., 1981; Dieterich and Okubu, 1996).

Pre-seismic RSL rise does appear to be a common feature of Holocene great earthquakes in Alaska. Seismological models developed on observational data need to take account of these late Holocene relative sea-level movements.

If it is possible to resolve the seismological models, short-term, present-day geodetic observations and the Holocene evidence, then we may be able to move forward in identifying future great earthquakes.

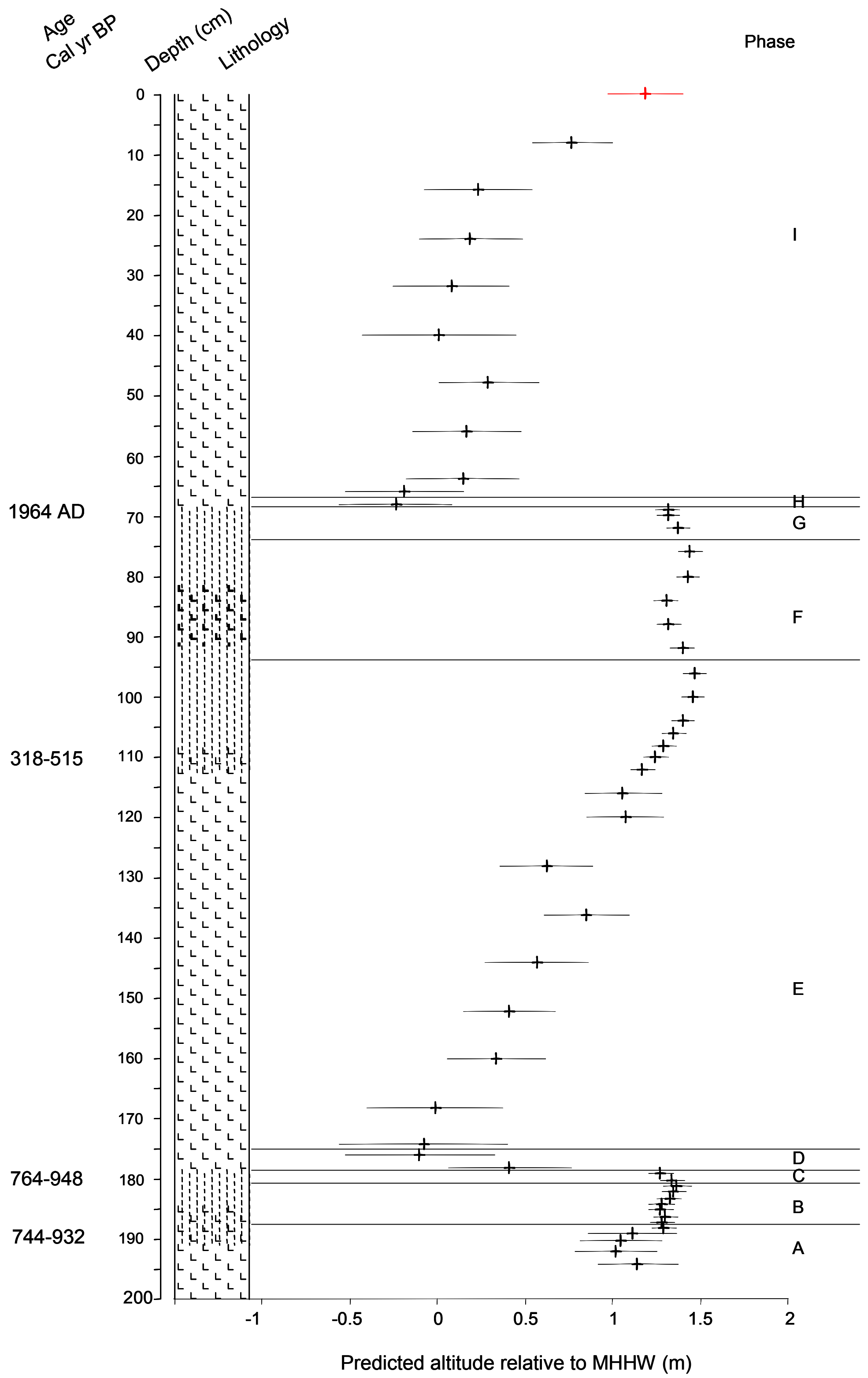

Figure 1

Figure 1. Reconstruction of relative sea-level change for two earthquake cycles at Girdwood, Alaska. Phases C and G record pre-seismic relative sea level rise.

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