Late Holocene great earthquakes in the eastern part of the Aleutian megathrust

Ian Shennan¹, Ronald Bruhn², Natasha Barlow¹, Kelly Good², Emma Hocking¹,³

¹ Sea Level Research Unit, Department of Geography, Durham University, Durham, DH1 3LE, UK
² Department of Geology and Geophysics, University of Utah, Salt Lake City, UT 84112-0111, USA
³ Current address: Department of Geography, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK

ABSTRACT

The great earthquake, Mw 9.2, of AD 1964 may not be typical of other megathrust earthquakes in the region during the last 4000 years. We present new field data from three sites: Copper River Delta, the lower Katalla River valley and Puffy Slough, to enhance the temporal and spatial resolutions of the paleoseismic records of multiple great earthquakes. Differences in the spatial patterns of coseismic uplift and subsidence suggest different rupture combinations of the Kodiak, Prince William Sound and western Yakutat segments of the plate boundary. The longest and most comprehensive records all come from the Prince William Sound segment. Most sites here reveal net subsidence over multiple earthquake cycles except where probable upper plate faulting contributes locally to net uplift, with measurable differences between sites only a few kilometers apart. We identify the Katalla area as a source of local seismic hazard, similar to other locations in the western part of the Yakutat microplate, including the two Mw8+ ruptures in AD 1899. We use a Bayesian radiocarbon modeling
approach to estimate the age and recurrence intervals of multiple great earthquakes for
the Prince William Sound segment of the megathrust. The long interval, $883 \pm 34$ (2σ) years, between the penultimate earthquake and AD 1964 contrasts with the older earthquakes that have intervals ranging from ~420 to ~610 years, with a mean of ~535 years.

1. INTRODUCTION

Paleoseismological investigations provide both major inputs and challenges for seismic hazard assessment. While the classic notion of the characteristic earthquake, with constant dimensions and recurrence interval over multiple earthquake cycles, forms the basis for the time-independent seismic hazard maps of Alaska (Wesson et al., 2007), the growth of paleoseismological studies and improvements in analytical methods (Boyd et al., 2008) raise fundamental questions that require further analysis, including segmentation and magnitude-frequency relationships (Wesson et al., 2008). The great Alaskan earthquake, $M_w 9.2$, of March 1964, ruptured ~950 km of the Aleutian megathrust, encompassing the Kodiak and Prince William Sound segments (Carver and Plafker, 2008), and resulted in coseismic uplift adjacent to the trench and a zone of subsidence to the north and northwest (Figure 1).

Coastal marshes can register coseismic vertical land motions through changes in sediment lithology and biostratigraphy, providing records of 1964 and previous great earthquakes. The latest of these occurred ~500 years ago and ruptured only the Kodiak
segment (Carver and Plafker, 2008), while correlation of radiocarbon ages suggest earlier great earthquakes involved either multi-segment ruptures or closely timed sequences of single segment ruptures (Carver and Plafker, 2008; Hutchinson and Crowell, 2007; Shennan et al., 2009). The longest records come from the eastern part of the Prince William Sound segment, at Copper River Delta, with ten great earthquakes since ~5000 cal yr BP (Carver and Plafker, 2008). Farther east, uplifted coastal sediments suggest that earthquakes ~900 and ~1500 years ago may have simultaneously ruptured adjacent segments of the Aleutian megathrust and the Yakutat microplate (Shennan et al., 2009).

Here we use new field data from Copper River Delta, the lower Katalla river valley and Puffy Slough (Figure 2) to enhance the temporal and spatial resolutions of the paleoseismic records of multiple great earthquakes. We provide a new synthesis and temporal model of earthquake recurrence through the Late Holocene using the Bayesian modeling approach outlined by Lienkaemper and Bronk Ramsey (2009) and aim to explain variations in the spatial pattern of coseismic deformation between sites during the Late Holocene.

2. FIELD AND LABORATORY METHODS

In analyzing coastal sediment sequences, four critical criteria help determine a co-seismic signal and discriminate from non-seismic processes that might cause abrupt wetland submergence or emergence: lateral extent of peat-mud couplets with sharp contacts; suddenness of subsidence or emergence; amount of vertical motion; and
synchronicity with other sites (Nelson et al., 1996). Presence of tsunami sediments may also help in certain geographical settings. We use exposures and sediment cores to assess the lithological evidence for these criteria, diatom-based transfer function models to quantify the vertical motion, and AMS radiocarbon dating of in situ herbaceous macrofossils to provide a chronology for each site. For the transfer function models we use a regional-scale modern training set collected from a wide range of marshes across ~1000 km of south central Alaska in order to seek the best fit between fossil and modern diatom assemblages (Watcham et al., 2013). We use three models, constrained by the lithology of the Holocene sediment sequence (Table 1); one for peat sediment, a second for silt units with visible plant rootlets and a third for silt units with no rootlets (Hamilton and Shennan, 2005). We assess goodness of fit between each fossil sample and the modern dataset using a dissimilarity coefficient, using the 20th percentile of the dissimilarity values for the modern samples as the cut-off between ‘close’ and ‘poor’ modern analogues for fossil samples, and the 5th percentile as the threshold for defining ‘good’ modern analogues (Hamilton and Shennan, 2005). For reconstructions of the elevation at which the fossil sediment was laid down, termed paleo marsh surface elevation, we present sample-specific 95% error terms.

3. NEW FIELD DATA

3.1 Copper River Delta

During the 1964 earthquake the delta was raised on the order of 2 to 3 m (McCalpin and Carver, 2009; Plafker, 1969). Previous investigations record up to nine pre-1964
earthquakes, revealed by multiple couplets of silt overlain by peat, representing coseismic uplift of intertidal mud flats, colonization by freshwater marshes, and gradual interseismic subsidence (Carver and Plafker, 2008; Plafker et al., 1992). The vertical sequence of couplets seen in cores, some more than 11 m in depth, and sections indicates net submergence over multiple earthquake cycles, i.e. the sum of non-seismic relative sea-level change (glacio-isostasy and eustasy), sediment compaction and inter-seismic subsidence is greater than coseismic uplift.

Two pre-1964 silt-peat sequences are widely exposed in the uppermost ~4 m of the delta sediments exposed along tidal channels (Figure 3) but correlation of some of the older couplets recorded from coring is problematical (Carver and Plafker, 2008). Our primary aim of collecting new material from Copper River Delta was to obtain estimates of the coseismic uplift for different Late Holocene earthquakes. We sampled at three locations along an 8 km stretch of Alaganik Slough (Figure 4), one of the tributaries in the delta west of the main river, using exposures and cores to establish the lateral continuity of each silt-peat couplet in the field.

Our diatom analyses highlight a key challenge of reconstructing land-level changes in this large delta. We found highly variable diatom preservation in the silt units. For each silt-peat couplet sampled and dated (Table 2) we could count sufficient diatoms in the silt unit to at least confirm formation within an intertidal environment but about half of the samples had insufficient numbers to reach the minimum sum, 200, that we consider suitable for quantitative analysis. We believe one of the major controls on diatom
abundance in tidal silt is the very high sediment concentration of the Copper River, the
delta and adjacent coastal waters. Of the surface samples we collected from Copper
River Delta to contribute to the modern training set described above, 14 of the 26 that
came from unvegetated tidal flat contained insufficient diatom numbers to reach the
minimum count so it is perhaps not unexpected to encounter similar limitations with
fossil sequences.

The most complete records are for the youngest pre-1964 silt-peat couplet, sampled at
all three sites. Diatom assemblages (Figure 4) record the greatest changes in salinity at
the most seaward site, 3, with lesser changes progressively upstream, as expected
where the influence of freshwater discharge becomes more dominant. At site 3 the
transfer function model estimates coseismic uplift ~1.3 m (Figure 5), at site 2 it is in the
order of 0.5 m, but with overlapping error terms, and at site 1 there is no clear change in
elevation. This may reflect the true pattern of differential uplift but it may also reflect the
increasing importance of river discharge as the controlling variable in sedimentation with
increasing distance from the open coast. For example, had we only studied this couplet
in the area around site 1 we would not be able to satisfy the demonstrable vertical
motion criterion outlined by Nelson et al. (1996) for attributing a couplet to a great
earthquake. In large coastal systems we recognize that certain areas will be sensitive
recorders of rapid emergence or submergence whereas other parts of the system are
relatively insensitive, as other parameters become more important controls on
sedimentation.
The radiocarbon age for the peat-silt couplet at site 1 also illustrate the limitations of
dating just the base of the peat unit as there may be a hiatus following uplift before plant
colonization and peat accumulation. It is preferable to bracket the event horizon with
two or more dated samples (Carver and Plafker, 2008; Shennan et al., 2009).

Low diatom abundances prevent us obtaining quantitative reconstructions for the older
couplets, except for the middle peat at site 3, where estimated uplift is ~1.1 m. We note
that the samples from this peat have poor modern analogues but their reconstructed
elevations are very similar to all the other samples from peat layers (Figure 5). In a
following section we consider this issue further alongside others that may complicate
the reconstruction of coseismic uplift.

3.2 Katalla River Valley

The Ragged Mountain Fault is located along the west side of the Katalla valley and
marks the western edge of the Yakutat Microplate (Figure 1). At the mouth of the Katalla
River, coseismic uplift of 1 to 3 m in 1964 raised the tidal marshes in the lee of a
vegetated storm ridge above the elevation of storm tides (McCalpin and Carver, 2009;
Plafker, 1969). Numerous prominent ridges occur upstream with low lying marshes
between them (Figure 6). Strata within the marshes record a Late Holocene archive of
net coastal progradation and relative land and sea-level change driven by repeated
cycles of coseismic uplift, interseismic relative sea-level rise/land subsidence, glacio-
isostasy and eustasy (McCalpin and Carver, 2009; Plafker, 1969; Richards, 2000; Sirkin
and Tuthill, 1971). A silt horizon, at river level and ~7 m above mean sea level
(Richards, 2000; Sirkin and Tuthill, 1971) contains mollusc species indicative of intertidal conditions and dated to ~7 ka BP. Assuming a tidal range similar to present (MHHW ~+1.55 m MSL and HAT ~2.65 m MSL), the mollusc bed indicates at least 4.35 m relative uplift over the past 7000 years. Sirkin and Tuthill (1971) indicate even older marine deposits, >14 ka BP, may occur further up the valley.

The marsh stratigraphy between the ridges in the lower valley (Figure 6) provides evidence of five episodes of coseismic uplift prior to 1964. The oldest is a minimum limiting age of ~2650 – 2350 cal yr BP obtained from the base of peat overlying silt, in marsh 5, location 5.3 (Figure 6). None of the samples contained sufficient diatom abundances to provide quantitative reconstructions but the species present across this abrupt silt-peat couplet, which could be traced laterally in a series of cores, indicate freshwater marsh developed on uplifted intertidal sediment. The gradual transition up the core from peat to silt indicates relative sea-level rise and return to intertidal sedimentation. The same location records a second cycle of coseismic uplift, minimum limiting age, ~2120 – 1950 cal yr BP, and interseismic relative sea-level rise.

We infer the next uplift event from the incision of intertidal/subtidal sand that is abruptly overlain by lagoon mud at location 3.1, dated ~1510 – 1340 cal yr BP. Plant macrofossils within the top of the silt unit and the base of the surface peat of marshes 3, 4 and 5 bracket the next earthquake horizon between 1120 – 960 cal yr BP and the three minimum ages 930 – 790, 790 – 690 and 760 – 680 cal yr BP (Figure 6). Diatom abundances were low in most samples across each of these silt-peat contacts; only that
from location 3.1 containing sufficient numbers to allow quantitative reconstructions of
elevation. Frequencies of individual species and the salinity summary classes show a
distinct change across the contact (Figure 7), with possibly some mixing within the top 2
cm of the silt horizon. Transfer function reconstructions indicate uplift in the order of 0.5
to 1 m between the silt and peat samples with close modern analogues while the two
samples from the top of the silt have poor modern analogues. We discuss further the
evidence for potential sediment and diatom mixing in a later section.

The final earthquake horizon is the contact between a subsurface peat and intertidal
sand that lies below the intertidal flat deposits that were uplifted in 1964 to become
freshwater marsh behind the prominent pre-1964 dune ridge (Figure 6). Samples from
two cores 2.5 km apart give minimum ages of 550 – 500 and 510 – 310 cal yr BP for
coseismic uplift, followed by freshwater marsh developed on raised intertidal sediment
surface, then relative sea-level rise and return to intertidal sedimentation in the tidal inlet
seen on pre-1964 aerial photographs (Figure 6b).

In summary, the record at Katalla shows a complicated interaction of multiple
earthquake cycles, with coseismic uplift and interseismic submergence, superimposed
on coastal progradation and non-seismic sea-level change. The net effect of eustasy
and glacio-isostasy is poorly understood for the area. While we see net relative uplift
over the past 7000 years, from the mollusc bed (Figure 6), the silt-peat couplets at site
3.3 are much closer to the formation elevations we get from the transfer function
estimates for peats at both Katalla and Copper River Delta, ~0.5 to 1 m above MHHW.
Therefore net uplift over the last 2500 years is very small. In contrast, the peat-silt contact dated by minimum ages ~700 to 900 years ago at sites in three of the marshes (Figure 6) is well above the modern formation elevation, indicating recent net uplift. This may relate to a different seismic source for the most recent pre-1964 earthquake, recorded ~500 cal yr BP at sites in marsh 2, which we discuss further in the discussion section below.

3.3 Puffy Slough

Preliminary investigations of exposed sections and cores at Puffy Slough, an intertidal tidal marsh pre-1964, east of the Don Millar Hills and 2 to 5 km east of the Katalla sites, reveal >6 m of silt with up to three silt-peat couplets, all with sharp lower contacts and gradational upper contacts. These suggest at least three episodes of rapid uplift separated by gradual submergence (Figure 6d). With only seven cores taken across the marsh and low diatom counts in the silt units we simply note that the site appears to record a paleoseismic record with net submergence over multiple earthquake cycles, resulting from the combination of seismic and non-seismic land and sea-level change. The record at Puffy Slough contrasts with Katalla in at least two key respects. First, the absence of evidence for the earthquake and uplift recorded in marsh 2 at Katalla, dated ~500 cal yr BP. Second, the youngest pre-1964 couplet, minimum age 760 – 670 cal yr BP, at Puffy Slough is at a lower elevation than the equivalent contact at Katalla, where it is at the base of the surface peat and not recording net submergence reverting to intertidal sedimentation.
4. QUANTIFYING COSEISMIC UPLIFT

Whereas coseismic subsidence may result in a peat-silt couplet, caused by submergence of freshwater marsh and rapid sedimentation of intertidal minerogenic deposits commencing hours to weeks after the earthquake (Atwater et al., 2001), peat formation on uplifted intertidal mudflat will not be instantaneous. There will be a time-lag before the colonization of the exposed sediment surface by terrestrial plant communities. Therefore, as noted above, we treat radiocarbon dates from the base of the peat as minimum ages for the earthquake. Diatom analyses across the silt-peat contacts from Katalla revealed a common phenomenon of mixed salinity assemblages in the upper part of the silt unit. In some cases it was limited to the single sample at the contact (Figure 7), but in others it extended further (Figure 8). At Katalla 5.5 we see a peak of *Tabellaria flocculosa* across the silt-peat contact, commencing ~4cm below the base of the peat. *T. flocculosa* is a freshwater species most commonly found attached to the submerged stems of littoral species of sedges and reeds (Knudson, 1954; Patrick and Reimer, 1966). We interpret this as evidence of ponding of freshwater on the surface of the uplifted tidal flat, now above the limit of tidal inundation. Diatoms can colonise and grow within a few weeks, therefore reflecting the environment following uplift but before colonization by terrestrial plants. During this time we may expect redistribution of surface sediment by a variety of processes, including rain, wind, surface water flow and winter ice freeze-thaw. Where this occurs the redeposited silt with freshwater diatoms does not represent the pre-earthquake environment and elevation. At Katalla 5.5 low diatom counts prevent us taking this analysis further but it may be that
the base of the visibly coarser layer at 102 cm (Figure 8 and 9) is the earthquake
devolution horizon, overlain by 5 cm of reworked silt with mix of diatoms from two main sources;
those already in the silt and those growing during the period of sediment reworking and
deposition. We have seen comparable evidence for similar sequences of events
between the time of uplift and peat formation at other sites. Figure 10c shows a box
sample from a tidal exposure at Copper River Delta that we declined to analyse further
as we could not trace the lateral continuity of the coarse layer more than a few meters in
the time available during the fieldwork. Mixed diatom assemblages below the modern
peat on the marsh at Cape Suckling uplifted in 1964 (Shennan, 2009) may also be the
result of sediment reworking on the uplifted surface prior to peat growth.

In summary, up to four factors may combine to make it probable that reconstructions
based on sediment and diatom stratigraphies will give minimum estimates of both the
age of a Holocene earthquake and the amount of coseismic uplift. First, there is the
time interval between uplift and peat accumulation. Second, there may be sediment
reworking at the top of the silt unit so it may be difficult to establish the pre earthquake
paleo surface elevation; mixing of tidal flat and purely freshwater diatom communities
would produce a too high estimate. Third, there will be initially rapid post-seismic
subsidence during the time interval between uplift and peat accumulation. For example,
at Cordova, only a few kilometers west of Copper River Delta, following uplift in 1964,
the tide gauge shows ~20 cm sea-level rise 1964 to 1979 and ~ 5 cm further rise 1979
to 2012 (NOAA, 2013). Finally, ground shaking of the unconsolidated tidal flat sediment
column during the earthquake may cause compaction and dewatering of unconsolidated sediment and surface lowering.

5. AGE MODELLING

The OxCal Bayesian modeling approach outlined by Bronk Ramsey and Lienkaemper (Bronk Ramsey, 2009; Lienkaemper and Bronk Ramsey, 2009) determines the best-fit ages and recurrence intervals of multiple great earthquakes. It allows us to combine the ages on earthquake horizons from all sites across the Prince William Sound segment, whether they record coseismic uplift or coseismic subsidence. This a fundamental difference to previous studies which first determine the chronology at each site, then compare the patterns between sites (Carver and Plafker, 2008; Shennan and Hamilton, 2006).

This new approach assumes that the dated indicators of uplift or subsidence are either minimum or maximum ages on the earthquake horizon. For coseismic subsidence, maximum ages come from a peat contact below an intertidal silt unit and minimum ages from samples within the silt unit. For coseismic uplift, maximum ages come from the top part of intertidal silt below peat, and minimum ages from the peat (e.g. Figures 4 and 6).

Previous studies from Cook Inlet demonstrated the potential of contamination of bulk peat samples by older carbon, such as coal deposits in the catchment (Hamilton et al., 2005), so we exclude bulk peat samples from that area. With many bulk peat dates available for other areas, particularly the key record from Copper River Delta published
previously (Carver and Plafker, 2008) we compared ages using bulk peat and AMS
dated samples on in situ plant macrofossils from the same locations. Whereas we see
major differences in the ages of the paired samples for sites around Cook Inlet we find
no significant differences for the four from Copper River Delta (Figure 10). Therefore
we include bulk peat ages from Copper River Delta in our analysis, but only ages for
samples of macrofossils at all other sites.

The OxCal Bayesian model seeks to estimate the age of each earthquake that is
bracketed by dated samples assuming no knowledge of sedimentation rate pre- or post-
earthquake. Samples are grouped into “phases”, where one phase is all the samples
giving a minimum age on earthquake \( n \), and another phase will be all the maximum
ages for earthquake \( n \) (Lienkaemper and Bronk Ramsey, 2009). There is no
chronological ordering within a phase, but the stratigraphic ordering of phases and
earthquake horizons is a powerful constraint (Figure 11a). Our full model uses 9 pre-
historic earthquakes of unknown age and the 1964 earthquake as a known boundary.
We exclude the ~ 500 cal yr BP earthquakes at Kodiak and Katalla as we have no
evidence for them rupturing other parts of the 1964 rupture zone. Between each pair of
earthquakes we have two phases, assuming the phase of minimum ages for the older
earthquake occurs before the phase of maximum ages for the younger earthquake
(Figure 11a). OxCal provides graphical output (Figure 11b) of the modeled probability
density functions for each sample along with the likelihood distribution from the
radiocarbon measurement, and the probability density function of each earthquake age
and interval between earthquakes, which we summarise with the mean and 95.5% probability range (Table 3).

6. EARTHQUAKE AGES AND RECURRENCE

The OxCal Bayesian model gives the age of the penultimate great earthquake as 870 ± 34 BP (2σ) with decreasing precision for each older earthquake (Figure 12a and Table 3). This is a function of both the number of samples available, in part reflecting the limits to coring depth, and the number of sites which record the earthquake. We do not consider further the oldest three earthquakes (not shown in figure 12) as they are only constrained by samples from one site (Copper River Delta) and the precision of the estimated ages is poor, ± 180 to ± 300 years.

The mean recurrence interval for the seven earthquakes from EQ6, ~3550 cal yr BP, to 1964 is ~595 years. This average is heavily influenced by the relatively long interval, 883 ± 34 (2σ) years, between the EQ1 and 1964, compared to the intervals between the older earthquakes (Figure 12b). The pre-1964 earthquakes have recurrence intervals that range from ~420 to ~610 years, with a mean ~535. While it would be preferable to have more samples from more sites for EQ5 and EQ6 in order to better constrain their ages and interval, it seems clear that the interval between the penultimate great earthquake and 1964 is the longest recorded.

7. DISCUSSION AND CONCLUSIONS
Is the 1964 earthquake typical of other Late Holocene great earthquakes? In terms of coastal stratigraphy we certainly see comparable sediments and biostratigraphy, but in addition to the temporal variations discussed above, there are also spatial differences in the paleoseismic record (Carver and Plafker, 2008; Hamilton and Shennan, 2005b; Shennan and Hamilton, 2006). For example, the coseismic uplift recorded east of Cape Yakataga correlates with the penultimate earthquake at numerous other sites (Figure 13), and may indicate a greater area of rupture than in 1964 (Shennan et al., 2009) yet there is no evidence of coseismic subsidence at Kenai and Kasilof, on the Cook Inlet shore of the Kenai Peninsula (Shennan and Hamilton, 2006) (Figure 1). The Kenai record, along with archaeological evidence, led Hutchinson and Crowell (2007) to suggest that the 1964 rupture zone comprises three segments that may not always rupture together: Kodiak, Kenai and Prince William Sound.

It is critical to note that the longest and most comprehensive records all come from the Prince William Sound segment and the area of flat slab subduction of the Yakutat microplate (Figures 1 and 13) and at this stage we can draw three main conclusions with respect to this region. First, multiple earthquake cycles over at least the past 4000 years in the Prince William Sound segment follow the same general pattern of coseismic uplift and subsidence as 1964 yet show net subsidence over this period at most sites. To separate the effects of glacial isostatic adjustment, eustasy and interseismic tectonic motions will require expansion of existing modeling approaches (Barlow et al., 2012). Glacio-isostasy and eustasy produce differences in relative land and sea levels.
that occur gradually through time and over distances on the order of 10s to 100s of kilometers.

In contrast, we observe measurable differences in net motion over shorter distances, for example, between Katalla and Puffy Slough, Katalla and Copper River Delta, described above, and between the Suckling Hills/Cape Suckling and the marsh immediately to the west, discussed by Shennan (2009). Therefore we consider the possibility of upper plate faulting and slip on the megathrust contributing to these differences over short distances, superimposed on the broader scale effects of glacio-isostasy (Barlow et al., 2012; Shennan and Hamilton, 2010).

A schematic cross section of the plate boundary from Cook Inlet to the Malaspina Glacier places the paleoseismic sites in a structural framework relative to the Aleutian megathrust and either known or inferred upper plate faults (Figure 13). Accretion of the upper crustal section of the Yakutat microplate begins at the Malaspina Glacier and extends to the Ragged Mountain fault in the west. The upper plate is imbricated by several faults with Holocene displacement. These include the Hanning and Patton Bay faults at Montague Island which ruptured beneath Prince William Sound in 1964, the Ragged Mountain fault at Katalla, the Cape Suckling – Bering Glacier fault, and several faults located in the vicinity of Icy Bay and the Malaspina Glacier.

The pattern of regional surface displacement and upper crustal faulting during the 1964 earthquake provides some insight into viable hypotheses for contributing to net
Holocene uplift of at least 4 m at Katalla, and similar amounts indicated by mid-Holocene marine molluscs at Bering Glacier (Shennan, 2009) and Cape Suckling (Plafker and Rubin, 1967). Rupturing of the Prince William Sound segment of the megathrust extended from beneath the southeastern edge of Cook Inlet to the Bering Glacier region, whilst upper plate faulting propagated to the surface on the Hanning and Patton Bay faults within Prince William Sound (Figure 13; Plafker, 1969). There was no surface faulting at Cape Suckling, although a spike in uplift suggests reverse motion on the Suckling Hills – Bering Glacier fault that was confined to the subsurface. There is no evidence for surface faulting at Ragged Mountain in 1964.

We infer a local earthquake beneath Katalla that caused uplift ~500 cal yr BP and was followed by interseismic subsidence prior to uplift of the coast in 1964. Does the former event reflect blind reverse faulting beneath the Katalla Valley that is temporally decoupled from great megathrust earthquakes? Certainly the structural setting of the valley is amendable to the presence of a blind thrust given the complexly folded and faulted rocks mapped at the surface (Winkler and Plafker, 1993) and evidence for duplex thrust faulting where roof and floor thrusts cause doubling up of the crustal section (Pavlis et al., 2012). Furthermore, modeling of GPS geodetic data shows that the valley is part of a small tectonic block that is currently deforming and rotating separately relative to the regions east of the Bering Glacier and west of Ragged Mountain (Elliott, 2011).
We consider two hypotheses for faulting contributing to net Holocene uplift at Katalla, the first focuses solely on the history of rupturing on the megathrust, the second invokes uplift driven by a blind fault beneath the valley. We prefer the second hypothesis, but cannot discount the first given the circumstantial nature of the paleoseismic and geologic data.

Hypothesis 1: The megathrust beneath Katalla is subject to large earthquakes from time to time that do not rupture the entire Prince William Sound segment. This is certainly plausible given the expected heterogeneity of the megathrust interface near the western edge of Yakutat microplate accretion. The ~500 cal yr BP uplift at Katalla may be such an event, if so, it reversed the pattern of interseismic subsidence following the penultimate great earthquake, that is, the great earthquake ~870 cal yr BP. If localized uplift beneath the valley is repeated from time to time independent of great earthquakes on the Prince William Sound segment then a modest amount of net uplift could accumulate, contributing to the 4+ m over 7000 years. The primary problem with this hypothesis is that we have found no evidence within cores for older events like that of ~500 cal yr BP. All the other silt-peat couplets that indicate coseismic uplift at Katalla correlate with similar horizons at Copper River Delta, Puffy Slough and the marshes west of Cape Suckling over the last 2600 years. This implies a return period for localized slip that is greater than 2100 years, a recurrence period that is of course, common (Wesson et al., 2008) on upper plate faults that operate independent of the megathrust for much of their history.
Hypothesis 2: There is a blind reverse fault beneath Katalla Valley, with a long recurrence interval, which contributed to net uplift of 4+ m in the last 7000 years, even though coseismic uplift in great megathrust earthquakes was followed by interseismic subsidence. This hypothesis has the following merits: 1) the blind reverse fault model is consistent with net uplift at Katalla but net subsidence at Copper River Delta and Puffy Slough; 2) similar net uplift at Cape Suckling and Bering Glacier is explained by activation of the Suckling Hills – Bering Glacier upper plate fault (Chapman et al., 2011), with net subsidence in the marshes to the west, including Puffy Slough. 3) The blind fault model is consistent with the complex structural geology (Bruhn et al., 2004; Pavlis et al., 2012; Winkler and Plafker, 1993; T.L. Pavlis, personal communications, 2013) surrounding and inferred to underlie the Katalla Valley.

Therefore our second conclusion is that contributions to net uplift may occur by both slip on the megathrust and upper plate faulting (Figure 13), the latter leading to measurable differences in coseismic uplift over a few kilometers.

Thirdly, the long interval between the penultimate and 1964 earthquake appears unusual given the paleoseismic record for the last several thousand years. The reason for this difference is uncertain given the available data. One possibility is that the long return period simply reflects part of the natural variability in the time dependent behavior of the megathrust. Another, is that the two events ~500 cal yr BP, one at Kodiak and the other in the vicinity of Katalla, reduced the level of stress on the megathrust and retarded rupturing across the whole area until 1964. The nature of the ~500 cal yr BP
events remains uncertain - slip on the megathrust is inferred by Carver and Plafker (2008) at Kodiak, while imbricate faulting within the crust above the megathrust seems more likely at Katalla. Whether it was it was a slipping patch on the megathrust or an upper plate fault at Katalla, the Katalla and Kodiak events would have reduced stress in those two regions, and possibly initiated creep, and hence time-dependent stress release, on the megathrust beneath Prince William Sound, delaying the onset of seismic rupturing until 1964?

One of the changes made in the 2007 modification to the seismic hazard maps for Alaska was to change the assumed recurrence interval of great earthquakes in the Prince William sound segment from 750 to 650 years, based upon the paleoseismic research published at the time (Wesson et al., 2007). Although this made little change to the hazard for most locations, enhancement of the paleoseismic records provides better characterization of the megathrust and upper plate faults and therefore a more satisfactory justification in terms of observation and understanding for calculating seismic hazard. The age modeling results described above provide more reliable and precise estimates of earthquake recurrence and could contribute to enhancements of both time-dependent and time-independent seismic hazard analyses for Alaska. A further enhancement would be to include the Katalla area as a source of seismic hazard, similar to other locations in the western part of the Yakutat microplate, such as the two Mw8+ ruptures in 1899 (Plafker and Thatcher, 2008).
ACKNOWLEDGMENTS

Sarah Cervera Heinlein, Peter Haeussler and Rich Koehler for help in the field;
Christopher Bronk Ramsey for guidance on Oxcal modeling; Gary Carver, George
Plafker and Terry Pavlis for discussions and comments concerning paleoseismology
and tectonics. This work is supported by the Saint Elias Erosion and Tectonics project
(STEEP), NSF 0408959, the U.S. Geological Survey, Department of the Interior,
earthquake hazards projects awards 06HQGR0033, G09AP00105 and G10AP00075
(The views and conclusions contained in this document are those of the authors and
should not be interpreted as necessarily representing the official policies, either
expressed or implied, of the U.S. Government) and NERC Radiocarbon Facility (grants
#935.0901 and #1339.1008). This work forms a contribution to IGCP Project 588
“Preparing for Coastal Change”.

REFERENCES

Atwater, B.F., Yamaguchi, D.K., Bondevik, S., Barnhardt, W.A., Amidon, L.J., Benson,
estuarine recorder of the 1964 Alaska earthquake: Geological Society of America

Ice Age ice mass change in south central Alaska: Reconciling model predictions

Toward a time-dependent probabilistic seismic hazard analysis for Alaska, in
Freymueller, J.T., Haeussler, P.J., Wesson, R., and Ekström, G., eds., Active
Tectonics and Seismic Potential of Alaska, Volume 179: Geophysical Monograph

Bronk Ramsey, C., 2009, Bayesian analysis of radiocarbon dates: Radiocarbon, v. 51,
p. 337-360.

accretion in the Saint Elias orogen, Alaska: Geological Society of America

Carver, G., and Plafker, G., 2008, Paleoseismicity and Neotectonics of the Aleutian
Subduction Zone - An Overview, in Freymueller, J.T., Haeussler, P.J., Wesson,
R., and Ekstrom, G., eds., Active tectonics and seismic potential of Alaska:
43-63.


Plafker, G., Lajoie, K.R., and Rubin, M., 1992, Determining intervals of great subduction zone earthquakes in southern Alaska by radiocarbon dating, in Taylor, R.E.,


Richards, S.W., 2000, Holocene history of the Katalla River Valley, Alaska: Salt Lake City, University of Utah.


FIGURE CAPTIONS

Figure 1: Tectonic setting of south central Alaska. Approximate area of coseismic subsidence (light grey) and uplift (dark grey) in 1964 and the western segment of the Yakutat microplate (dotted). Extent of subducted Yakutat slab shown to 50 km depth. Star symbols indicate epicentre of two $M_{w}$8+ earthquakes in 1899. Note that Hutchinson and Crowell (2007) adopt a further subdivision, with the Prince William Sound segment partitioned into two, distinguishing a Kenai segment, the part beneath the Kenai Peninsula not underlain by the subducted Yakutat slab.

Figure 2: LANDSAT image, 2013, of the coastal setting of the new field sites.

Figure 3: Copper River Delta: exposure of two silt-peat couplets at location 3 discussed in the text; coring revealed a third couplet.

Figure 4: Copper River Delta - Alaganik Slough sampling locations; a) 2013 LANDSAT image; b) air photo, August 1952; c) summary stratigraphy at sample locations, black = peat, adjacent triangle = sharp contact, white = silt, tree root symbol where present, calibrated age 95% age ranges BP (details in table 2); d) summary diatom diagram showing species accounting for >10% in at least one sample, and summary salinity classes, depths in cm relative to silt-peat contact.

Figure 5: Copper River Delta, mean and 95% uncertainty model estimates of paleo marsh surface elevation change across silt-peat couplets using the diatom-based transfer function method described in the text.

Figure 6: a) LANDSAT image of Katalla River Valley and Puffy Slough, with marshes numbered and individual sample locations indicated by white circles; b) air photo mosaic of the area, August 1950. Note the extent of tidal inundation and difference in vegetation extent, c) Katalla River summary stratigraphy and geomorphology along
transect X’ - X, black = peat, white = silt, stipple = sand (top contacts of all silt and sand units shown are sharp) and calibrated age 95% age ranges cal yr BP (details in table 2);
d) Puffy Slough, example of a core recording four episodes of coseismic uplift (the base of the surface peat represents uplift in 1964) superimposed upon net submergence.

Figure 7: Katalla site 3.10 summary diatom diagram and reconstruction estimates of paleo surface marsh elevations with 95% confidence limits: showing species accounting for >10% in at least one sample, total count per sample, radiocarbon ages cal yr BP and summary salinity classes, depths in cm relative to present ground surface; for elevation reconstructions, diamond symbol indicates low count, 125 diatoms, all others shown are based on >200. Grey symbol fill indicates close modern analogue, white indicates poor modern analogue.

Figure 8: Katalla site 5.5 summary diatom diagram and photograph of box sample across the contact, showing species accounting for >10% in at least one sample, total count per sample, and summary salinity classes, depths in cm relative to present ground surface.

Figure 9: a) marsh stratigraphy exposed along Katalla River, at site 5.5; b) 25 cm box section sampled across the contact at site 5.5; c) box sample across silt-peat contact, showing sand layer within the silt unit, sample taken near to Copper River Delta site 3.

Figure 10: Comparison of radiocarbon ages on paired samples of bulk peat and herbaceous macrofossils.

Figure 11: Age model of earthquake recurrence, a – Oxcal model structure of phases for constraining earthquake ages (Lienkaemper and Bronk Ramsey (2009) ; b – example of model input and output, for just EQ 1. The full model repeats this for each earthquake. Input:for each sample within a phase the calibrated age, in grey. Outputs in black, the probability density function from Bayesian modelling for each input sample and the 95.4% probability age of the intervening earthquake.
Figure 12: Probability density functions for earthquake ages (a) and intervals (b).

Figure 13: Schematic cross section of the plate boundary from Cook Inlet to the Malaspina Glacier, with summary of major earthquakes, direction of coseismic deformation and net Holocene motion: grey = no data of that age, ⬆ uplift, ⬇ subsidence, ⬇ no deformation. Large crustal faults are either known from surface offsets or inferred from paleoseismology and/or geologic mapping. The Ragged Mountain fault is a thrust fault that sutures the Yakutat terrane to the Early Tertiary Alaskan plate margin. That fault is marked by a 30 km-long system of Quaternary normal fault scarps that may reflect reactivation in extension (Tysdal et al., 1976), or possibly flexure above the tip of a buried thrust fault. The faults between Ragged Mountain and the Suckling Hills are inferred blind thrust faults within a complicated stack of imbricate thrusts that form an anticline beneath the Katalla Valley, but may have little or no surface manifestation other than uplift in the valley. The faults are inferred from geologic mapping (T.L. Pavlis, personal communications, 2013) and local uplift in the valley ~500 cal yr BP as discussed in section 7. The Suckling Hills and Bering Glacier faults are part of the same fault system that link to the Kayak Island Zone offshore (Chapman et al., 2011). The fault beneath Icy Bay is the Malaspina thrust fault which is known from both drill hole data (Chapman et al., 2011; Plafker, 1987) and geodetic observations (e.g. (Elliott, 2011).
North American Plate

Sites:
- Kas Kasilof
- Ke Kenai
- Anc Anchorage
- BP Bird Point
- Gw Girdwood
- CRD Copper River Delta
- Kat Katalla
- PS Puffy Slough
- CS Cape Suckling
- Ya Yakataga Coast

1964 epicenter, Prince William Sound

North American Plate

Subducted Yakutat slab

Denali Fault

Transition Fault

Queen Charlotte Fault

Kodiak Island

Aleutian Megathrust

Pacitc Plate

55 mm yr$^{-1}$

0  200km  140°  150°
Depth below surface of modern high marsh
~0.50 m
~1.25 m
~2.70 m
Top peat – site 3
- Navicula diaphotoplasta
- Nitzschia frustulum
- Cymbella forensis
- Navicula exquisitae

Navicula exquisitae
Cymbella forensis
Navicula exquisitae

Summary

Top peat – site 2
- Navicula diaphotoplasta
- Nitzschia frustulum
- Nitzschia frustulum
- Nitzschia frustulum
- Pinnularia messepla
- Pinnularia sulcata

Navicula diaphotoplasta
Nitzschia frustulum
Nitzschia frustulum
Nitzschia frustulum
Pinnularia messepla
Pinnularia sulcata

Summary

Top peat – site 1
- Navicula diaphotoplasta
- Nitzschia frustulum
- Nitzschia frustulum
- Nitzschia frustulum
- Pinnularia messepla
- Pinnularia sulcata

Navicula diaphotoplasta
Nitzschia frustulum
Nitzschia frustulum
Nitzschia frustulum
Pinnularia messepla
Pinnularia sulcata

Summary

Summary salinity classes
- Marine
- Brackish
- Freshwater – low salinity
- Freshwater – salt tolerant
- Salt intolerant
Length of section: approx 6 km

Samples giving maximum age of uplift

Samples giving minimum ages of uplift
ea aurita
u
alas lanceolata
i
onema angustatum
i
aria subcapitata

e Odontea aurita
Navicula peregrina
Synedra fasciculata
Synedra pulchella
Achnanthes lanceolata
Eunotia Luneis
Gomphonema angustatum
Eunotia arcus
Frustulia rhomboideae
Nedium bisulcatum
Pinnularia subcapitata

Summary salinity classes
Marine
Brackish
Freshwater – low salinity
Freshwater – salt tolerant
Salt intolerant

paleo marsh surface elevation m MHHW
Marine
Brackish
Freshwater - low salinity
Freshwater - salt tolerant
Freshwater - salt intolerant

Biddulphia biddulphiana
Odontella aurita
Diploneis interrupta
Navicula elegans
Nitzschia cari var cineta
Achnanthes lanceolata
Achnanthes minutissima
Achnanthes minitissima

Eunotia serra
Pinnularia microstauron
Pinnularia viridis
Staurospora pruvata
Actinella punctata
Actinella punctata

Fusutilia rhombodes
Pinnularia subcapitata
Tabellaria flocculosa

Total count

<table>
<thead>
<tr>
<th>Marine</th>
<th>Brackish</th>
<th>Freshwater - low salinity</th>
<th>Freshwater - salt tolerant</th>
<th>Freshwater - salt intolerant</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>86</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>94</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>102</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>106</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Radiocarbon age comparisons

- Bulk peat sample cal yr BP
- Macrofossil sample cal yr BP

- Cook Inlet
- Copper River Delta
a) Full model structure

b) Example model output: EQ1

INPUT
Phase: all the maximum ages on earthquake 1

OUTPUT
Earthquake 1 modelled age

INPUT
Phase: all the minimum ages on earthquake 1

1000 500
cal yr BP
<table>
<thead>
<tr>
<th></th>
<th>Anchorage</th>
<th>Bird Point</th>
<th>Girdwood</th>
<th>Copper River Delta</th>
<th>Katasia</th>
<th>Pungy Slough</th>
<th>Cape Suckling Marsh</th>
<th>Bering Glacier</th>
<th>Yakataga</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Horizontal distance: ~650 km
Table 1: Summary statistics for transfer function models used to reconstruct paleo marsh surface elevations. All models use modern samples from the regional-scale dataset covering sites across south-central Alaska (Full details of modern samples and model development in Hamilton and Shennan (2005) and Watcham et al., (2013)).

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of samples in modern training set</td>
<td>100</td>
<td>206</td>
<td>255</td>
</tr>
<tr>
<td>Number of components in weighted averaging partial least squares model(^1)</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Squared correlation between bootstrap predicted and observed values ((r^2))</td>
<td>0.75</td>
<td>0.68</td>
<td>0.76</td>
</tr>
<tr>
<td>Root mean squared error of prediction (bootstrap RMSEP)</td>
<td>6.31</td>
<td>11.94</td>
<td>17.48</td>
</tr>
<tr>
<td>Improvement in RMSEP over one-component model</td>
<td>14.7%</td>
<td>11.4%</td>
<td>10.5%</td>
</tr>
<tr>
<td>RMSEP scaled to tidal range at Katalla and Copper River Delta</td>
<td>0.10 m</td>
<td>0.19 m</td>
<td>0.27 m</td>
</tr>
<tr>
<td>Model applicable to lithology of fossil sample</td>
<td>Peat</td>
<td>Silt with herbaceous rootlets(^2)</td>
<td>Silt , no visible rootlets</td>
</tr>
</tbody>
</table>

\(^1\) We assessed model performance using \(r^2\), scatterplots of observed and predicted values, and RMSEP, with the best models being those with the highest \(r^2\) value, a linear distribution of observed plotted against predicted values, and the lowest RMSEP, but only if the RMSEP was improved by at least 5% with the addition of an extra component.

\(^2\) Where there was no good or close modern analogue using model 2 for a silt unit with herbaceous rootlets we would apply model 3 if it gave at least a close modern analogue, indicating a better fit but with a larger uncertainty term.
Table 2: New Radiocarbon dates
All samples on herbaceous macrofossil stem/leaves picked from peat or silt matrix

<table>
<thead>
<tr>
<th>Lab code</th>
<th>Site</th>
<th>Sample</th>
<th>Description</th>
<th>depth below core or section datum</th>
<th>core or section datum MHHW</th>
<th>14C BP</th>
<th>SD</th>
<th>Range (cal yr BP)</th>
</tr>
</thead>
</table>
| Copper River Delta: Alaganik Slough

Beta-223760  AS 1  AS/06/1/2  Base of peat 1  110  ~1  700  40  559  to  721
Beta-223761  AS 1  AS/06/1/3  Base of peat 2  310  ~1  1610  40  1403  to  1601
Beta-266415  AS 3  AS/09/3/1  Base of peat 1  75  ~1  880  20  733  to  901
Beta-266416  AS 3  AS/09/3/2  Base of peat 2  145  ~1  1480  20  1318  to  1402
Beta-266417  AS 2  AS/09/4  Base of peat 1  75  ~1  930  20  793  to  915
Beta-266418  AS 3  AS/09/5  Base of peat 3  436  ~1  2020  20  1900  to  2037
Beta-266419  AS 2  AS/09/8  Base of peat 2  175  ~1  1430  20  1296  to  1356

Katalla

Beta - 318153  Ka 2.1  KR/07/18/40  5cm above base of peat  40  ~2.4  240  30  1  to  424
Beta - 318154  Ka 2.1  KR/07/18/42  3cm above base of peat  42  ~2.4  270  30  0  to  435
Beta - 239237  Ka 2.1  KA/07/1A/45  Base of peat layer  45  ~2.4  400  40  318  to  518
Beta - 239238  Ka 2.4  KA/07/4/71  Base of peat layer  71  ~2.4  530  40  506  to  638
Beta - 316245  Ka 3.1  KR11-1-381  Within silt layer, above sand  381  ~3.9  1510  30  1319  to  1515
Beta - 316246  Ka 5.3  KR11-3-35  Top of peat layer  35  ~2  1740  30  1562  to  1715
Beta - 316247  Ka 5.3  KR11-3-50  1cm above base of peat layer  50  ~2  2030  30  1898  to  2105
Beta - 316248  Ka 5.3  KR11-3-51  Base of peat layer  51  ~2  2060  30  1948  to  2118
Beta - 316249  Ka 5.3  KR11-3-62  Top of peat layer  62  ~2  2270  30  2158  to  2347
Beta - 316250  Ka 5.3  KR11-3-81  Base of peat layer  81  ~2  2390  30  2344  to  2675
Beta - 316251  Ka 5.5  KR11-5-27  Base of peat layer above freshwater silt unit  27  ~4.2  110  30  4  to  269
Beta - 316252  Ka 5.5  KR11-5-96  1cm above base of peat layer  96  ~4.2  830  30  686  to  789
Beta - 316253  Ka 5.5  KR11-5-97  Base of peat layer  97  ~4.2  950  30  794  to  926
Beta - 316254  Ka 4.6  KR11-6-122  2cm above base of peat layer  122  ~3.9  880  30  729  to  907
Beta - 316255  Ka 4.6  KR11-6-124  Base of peat layer  124  ~3.9  840  30  685  to  892
Beta - 316256  Ka 4.6  KR11-6-127  Within silt layer, below peat contact  127  ~3.9  1130  30  962  to  1167
Beta - 316257  Ka 4.8  KR11-8-190  Within silt layer, above sand  190  ~3.9  1250  30  1082  to  1273
Beta - 316258  Ka 3.10  KR11-10-111  4cm above base of peat layer  111  ~3.9  530  30  510  to  629
Beta - 316259  Ka 3.10  KR11-10-113  2cm above base of peat layer  113  ~3.9  790  30  671  to  761
Beta - 316260  Ka 3.10  KR11-10-115  Base of peat layer  115  ~3.9  800  30  675  to  765

Puffy Slough

Beta - 328272  PF 4  PF/07/4 - 374  Base of lowest peat  374  ~2  2370  40  2331  to  2682
Beta - 328271  PF 4  PF/07/4 - 370  Above base of lowest peat  370  ~2  2170  30  2065  to  2311
Beta - 328270  PF 4  PF/07/4 - 260  Base of middle peat  260  ~2  2120  30  1999  to  2293
Beta - 328269  PF 4  PF/07/4 - 258  2 cm above base of middle peat  258  ~2  1320  30  1179  to  1298
Beta - 328268  PF 4  PF/07/4 - 153  Base of upper peat  153  ~2  790  30  671  to  761
Beta - 328267  PF 4  PF/07/4 - 152  1cm above base of upper peat  152  ~2  390  30  320  to  509
Table 3: Age model summary of earthquake ages and intervals. Oxcal model outputs for individual probability density functions, showing range (95.4% probability), mean, standard deviation, and median; and number of sites and number of samples recording each earthquake in model input. Older earthquakes not shown as they are less well constrained due to small sample sizes and are recorded at a single site.

<table>
<thead>
<tr>
<th>Modelled age (years BP)</th>
<th>from</th>
<th>to</th>
<th>%</th>
<th>μ</th>
<th>σ</th>
<th>m</th>
<th>n_{sites}</th>
<th>n_{samples}</th>
</tr>
</thead>
<tbody>
<tr>
<td>EQ1</td>
<td>902</td>
<td>837</td>
<td>95.4</td>
<td>870</td>
<td>17</td>
<td>871</td>
<td>9</td>
<td>34</td>
</tr>
<tr>
<td>EQ2</td>
<td>1484</td>
<td>1397</td>
<td>95.4</td>
<td>1440</td>
<td>21</td>
<td>1441</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>EQ3</td>
<td>2102</td>
<td>2006</td>
<td>95.4</td>
<td>2052</td>
<td>27</td>
<td>2050</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>EQ4</td>
<td>2685</td>
<td>2540</td>
<td>95.4</td>
<td>2615</td>
<td>38</td>
<td>2618</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>EQ5</td>
<td>3216</td>
<td>3037</td>
<td>95.4</td>
<td>3131</td>
<td>43</td>
<td>3131</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>EQ6</td>
<td>3662</td>
<td>3475</td>
<td>95.4</td>
<td>3550</td>
<td>47</td>
<td>3541</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Modelled interval (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AD1964 to EQ1</td>
<td>850</td>
<td>915</td>
<td>95.4</td>
<td>883</td>
<td>17</td>
<td>885</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ1 to EQ2</td>
<td>517</td>
<td>625</td>
<td>95.4</td>
<td>571</td>
<td>27</td>
<td>571</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ2 to EQ3</td>
<td>545</td>
<td>680</td>
<td>95.4</td>
<td>611</td>
<td>35</td>
<td>611</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ3 to EQ4</td>
<td>470</td>
<td>653</td>
<td>95.4</td>
<td>563</td>
<td>47</td>
<td>565</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ4 to EQ5</td>
<td>403</td>
<td>635</td>
<td>95.4</td>
<td>517</td>
<td>58</td>
<td>516</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQ5 to EQ6</td>
<td>299</td>
<td>550</td>
<td>95.4</td>
<td>419</td>
<td>64</td>
<td>415</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean interval AD1964 to EQ6</td>
<td>518</td>
<td>558</td>
<td>95.4</td>
<td>536</td>
<td>10</td>
<td>535</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean interval EQ1 to EQ6</td>
<td>579</td>
<td>612</td>
<td>95.4</td>
<td>594</td>
<td>8</td>
<td>593</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Shennan et al: supplementary information table
Radioacarbon data and age model structure for Oxcal age modelling

Site Codes
Kas Kasilo; Ke Kenai; Anc Anchorage; BP Bird Point; Gw Girdwood; CRD Copper River Delta; Kat Katalla; PS Puffy Slough; CS Cape Suckling; Ya Yakataga Coast

Literature sources
New: this paper table 2
1: Carver & Plafker 2008
2: Shennan et al. 2008
3: Barlow et al., 2012
4: Hamilton & Shennan, 2005
5: Shennan & Hamilton, 2006
6: Hamilton et al., 2005
7: Shennan 2009
8: Shennan et al., 2009

<table>
<thead>
<tr>
<th>Lab code</th>
<th>14C BP</th>
<th>SD</th>
<th>Site</th>
<th>Sample code</th>
<th>Source</th>
<th>Description</th>
<th>Boundary</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-6356</td>
<td>4860</td>
<td>90</td>
<td>CRD</td>
<td>91APR604N2</td>
<td>1</td>
<td>Alaganic Slough 0.5km below boat ramp</td>
<td>Earthquake 9</td>
<td>Minimum</td>
</tr>
<tr>
<td>W6360</td>
<td>4650</td>
<td>100</td>
<td>CRD</td>
<td>91APR606Y</td>
<td>1</td>
<td>Upper Alaganic Slough redrill</td>
<td>Earthquake 9</td>
<td>Minimum</td>
</tr>
<tr>
<td>CAMS-16583</td>
<td>4340</td>
<td>90</td>
<td>CRD</td>
<td>93APR25R</td>
<td>1</td>
<td>Alaganic Slough 0.1km above boat ramp</td>
<td>Earthquake 8</td>
<td>Minimum</td>
</tr>
<tr>
<td>CAMS-16573</td>
<td>4210</td>
<td>60</td>
<td>CRD</td>
<td>93APR215S</td>
<td>1</td>
<td>Alaganic Slough 0.5km below boat ramp</td>
<td>Earthquake 8</td>
<td>Minimum</td>
</tr>
<tr>
<td>W-6355</td>
<td>4180</td>
<td>80</td>
<td>CRD</td>
<td>91APR604L</td>
<td>1</td>
<td>Alaganic Slough 0.5km below boat ramp</td>
<td>Earthquake 7</td>
<td>Minimum</td>
</tr>
<tr>
<td>CAMS-16579</td>
<td>3810</td>
<td>70</td>
<td>CRD</td>
<td>93APR23W</td>
<td>1</td>
<td>Alaganic Slough 1.4km above boat ramp</td>
<td>Earthquake 7</td>
<td>Minimum</td>
</tr>
<tr>
<td>W-6353</td>
<td>3690</td>
<td>50</td>
<td>CRD</td>
<td>91APR604I</td>
<td>1</td>
<td>Alaganic Slough 0.5km below boat ramp</td>
<td>Earthquake 7</td>
<td>Minimum</td>
</tr>
<tr>
<td>CAMS-16581</td>
<td>3680</td>
<td>60</td>
<td>CRD</td>
<td>93APR25N</td>
<td>1</td>
<td>Alaganic Slough 0.1km above boat ramp</td>
<td>Earthquake 7</td>
<td>Minimum</td>
</tr>
<tr>
<td>CAMS-16578</td>
<td>3640</td>
<td>90</td>
<td>CRD</td>
<td>93APR23T</td>
<td>1</td>
<td>Alaganic Slough 1.4km above boat ramp</td>
<td>Earthquake 7</td>
<td>Minimum</td>
</tr>
<tr>
<td>W6358</td>
<td>3600</td>
<td>90</td>
<td>CRD</td>
<td>91APR606R</td>
<td>1</td>
<td>Upper Alaganic Slough redrill</td>
<td>Earthquake 7</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta-223764</td>
<td>3490</td>
<td>40</td>
<td>Gw</td>
<td>GWS/1</td>
<td>2</td>
<td>Upper boundary of Girdwood peat Y</td>
<td>Phase boundary</td>
<td>Maximum</td>
</tr>
<tr>
<td>CAMS-16577</td>
<td>3280</td>
<td>60</td>
<td>CRD</td>
<td>93APR23M</td>
<td>1</td>
<td>Alaganic Slough 1.4km above boat ramp</td>
<td>Phase boundary</td>
<td>Maximum</td>
</tr>
</tbody>
</table>

Page 1 of 4
<table>
<thead>
<tr>
<th>Code</th>
<th>X</th>
<th>Y</th>
<th>CRD</th>
<th>Date</th>
<th>Description</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Earthquake 6</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W6549</td>
<td>3420</td>
<td>60</td>
<td>CRD</td>
<td>93APR25G</td>
<td>1 Alaganic Slough 0.1km above boat ramp</td>
<td>Minimum</td>
</tr>
<tr>
<td>AA5764</td>
<td>3279</td>
<td>102</td>
<td>CRD</td>
<td>89APR503M</td>
<td>1 Upper Alaganic Slough</td>
<td>Minimum</td>
</tr>
<tr>
<td>CAMS-16572</td>
<td>3180</td>
<td>60</td>
<td>CRD</td>
<td>93APR21FF</td>
<td>1 Alaganic Slough 0.5km below boat ramp</td>
<td>Minimum</td>
</tr>
<tr>
<td>AA5639?</td>
<td>3096</td>
<td>73</td>
<td>CRD</td>
<td>89APR502W</td>
<td>1 100 m upstream of boat ramp</td>
<td>Minimum</td>
</tr>
<tr>
<td>CAMS-16576</td>
<td>3060</td>
<td>60</td>
<td>CRD</td>
<td>93APR23L</td>
<td>1 Alaganic Slough 1.4km above boat ramp</td>
<td>Minimum</td>
</tr>
<tr>
<td><strong>Phase boundary</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta-184329</td>
<td>3040</td>
<td>40</td>
<td>Gw</td>
<td>G/03/4P#20</td>
<td>2 Upper boundary of Girdwood peat A</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-223766</td>
<td>3020</td>
<td>40</td>
<td>Gw</td>
<td>GWS/3</td>
<td>2 Upper boundary of Girdwood peat A</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-223763</td>
<td>3010</td>
<td>40</td>
<td>Gw</td>
<td>GW1/1</td>
<td>2 Upper boundary of Girdwood peat A</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-223767</td>
<td>2930</td>
<td>40</td>
<td>Gw</td>
<td>GW6/1</td>
<td>2 Upper boundary of Girdwood peat A</td>
<td>Maximum</td>
</tr>
<tr>
<td><strong>Earthquake 5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W6547</td>
<td>3070</td>
<td>50</td>
<td>CRD</td>
<td>93APR21AA</td>
<td>1 Alaganic Slough 0.5km below boat ramp</td>
<td>Minimum</td>
</tr>
<tr>
<td><strong>Phase boundary</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA4905</td>
<td>2855</td>
<td>95</td>
<td>CRD</td>
<td>89APR503J</td>
<td>1 Upper Alaganic Slough</td>
<td>Maximum</td>
</tr>
<tr>
<td>AA5637</td>
<td>2662</td>
<td>67</td>
<td>CRD</td>
<td>89APR502O</td>
<td>1 100 m upstream of boat ramp</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-266422</td>
<td>2580</td>
<td>20</td>
<td>BP</td>
<td>BP/09/1/3</td>
<td>3 Top of Bird Point peat D</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-184327</td>
<td>2560</td>
<td>40</td>
<td>Gw</td>
<td>G/03/4P#18</td>
<td>2 Top of Girdwood peat D</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-223768</td>
<td>2490</td>
<td>40</td>
<td>Gw</td>
<td>GW6/2</td>
<td>2 Top of Girdwood peat D</td>
<td>Maximum</td>
</tr>
<tr>
<td>CAMS-93961</td>
<td>2425</td>
<td>35</td>
<td>Gw</td>
<td>GW/02/1C#5</td>
<td>2 Top of Girdwood peat D</td>
<td>Maximum</td>
</tr>
<tr>
<td><strong>Earthquake 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA5644</td>
<td>2614</td>
<td>89</td>
<td>CRD</td>
<td>89APR503I</td>
<td>1 Upper Alaganic Slough</td>
<td>Minimum</td>
</tr>
<tr>
<td>AA5636</td>
<td>2614</td>
<td>65</td>
<td>CRD</td>
<td>89APR502M</td>
<td>1 100 m upstream of boat ramp</td>
<td>Minimum</td>
</tr>
<tr>
<td>CAMS-16574</td>
<td>2570</td>
<td>60</td>
<td>CRD</td>
<td>93APR21W</td>
<td>1 Alaganic Slough 0.5km below boat ramp</td>
<td>Minimum</td>
</tr>
<tr>
<td>W6452</td>
<td>2550</td>
<td>90</td>
<td>CRD</td>
<td>91APR606H</td>
<td>1 Upper Alaganic Slough redrill</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta - 316250</td>
<td>2390</td>
<td>30</td>
<td>Kat</td>
<td>KR11-3-81</td>
<td>new Base of peat layer</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta - 328272</td>
<td>2370</td>
<td>40</td>
<td>PS</td>
<td>PF/07/4 - 374</td>
<td>new Puffy Slough 4 - base of lowest peat</td>
<td>Minimum</td>
</tr>
<tr>
<td>AA4892</td>
<td>2342</td>
<td>78</td>
<td>CRD</td>
<td>89APR503G</td>
<td>1 Upper Alaganic Slough</td>
<td>Minimum</td>
</tr>
<tr>
<td><strong>Phase boundary</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta-266421</td>
<td>2170</td>
<td>20</td>
<td>BP</td>
<td>BP/09/1/2</td>
<td>2 Top of Bird Point peat E</td>
<td>Maximum</td>
</tr>
<tr>
<td>AA-48170</td>
<td>2140</td>
<td>47</td>
<td>Gw</td>
<td>GW1A-20</td>
<td>2 Top of Girdwood peat E</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-184324</td>
<td>2120</td>
<td>50</td>
<td>Gw</td>
<td>G/03/3#15</td>
<td>2 Top of Girdwood peat E</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-266423</td>
<td>2040</td>
<td>20</td>
<td>Hope</td>
<td>HP/09/8</td>
<td>3 Top of Hope fourth peat (E)</td>
<td>Maximum</td>
</tr>
<tr>
<td><strong>Earthquake 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Page 2 of 4
<table>
<thead>
<tr>
<th>Site Code</th>
<th>Site Type</th>
<th>Site Name</th>
<th>Date</th>
<th>Depth</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta-328270</td>
<td>PS</td>
<td>PF/07/4 - 260</td>
<td>new</td>
<td>Puffy Slough 4 - base of middle peat</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta-316248</td>
<td>Kat</td>
<td>KR11-3-51</td>
<td>new</td>
<td>Base of peat layer</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta-316247</td>
<td>Kat</td>
<td>KR11-3-50</td>
<td>new</td>
<td>1cm above base of peat layer</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta-266418</td>
<td>CRD</td>
<td>AS/09/5</td>
<td>1</td>
<td>Bottom of Alaganic Slough peat 3</td>
<td>Minimum</td>
</tr>
<tr>
<td>AA4890</td>
<td>CRD</td>
<td>89APR503F</td>
<td>1</td>
<td>Upper Alaganic Slough</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta-184332</td>
<td>Ke</td>
<td>KE/03/5#23</td>
<td>4</td>
<td>Top of Kenai peat A</td>
<td>Maximum</td>
</tr>
<tr>
<td>CAMS-93964</td>
<td>Ke</td>
<td>KE/2000/7#8</td>
<td>4</td>
<td>Top of Kenai peat A</td>
<td>Maximum</td>
</tr>
<tr>
<td>W6085</td>
<td>CRD</td>
<td>88APR11B</td>
<td>1</td>
<td>Pete Dahl Cutoff</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-266420</td>
<td>BP</td>
<td>BP/09/1/1</td>
<td>3</td>
<td>Top of Bird Point peat F</td>
<td>Maximum</td>
</tr>
<tr>
<td>CAMS-93966</td>
<td>Kas</td>
<td>KS/01/1#10</td>
<td>5</td>
<td>Top of Kasilof lowest peat</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-184326</td>
<td>Gw</td>
<td>G/03/2#17</td>
<td>2</td>
<td>Top of Girdwood peat F</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-184318</td>
<td>Anc</td>
<td>OV/02/2#9</td>
<td>6</td>
<td>Top of Ocean View peat C</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-184311</td>
<td>Anc</td>
<td>OV/03/23#2</td>
<td>6</td>
<td>Top of Ocean View peat C</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-223761</td>
<td>CRD</td>
<td>AS1/3</td>
<td>new</td>
<td>Bottom boundary of peat 'A'</td>
<td>Minimum</td>
</tr>
<tr>
<td>W6361</td>
<td>CRD</td>
<td>91APR609J</td>
<td>1</td>
<td>Upper Alaganic Slough</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta-316245</td>
<td>Kat</td>
<td>KR11-1-381</td>
<td>new</td>
<td>Stems within silt layer, above sand</td>
<td>Minimum</td>
</tr>
<tr>
<td>W6088</td>
<td>CRD</td>
<td>88APR11 C</td>
<td>1</td>
<td>Pete Dahl Cutoff</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta-266416</td>
<td>CRD</td>
<td>AS/09/3/2</td>
<td>1</td>
<td>Bottom of Alaganic Slough peat 2</td>
<td>Minimum</td>
</tr>
<tr>
<td>W6454</td>
<td>CRD</td>
<td>91APR606C</td>
<td>1</td>
<td>Upper Alaganic Slough</td>
<td>Minimum</td>
</tr>
<tr>
<td>AA4897</td>
<td>CRD</td>
<td>89APR503D</td>
<td>1</td>
<td>Upper Alaganic Slough</td>
<td>Minimum</td>
</tr>
<tr>
<td>AA4893</td>
<td>CRD</td>
<td>89APR502F</td>
<td>1</td>
<td>100 m upstream of boat ramp</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta-266419</td>
<td>CRD</td>
<td>AS/09/8</td>
<td>new</td>
<td>Bottom of Alaganic Slough peat 2</td>
<td>Minimum</td>
</tr>
<tr>
<td>Beta-316256</td>
<td>Kat</td>
<td>KR11-6-127</td>
<td>new</td>
<td>Within silt layer, below peat contact</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-184315</td>
<td>Anc</td>
<td>OV/01/18#6</td>
<td>6</td>
<td>Top of Ocean View peat D</td>
<td>Maximum</td>
</tr>
<tr>
<td>SUERC-22676</td>
<td>BP</td>
<td>BP086R12</td>
<td>3</td>
<td>Top of Bird Point peat G</td>
<td>Maximum</td>
</tr>
<tr>
<td>AA5624</td>
<td>CRD</td>
<td>88APR13AA</td>
<td>new</td>
<td>Lower Pete Dahl Slough</td>
<td>Maximum</td>
</tr>
<tr>
<td>SUERC-22673</td>
<td>BP</td>
<td>BP086R11</td>
<td>3</td>
<td>Top of Bird Point peat G</td>
<td>Maximum</td>
</tr>
<tr>
<td>W6098</td>
<td>CRD</td>
<td>88APR11H</td>
<td>1</td>
<td>Pete Dahl Cutoff</td>
<td>Maximum</td>
</tr>
<tr>
<td>CAMS-93958</td>
<td>Gw</td>
<td>GW/02/18#2</td>
<td>2</td>
<td>Top of Girdwood peat G</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-45199</td>
<td>Gw</td>
<td>GW/91-4-1</td>
<td>2</td>
<td>Rooted wood at top of Girdwood peat G</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-184317</td>
<td>Anc</td>
<td>OV/03/25#8</td>
<td>6</td>
<td>Top of Ocean View peat D</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta-184321</td>
<td>Gw</td>
<td>G/03/1#12</td>
<td>2</td>
<td>Top of Girdwood peat G</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beta</td>
<td>860</td>
<td>60</td>
<td>Gw</td>
<td>GW91-2-1</td>
<td>2</td>
</tr>
<tr>
<td>----------</td>
<td>------</td>
<td>-----</td>
<td>----</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td>Beta - 212211</td>
<td>970</td>
<td>40</td>
<td>CS</td>
<td>CS 05/2 268cm</td>
<td>7</td>
</tr>
<tr>
<td>Beta - 242795</td>
<td>970</td>
<td>20</td>
<td>Ya</td>
<td>YK/5-2</td>
<td>8</td>
</tr>
<tr>
<td>Beta - 316253</td>
<td>950</td>
<td>30</td>
<td>Kat</td>
<td>KR11-5-97</td>
<td>new</td>
</tr>
<tr>
<td>Beta - 266417</td>
<td>930</td>
<td>20</td>
<td>CRD</td>
<td>AS/09/4</td>
<td>new</td>
</tr>
<tr>
<td>Beta - 212213</td>
<td>920</td>
<td>40</td>
<td>CS</td>
<td>CS 05 2 269cm</td>
<td>7</td>
</tr>
<tr>
<td>Beta - 239243</td>
<td>920</td>
<td>20</td>
<td>Ya</td>
<td>YK/2</td>
<td>8</td>
</tr>
<tr>
<td>Beta - 239245</td>
<td>920</td>
<td>20</td>
<td>Ya</td>
<td>YK/5-1</td>
<td>8</td>
</tr>
<tr>
<td>M2873</td>
<td>895</td>
<td>50</td>
<td>CRD</td>
<td>89APR505H reri</td>
<td>1</td>
</tr>
<tr>
<td>Beta - 266415</td>
<td>880</td>
<td>20</td>
<td>CRD</td>
<td>AS/09/3/1</td>
<td>new</td>
</tr>
<tr>
<td>Beta - 212212</td>
<td>880</td>
<td>40</td>
<td>CS</td>
<td>CS 05/2 266cm</td>
<td>7</td>
</tr>
<tr>
<td>Beta - 316254</td>
<td>880</td>
<td>30</td>
<td>Kat</td>
<td>KR11-6-122</td>
<td>new</td>
</tr>
<tr>
<td>M2874</td>
<td>865</td>
<td>45</td>
<td>CRD</td>
<td>89APR505H</td>
<td>1</td>
</tr>
<tr>
<td>W6123</td>
<td>850</td>
<td>120</td>
<td>CRD</td>
<td>88APR13B</td>
<td>1</td>
</tr>
<tr>
<td>Beta - 316255</td>
<td>840</td>
<td>30</td>
<td>Kat</td>
<td>KR11-6-124</td>
<td>new</td>
</tr>
<tr>
<td>Beta - 239239</td>
<td>840</td>
<td>20</td>
<td>PS</td>
<td>Puffy_Slough</td>
<td>new</td>
</tr>
<tr>
<td>W6102</td>
<td>830</td>
<td>120</td>
<td>CRD</td>
<td>88APR11I</td>
<td>1</td>
</tr>
<tr>
<td>Beta - 316252</td>
<td>830</td>
<td>30</td>
<td>Kat</td>
<td>KR11-5-96</td>
<td>new</td>
</tr>
<tr>
<td>Beta - 316260</td>
<td>800</td>
<td>30</td>
<td>Kat</td>
<td>KR11-10-115</td>
<td>new</td>
</tr>
<tr>
<td>Beta - 316259</td>
<td>790</td>
<td>30</td>
<td>Kat</td>
<td>KR11-10-113</td>
<td>new</td>
</tr>
<tr>
<td>Beta - 328268</td>
<td>790</td>
<td>30</td>
<td>PS</td>
<td>PF/07/4 - 153</td>
<td>new</td>
</tr>
<tr>
<td>AA5626</td>
<td>706</td>
<td>54</td>
<td>CRD</td>
<td>88APR16A</td>
<td>1</td>
</tr>
<tr>
<td>Beta - 223760</td>
<td>700</td>
<td>40</td>
<td>CRD</td>
<td>AS1/2</td>
<td>new</td>
</tr>
<tr>
<td>W6139</td>
<td>630</td>
<td>140</td>
<td>CRD</td>
<td>88APR16C</td>
<td>1</td>
</tr>
<tr>
<td>Beta - 232338</td>
<td>530</td>
<td>40</td>
<td>Kat</td>
<td>KA/07/4/71</td>
<td>new</td>
</tr>
<tr>
<td>Beta - 239237</td>
<td>400</td>
<td>40</td>
<td>Kat</td>
<td>KA/07A/1/45</td>
<td>new</td>
</tr>
<tr>
<td>Beta - 318154</td>
<td>270</td>
<td>30</td>
<td>Kat</td>
<td>KR-07B-1-42</td>
<td>new</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beta</th>
<th>800</th>
<th>60</th>
<th>Gw</th>
<th>GW91-2-1</th>
<th>2</th>
<th>Rooted wood at top of Girdwood peat G Maximum Earthquake 0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta - 239238</td>
<td>530</td>
<td>40</td>
<td>Kat</td>
<td>KA/07/4/71</td>
<td>new</td>
<td>herbaceous roots/stems, base of peat Minimum</td>
</tr>
<tr>
<td>Beta - 239237</td>
<td>400</td>
<td>40</td>
<td>Kat</td>
<td>KA/07A/1/45</td>
<td>new</td>
<td>herbaceous roots/stems, base of peat Minimum</td>
</tr>
<tr>
<td>Beta - 318154</td>
<td>270</td>
<td>30</td>
<td>Kat</td>
<td>KR-07B-1-42</td>
<td>new</td>
<td>Herbaceous leaf/stem fragments Minimum</td>
</tr>
</tbody>
</table>