Late Holocene relative sea-level changes and earthquakes around the upper Cook Inlet, Alaska, USA

Hamilton, Sarah Louise

How to cite:
Hamilton, Sarah Louise (2003) Late Holocene relative sea-level changes and earthquakes around the upper Cook Inlet, Alaska, USA, Durham theses, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/4094/

Use policy
The full-text may be used and/or reproduced, and given to third parties in any format or medium, without prior permission or charge, for personal research or study, educational, or not-for-profit purposes provided that:

- a full bibliographic reference is made to the original source
- a link is made to the metadata record in Durham E-Theses
- the full-text is not changed in any way

The full-text must not be sold in any format or medium without the formal permission of the copyright holders.

Please consult the full Durham E-Theses policy for further details.
## Contents of Volume Two

List of figures: ii
Contents of Appendices: vii

## List of Figures

<table>
<thead>
<tr>
<th>Chapter 1</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Schematic diagrams of the EDC model</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Schematic diagram of co-seismic submergence</td>
<td>2</td>
</tr>
<tr>
<td>1.3 The Cascadia subduction zone</td>
<td>3</td>
</tr>
<tr>
<td>1.4 Region affected by the 1964 Alaskan earthquake</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 2</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Location of field sites around the upper Cook Inlet</td>
<td>5</td>
</tr>
<tr>
<td>2.2 Satellite image showing the location of the Kenai River Flats and Kenai City Pier transects</td>
<td>6</td>
</tr>
<tr>
<td>2.3 Oblique aerial photograph of Kenai River Flats</td>
<td>7</td>
</tr>
<tr>
<td>2.4 Altitude (m) of vegetation zones found at Kenai</td>
<td>8</td>
</tr>
<tr>
<td>2.5 Contemporary environments at Kenai River Flats</td>
<td>9</td>
</tr>
<tr>
<td>2.6 Oblique aerial photograph of Kenai City Pier</td>
<td>10</td>
</tr>
<tr>
<td>2.7 Contemporary environments at Kenai City Pier</td>
<td>11</td>
</tr>
<tr>
<td>2.8 Oblique aerial photograph of Kasilof</td>
<td>12</td>
</tr>
<tr>
<td>2.9 Bank section at Kasilof</td>
<td>13</td>
</tr>
<tr>
<td>2.10 Oblique aerial photograph of Girdwood</td>
<td>14</td>
</tr>
<tr>
<td>2.11 Cliff face at Girdwood</td>
<td>15</td>
</tr>
<tr>
<td>2.12 Winter conditions at Girdwood</td>
<td>16</td>
</tr>
<tr>
<td>2.13 Winter conditions at Kenai</td>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 3</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Schematic diagram of organic content changes associated with the EDC model</td>
<td>18</td>
</tr>
<tr>
<td>3.2 Transfer function development</td>
<td>19</td>
</tr>
</tbody>
</table>
Chapter 4

4.1 Tidal observations for Kenai River Flats

4.2 High tide observations at Girdwood

4.3 Hours inundated per year for the Kenai contemporary samples

4.4 Kenai contemporary diatom data and cluster analysis using Euclidian distance

4.5 Altitude range of classes produced using Euclidian distance

4.6 Kenai contemporary diatom data and cluster analysis using Chord distance

4.7 Altitude range of classes produced using Chord distance

4.8 Regression optima and tolerances based upon WA model

4.9 Regression results for the full contemporary data set (altitude (m) relative to MHHW)

4.10 Regression results using hours inundated per year for the full contemporary data set

4.11 Regression results for contemporary samples found below MHHW

4.12 Regression results using altitude (m) relative to MHHW for contemporary samples above +1.0 m MHHW

4.13 Regression results using hours inundated per year for contemporary samples above +1.0 m MHHW

4.14 Back calculation for hours inundated per year to altitude (m) relative to MHHW

4.15 Regression results using altitude (m) relative to MHHW for contemporary samples above -0.5 m MHHW

4.16 Observed against predicted altitude (m) relative to MHHW for contemporary Kenai data using MAT

4.17 Cumulative frequency distribution of MAT minimum dissimilarity coefficients

Chapter 5

5.1 Summary litho-stratigraphy at Kenai River Flats

5.2 Surface vegetation at Kenai 2000-7

5.3 Lithology of Kenai 2000-7 showing the upper peat-silt boundary

5.4 Detailed litho-stratigraphy of Kenai 2000-7

5.5 Loss on ignition values for Kenai 2000-7

5.6 (a) Kenai 2000-7 diatom data (polyhalobous, mesohalobous and
5.7 Chrono-stratigraphy of Kenai 2000-7
5.8 Comparison of radiocarbon dates for Kenai
5.9 Calibration results for Kenai 2000-7 using different models
5.10 Minimum dissimilarity coefficient values from MAT for Kenai 2000-7
5.11 Reconstruction of relative sea-level change for Kenai 2000-7 using the best combination of models

Chapter 6
6.1 Summary litho-stratigraphy at Girdwood
6.2 Location of sampling sites at Girdwood
6.3 Chrono-stratigraphy of Girdwood
6.4 Comparison of radiocarbon dates for Girdwood
6.5 (a) Detailed litho-stratigraphy of Girdwood G-800
(b) Girdwood G-02-2 showing increase in silt content within the upper peat
6.6 Girdwood G-800 diatom data
6.7 Calibration results for Girdwood G-800 using different models
6.8 Minimum dissimilarity coefficient values from MAT for Girdwood G-800
6.9 Reconstruction of relative sea-level change for Girdwood G-800 using the best combination of models
6.10 Detailed litho-stratigraphy of Girdwood G-01-1A
6.11 (a) Girdwood G-01-1A diatom data
(b) Girdwood G-01-1A pollen data
6.12 Calibration results for Girdwood G-01-1A using different models
6.13 Minimum dissimilarity coefficient values from MAT for Girdwood G-01-1A
6.14 Reconstruction of relative sea-level change for Girdwood G-01-1A using the best combination of models
6.15 Detailed litho-stratigraphy of Girdwood G-01-1C
6.16 Girdwood G-01-1C diatom data
6.17 Calibration results for Girdwood G-01-1C using different models
6.18 Minimum dissimilarity coefficient values from MAT for Girdwood G-01-1C
6.19 Reconstruction of relative sea-level change for Girdwood G-01-1C using the best combination of models
6.20 Detailed litho-stratigraphy of Girdwood G-01-1E
6.21 Girdwood G-01-1E diatom data
6.22 Calibration results for Girdwood G-01-1E using different models
6.23 Minimum dissimilarity coefficient values from MAT for Girdwood G-01-1E
6.24 Reconstruction of relative sea-level change for Girdwood G-01-1E using the best combination of models
6.25 Detailed litho-stratigraphy of Girdwood G-01-1F
6.26 Girdwood G-01-1F diatom data
6.27 Calibration results for Girdwood G-01-1F using different models
6.28 Minimum dissimilarity coefficient values from MAT for Girdwood G-01-1F
6.29 Reconstruction of relative sea-level change for Girdwood G-01-1F using the best combination of models
6.30 Detailed litho-stratigraphy of Girdwood G-01-9
6.31 Girdwood G-01-9 diatom data
6.32 Calibration results for Girdwood G-01-9 using different models
6.33 Minimum dissimilarity coefficient values from MAT for Girdwood G-01-9
6.34 Reconstruction of relative sea-level change for Girdwood G-01-9 using the best combination of models

Chapter 7
7.1 (a) Detailed litho-stratigraphy of Kasilof KS-01-1
(b) Detailed litho-stratigraphy of Kasilof KS-3
7.2 Chrono-stratigraphy of Kasilof
7.3 Comparison of radiocarbon dates for Kasilof
7.4 $^{137}$Cs results for the upper part of Kasilof KS-3
7.5 Kasilof KS-01-1 diatom data
7.6 Calibration results for Kasilof KS-01-1 using different models
7.7 Minimum dissimilarity coefficient values from MAT for Kasilof KS-01-1
Chapter 8

8.1 Models of reconstructed relative sea-level change showing effects of different types of reworked sediment following co-seismic submergence 98

8.2 Relationship between the magnitude of co-seismic and pre-seismic relative sea-level rise 99

8.3 Possible pre-1964 periods of co-seismic submergence using dates from this thesis 100

8.4 Radiocarbon dates from around the Cook Inlet comparing possible periods of co-seismic submergence from this thesis against those suggested by Combellick (1994) 101

8.5 Schematic models of co-seismic submergence, post- and inter-seismic uplift, sediment accumulation and marsh peat burial 102

8.6 Relationship between age of peat layers and depth below present marsh surface at different sites around the Cook Inlet compared to eustatic and GIA models 103
## Contents of Appendices

**Stored on CD**

<table>
<thead>
<tr>
<th>Appendix Number and File Name</th>
<th>Summary of contents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Appendix 1</strong></td>
<td></td>
</tr>
<tr>
<td>Optima &amp; tol.doc</td>
<td>Optima and tolerance of contemporary diatom species</td>
</tr>
<tr>
<td><strong>Appendix 2</strong></td>
<td></td>
</tr>
<tr>
<td>Graphs above -1.6.doc</td>
<td>Regression results using altitude (m) relative to MHHW for contemporary samples above -1.6 m MHHW</td>
</tr>
<tr>
<td>Graphs above -1.0.doc</td>
<td>Regression results using altitude (m) relative to MHHW for contemporary samples above -1.0 m MHHW</td>
</tr>
<tr>
<td>Graphs above -0.5.doc</td>
<td>Regression results using altitude (m) relative to MHHW for contemporary samples above -0.5 m MHHW</td>
</tr>
<tr>
<td>Graphs above 0.doc</td>
<td>Regression results using altitude (m) relative to MHHW for contemporary samples above 0 m MHHW</td>
</tr>
<tr>
<td>Graphs above +0.5.doc</td>
<td>Regression results using altitude (m) relative to MHHW for contemporary samples above +0.5 m MHHW</td>
</tr>
<tr>
<td>Graphs above +1.0 MHHW.doc</td>
<td>Regression results using altitude (m) relative to MHHW for contemporary samples above +1.0 m MHHW</td>
</tr>
<tr>
<td>Graphs above +1.0hrs.doc</td>
<td>Regression results hours inundated per year for contemporary samples above +1.0 m MHHW</td>
</tr>
<tr>
<td><strong>Appendix 3</strong></td>
<td></td>
</tr>
<tr>
<td>14Cdates.xls</td>
<td>Radiocarbon dates from this study, Combellick (1991) and Combellick and Reger (1994)</td>
</tr>
<tr>
<td><strong>Appendix 4</strong></td>
<td></td>
</tr>
<tr>
<td>Girdwood Troels Smith.doc</td>
<td>Troels Smith descriptions of sediment from Girdwood</td>
</tr>
<tr>
<td>Kasilof Troels Smith.doc</td>
<td>Troels Smith descriptions of sediment from Kasilof</td>
</tr>
<tr>
<td>Kenai Troels Smith.doc</td>
<td>Troels Smith descriptions of sediment from Kenai</td>
</tr>
<tr>
<td><strong>Appendix 5</strong></td>
<td></td>
</tr>
<tr>
<td>Diatom count.doc</td>
<td>Information on diatom counts</td>
</tr>
<tr>
<td><strong>Appendix 6</strong></td>
<td></td>
</tr>
<tr>
<td>KE 2000-7.xls</td>
<td>Transfer function results for Kenai 2000-7</td>
</tr>
<tr>
<td>G-800.xls</td>
<td>Transfer function results for Girdwood G-800</td>
</tr>
</tbody>
</table>
G-01-1A.xls  Transfer function results for Girdwood G-01-1A
G-01-1C.xls  Transfer function results for Girdwood G-01-1C
G-01-1E.xls  Transfer function results for Girdwood G-01-1E
G-01-1F.xls  Transfer function results for Girdwood G-01-1F
G-01-9.xls   Transfer function results for Girdwood G-01-9
KS-01-1.xls  Transfer function results for Kasilof KS-01-1
KS-3.xls    Transfer function results for Kasilof KS-3

Appendix 7
Contemp.xls  Altitude & vegetation description of contemporary samples
Figure 1.1
Schematic diagrams showing the pattern of (A) inter-seismic and (B) co-seismic deformation associated with a subduction zone earthquake during the earthquake deformation cycle. Adapted from Nelson et al. (1996) to reflect the spatial pattern of co-seismic deformation during the 1964 earthquake in Alaska. Site locations are shown in figure 1.4
Figure 1.2
Schematic diagram showing the development of peat-silt couplets following coseismic submergence together with associated possible tsunami deposits and liquefaction features (Atwater & Hemphill-Haley, 1997)
Figure 1.3
The Cascadia subduction zone off the coast of the Pacific Northwest of the USA and Canada (Long & Shennan, 1994)
Figure 1.4
Region affected by the 1964 Alaskan earthquake showing location of sites studied, generalised contours of co-seismic uplift and subsidence (modified from Plafker, 1969) and eight volcanoes (solid triangles) marking the eastern end of the Aleutian volcanic arc.
Figure 2.1
Location of field sites around the upper Cook Inlet and Turnagain Arm, major rivers and ice fields
Figure 2.2
Satellite image showing the location of the Kenai River Flats and Kenai City Pier transects in relation to the Kenai River entrance (Rod Combellick, State of Alaska Geological and Geophysical Survey)
Figure 2.3
Oblique aerial photograph of Kenai River Flats showing the transect across the marsh, location of coring site Kenai 2000-7 and tidal channel. The contemporary transect incorporates all environments from unvegetated mudflat through to raised bog.
Figure 2.4

Altitude (m) of vegetation zones (described in table 2.1) found at Kenai River Flats and Kenai City Pier
Vegetation zone 7
Towards the landward limit of the transect, diverse raised bog communities develop comprising Poaceae, Carex lyngbyei, Sphagnum sp., Vaccinium sp., Empetrum nigrum, Salix sp., Alnus sp., Picea sp. and Betula sp. The ground at the most landward site is completely waterlogged with a floating mat of vegetation.

Vegetation zones 4 and 5
Midway along the transect there is a transition from mid marsh to high marsh. Vegetation consists of Poaceae, Juncus sp., Triglochin maritima, Carex lyngbyei with rare Potentilla egedii, Puccinellia sp. and Plantago maritima.

Vegetation zones 1, 2 and 3
Towards the river, a small levee separates the unvegetated mudflat from the marsh surface, and so there is a poor transition between the two. Vegetation at the marsh front consists of Poaceae, Triglochin maritima, Potentilla egedii and Juncus sp.

Figure 2.5
Contemporary environments at Kenai River Flats
Figure 2.6
Oblique aerial photograph of Kenai City Pier. The contemporary marsh transect at this site has a more extensive tidal flat that gently grades into low marsh.
Vegetation zone 7
At the landward limit of the transect diverse raised bog communities develop, similar to those found at Kenai River Flats.

Vegetation zone 4
Along the transect, vegetation changes to mid marsh consisting of Poaceae, Juncus sp., Triglochin maritima with rare Potentilla egedii, Puccinellia sp. and Plantago maritima together with the introduction of Carex lyngbyei.

Vegetation zones 1 and 2
At Kenai City Pier, the mudflat is more extensive and there is gentle transition into the upper tidal flat/marsh pioneer zone and then into low marsh.

Figure 2.7
Contemporary environments at Kenai City Pier
Figure 2.8
Oblique aerial photograph (looking upstream) of the marsh and Kasilof River showing location of the bank section with the three laterally extensive peat layers. The sampling site lies 3.75 km from the river entrance into the Cook Inlet.
Figure 2.9
Bank section at Kasilof showing three buried peat layers. The lowest is approximately 1 m thick and contains distinctive wood layers and tephras. Ages shown are recalibrated radiocarbon dates from Combellick and Reger (1994)
Figure 2.10
Oblique aerial photograph of Girdwood showing extensive tidal flat areas, a small cliff separating the tidal flat from the marsh surface and ghost forests rooted in the 1964 buried peat layer (Rod Combellick, State of Alaska Geological and Geophysical Survey)
Figure 2.11
Cliff face (~1 m) at Girdwood separating the contemporary tidal flat from the marsh surface exposing the 1964 peat in which the ghost forest is rooted
Snow covers the frozen marsh surface at Girdwood.

The small cliff face separating the mudflat from the marsh surface is not visible due to the amount of ice in the Turnagain Arm. Highest tides deposit some ice blocks onto the marsh surface.

Melting ice blocks on the marsh surface deposit a significant amount of sediment that becomes part of the annual sediment accumulation.

Figure 2.12
Winter conditions at Girdwood, April 2002
Snow covers the frozen marsh surface at Kenai. The tidal channel that dissects the contemporary transect is not visible due to the amount of ice contained within it.

The Kenai River (same location as figure 2.5) is frozen, with ice blocks pushed up the riverbank onto the contemporary marsh surface. No contemporary mudflats are visible.

Further downstream at Kenai City Pier, the Kenai River is not frozen. Large ice blocks are deposited on the mudflat that is frozen down to a depth of approximately 0.5 m.

Figure 2.13
Winter conditions at Kenai, April 2002
Rapid co-seismic submergence and the deposition of minerogenic material results in a dramatic decrease in the amount of organic material.

Increase in organic matter as marsh vegetation redevelops on uplifted intertidal flats.

Decrease in organic matter towards the top of the peat due to a pre-seismic relative sea-level rise.

Figure 3.1
Schematic diagram of organic content changes (Hamilton, 1998) associated with the EDC model.
The primary aim of a transfer function is to predict the value of one or more environmental variables ($X_o$) from fossil biological data ($Y_o$) consisting of $m$ species in $t$ samples. To estimate values of $X_o$ the contemporary response of the same $m$ species to the environmental variable(s) of interest is modelled. This involves a contemporary ‘training set’ of $m$ species at $n$ sites ($Y$) studied as surface assemblages with an associated set of contemporary environmental variables ($X$) for the same $n$ sites. The modern relationships between $Y$ and $X$ are modelled and the resulting function is then used as a transfer function to transform the fossil data ($Y_o$) into quantitative estimates of the past environmental variable(s) $X_o$ (diagram and text from Birks, 1995).
Figure 4.1

Tidal observations (m relative to TBM = 100) for Kenai River Flats. Figure 4.1(a) shows the relationship between observed low tide at Kenai River Flats (m TBM) and predicted low tide at Kenai City Pier (m MLLW) and figure 4.1(b) shows the same relationship for high tide.
Figure 4.2
High tide observations at Girdwood against predicted at Sunrise
Figure 4.3

Hours inundated per year for the contemporary samples from Kenai River Flats and Kenai City Pier calculated using hourly water level data for Seldovia
Figure 4.4

Kenai contemporary diatom data (>5% total diatom valves) and cluster analysis using Euclidian distance. Summary salinity classes: polyhalobian (P), mesohalobian (M), oligohalobian-halophile (O-h), oligohalobian-indifferent (O-i), halophobe (H)
Figure 4.5
Altitude range of classes produced using Euclidian distance
Figure 4.6

Kenai contemporary diatom data (>5% total diatom valves) and cluster analysis using Chord distance. Summary salinity classes: polyhalobian (P), mesohalobian (M), oligohalobian-halophile (O-h), oligohalobian-indifferent (O-i), halophobe (H)
Figure 4.7

Altitude range of classes produced using Chord distance
Figure 4.8 Diatom optima and tolerance based upon WA model. Main diagram shows species that account for over 5% total diatom valves counted in at least one sample and solid circles indicate those that occur in five or fewer. Inset shows the full data set (appendix 1).
WA PLS - full data set
Component 1
RMSEP = 0.97, $r^2 = 0.61$

WA PLS - full data set
Component 2
RMSEP = 0.93, $r^2 = 0.65$

WA PLS - full data set
Component 3
RMSEP = 0.94, $r^2 = 0.64$

Figure 4.9
Regression results for the full contemporary data set using WA-PLS components 1, 2 and 3 (altitude (m) relative to MHHW)
Figure 4.10
Regression results using hours inundated per year for the full contemporary data set (WA-PLS components 1, 2 and 3)
Regression results for contemporary samples found below MHHW using PLS component 3 with a square root transformation for both altitude (m) relative to MHHW and hours inundated per year.
WA PLS for samples above 1.0 m MHHW
Component 1
RMSEP = 0.07, $r^2 = 0.85$

WA PLS for samples above 1.0 m MHHW
Component 2
RMSEP = 0.07, $r^2 = 0.85$

WA PLS for samples above 1.0 m MHHW
Component 3
RMSEP = 0.06, $r^2 = 0.87$

Figure 4.12
Regression results using altitude (m) relative to MHHW for contemporary samples above +1.0 m MHHW (WA-PLS components 1, 2 and 3)
Figure 4.13
Regression results using hours inundated per year for contemporary samples above +1.0 m MHHW (WA-PLS components 1, 2 and 3)
Figure 4.14

Hours inundated per year for sites above +0.8 m MHHW showing observations (solid symbols) and equation (solid line) used to back calculate predicted altitude (m) from regression models based on hours inundated data sets.
WA PLS - above -0.5 MHHW
Component 1
RMSEP = 0.24, $r^2 = 0.78$

WA PLS - above -0.5 MHHW
Component 2
RMSEP = 0.20, $r^2 = 0.84$

WA PLS - above -0.5 MHHW
Component 3
RMSEP = 0.21, $r^2 = 0.84$

Figure 4.15
Regression results using altitude (m) relative to MHHW for contemporary samples above -0.5 m MHHW (WA-PLS components 1, 2 and 3)
Figure 4.16
Observed against predicted altitude (m) relative to MHHW for contemporary Kenai data using MAT and 1, 2, 5 or 10 closest dissimilarity coefficients.

A  Using 1 closest dissimilarity coefficient
RMSE = 0.87, $r^2 = 0.69$

B  Using 2 closest dissimilarity coefficients
RMSE = 0.92, $r^2 = 0.68$

C  Using 5 closest dissimilarity coefficients
RMSE = 0.87, $r^2 = 0.70$

D  Using 10 closest dissimilarity coefficients
RMSE = 0.86, $r^2 = 0.70$
Figure 4.17

Cumulative frequency distribution of MAT minimum dissimilarity coefficients showing the extreme 2.5% and 5% thresholds used to define "good", "close" and "poor" analogues
Figure 5.1
Summary litho-stratigraphy at Kenai River Flats
Figure 5.2
Surface vegetation at Kenai 2000-7 consisting of Poaceae, Carex lyngbyei and rare Triglochin maritima. Dead trees rooted in the uppermost peat layer (figure 5.1) were killed following submergence during the 1964 earthquake
Figure 5.3
Lithology of Kenai 2000-7 showing the upper peat-silt boundary that represents coseismic submergence during the 1964 earthquake. This sample was taken within 1 m of the monolith used for laboratory analyses, hence slightly different depth values.
### Lithology

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
</table>
| 0-1.5      | Silty peat and modern root layer  
             | Th⁺³, Ag¹, Sh⁺  
             | 3,0,2,2,-     |
| 1.5-5.5    | Grey clay silt with herbaceous roots  
             | As¹, Ag¹, Th⁺²  
             | 2,0,2,0,0    |
| 5.5-21.5   | Brown bryophyte herbaceous peat  
             | Tb⁺³, Th⁺²⁺¹, Sh⁺⁺, DI⁺  
             | 3,0,2,2,2  
             | Tephra @ 14 cm |
| 21.5-160.5 | Grey silt with occasional rootlets  
             | Ag⁴, Th⁺³  
             | 2,0,2,0,1 |
| 160.5-163.5| Grey silt with herbaceous rootlets  
             | Ag³, Th⁺²⁺¹  
             | 2,0,2,0,0 |
| 163.5-165.5| Herbaceous peat with silt  
             | Th⁺²⁺¹, Sh⁺¹, Ag¹  
             | 3,0,2,0,0 |
| 165.5-198.5| Mottled bryophyte herbaceous peat  
             | Tb⁺³⁺², Th⁺²⁺², Sh⁺  
             | 3,2,2,1,0  
             | Tephra @ 180 cm and 193 cm |
| 198.5-206  | Grey silt with rare herbaceous rootlets  
             | Ag⁴, Th⁺  
             | 2,0,2,0,0 |

**Figure 5.4**  
Detailed litho-stratigraphy of Kenai 2000-7
Figure 5.5

Loss on ignition (LOI) values for the upper part of Kenai 2000-7. Lithology symbols as figure 5.4
Figure 5.6a

Kenai 2000-7 diatom data (>2% total diatom valves) showing polyhalobian (P), mesohalobian (M) and oligohalobian-halophile (O-h) salinity classes, ordered left to right in summary graph with oligohalobian-indifferent (O-i) and halophobe (H)
Figure 5.6b

Kenai 2000-7 diatom data (>2% total diatom valves) showing oligohalobian-indifferent (O-i) and halophobe (H) salinity classes, ordered left to right in summary graph after polyhalobian (P), mesohalobian (M) and oligohalobian-halophile (O-h)
Figure 5.7

Chrono-stratigraphy of Kenai 2000-7 (a) radiocarbon results (cal yr BP) and (b) $^{137}$Cs results
Figure 5.8

Radiocarbon dates for Kenai from this study (values in red) compared to re-calibrated dates of Combellick and Reger (1994, values in black) showing median age and 95% range.
Figure 5.9

Calibration results for Kenai 2000-7 using the full model, samples above -0.5 m MHHW and samples above +1.0 m for both altitude (m) relative to MHHW and hours inundated per year (back calculated to altitude)
Figure 5.10
Minimum dissimilarity coefficient values from MAT for Kenai 2000-7
Figure 5.11

Reconstruction of relative sea-level change for Kenai 2000-7 using the best combination of models (table 5.2). Samples in red have 'poor' modern analogues.
Figure 6.1
Summary litho-stratigraphy at Girdwood
Figure 6.2

Location of sampling sites at Girdwood
Figure 6.3
Chrono-stratigraphy of Girdwood G-800, G-01-1 and G-01-9 (cal yr BP)
Figure 6.4

Radiocarbon dates for Girdwood from this study (values in red) compared to recalibrated dates of Combellick and Reger (1994, values in black) showing median age and 95% range.
<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
</table>
| 0-30      | Grey silt with herbaceous rootlets
Ag3, As1, Th$^{2+}$
2,0,2,0,- |
| 30-55     | Grey silt with herbaceous rootlets with slight sand increase
Ag4, Th$^{2+}$, Ga++
2,0,2,0,0 |
| 55-68.5   | Grey silt with herbaceous rootlets and trace of sand
Ag4, Th$^{2+}$, Ga+
2,0,2,0,0 |
| 68.5-81.5 | Brown herbaceous peat
Th$^{2+}$, Sh1
3,0,2,+4 |
| 81.5-91.5 | Brown herbaceous peat with slight increase in silt content
Th$^{2+}$, Sh1, Ag1
3,0,2,0,0 |
| 91.5-108.5| Brown herbaceous peat
Th$^{2+}$, Sh1
3,0,2,+0 |
| 108.5-112.5| Silty herbaceous peat
Th$^{2+}$, Ag1
2,0,2,0,0 |
| 112.5-150 | Grey silt with herbaceous rootlets
Ag3, As1, Th$^{2+}$
2,0,2,0,0 |
| 150-178.5 | Grey silt with herbaceous rootlets with trace of sand
Ag3, As1, Th$^{2+}$, Ga+
2,0,2,0,0 |
| 178.5-184.5| Brown herbaceous peat, sharp upper contact
Th$^{2+}$, Sh2
3,0,2,+4 |
| 184.5-188.5| Silty peat with herbaceous rootlets
Th$^{2+}$, Sh1, Ag1
2,0,2,0,0 |
| 188.5-194.5| Peaty silt
Ag3, Th$^{2+}$
2,0,2,0,0 |
| 194.5-200 | Grey silt with herbaceous rootlets
Ag3, As1, Th$^{2+}$
2,0,2,0,0 |

Core ends in this unit

**Figure 6.5a**

Detailed litho-stratigraphy of Girdwood G-800
Figure 6.5b

Girdwood G-02-2 showing increase in silt content (~10 cm) within the upper peat layer. This section was not exposed during sampling in 2000 and 2001.
Girdwood G-800 diatom data (>2% total diatom valves). Summary salinity classes: polyhalobian (P), mesohalobian (M), oligohalobian-halophile (O-h), oligohalobian-indifferent (O-i), halophobe (H) ordered left to right in summary graph

Figure 6.6
Figure 6.7
Calibration results for Girdwood G-800 using the full model, samples above -0.5 m MHHW and samples above +1.0 m for both altitude (m) relative to MHHW and hours inundated per year (back calculated to altitude)
Figure 6.8
Minimum dissimilarity coefficient values from MAT for Girdwood G-800
Figure 6.9

Reconstruction of relative sea-level change for Girdwood G-800 using the best combination of models (table 6.4). The sample in red has a ‘poor’ modern analogue.
<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
</table>
| 0-19.5    | Clay silt with occasional rootlets  
Ag3, As1, Th²⁺  
2,0,2,0,- |
| 19.5-38.5 | Bryophyte peat with woody and herbaceous rootlets. Sharp upper boundary  
Tb³⁺, Th²⁺₁, Ti²⁺  
3,1,2,2,4 |
| 38.5-43.5 | Organic silty peat  
Ag₁, As₁, Th²⁺₁, Tb³⁺₁  
2+,0,2,0,0 |
| 43.5-50   | Clay silt with herbaceous rootlets  
Ag₃, As₁, Th²⁺⁺  
2,0,2,0,0 |

Figure 6.10
Detailed litho-stratigraphy of Girdwood G-01-1A
Figure 6.11a

Girdwood G-01-1A diatom data (>2% total diatom valves). Summary salinity classes: polyhalobian (P), mesohalobian (M), oligohalobian-halophile (O-h), oligohalobian-indifferent (O-i), halophobe (H) ordered left to right in summary graph.
Figure 6.11b

Girdwood G-01-1A pollen data (>2% total pollen, counted by I. Shennan)
**Figure 6.12**

Calibration results for Girdwood G-01-1A using the full model, samples above -0.5 m MHHW and samples above +1.0 m for both altitude (m) relative to MHHW and hours inundated per year (back calculated to altitude)
Figure 6.13
Minimum dissimilarity coefficient values from MAT for Girdwood G-01-1A
Figure 6.14

Reconstruction of relative sea-level change for Girdwood G-01-1A using the best combination of models (table 6.11). As diatoms are absent throughout the peat layer, pollen indicates it is well developed and probably formed between +1.35 and +1.57 m MHHW.
<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2.5</td>
<td>Silt with herbaceous rootlets</td>
</tr>
<tr>
<td></td>
<td>Ag4, Th+</td>
</tr>
<tr>
<td></td>
<td>2,0,2,0,0</td>
</tr>
<tr>
<td>2.5-12.5</td>
<td>Grey silt</td>
</tr>
<tr>
<td></td>
<td>Ag4</td>
</tr>
<tr>
<td></td>
<td>2,0,2,0,0</td>
</tr>
<tr>
<td>12.5-23.5</td>
<td>Peat with abundant herbaceous rootlets</td>
</tr>
<tr>
<td></td>
<td>Th23, Sh1, Ag+</td>
</tr>
<tr>
<td></td>
<td>3,0,2,0,4</td>
</tr>
<tr>
<td>23.5-26</td>
<td>Silt with herbaceous rootlets</td>
</tr>
<tr>
<td></td>
<td>Ag4, Th+</td>
</tr>
<tr>
<td></td>
<td>2,0,2,0,0</td>
</tr>
</tbody>
</table>

**Figure 6.15**

Detailed litho-stratigraphy of Girdwood G-01-1C
Figure 6.16

Girdwood G-01-1C diatom data (>2% total diatom valves). Summary salinity classes: polyhalobian (P), mesohalobian (M), oligohalobian-halophile (O-h), oligohalobian-indifferent (O-i), halophobe (H) ordered left to right in summary graph.
Figure 6.17

Calibration results for Girdwood G-01-1C using the full model, samples above -0.5 m MHHW and samples above +1.0 m for both altitude (m) relative to MHHW and hours inundated per year (back calculated to altitude)
Figure 6.18
Minimum dissimilarity coefficient values from MAT for Girdwood G-01-1C
Figure 6.19

Reconstruction of relative sea-level change for Girdwood G-01-1C using the best combination of models (table 6.15). Samples in red have ‘poor’ modern analogues and it illustrates the difference in using the full and -0.5 m models when estimating the altitude of silt units.
<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
</table>
| 68-88.5    | Grey silt with herbaceous rootlets  
Ag4, Th$^3^+$  
2,0,2,0,0 |
| 88.5-100.5 | Herbaceous peat with sharp upper contact. Increase in silt content between 93.5 to 96.5 cm  
Th$^3^3$, Sh1, Ag++  
3,0,2,0,4 |
| 100.5-102  | Grey silt with herbaceous rootlets  
Ag4, Th+  
2,0,2,0,0 |

Figure 6.20

Detailed litho-stratigraphy of Girdwood G-01-1E
Figure 6.21

Girdwood G-01-1E diatom data (>2% total diatom valves). Summary salinity classes: polyhalobian (P), mesohalobian (M), oligohalobian-halophile (O-h), oligohalobian-indifferent (O-i), halophobe (H) ordered left to right in summary graph.
Figure 6.22

Calibration results for Girdwood G-01-1E using the full model, samples above -0.5 m MHHW and samples above +1.0 m for both altitude (m) relative to MHHW and hours inundated per year (back calculated to altitude)
Figure 6.23
Minimum dissimilarity coefficient values from MAT for Girdwood G-01-1E
<table>
<thead>
<tr>
<th>Age Cal y BP</th>
<th>Depth (cm)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>3212-3634</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3724-4076</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.24

Reconstruction of relative sea-level change for Girdwood G-01-1E using the best combination of models (table 6.20). Samples in red have 'poor' modern analogues.
Figure 6.25
Detailed litho-stratigraphy of Girdwood G-01-1F
Figure 6.26

Girdwood G-01-1F diatom data (>2% total diatom valves). Summary salinity classes: polyhalobian (P), mesohalobian (M), oligohalobian-halophile (O-h), oligohalobian-indifferent (O-i), halophobe (H) ordered left to right in summary graph
Figure 6.27

Calibration results for Girdwood G-01-1F using the full model, samples above -0.5 m MHHW and samples above +1.0 m for both altitude (m) relative to MHHW and hours inundated per year (back calculated to altitude)
Figure 6.28
Minimum dissimilarity coefficient values from MAT for Girdwood G-01-1F
Figure 6.29

Reconstruction of relative sea-level change for Girdwood G-01-1F using the best combination of models (table 6.25)
<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-9.5</td>
<td>Silt with herbaceous rootlets</td>
</tr>
<tr>
<td></td>
<td>Ag4, As+, Th$^2+$</td>
</tr>
<tr>
<td></td>
<td>2,0,2,0,0</td>
</tr>
<tr>
<td>9.5-10.5</td>
<td>Silty herbaceous peat</td>
</tr>
<tr>
<td></td>
<td>Th$^2$3, Ag1</td>
</tr>
<tr>
<td></td>
<td>3,0,2,0,4</td>
</tr>
<tr>
<td>10.5-18.5</td>
<td>Herbaceous peat</td>
</tr>
<tr>
<td></td>
<td>Th$^2$3, Sh1</td>
</tr>
<tr>
<td></td>
<td>3,0,2,0,0</td>
</tr>
<tr>
<td>18.5-19.5</td>
<td>Silty herbaceous peat</td>
</tr>
<tr>
<td></td>
<td>Th$^2$3, Ag1</td>
</tr>
<tr>
<td></td>
<td>3,0,2,0,0</td>
</tr>
<tr>
<td>19.5-22</td>
<td>Silt with herbaceous rootlets</td>
</tr>
<tr>
<td></td>
<td>Ag4, As+, Th$^2$</td>
</tr>
<tr>
<td></td>
<td>2,0,2,0,0</td>
</tr>
</tbody>
</table>

Figure 6.30
Detailed litho-stratigraphy of Girdwood G-01-9
Figure 6.31

Girdwood G-01-9 diatom data (>2% total diatom valves). Summary salinity classes: polyhalobian (P), mesohalobian (M), oligohalobian-halophile (O-h), oligohalobian-indifferent (O-i), halophobe (H) ordered left to right in summary graph.
Figure 6.32

Calibration results for Girdwood G-01-9 using the full model, samples above -0.5 m MHHW and samples above +1.0 m for both altitude (m) relative to MHHW and hours inundated per year (back calculated to altitude)
Figure 6.33
Minimum dissimilarity coefficient values from MAT for Girdwood G-01-9
Figure 6.34

Reconstruction of relative sea-level change for Girdwood G-01-9 using the best combination of models (table 6.30). Samples in red have 'poor' modern analogues.
<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
</table>
| 54-67.5   | Clay silt with rare plant fragments  
Ag3, As1  
2.0,2,0,0. |
| 67.5-95.5 | Grey clay silt with herbaceous rootlets and organic matter  
Ag3, As1, Th+  
2.0,2,0,0 |
| 95.5-102.5| Fibrous peat with some silt. Distinct upper boundary  
Th3,2, Sh2  
3,0,2,0,4 |
| 102.5-108.5| Clay silt with rootlets  
Ag3, As1, Th+  
2.0,2,0,0 |
| 108.5-208.5| Bryophyte Peat with distinct tephras and wood layers throughout. Tephras @ 111, 134-138, 157-160, 163-164, 183-187. Wood @100-105, 138 and 185.  
Tb3,4  
3,1,2,0,4 |
| 208.5-216  | Compacted clay with fine rootlets  
Ag4, Th+  
2.0,2,0,0 |

Silt  
Herbaceous peat  
Bryophyte (Sphagnum) peat

**Figure 7.1a**  
Detailed litho-stratigraphy of the lower and middle peat layers at Kasilof (KS-01-1)
Figure 7.1b
Detailed litho-stratigraphy of the upper peat layer at Kasilof (KS-3)
Figure 7.2
Chrono-stratigraphy of Kasilof. All dates are cal yr BP with those on the left from this thesis and those on the right re-calibrated from Combellick and Reger (1994)
Figure 7.3

Radiocarbon dates for Kasilof from this study (values in red) compared to re-calibrated dates of Combellick and Reger (1994, values in black) showing median age and 95% range

$y = -0.0219x - 69.963$

$R^2 = 0.93$
Figure 7.4

$^{137}$Cs results for the upper part of KS-3
Figure 7.5

Kasilof KS-01-1 diatom data (>2% total diatom valves). Summary salinity classes: polyhalobian (P), mesohalobian (M), oligohalobian-halophile (O-h), oligohalobian-indifferent (O-i), halophobe (H) ordered left to right in summary graph.
Figure 7.6

Calibration results for Kasilof KS-01-1 using the full model, samples above -0.5 m MHHW and samples above +1.0 m for both altitude (m) relative to MHHW and hours inundated per year (back calculated to altitude)
Figure 7.7

Minimum dissimilarity coefficient values from MAT for Kasilof KS-01-1

Depth (cm)
Reconstruction of relative sea-level change for Kasilof KS-01-1 using the best combination of models (table 7.4). Samples in red have 'poor' modern analogues.
Figure 7.9

Kasilof KS-3 diatom data (>2% total diatom valves). Summary salinity classes: polyhalobian (P), mesohalobian (M), oligohalobian-halophile (O-h), oligohalobian-indifferent (O-i), halophobe (H) ordered left to right in summary graph.
Figure 7.10

Calibration results for Kasilo F KS-3 using the full model, samples above -0.5 m MHHW and samples above +1.0 m for both altitude (m) relative to MHHW and hours inundated per year (back calculated to altitude)
Figure 7.11
Minimum dissimilarity coefficient values from MAT for Kasilof KS-3
Figure 7.12

Reconstruction of relative sea-level change for Kasilof KS-3 using the best combination of models (table 7.9). The sample in red has a 'poor' modern analogue.
Figure 8.1

Models of reconstructed relative sea-level change showing effects of different types of reworked sediment (solid circle) following co-seismic submergence
Figure 8.2

Relationship between the magnitude of pre-seismic and co-seismic relative sea-level rise for the nine EDC events with a quantified estimate of the pre-seismic sea-level rise (table 8.1)
Figure 8.3

Possible pre-1964 periods of co-seismic submergence using AMS dates from this thesis

A: All ages from the top of peat layers and start of any pre-seismic signal at each site

B: Best estimate for each peat-silt boundary by comparing the stratigraphic order of all radiocarbon dates. Shaded areas represent possible co-seismic periods (table 8.2)

Both graphs show median ages and 95% ranges for both certain and possible EDC related events (table 8.1). Solid squares represent peats at Girdwood with freshwater diatoms characterising the overlying silt
Figure 8.4

Radiocarbon dates from sites around the Cook Inlet, from this thesis (in red) and elsewhere (see text). Symbols indicate the median age and 95% range. For dates from this study, red vertical lines represent the median age of definite co-seismic events, red diamonds possible co-seismic events and red squares probable non-seismic events (table 8.1). Shaded boxes in A show possible pre-1964 co-seismic periods based on radiocarbon dates from this study (table 8.2) and in B the 4 main periods of co-seismic submergence suggested by Combellick (1994). For explanation of the dashed box see text.
No RSL rise

\[ \Delta \xi_{\text{cos}}(t) > \Delta \xi_{\text{inl}}(t) \]

With RSL rise

\[ \Delta \xi_{\text{cos}}(t) > \Delta \xi_{\text{inl}}(t) \]

\[ \Delta \xi_{\text{inl}}(t) = \text{post- and inter-seismic uplift} \]
\[ \Delta \xi_{\text{rsl}}(t) = \text{non-seismic sea-level change over the time period in question} \]
\[ \Delta \xi_{\text{cos}}(t) = \text{co-seismic submergence accompanying an earthquake} \]
\[ \Delta \xi_{\text{sed}}(t) = \text{sedimentation between the tops of two peat layers} \]
\[ \xi_{\text{peat1}}(t) = \text{formation height of the top of the first buried peat} \]
\[ \xi_{\text{peat2}}(t) = \text{formation height of the top of the second buried peat} \]

Figure 8.5

Schematic models of co-seismic submergence, post- and inter-seismic uplift, sediment accumulation and marsh peat burial with no background relative sea-level rise (A and B) and with background relative sea-level rise (C and D)
Figure 8.6

Relationship between age of peat layers and depth below present marsh surface at different sites around the Cook Inlet compared to eustatic and GIA models.