Radiocarbon ages constraining earthquake event horizons

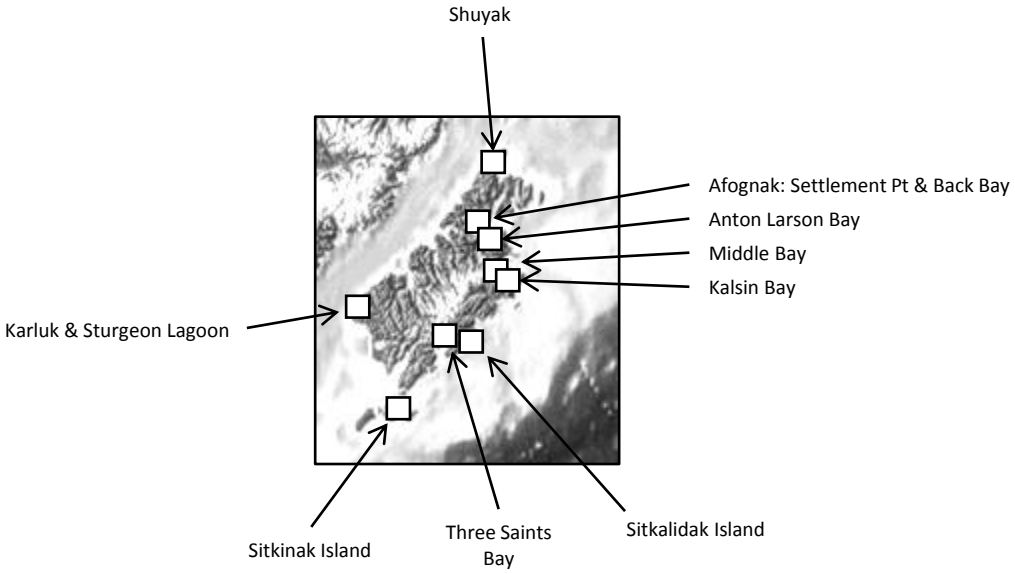


Table DR1 Radiocarbon ages constraining earthquake event horizons

Sources: 1: Carver & Plafker 2008
2: Gilpin 1995
3: This paper

Laboratory Code	14C BP	SD	Site	Code in original source	Context	Maximum or minimum constraint on event	Source
Outer Kodiak locations							
QL-4746	770	25	Sitkalidak - Rolling Bay	SDI-92-RB-1-83-4	Peat below event horizon	Max	1, 2
Beta-????	740	80	Karluk Village	Karluk-Archeo	Charcoal below event horizon	Max	1, 2
QL-4671	625	30	Sitkalidak - Seal Bay	SDI-92-2-1-73	Triglochin peat below event horizon	Max	1, 2
QL-4743	615	15	Karluk Village	Karluk-Archeo	Wood below event horizon	Max	1, 2
QL-4597	494	23	Shuyak - Deer Marsh	SI-A-5-2.80	Triglochin peat below event horizon	Max	1, 2
QL-4750	490	20	Shuyak - Bear Trail Marsh	SI-93-A-7-1-46	Peat below event horizon	Max	1, 2
QL-4667	483	26	Afognak - Back Bay	AI-A-1-51	Sphagnum peat below event horizon	Max	1, 2
QL-4592	443	14	Shuyak - Skiff Passage Marsh	SI-A-4-2.15	Sphagnum peat below event horizon	Max	1, 2
QL-4590	330	30	Shuyak - Koniag Marsh	SI-A-2-1.55	Sphagnum peat below event horizon	Max	1, 2
QL-4742	330	25	Shuyak - Skiff Passage Marsh	SI-A-4-70-72	Peat below event horizon	Max	1, 2
QL-4669	330	30	Sturgeon Lagoon	KI-KK-A-2-61	Sphagnum peat below event horizon	Max	1, 2
Earthquake age to model							
QL-4745	610	70	Sitkalidak - Seal Bay	SDI-92-2-1-72	Peat above event horizon	Min	1, 2
Beta-48802	580	60	Sturgeon Lagoon	KI-KK-A-2-59	Triglochin peat above event horizon	Min	1, 2
Beta-48806	460	50	Shuyak - Deer Marsh	SI-A-5-1.9	Triglochin peat above event horizon	Min	1, 2
QL-4596	447	30	Shuyak - Deer Marsh	SI-A-5-2.75	Triglochin peat above event horizon	Min	1, 2
QL-4595	416	14	Shuyak - Deer Marsh	SI-A-5-1.9	Triglochin peat above event horizon	Min	1, 2
Beta-48804	380	60	Afognak - Back Bay	AI-A-1-49	Triglochin peat above event horizon	Min	1, 2
QL-4589	310	30	Shuyak - Koniag Marsh	SI-A-2-1.50	Triglochin peat above event horizon	Min	1, 2
QL-4741	260	20	Shuyak - Skiff Passage Marsh	SI-A-4-66-68	Triglochin peat above event horizon	Min	1, 2
QL-4749	180	25	Shuyak - Bear Trail Marsh	SI-A-7-1-35	Peat above event horizon	Min	1, 2
Katmai tephra AD 1912							
SE Kodiak locations							
AA357775	770	30	Kalsin Bay	KB13/27 109cm	Base of organic sequence	Max	3
AA357772	730	30	Kalsin Bay	KB13/5 110cm	Within silt-peat below event horizon	Max	3
QL-4587	710	30	Middle Bay	KI-SC-1-150	Triglochin peat below event horizon	Max	1,2
AA299879	700	30	Middle Bay	MB10/8 153.5cm	Base of peat below event horizon	Max	3
AA356279	670	30	Middle Bay	MB13/1 143cm	Base of organic sequence	Max	3
Beta-101551	620	50	Afognak - Settlement Point	House 1 hearth	Charcoal below event horizon	Max	1
AA356272	590	30	Kalsin Bay	KB13/29 69.5cm	Top of peat below event horizon	Max	3
Beta-118300	570	60	Afognak - Settlement Point	House 2 hearth	Charcoal below event horizon	Max	1
QL-4586	500	20	Kalsin Bay	KI-KL-3A-4.8	Sphagnum peat below event horizon	Max	1,2
AA357774	450	30	Kalsin Bay	KB13/27 89cm	Top of peat below event horizon	Max	3
AA357411	450	30	Middle Bay	MB13/1 119cm	Within peat below event horizon	Max	3
Beta-114204	450	50	Afognak - Settlement Point	House 7 floor	Charcoal below event horizon	Max	1
Beta-114202	440	60	Afognak - Settlement Point	House 5 floor	Charcoal below event horizon	Max	1
Beta-101912	440	50	Afognak - Settlement Point	Midden bottom L2	Charcoal below event horizon	Max	1
AA295551	420	30	Middle Bay	MB10/12 93cm	Base of peat below event horizon	Max	3
AA287207	410	40	Middle Bay	MB10/5C 107cm	Top of peat below event horizon	Max	3
Beta-101913	390	50	Afognak - Settlement Point	Midden	Charcoal below event horizon	Max	1
AA287205	370	40	Anton Larson Bay	ALB10/4 78.5cm	Top of peat below event horizon	Max	3
Beta-114096	370	80	Afognak - Settlement Point	Midden L1	Settlement Point Charcoal K-Max	Max	1
Beta-114097	350	70	Afognak - Settlement Point	House 3 floor	Settlement Point Charcoal K-Max	Max	1
Beta-114098	340	60	Afognak - Settlement Point	Midden L2G	Settlement Point Charcoal K-Max	Max	1
AA287208	330	40	Middle Bay	MB10/5C 124cm	Within peat below event horizon	Max	3
AA299878	330	30	Middle Bay	MB10/8 130cm	Top of peat below event horizon	Max	3
Beta-114203	330	60	Afognak - Settlement Point	House 4 floor	Settlement Point Charcoal K-Max	Max	1
AA295550	320	30	Middle Bay	MB10/12 90cm	Peat below event horizon	Max	3
Beta-101552	300	50	Afognak - Settlement Point	House 1 floor	Charcoal below event horizon	Max	1
Beta-114205	300	50	Afognak - Settlement Point	House 6 floor	Charcoal below event horizon	Max	1
AA295548	270	30	Middle Bay	MB10/12 70cm	Top of peat below event horizon	Max	3
AA357821	220	30	Middle Bay	MB13/1 88cm	Peat below event horizon	Max	3
AA295549	210	30	Middle Bay	MB10/12 83cm	Peat below event horizon	Max	3
AA357408	200	30	Kalsin Bay	KB13/5 116cm	Peat below event horizon	Max	3
AA356276	160	30	Middle Bay	MB13/1 82cm	Top of peat below event horizon	Max	3
AA357409	150	30	Kalsin Bay	KB13/17 101cm	Top of peat below event horizon	Max	3
AA356271	90	30	Kalsin Bay	KB13/22 72cm	Top of peat below event horizon	Max	3
AA356280	40	30	Middle Bay	MB13/4 91cm	Top of peat below event horizon	Max	3
AA356266	10	30	Kalsin Bay	KB13/5 92cm	Top of peat below event horizon	Max	3
Earthquake age to model							
AA357771	130	40	Kalsin Bay	KB13/5 77cm	Base of peat below Katmai tephra	Min	3
Beta-48801	90	60	Kalsin Bay	KI-KL-3B-4.88	Wood above event horizon	Min	1
Katmai tephra AD 1912							

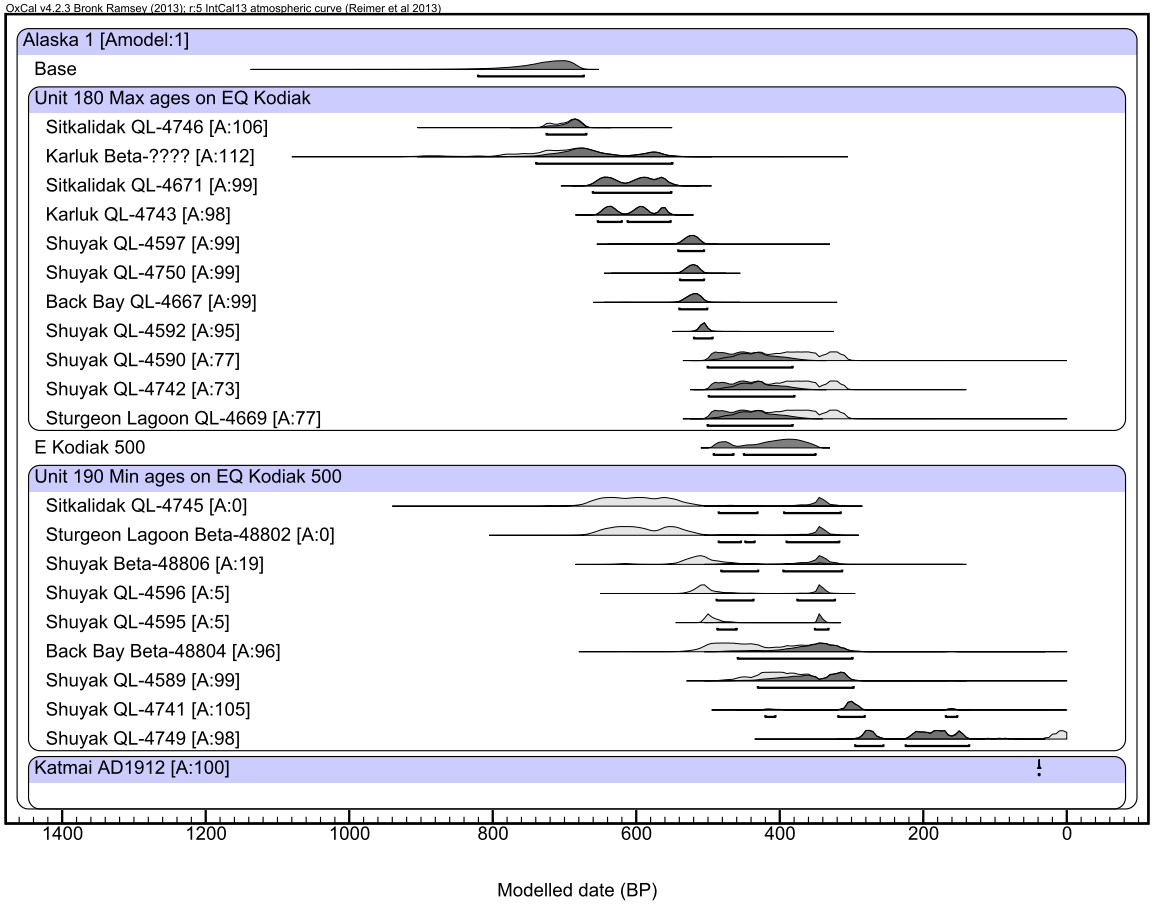
Age model outputs

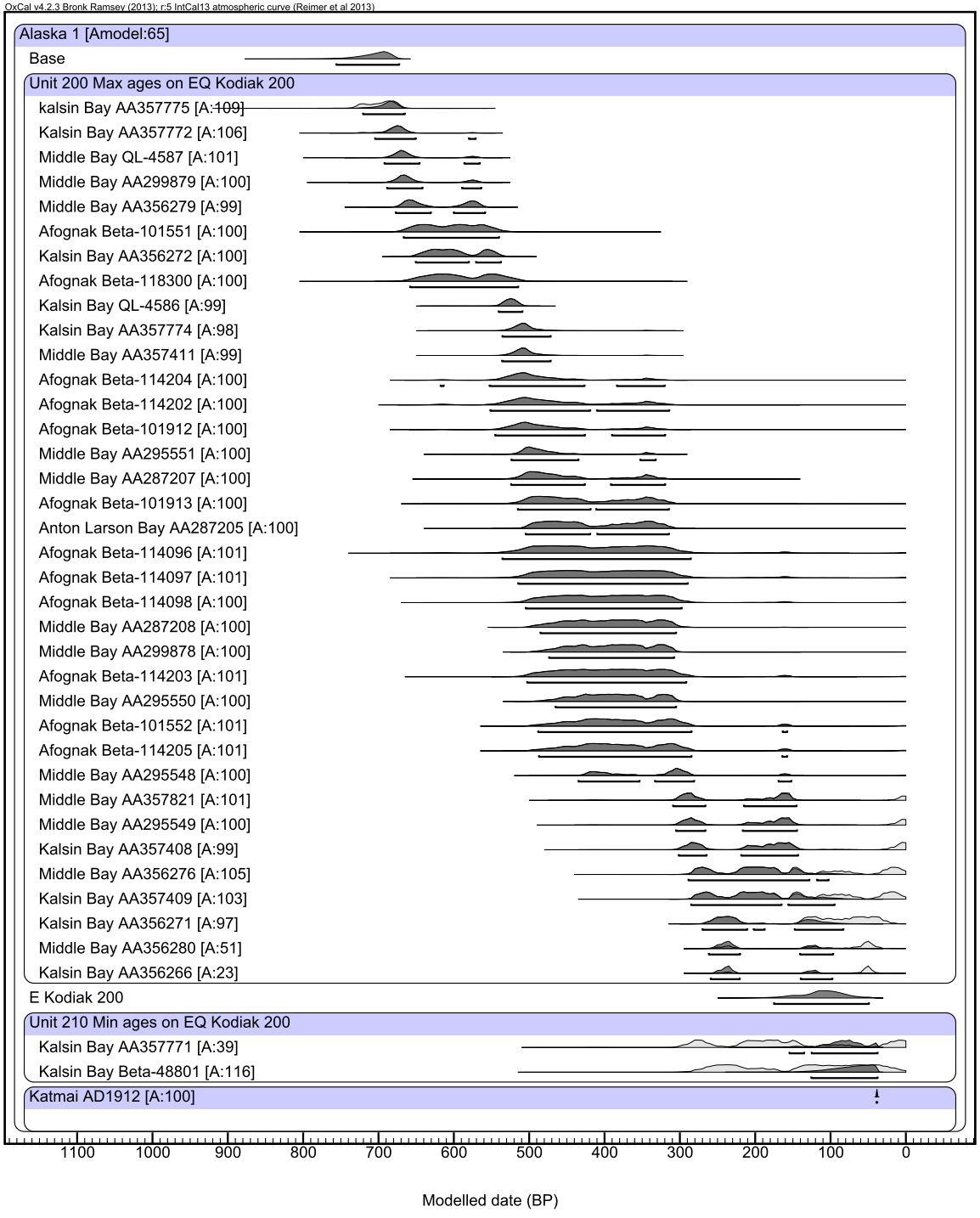
Software: OxCal v4.2.3 https://c14.arch.ox.ac.uk Bronk Ramsey (2013)

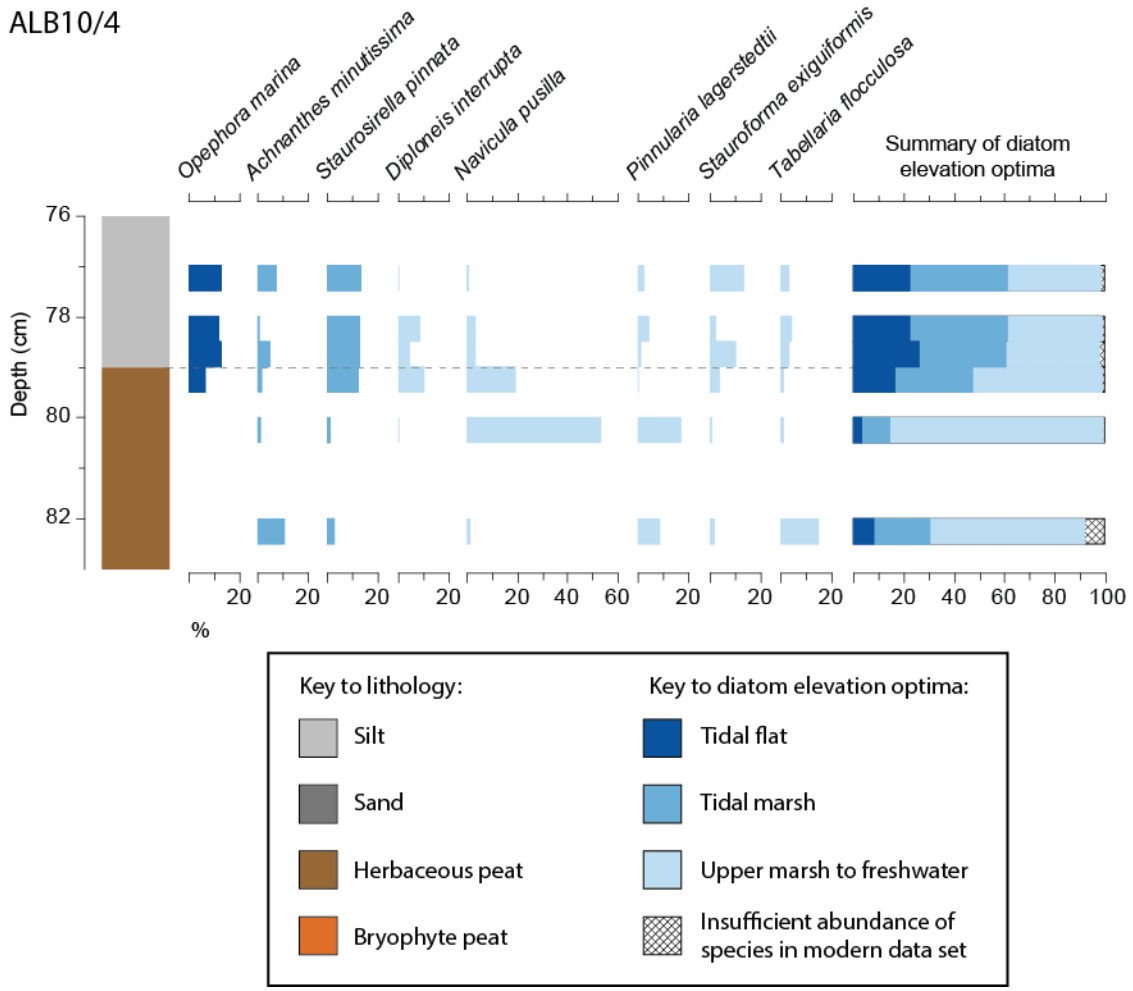
Model 1: All data from Kodiak Region (details of all samples in Supplementary Information file "Radiocarbon Ages"); assume that the earthquake horizon at each site is the same event. This model fails to converge to provide any solution. Therefore we split the dataset into sites from two geographical areas "Outer Kodiak" and "SE Kodiak"

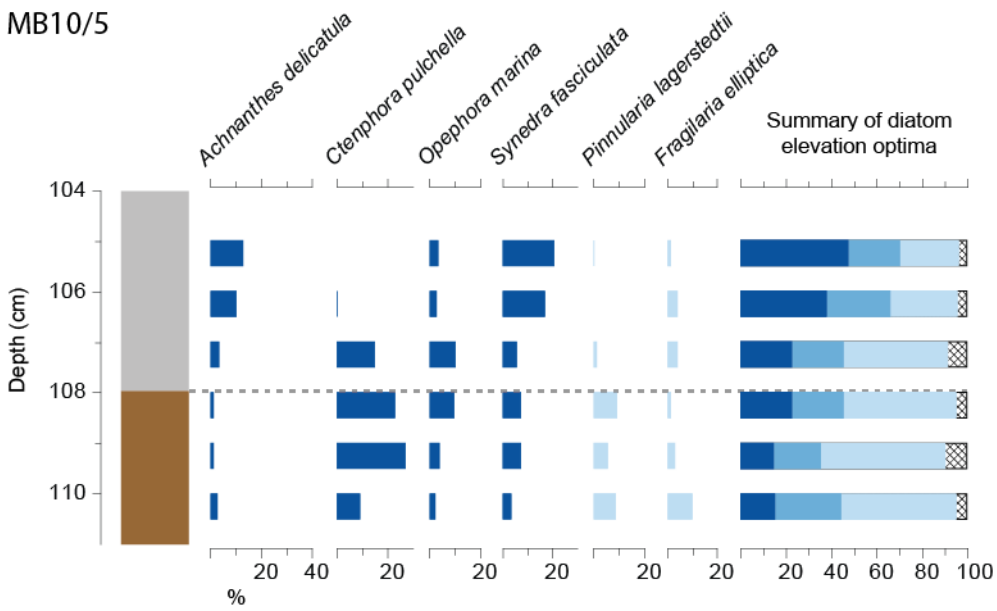
Model 2: "Outer Kodiak" OxCal model results on page 2, showing the model input in grey, the calibrated age of the radiocarbon sample; in black, the probability density function from Bayesian modelling for each input sample and the 95.4% probability age of the intervening earthquake, labelled "E Kodiak 500". The agreement index [A:] identifies 5 samples that do not agree with the model, where A<60%.

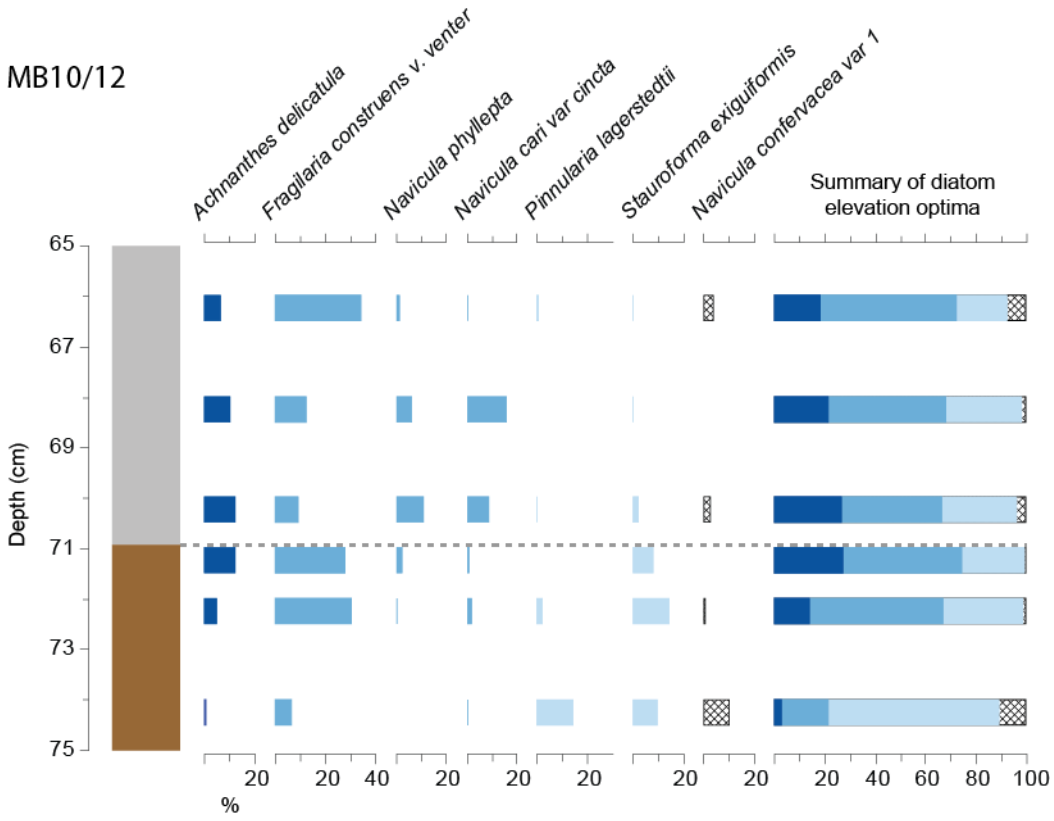
Model 3: "SE Kodiak" OxCal model results on page 3, showing the model input in grey, the calibrated age of the radiocarbon sample; in black, the probability density function from Bayesian modelling for each input sample and the 95.4% probability age of the intervening earthquake, labelled "E Kodiak 200". The agreement index [A:] identifies 3 samples that do not agree with the model, where A<60%.

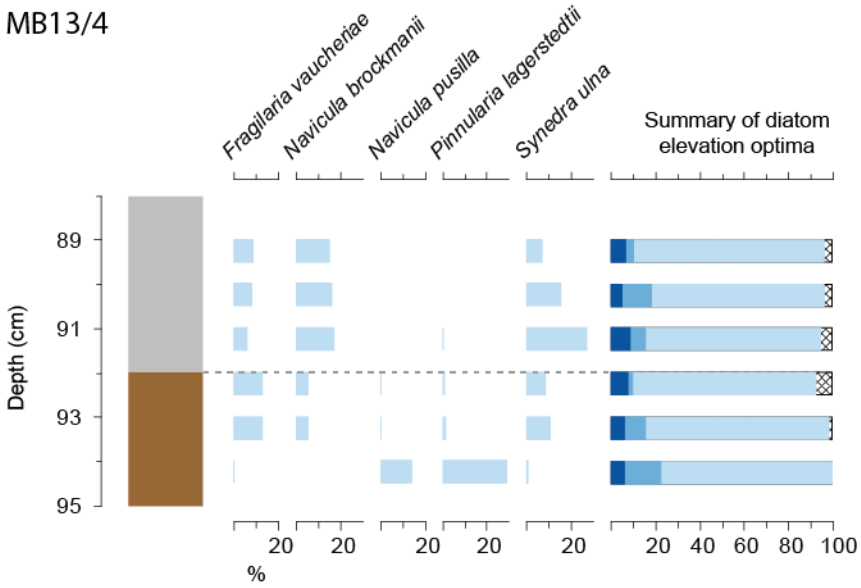

OxCal v4.2.3 Bronk Ramsey (2013); r:5 IntCal13 atmospheric curve (Reimer et al 2013)
Alaska 1 [Amodel:1]
Base
Unit 180 Max ages on EQ Kodiak
Sitkalidak QL-4746 [A:106]
Karluk Beta-???? [A:112]
Sitkalidak QL-4671 [A:99]
Karluk QL-4743 [A:98]
Shuyak QL-4597 [A:99]
Shuyak QL-4750 [A:99]
Back Bay QL-4667 [A:99]
Shuyak QL-4592 [A:95]
Shuyak QL-4590 [A:77]
Shuyak QL-4742 [A:73]
Sturgeon Lagoon QL-4669 [A:77]
E Kodiak 500
Unit 190 Min ages on EQ Kodiak 500
Sitkalidak QL-4745 [A:0]
Sturgeon Lagoon Beta-48802 [A:0]
Shuyak Beta-48806 [A:19]
Shuyak QL-4596 [A:5]
Shuyak QL-4595 [A:5]
Back Bay Beta-48804 [A:96]
Shuyak QL-4589 [A:99]
Shuyak QL-4741 [A:105]
Shuyak QL-4749 [A:98]
Katmai AD1912 [A:100]
1400
1200
1000
800
600
400
200
0
Modelled date (BP)

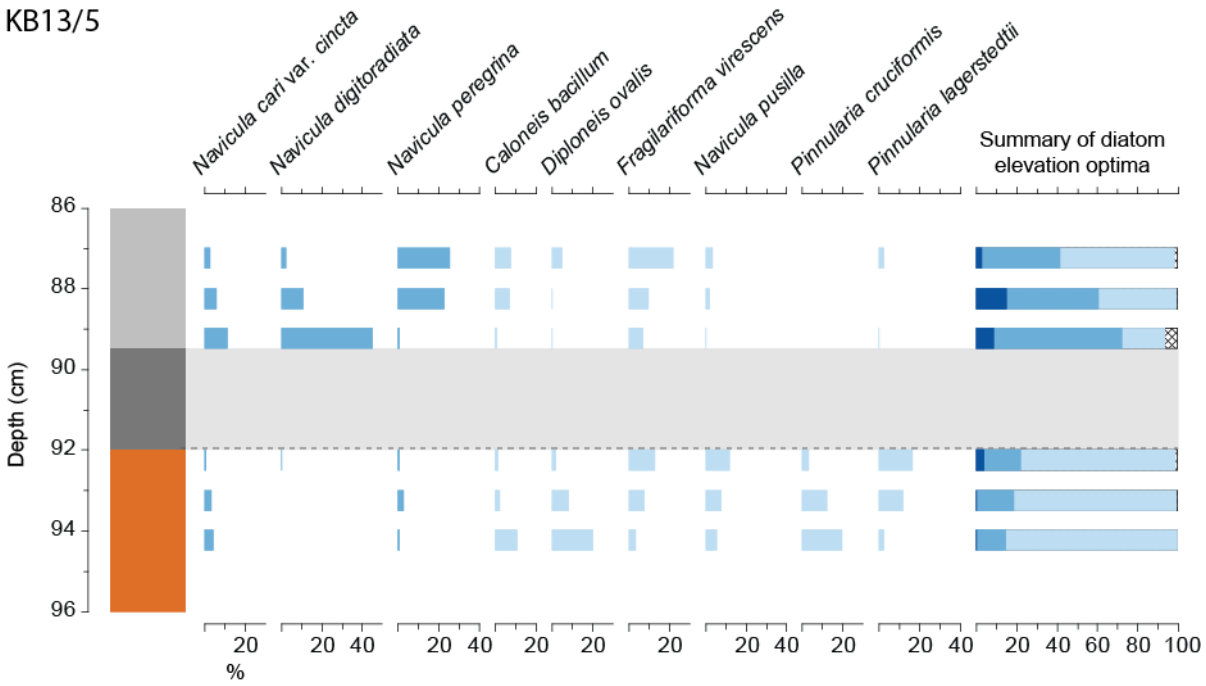

OxCal v4.2.3 Bronk Ramsey (2013); r:5 IntCal13 atmospheric curve (Reimer et al 2013)
Alaska 1 [Amodel:65]
Base
Unit 200 Max ages on EQ Kodiak 200
kalsin Bay AA357775 [A:109]
Kalsin Bay AA357772 [A:106]
Middle Bay QL-4587 [A:101]
Middle Bay AA299879 [A:100]
Middle Bay AA356279 [A:99]
Afognak Beta-101551 [A:100]
Kalsin Bay AA356272 [A:100]
Afognak Beta-118300 [A:100]
Kalsin Bay QL-4586 [A:99]
Kalsin Bay AA357774 [A:98]
Middle Bay AA357411 [A:99]
Afognak Beta-114204 [A:100]
Afognak Beta-114202 [A:100]
Afognak Beta-101912 [A:100]
Middle Bay AA295551 [A:100]
Middle Bay AA287207 [A:100]
Afognak Beta-101913 [A:100]
Anton Larson Bay AA287205 [A:100]
Afognak Beta-114096 [A:101]
Afognak Beta-114097 [A:101]
Afognak Beta-114098 [A:100]
Middle Bay AA287208 [A:100]
Middle Bay AA299878 [A:100]
Afognak Beta-114203 [A:101]
Middle Bay AA295550 [A:100]
Afognak Beta-101552 [A:101]
Afognak Beta-114205 [A:101]
Middle Bay AA295548 [A:100]
Middle Bay AA357821 [A:101]
Middle Bay AA295549 [A:100]
Kalsin Bay AA357408 [A:99]
Middle Bay AA356276 [A:105]
Kalsin Bay AA357409 [A:103]
Kalsin Bay AA356271 [A:97]
Middle Bay AA356280 [A:51]
Kalsin Bay AA356266 [A:23]
E Kodiak 200
Unit 210 Min ages on EQ Kodiak 200
Kalsin Bay AA357771 [A:39]
Kalsin Bay Beta-48801 [A:116]
Katmai AD1912 [A:100]
1100
1000
900
800
700
600
500
400
300
200
100
0
Modelled date (BP)

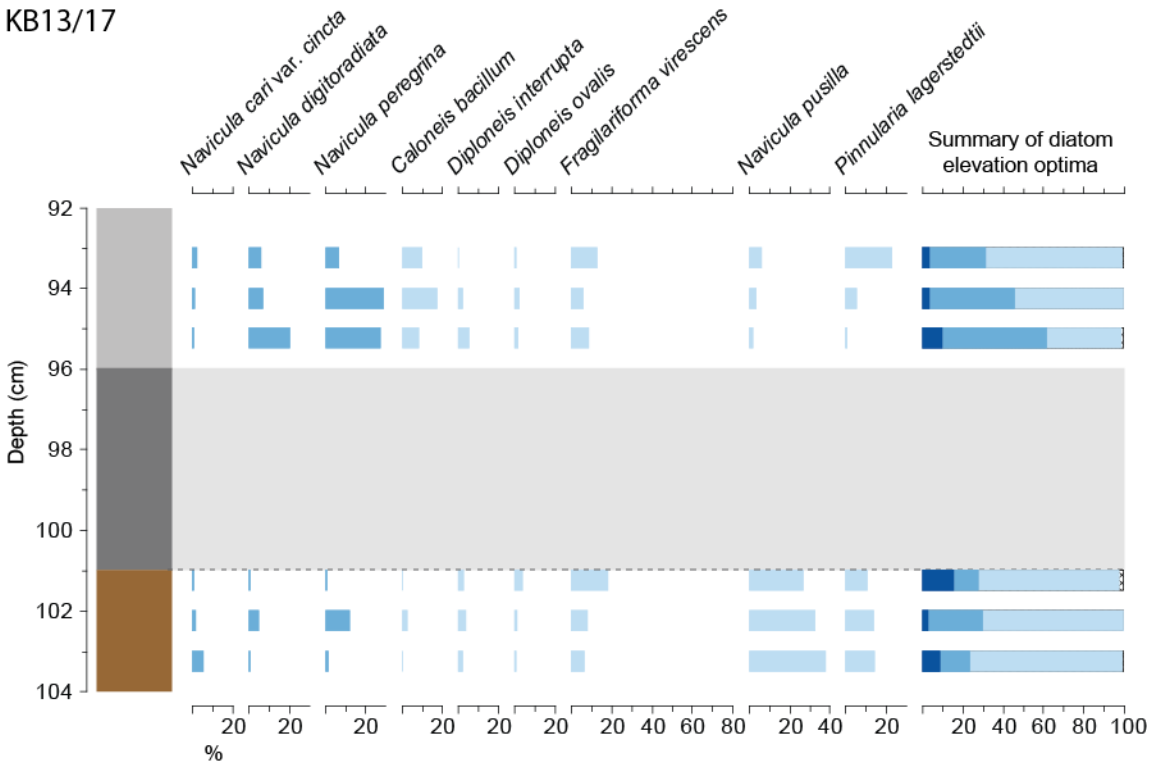

ALB10/4
Opephora marina
Achnanthes minutissima
Staurosirella pinnata
Diploneis interrupta
Navicula pusilla
Pinnularia lagerstedtii
Stauroforma exiguiformis
Tabellaria flocculosa
Summary of diatom elevation optima
Depth (cm)
76
78
80
82
20
20
20
20
20
40
60
20
20
20
20
40
60
80
100
%
Key to lithology:
Silt
Sand
Herbaceous peat
Bryophyte peat
Key to diatom elevation optima:
Tidal flat
Tidal marsh
Upper marsh to freshwater
Insufficient abundance of species in modern data set


MB10/5
Achnanthes delicatula
Ctenphora pulchella
Opephora marina
Synedra fasciculata
Pinnularia lagerstedtii
Fragilaria elliptica
Summary of diatom elevation optima
Depth (cm)
104
106
108
110
20
40
20
20
20
20
20
20
40
60
80
100
%


MB10/12
Achnanthes delicatula
Fragilaria construens v. venter
Navicula phyllepta
Navicula cari var cincta
Pinnularia lagerstedtii
Stauroforma exiguiformis
Navicula confervacea var 1
Summary of diatom elevation optima
Depth (cm)
65
67
69
71
73
75
20
20
40
20
20
20
20
20
20
40
60
80
100
%


MB13/4
Fragilaria vaucheriae
Navicula brockmanii
Navicula pusilla
Pinnularia lagerstedtii
Synedra ulna
Summary of diatom elevation optima
Depth (cm)
89
91
93
95
20
20
20
20
20
20
40
60
80
100
%


KB13/5
Navicula cari var. cincta
Navicula digitoradiata
Navicula peregrina
Caloneis bacillum
Diploneis ovalis
Fragilariforma virescens
Navicula pusilla
Pinnularia cruciformis
Pinnularia lagerstedtii
Summary of diatom elevation optima
Depth (cm)
86
88
90
92
94
96
20
20 40
20 40
20
20
20
20 40
20
20 40
20 40 60 80 100
%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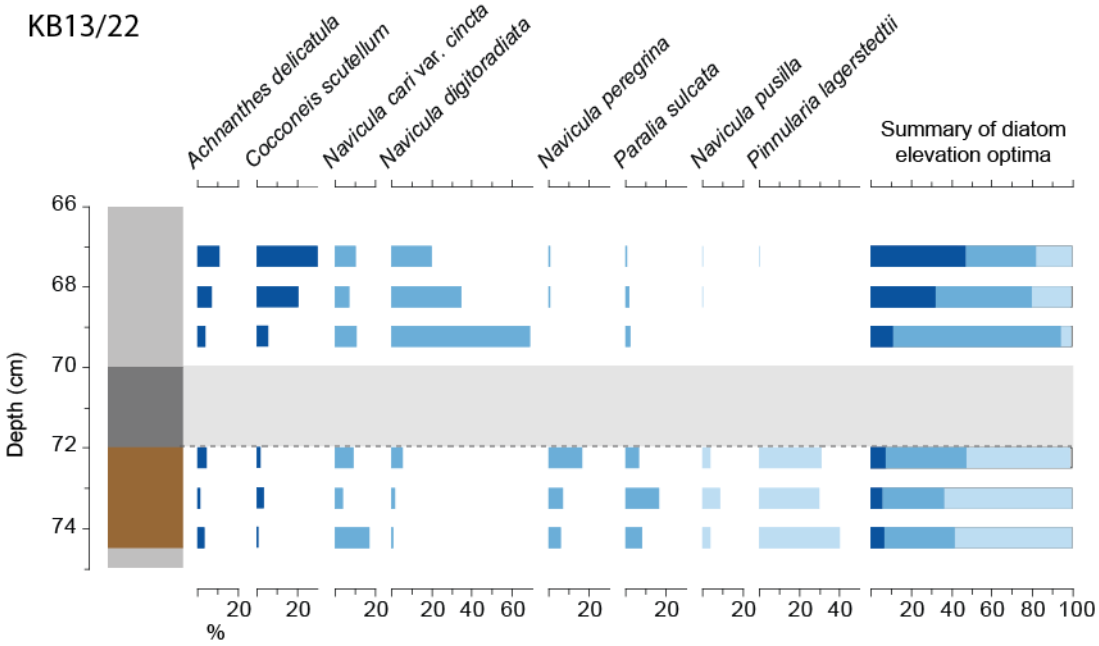
Navicula digitoradiata
Navicula peregrina
Caloneis bacillum
Diploneis interrupta
Diploneis ovalis
Fragilariforma virescens
Navicula pusilla
Pinnularia lagerstedtii
Summary of diatom elevation optima
Depth (cm)
92
94
96
98
100
102
104
20
20
20
20
20
20
20
40
60
80
20
40
20
20
40
60
80
100
%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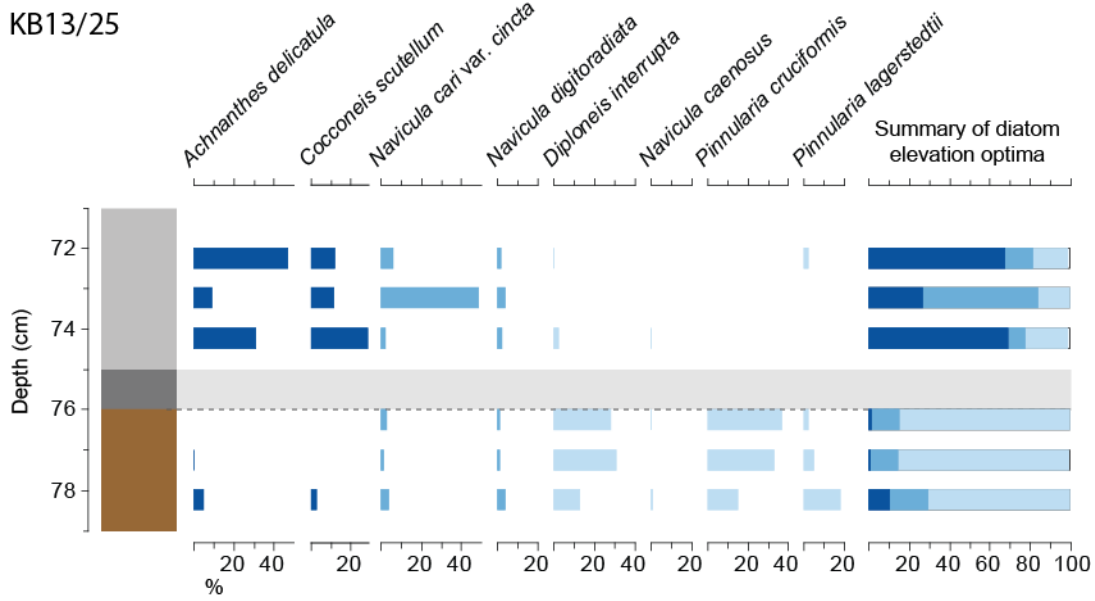
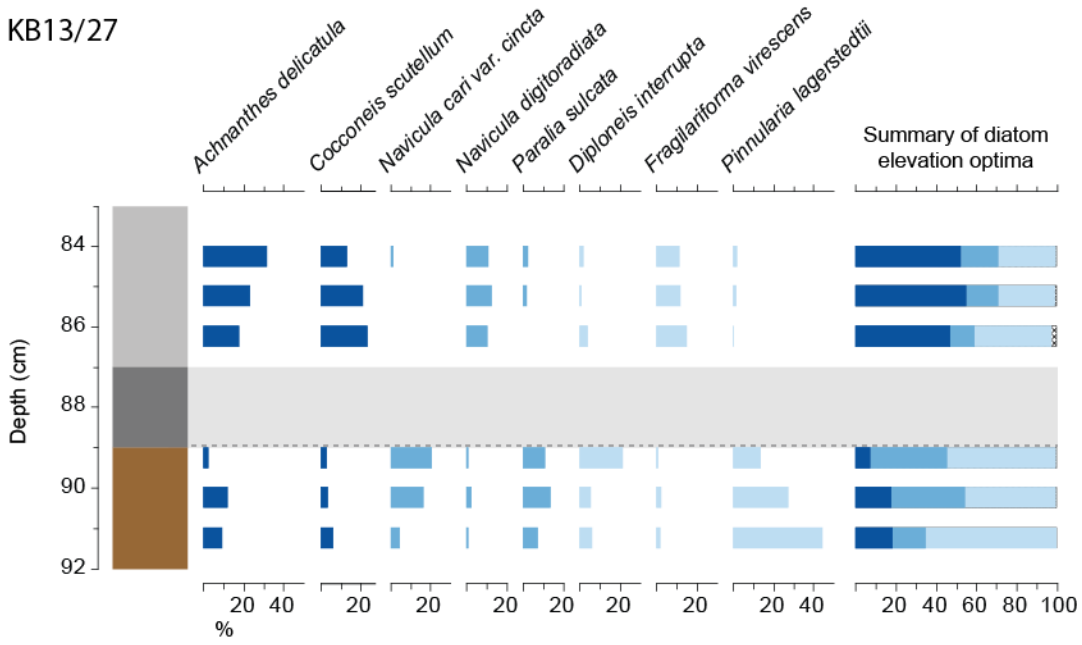
Cocconeis scutellum
Navicula cari var. cincta
Navicula digitoradiata
Navicula peregrina
Paralia sulcata
Navicula pusilla
Pinnularia lagerstedtii
Summary of diatom elevation optima
Depth (cm)
66
68
70
72
74
%
20
20
20
20
40
60
20
20
20
20
40
20
40
60
80
100


KB13/25
Achnanthes delicatula
Cocconeis scutellum
Navicula cari var. cincta
Navicula digitoradiata
Diploneis interrupta
Navicula caenosus
Pinnularia cruciformis
Pinnularia lagerstedtii
Summary of diatom elevation optima
Depth (cm)
72
74
76
78
20 40
20
20 40
20
20 40
20
20 40
20
20 40 60 80 100
%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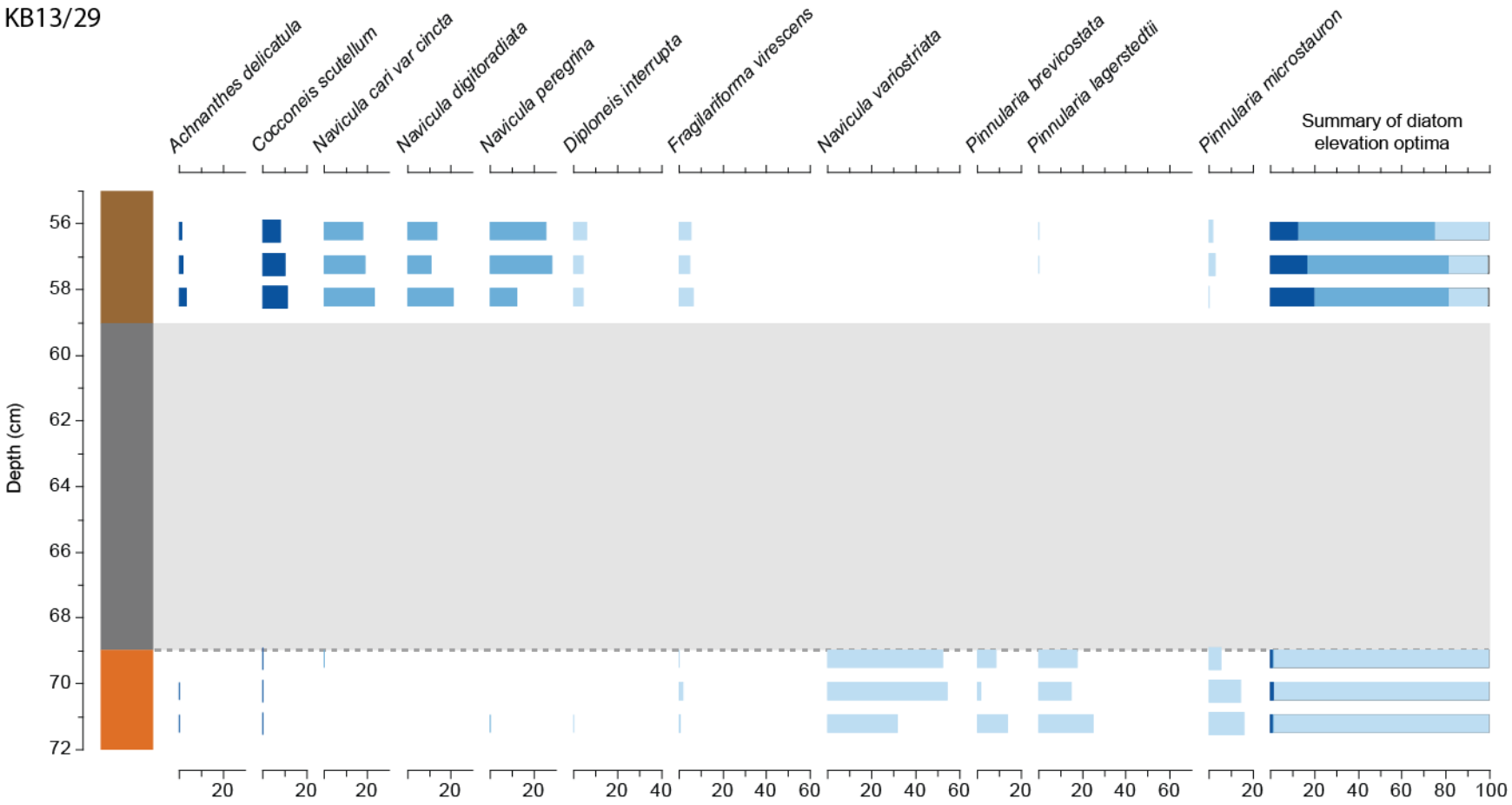
Achnanthes delicatula
Cocconeis scutellum
Navicula cari var. cincta
Navicula digitoradiata
Paralia sulcata
Diploneis interrupta
Fragilariforma virescens
Pinnularia lagerstedtii
Summary of diatom elevation optima
Depth (cm)
84
86
88
90
92
20 40
20
20
20
20
20
20
20 40
20 40 60 80 100
%


KB13/29
Achnanthes delicatula
Cocconeis scutellum
Navicula cari var cincta
Navicula digitoradiata
Navicula peregrina
Diploneis interrupta
Fragilariforma virescens
Navicula variostriata
Pinnularia brevicostata
Pinnularia lagerstedtii
Pinnularia microstauron
Summary of diatom elevation optima
Depth (cm)
56
58
60
62
64
66
68
70
72
20
20
20
20
20
20
40
20
40
60
20
40
60
20
20
40
60
20
20
40
60
80
100

Diatom-based transfer function reconstructions from separate sample locations

We use quantitative methods based on transfer function models derived from the distribution of modern diatom assemblages to reconstruct paleo marsh surface elevations for samples from sediment sequences and their diatom assemblages. From these elevation reconstructions we calculate coseismic relative land/sea-level change across an earthquake horizon. Diatom sums are >150 valves and >200 in the majority of cases. We use a modern training set of 206 samples collected from a wide range of marshes across ~1000 km of south central Alaska (Hamilton and Shennan, 2005; Watcham et al., 2013) and from these develop two models to reconstruct elevation. The adoption of which model depends on the lithology of the sediment of each fossil sample (Hamilton and Shennan, 2005); for peat sediment, a model using a subset of 100 modern samples from elevations at which organic sediment or peat was the substrate in the modern sample, and a second for organic silt units and silt units with visible plant rootlets, using all 206 samples. Since none of our fossil samples were from minerogenic units with no visible plant rootlets we did not use the model for those sediments (Hamilton and Shennan, 2005). We assess elevation reconstruction precision using the sample-specific 95.4 % error terms and the goodness of fit between each fossil sample and the modern dataset with 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. We do not estimate elevation from the diatom assemblages of tsunami deposits due to the high probability of sediment mixing.

Hamilton, S., and Shennan, I., 2005, Late Holocene relative sea-level changes and the earthquake deformation cycle around upper Cook Inlet, Alaska: Quaternary Science Reviews, v. 24, p. 1479-1498.

Watcham, E.P., Shennan, I., and Barlow, N.L.M., 2013, Scale considerations in using diatoms as indicators of sea-level change: lessons from Alaska: Journal of Quaternary Science, v. 28, p. 165-179.

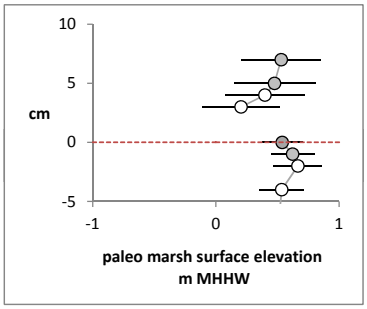
Supplementary Information: Diatom-based transfer function reconstructions from separate sample locations

Anton Larson Bay (ALB), Kalsin Bay (KB) and Middle Bay (MB).

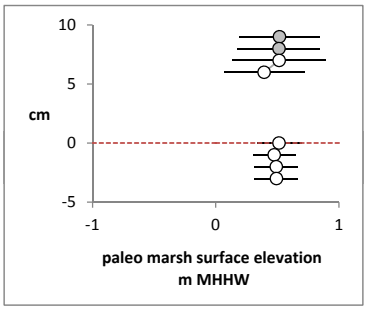
Vertical axis: zero = top contact of peat
Gap = tsunami sand, no reconstruction

Transfer function reconstructions
Error bars = 2 SD
White = poor modern analogue
Grey = close modern analogue

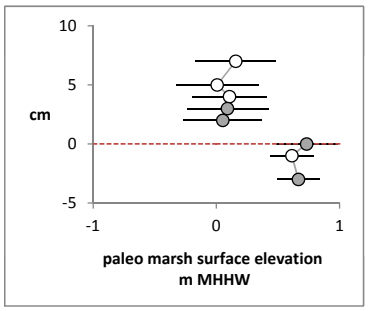
KB13-5



KB13-17



KB 13-25



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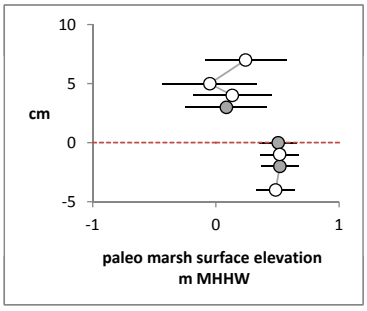

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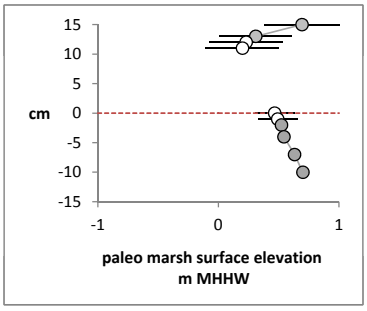
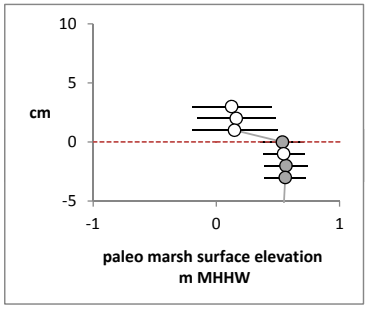
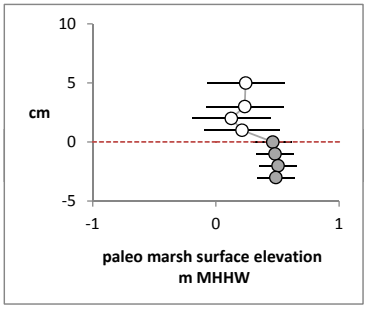


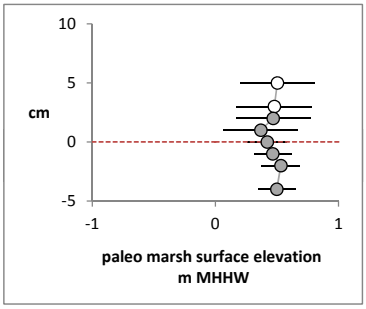
MB 10-5



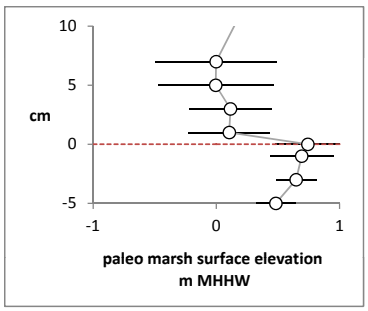
MB 13-1



MB 13-4



MB 10-12



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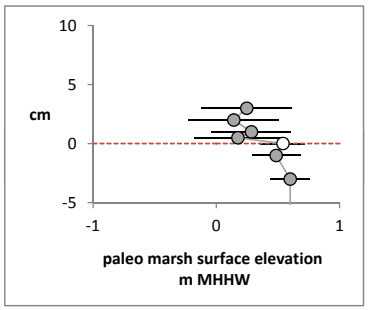

Kalsin Bay stratigraphy and radiocarbon ages