# Supplementary Files for:

"Identifying the greatest earthquakes of the past 2000 years at the Nehalem River estuary, northern coast Oregon, USA" by Nelson, Hawkes, Sawai, Engelhart, Witter, Grant-Walter, Bradley, Dura, Cahill, and Horton

## Introduction - Part 1

The Supplementary Files for this paper include the following detailed information and data for sites described in the paper that are not summarized elsewhere. The captions for the additional figures included in the Supplementary Files are listed below (Part 2), but the figures are in a separate pdf file (Part 3). The methods used to determine sampling and core elevations (Part 4), the explanation of variance added to radiocarbon age errors (Part 5), and the listing of code for selected OxCal radiocarbon age models (Part 6) also appear in this pdf file. An historically important, unpublished report by Grant (1994) is a separate pdf file (Part 7). The three tables of micropaleontologic data are also separate Excel files (Part 8). References cited in captions for the figures and elsewhere in the Supplementary Files are listed under References Cited at the end of this pdf file.

## Part 2 - Captions for Supplementary File figures

(the figures are included in a separate pdf file without captions, Part 3)

**Figure S1.** Lithologic descriptions (methods of Troels-Smith 1955; Nelson 2015) and correlations of contacts A, B, D, and E (dashed lines) in four cores across the northern part of Botts marsh. Level x and level z are too indistinct to be considered mappable contacts (discussed in the text). The comparison of detailed lithology descriptions next to the simplified lithologies shown by colors illustrates how upward and lateral changes in lithology are considerably more subtle and variable than suggested by the simplified lithology colors. For this reason, changes in simplified lithologies are commonly misleading. Laboratory descriptions (core V1, core R5, and parts of core R24) identify more lithologic units than cores described in the field (e.g., gouge core 15).

**Figure S2.** Locations of gouge cores, vibracores (V), and samples collected along the East Bank outcrop, and gouge and Russian (R) cores described from Botts marsh (UTM Zone 10T E coordinates in meters). Locations in purple are labeled with the field numbers of Grant and McLaren 1987), Grant (1989), and Grant (unpublished 1994 report in Supplementary Files), approximately located by Nelson from Grant's field notes. Locations in red are labeled with the field numbers of Nelson, Hawkes, Engelhart, Witter, Briggs, and Maharrey in 2006-2009. Red dots with blue rings show locations of cores selected for Figures 5 and S1 from west to east. White arrow shows approximate flow direction of inferred channel of the Nehalem River active about 1.2-1.3 ka. Imagery from Oregon Explorer in 2009 (http://oregonexplorer.info/topics/imagery?ptopic=98).

**Figure S3.** Simplified lithology; certain (solid red lines), probable (dashed red lines), and possible (dotted red lines) correlation of distinct contacts; lithologic descriptions (methods of Troels-Smith 1955; Nelson 2015), and $^{14}C$ ages in selected gouge and other cores (vibracore V1, Russian cores R5, R17, and R24) between the East Bank outcrop and the east edge of Botts marsh (Figures 2, 3, 4, S1, and S2). Cores are positioned along their projection to an east-west line from the outcrop to core 03, and from there along a southeast line to the forested upland. As shown by the descriptions and notes, upward and lateral changes in lithology are considerably more subtle and variable than suggested by the simplified lithology colors. Table 1 lists data for radiocarbon ages. Core elevations measured relative to tide levels with kinematic GPS (RTK) relative to NAV88. Unit thicknesses in core V1 have been approximately corrected for compaction based on key contacts in nearby gouge cores. Contact A is sharp and distinct in almost all cores. Contact B is distinct along the outcrop and in cores in much of the northwestern and northeastern marsh, but its correlation is uncertain in the central marsh. Level x and level z are too indistinct to be considered mappable contacts (discussed in text). Contact C is mapped along parts of the East Bank outcrop (Figure 4), but possible correlative contacts were found in only five cores in Botts marsh. Contact D has been eroded in most cores near the river, but it is sharp and distinct in core R5 and in cores in the central and northeastern marsh. Contact E can be correlated intermittently among two-thirds of the cores that reach its depth in the central and eastern marsh.

**Figure S4.** Reconstructed elevation (relative to NAVD88) near level x, contact E, and level z in vibracore V1 at the East Bank outcrop (Figures 3 and 4) and Russian core R5 from Botts marsh (Figure 5) using the Bayesian foraminiferal transfer function of Kemp et al. (2018) with fossil assemblages (data in Table S1). Approximate gradational boundaries between elevational zones based on vascular plant communities observed by Eilers (1975; 1976) on West Island, Hawkes et al. (2010) west of Dean marsh, by Laura Brophy and others (written communication, 2018) on West and Lazarus islands, and by us in Botts marsh (e.g., Janousek-Folger et al. 2014). SWLI values follow Kemp et al. (2018). Gray bars mark the depths of analyzed samples with too few foraminifers to be meaningful in reconstructing elevation (Table S1). Because the reconstructed elevations are inconsistent with the sampled lithologies and show no distinct or long-lasting change in elevation near the contact, we do not calculate the change in elevation across the contacts. Photographs to the right show sections of core: (A) level x, 220-270 cm depth in core V1; (B) contact E, 250-300 cm depth in core R5; (C) level z, 140-170 cm depth in core R5. Although level x (A) is too indistinct to be a mappable contact, we sampled across it to determine if any significant changes in RSL could be identified. Note *Triglochin maritima* rhizomes in growth position in tidal flat mud 5-10 cm above level x. In (B), gray bars within 1 cm depth of each other mark samples from adjacent (~1 m apart) Russian core segments. The general lack of foraminifera near contact E suggests that this section of core may record largely freshwater environments. In (C), level z is too indistinct to be a widely mappable contact and the reconstructed elevations show no significant or long-lasting change in RSL near the contact.

**Figure S5.**

(A) Histograms of the posterior distributions for the pre-contact B elevation reconstruction (below) obtained from core V1, and the posterior distribution for the post- contact B elevation reconstruction (above). Samples from the posterior distributions for pre- and post-contact elevation reconstructions were obtained from a Bayesian transfer function (Cahill et al. 2016; Kemp et al. 2018) using a Markov chain Monte Carlo algorithm, implemented in the software packages of R Development Core Team (2011) and Plummer (2003). The Bayesian transfer function produces sample-specific 95% credible intervals for each sample elevation in Standardized Water Level Index (SWLI) units. Red vertical lines show reconstruction means.

(B) The distribution calculated from the difference (inferred subsidence) between the posterior distributions for the pre-contact B elevation and the post-contact B elevation. The distribution for the difference is given by:

$$E_{pre}^{(j)} - E_{post}^{(j)}$$

where $E_{pre}^{(j)}$ represents the $j^{th}$ sample from the posterior distribution for the pre-contact elevation reconstruction and $E_{post}^{(j)}$ represents the $j^{th}$ sample from the posterior distribution for the post-contact elevation reconstruction. The mean subsidence estimate and its uncertainty are obtained from the difference between the distributions. To compare these estimates with the results of previous foraminiferal transfer function reconstructions elsewhere, we report subsidence with $\pm 1\sigma$ errors in meters (Figures 7 and S4; Table S1).

## Part 4 - Methods of determining sampling and core elevations

Tides in the Nehalem River estuary are semidiurnal and mesotidal (tidal range is 2.59 m). Hawkes et al. (2010) made tidal measurements over two days on the east bank of Lazarus Island (Figure 2) and used tidal simulations run with a nonlinear hydrodynamic circulation model with 3-km nodes along the coast to determine tidal datums to which core and sample elevations are referenced. We adopt tidal datums (referenced to the North American vertical datum, NAVD88) calculated for Botts marsh with vDatum (NOAA, accessed 31May18): Mean Highest High Water (MHHW), 2.38 ± 0.21 m; Mean High Water (MHHW), 2.17 ± 0.21 m; Mean Tide Level (MTL), 1.18 ± 0.20 m; Mean Sea Level (MSL), 1.17 ± 0.20 m; Mean Low Water (MLLW), 0.19 ± 0.21 m; Mean Lowest Low Water (MLLW), -0.21 ± 0.22 m. The datums of Hawkes et al. (2010) are well within the errors of the vDatum datums (means for the same datum differ by 0.05-0.12 m). Our core and site elevations were determined with a Real Time Kinematic-Global Positioning System (RTK-GPS) with a vertical precision of <20 mm, referenced to NAVD88.

## Part 5 - Radiocarbon-age errors adjusted with added variance

Errors in the precision and accuracy of radiocarbon dating have been widely discussed since introduction of the method (Libby, Anderson & Arnold 1949; Taylor, 1987; Trumbore, 2000; Bronk Ramsey, 2008; Taylor and Bar-Yosef, 2014). Radiocarbon ages listed in column 2 of Table 1 are those reported by the radiocarbon laboratory. By convention, the reported one standard deviation (1σ) errors for AMS ages from these laboratories are the larger of counting error or target reproducibility error. However, many laboratories have attempted to measure small additional errors introduced during the complete processing of routine samples in their laboratories. These additional errors are commonly referred to as “added variance.” Such errors do not include differences in ages on identical samples among different laboratories (e.g., Scott et al., 2010; Millard 2014), or the commonly much greater uncertainties in sample stratigraphic context (e.g., Waterbuck, 1971; Taylor, 1987; Wright, 2017).

Most (71%) of the ages reported in this paper were measured by the National Ocean Sciences AMS Facility (NOSAMS) at Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. A recent (2015-2016) assessment of added variance on the modern fractions

(used to calculate reported ages) measured on organic carbon samples submitted to the NOSAMS laboratory was 2.6‰ (website accessed, 29 August 2019). Elder, McNichol & Gagnon 1998, estimated the added variance associated with sample processing at NOSAMS at 2.4‰ for 73 sets of replicate samples of seawater, and 2.2‰ for 24 sets of replicate samples of marine coral.

In this paper, because we use probability density function distributions derived from our radiocarbon age models to compare the times of earthquakes and their accompanying tsunamis from site to site (Figure 9), it is important to accurately estimate analytical errors on our ages from the Nehalem River estuary. For this reason, in our age models for Nehalem River (Table 1) we increase the errors on reported ages by the following amounts:

1) For ages from 1987 to 1998 with reported errors of $<\pm 80$ $^{14}$C yr BP, we increase the errors to $\pm 80$ $^{14}$C yr BP, as suggested by Taylor, Stuiver & Reimer (1996).

2) For ages NOSAMS from 1998-2018, we add 2.6‰ of additional variance to age errors for ages shown in Table 1.

These adjustments of added variance increase the 1σ errors on the reported ages from the Nehalem River estuary by 6-33%, with a mean of 18%.

For many of the published ages from other sites that we used to develop the age models on Figure 9, we lack fraction modern $^{14}$C values for ages as well as information about the possible need for added variance on age errors. For ages from 1987 to 1998 for these other sites, we follow 1) above. For our unpublished NOSAMS ages for 1998-2018 from these other sites, we follow 2) above. For the age intervals (purple bars on Figure 9) from Willapa Bay, Atwater et al. (2004) and Hagstrum, Atwater & Sherrod (2004) use the added variance (error multipliers) of Stuiver and Pearson (1986). Intervals for ages of turbidites (brown bars on Figure 9) are those of Goldfinger et al. (2012; averaged corrected ages, Appendix 1, Land-marine data tab; see discussion of those ages in Atwater and Griggs 2012). For other published and unpublished ages, we use the laboratory reported age and errors without modification.

## Part 6 - Radiocarbon code for OxCal age models using $^{14}C$ ages from the East Bank outcrop and Botts marsh sites, Nehalem River estuary

This section lists selected OxCal (version 4.3) age models used to evaluate radiocarbon dated samples and to date contacts A, B, C, and D at the East Bank outcrop, contacts A and B and level x in the vibracores (V1, V3, and V4) adjacent to the outcrop, and level z and contacts B, D, and E in cores R5, R17, and R24 in Botts marsh. Separate models were run with ages from the East Bank outcrop and the vibracores, and from Botts marsh.

```
Plot(Nehalem East Bank - outlier sequence boundary model - v1 20May19)
 {
// This is an Outlier model using the Sequence command. All available (30) ages are placed above or below stratigraphic contacts depending on whether we assessed them as being detrital or in growth position. Most ages are further grouped into phrases, inferred to be older or younger than the nearest contact. Younger lab-reported ages from the same stratigraphic unit whose means are within 40 14C years of each other are averaged (combined). These combined ages meet the criteria of Ward and Wilson (1976) for being considered from the same population of ages at the 0.05 confidence level. Where no minimum ages are available for a contact, or in one case no maximum ages, the Zero_Boundary command is used to skew the age probability distributions towards the available limiting ages for the contact (e.g., DuRoss et al. 2011).

 Outlier_Model("General", T(5), U(0,4),"t");
 Sequence("Nehalem East Bank - outlier sequence boundary model - v1 20May19")
 {
  Boundary("Sequence start");
  R_Combine("below stumps max")
  {
   R_Date("below stumps max1", 1306, 41);
   {
    Outlier(0.05);
   };
   R_Date("below stumps max2", 1260, 43);
   {
    Outlier(0.05);
   };
  };
  Phase("max contact D")
  {
   R_Date("Contact D max1", 2060, 80);
   {
    Outlier(0.05);
   };
   R_Date("Contact D max2", 1736, 48);
   {
    Outlier(0.05);
   };
    R_Combine("Contact D max")
    {
     R_Date("Contact D max3", 1700, 80);
     {
     Outlier(0.05);
     };
     R_Date("Contact D max4", 1691, 35);
     {
     Outlier(0.05);
```

```
   };
  };
 };
 Boundary("Contact D");
 Zero_Boundary("Contact D");
 R_Date("Contact C min", 1970, 80);
 {
  Outlier(0.05);
 };
 Phase(“max level x”)
 {
  R_Date("level x max1", 1306, 41);
  {
   Outlier(0.05);
  };
  R_Date("level x max2", 1260, 43);
  {
   Outlier(0.05);
  };
  R_Combine("level x max")
  {
   R_Date("level x max3", 1190, 38);
   {
    Outlier(0.05);
   };
   R_Date("level x max4", 1192, 35);
   {
    Outlier(0.05);
   };
  };
 };
 Boundary("level x");
  R_Combine("level x min")
  {
   R_Date("level x min2", 1197, 38);
   {
    Outlier(0.05);
   };
   R_Date("level x min1", 1203, 34);
   {
    Outlier(0.05);
   };
  };
 Zero_Boundary("Contact C");
 Boundary("Contact C");
 R_Date("Contact C min1", 1160, 80);
  {
   Outlier(0.05);
  };
 Phase(“max contact B”)
 {
  R_Combine("Contact B max")
  {
   R_Date("Contact B max2", 980, 40);
   {
    Outlier(0.05);
   };
   R_Date("Contact B max3", 942, 50);
   {
    Outlier(0.05);
   };
  };
```

```
};
Boundary("Contact B");
Phase(“min contact B”)
{
 R_Date("Contact B min1", 970, 80);
 {
  Outlier(0.05);
 };
 R_Combine("Contact B min")
 {
  R_Date("Contact B min2", 902, 36);
  {
   Outlier(0.05);
  };
  R_Date("Contact B min3", 879, 35);
  {
   Outlier(0.05);
  };
 };
 R_Date("Contact B min4", 790, 80);
 {
  Outlier(0.05);
 };
 R_Date("Contact B min5", 630, 80);
 {
  Outlier(0.05);
 };
};
Phase(“max contact A”)
{
 R_Date("Contact A max1", 350, 80);
 {
  Outlier(0.05);
 };
 R_Date("Contact A max2", 290, 90);
 {
  Outlier(0.05);
 };
 R_Combine("Contact A max")
 {
  R_Date("Contact A max3", 176, 80);
  {
   Outlier(0.05);
  };
  R_Date("Contact A max4", 170, 80);
  {
   Outlier(0.05);
  };
  R_Date("Contact A max5", 130, 80);
  {
   Outlier(0.05);
  };
  R_Date("Contact A max6", 179, 15);
  {
   Outlier(0.05);
  };
  R_Date("Contact A max7", 128, 9);
  {
   Outlier(0.05);
  };
 };
Boundary("Contact A");
```

```
  R_Date("Contact A min1", 260, 80);
  {
   Outlier(0.05);
  };
  R_Date("Contact A min2", 110, 80);
  {
   Outlier(0.05);
  };
  Boundary("Sequence end historic constraint", 1850);
 };
};
```

Plot(Nehalem East Bank - outlier sequence boundary model – v2 20May19)
 {
// This is an Outlier model using the Sequence command that uses 21 of the original 30 ages used in model v1. The below stumps outlier ages and the 1970±60 $^{14}$C a BP outlier age were eliminated, as well as the oldest 1-2 ages in the maximum-age phases of model v1. Although its overall agreement index is 102%, the 260±65 $^{14}$C a BP minimum age for contact A was also eliminated as being too old. This eliminated all phases except the contact-B minimum phase. Younger lab-reported ages from the same stratigraphic unit whose means are within 40 $^{14}$C years of each other are averaged (combined). The Zero_Boundary command is used for contact D, which has no minimum ages, and for contact C, which has no maximum ages.

```
 Outlier_Model("General", T(5), U(0,4),"t");
 Sequence("Nehalem East Bank - outlier sequence boundary model – v2 20May19")
 {
  Boundary("Sequence start");
   R_Combine("Contact D max")
   {
    R_Date("Contact D max2", 1736, 48);
    {
     Outlier(0.05);
    };
    R_Date("Contact D max3", 1700, 80);
    {
     Outlier(0.05);
    };
    R_Date("Contact D max4", 1691, 35);
    {
     Outlier(0.05);
    };
   };
  Boundary("Contact D");
  Zero_Boundary("Contact D");
   R_Combine("level x max")
   {
    R_Date("level x max3", 1190, 38);
    {
     Outlier(0.05);
    };
    R_Date("level x max4", 1192, 35);
    {
     Outlier(0.05);
    };
   };
  Boundary("level x");
   R_Combine("level x min")
   {
    R_Date("level x min2", 1197, 38);
    {
     Outlier(0.05);
```

```
 };
 R_Date("level x min1", 1203, 34);
 {
  Outlier(0.05);
 };
};
Zero_Boundary("Contact C");
Boundary("Contact C");
R_Date("Contact C min1", 1160, 80);
{
 Outlier(0.05);
};
R_Combine("Contact B max")
{
 R_Date("Contact B max2", 980, 40);
 {
  Outlier(0.05);
 };
 R_Date("Contact B max3", 942, 50);
 {
  Outlier(0.05);
 };
};
Boundary("Contact B");
Phase(“min contact B”)
{
 R_Date("Contact B min1", 970, 80);
 {
  Outlier(0.05);
 };
 R_Combine("Contact B min")
 {
  R_Date("Contact B min2", 902, 36);
  {
   Outlier(0.05);
  };
  R_Date("Contact B min3", 879, 35);
  {
   Outlier(0.05);
  };
 };
 R_Date("Contact B min4", 790, 80);
 {
  Outlier(0.05);
 };
 R_Date("Contact B min5", 630, 80);
 {
  Outlier(0.05);
 };
};
 R_Combine("Contact A max")
 {
  R_Date("Contact A max3", 176, 80);
  {
   Outlier(0.05);
  };
  R_Date("Contact A max4", 170, 80);
  {
   Outlier(0.05);
  };
  R_Date("Contact A max5", 130, 80);
  {
```

```
    Outlier(0.05);
   };
   R_Date("Contact A max6", 179, 15);
   {
    Outlier(0.05);
   };
   R_Date("Contact A max7", 128, 9);
   {
    Outlier(0.05);
   };
  };
  Boundary("Contact A");
  R_Date("Contact A min2", 110, 80);
  {
   Outlier(0.05);
  };
  Boundary("Sequence end historic constraint", 1850);
 };
};
```

Plot(Nehalem East Bank - sequence boundary model – v3 20May19)
{
// This is a Sequence model that uses only the 11 ages in bold in Table 1, which we infer to be the most accurate ages for contacts based on materials dated, stratigraphic context, and resulting ages. Lab-reported ages from the same stratigraphic unit whose means are within 40 $^{14}$C years of each other are averaged (combined). The Zero_Boundary command is used for contact D, which has no minimum ages, and for contact C, which has no maximum ages.

```
 Sequence("Nehalem East Bank - outlier sequence boundary model – v3 20May19")
 {
  Boundary("Sequence start");
   R_Date("Contact D max4", 1691, 35);
  Boundary("Contact D");
  Zero_Boundary("Contact D");
   R_Combine("level x max")
   {
    R_Date("level x max3", 1190, 38);
    R_Date("level x max4", 1192, 35);
   };
  Boundary("level x");
   R_Combine("level x min")
   {
    R_Date("level x min2", 1197, 38);
    R_Date("level x min3", 1203, 34);
   };
  Zero_Boundary("Contact C");
  Boundary("Contact C");
   R_Date("Contact C min1", 1160, 80);
   R_Combine("Contact B max")
   {
    R_Date("Contact B max1", 980, 40);
    R_Date("Contact B max2", 942, 50);
   };
  Boundary("Contact B");
   R_Date("Contact B min", 970, 80);
   R_Date("Contact A max7", 128, 9);
  Boundary("Contact A");
   R_Date("Contact A min2", 110, 80);
  Boundary("Sequence end historic constraint", 1850);
 };
```

```
};
```

Plot(Nehalem Botts marsh - outlier sequence boundary model - v1 20May19)

```
 {
```

// This is an Outlier model using the Sequence command. All 25 ages from Botts marsh are placed above or below stratigraphic contacts depending on whether we assessed them as being detrital or in growth position. Most ages are further grouped into phrases, inferred to be older or younger than the nearest contact. Younger lab-reported ages from the same stratigraphic unit whose means are within 40 $^{14}$C years of each other are averaged (combined). These combined ages all meet the criteria of Ward and Wilson (1978) for being considered from the same population of ages at the 0.05 confidence level. Where no minimum ages are available for a contact, the Zero_Boundary command is used to skew the age probability distributions towards the available limiting ages for the contact (e.g., DuRoss et al. 2011).

```
 Outlier_Model("General", T(5), U(0,4),"t");
 Sequence("Nehalem Botts marsh - outlier sequence boundary model - v1 20May19")
 {
  Boundary("Sequence start");
  R_Date("unconformity max", 2210, 33);
  Phase("max contact E")
  {
   R_Date("Contact E max1", 2008, 38);
   {
    Outlier(0.05);
   };
   R_Date("Contact E max2", 1906, 28);
   {
    Outlier(0.05);
   };
   R_Date("Contact E max3", 1889, 29);
   {
    Outlier(0.05);
   };
   R_Combine("Contact E max")
   {
    R_Date("Contact E max4", 1875, 34);
    {
     Outlier(0.05);
    };
    R_Date("Contact E max5", 1861, 34);
    {
     Outlier(0.05);
    };
    R_Date("Contact E max6", 1843, 33);
    {
     Outlier(0.05);
    };
   };
  };
  Boundary("Contact E");
  Zero_Boundary("Contact E");
  Phase("max contact D")
  {
   R_Date("Contact D max1", 2143, 45);
   {
    Outlier(0.05);
   };
   R_Date("Contact D max2", 1812, 33);
   {
    Outlier(0.05);
   };
```

```
 R_Date("Contact D max3", 1739, 30);
 {
  Outlier(0.05);
 };
 R_Date("Contact D max4", 1714, 31);
 {
  Outlier(0.05);
 };
 R_Date("Contact D max5", 1713, 32);
 {
  Outlier(0.05);
 };
 R_Date("Contact D max6", 1698, 28);
 {
  Outlier(0.05);
 };
 R_Date("Contact D max7", 1701, 30);
 {
  Outlier(0.05);
 };
 R_Combine("Contact D max")
 {
  R_Date("Contact D max8", 1629, 53);
  {
   Outlier(0.05);
  };
  R_Date("Contact D max9", 1620, 45);
  {
   Outlier(0.05);
  };
 };
};
Boundary("Contact D");
R_Date("Contact D min", 1523, 43);
{
 Outlier(0.05);
};
Phase(“max contact B”)
{
 R_Date("Contact B max1", 1668, 29);
 {
  Outlier(0.05);
 };
 R_Date("Contact B max2", 1103, 27);
 {
  Outlier(0.05);
 };
};
Boundary("Contact B");
R_Date("Contact B min", 855, 33);
R_Date("level z max", 832, 26);
R_Combine("level z max")
{
 R_Date("level z max1", 760, 28);
 {
  Outlier(0.05);
 };
 R_Date("level z max2", 727, 28);
 {
  Outlier(0.05);
 };
};
```

```
  Boundary("level z");
  Zero_Boundary("level z");
  Phase("max contact A")
  {
   R_Date("Contact A max1", 445, 34);
   {
    Outlier(0.05);
   };
   R_Date("Contact A max2", 190, 32);
   {
    Outlier(0.05);
   };
  };
  Boundary("Contact A");
  Zero_Boundary("Contact A");
  Boundary("Sequence end historic constraint", 1850);
 };
};
```

Plot(Nehalem Botts marsh - outlier sequence boundary model – v2 28May19)
{
// This is an Outlier model using the Sequence command that uses 16 of the original 25 ages used in model v1. Outlier ages as well as the oldest 1-3 ages in the maximum-age phases of model v1 were eliminated. Younger lab-reported ages from the same stratigraphic unit whose means are within 40 $^{14}$C years of each other are averaged (combined). The Zero_Boundary commands is used for contacts D and A, which have no minimum ages.

```
 Outlier_Model("General", T(5), U(0,4),"t");
 Sequence("Nehalem Botts marsh - outlier sequence boundary model – v2 28May19")
 {
  Boundary("Sequence start");
  Phase("max contact E")
  {
   R_Date("Contact E max3", 1889, 29);
   {
    Outlier(0.05);
   };
   R_Combine("Contact E max")
   {
    R_Date("Contact E max4", 1875, 34);
    {
     Outlier(0.05);
    };
    R_Date("Contact E max5", 1861, 34);
    {
     Outlier(0.05);
    };
    R_Date("Contact E max6", 1843, 33);
    {
     Outlier(0.05);
    };
   };
  };
  Boundary("Contact E");
  Zero_Boundary("Contact E");
  Phase("max contact D")
  {
   R_Date("Contact D max4", 1714, 31);
   {
    Outlier(0.05);
   };
```

```
   R_Date("Contact D max5", 1713, 32);
   {
    Outlier(0.05);
   };
   R_Date("Contact D max6", 1698, 28);
   {
    Outlier(0.05);
   };
   R_Date("Contact D max7", 1701, 30);
   {
    Outlier(0.05);
   };
   R_Combine("Contact D max")
   {
    R_Date("Contact D max8", 1629, 53);
    {
     Outlier(0.05);
    };
    R_Date("Contact D max9", 1620, 45);
    {
     Outlier(0.05);
    };
   };
  };
  Boundary("Contact D");
  R_Date("Contact D min", 1523, 43);
  {
   Outlier(0.05);
  };
  R_Date("Contact B max2", 1103, 27);
  {
   Outlier(0.05);
  };
  Boundary("Contact B");
  R_Date("Contact B min", 855, 33);
  R_Combine("level z max")
  {
   R_Date("level z max", 760, 28);
   {
    Outlier(0.05);
   };
   R_Date("level z max2", 727, 28);
   {
    Outlier(0.05);
   };
  };
  Boundary("level z");
  Zero_Boundary("level z");
  R_Date("Contact A max2", 190, 32);
  {
   Outlier(0.05);
  };
  Boundary("Contact A");
  Zero_Boundary("Contact A");
  Boundary("Sequence end historic constraint", 1850);
 };
};

Plot(Nehalem Botts marsh - sequence boundary model – v3 28May19)
 {
```

// This is a Sequence model that uses only the 11 ages from Botts marsh in bold in Table 1, which we infer to be the most accurate ages for contacts based on materials dated, stratigraphic context, and resulting ages. Younger lab-reported ages from the same stratigraphic unit whose means are within 40 $^{14}$C years of each other are averaged (combined). The Zero_Boundary command is used for contacts D and A, which have no minimum ages.

```
Sequence("Nehalem Botts marsh - sequence boundary model – v3 28May19")
{
 Boundary("Sequence start");
 R_Combine("Contact E max")
 {
  R_Date("Contact E max4", 1875, 34);
  R_Date("Contact E max5", 1861, 34);
  R_Date("Contact E max6", 1843, 33);
 };
 Boundary("Contact E");
 Zero_Boundary("Contact E");
 R_Combine("Contact D max")
 {
  R_Date("Contact D max8", 1629, 53);
  R_Date("Contact D max9", 1620, 45);
 };
 Boundary("Contact D");
 R_Date("Contact D min", 1523, 43);
 R_Date("Contact B max2", 1103, 27);
 Boundary("Contact B");
 R_Date("Contact B min", 855, 33);
 R_Combine("level z max")
 {
  R_Date("level z max1", 760, 28);
  R_Date("level z max2", 727, 28);
 };
 Boundary("level z");
 Zero_Boundary("level z");
 R_Date("Contact A max2", 190, 32);
 Boundary("Contact A");
 Zero_Boundary("Contact A");
 Boundary("Sequence end historic constraint", 1850);
};
};
```

# Other Supplementary Files

## Part 7 - Unpublished report – Grant (1994) (separate pdf file)

This is an historically important report, including much key information for this paper, that is not available anywhere else.

## Part 8 - Tables (separate Excel files)

**Table S1.** Foraminiferal species abundance, concentration, and reconstructed elevations for samples from cores V1 and R5

**Table S2.** Total diatom valves counted in core V1

**Table S3.** Diatom species abundance for most common species in core V1

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