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Post-glacial sea-level change along the Pacific coast of North America

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A R T I C L E I N F O

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A B S T R A C T

Sea-level history since the Last Glacial Maximum on the Pacific margin of North America is complex and heterogeneous owing to regional differences in crustal deformation (neotectonics), changes in global ocean volumes (eustasy) and the depression and rebound of the Earth's crust in response to ice sheets on land (isostasy). At the Last Glacial Maximum, the Cordilleran Ice Sheet depressed the crust over which it formed and created a raised forebulge along peripheral areas offshore. This, combined with different tectonic settings along the coast, resulted in divergent relative sea-level responses during the Holocene. For example, sea level was up to 200 m higher than present in the lower Fraser Valley region of southwest British Columbia, due largely to isostatic depression. At the same time, sea level was 150 m lower than present in Haida Gwaii, on the northern coast of British Columbia, due to the combined effects of the forebulge raising the land and lower eustatic sea level. A forebulge also developed in parts of southeast Alaska resulting in post-glacial sea levels at least 122 m lower than present and possibly as low as 165 m. On the coasts of Washington and Oregon, as well as south-central Alaska, neotectonics and eustasy seem to have played larger roles than isostatic adjustments in controlling relative sea-level changes.

1. Introduction

The northwestern coast of North America has undergone dramatic and spatially heterogeneous sea-level changes since the Last Glacial Maximum (LGM). Relative sea level (RSL) histories vary with distance from ice loading and associated factors such as time-transgressive ice retreat, diverse tectonic settings, and differential crustal responses. On the Oregon and much of Washington State's coasts, which were not glaciated, RSL history is governed primarily by eustatic sea level rise, overprinted by seismicity, with over a dozen great subduction-zone earthquakes (M 8–9) occurring throughout the Holocene. In British Columbia, the magnitudes of RSL change are greater than in southern Washington and Oregon. Further, RSL curves in British Columbia are spatially and temporally heterogeneous, owing primarily to isostatic effects. In southeast Alaska, the main driver of RSL changes has been isostasy. Parts of southeast Alaska presently have the fastest crustal uplift rates in the world (Larsen et al., 2005), due largely to extensive post-Little Ice Age (LIA) ice retreat in Glacier Bay. In contrast, the main driver of RSL change in south-central Alaska has been, and continues to be, neotectonics, due to the subduction of the Pacific Plate along the Aleutian megathrust zone.

In this paper, we provide a comprehensive survey of the extensive literature and related datasets on RSL change along the northwestern coast of North America (Fig. 1). From this, we assess the main geophysical contributions to RSL dynamics throughout the region since the LGM and provide comprehensive sub-regional interpretations of how these contributions may have combined and varied from Alaska through British Columbia and Cascadia. One of our central arguments is that RSL changes in western North America during the late Quaternary period were highly localized due to substantial differences in geophysical forcing mechanisms.

1.1. Database of sea-level points, sea-level datums and dating conventions

The database (available as a Supplementary Table) and the age–elevation plots presented here, include 2191 sea-level

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Fig. 1. Map of western North America showing the sub-regions described in text. Also shown are major cities and physiographic features. Abbreviated features include QC (Queen Charlotte) Sound, GLBA (Glacier Bay), and PWS (Prince William Sound).

indicators from previously published sources. Metadata for each entry includes a location and material description, latitude, longitude, sample elevation, published elevation datum, correction factor to mean sea level (msl), and a citation reference. Additionally, a radiocarbon lab identifier, published radiocarbon age, radiocarbon age 'uncorrected' (if applicable) for marine reservoir effects, median and 2σ calibrated age range are included for each sample. Many of the data were collected decades ago, and are missing important information that would facilitate assigning an 'indicative meaning', which requires both a reference water level and an indicative range (the range over which the sediment or organism was deposited or lived) (c.f. Shennan, 1986; Shennan et al., 2006; Engelhart et al., 2009). For example, many samples are described only as 'marine shells', which provide no information on the indicative range. Further, many samples of freshwater peats, shell middens, etc., represent limiting ages, as they do not show a direct relationship to tidal levels. For example, freshwater peats may have formed at approximately mean high spring tide or at some unknown height above that datum (e.g. Shennan and Horton, 2002). Instead, and for consistency, samples included in the database are assigned an 'RSL significance' of supratidal, intertidal, or marine.

Reported elevations in this paper are relative to present mean sea level. Where originally reported relative to a different datum (e.g. high tide), elevations have been converted using either the NOAA Datums website (tidesandcurrents.noaa.gov) or by employing data from the Canadian Hydrographic Service (Bodo de Lange Boom, *pers. comm.*, 2013). If not specified in the original publication, msl was assumed. Tidal ranges were assumed not to have changed since the time of deposition, although previous studies have argued that this is unlikely due to changes to coastline shape and bathymetry (c.f. Shennan et al., 2006).

Calibration of published radiocarbon ages was carried out using the Calib 7.0 program (Stuiver et al., 2013) using the INTCAL13 radiocarbon dataset for terrestrial samples and MARINE13 dataset for marine samples, with a lab error multiplier of 1.0. A regional reservoir correction was applied to marine samples, based on a weighted mean, ΔR, of up to the 10 nearest known-age samples