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A sea-level database for the Pacific coast of central North America

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ABSTRACT

A database of published and new relative sea-level (RSL) data for the past 16 ka constrains the sea-level histories of the Pacific coast of central North America (southern British Columbia to central California). Our reevaluation of the stratigraphic context and radiocarbon age of sea-level indicators from geological and archaeological investigations yields 600 sea-level index points and 241 sea-level limiting points. We subdivided the database into 12 regions based on the availability of data, tectonic setting, and distance from the former Cordilleran ice sheet. Most index (95%) and limiting points (54%) are <7 ka; older data come mainly from British Columbia and San Francisco Bay. The stratigraphic position of points was used as a first-order assessment of compaction. Formerly glaciated areas show variable RSL change; where data are present, highstands of RSL occur immediately post-deglaciation and in the mid to late Holocene. Sites at the periphery and distant to formerly glaciated areas demonstrate a continuous rise in RSL with a decreasing rate through time due to the collapse of the peripheral forebulge and the reduction in meltwater input during deglaciation. Late Holocene RSL change varies spatially from falling at 0.7 ± 0.8 mm a^{-1} in southern British Columbia to rising at 1.5 ± 0.3 mm a^{-1} in California. The different sea-level histories are an ongoing isostatic response to deglaciation of the Cordilleran and Laurentide Ice Sheets.

1. Introduction

Regional databases of relative sea level (RSL)—for example, in Great Britain (e.g., Shennan and Horton, 2002; Bradley et al., 2011) and along the coasts of North America (e.g., Engelhart and Horton, 2012; Shugar et al., 2014)—provide a framework for developing our understanding of the primary mechanisms of RSL change since the Last Glacial Maximum (~26 ka, e.g., Peltier et al., 2002). Regional databases also represent a long-term baseline against which to gauge changes in sea level during the 20th century (e.g., Mazzotti et al., 2008; Engelhart et al., 2009), forecasts for the 21st century (e.g., Horton et al., 2014), and the basis for identifying regional variations in RSL (e.g., Shennan and Horton, 2002). Further, deglacial RSL reconstructions are used to constrain geophysical models of glacial isostatic adjustment (GIA, e.g., Peltier et al., 2002; Mitrovica, 2003; Lambeck et al., 2004; Milne and Peros, 2013). Late-Holocene data are crucial to assess spatial variability of rates of ongoing GIA (e.g., Engelhart et al., 2009). Such information is particularly important to correct sea-level measurements obtained by instrumental methods (e.g., Church and White, 2011).

Changes in RSL are the net effect of simultaneous contributions from eustatic, isostatic (glacio and hydro), tectonic and local factors, all of which have different response timescales. The relative importance of these factors varies in time and space along the central Pacific coast of North America. The greatest RSL change since the Last Glacial Maximum was caused by the melting of approximately 50 million km^3 of ice in land-based ice sheets, raising RSL in regions distant from the major glaciation centers (far-

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field sites) by ~120–130 m (e.g., Lambeck, 2002; Peltier and Fairbanks, 2006; Lambeck et al., 2014). This meltwater (or eustatic) contribution to far-field RSL rise during deglaciation averaged 12 mm a^{-1}, although peak rates potentially exceeded 40 mm a^{-1} during “meltwater pulses” at 19 and 14.5 ka (e.g., Deschamps et al., 2012; Lambeck et al., 2014). Empirical and glacial isostatic adjustment (GIA) modeling studies suggest a significant reduction in the meltwater contribution to RSL change at 8 ka, following which ocean volume changed by less than a few meters (Mitrovica and Milne, 2002; Bassett et al., 2005; Lambeck et al., 2014). RSL dropped by over 100 m in regions once covered by ice sheets (near-field sites) as a consequence of glacial isostatic adjustment, or isostatic rebound of Earth's crust (e.g., Clague et al., 1982; Roe et al., 2013). Growth and thickening of an ice sheet results in subsidence of land beneath the ice mass, which is compensated for by an outward flow of mantle material that uplifts a peripheral bulge around the ice margin. When the ice sheet melts and loading is diminished, land beneath the melted ice is uplifted at rates which may locally reach 50–100 mm a^{-1} (e.g., Shaw et al., 2002). The peripheral forebulge subsides and moves progressively toward the center of the diminishing load as mantle material is redistributed (Peltier, 2004).

Along parts of the Pacific coast of central North America (Fig. 1a), RSL histories are also of fundamental importance in recording vertical tectonic land-level changes (uplift or subsidence) caused by (1) localized folding and faulting in Earth's upper crust, and (2) regional deformation—both elastic and permanent—during cycles of strain accumulation and release on the megathrust fault where the Juan de Fuca plate subducts beneath North America at the Cascadia subduction zone (e.g., Wells and Simpson, 2001; Wang et al., 2012; McCaffrey et al., 2013; Fig. 1b). Such histories of tectonic land-level change, in turn, have helped build more realistic models of plate-boundary and upper-plate deformation and more accurate assessments of the hazard posed by earthquakes on local and regional faults (e.g., Burgette et al., 2009; Wang et al., 2013; Nelson et al., 2014). As discussed for each region below, vertical rates of uplift or subsidence—integrated over the centuries to millennia spanned by the data points of this compilation—are only high enough to influence rates of RSL change near Holocene faults or folds with high rates of deformation in the shallow crust (<25 km depth; e.g., James et al., 2009).

Local but highly spatially variable factors may influence RSL history. These include changes in the tidal regime (e.g., Shennan et al., 2000a; Uehara et al., 2006; Hill et al., 2011; Hall et al., 2013; Horton et al., 2013a) due to changes in local geomorphology (e.g., Shennan et al., 2003) or to global changes in tidal amplitudes. The latter may be the result of changes in the availability of sites for dissipation of tidal energy, such as Hudson Bay, that are affected by continental glaciation (e.g., Hill et al., 2011). Sediment consolidation due to compaction of pre-Holocene strata (e.g., Miller et al., 2013) through the accumulation of overlying sediment and land drainage (e.g., Kaye and Barghoorn, 1964; Törnqvist et al., 2008) can also produce significant errors in RSL reconstructions.

After summarizing previous Holocene sea-level studies along the Pacific coast of central North America, we explain how a

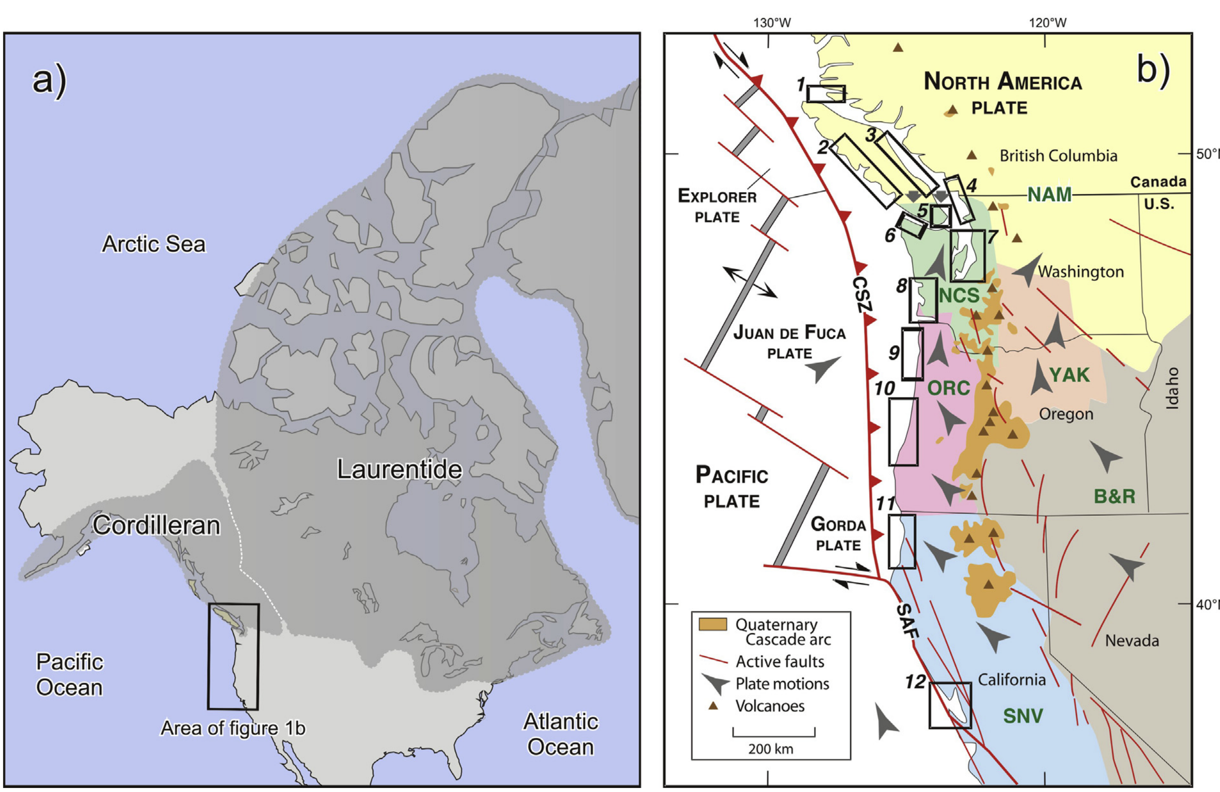

Fig. 1. (a) Approximate spatial extent of the Cordilleran and Laurentide ice sheet at ~ 21.5 ka redrawn from Clague and James (2002) and Dyke et al. (2002). b) Simplified tectonics of central western North America showing active faults and plate motions (based on Wells and Simpson, 2001; Kelsey et al., 2012; McCaffrey et al., 2013). Gray arrows show direction of modeled block movements from McCaffrey et al. (2013). Oblique subduction of the Juan de Fuca plate beneath North America along the Cascadia subduction zone (CSZ) at 35 mm a^{-1} causes rotation and northward movement of the Oregon Coast Range block against the buttress rocks of Vancouver Island (southward pointing short arrows) producing compression with active faulting in the Puget Lowland of northwest Washington. The San Andreas Fault (SAF) accommodates most of the motion between the Pacific plate and the Sierra Nevada block. Numbered rectangles show the location of sea-level data of this paper grouped into regions as explained in text. B&R – Basin and Range; NCS – Northern Cascadia; ORC – Oregon Coast Range; SNV – Sierra Nevada; and YAK – Yakima Fold Belt.