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The surface expression of radiocarbon anomalies near Baja California during deglaciation

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ABSTRACT

Periods of declining atmospheric radiocarbon activity ($\Delta^{14}C$) during the Heinrich 1 (~17.8–14.6 ka) and Younger Dryas (~12.8–11.5 ka) stadials of the last deglaciation coincide with intervals of rising atmospheric CO_2, as well as evidence of ^{14}C-depleted carbon at intermediate ocean depths near Baja California, Mexico and in the Arabian Sea. The latter has been interpreted as the signature of aged carbon emerging through the intermediate ocean to the atmosphere from a previously isolated deep ocean reservoir. Here we report measurements from near Baja California that enable us to reconstruct the $\Delta^{14}C$ of surface waters as recorded by three different species of planktonic foraminifera. We find that surface ocean $\Delta^{14}C$ recorded by planktonic foraminifera was anomalously low relative to the coeval atmosphere during previously documented periods of low benthic $\Delta^{14}C$, consistent with upwelling and subsequent mixing and/or partial atmospheric equilibration of the intermediate-depth benthic signal. We also propose an oceanographic explanation for observed $\Delta^{14}C$ differences between individual planktonic species during deglaciation at this location, based on seasonal growth habitats and a seasonal change in the source of coastal upwelling waters: from northern in the spring to southern in late summer, as the shelf-trapped poleward California Undercurrent strengthens. An analysis of the contemporary hydrography and planktic habitat preferences suggests that *G. bulloides* and *G. sacculifer* record primarily springtime conditions off Baja California, when the local influence of waters sourced from the surface of the North Pacific is greatest. This is supported by the strong resemblance of the $\Delta^{14}C$ of those species and a recent record of planktic $\Delta^{14}C$ from the Northeast Pacific during deglaciation. Lower $\Delta^{14}C$ recorded by the late-summer species *G. ruber* suggests that locally upwelling waters carried ^{14}C-depleted carbon that was proximately sourced from equatorial subsurface waters entrained by the California Undercurrent. Together with the benthic record, these observations are consistent with transport of an anomalous ^{14}C-depletion signal carried primarily by Antarctic Intermediate Water from an ultimate source in the Southern Ocean.

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1. Introduction

Radiocarbon (^{14}C) is a rare isotope of carbon that is produced by cosmic ray interactions in the upper atmosphere, and radioactively decays in global carbon pools with a half-life of ~5700 years (Godwin, 1962; National Nuclear Data Center, Brookhaven National Laboratory, www.nndc.bnl.gov). Atmospheric ^{14}C activity (expressed as $\Delta^{14}C$) decreased markedly during the most recent deglaciation (Reimer et al., 2004), at rates greater than can be explained by changes in the strength of geomagnetic field shielding alone (Hughen et al., 2004). A 2007 study including three of the present authors (Marchitto et al., 2007) observed that the pace of atmospheric $\Delta^{14}C$ decline coincided with that of the deglacial atmospheric CO_2 rise, suggesting dilution of the atmospheric ^{14}C pool by addition of aged, ^{14}C-depleted carbon that could only have been sourced from the deep ocean. The same study (Marchitto et al., 2007) also presented evidence of extreme ^{14}C-depletion in deglacial-age intermediate-depth sediments near Baja California in the eastern tropical Pacific, which they suggested was the signature of aged, sequestered dissolved inorganic carbon upwelled in the Southern Ocean and advected to the Baja California Margin by Antarctic Intermediate Water (AAIW). Other studies have

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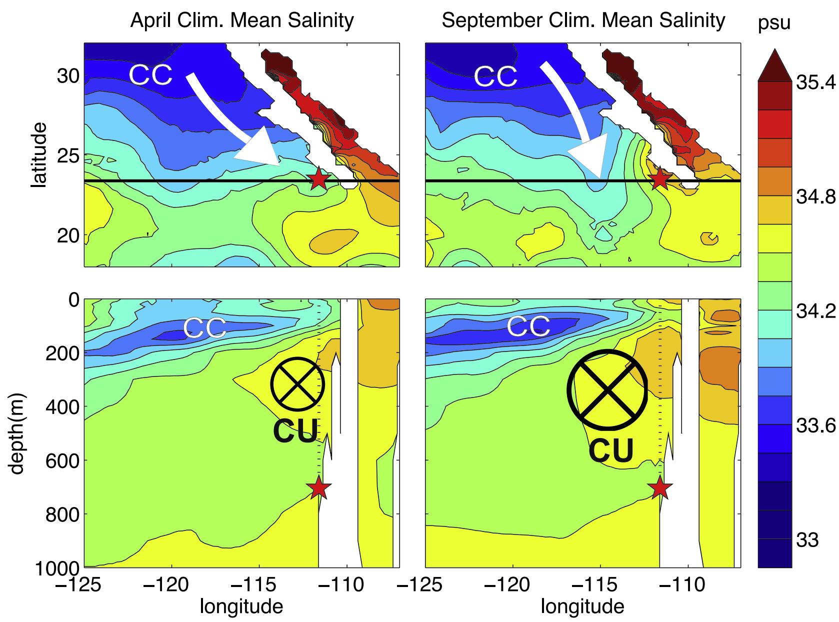

Fig. 1. Map view (top panels) and zonal transect (lower panels) of contoured April and September climatological salinity near Baja California, from the World Ocean Atlas 2009 (Antonov et al., 2010). In the top panels, arrows marked CC indicate the California Current and the black line indicates the latitude of the zonal transect. In the lower panels, vector symbols marked CU indicate the California Undercurrent, and the salinity minimum associated with the California Current is labeled CC. The red star indicates the location of core PC08.

since found evidence of pronounced deglacial ^{14}C depletion at intermediate-depth locations in the eastern equatorial Pacific (Stott et al., 2009) and the Arabian Sea (Bryan et al., 2010), and there is also evidence that the deep Southern Ocean was substantially less well ventilated during the last glacial maximum and early deglacial period than today (Burke and Robinson, 2012; Sikes et al., 2000; Skinner et al., 2010). However, despite several attempts, no study has yet found evidence of substantial deglacial ^{14}C depletion near the present-day sources of AAIW in the southern hemisphere (Burke and Robinson, 2012; De Pol-Holz et al., 2010; Rose et al., 2010; Siani et al., 2013; Sortor and Lund, 2011).

Here we present new ^{14}C measurements in foraminifera tests from the same sediment core studied by Marchitto et al. (2007) that increase the resolution of the intermediate-depth $\Delta^{14}C$ record off Baja California and reveal that surface waters at the site were also depleted in ^{14}C during deglaciation. Observed $\Delta^{14}C$ differences between planktic species are consistent with seasonal changes in the source of locally-upwelled waters today, and point to the equatorial Pacific as the proximate source of aged carbon to intermediate and surface waters near Baja California during deglaciation.

2. Study site

Composite core MV99-MC19/GC31/PC08 was raised from 705 m water depth at a location about 85 km west of Baja California Sur (Fig. 1; van Geen et al., 2003). At the seafloor, the core location lies near the present boundary between North Pacific Intermediate Water (NPIW) and Equatorial Pacific Intermediate Water (EqPIW), which itself is a mixture of Antarctic Intermediate Water (AAIW) and Pacific Deep Water (Bostock et al., 2010). The ocean surface near the core site is influenced by coastal upwelling throughout the year as a result of climatological mean northwesterly winds, with maximum upwelling during the spring (Bakun and Nelson, 1977). The California Current (CC) brings relatively cold, fresh North Pacific sub-arctic water southward along the margin, visible in climatological salinity data from the 2009 World Ocean Atlas (Antonov et al., 2010) as a tongue of low salinity values about 100 km offshore (Fig. 1, upper panels). The CC can also be seen in ocean sections (Fig. 1, lower panels) as a shallow (50–150 m) salinity minimum near the southern Baja California coast (Hickey, 1979; Lynn and Simpson, 1987). The CC is strongest near the shore during the spring (Hickey, 1979; Lynn and Simpson, 1987), coinciding with the time of maximum upwelling. The California Undercurrent (CU) flows at a depth of ∼250 m, carrying relatively warm, salty equatorial subsurface water (ESSW) from the Eastern Equatorial Pacific northward along the edge of the shelf break (Hickey, 1979; Lynn and Simpson, 1987). The physical forcing of the CU is not fully understood, but is thought to arise from a combination of the along-shore pressure gradient and the positive curl of the wind stress field near the coast (Connolly et al., 2014; Hickey, 1979, 1998). In response to seasonal wind stress and changes in dynamic height of the sea surface, the CU gains strength in the summer and fall, expanding into shallower depths (Connolly et al., 2014; Hickey, 1979; Lynn and Simpson, 1987). The seasonal shift is characterized by greater extent and shoaling of salty CU water in section and an increase in surface salinity near the coast in September relative to April (Fig. 1).

Elevated surface salinity near Southern Baja is caused primarily by regional and localized upwelling of high-salinity ESSW from the CU (Durazo, 2009). ESSW carried by the CU appears to be sourced from the deeper portions of the Northern Subsurface Countercurrent (NSCC), also known as the northern Tsuchiya jet, a subthermocline eastward current that shoals as it crosses the Pacific at about 5°N (Fiedler and Talley, 2006; Kessler, 2006). The NSCC originates near the western boundary of the Equatorial Pacific carrying AAIW from near Papua New Guinea (Rowe et al., 2000; Tsuchiya, 1991) that mixes with high salinity North Pacific Eastern Subtropical Mode Water (NPESTMW) and, possibly, North Pacific Intermediate Water (NPIW) as it is carried in the jet (Fiedler and Talley, 2006).

3. Methods

Foraminifera samples were picked from the >250 μm size fraction of washed sediment samples from the deglacial sections of core MV99-PC08. In some cases, samples that were too small for radiocarbon measurement were brought up to weight by adding

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