Quaternary Research 75 (2011) 91–103

Contents lists available at ScienceDirect

Quaternary Research

journal homepage: www.elsevier.com/locate/yqres

Marine radiocarbon reservoir effect along the northern Chile–southern Peru coast (14–24°S) throughout the Holocene

Luc Ortlieb [a,c,*], Gabriel Vargas [b], Jean-François Saliège [c]

[a] PALEOTROPIQUE, Institut de Recherche pour le Développement, 32 Avenue Henri Varagnat, 93143 Bondy Cedex, France
[b] Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile
[c] LOCEAN, UMR 7159 (Université Pierre & Marie Curie, CNRS, IRD, MNHN), 4 place Jussieu, 75230 Paris Cedex 05, France

ARTICLE INFO

Article history:
Received 17 July 2006
Available online 19 September 2010

Keywords:
Radiocarbon reservoir effect
Holocene
Paleoceanographic circulation
Upwelling
Southeastern Pacific
Peru
Chile

ABSTRACT

Through an extensive sampling and dating of pairs of associated shells and charcoal fragments combined with reanalysis of all the available previous data, we reconstruct the evolution throughout the Holocene of the regional marine radiocarbon reservoir effect (ΔR) values along the northern Chile–southern Peru area (14°–24°S). After elimination of the cases in which the terrestrial component yielded older ages than the marine shells to which they were associated, the study is based upon data from 47 pairs of associated marine and terrestrial material.

Our results suggest major changes in both the magnitude and variability range of ΔR during the whole Holocene Period: (1) between 10,400 and 6840 cal yr BP, high values (511 ± 278 yr) probably result from a strengthened SE Pacific subtropical anticyclone and shoaling of equatorial subsurface waters during intensified upwelling events; (2) between 5180 and 1160 cal yr BP, lower values (226 ± 98 yr) may reflect a major influence of subtropical water and diminished coastal upwelling processes; (3) during the last ~thousand years, high values (between 355 ± 105 and 253 ± 207 yr) indicate an increased influence of ^{14}C-depleted water masses and of ENSO. For the early twentieth century a ΔR value of 253 ± 207 yr was calculated.

Introduction

The regional reservoir effect

Radiocarbon dating of marine biogenic carbonates involves estimates of the global marine reservoir effect (R) (Taylor, 1987) which has varied in time and space in response to global ocean-climate changes. This is partly due to oceanographic variations that reflect different ventilation rates of deep waters through time, changes in the input of ^{14}C-depleted dissolved inorganic carbon from deeper to surficial layers of the ocean and latitudinal variations of the concentration of radiocarbon in the ocean surface. Because at any geological time and even close to the ocean surface, the oceanic carbon is not in isotopic equilibrium with the atmospheric reservoir, radiocarbon measurements of marine materials tend to provide older apparent ages than contemporaneous terrestrial counterparts. Deep ocean water masses with low radiocarbon concentrations show that marine organisms may yield apparent ages that are older by several hundred years (up to 800–1000 yr) than their true age (Robinson and Thompson, 1981; Southon et al., 1990; Kovanen and Easterbrook, 2002). Global marine reservoir values at a decadal resolution have been estimated for the last roughly 22,000 yr from global models and the comparison of terrestrial and marine radiocarbon measurements, with a current R value estimated to ca. 400 yr (Stuiver et al., 1986; Stuiver and Braziunas, 1993). However, in most of the cases the marine correction may also incorporate an additional regional reservoir effect referred to as ΔR. This regional effect can reach particularly high values in high-latitude coastal zones and regions affected by strong upwelling processes. In coastal areas of tropical regions, upwelling systems bring ^{14}C-depleted waters to the sea surface and, subsequently, high regional reservoir effects are observed in marine organisms.

As the magnitude of the regional reservoir effect is related to ocean circulation changes and coastal upwelling regime, it has varied both through time and from one area to another one. Hence, in each study area, solving the problems of chronological correlation between radiocarbon results from marine and terrestrial samples requires that some assumption be made regarding the non-stationary, or permanent, value of ΔR. Testing whether the parameter ΔR varied in the past, or was different than modern ΔR values, may involve precise dating of coeval terrestrial and marine samples by independent methods based upon tephrachronology (e.g. Eiriksson et al., 2004) or cosmogenic and radiogenic measurements (Muscheler et al., 2000; van Beek et al., 2002). However, the most common method consists of comparing the results of radiocarbon analyses on contemporaneous terrestrial and

* Corresponding author. LOCEAN, UMR 7159 (CNRS, IRD, MNHN, Université Pierre et Marie Curie), Centre IRD France-Nord, 32 Avenue Henri Varagnat, 93143 Bondy Cedex, France. Fax: +33 148025554.
E-mail address: Luc.Ortlieb@ird.fr (L. Ortlieb).

0033-5894/$ – see front matter © 2010 University of Washington. Published by Elsevier Inc. All rights reserved.
doi:10.1016/j.yqres.2010.07.018

marine samples and inferring the ΔR values from the variation through time of the total marine reservoir R calculations (Head et al., 1983; Albero et al., 1986; Little, 1993; Southon et al., 1995; Ingram, 1998; Kennett et al., 1997; Phelan, 1999; Ulm, 2002).

Estimates of ΔR variation in time have been used for global paleoclimate reconstructions involving particular time periods, as the Last Glacial Maximum (Shackleton et al., 1988; Broecker et al., 1988; Sikes et al., 2000), the last deglaciation (Hughen et al., 1998; Kwiecien et al., 2008) or the Younger Dryas (Bard et al., 1994; Goslar et al., 1995; Muscheler et al., 2000; Kovanen and Easterbrook, 2002; Burr et al., 2009). In several regions of the world, the determination of former values of ΔR begins to play a major role in paleoceanographic studies concerned with circulation pattern and evolution of water masses (Angulo et al., 2007; Petchey et al., 2008; Fallon and Guilderson, 2008; Lewis et al., 2008; Ndeye, 2008; Burr et al., 2009).

Oceanographic setting and evidence for ΔR variation along southern Peru and northern Chile

The Humboldt Current System or Peru-Chile Current is affected by Eckman pumping and strong coastal upwelling activity driven by the upwelling-favorable equatorward winds associated with the south-eastern Pacific subtropical anticyclone (SEPSA), which drives southerly winds along the coast of central-northern Chile and southern Peru (Strub et al., 1998). The surficial components of this current transport subantarctic water equatorward and, in tropical and subtropical regions, subtropical water poleward (Strub et al., 1998). The subsurface Poleward Undercurrent (Strub et al., 1998) transports equatorial subsurface water (ESSW) to the south (Brandhorst, 1971; Morales et al., 1996) and below 500 m, the Antarctic intermediate water flows toward the equator (Fig. 1). The ESSW are ^{14}C-depleted (Toggweiler et al., 1991) and the shoaling of these water masses during strong coastal upwelling processes (Torres et al., 2002), certainly contributes to increasing the ΔR values in the northern Chile-southern Peru coastal region.

A modern ΔR value, measured on three pre-bomb mollusk shells of known age, was determined as 190 ± 40 yr (Taylor and Berger, 1967; Stuiver and Braziunas, 1993). This value was estimated from 20th-century samples and was later extrapolated to the last thousand years (Southon et al., 1995). However, older Peruvian archaeological sites provided marine shells which yielded radiocarbon apparent ages much older than coeval charcoal fragments (Rowe, 1965; Owen, 2002). This suggested that the regional reservoir effect probably fluctuated in the past and could have been significantly higher during some periods of the Holocene.

In an attempt to determine the ΔR value for the mid-Holocene (6–4 ka) in the region of Ilo (17°S, southern Peru), Kennett et al. (2002) generated a series of ^{14}C measurements of paired marine shells and charcoal fragments in a well-layered archeological site referred to as "Km 4" of a private railroad, north of Ilo. They observed that many pairs did not yield consistent age differences between mollusks and charcoal, and that some charcoal ages suggested anomalously old ages, by up to several centuries, with respect to contemporaneous marine shells. The anomalously old terrestrial samples reflect the fact that in the hyper-arid coastal environment of southern Peru (Schwerdtfeger, 1976), like other desert areas (Schiffer, 1986), early inhabitants probably used "old wood" fragments, either driftwood or dead trees which had ceased to live decades or centuries before they were used as fuel. This problem, of particular concern along coastal deserts, limits our ability to estimate ΔR values from comparisons of radiocarbon ages between marine shells and charcoal or wood fragments from archaeological sites.

In another study in the same region of Ilo, Owen (2002) dated pairs of marine and terrestrial materials in two small time windows (AD 1280–1380 and 1870–1680 BC). The terrestrial samples are small (1 to 3 mm in diameter) unburned twigs of *Schinus molle* (California pepper tree, or "*molle*") with bark which should not have been reworked, and hence should not present the "old wood" effect. Owen results indicated that ΔR had indeed varied, and much more than previously assumed by Southon et al. (1995). He concluded that if his and previous published results were accurate, there had been a considerable spatial/temporal variation of the regional reservoir effect in southernmost Peru.

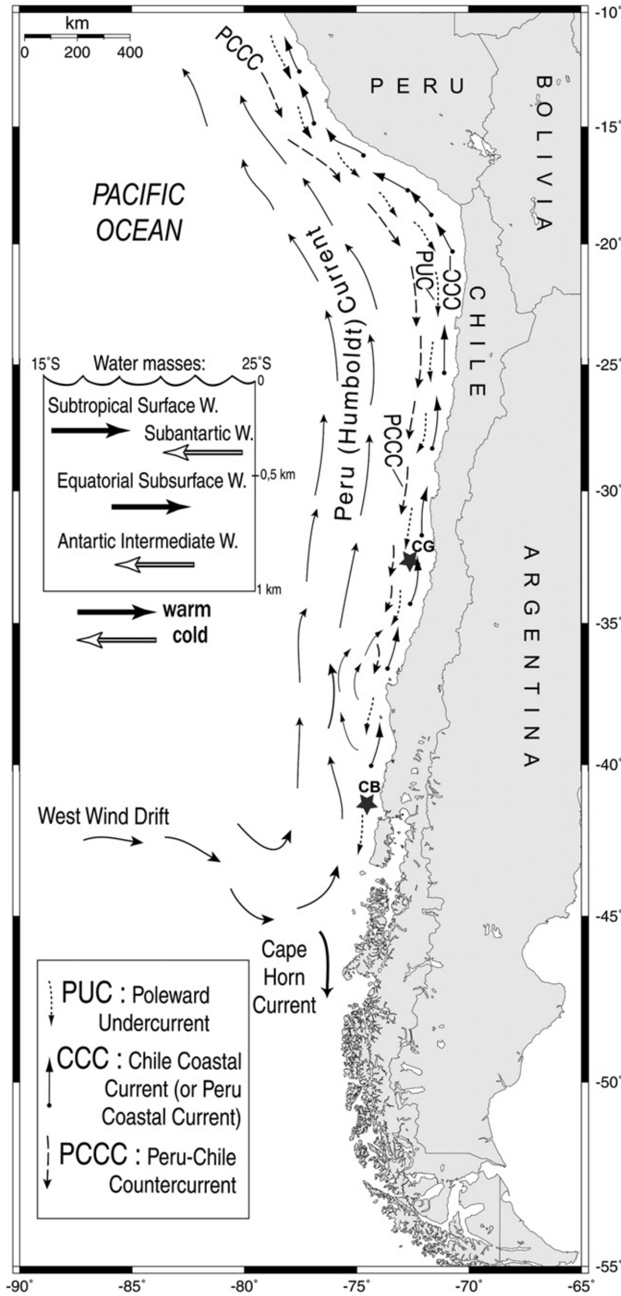

Figure 1. Regional oceanographic setting of the Peru-Chile study area, with major components of the Humboldt Current System during a typical summer situation (modified from Strub et al., 1998). Schematic sketch (inset) shows the disposition of the principal water masses. The location of sediment cores GIK17748-2 (CG) and GeoB3313-1 (CB), from Kim et al. (2002) and Lamy et al. (2002) are also shown.

More recently, Fontugne et al. (2004) reported differences of ^{14}C ages between marine shells and terrestrial organic materials from another Peruvian archaeological site (Quebrada de los Burros), near the Chilean border. These authors did not rely upon charcoal samples but on organic samples related to the meager vegetation which grew in the bed of a *quebrada* (dry-river talweg). In this case also, it can be assumed that the vegetation remains were most probably devoid of any "old wood" effect. They interpreted that the reservoir effect value increased ca.