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A TENTATIVE DETERMINATION OF UPWELLING INFLUENCE ON THE PALEO-SURFICIAL MARINE WATER RESERVOIR EFFECT IN SOUTHEASTERN BRAZIL

Rodolfo J Angulo[1] • Paula J Reimer[2] • Maria C de Souza[1] • Rita Scheel-Ybert[3] • Maria C Tenório[3] • Sibelle T Disaró[4] • Maria D Gaspar[3]

ABSTRACT. Previous work has suggested that seasonal and interannual upwelling of deep, cold, radiocarbon-depleted waters from the South Atlantic has caused variations in the reservoir effect (*R*) through time along the southern coast of Brazil. This work aims to examine the possible upwelling influence on the paleoreservoir age of Brazilian surficial coastal waters based on paired terrestrial/marine samples obtained from archaeological remains. On the Brazilian coast, there are hundreds of shell middens built up by an ancient culture that lived between 6500 to 1500 yr ago, but there are few shell middens located on open-coast sites with a known upwelling influence. Three archaeological sites located in a large headland in Arraial do Cabo and Ilha de Cabo Frio on the southeastern coast of Brazil, with open-ocean conditions and a well-known strong and large upwelling of the Malvinas/Falkland current, were chosen for this study. The ^{14}C age differences between carbonized seed and marine samples varied from 281 ± 44 to 1083 ± 51 ^{14}C yr. There are also significant age differences between carbonized seed samples (977 ^{14}C yr) and marine samples (200 and 228 ^{14}C yr) from the same archaeological layer that cannot be explained by a reservoir effect or an old-wood effect for charcoal. Therefore, the present data from the southeastern Brazilian coast are inconclusive for identifying an upwelling effect on *R*. To do so, it would be necessary to more precisely define the present–pre-bomb *R* in upwelling regions, and to analyze paired marine/terrestrial samples that are contemporaneous beyond doubt.

INTRODUCTION

Seasonal upwelling off the southern coast of Brazil brings deep, cold, radiocarbon-depleted waters from the South Atlantic to the sea surface (Carbonel and Valentin 1999). Previous work has suggested that such seasonal and interannual upwelling along the southern coast of Brazil has caused variations in the reservoir effect (*R*) through time (Eastoe et al. 2002). To obtain more accurate ^{14}C ages, it is necessary to know the long and short time variability of upwelling effect on *R*.

This work aims to examine the possible upwelling influence on the paleoreservoir age of Brazilian surficial coastal waters based on paired terrestrial/marine samples obtained from archaeological remains.

On the Brazilian coast, there are hundreds of shell middens built up by ancient cultures that lived between 6500 to 1500 yr ago. Previously, shell middens were considered as food remains of successive occupations, but more recently they have been considered as complex burial monuments and landmarks (Gaspar 2000). Most of the Brazilian shell middens are located next to the present, paleoestuarine, or paleolagoonal coasts (Bigarella 1950–1951a,b; Emperaire and Laming 1956; Laming-Emperaire 1968; Hurt 1974; Martin et al. 1984, 1986; Suguio et al. 1992). There are few located on open coasts with a known upwelling influence. Three of these were chosen for this work.

SITE DESCRIPTION AND SAMPLING

Archaeological sites chosen are located in a large headland in Arraial do Cabo and Ilha de Cabo Frio, on the southeastern coast of Brazil, with open-ocean conditions and a well-known strong and

[1]Laboratório de Estudos Costeiros (LECOST), Universidade Federal do Paraná, Departamento de Geologia, Setor de Ciências da Terra, Curitiba, Paraná, Brazil.
[2]School of Archaeology and Palaeoecology, ^{14}CHRONO Centre for Climate, the Environment and Chronology, Queen's University Belfast, Belfast BT7 1NN, United Kingdom.
[3]Departamento de Antropologia, Museu Nacional, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil.
[4]Laboratório de Micropaleontologia, Centro de Estudos do Mar (CEM), Setor de Ciências da Terra, Universidade Federal do Paraná, Curitiba, Paraná, Brazil.

large upwelling of the Malvinas/Falkland current (Moreira da Silva 1973; Lorenzzetti and Gaeta 1996; Mahiques et al. 2005). The Arraial do Cabo headland and Ilha de Cabo Frio are composed mainly of Proterozoic–Cambrian orthogneisses and metagranitoids (Schmitt et al. 2004), and there are no records of calcareous rock in the area. Samples were selected from archaeological layers at the Boqueirão, Usiminas, and Ilha de Cabo Frio sites (Tenório et al. 2005; Figure 1).

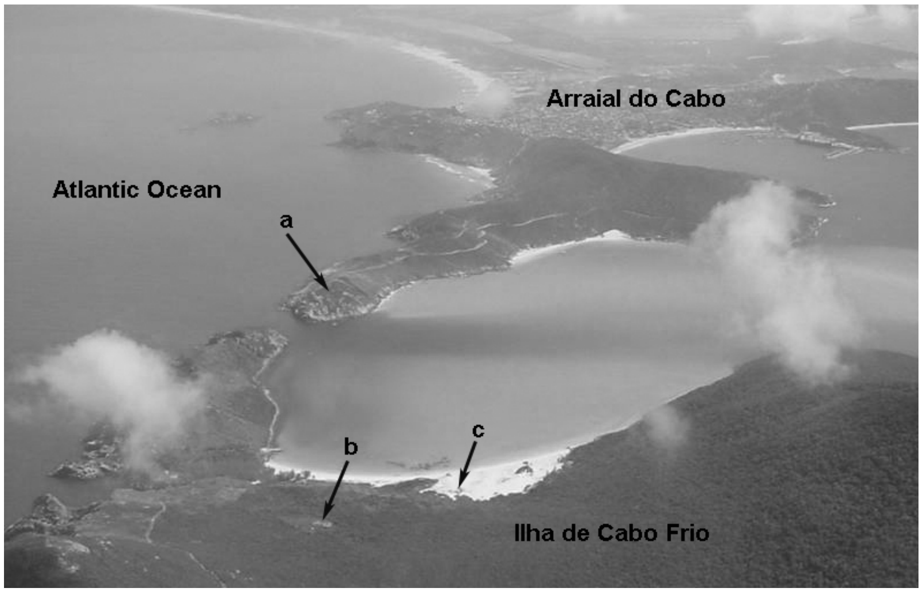

Figure 1 Arraial do Cabo and Cabo Frio archaeological site locations: a) Boqueirão; b) Usiminas; and c) Ilha de Cabo Frio.

The Boqueirão site is located on a rocky hill at the southern extreme of the Arraial do Cabo peninsula, at 30 m asl (Figure 1). At this site, there is an archaeological bed between 20 and 55 cm deep, with numerous campfire remains containing mollusk shells and shell fragments, fish bones and teeth, sea urchin remains, charcoal, and quartz archaeological industrial remains. At this site, triplet samples of charcoal/shell/sea urchin pin were collected at 30–40 cm depth, inside a campfire related to a burial, and dated by ^{14}C accelerator mass spectrometry (AMS). The charcoal sample corresponds to a palm seed (Boqueirão T1), the shell sample to a gastropod *Astraea tecta olfersii* shell fragment (Boqueirão M1), and the sea urchin to a pin fragment (Boqueirão M2).

The Usiminas site is located over a stabilized dune that climbed over a rocky hill at the southwestern sector of Cabo Frio Island, at 30 m asl (Figure 1). This site contains an archaeological bed between 27 and 102 cm deep that is composed of terrestrial and marine shells, big fish bones, gravel, and archaeological industrial remains. At this site, 2 pairs of charcoal/shell and 1 triplet charcoal/shell/shell were dated. The pairs were collected at 43 cm and 40–50 cm depth, and the triplet sample at 45–50 cm, at different points in the archaeological bed. The charcoal samples for the 2 pairs are palm seed, and the shell samples are gastropod *Astraea tecta olfersii* shell fragments. The triplet charcoal sample is a palm seed and the shell samples are a gastropod *Astraea tecta olfersii* shell fragment and an un-identified marine gastropod shell fragment.

The site Ilha de Cabo Frio is located on a stabilized dune near the coast of the southwestern sector of the Ilha de Cabo Frio (Figure 1). Part of the archaeological site was buried by more recent sand dunes. Four samples were collected at the base of the archaeological bed at 80–90 cm. The 2 charcoal samples are a palm seed fragment and an undetermined seed, and the 2 shell samples are a gastropod *Astraea* sp. shell fragment and a pelcypod *Pinctada imbricata* shell fragment.

METHODS

Samples were pretreated and converted to graphite at the ^{14}CHRONO Centre, Queen's University Belfast (lab code: UB). Organic samples underwent a standard acid-base-acid pretreatment and were combusted with CuO in sealed quartz tubes to produce CO_2. Shell samples were etched with 1% HCl to remove ~25% of the initial weight, and then hydrolyzed to CO_2 with phosphoric acid. All CO_2 samples were converted to graphite on an iron catalyst using the zinc reduction method (Slota et al. 1987; Hua et al. 2001; Mueller and Muzikar 2002). The $^{14}C/^{12}C$ ratio and $\delta^{13}C$ were measured by AMS at the Oxford Radiocarbon Accelerator Unit. The ^{14}C age and 1 standard deviation are calculated using the Libby half-life of 5568 yr, following the conventions of Stuiver and Polach (1977).

RESULTS AND DISCUSSION

The dating results of the 14 samples are presented in Table 1. The ^{14}C age differences between carbonized seed and marine (shell and urchin pin) samples varied from 281 ± 44 to 1083 ± 51 ^{14}C yr. There are also significant age differences between carbonized seed samples (977 ^{14}C yr) and marine samples (200 and 228 ^{14}C yr) from the same archaeological layer (Ilha de Cabo Frio T1/T2 and M1/M2, and Boqueirão M1/M2 samples) that cannot be explained by reservoir effect or old-wood effect for charcoal. The gastropod/sea urchin and pelecypod/gastropod age differences probably are not related to the feeding differences, because there are no calcareous rocks in the area that can add old carbon to the samples. These age differences indicate that different age samples were lying very close or in contact, possibly due either to bioturbation or dune action, which therefore could not be separated by the archaeological sampling techniques. As noted in earlier studies, archaeological site architecture and sample techniques are important factors that need to be considered when the purpose is to obtain contemporaneous samples (Ascough et al. 2005). The age differences between the gastropod shell and the sea urchin pin samples at the Boqueirão site, collected inside a campfire related to a burial, could be attributed to different depositional time in the 10-cm-thick archaeological level. On the other hand, at the Usiminas site, gastropod shell samples from the same 5-cm-thick archaeological level gave similar ages (1891 ± 31 and 1910 ± 30 ^{14}C yr).

At the Boqueirão and Usiminas archaeological sites, the age differences between charcoal and shell range between 565 ± 44 and 281 ± 44 ^{14}C yr, which are similar to the reservoir effect ages obtained for southeastern Brazilian surficial coastal waters using shells collected before nuclear explosions in the atmosphere that range between 656 ± 46 and 320 ± 44 ^{14}C yr (Nadal de Massi 2001; Eastoe et al. 2002; Angulo et al. 2005). Looking at the sampled site locations, there is apparently no correlation between reservoir effect and the expected exposure to upwelling waters that could induce a higher reservoir effect. For example, the area with the largest expected upwelling effect is Campeche on the Santa Catarina coast, which gave R = 485 ± 42, whereas shells from a protected coast far from upwelling areas gave R values between 500 ± 40 and 720 ± 40 at Canasvierias and Ponta das Canas, located inside a bay at the northern coast of Santa Catarina or Jurujuba, at the mouth of Guanabara Bay on the Rio de Janeiro coast. However, more detailed oceanographic control is needed to determine the actual contribution of older waters in each area.

The Arraial do Cabo terrestrial/marine pair samples (Usiminas and Boqueirão sites) age differences were between 281 ± 44 and 565 ± 44 yr, around the 1200–1600 cal BP period. At the Jabuticabeira archaeological site, the age differences were between 97 to 323 yr (mean 220 ± 20) at ~2000–2700

Table 1 Results of the terrestrial and marine samples from archaeological sites of at Arraial do Cabo and Ilha de Cabo Frio, Rio de Janeiro, southeastern Brazil.

Archaeo-logical site	Sample	Material	Lab code	$\delta^{13}C$	pMC	Error	^{14}C BP	*R* (^{14}C yr)
Ilha de Cabo Frio	T1	Charcoal from palm seed fragment	UB-6431	–25.3	75.86	0.30	2219 ± 32	—
Ilha de Cabo Frio	T2	Unidentified seed	UB-6432	–27.5	85.67	0.33	1242 ± 31	—
Ilha de Cabo Frio	M1	Shell fragment from gastropod *Astraea* sp.	UB-6433	2.1	68.21	0.28	3074 ± 33	855 ± 46
Ilha de Cabo Frio	M2	Shell fragment from pelecypod *Pinctada imbricata*	UB-6434	3.5	66.29	0.33	3302 ± 40	1083 ± 51
Boqueirão	T1	Charcoal from palm seed fragment	UB-6435	–21.4	81.70	0.33	1623 ± 32	—
Boqueirão	M1	Shell fragment from gastropod *Astraea tecta olfersii*	UB-6436	1.1	78.90	0.30	1904 ± 30	281 ± 44
Boqueirão	M2	Sea urchin pin fragment	UB-6952	—	—	—	2104 ± 29	—
Usiminas	F31A–T1	Charcoal from palm seed fragment	UB-6437	–26.4	82.93	0.32	1503 ± 31	—
Usiminas	F31A–M1	Shell fragment from gastropod *Astraea tecta olfersii*	UB-6438	3.8	77.30	0.30	2068 ± 31	565 ± 44
Usiminas	F31D–T1	Charcoal from palm seed fragment	UB-6439	–23.6	82.62	0.31	1533 ± 31	—
Usiminas	F31D–M1	Shell fragment from gastropod *Astraea tecta olfersii*	UB-6440	0.7	79.02	0.31	1891 ± 31	358 ± 44
Usiminas	F31D-M2	Shell fragment from marine gastropod	UB-6953	—	—	—	1910 ± 32	—
Usiminas	L43–T1	Charcoal from palm seed fragment	UB-6441	–26.4	83.62	0.36	1437 ± 34	—
Usiminas	L43–M1	Shell fragment from gastropod *Astraea tecta olfersii*	UB-6442	3.1	78.42	0.30	1952 ± 30	515 ± 45

cal BP (Eastoe et al. 2002), which is smaller than the regional *R* (408 ± 18 yr) for the southern Brazilian coast (Angulo et al. 2005). This difference could indicate archaeological uncertainty, like at the Arraial do Cabo and Cabo Frio sites.

Therefore, the present data from the southeastern Brazilian coast are inconclusive for identifying an upwelling effect on *R*. To identify upwelling induced changes in *R*, it would be necessary to define more precisely the present–pre-bomb *R* and the paleo-*R* at different periods. To determine present *R* more accurately, it would be necessary to date more marine samples collected before nuclear explosions in the atmosphere, with well-known dates of death and collection locations, so that *R* could be related to local oceanographic conditions. As in the southeastern Brazilian coast, the upwelling old water is cold South Atlantic water, so the $^{16}O/^{18}O$ isotope ratios in the shells could help to determine the mixing proportion in a particular location. To determine paleo-*R*, paired terrestrial/marine archaeological samples must be truly contemporaneous, or come from sites with detailed and well-dated stratigraphic units, where Bayesian age-depth modeling may constrain the uncertainty in the terrestrial chronology for the site.

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