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ANTARCTIC RADIOCARBON RESERVOIR: THE CASE OF THE MUMMIFIED CRABEATER SEALS (*LOBODON CARCINOPHAGA*) IN BODMAN CAPE, SEYMOUR ISLAND, ANTARCTICA

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ABSTRACT. At least 50% of the world's seal population is distributed in the pack-ice region surrounding Antarctica. Among the Antarctic seals, *Lobodon carcinophaga* (commonly known as "crabeater seals") are the most abundant. This is a krill-feeding species, subsisting primarily on *Euphausia superba*. The occurrence of mummified seals has been documented since 1900 in several Antarctic regions, and different hypotheses about age and what happened to them have been proposed. Taking into account the depletion of ^{14}C concentration in marine waters, we dated a recently deceased and a mummified *L. carcinophaga* along with a mollusk (*Nacella concinna)* collected alive from different locations around Antarctica. We discuss their relationship in light of the ^{14}C reservoir. The age obtained for the recently deceased crabeater seals suggests a reservoir age of around 1300 yr for these waters, which is in agreement with the correction value for reservoir age obtained for the same species in the area. We applied this reservoir correction value to the conventional age of 1180 ^{14}C yr BP obtained for the mummified seal. The results indicate that the death event probably occurred within the last 100 yr. The age obtained for the mollusk specimen confirms that the correction values of the reservoir effect for the Antarctic continent vary according to geographical location and to the type of sample dated.

INTRODUCTION

The pack-ice region surrounding Antarctica contains at least 50% of the world's seal population. Of the 6 species of Antarctic pinnipeds, 4 of them, known as pack-ice seals (APIS 1995), inhabit the pack-ice region: crabeater seals (*Lobodon carcinophaga*), leopard seals (*Hydrurga leptonyx*), Weddell seals (*Leptonychotes weddelli*), and Ross seals (*Ommatophoca rossii*). Crabeater seals are by far the most abundant, comprising 80–95% of all the seals observed on the pack ice (Laws 1984; Adam 2005). These seals are krill-feeding specialists (Lowry et al. 1988; Nordøy et al. 1995; Adam 2005). Although *L. carcinophaga* are widely dispersed on the heavy pack ice, little is known about their distribution and behavior, especially during winter (Lowry et al. 1988; Nordøy et al. 1995).

The occurrence of mummified seals, mainly crabeater seals, has been reported since 1900 in different Antarctic regions (Figure 1). Several possible explanations have been discussed, from tidal waves to climate change or glacial retreat. Some authors proposed that the internal guidance system of the animals went astray and led them to disorientation and starvation; even suicide theories have been put forward (see Balham 2007). The ages that have been suggested range from decades to several thousand years (see Barwick and Balham 1967; Dort 1975, 1981; Nelson et al. 2008).

It is known that organisms that live in marine waters show a significantly older age than those living on land, as a result of the depletion of the radiocarbon concentration in marine waters. This is called the "reservoir effect," which in Antarctic waters varies geographically (Stuiver and Braziunas 1985; Gordon and Harkness 1992). To determine the magnitude of the reservoir offset, samples of known calendar age, collected prior to atmospheric nuclear testing, are dated (Stuiver et al. 1986; Stuiver and Braziunas 1993). Samples selected must be identified at species level; the organisms must be

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collected alive or with reliable known date of death; their geographical location and diet must be specified; and the habitat must represent the reservoir that is being investigated (Petchey et al. 2008a,b). An alternative method is to date samples collected after nuclear testing; the ^{14}C age in these specimens will incorporate the impact signal of the nuclear explosions and will be at least older than their terrestrial counterparts. Although these methods do not provide absolute estimates for correcting apparent ages, they give an idea of the magnitude of this reservoir correction (Gordon and Harkness 1992).

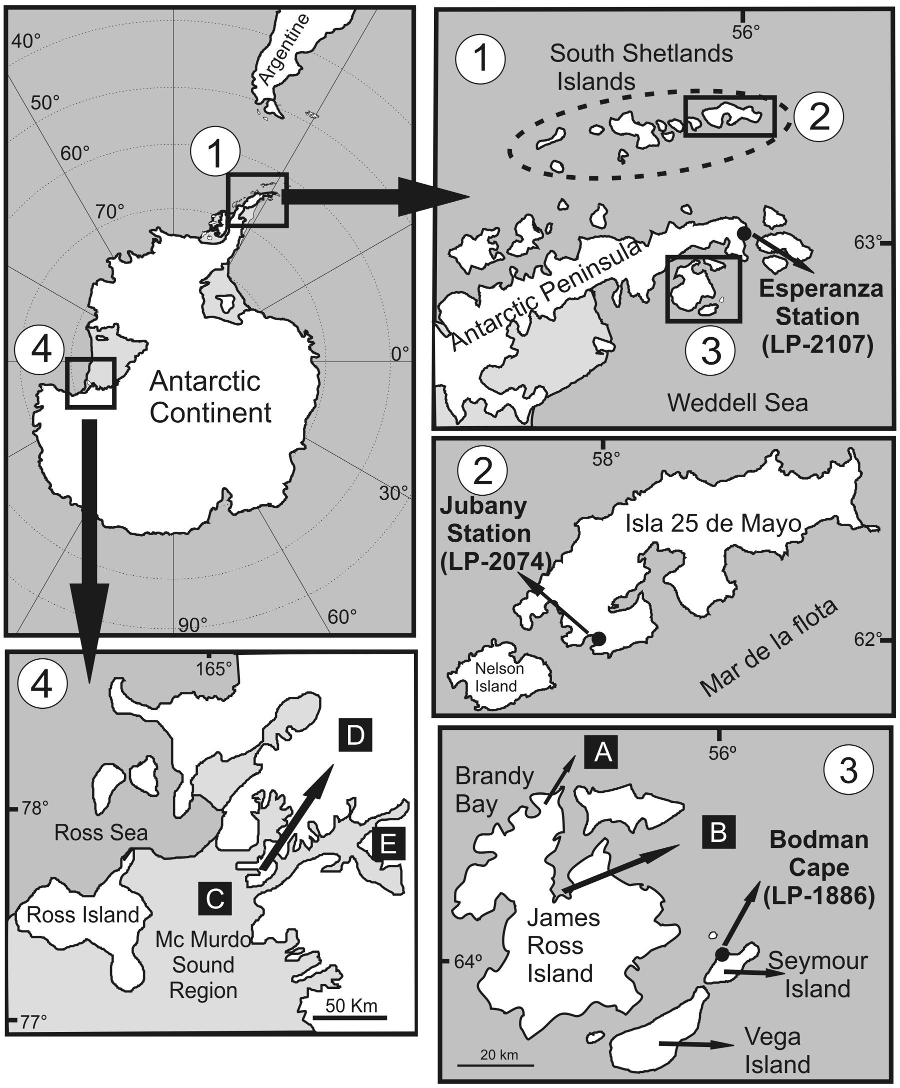

Figure 1 Map of Antarctic continent showing the different locations named in the text and the geographic provenance of the samples collected in this study (black circles). Light gray areas represent the ice shelf. A–E denote ^{14}C dates of different authors: **A:** Nelson et al. (2008) mummified seals 1197 ± 35 and 872 ± 35 yr BP; **B:** Björck et al. (1991) *Nacella concinna* 920 ± 80 yr BP; **C**: Broecker and Olson (1961) seal flesh 1300 ± 70 yr BP; **D:** Siegel and Dort (1968) seal bone 3125 ± 210 yr BP; **E:** Péwé et al. (1959) seal carcasses between 1600 to 2600 yr BP and Gordon and Harkness (1992) seal skin 615 ± 100 yr BP.

In this paper, we use ^{14}C techniques to date crabeater seals, one deceased and another mummified, along with a sample of the mollusk *Nacella concinna* collected alive, all of which come from the Antarctic (Figure 1). Based on these ^{14}C dates, the relationships with the ^{14}C reservoir in Antarctic waters are discussed.

MATERIALS AND METHODS

The mummified crabeater seal (sample LP-1886) consisted of lower jaw and teeth taken from an individual with minimal soft tissue preservation. The seal was found next to a large number of young and adult mummified specimens of *L. carcinophaga* scattered in Bodman Cape, Seymour Island, in the eastern flank of the Antarctic Peninsula (64°15′S, 56°40′W; Figure 1; see Montes et al. 2007). We found a concentration of 78 adults and 2 pups along present-day courses of ephemeral streams, similar to those reported by Péwé et al. (1959) in the McMurdo Sound region.

The recently deceased crabeater seal (sample LP-2074) was found near the Antarctic Jubany Station, on Isla 25 de Mayo (King George Island, 62°14′S, 58°40′W) in the South Shetland Islands (Figure 1). The littoral zone where LP-2074 was found was designated as Antarctic Specially Protected Area (ASPA) number 132. Monthly censuses conducted in this area allowed us to find the deceased specimen (July 1993), and the sample was collected by one of the authors (AC) during the 1993 (field) season.

The mollusk *Nacella concinna* (sample LP-2107) was collected alive in the surroundings of the Argentine Antarctic station "Base Esperanza" (Esperanza Station) on the southern coast of Bahía Esperanza (63°30′S, 57°00′W) in the Antarctic Peninsula. Specimens were collected in 1992 by members of the Museo de La Plata (MLP) during Antarctic expeditions. The samples were frozen and stored in the collection of the LATYR (Laboratorio de Tritio y Radiocarbono), where they were kept until they were dated.

Bone samples of mummified and recently deceased *L. carcinophaga* (LP-1886 and -2074, respectively) were washed with distilled water. The mineral fraction was eliminated by acid hydrolysis with HCL 8% in a vacuum system for 48 hr. The insoluble protein residue was isolated with centrifugation. The protein content was extracted at pH 3, at 80 °C for 24 hr following the methodology of Longin (1971).

Of the set of collected shells of *Nacella concinna* (LP-2107), 65 specimens younger than 2 yr of age were used. The soft tissues of the mollusk were eliminated with NaOCl. The 20% w/w of the calcium carbonate of the outer valves was acid-etched to avoid contamination. The inner 80% w/w of the valve was used to produce CO_2 by acid hydrolysis for ^{14}C dating.

^{14}C dating was performed by the LATYR (Laboratorio de Tritio y Radiocarbono, Museo de La Plata, Argentina) by means of benzene synthesis and the liquid scintillation counting (LSC) method (Huarte and Figini 1988) with PerkinElmer TriCarb 3170 TR/SL and Packard TriCarb 1050 TR/LL spectrometers. For statistical comparison of the ^{14}C ages (samples of mummified and recently deceased seals), we used the procedure of Ward and Wilson (1978).

The laboratory where the samples were processed does not have a mass spectrometer, so $\delta^{13}C$ values were estimated by tables, as recommended in Stuiver and Polach (1977), using –15 ± 2‰ for seals and 0‰ for marine shells.

RESULTS

For both mummified (LP-1886) and recently deceased (LP-2074) specimens of *L. carcinophaga*, the conventional ^{14}C ages were 1180 ± 80 and 1300 ± 70 yr BP, respectively. The conventional ^{14}C age obtained for the *Nacella concinna* specimen was 750 ± 60 yr BP (LP-2107) (see Table 1). Therefore, we conclude a reservoir correction of around 1300 yr is appropriate.

Table 1 Sample information and radiocarbon results for Antarctic specimens.

Sample nr	Location (latitude, longitude)	Material	^{14}C activity (pMC)	Conventional ^{14}C age (yr BP)
LP-1886	64°15′S, 56°40′W	Lower jaw and teeth, adult individual	86.95 ± 0.69	1180 ± 80
LP-2074	62°14′18″S, 58°40′00″W	Lower jaw and teeth, adult individual	84.45 ± 0.65	1300 ± 70
LP-2107	63°30′S, 57°00′W	Shells	90.44 ± 0.93	750 ± 60

DISCUSSION

Different hypotheses have been proposed concerning the death of the mummified crabeater seals, with ages ranging from some decades to millennia. Dort (1975, 1981) states that "…the partial skeletons may have ages to be measured in decades rather than millenia" (1975:69). However, the author does not take into account a reservoir effect to explain the differences between the inferred ages and those obtained by radiometric dating.

Interpreting ^{14}C is not simple or straightforward, since a lot of different reservoir corrections have been proposed for material of the Southern Ocean with values ranging from 750 to 5500 yr (Berkman et al. 1998). ^{14}C ages on marine-derived material from Antarctica are usually old when compared with terrestrial ^{14}C timescales, which is the result of the upwelling of deep ocean waters (see references for a more detailed description of the causes of depleted values in Antarctica). Moreover, the ^{14}C activity will vary regionally and as the result of the lifestyle of a particular animal. Although the specific area where the collected specimens of crabeater seal feed is unknown, crabeater seals are year-round residents of the Antarctic pack ice, feeding mainly on Antarctic krill (Laws 1985; Lowry et al. 1988; Adam 2005), and never travel in open water for more than a few days (Nordøy et al. 1995). This suggests that the mummified specimens were feeding mostly on krill and in an area near the place where they were found. The reservoir correction of 1300 yr applied in this study agrees with the suggestion of Gordon and Harkness (1992), who conclude that correction factors of ~1400 yr are generally applicable to seal samples in Antarctica.

The conventional ^{14}C ages for the recently deceased *L. carcinophaga* (LP-2074) will be 1300 ± 70 yr BP (Table 1). If we apply this age as a reservoir correction value to the conventional age of 1180 yr BP obtained for the mummified seal, the death occurred in the last 100 yr. Moreover, the age obtained for LP-1886 (1180 ± 80 yr BP) (lower jaw and teeth of an adult specimen), selected from the group of the mummified population is statistically the same as the recently deceased LP-2074 (at 95% confidence level, following the procedure by Ward and Wilson 1978).

Near our sample area in Brandy Bay, James Ross Island (~70 km away from Bodman Cape, Figure 1), Nelson et al. (2008) found 154 mummified crabeater seals, randomly distributed. ^{14}C dating on 2 specimens of different areas and different states of decay revealed conventional ^{14}C ages of 1197 ± 35 and 872 ± 35 yr BP, respectively. The first value agrees with our measurement. Since the state of preservation of that sample (Nelson et al. 2008:489) is similar to ours (LP-1886 and LP-2074), we assume that both had similar ages; thus, comparison between them seems reasonable. Our data strengthens the results obtained by Nelson et al. (2008) regarding the ages of these mummified seals. Although in this paper, we do not intend to address possible explanations for the cause of death, the similarities between our date and those obtained by Nelson et al. (2008), along with the relatively short distance between the sampling areas, allow us to presume that the same mortality event operates in both areas. The fact that the death was within the last 100 yr may help to dismiss some speculations about the phenomenon of inland mummified seals, such as sea-level changes or glacier melt-back (Stirling and Rudolph 1968), which are very unlikely to have occurred in the last century.

As previously discussed, our dates agree with those of Nelson et al. (2008) and also are within the correction value suggested by Gordon and Harkness (1992:707), who state that "For the South Shetland Islands and Antarctic Peninsula, a correction value of up to about 1250–1300 years seems applicable to most marine life forms." Although in the above quoted article the authors gave lower ^{14}C values for seal samples (ranging from 415 to 970 yr BP), direct comparison with our samples is not appropriate since the material was not identify to species level. Also, Hall et al*.* (2006) used a 1300-yr correction for the coastal region of Ross Sea.

On the other hand, the date obtained for the *Nacella concinna* specimen confirms that the correction values of the reservoir effect for the Antarctic continent vary according to geographical location and to the type of sample dated (Gordon and Harkness 1992). The conventional ^{14}C age of 750 ± 60 yr BP (LP-2107) is similar to that reported by Gordon and Harkness (1992) for modern shells of post-nuclear age from the Antarctic Peninsula (see Björck et al. 1991).

CONCLUSIONS

The conventional ^{14}C age obtained for a recently deceased specimen of *L. carcinophaga* allowed us to apply the reservoir correction factor to the conventional ^{14}C age of the mummified seal sample (1180 ± 80 yr BP). Although the reservoir effect varies among different Antarctic locations, we concluded that the death event of this mummified seal occurred in the last 100 yr.

It is interesting to note the similarity between the date for the mummified seal in our study and the dates given by Nelson et al. (2008). This, along with the relatively short distance between the sampling areas, allows us to assume that the same mortality event operates in both areas. Finally, the dates obtained for *Nacella concinna* and the recently deceased specimen of *L. carcinophaga* strengthen the hypothesis that different species have different reservoir corrections for the same ocean region.

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