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A Local Marine Reservoir Correction Value (ΔR) for Watom Island, Papua New Guinea

Fiona Petchey[1], Roger Green[2], Martin Jones[3] and Matthew Phelan[4]

ABSTRACT

Marine shell has several advantages for radiocarbon (^{14}C) dating in the Pacific. It is ubiquitous in archaeological sites, is easy to identify to the species level, and can often be related directly to human activity. Consequently, shells are one of the most commonly dated ^{14}C sample types within this region. A suitable local marine correction (ΔR) needs to be applied to shell determinations, however, in order to correct for surface ocean ^{14}C variability and obtain calendar ages. This can be achieved using carefully selected charcoal and shell samples recovered from archaeological sites. In this paper, new and extant charcoal and shell ^{14}C determinations from the Kainapirina (SAC) locality on Watom Island in Papua New Guinea have been used to calculate a ΔR of 261 ± 101 ^{14}C years. Because of complexities with the stratigraphy of SAC, we have followed a methodology outlined in Nicholls and Jones (2001) and Jones *et al*. (in press) that allows some uncertainty in the dated events to be incorporated in the calculation. This ΔR value is in accord with our expectations for the Papua New Guinea region.

Keywords: WATOM, RADIOCARBON, MARINE RESERVOIR, DATELAB.

INTRODUCTION

A plant or animal that obtains carbon from a marine source (or reservoir) yields what is termed an 'apparent age'. The surface ocean (down to around 200 m depth) has an apparent ^{14}C age that is, on average, 400 years older than the terrestrial (atmospheric) reservoir. This is known as the marine reservoir effect and is caused both by a delay in ^{14}C exchanged between the atmosphere and ocean, and by the mixing of surface waters with upwelled, ^{14}C depleted, deep ocean water (Stuiver *et al.* 1986: 982). This reservoir effect is automatically corrected for when a marine shell conventional radiocarbon age (CRA)[5] is calibrated using the modelled marine ^{14}C calibration curve (e.g. MARINE04:

[1] Radiocarbon Dating Laboratory, University of Waikato, Private Bag 3105, Hamilton, New Zealand
[2] Department of Anthropology, University of Auckland, Private Bag 92019, Auckland, New Zealand
[3] Department of Anthropology, University of Otago, PO Box 56, Dunedin, New Zealand
[4] Aboriginal Affairs Victoria, PO Box 515, East Melbourne, VIC 3002, Australia
[5] A conventional radiocarbon age is obtained from a radiocarbon measurement following the conventions set out by Stuiver and Polach (1977). A CRA must be calibrated to determine a calendar age. By convention, the symbol BP means 'conventional radiocarbon years before AD 1950', whereas the symbols cal BP or BC/AD are used to express calibrated radiocarbon ages.

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Hughen *et al.* 2004). This calibration curve represents a global average of the surface ocean ^{14}C as it changes over time. However, the ^{14}C of the ocean surface may deviate from this modelled marine curve because of variations in upwelling, ocean currents, and differences in atmospheric ^{14}C between the hemispheres (Stuiver and Braziunas 1993). Local and regional deviation from this global average complicates the calibration of marine samples. To account for this deviation a local correction factor, or ΔR — the difference between the modelled ^{14}C age of surface water and the actual ^{14}C age of surface water at that locality — can be calculated from contemporaneous terrestrial/marine samples or from shells collected before 1950 whose age of death is known precisely (Stuiver and Braziunas 1993). Data collected over the last decade (Druffel and Griffin 1993, 1999; Godfrey *et al*. 2001; Petchey *et al*. 2004) indicate that ΔR values in this southwest Pacific region vary significantly both geographically and over time (Fig. 1). The lack of information on appropriate ΔR values for each island within the Bismarck region has been a continuing problem for the accurate calibration of marine shell determinations from archaeological sites and makes comparison of the chronology between, and sometimes within, Lapita sites difficult (White and Harris 1997; Specht and Gosden 1997; Summerhayes 2001).

This paper presents four new ^{14}C analyses and uses these and published ^{14}C results to calculate a ΔR for archaeological samples collected from the Kainapirina (SAC) excavation on Watom Island in the Bismarck Sea (Table 1 and Fig. 1). The calculated Watom ΔR value is compared to published ΔR values of pre-1950 shells of known age from this region (Petchey *et al*. 2004).

WATOM ISLAND

Watom Island is located just off the northeast coast of New Britain (Fig. 1). Archaeological excavation of the Reber-Rakival site ('Watom') has been carried out at three separate localities: Kainapirina (SAC), Vunavaung (SDI) and Maravot (SAD). Research at this site has been sporadic, beginning in the early 1900s with collections and observations made by Father Otto Meyer, and archaeological excavations in 1965 at various locations (Specht 1968), and again in 1985 at SAC (Green and Anson 2000a) and SDI (Anson 2000a). The excavations at SAC identified two main cultural layers (Fig. 2): zones C1 and C2 — described by Specht (1968: 122–123) as black loamy clay and a discoloured, calcareous beach sand respectively. The excavations of Green and Anson (2000a) (see key to Fig. 2, this paper) and the soil analysis of Lentfer and Green (2004: 77, Table 1) have expanded this description. Both layers contained different amounts and kinds of pottery, obsidian and other stone artefacts, marine shells, human, animal and fish bones, and oven stones. The lower of the two layers (Zone C2) graded into a coralline beach sand (Zone D) (Green and Anson 2000a: 35–37).

Five ^{14}C determinations were obtained of material collected from these excavations. A sample of human bone from the burials (ANU-37b; 2420 ± 110 BP) was dated in 1965 (Specht 1968), but the result was considered to be difficult to interpret because of the uncertain effect of human diet (Green and Anson 2000a: 39). Two ^{14}C determinations were later measured of a single *Tridacna* sp. shell sample (ANU-5336 and Beta-16835) collected in 1985 from Zone C2 (Table 1). This shell was lodged within the infill of a pit under a pile of stones that had spilled into the pit. This stone pile was considered to belong to part of an alignment that delineated the burial area (Green and Anson 2000a: 38–39, 45). These two ^{14}C analyses returned a pooled calibrated result of 2241–2063 BP at 1σ (291–113 BC) (using a ΔR of 0). A ^{14}C determination was also obtained on a

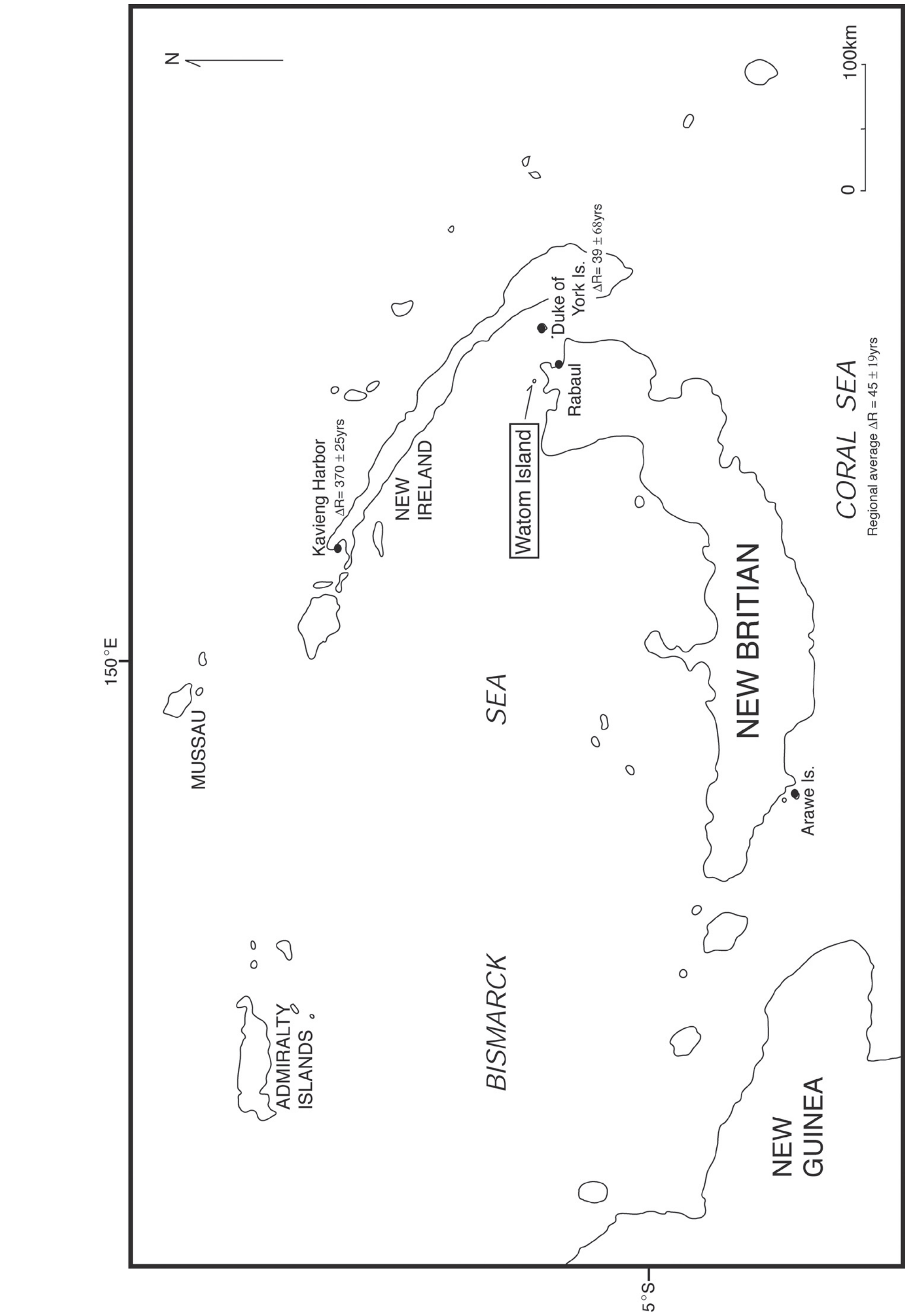

Figure 1: Map of the Southwest Pacific Ocean showing Watom Island and published ΔR values for pre-1950 shells of known age. From Petchey *et al*. (2004).

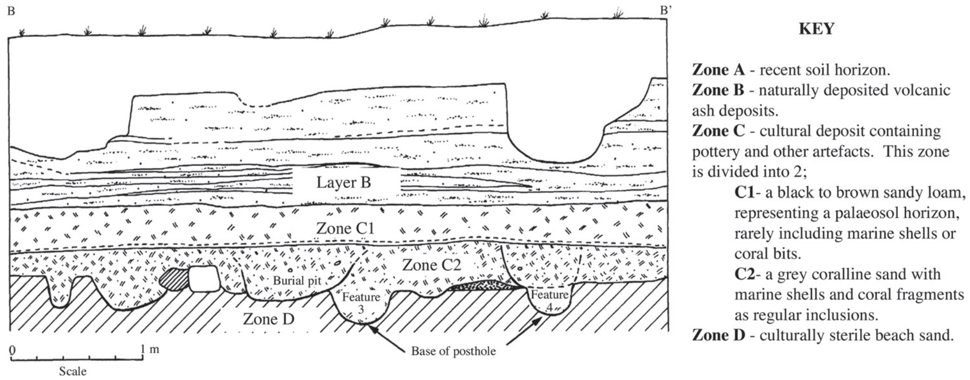

Figure 2: East–west stratigraphic profile of layers at SAC. From Green and Anson 2000a: 35, fig. 3.

sample of *Trochus niloticus* (ANU-5339) recovered from the very basal deposits of SAC. Green and Anson (2000a: 38–39) could not conclusively identify the shell as belonging to a natural event because the interface of zones C2 and D was irregular and difficult to define. The result of 3459–3300 cal BP at 1σ (1509–1350 BC) was, however, considered to be too old to date the activity within Zone C2, given the other ^{14}C results and associated pottery. Using the ^{14}C data and artefact similarities between SAC, SDI and SAD, Green and Anson (2000b: 184) concluded that there were several stages of building activity followed by abandonment of the site as a residential location and use as a burial ground. They attributed all of these activities to the very late end of the Lapita horizon, around 2450 to 2150 years ago (500–200 BC).

The formation of Zone C2 was followed by a short hiatus, during which water-laid volcanic loam covered the surface of Zone C2 to a depth of 25 to 30 cm. This was followed by a brief occupation on the surface of Zone C1 that cut into the upper spit of Zone C2 (Green and Anson 2000a: 84). A sample of *Tridacna* sp. (ANU-5330) was selected from the interface of zones C1 and C2 and returned a calibrated date of 2110–1912 BP at 1σ (160 BC–AD 38) using a ΔR of 0 (Table 1). This domestic occupation was cut into by subsequent gardening activities. Lastly, Zone C1 was sealed by *in situ* and re-deposited ash fall deposits (zones B2 and B1 respectively) derived from the Rabaul eruption around 1400 years ago (Walker *et al*. 1981: 181; Anson 2000a: 102; Green and Anson 2000a: 40–42; Lentfer and Green 2004).

Disturbance by gardening activities, uncertainties with ΔR, and ambiguities between the ^{14}C determinations, stratigraphy and artefact associations have led to debate over this chronological interpretation (e.g., Gosden *et al*. 1989: 563; Spriggs 2001: 241; Best 2002: 86–89). Recent examination of the faunal remains from SAC (Lentfer and Green 2004: 83) has confirmed Specht's (1968, 2003: 132) assertion that there is no evidence of contamination between zones C1 and C2. However, post depositional reworking of the deposits within Zone C2 has resulted in a highly complex stratigraphy that is difficult to interpret. New ^{14}C determinations for burials 1 and 3 (Petchey and Green 2005) have refuted some aspects of the sequence of events given above. There is now definitive evidence for the use of SAC as a burial ground in the first half of the first millennium BC. Moreover, there is no evidence to tie the stone alignments to the burials. The occupation within Zone

C2 also covers a longer time period than previously thought, and the ^{14}C analyses point to at least two event phases (here defined as early and late Zone C2).

SAMPLING

When calculating ΔR using charcoal and shell ^{14}C results from archaeological sites, the standard approach has been to convert the 1σ age range of the calibrated terrestrial ^{14}C value to a model marine ^{14}C age (Q_{at}) using the relevant calibration curve (e.g., MARINE04 (Hughen *et al*. 2004)). This value is then subtracted from the paired marine shell CRA (P_{ma}) using the formula $\Delta R = P_{ma} - Q_{at}$ with the ΔR standard error calculated by the formula: $\Delta R\sigma = \sqrt{(\sigma_{ma}^2 + \sigma_{at}^2)}$ (Stuiver and Braziunas 1993). For this to give an accurate result, the paired charcoal/shell samples must belong to penecontemporaneous[6] events, and association with a particular layer may not be sufficient, especially where that layer could have accumulated over many years. This is a common problem for archaeological shell/charcoal pairs and is one reason why ΔR values calculated from such pairs using the Stuiver and Braziunas (1993) methodology are not included in the Reimer and Reimer (2001) marine reservoir correction database (http://radiocarbon.pa.qub.ac.uk/marine), which instead favours values calculated from pre-1950 shells of known age. Because of the stratigraphic complexities at SAC we have used an alternative approach to calculating ΔR, following the methodology given by Nicholls and Jones (2001) and Jones *et al*. (in press). This methodology does not require the dated events to be tightly constrained temporally, since uncertainty in the temporal relationship between samples is incorporated within the calculation procedure. This analysis uses data from all charcoal and shell determinations, not just contemporary pairs.

For this research we opted to calculate a ΔR on ^{14}C analyses from SAC alone, in order to avoid complications caused by different depositional histories at each of the excavation locations. This includes four ^{14}C determinations for SAC published previously by Green and Anson (2000a: 38–39): ANU-5330, ANU-5336, Beta-16835 and ANU-5339. Four new ^{14}C determinations have been obtained to supplement these results and provide both short-lived charcoal and shell samples for ΔR calculation, including three of coconut shell charcoal (Wk-7372, Wk-7371 and Wk-7370) and one of *H. hippopus* shell (Wk-7846) (Table 1). These are discussed below. The human bone determination (ANU-37b) is excluded from this analysis since the simple acid wash pretreatment used at the time to isolate the bone protein would not have been sufficient to remove contamination (van Klinken and Hedges 1995: 268). The two new human bone determinations reported by Petchey and Green (2005) are also excluded from this analysis because of the added complexity the required dietary corrections would give to the calculations.

A shell sample (Wk-7846: 2650 ± 40 BP, *H. hippopus*) was selected to check the previous results obtained for the stone alignment (Table 1). Wk-7846 came from the fill of a pit under a rock alignment on the eastern boundary of the excavation (Green and Anson 2000a: 43, fig. 8), and gives a result that is statistically indistinguishable from ANU-5336 and Beta-16835 [$T' = 5.17$; $\chi^2_{4:0.05} = 5.99$] (see Ward and Wilson 1978). There was no charcoal available to compare with any of these samples.

A sample of charcoal (Wk-7370: 2860 ± 60BP) from the very base of Zone C2 was collected to check the result for ANU-5339. This new result is much older than any of the

[6] Nearly or almost contemporary.

TABLE 1
RADIOCARBON DATA FOR SAMPLES FROM ZONES C1 AND C2 AT SAC, WATOM ISLAND

Lab No.	Location	Material	CRA	$\delta^{13}C$	Cal BP 68.2% (1 σ)[2]	Cal BP 95.4% (2 σ)[2]
Zone C1						
ANU-5330	Sq G14 (base of layer)	*Tridacna maxima*	2390 ± 80	0.0**	1870–1550	2050–1350
Wk-7371	Sq F15, spit 1	Coconut shell	1730 ± 60	-27.2	1710–1560	1820–1520
Late Zone C2						
Wk-7372	E15, Spit 2	Coconut shell	100 ± 60	-25.7	Modern	
Wk-7846	Sq E12, fill of feature (a)	*H. hippopus*	2650 ± 40	2.75	2160–1870	2350–1750
ANU-5336	Sq 1-J 13/14, fill of feature (g)	*Tridacna maxima*	2530 ± 90	0.0**	2050–1700	2280–1500
Beta-16835			2470 ± 75	0.0**	1970–1650	2150–1500
Early Zone C2						
Wk-7370	Sq G13, spit 2	Coconut shell	2860 ± 60	-24.7	3080–2920 & 2910–2880	3210–3180 & 3170–2840
ANU-5339	Sq G10, 1.85m below surface	*Trochus niloticus*[1]	3490 ± 80	0.0**	3210–2870	3350–2750

** $\delta^{13}C$ assumed

[1]Anomalous ΔR values for algae grazers such as *Trochus niloticus* are well documented in areas where limestone bedrock dominates (Dye 1994; Spenneman and Head 1998). This is unlikely to be a concern for ANU-5339 because Watom Island and the nearby coastline of New Britain are primarily volcanic (Hohnen and Cooper 1973).

[2]Calibrated using a ΔR of 261 ± 101 ^{14}C years.

other charcoal ^{14}C determinations obtained for SAC, and closer in age to the burials. This makes it more likely that ANU-5339 was a discarded food shell associated with an earlier period of human activity. Needless to say, there remains some doubt about the relationship between ANU-5339 and the cultural material in Zone C2. A third determination (Wk-

7372) from Zone C2 gave a modern result and has been excluded from our ΔR analyses (see Table 1)[7].

A sample of charcoal was also selected from Zone C1 (Wk-7371: 1730 ± 60 BP). Although this charcoal determination is not directly associated with ANU-5330, both samples belong to a period of occupation on the surface of Zone C1 and are not connected to subsequent gardening activities, which truncated the layer (see Green and Anson 2000: 41, fig. 7).

RESULTS AND METHODOLOGY

The ΔR for SAC has been calculated with the DateLab software (Jones and Nicholls 2002) using the Metropolis-Hastings MCMC sampler described by Nicholls and Jones (2001). Readers are referred to Jones and Nicholls (2002) for details on how this type of analysis is conducted. In this instance, we have eight ^{14}C determinations that date events which fall somewhere within the event phases represented by the three archaeological units being examined (early and late zones C2, and Zone C1). Model parameters are given in Table 2. Here the modelled phases (*m*) describe the activity associated with each of these archaeological units. The phase associations (*n*) are an abstraction for this particular analysis that simply represent the relative ordering of the ^{14}C determinations within associated phases and are based on the archaeological evidence presented above. In this model, the lower the phase number the more recent the sample. So, for example, ANU-5330 and Wk-7371 are grouped within the same general phase of activity (that associated with Zone C1) and post-date all of the other samples. The model allows for some (undated) time gap between each of the three general phases of activity identified in the archaeological record.

TABLE 2
CHRONOMETRIC DATA USED IN THIS ANALYSIS

Date	CRA	Error	Phase		Reservoir
			m	*n*	
ANU-5330	2390	80	1	1	Marine
WK-7371	1730	60	1	2	Terrestrial
Pooled shell result (ANU-5336/ Beta-16835)	2495	58	3	1	Marine
WK-7846	2650	40	3	2	Marine
WK-7370	2860	60	6	1	Terrestrial
ANU-5339	3490	80	6	2	Marine

[7] Green and Anson (2000a: 38) have also reported a modern charcoal result from Zone C1. This sample contained a cigarette filter that had been introduced during the 1965 excavation. Therefore, it is possible that Wk-7372 — a small AMS sample — was introduced during excavations.

The distribution results for the SAC ΔR calculation are given in Figure 3. This distribution is unimodal and dominated by a near Gaussian peak so it can be approximated as a normally distributed variable of 261 ± 101 ^{14}C years. This value is consistent with ΔR values calculated for Zone C1 (ΔR=320 ± 103 ^{14}C years) and early Zone C2 (ΔR=305 ± 106 ^{14}C years) using the method of Stuiver and Braziunas (1993), but has a higher variance than the weighted mean ΔR result (313 ± 74 ^{14}C years) for these paired sample analyses (Table 3). This is to be expected given that uncertainty in the temporal association amongst the dated samples is incorporated in the result. We, therefore, believe 261 ± 101 ^{14}C years is a more accurate representation of our true state of understanding than would arise through the use of the standard Stuiver and Braziunas (1993) approach. For a detailed discussion on this matter see Jones *et al*. (in press).

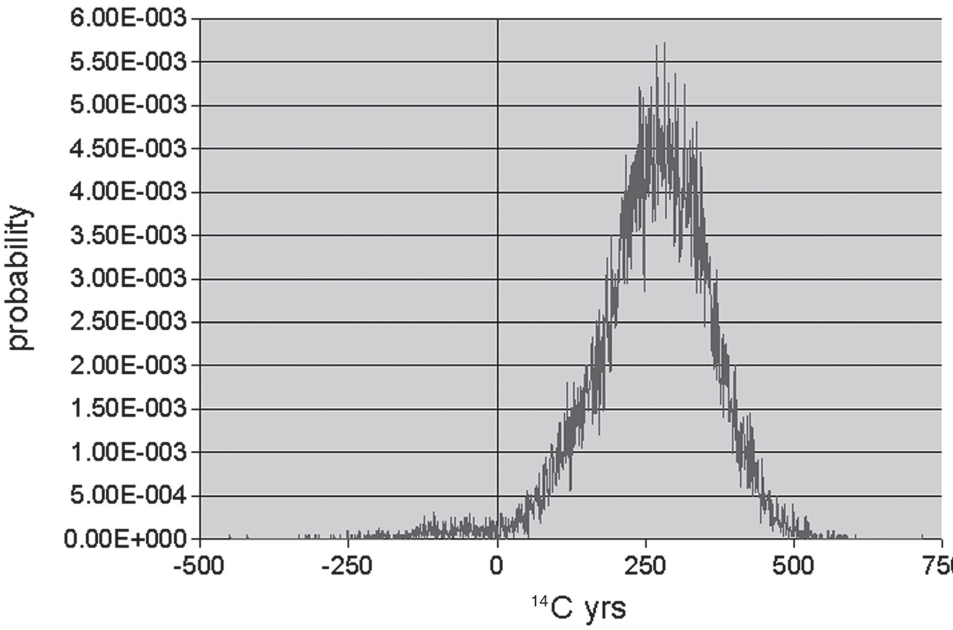

Figure 3: ΔR Distribution for Watom, SAC.

DISCUSSION

Jones *et al.* (in press) noted that where archaeological evidence enables the dated events to be tightly temporally constrained, the approach presented here and that described by Stuiver and Braziunas (1993) give very similar results. Where temporal constraints are less certain, however, the two approaches can give rise to differing results. In this instance, although the results obtained by the two techniques are similar, we recommend the use of 261 ± 101 years because of the small number of ^{14}C determinations used in the calculation and the complexity of the stratigraphy. We stress that our current understanding of the sequence of events at Watom is incomplete and additional dating is required to confirm this result.

The reliability of this result can be assessed by comparison with extant ΔR values from this region. A similarly high ΔR value of 370 ± 25 years has been reported for pre-1950

TABLE 3
SHELL/CHARCOAL PAIRS SELECTED FOR ΔR CALCULATION
USING THE METHOD OF STUIVER AND BRAZIUNAS (1993)

Lab No.	**Material**	**^{14}C CRA ± error (BP)**	**Marine modelled age (Q_{at})[1]**	**ΔR (years)** P_{ma} - Q_{at} [2]
Zone C1				
ANU-5330	Shell	2390 ± 80	-	320 ± 103
Wk-7371	Charcoal	1730 ± 60	2070 ± 65	
Early Zone C2				
ANU-5339	Shell	3490 ± 80	-	305 ± 106
Wk-7370	Charcoal	2860 ± 60	3185 ± 70	

[1]An estimate of the atmospheric calibration curve error (INTCAL04: Reimer *et al*. 2004) over the 1σ span of the radiocarbon age was used to derive the calculated marine modelled age. Therefore, atmospheric age $\sigma = \sqrt{(\sigma^{14}\text{C age}^2 + \text{average of calibration curve error}^2)}$.
[2]The weighted mean of these two ΔR values is 313 ± 74 years with a scatter σ in the un-weighted mean of 7.5 years. The larger of the two errors is used following the recommendations of Stuiver *et al.* (1986: 982) and indicates that there is no additional uncertainty in the ΔR introduced by non-uniform ^{14}C content of the shellfish.

shells of known age collected from the northeast coast of New Ireland (Petchey *et al*. 2004). Petchey *et al*. (2004) attributed this value to weak equatorial upwelling of ^{14}C depleted waters from the deep ocean in response to major current reversals during the monsoons (i.e., the northern branch of the South Equatorial Current (SEC) and the North Equatorial Counter Current (NEC)). In contrast, the Duke of York Island group, less than 40 km from Watom Island, has a lower ΔR value of 39 ± 68 years — more in line with published ΔR values for the southern branch of the SEC which flows past the Duke of Yorks from the Coral Sea (Druffel and Griffin 1993, 1999; Petchey *et al*. 2004) (Fig. 1). At the present time, no ΔR data are available for the Bismarck Sea. Upwelling along the New Guinea coastline in response to seasonal reversals in the SEC and NEC (Kuroda 2000) and circulatory current patterns within the Bismarck Sea (see Butt and Lindstrom 1994: 12, 511, fig. 7) lend support to the notion that these surface waters are depleted in ^{14}C. Therefore, the high ΔR value of 261 ± 101 years is in keeping with these observations. Further ΔR research is needed in this region to confirm these observations.

This kind of regional ΔR variation could result in a 300-year difference between shells collected from the Bismarck Sea region and contemporary shells collected from coastlines bordering the Coral and Solomon Seas. Seasonal climatic fluctuation could further exaggerate this spread. Longer-term change over time in ΔR values has also been seen in various locations (i.e., Reimer and McCormac 2002) and must be a further consideration when comparing ^{14}C results from archaeological sites of varying age. Refinement of the ^{14}C chronology for this region and development of colonisation models become somewhat problematic, therefore, without a more extensive knowledge of marine ΔR variation.

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