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NEW ΔR VALUES FOR THE SOUTHWEST PACIFIC OCEAN

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ABSTRACT. ΔR results of known-age shells from the Solomon and Coral Seas and the northwest coast of New Ireland are presented. The results are too few to be conclusive but indicate that ΔR in this region is variable. An average ΔR value of 370 ± 25 yr is recorded for a range of shell species from Kavieng Harbor, New Ireland, and is primarily attributed to weak equatorial upwelling of depleted ^{14}C due to seasonal current reversals. In contrast, values from the Solomon and Coral Seas are lower (average ΔR = 45 ± 19 yr). Higher ΔR values for some shellfish from these 2 seas is attributed to ingestion of ^{14}C-depleted sediment by deposit-feeding species.

INTRODUCTION

Marine shell is ubiquitous in archaeological sites throughout the Pacific. The ability to accurately calibrate marine shell radiocarbon dates is, therefore, vital to the development of regional chronologies for human colonization (e.g. Spriggs 1996; White and Murray-Wallace 1996; Specht and Gosden 1997; Best 2002). Regionally, the ^{14}C of the ocean surface deviates from the modeled marine curve of Stuiver et al. (1998) due to variations in upwelling, ocean currents, and inter-hemispheric atmospheric ^{14}C (Stuiver and Braziunas 1993). Therefore, when dating marine shells, it is essential to know the difference (ΔR) between the global average [Rg(t)] and the actual ^{14}C activity of the surface ocean at a particular location [Rs(t)]. The ΔR for a specific location(s) can be calculated from known-age shells collected prior to atmospheric bomb testing using the formula: $Rs(t) - Rg(t) = \Delta R(s)$ (Stuiver et al. 1998).

Unfortunately, there are few published ΔR results for the southwest Pacific (see Reimer and Reimer 2003). Moreover, marine shell ^{14}C determinations can be difficult to interpret because they may incorporate ^{14}C from a range of carbon reservoirs. High ΔR values are typically produced by the incorporation of dissolved (i.e. hardwater effect) or particulate carbonates derived from calcareous bedrock or the upwelling of ^{14}C-depleted water. Lower values have been attributed to well-mixed water and the incorporation of freshwater—either derived from river-borne dissolved and particulate organic matter or high rainfall (Stuiver and Braziunas 1993; Ingram 1998; Southon et al. 2002). The effect of these varying sources of ^{14}C on shellfish will depend upon the degree of water exchange with the open ocean coupled with peculiarities of habitat and diet (Tanaka et al. 1986; Hogg et al. 1998). Anomalous ΔR values for algae grazers[4] and deposit feeders have been attributed to the intake of detrital matter, which can vary in age depending on local geology (Dye 1994; Spenneman and Head 1998; Hogg et al. 1998). Suspension feeders generally consume suspended phytoplankton and dissolved inorganic carbon from seawater, though some bivalve species will also engage in deposit-feeding activities depending on local circumstances (Snelgrove and Butman 1994). Consequently, anomalous ΔR values could be caused by a hardwater effect or the incorporation of riverine material, while some filter feeders may also be affected by similar sources of error

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[4] Algae grazers feeding on a living coral substrate should only incorporate very recent carbon, although this could vary where fossil and/or sub-fossil coral are present. Algal grazers that target species restricted to seaweed surfaces should not present this problem.

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RADIOCARBON, Vol 46, Nr 2, 2004, p 1005–1014

as deposit-feeding species. Little data is available for carnivorous shellfish, but they are presumed to show an averaging effect depending on the carbon reservoirs of their prey.

This paper presents preliminary results of research undertaken to increase our knowledge of ΔR variation in a region stretching from the Bismarck Archipelago to New Caledonia.

ΔR RESULTS AND DISCUSSION

A total of 16 prebomb age shells have been dated as part of this study (Figure 1). Samples were obtained from collections housed in the University of Auckland and the Auckland Museum in New Zealand, the Australian Museum, and the National Museum of Natural History, Paris. The shellfish were identified as coming from Buka and Bougainville Islands, New Ireland; the Duke of York Islands; New Britain; Malaita, Russell, and Masighe Islands in the Solomon Group; Ambrym Island in Vanuatu; and New Caledonia. ^{14}C measurements were made at either the Waikato Radiocarbon Dating Laboratory at the University of Waikato, New Zealand, or the Australian Nuclear Science and Technology Organization (ANSTO). ^{14}C data and ΔR values are shown in Table 1.

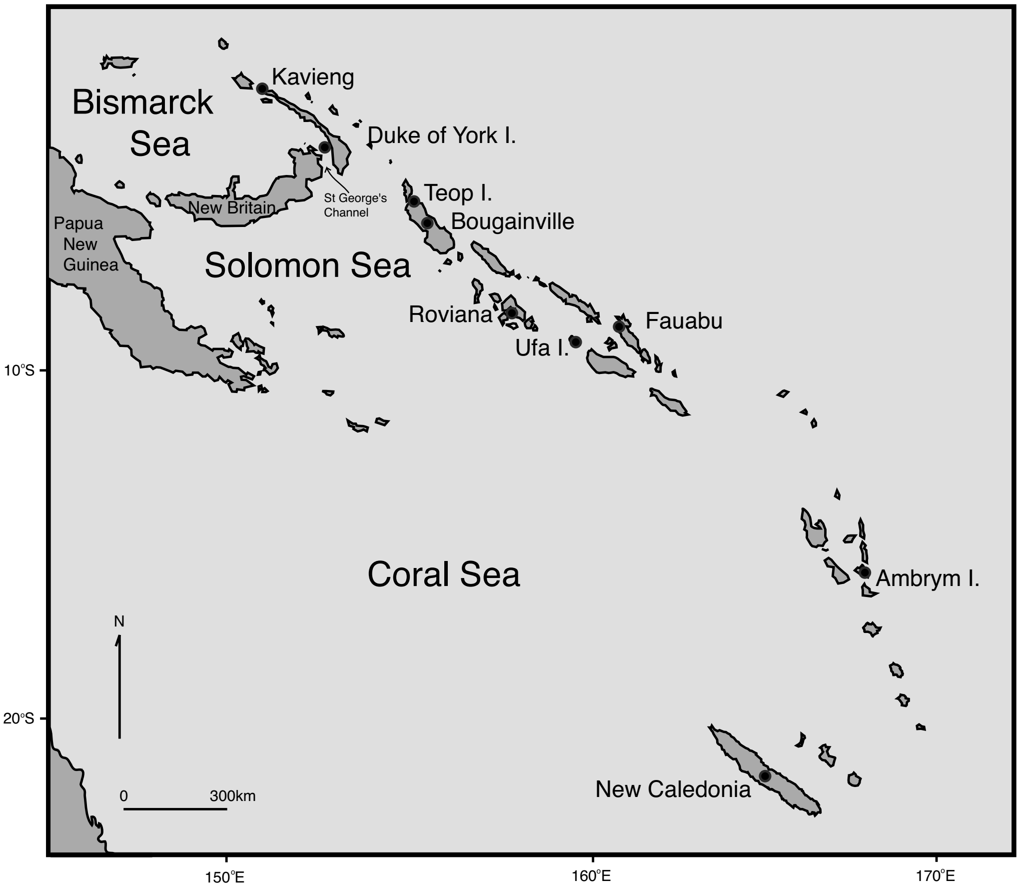

Figure 1 Map of the southwest Pacific Ocean showing location of known-age marine shells collected for this research

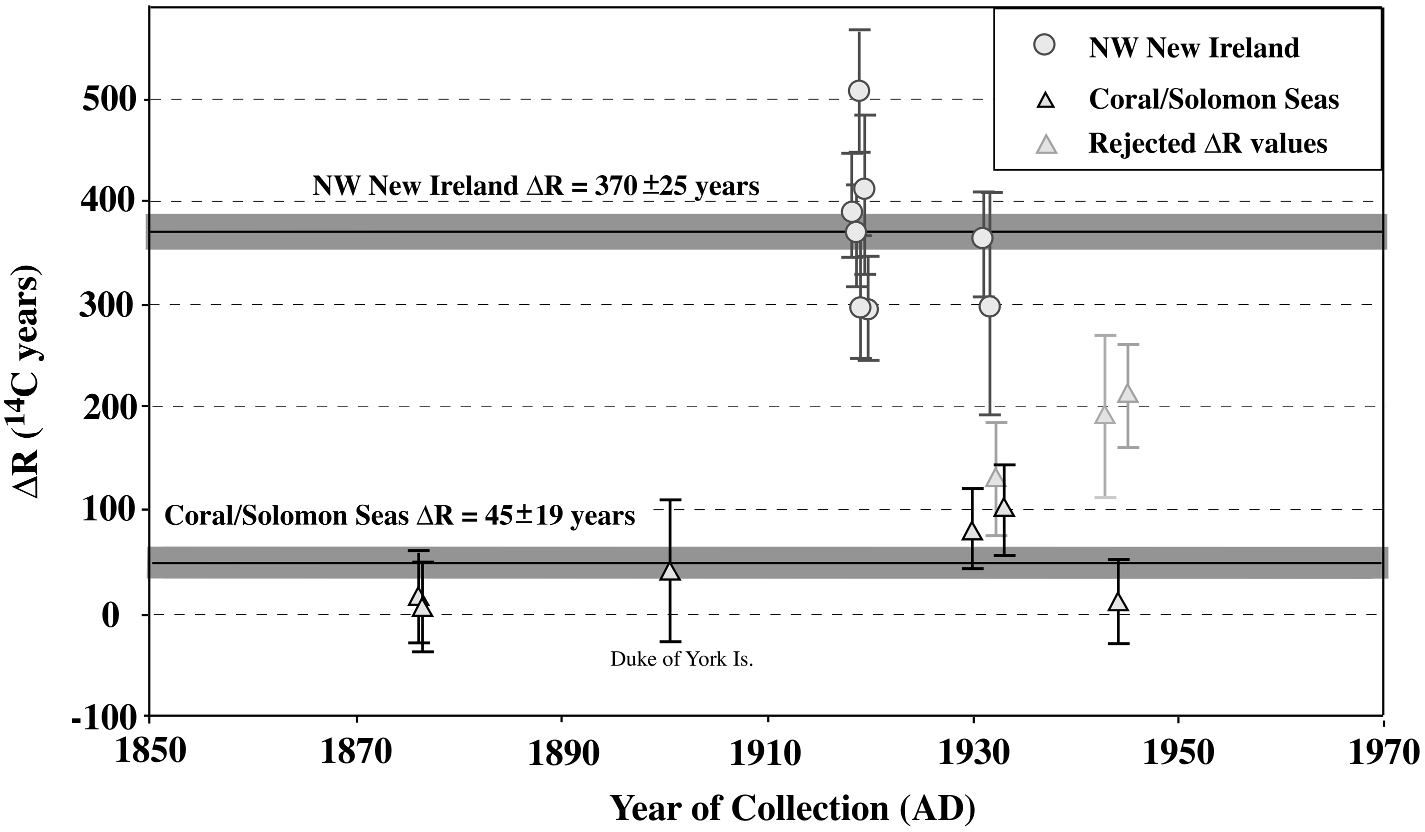

Figure 2 ΔR values obtained from this study for the Coral/Solomon Seas and northwest New Ireland plotted against year of collection. Error bars denote 1 standard deviation from the mean.

New Ireland and Duke of York Islands

Eight shells were collected from Kavieng Harbor (Figure 1) and provide a ΔR weighted mean of 370 ± 21 yr with a 1-σ scatter in the data of 25 yr (Figure 2). The slightly larger scatter sigma indicates an additional uncertainty in ΔR introduced by non-uniform ^{14}C content of the shellfish. Stuiver et al. (1986) recommend the use of the larger standard error to account for this uncertainty.

The shells selected come from 2 species of *Conus*, a carnivorous gastropod: *Nerita plicata*, an algae grazer; and *Barbatia foliata*, a suspension-feeding bivalve. The close proximity of Pleistocene-aged limestone islands to the southwestern edge of the harbor (Hohnen and Cooper 1973a) may be responsible for the elevated ΔR values. Dye (1994) has previously demonstrated that *Nerita* may give unreliable ^{14}C values if living on a limestone substrate (see also Anderson et al. 2001). Similarly, *Conus* sp. could incorporate depleted ^{14}C from prey living on these sands. The ΔR values of *Nerita* (360 ± 50 yr) and *Conus* sp. (range from 298 ± 50 yr to 508 ± 60 yr) are, however, indistinguishable [$T' = 9.42$; $\chi^2_{7:0.05} = 14.07$ (Ward and Wilson 1978)] from *Barbatia* (ΔR = 300 ± 110 yr). The general agreement between all shellfish species suggests this high ΔR value is a true reflection of the surface waters at this location. High values have also been calculated for archaeological terrestrial/marine pairs from Watom Island in the Bismarck Sea (Petchey, unpublished data). Similar ΔR values are found in regions of upwelled deep ocean water [e.g. the east coast of North America (Stuiver and Braziunas 1993) and the Arabian Sea (Southon et al. 2002)].

New Ireland is situated within the northern branch of the South Equatorial Current (SEC). Typically, ΔR values obtained for locations within the SEC are much lower than that for Kavieng Harbor [e.g. Fanning Island (4°N, 159°W) ΔR = 19 ± 21 yr (Druffel 1987); Nauru (0°S, 166°W) ΔR = 6 ± 14 yr (Guilderson et al. 1998)]. This suggests a localized effect is responsible for the elevated ΔR for New Ireland. Ocean circulation within this New Ireland/New Britain region is typified by large seasonal reversals of the major current systems [the northern branch of the SEC and the North Equatorial Counter Current (NECC)] (Figure 3). In summer (June/July), the NECC flows to the northwest. During 1995/96, Kuroda (2000) observed that this intrusion caused a reversal in the sub-surface current that resulted in surface water accumulation along the New Guinea coast and weak Ekman upwelling at the Equator. In winter (January/February), the currents reversed and Kuroda (2000) noted that upwelling occurred along the New Guinea coastline. It seems probable that this summer Ekman upwelling is responsible for elevated ΔR values off the north coast of New Ireland.

Table 1 presents a wide range of Δ^{14}C values (–88.4 to –111‰) for the Kavieng Harbor shellfish. Variation in Δ^{14}C of 25–30‰ has also been noted for banded corals in the southwest Pacific (Druffel and Griffin 1993, 1999) and western equatorial Pacific (Druffel 1987; Guilderson et al. 1998). These authors attributed this variation to seasonal differences in climate and currents, with longer term differences possibly associated with El Niño/Southern Oscillation events (ENSO). During normal years, ^{14}C-depleted water upwells in the east and is advected westward at the surface, primarily within the SEC, where it mixes with water from the sub-tropics. During each warm phase (El Niño), upwelling of low-^{14}C water slows in the eastern Pacific and the equatorial trade winds relax or reverse. As a result, Δ^{14}C values began to increase and subtropical water with higher concentrations of ^{14}C invade the SEC (Guilderson et al. 1998).

A much lower ΔR value was obtained for the Duke of York Islands (39 ± 68 yr), which are located between New Britain and New Ireland (Figure 1). The Duke of Yorks are composed primarily of Pleistocene-age raised corals (Hohnen and Cooper 1973b). A high ΔR value could, therefore, be expected if *Nassarius camelus*, a carnivorous gastropod, fed on animals which had digested this material. However, this is not supported by the ΔR value. Instead, we favor an explanation whereby

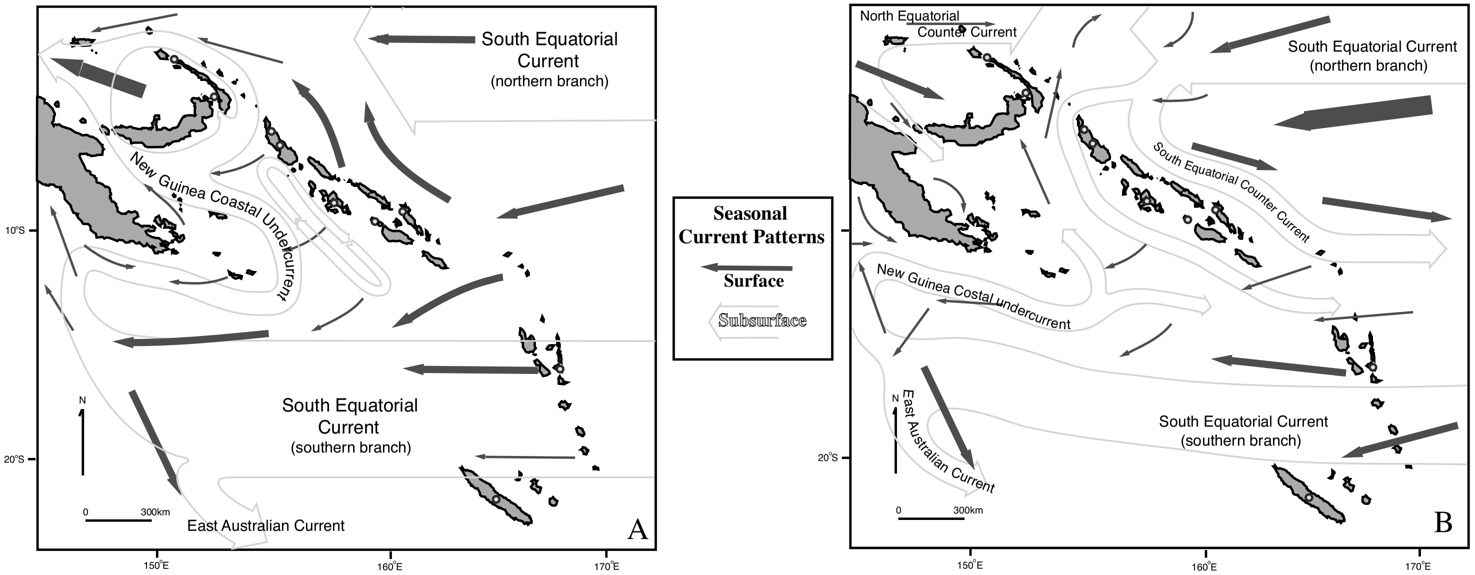

Figure 3 Map of the southwest Pacific Ocean showing major current patterns during 1999/2000 for (a) Summer (June/July); (b) Winter (Jan/Feb) [Current data: AIMS (1998)]

the New Guinea Coastal Undercurrent brings higher $\Delta^{14}C$ waters from the Coral and Solomon Seas (see below) into the St George's Channel (Butt and Lindstrom 1994), shielding the Duke of York Islands from the effects of the upwelling noted above.

The Coral and Solomon Seas

Nine ΔR values have been measured for the Coral/Solomon Sea region (Figure 1 and Table 1).

The high ΔR results from Ufa Island (211 ± 50 yr) and Fauabu, Malaita (130 ± 55 yr) are suspect because they are of a deposit-feeding gastropod (*Asaphis violascens*) collected from areas dominated by calcareous bedrock of Pleistocene, Miocene, and Pliocene age (British Solomon Islands. Dept of Geological Surveys 1969). A lower ΔR value of 82 ± 40 yr was obtained for the carnivore *Chicoreus ramosus* collected from Roviana Lagoon on the southern coast of New Georgia Island. Roviana Lagoon is largely bounded by volcanic bedrock with only minor Pleistocene limestone to the west of the lagoon, and on Rendova Island to the south.

Two ΔR results are available for Bougainville. The ΔR of 100 ± 45 yr for *Anadara* (Wk-8380), a suspension-feeding bivalve collected from Teop Island just off the northern coast of Bougainville, is indistinguishable ($T' = 2.14$; $\chi^2_{1:0.05} = 3.84$) from the ΔR of 12 ± 40 yr for the *Conus* sp. gastropod (Wk-8381). Unfortunately, the exact collection location for Wk-8381 is unknown. The ΔR value does not, however, suggest any influence from Pleistocene-age limestone that is located sporadically around the coast of Bougainville (Blake and Miezitis 1967), though the influence of riverine input cannot be excluded.

Only 1 value is available from Ambrym Island, Vanuatu ($\Delta R = 192 \pm 80$ yr). This result is indistinguishable [$T' = 1.52$; $\chi^2_{1:0.05} = 3.84$] from a ΔR of ~94 ± 10 yr obtained by Burr et al. (1998).[5] The possibility that these results are also influenced by incorporation of depleted carbon from limestone bedrock on the island cannot be discounted. Although Ambrym is a basaltic island formed by an active shield volcano, Pliocene and Pleistocene limestone sands from islands 10 km away (British Govt. Ministry of Overseas Development 1976) are available to the deposit-feeding *Tellina linguafelis*. Localized volcanic activity on the island may also affect ^{14}C. The influence of geothermal activity on the ^{14}C content of terrestrial and aquatic plant material is well documented (Rubin et al. 1987; Shutler 1971; Sveinbjörnsdóttir et al. 1992), and the venting of CO_2 and carbonates depleted in ^{14}C (Pichler et al. 1999) could be responsible for localized anomalies in shell ΔR.

Two very similar ΔR values are available for 2 species of Venus shells from New Caledonia ($\Delta R = 15 \pm 45$ yr and 5 ± 45 yr). Since *Venerines* are suspension-feeders, it is possible that the low ΔR values are caused by the incorporation of river-borne organic matter. Unfortunately, the collection location for these samples is unknown.

The 9 ΔR results presented here for the Coral and Solomon Seas and Duke of York Islands are highly variable [$T' = 17.83$; $\chi^2_{8:0.05} = 15.51$]. This variation may, in part, reflect peculiarities of ocean circulation within this region (Figure 3). The primary inflow to the Coral Sea is supplied by the west-flowing SEC. This current reaches the western boundary through a complex of islands, resulting in localized eddies and wakes (Coutis and Middleton 1999). The East Australian Current also introduces water with a higher $\Delta^{14}C$ signature than the SEC into the Coral Sea (Rafter 1968), and high

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[5] Burr et al. (1998) give a reservoir value of 494 ± 10 yr for the island of Espiritu Santo, Vanuatu, which was calculated from the average of 35 prebomb samples of known age. The ΔR value of ~94 ± 10 yr given here assumes a 400-yr difference from the modeled marine curve (Stuiver et al. 1998).

Table 1 ^{14}C ages and ΔR results for known age shells from the Coral/Solomon Seas and northwest New Ireland.

Location	Lab nr[a]	Species[b]	δ^{13}C‰[c]	Year collected[d]	Δ^{14}C‰[e]	CRA [Rs(t)] + error[f]	Marine modeled age [Rg(t)][g]	ΔR (yr): Rs(t)–Rg(t)
New Ireland								
Kavieng Harbor	Wk-8377	*Nerita plicata* (AG)	1.06	1931	–96.8 ± 5.3	820 ± 50	459 ± 4	360 ± 50
	Wk-8379	*Barbatia foliata* (SF)	0.39		–90.4 ± 12.4	760 ± 110		300 ± 110
	OZB-768	*Conus lividus* (C)	1.94	1919*	–89.2 ± 6.5	760 ± 60	452 ± 4	308 ± 60
	OZB-769	*Conus lividus*	2.62		–111.2 ± 5.9	960 ± 60		508 ± 60
	OZB-770	*Conus lividus*	2.63		–95.7 ± 4.7	820 ± 50		368 ± 50
	OZB-771	*C. sanguinolentus* (C)	1.67		–100.4 ± 8.9	860 ± 80		408 ± 80
	OZB-772	*C. sanguinolentus*	1.96		–88.4 ± 5.1	750 ± 50		298 ± 50
	OZB-773	*C. sanguinolentus*	1.19		–100.7 ± 4.7	850 ± 50		398 ± 50
Solomon Sea/Coral Sea								
Duke of York Is.	Wk-9219	*Nassarius camelus* (C)	2.72	~1905*	–59.4 ± 7.9	492 ± 68	453 ± 5	39 ± 68
Bougainville	Wk-8381	*Conus* sp.(C)	2.12	1944	–57.5 ± 4.7	480 ± 40	468 ± 10	12 ± 40
Bougainville; Teop Is.	Wk-8380	*Anadara antiquita* (SF)	3.13	1933	–67.7 ± 4.9	560 ± 45	460 ± 5	100 ± 45
New Georgia	Wk-7828	*Chicoreus ramosus* (C)	3.83	1930*	–64.7 ± 4.9	540 ± 40	458 ± 4	82 ± 40
Fauabu, Malaita	Wk-8382	*Asaphis violascens* (DF)	–0.96	1932	–71.0 ± 6.2	590 ± 55	460 ± 5	130 ± 55
Ufa Is.; Russel Islands	Wk-8383	*Asaphis violascens*	1.71	1945	–80.7 ± 5.3	680 ± 50	469 ± 10	211 ± 50
Ambrym Is.; Vanuatu	Wk-8384	*Tellina linguafelis* (DF)	2.46	1943	–79.4 ± 8.6	660 ± 80	468 ± 9	192 ± 80
New Caledonia	Wk-8046	*Venus peupera* (SF)	1.66	1876*	–58.9 ± 4.9	490 ± 45	475 ± 4	15 ± 45
	Wk-8047	*Venus reticulata* (SF)	2.46		–57.7 ± 5.2	480 ± 45		5 ± 45

[a] Lab prefixes: Wk = Waikato Radiocarbon Dating Laboratory; OZ = Australian Nuclear Sciences and Technology Organisation (ANSTO).

[b] SF = suspension feeder; DF = deposit feeder; C = carnivore; AG = algae grazer. Diet information from Beesley et al. (1998).

[c] δ^{13}C reported relative to the PDB standard with a precision of 0.2‰.

[d] Although museum records were not always adequate to indicate if the shellfish were collected live, all shells used were unweathered and bivalves in articulation. Samples are marked with an * where live collection unknown. Wk-9219 was collected prior to 1910 and we have assumed a 1905 date.

[e] Δ^{14}C calculated following the conventions of Stuiver and Polach (1977).

[f] No Suess correction has been applied to these calculations due to uncertain effect of anthropogenic ^{14}C in the southwest Pacific (Druffel and Griffin 1993).

[g] Marine model age calculated from 1998 marine calibration dataset (Stuiver et al. 1998).

precipitation associated with the winter monsoon and the Southern Oscillation adds a thin layer of freshwater into the ocean north of 17°S (Sokolov and Rintoul 2000). These factors combine to produce inter-annual and seasonal changes that have previously been documented for the Coral Sea (Druffel and Griffin 1993, 1999; Godfrey et al. 2001). However, if ΔR values of deposit-feeders are excluded (i.e. those from Ufa Island, Malaita, and Ambrym Island) the 6 remaining values have a weighted mean of 45 ± 19 yr and a scatter σ in the unweighted mean of 16 yr (Figure 2). This suggests that much of this variability can be attributed to the habitat and dietary preferences of some shellfish species.

CONCLUSIONS

The limited results presented here indicate a wide range of ΔR values for the Coral and Solomon Seas and the northern coast of New Ireland. High ΔR values recorded around Kavieng Harbor, New Ireland are possibly the result of Ekman upwelling caused by seasonal reversals in the SEC and NECC. In contrast, values obtained for the Coral and Solomon Seas are lower. Significant differences in ΔR, especially for shells from Kavieng Harbor, highlight that this entire southwest Pacific region is influenced by ENSO and seasonal climatic variation that will make designation of a specific ΔR difficult. Some variability in ΔR is also attributed to the incorporation of material depleted in ^{14}C by deposit-feeding shellfish, and it is recommended that these species are avoided for dating. Unfortunately, there are too few results currently available to fully evaluate the reliability of different species or the range of ΔR values that can be expected. Moreover, changes to ocean circulation and climate due to anthropogenic influences have been recorded in banded coral records from this region as early as the 1850s (Druffel and Griffin 1993, 1999; Tudhope et al. 1995; Quinn et al. 1993, 1998) and may influence the results presented here.

A range of modern shell species and environmental samples have been collected from Roviana Lagoon as part of ongoing research investigating variation in ΔR, with specific focus on marine, estuarine, sea-grass meadows, and coral reef environs. A change in ocean reservoir effects over time as climatic regimes change and influence rainfall patterns, ocean currents, and upwelling is also likely. To assess the impact of longer term fluctuations in ΔR, paired marine/terrestrial samples have been selected from archaeological sites in Vanuatu, the Reef/Santa Cruz Islands, Babase Island, and New Britain. These data are still to be fully investigated.

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