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Last millennium climate change in the occupation and abandonment of Palau's Rock Islands

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Abstract

The role of AD 1300 climate change in widespread societal change in Palau and the Pacific Basin has recently been debated by Fitzpatrick (2010, 2011) and Nunn and Hunter-Anderson (2011). The central proposition examined here is the link between a sea-level driven food crisis and the outbreak of conflict, which is hypothesized in the AD 1300 event model to have led people to shift from unprotected coastal parts of large islands (e.g. volcanic Babeldaob) to more readily defensible offshore islands (e.g. limestone 'Rock Islands') during the transition between the Medieval Warm Period (MWP) and the Little Ice Age (LIA). Revision of radiocarbon dates from village sites in the Rock Islands suggests instead that permanent settlements were established on small offshore islands during the MWP with village abandonment during the LIA. Palaeoclimate records from equatorial islands show that during the LIA Palau had less rainfall from the southward movement of the Intertropical Convergence Zone (ITCZ). The abandonment of multiple limestone islands by a population estimated at 4000–6000 people may have been influenced by decreased precipitation and more tentatively from a decline in near-shore marine foods as a result of sea-level fall.

Climate fluctuations are viewed as a critical context of major cultural transformation implicated in the origins of agriculture (Bonsall *et al*. 2002; Pipereno *et al*. 2007), the growth and catastrophic collapse of complex societies (Sandweiss *et al*. 2001; Fagan 2008; Buckley *et al*. 2010) and are held responsible for profound shifts in subsistence, settlement and migration (Faust and Ashkenazy 2007; Amesbury *et al*. 2008). Landscape abandonment in prehistory due to climate change is implicated potentially in the removal of humans from large landmasses (Kuman *et al*. 2005; Kaniewski *et al*. 2010; Parker-Pearson 2010) and islands in the Mediterranean, Atlantic and Pacific Oceans (Anderson 2001; Cherry 2004; Dugmore *et al*. 2007; Petrie and Torrence 2008). In the Indo-Pacific (Field 2008; Field and Lape 2010), as elsewhere, attention has focused on the societal effects of cooling and drought, prior to and during, the Little Ice Age (LIA: AD 1400–1800), which followed the relatively warm Medieval Warm Period (MWP: AD 800–1300). The timing and expression of the MWP-LIA is geographically variable, however, and the effects of climate change in the last millennium are fiercely debated in the Pacific Basin (Gehrels 2001; Allen 2006; Nunn 2007a). There, there is an hypothesis that between the MWP and the LIA there was a century or two of rapid cooling in the Pacific termed the 'AD 1300 event', which marked a rapid transition from a warmer to a cooler, stormier period when sea levels dropped 50–80 cm (Nunn 2000).

The AD 1300 event is argued to represent a pan-Pacific environmental catastrophe that caused a dramatic reduction in available food resources of up to 80% (Nunn 2003: 224, 2007c: 121) resulting in increased competition and conflict, and the rise of practices such as cannibalism, headhunting and the cessation of long-distance ocean voyaging. The establishment of substantial prehistoric villages on small limestone islands (Rock Islands) in the Southern Lagoon in the Republic of Palau (Figure 1) is seen as a key example of climate forcing causing the relocation of people from coastal sites to more readily defensible offshore islands (Nunn 2007a: 189-190). The abandonment of these islands is linked to the easing of the resource crisis as climate ameliorated (Nunn 2007a: 190), or the combined effects that climate change, population increase, resource stress and increasing warfare had on Rock Island settlements (Masse *et al*. 2006). The significance of climate change to Palauan society has been questioned by Fitzpatrick (2010, 2011) who noted that several aspects of the prehistoric sequence have a broad temporal span across the AD 1300 event (e.g. long-distance voyaging), were geographically variable within the archipelago (e.g. marine subsistence), and that population growth was an alternative explanation for conflict and a change to a defensive settlement pattern; arguments that were dismissed by Nunn and Hunter-Anderson (2011).

This paper examines the chronology of prehistoric villages in Palau's Rock Islands, which is central to understanding societal responses to past climate change. The radiocarbon sequence for Rock Island villages has been compromised by: (1) a reliance on marine shell determinations and uncertainty over the magnitude of the local reservoir value (ΔR); (2) application of an in-house laboratory standard to shell dates from the Rafter Radiocarbon Laboratory, and (3) inclusion of ^{14}C results from the Dicarb Radioisotope Company. Revision of the chronological sequence suggests that the Rock Islands were initially inhabited during the MWP and abandoned during

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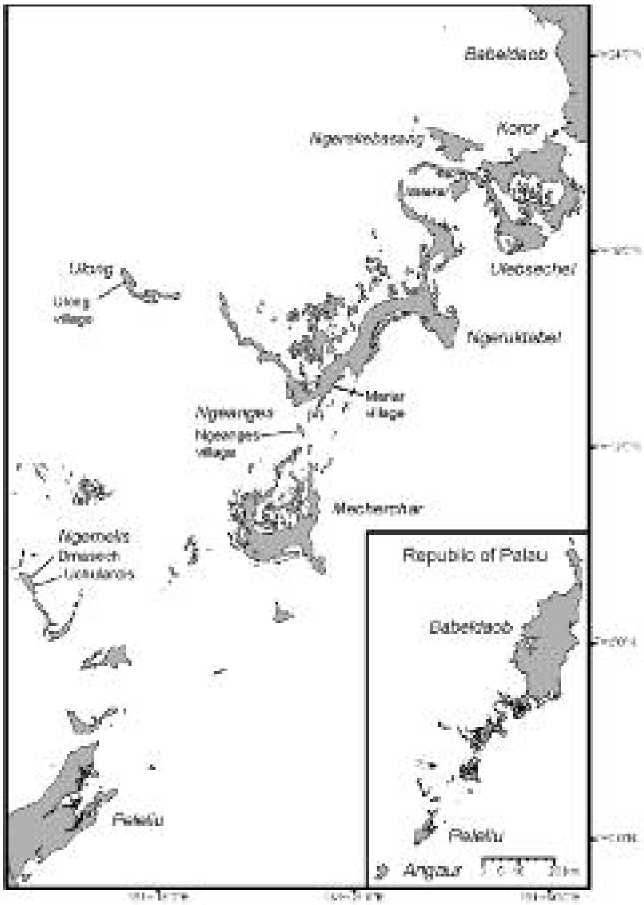

Figure 1. Republic of Palau in Western Micronesia showing islands mentioned in the text (italics) and the location of ^{14}C dated village sites in the Rock Islands, Southern Lagoon.

the LIA, when precipitation levels were diminished by the southward movement of the Intertropical Convergence Zone (ITZC). Thus, climate change is likely to be implicated in the occupation and abandonment of Rock Islands in Palau but not as modeled in the AD 1300 event.

The Rock Islands of Palau

The Rock Islands consist of several hundred raised reef islands of Miocene age in six main island groups (Ulong, Ngeruktabel, Ngerukewid, Mecherchar, Kmekumer, Babelomekang) with an aggregate area of 47 km^2. Palau is located in the Indo-Pacific Warm Pool (IPWP) and meteorological core of the Intertropical Convergence Zone (ITCZ), 7° north of the equator and 134° longitude east. The Rock Islands lie south of the main volcanic island of Babeldaob (333 km^2) and several nearby volcanic/volcanic limestone islands (Koror, Malakal, Ngerekebasang), and north of the platform reef islands of Angaur and Peleliu in the Southern Lagoon (Figure 1). The limestone islands are highly weathered with steep slopes, narrow ridges and pinnacles fronted by fringing sand plains and wave-cut limestone perimeters. They are sensitive barometers of human-climate interaction as terrestrial resources are subject to recurrent droughts that limit the production of starchy crops to sinkholes and back beach swamps, and access to potable water is dependent on a high and consistent level of precipitation as the freshwater aquifer (Ghyben-Herzberg lens) tapped by humans has to be continuously recharged by rainfall (Bear *et al*. 1999). The availability of marine foods is subject to changes in tidal range, sea temperature and nutrient concentration (Brown *et al*. 2008; Colin 2009).

European contact with Palau began in AD 1783 when the East India Company packet *Antelope* was wrecked on the west barrier reef and the crew spent three months building a schooner which they sailed to China (Clark and de Biran 2010). During their stay the crew recorded that the Rock Islands in the vicinity of Ulong were uninhabited apart from one island close to Peleliu (Keate 1789: 202); an observation confirmed in survey of the island group by Captain John McCluer in the early 1790s (Hockin 1803). However, Palauan traditions recorded that there had once been extensive permanent settlement of the Rock Islands: "It is a curious fact which derives from countless stories and traditions that in former times the high lime rocks in the south have been settled, but are now uninhabited" (Krämer 1919: 5).

Archaeological evidence of abandoned village sites was first recorded by Osborne (1966) with subsequent investigations on Ulong (Osborne 1979; Clark 2005) and Ulebsechel (Takayama 1979), and by Masse and colleagues on Ngeruktabel, Uchularois-Dmasech (Ngemelis Group) and Ngeanges (Masse *et al*. 1982; Masse 1990; Masse *et al*. 2006). There are at least 12 abandoned village sites in the Rock Islands with more likely to be recorded when the large island groups of Ngeruktabel and Mecherchar receive complete archaeological survey. Village sites are defined by stone structures on sand plains and adjacent steep hill slopes representing house, cooking and resting platforms, defensive walls, causeways, docks and wells. Stone structures on coastal sand flats are associated with substantial midden deposits composed of pottery, marine shell, fish bone, turtle, charcoal and artefacts made of shell, bone and volcanic stone (Masse 1990; Clark 2005; Masse *et al*. 2006). Large quantities of marine shellfish and finfish remains indicate a heavy reliance on marine resources (Masse 1990; Carucci 1992; Fitzpatrick and Donaldson 2007; Ono and Clark 2010) while stone tools and large quantities of pottery imported from volcanic islands demonstrate that villages in the Rock Islands were connected to communities in other parts of Palau. For example, a conservative weight estimate of ceramics from the Ulong Island village site suggests the minimum importation of 60 metric tons of pottery from volcanic islands (Clark and Reepmeyer 2010).

^{14}C age results from the Rock Islands

Assemblages of radiocarbon dates are routinely screened to tighten colonization chronologies and determine the timing and duration of significant cultural changes. Unlike many instances of 'chronometric hygiene' in the Pacific that focus on ^{14}C sample integrity and cultural association (Anderson

1991; Hunt and Lipo 2006; Wilmshurst *et al*. 2011) the reassessment of radiocarbon dates from Rock Island village sites is largely the result of inconsistencies in laboratory measurement and reporting of radiocarbon ages in the 1970–1980s. Marine shell determinations from Ulebsechel measured at the Japan Isotope Association are excluded as they were reported without measuring isotope fractionation, and it is unclear if the laboratory normalized to NBS Oxalic acid (Omoto *et al*. 2010); without this information we are unable to report the correct ^{14}C age or to calibrate results to a calendar age. Age results on pot sherds from Ulong (Osborne 1979: 237) are unreliable (Anderson *et al*. 2005), and we also exclude determinations from burial caves, temporary camps and Yapese stone money quarries in the Rock Islands (Metuker ra Bisech, Orrack, Chomedokl) as samples came from potentially mixed sediments affected by wave action, grave digging and limestone extraction (Fitzpatrick 2003a, 2003b: 105; Berger *et al*. 2008). Age results from the Uchularois cave deposit – a small elevated (30m asl) complex on Uchularois Island – were not associated with stone work and the remains may be the result of temporary camps. The cave dates are included in Table 1, however, as Masse (1990: 350-351) argued that the older results, which were associated with rich marine faunal remains, likely represent permanent occupation of the Rock Islands by a small number of people while the upper ages derived from the stone work villages established on Uchularois and Dmasech.

There are 32 radiocarbon dates listed in Table 1 associated with abandoned village sites in the Rock Islands including NZ-6291 on natural shell/pre-village midden from Mariar on Ngeruktabel (Masse 1990: 66). The remaining 31 determinations contain seven results on unidentified charcoal, one on pot soot/residue and 23 ^{14}C results on marine shellfish taxa collected from the Southern Lagoon. The majority of all determinations (n=28) were obtained during Masse's (1990) seminal PhD thesis research in Palau in the 1980s that involved detailed site mapping and the analysis of fishbone assemblages from village sites on the main island of Babeldaob, the nearby island of Koror and abandoned village/village components on four Rock Islands (Dmasech and Uchularois Islands in the Ngemelis Group, Ngeruktabel Island and Ngeanges Island). The 22 marine shell samples from these Rock Island village sites were analysed at the Rafter Radiocarbon Laboratory in New Zealand and were reservoir-corrected ages that had been adjusted for an in-house laboratory standard (Fiji marine shell standard; see Petchey *et al*. 2010). This meant that shell dates had already been adjusted for a marine offset (~400-year difference from terrestrial samples) and could be calibrated as terrestrial samples with the Klein *et al*. (1982) calibration dataset (Masse 1990).

The presentation of the dates in conventional radiocarbon age format, undisclosed laboratory marine offset and subsequent development of marine calibration curves (Stuiver *et al*. 1986; Stuiver and Braziunas 1993) led to the incorrect reporting and calibration of these dates by all subsequent researchers including by the lead author (Phear *et al*. 2003; Liston 2005; Masse *et al*. 2006; O'Reilly 2010). In effect, applying a marine calibration to ^{14}C ages already adjusted for a marine offset made them too recent and resulted in a suggested ΔR value of -200 to -300 years to bring the shell results into line with contemporaneous charcoal determinations (Masse *et al*. 2006: 117).

Island and context	**Lab number**	**[3]Association**	**[4]Material**	**CRA**	**^{13}C**	**[5]Calibrated 95.4%**
Ulong Island: Ulong Village						
Ulong, TP 1, Layer 1, 10-20 cm	ANU-11932	midden associated with stonework; sand plain	*Tridacna* sp. (FF)	1070 ± 70	~	AD 1123-AD 1413
Ulong, TP 1, Layer 1, 20-30 cm	ANU-12096	midden associated with stonework; sand plain	*Hippopus* sp. (FF)	1400 ± 60	~	AD 785-AD 1074
Ulong, TP 1, Layer 1, 20-30 cm	ANU-12097	midden associated with stonework; sand plain	Charcoal	660 ± 150	~	AD 1026-AD 1520
Ulong, Unit 4, Layer 1, 30-40cm	Wk-15645	midden associated with stonework; sand plain	Charcoal	582 ± 49	-25.56 ± 0.2	AD 1294-AD 1425
Ulong, Unit 3, Layer 2, 50-60 cm	OZG-276	midden associated with stonework; sand plain	Pot residue	940 ± 50	-23.2	AD 1018-AD 1209
Ngeruktabel Island: Big Mariar and Little Mariar Village						
Big Mariar, Fea. 1, EU-4, 0-10cm	NZ-6254	midden associated with "definite" stone platform; sand plain	*Strombus luhuanus* (H); <0.1% calcite, composite	1712 ± 31	2.69 ± 0.05	AD 559-AD 709
Big Mariar, Fea. 1 area, EU-4, 30-40cm	NZ-6290	midden associated with "definite" stone platform; sand plain	*Stombus luhuanus* (H); <0.1% calcite	1725 ± 34	2.33 ± 0.05	AD 543-AD 705
Big Mariar, Fea. 1 area, EU-4, 60-70cm	NZ-6291	midden below "definite" stone platform; sand plain	*Tridacna cf crocea* (FF); 0.5% calcite	2671 ± 35	2.52 ± 0.02	BC 625-BC 369
Big Mariar, EU-6, 40-50cm	NZ-6311	below stones from defensive wall (F-3); sand plain	*Tridacna squamosa* (FF); 0.7% calcite	1061 ± 33	2.37 ± 0.07	AD 1193-AD 1314

Island and context	Lab number	[3]Association	[4]Material	CRA	^{13}C	[5]Calibrated 95.4%
Ngeruktabel Island: Big Mariar and Little Mariar Village						
Big Mariar, EU-8, 20-40cm	DIC-2532	midden below stone structure (?bai platform); sand plain	*Stombus luhuanus* (H); composite	2600 ± 40	~	AD 1294-AD 1411
Little Mariar, EU-10, 10-20cm	NZ-6295	midden associated with stones from defensive wall (F-49); sand plain	*Strombus luhuanus* (H); <0.1% calcite, composite	1102 ± 33	1.77 ± 0.02	AD 1169-AD 1314
Mariar, EU-12, 10-30cm	NZ-6296	midden below stonework complex (F-33); elevated	*Strombus luhuanus* (H); <0.1% calcite, composite	1284 ± 34	2.34 ± 0.03	AD 1041-AD 1212
Ngeanges Island: Ngeanges Village						
B:OR:14, SE midden, EU-1, 10-20cm	NZ-6312	midden deposit; sand plain	*Strombus gibberulus* (H); 0.1% calcite, composite	1336 ± 33	3.37 ± 0.06	AD 910-AD 1119
B:OR:14, SE midden, EU-1, 10-20cm	NZ-6313	midden deposit; sand plain	*Strombus luhuanus* (H); <0.1% calcite, composite	1237 ± 33	2.47 ± 0.08	AD 1033-AD 1217
B:OR:15, NW midden 15, EU-1, 20-30cm	NZ-6320	midden deposit; sand plain	*Strombus luhuanus* (H); 0.4% calcite, composite	1636 ± 33	2.32 ± 0.02	AD 628-AD 793
B:OR:15, NW midden, EU-2, 0-10cm	NZ-6345	midden deposit with intact flange rim bowl; sand plain	*Strombus luhunanus* (H); 0.2% calcite, composite	1250 ± 33	2.33 ± 0.01	AD 1025-AD 1209
B:OR:15, NW midden, EU-2, 40-50cm	NZ-6350	midden deposit with intact flange rim bowl; sand plain	*Strombus luhuanus* (H); 0.2% calcite, composite	1410 ± 33	2.46 ± 0.02	AD 836-AD 1032
B:OR:16, platform area, EU-1, 10-20cm	DIC-2531	midden associated with stone structure (F-7); elevated	*Strombus luhunanus* (H); composite	2550 ± 35	~	AD 1308-AD 1435
Dmasech Island: Beluu Ngemelis, Tmasch and Ikulauol						
Beluu Ngemelis, EU-1, 40-50cm	DIC-2530	midden associated with buried stonework; sand plain	*Strombus gibberulus* (H); composite	2600 ± 45	~	AD 1291-AD 1414
Tmasch EU-1, 0-10cm	NZ-6245	midden associated with buried pit feature; sand plain	*Strombus luhuanus* (H); <0.1% calcite, composite	1261 ± 33	2.42 ± 0.06	AD 1012-AD 1199
Tmasch, EU-1, 30-40cm	NZ-6246	midden associated with buried pit feature; sand plain	*Strombus gibberulus* (H); < 0.1% calcite, composite	1158 ± 28	3.70 ± 0.02	AD 1098-AD 1282
Tmasch, EU-1, 70-80cm	NZ-6253	midden associated with buried pit feature; sand plain	*Strombus gibberulus* (H); 0.2% calcite, composite	1159 ± 30	5.82 ± 0.07	AD 1093-AD 1282
Ikulauol, EU-1, 0-10cm	NZ-6247	midden in sinkhole 35m south of stone structures; low ridge	*Strombus gibberulus* (H); 0.2% calcite, composite	1434 ± 33	4.00 ± 0.03	AD 810-AD 1018
Uchularois Island: Uchularois Cave and Rois platform						
Uchularois Cave, EU-1, 30-40cm	NZ-5640	midden in cave/rock shelter; elevated	Charcoal; composite	634 ± 83	-26.8	AD 1228-AD 1438
Uchularois Cave, N. ext. 40-45cm	NZ-5639	midden in cave/rock shelter; elevated	Charcoal	395 ± 113	-26.0	AD 1302-Modern
Uchularois Cave, N. ext. 70-80cm	NZ-5637	midden in cave/rock shelter; elevated	Charcoal; composite	1268 ± 54	-24.3	AD 660-AD 879
[1]Uchularois Cave, EU-1, 90-100cm	DIC-2387	midden in cave/rock shelter; elevated	Charcoal; composite	21070 ± 40	~	AD 892-AD 1023
Uchularois Cave, N. ext. 90-100cm	NZ-6351	midden in cave/rock shelter; elevated	*Strombus gibberulus* (H); 0.1% calcite, composite	1759 ± 34	3.87 ± 0.04	AD 488-AD 678
Uchularois Cave, N. ext. 90-100cm	NZ-6352	midden in cave/rock shelter; elevated	*Strombus luhuanus* (H); <0.1% calcite, composite	1637 ± 33	3.59 ± 0.04	AD 627-AD 792
Uchularois Cave, N. ext. 110-120cm	NZ-5638	midden in cave/rock shelter; elevated	Charcoal; composite	1162 ± 86	-25.6	AD 684-AD 1017
Uchularois Cave, N. ext. 163-175cm	DIC-2388	midden in cave/rock shelter; elevated	*Strombus gibberulus* (H); composite	21110 ± 50	~	AD 781-AD 1019
Rois platform, 20-30cm	DIC-2529	midden associated with stonework (F-1); elevated	*Strombus gibberulus* (H); composite	2650 ± 50	~	AD 1288-AD 1417

Table 1. Radiocarbon ages from Rock Island village sites.

The following assumptions are explicit in a conventional radiocarbon age; the age is calculated using the Libby half-life of 5568 years; 0.95 NBS oxalic acid provided the modern reference standard; AD 1950 is the reference year zero; and that radiocarbon years BP are the units used to express the age.

1. Masse *et al*. (1982:239) report sample DIC-2387 as from 80–90 cm depth (cf. Masse 1990:Table 8.1). 2. DIC marine shell results are calibrated as terrestrial samples after Masse (1990) and may not be CRAs. 3. Sample association was assessed from the original excavation report (Masse *et al*. 1982). 4. Material, H = herbivore, FF = filter feeder. 5. Calibrations with Calib Rev 5.1beta with a ΔR value of -51 ± 22 years applied to marine shell CRAs (Petchey and Clark (2010).

The conventional radiocarbon ages (CRAs) for Masse's charcoal and marine shell dates were recalculated with reference to the modern oxalic acid standard and are listed for the first time in Table 1. Recent work by Petchey and Clark (2010) calculated a ΔR value of -51 ± 22 years for the Southern Lagoon from dating scarid bone excavated from the AD 1783 survivor camp of the *Antelope* (Clark and de Biran 2010) and this value is applied to the marine shell ages. Within the Southern Lagoon the water residence time is likely to be variable due to restricted circulation caused by sill reefs and the small number of exchange points as at the northern bight of the Mecherchar Island complex (Colin 2009: 205-206) and further research is required to assess the ΔR variability of marine shellfish in the Southern Lagoon. It is also notable that most of the marine shell dates (n=20) are on *Strombus gibberulus/luhuanus* which are active algal/detritus feeders common on inner reef flats with coral/sand substrate and sea grass beds (Carucci 1992). Algae grazers feeding on living coral substrate and sea grass should not absorb old carbon, but it is unclear whether Strombus sp. in Palau also targets algae derived from fossil coral/limestone substrates. On Ulong Island, the algae grazer *Nerita undata* incorporated depleted ^{14}C from inter-tidal exposures of limestone (Clark *et al*. 2006) and *Strombus* sp. living in similar locations might also take in substrate carbon.

Clarification of the Rock Island village chronology is further hindered by charcoal and marine shell results from the inactive Dicarb Radioisotope Company (Dicarb/DIC). Testing of Dicarb results from an archaeological site in north Alaska with cross-check samples analysed at other laboratories (Beta Analytic, Geochron, NSF-Arizona AMS) demonstrated that the Dicarb dates were significantly more recent than those produced at other laboratories with differences ranging from 350 to 1440 years. The authors conclude that: "The use of Dicarb assays in chronology building should be viewed with skepticism" (Reuther and Gerlach 2005).

Figure 2 shows the probability distribution for the 31 CRAs and it is notable that the Dicarb results are the youngest in the series at Ngeanges (DIC-2531) and at the stonework village components on Dmasech and Uchularois Islands (DIC-2529, DIC-2530), which are likely to be part of the same village system. Direct comparison of the Dicarb results with other ^{14}C results in a sequence is only possible at the Uchularois cave site. A marine shell sample (DIC-2388) from the lowest excavation level of the cave (163-175 cm) gave a significantly younger age than overlying charcoal from 90–100 cm depth (NZ-6351, NZ-6352). Another Dicarb result on charcoal from 90–100 cm depth (DIC-2387) has a more recent age than two charcoal results from the same depth, although it does overlap with NZ-5638 from 110–120 cm depth. The Dicarb results ought not to be dismissed as they overlap with some charcoal and shell results from the Ulong village site, but they cannot be regarded as reliable as a tendency toward more recent ages noted by Reuther and Gerlach (2005) is also evident in the Dicarb results from Palau.

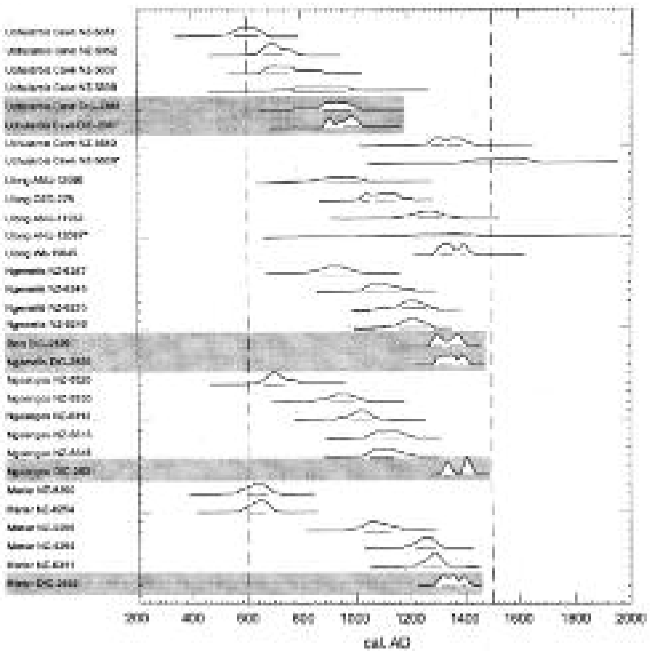

Figure 2. Calibrated radiocarbon ages from Rock Island village sites with suspect Dicarb determinations (DIC) shaded. Note that ANU-12097* and NZ-5639* have age ranges that extend past AD 1500 due to standard errors larger than ± 100 years (Table 1). Dashed vertical lines at AD 600 and AD 1500 indicate the maximum span for the establishment and abandonment of permanent settlements in the Rock Islands based on current data.

The radiocarbon data set for Rock Island village sites is clearly less than ideal, and age results on charcoal from short-lived species, archaeological marine shell-charcoal pairs and isotopic data from modern and archaeological marine animals are needed to expand our understanding of natural radiocarbon variation across the lagoon, estuarine and reef environments of Palau. Substantial midden deposits on sand plains associated with buried features like a flange-rim bowl and a pit on Dmasech, and on the mid-island limestone ridge of Ngeanges indicates that permanent settlements in the Rock Islands were established as early as AD 800–1100. Liston (2009) identified the dissolution of polities associated with monumental earthwork complexes on Babeldaob at AD 750–1250 during the period when permanent settlements were established in the Rock Islands, but the connection between the two events is unclear.

Elevated stone work components date to ~AD 1100-1300 on Ngeruktabel (NZ-6311, NZ-6296), while the suspect Dicarb results are slightly younger at AD 1300–1450 (DIC-2529, DIC-2531). Increasing use of marine resources near the start of the 2nd millennium AD is also evident on Peleliu where a large midden deposit (Roischemiangel, B:BE-2:7) of 13,500 m^2 is estimated to contain some two billion *Strombus gibberulus* shells (Osborne 1979: 33); a species described by Masse *et al*. (2006: 122) as a "nearly inexhaustible source of food" (also Giovas *et al*. 2010). In New Guinea, traditional gathering of *Strombus luhuanus* on

Yule Island was estimated to involve the collection of more than 2.5 million individuals/year with the species remaining common at the end of the two-year observation period (Poiner and Catterall 1988). The main phase of occupation at Roischemiangel is dated to AD 1100-1400 when the site reached its peak with the construction of stone walls, breast-works, gateway platforms and walled passes (Beardsley 1996: 16). Traditional history records that many of the occupants of villages in the Rock Island originally came from the Peleliu-Angaur area (Hijikata 1993, 1995) and several of the economic practices needed to live on the small karst islands such as the use of sinkholes to plant taro and specialised marine foraging (capture of sharks, collection of *Strombus* sp.) may have developed on the raised platform limestone islands of southern Palau.

It is striking that the majority of calibrated ^{14}C results, including the Dicarb ages, from village sites in the Rock Islands do not extend past ~AD 1400–1500, and the two determinations that do have wide ranges due to standard error values that exceed 100 years (NZ-5639, ANU-12097). Oral traditions suggest that islands were depopulated at different times with villages on Ulong and Ngeruktabel (Metukerikull) abandoned prior to villages in the Ngemelis Group and on Ulebsechel (Nero 1987), but the radiocarbon ages from Ulong, Uchularois-Dmasech and Ngeruktabel suggest a major phase of Rock Island abandonment at AD 1350–1500.

Discussion

Masse *et al*. (2006) suggested that permanent settlement of the Rock Islands began at AD 700–800 with the development of sizeable stone work villages at AD 1250 and island abandonment by a population estimated at 4000–6000 people from AD 1450 to AD 1650. Nunn (2007c: 143) thought the settlement pattern of Palau radically shifted from the effects of the AD 1300 event: "volcanic islands were the first to be occupied but then – around AD 1440 – they were abandoned almost entirely in favour of fortified 'stonework villages' on the inhospitable Rock Islands".

The revised chronology outlined above suggests instead that many of the Rock Islands were occupied in the MWP and abandoned during the LIA at AD 1350–1500. The potential role of climate events in the occupation and abandonment of Rock Islands can be examined with high-resolution palaeoprecipitation records from Palau, Washington Island (Teraina) and the Galápagos, which indicate that tropical rainfall patterns are highly sensitive to small changes in the Earth's radiation budget which cause the Intertropical Convergence Zone to migrate (Sachs *et al*. 2009). The ITCZ is the primary precipitation feature on the planet and is formed by opposing trade winds that create low pressure above equatorial ocean. The sun-heated water evaporates and condenses as a band of rain with an annual modern range of 3°N to 10°N latitude (Sachs and Myhrvold 2011). During the MWP elevated Northern Hemisphere temperatures moved the ITCZ north and cooler temperatures during the LIA shifted the rain band south with the most southerly position of the ITCZ reached about AD 1420 when it was south of 5°N (Sachs *et al*. 2009: 523). In the western Pacific the ITCZ extends from the Philippines south to northern Australia with a southeast tongue of the ITCZ called the SPCZ positioned east of the Solomon Islands.

In the mid-Pacific and further east the primary feature of the ITCZ is a narrow band of high precipitation lying north of the equator. Figure 3 illustrates how movement of the ITCZ affects precipitation according to island latitude. Assuming that the ITCZ had a similar latitude range of 7° during the last millennium then Palau (7°N) was within the core of the ITCZ during the MWP and since the 18th century, but received less rain when the ITCZ reached its most southerly position during the LIA (Smittenberg *et al*. 2011). The Galápagos (0°) in contrast were likely wetter during the LIA compared to the MWP, while Washington Island (5°N) at the southern margin of the ITCZ during the MWP was dry and then became very dry during the LIA when the main band of the ITCZ was probably south of 5°N (Sachs *et al*. 2009). Migration of the ITCZ south is indicated in previous research (Haug *et al*. 2001; Newton *et al*. 2006) and also by a weaker Asian monsoon (Zhang *et al*. 2008) and by wet conditions in Sulawesi (4°S) during the LIA (Tierney *et al*. 2010). The influence of the ITCZ on equatorial precipitation can be gauged from the 2900mm/year of rainfall recorded on Washington Island, which is separated by only 280km of latitude from Christmas Island (Kiritmati, ~2°N) where annual rainfall is 896mm/year. Due to its near-equator position south of the ITCZ Christmas Island is extremely dry and has net precipitation minus evaporation of -2mm/day (Saenger *et al*. 2006).

Superimposed on and potentially mitigating ITCZ-driven precipitation changes was a high frequency of El Niño events in the latter part of the MWP (Figure 3; Moy *et al*. 2002; Gagan *et al*. 2004) compared to the LIA, which may have increased precipitation in the central and east Pacific (Washington Island, Galápagos) and caused a higher frequency of drought in the west Pacific (Palau). Unfortunately, the high-resolution palaeoclimate sequence for Palau terminates at AD 1500 (Smittenberg *et al*. 2011) and we are unable to confirm the existence of high precipitation levels in the MWP relative to the LIA, which is the subject of future research. Nonetheless, the depopulation of small drought-prone limestone islands in Palau (Colin 2009: 329) during a phase of low precipitation (Sachs *et al*. 2009) is plausibly linked to climate change during the LIA, particularly if accompanied by a sea-level fall of 50–80cm (Nunn 2000, 2007a,b,c). Severe ENSO events in 1972/73, 1982/83 and 1997/98 in the West and Central Pacific were associated with a sea-level fall of 40–60cm, mass mortality of reef fauna and widespread coral death (Yamaguchi 1975; Glynn 1984, 2000; Augustin *et al*. 1999; see also Garpe *et al*. 2006), and ITCZ movement may be responsible for coral reef death during the LIA (Glynn *et al*. 1983). Sea-level fluctuations and severe ENSO events would have been detrimental to the bioproductivity of fringing reefs and shallow intertidal flats that supplied Rock

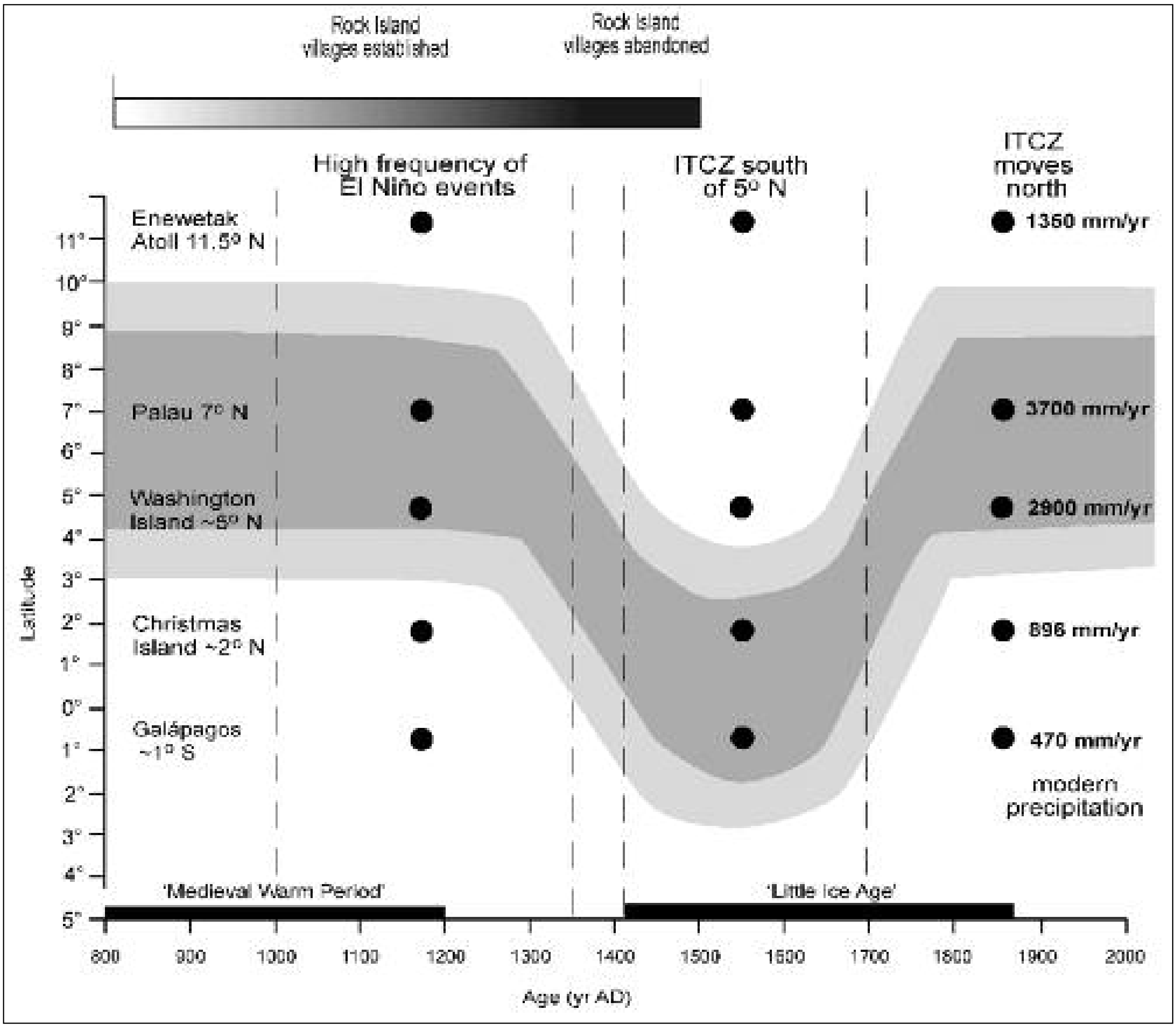

Figure 3. Southward movement of the Intertropical Convergence Zone after Sachs *et al*. (2009) resulted in lowered precipitation in Palau during the LIA (Smittenberg *et al*. 2011) apparently coinciding with a major phase of village abandonment in the Rock Islands. Black circles indicate the latitude of islands and annual precipitation levels in relation to the ITCZ. Annual precipitation values for Enewetak Atoll from Stoddart and Walsh (1992), for Palau from Hamner and Hamner (1998), for Washington Island and Christmas Island from Sachs *et al*. (2009) and the Galápagos from rainfall records (1965-2010) at Puerto Ayora, Santa Cruz Island. Precipitation records are a relatively crude index of rainfall inputs, however, which vary (seasonal/interannual/interdecadal) along latitudinal and longitudinal axes (Folland *et al*. 2002).

Island villages with large quantities of shellfish, especially *Strombus gibberulus/luhuanus*, and inshore finfish taxa (Masse *et al*. 2006; Fitzpatrick and Donaldson 2007; Ono and Clark 2010). It is necessary to note that there is currently no direct evidence for a sea-level fall in Palau during the last millennium and the impact of climate change on marine resources is currently equivocal in Palau's archaeological record (Masse *et al*. 2006; Giovas *et al*. 2010). The faunal record of climate change is likely to be difficult to extract, however, if the Rock Islands were abandoned within a short period, and a fine-grained analysis of marine fauna from several Rock Island village sites is needed to examine the possibility of a decline in marine resources from climate change, and to determine whether human overharvesting of marine foods occurred in pre-history (Masse *et al*. 2006).

Conclusion

Revision of the Rock Island village chronology in conjunction with palaeoclimate data demonstrates that climate change effects during the MWP-LIA in the Pacific Basin were geographically variable and involved human responses that differ from those in the AD 1300 event model as highlighted by the abandonment of islands in Palau during the LIA rather than their occupation. Geographic variability in climate/precipitation regimes across the Pacific Ocean during the MWP-LIA suggests that human reactions to climate events are likely to be similarly variable (Allen 2006; Fitzpatrick 2010). Precarious environments for human habitation such as the Rock Islands of Palau, the leeward landscapes of the Marquesas Islands and the northern atolls of the Marshall Islands (Weisler 2001; Masse *et al*. 2006; Allen 2010) are particularly vulnerable to climate oscillations and are key locations to detail human responses to past climate events. Among several pressing issues raised by this paper is the need for new chronological data to refine the Rock Island occupation-abandonment sequence, the reconstruction of palaeoclimate and social conditions during the MWP (particularly prehistoric population dynamics), and the use of Palauan traditional history to determine whether island abandonment is remembered as a catastrophic event (i.e. McLeman and Smit 2006). Resolving these and other questions will require modelling of past climate-environment-culture systems in the Pacific Basin with geographically focused high-resolution data.

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