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Sea levels, shorelines and settlements on Pacific reef islands

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ABSTRACT

A reassessment is made of the model of Dickinson (2003, Journal of Coastal Research*), which proposed that many Pacific island coasts were settled only after the palaeoreef flats or shore platforms that formed during the mid-Holocene sea-level highstand emerged above high-tide level: a point in time known as the crossover date. Focusing on reef (atoll) islands, the analysis suggests that this model has potential when applied to islands east of 178°E, with some, such as Funafuti (Tuvalu) and Atafu (Tokelau), being settled around the time of their crossover dates and others to the east and north-east a few centuries later. The model fails to explain the settlement of atolls in the north-west Pacific (Marshall Islands and eastern Kiribati), where islands formed well before crossover dates, something that can be attributed to the larger tidal range and complex interplay between sea level and reef upgrowth. The enduring legacy of Dickinson to Pacific archaeology is the demonstration that people were operating in a dynamic environment that presented them with new challenges and opportunities rather than in an environment that was static.*

Keywords: colonisation, crossover date, Pacific islands, reef islands, sea-level change, voyaging

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ON A PERSONAL NOTE

Many contributors to this volume probably cherish an image of William (Bill) Dickinson that is similar to mine; that of an angular man with an inadequately sized hat striding along the beach, from the end of each long arm dangling an equally weighted white linen carrier bag containing essential equipment and supplies. The image speaks to me now as it ever did of perseverance, a determination not just to reach the day's destination, but also to answer the questions to hand.

Working alongside Bill in the field, I was well aware of the day's questions that preoccupied him – he was rarely shy of talking through these – but far less of the deeper ones over which he mulled. It was only when reading his papers later that I became fully aware of these and felt surprise, sometimes even shock, at only then finally apprehending the full spectrum of his thinking on a particular topic, the web of interconnections he recognised or imaginatively posited.

Bill taught me the merits of empiricism. While never shrinking from speculation, he told me on numerous occasions, "Let the data speak." Never dig in your heels about an idea that cannot be demonstrated using observations and never be afraid to abandon an idea, even one to which you may be personally attached, if data are presented that convincingly disprove it.

INTRODUCTION

The peopling of the Pacific islands is a subject that has attracted the attention of many types of scientist, each inevitably focusing on it through their own disciplinary lenses. For Bill Dickinson (henceforth WRD), a grounding in Earth history led him to view the subject as one that might be more clearly understood through the novel application of techniques and ideas from the Earth Sciences. The legacy from ceramic sand-temper analysis that he left us (Dickinson 2006) illuminated many things, not least the migration pathways and exchange networks of early Pacific islanders, but it is on his ideas about the interaction of sea-level change, coastal environments and early settlement of Pacific islands that this paper is focused. Expressed most fully in a 2003 paper, WRD argued that falling sea level in the late Holocene transformed coastal environments of Pacific islands in ways that made them attractive to potential settlers. The short timespans that WRD calculated to have elapsed between the creation of attractive coastal environments and their sustained occupation led him to postulate that "changing sea level controlled . . . the pace of human migration into the Pacific" (Dickinson 2003: 498).

Through a review of WRD's data and the use of unconsidered sea-level data from the Pacific islands, this paper assesses the validity and the implications of this suggestion. Since it is problematic when applied to high

Table 1. Data used for comparison of reef-island crossover points and earliest settlement in Figure 3

Island country (group)	Island	Abbreviation in Figure 3	Latitude	Longitude	Crossover date (calBP)	Source of data	Age of earliest permanent settlement		Source of data	Time between crossover date and earliest settlement (cal yr)
							yrBP	calBP		
Cook Islands (northern)	Manihiki	Mn	10°25′38″S	160°59′25″W	1150	Dickinson, 2003	(830 ± 25)	731	Quoted in Yamaguchi et al., 2009	419
Cook Islands (northern)	Pukapuka	Pk	10°52′55"S	165°49′17″W	1150 (1350)	Dickinson, 2003 (this study)	750	750	Quoted in Yamaguchi et al., 2009	400
Cook Islands (northern)	Rakahanga	Rk	10°2′19″S	161°5′26″W	1150 (1350)	Dickinson, 2003 (this study)	(605 ± 25)	595	Quoted in Yamaguchi et al., 2009	555
Cook Islands (northern)	Tongareva (Penrhyn)	Tg	9°0′18″S	157°58′34″W	1150	Dickinson, 2003	(560 ± 50)	560	Quoted in Yamaguchi et al., 2009	590
French Polynesia (Gambier)	Temoe	Tm	23°20′2″S	134°28′8″W	500	This study		570	Deguilloux et al., 2011	–70
French Polynesia (Tuamotu)	Reao	Ro	18°33′17″S	136°20′1″W	550	Dickinson, 2003	(870 ± 80)	784	Sinoto, 1978	–234
Kiribati (Line)	Kiritimati (Christmas)	Kt	1°50′56″N	157°23′23″W	850	Dickinson, 2003	(690 ± 80)	650	Anderson et al., 2000	200
Kiribati Line)	Tabuaeran (Fanning)	Tb	3°51′48"N	159°20′45″W	850	Dickinson, 2003	(810 ± 50)	715	Pearthree and Di Piazza, 2003	135
Kiribati (Gilbert)	Makin	Mk	3°22′51"N	172°59′34"E	850	Dickinson, 2003	(1480 ± 75)	1368	Takayama and Takasugi, quoted in Di Piazza, 1999	–518
Kiribati (Gilbert)	Nikunau	Nu	1°21′48″S	176°27′35″E	850	Dickinson, 2003	(2050 ± 90)	2011	Di Piazza, 1999	–1161
Kiribati (Phoenix)	Manra	Mr	4°27′12″S	171°14′47″W	850	Dickinson, 2003		665	Pearthree and Di Piazza, 2003	185
Marshall Islands	Bikini	Bk	11°33′33"N	165°23′16"E	850	Dickinson, 2003	2520	2520	Streck, 1990	–1670
Marshall Islands	Kwajalein	Kw	9°3′10"N	167°26′6"E	850	Dickinson, 2003	(1920 ± 90)	1861	Beardsley, 1993	–1011
Marshall Islands	Majuro	Mj	7°8′34"N	171°2′22"E	850	Dickinson, 2003	2000	2000	Yamaguchi et al., 2009	–1150
Marshall Islands	Maloelap	Mp	8°46′24"N	171°1′52"E	850	Dickinson, 2003	1790	1790	Weisler et al., 2012	–940
Marshall Islands	Ujae	Uj	9°3′29"N	165°38′38"E	850	Dickinson, 2003	(1660 ± 60)	1556	Weisler, 1999	–706
Marshall Islands	Utrōk	Ut	11°16′8"N	169°47′45"E	850	Dickinson, 2003	1850	1850	Weisler et al., 2012	–1000
Tokelau	Atafu	At	8°33′23″S	172°28′21″W	850	Dickinson, 2003	740	740	Ono, 2013	110
Tuvalu	Funafuti	Fn	8°31′12″S	179°11′58"E	850	Dickinson, 2003	950	950	Dickinson et al., 1990	–100

islands – because people might have settled island interiors before their coasts became attractive – this paper uses data only from reef (atoll) islands, where such the situation is impossible. A key issue is not merely the fact of islands forming beyond the reach of high tides but also being habitable, something for which they would need to grow to a size sufficient to allow the development of a freshwater lens. In the case of Kaven Island (Maloelap Atoll, Marshall Islands), occupation did not take place for some 550 years after an island formed, by which time it was probably at least 200 m in diameter and supported a sizeable freshwater lens (Weisler et al. 2012). Another key issue is determining the time of earliest sustained occupation (colonisation) of such an island, an event that can be estimated only from dating the earliest material evidence of human occupation or an acceptable proxy (such as intentional vegetation burning or rapid avifaunal extinctions). Many dates used in this paper (see Table 1) are likely to be imprecise or subject to future revision.

Following an account of Holocene sea-level change and its effects on island coasts, this paper presents data for the late Holocene sea-level fall along atoll coasts and their earliest-known settlement in order to evaluate WRD's argument. The implications of this are then explored and an assessment of WRD's legacy in this debate is discussed.

LATE HOLOCENE SEA-LEVEL CHANGE AND SHORELINE SHIFT IN THE PACIFIC

Following the Last Glacial Maximum about 18000 years ago, the sea level began to rise, reaching its present level in most parts of the Pacific 7600–7100 years ago. Figure 1 shows representative sea-level data from various parts of the Pacific; empirical datasets from Papua New Guinea and Tahiti and ICE-4G model data for Fiji constrain the postglacial sea-level rise; data from Fiji (Bourewa) and New Caledonia are also shown. After the sea level first reached its present level, it rose above it to reach a maximum of 2–3 m in places; most datasets from the tropical Pacific show this maximum clearly, although it was subdued in equatorial parts. In the western Pacific, the sea level began falling from its Holocene maximum about 4000 years ago, while in the eastern Pacific the highstand endured longer, until around 2000 years ago; in both areas, the sea level had fallen to its present level by 1500–1000 calBP (Dickinson 2001; Grossman et al. 1998; Pirazzoli and Montaggioni 1988).

Important in terms of shaping tropical island coasts was the development of offshore fringing reef flats, which allowed the development of low-energy (lagoonal) nearshore environments that played a critical role in sustaining the earliest inhabitants. In most parts of the tropical Pacific, coral-reef upgrowth lagged behind postglacial sea-level rise, meaning that reef flats generally developed only after the sea level had begun to fall from its Holocene maximum. In contrast, in parts of the equatorial Pacific, it is likely that reef upgrowth kept pace with (later) postglacial sea-level rise, meaning that reef flats developed at the Holocene maximum and emerged as the sea level fell subsequently, forming cores of fossil reef around which sediments could be trapped to form reef islands.

During the period of postglacial sea-level rise, most high-island coasts would have been steeply shelving, with little (coastal) lowland and minimal offshore reef development – an unattractive prospect for settlement. By the time that the sea level was falling from its Holocene maximum and reefs had begun to develop offshore, the situation would have been quite different. Key to understanding when a particular island coast would have become available for coastal occupation is its crossover date (inset in Figure 1), a point in time at which shore platforms (or reef flats on islands where reef upgrowth had kept pace with sea-level rise) emerged beyond the reach of the falling sea level: as WRD put it, the crossover date is "the inferred time for each island group when declining late Holocene sea level first carried ambient high-tide level below mid-Holocene low-tide level" (Dickinson 2003: 492).

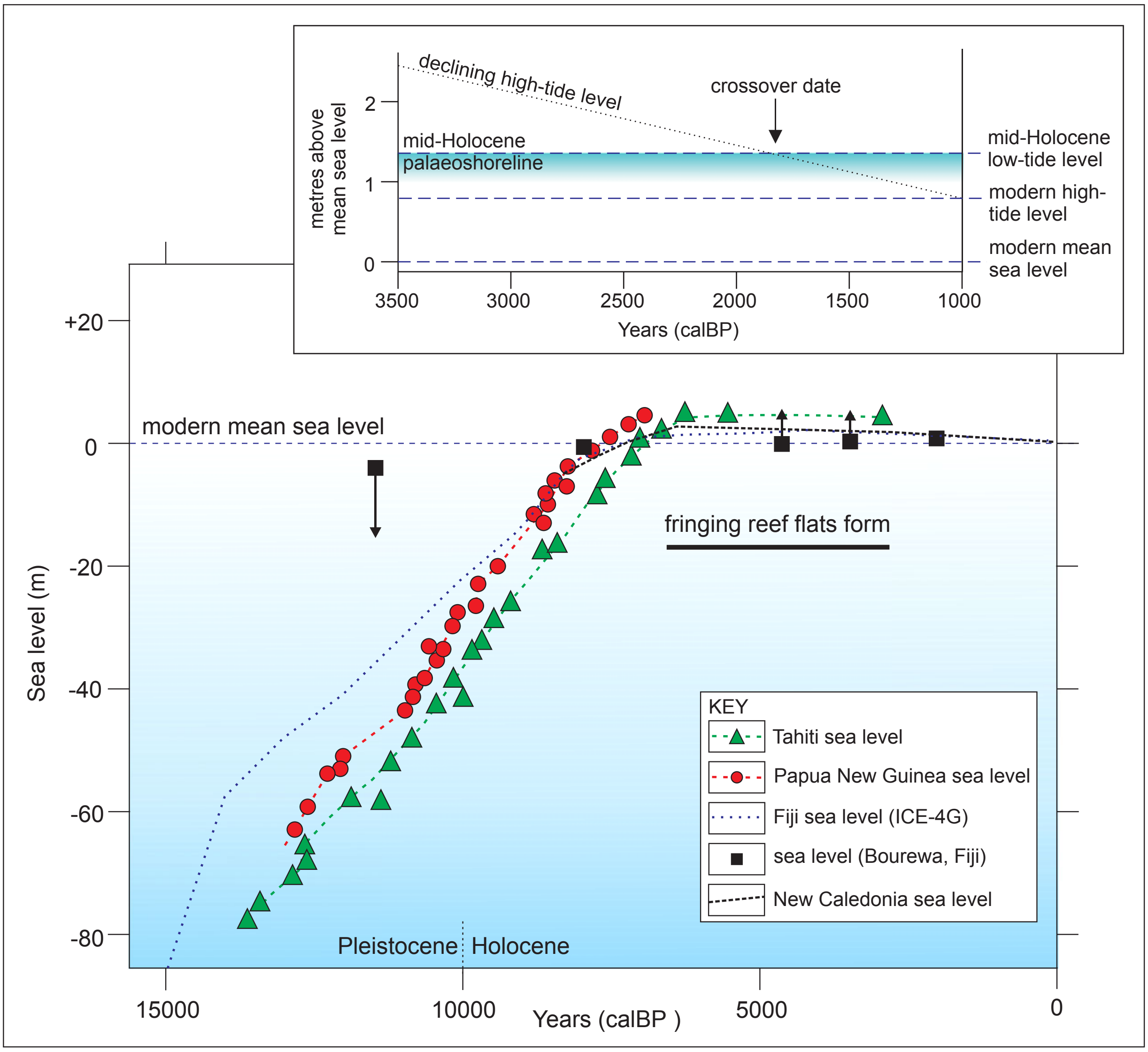
DID THE TIMING OF SEA-LEVEL FALL CONTROL THE TIMING OF REEF-ISLAND COLONISATION?

The crossover dates compiled by WRD are supplemented by those calculated for two other Pacific atolls (Figure 2) and listed in Table 1; note that a recent dataset from Kiritimati (Woodroffe et al. 2012) shows no crossover point (Figure 2a), although WRD's original calculation is given in Table 1. The calculated times between crossover dates and those for earliest settlement (shown in the last column of Table 1) are mapped in Figure 3. In interpreting this figure, it should be noted because the data are inevitably imprecise, a slight negative (such as –100 yr for Funafuti) may in fact be a positive. What is striking about Figure 3 is that there is a pattern between areas of Pacific atolls where the crossover date preceded first settlement and those where it did not, something that can be used to test WRD's suggestion that the changing sea level influenced the pace of the peopling of the Pacific islands.

The area where positive dates are mapped extends from Tuvalu–Tokelau in the west through to the northern Cook Islands and includes the Line Islands of eastern Kiribati. There is a gradient in this area that shows a west–east increase from around 0 (± 110) to ≥ 300 yr, which could be interpreted as meaning that atolls such as Funafuti (Tuvalu), Atafu (Tokelau) and Tabuaeran (Kiribati) were colonised shortly after their crossover dates, and that they then became bases from which other atolls in the area were colonised within the next few hundred years.

Figure 3 also shows two areas where colonisation preceded crossover dates. That in the south-east, defined by data from Reao and Temoe (French Polynesia), is only slightly negative and could well be within the error margins of (small) positive crossover dates. If this is the case, then it is possible that they also represent occupation shortly after crossover dates. Yet, as WRD acknowledged, the large

Figure 1. Late Quaternary (latest Pleistocene and Holocene) sea-level changes in the tropical Pacific. Tahiti sea-level data from Bard et al. (1996) and Papua New Guinea sea-level data from Chappell and Polach (1991), both datasets corrected by Woodroffe and Horton (2005). The Fiji sea-level data are model predictions refined with empirical data by Nunn and Peltier (2001) while the Bourewa (south-west Viti Levu Island, Fiji) point data are from Lal and Nunn (2011). The New Caledonia sea-level data are from south-west La Grande Terre, to which the timing of the fringing reef flat formation shown also refers (Yamano et al. 2014). The inset illustrates the concept of the "crossover date" (after Dickinson 2004).



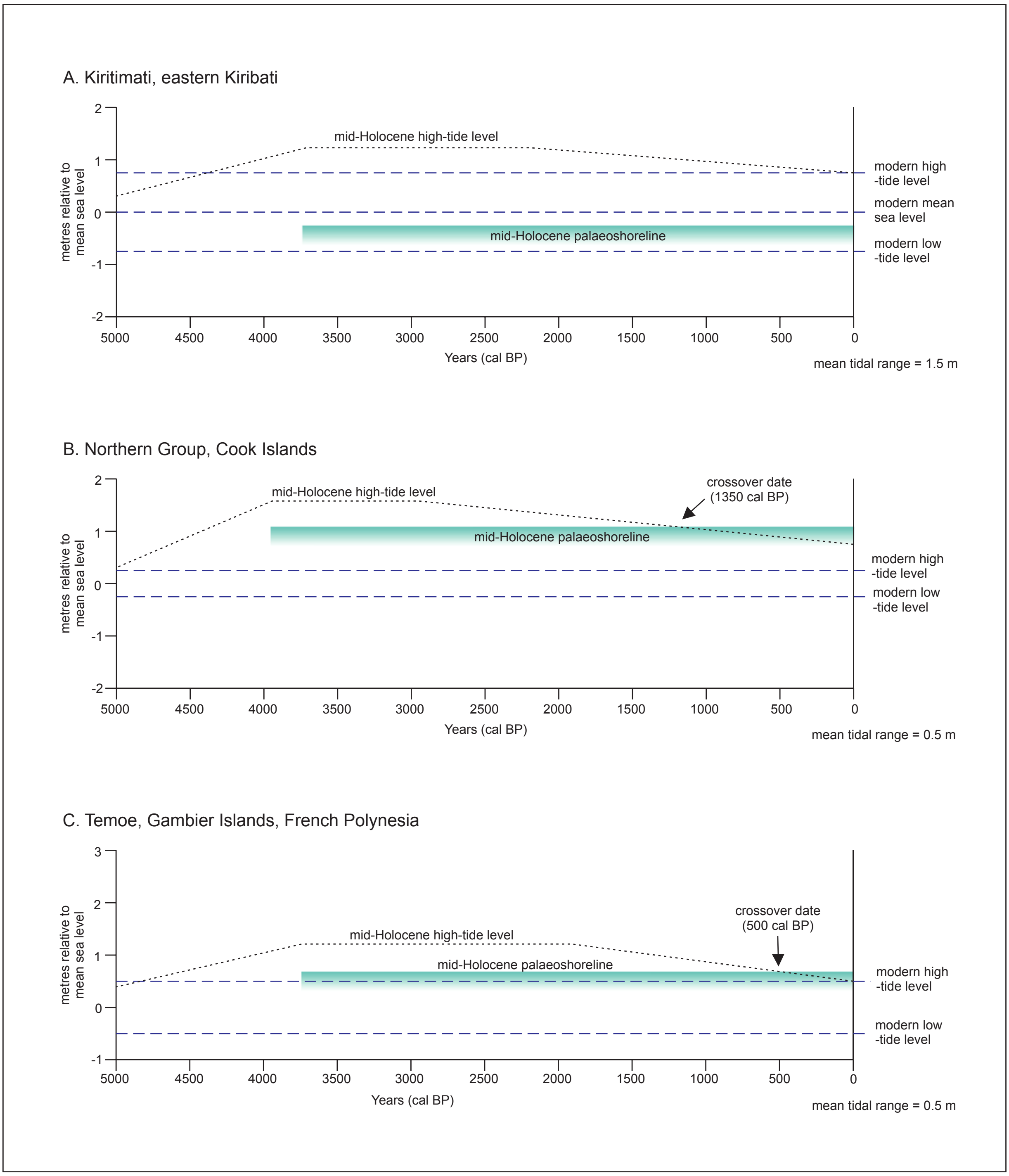
negative crossover dates for the north-west Pacific atolls (in the Marshall Islands and western Kiribati) are problematic for his model, because they show clearly that habitable land formed in these areas as much as 1670 yr (at Bikini) earlier than calculated crossover dates. WRD attributed this to the greater tidal range (~1.6 m) in this part of the north-west Pacific compared to elsewhere, that "would allow relict mid-Holocene paleoreef flats to project further above low-tide level, in positions more feasible for accumulation of unconsolidated sediment, at an earlier stage of sea-level decline" (Dickinson 2003: 497).

WRD also proposed that the existence of "voyaging pauses" in the colonisation of Pacific islands might be explained by variations in the pattern of crossover dates. His argument was that in those areas of the Pacific where the highstand endured longer (and the crossover dates were consequently later), prospective settlers might have been reluctant to try to occupy reef islands prone to flooding – and therefore delayed eastward colonisation until sea-level drawdown finally began. While there are currently insufficient data to test this idea – even in some cases to determine whether or not voyaging pauses existed – it is consistent with the general pattern shown in Figure 3.

IMPLICATIONS

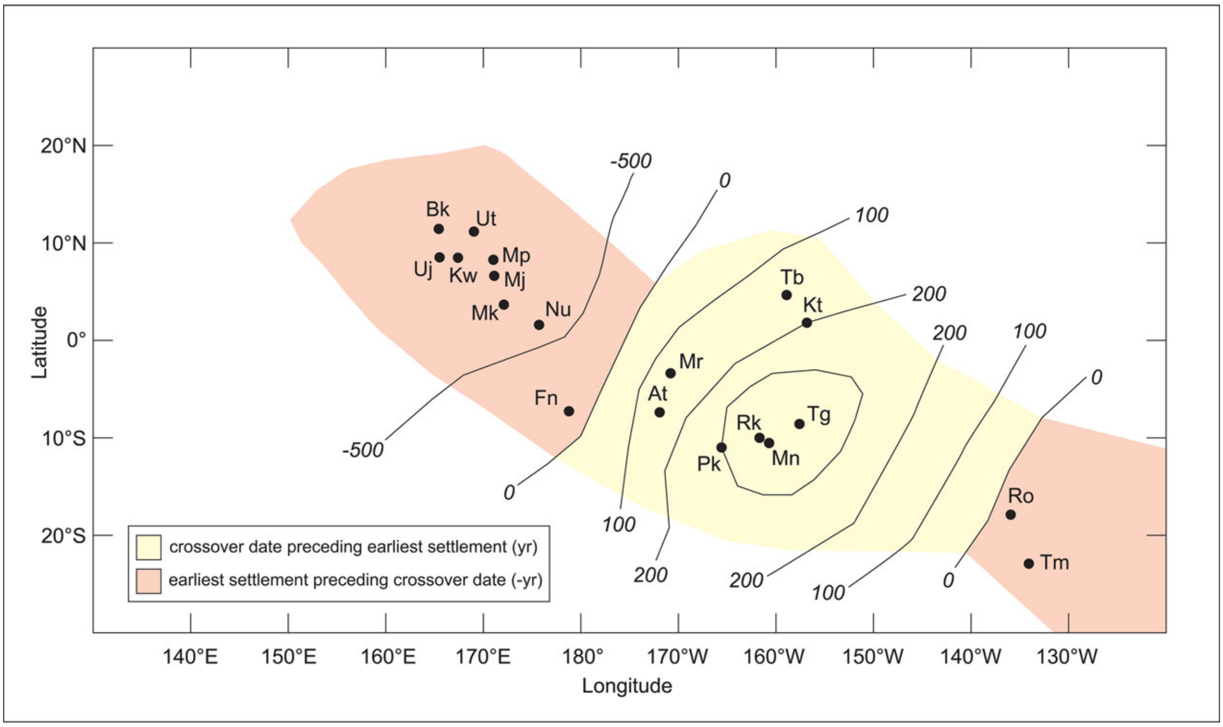
WRD's model of crossover dates being minima for reef-island colonisation does not work everywhere in the Pacific, but it may do so for atolls east of about 178°E. The

Figure 2. Data for Holocene sea-level change around tropical Pacific islands that were not used in Dickinson's (2003) analysis but are used in Figure 3. The crossover dates have been calculated for this study. (a) Kiritimati (Christmas) Island, eastern Kiribati (Line Islands group) (Woodroffe et al. 2012): mean tidal range = 1.5 m. Note that no crossover date can be calculated for Kiritimati because the mid-Holocene palaeoshoreline apparently never emerged above high-tide level. (b) Northern group (Pukapuka, Rakahanga), Cook Islands (Gray and Hein 2005): mean tidal range = 0.5 m. (c) Temoe Atoll (Gambier Islands) and north-west Tuamotu group, French Polynesia (Pirazzoli 1987; Pirazzoli and Montaggioni 1986): mean tidal range = 0.5 m.



data in Figure 3 are consistent with the idea that atolls such as Funafuti and Atafu were colonised shortly after their crossover dates, and that they then became springboards for colonisation of other atolls to the east and north-east within a few hundred years. If this is correct, it implies *either* that human discovery of atolls in the Funafuti–Atafu area at the time they became available for coastal settlement was fortuitous (or perhaps indicated by the flight paths of

Figure 3. A contour map of the calculated times between crossover dates and those for earliest settlement in the Pacific Islands (data in Table 1).



nesting birds) *or* that people were already sailing throughout this area and were, albeit at intervals of perhaps several decades, monitoring the state of these nascent landmasses with a view to their eventual settlement. Such a scenario is also applicable to the easternmost "negative" area in Figure 3, represented by data from Reao and Temoe, for if they in fact represent occupations shortly after their crossover dates (see above), the fact that these are comparatively recent – a function of the comparative lateness of the sea-level drawdown in this part of the Pacific – means that people were likely to already be sailing throughout this area at the time.

While the periodic evaluation of changing (coastal) environments of distant unoccupied islands could have been carried out by land-based people from islands to the west, it is worth noting that it may have been more readily carried out by sea nomads. Sea nomads of Indonesia are implicated in the settlement of Madagascar (Kusuma et al. 2015) while the group from which they derived – the Sama-Bajau – live and traditionally interacted within an ocean area of 3.25 million km^2 (Sather 1997; Stacey 2007). The idea that sea nomads played a significant role in the colonisation of Pacific islands has been mooted before (Di Piazza and Pearthree 1999; Nunn 2007) and might be regarded as a necessary preliminary to the intentional voyages of settlement that marked the Lapita occupation of south-west Pacific island groups.

The occupation of atolls in the north-west Pacific (Marshall Islands and western Kiribati) well before their crossover dates might be construed as a weakness in WRD's model, although, as more recent studies show (Kayanne et al. 2011; Yamaguchi et al. 2009), he correctly identified tidal range as one of the main reasons why islands formed on these reefs so comparatively early. Yet rather than sea-level change alone, it is now clear that island formation in such contexts also depended on the stage of development of offshore reefs that – combined with sea level – define "accommodation spaces" within which islands can form when there is adequate sediment supply. This model has been used to show that such islands formed while the sea level was still rising, during the highstand, and within the period of sea-level drawdown in the late Holocene (Kench et al. 2014).

CONCLUSIONS

There are many things yet to be learned about the peopling of Pacific Islands – "one of the grandest sagas of human history" (Dickinson 2003: 498). The intellectual challenge of understanding the pattern of Holocene sea-level change within the Pacific clearly captivated WRD (Dickinson 2000, 2001, 2004, 2013), but he was visionary in that he never lost sight of its implications for the "grand saga" (Dickinson 2003, 2009; Dickinson and Burley 2007). One of WRD's most recent papers making this connection reviewed "beach ridges as favoured locales for human settlement on Pacific islands" (Dickinson 2014); were he still with us, I have no doubt that WRD would now be working on a model about why people chose to occupy such environments, particularly when higher ground often existed inland. Was it merely to be "close to offshore reef resources and handy for water travel by boat" (Dickinson 2014: 264) or were there other reasons, related perhaps to the colonisers' views of terrestrial environments? WRD would have had some views on this.

In his 1995 Presidential Address to the Geological Society of America, WRD wrote that

> In a time of well-founded environmental concerns, the widespread impression that civilization is the only disjunct influence on an otherwise fixed tapestry of nature is a dangerous misperception that can lead to much folly. (Dickinson 1995: 1)

After this – what must have appeared to many as the pinnacle of his career – WRD then went on to turn his attention almost full-time to Pacific islands and it is likely for many readers of this volume that the research he subsequently carried out there will be his most enduring legacy. But he brought with him his belief about the importance of changing environments and made great efforts to inculcate other Pacific-focused scientists with this. His insights are there for all to understand.

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