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Friction zones in Lapita colonisation

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Introduction

A landscape can be conceived as composed of aggregates of factors that either impede or facilitate the movement of living organisms (Lee 1996). Landscapes that are hostile, fragmented, unfamiliar or difficult to reach are resistant to settlement and are colonisation 'friction zones', while those that are familiar, continuous, easy to reach and resource rich support species establishment. In this paper, we examine Lapita colonisation using the ecological concept of friction landscapes (i.e. Joly *et al.* 2003). We begin by reviewing the major points in the Lapita distribution where colonisation is argued to have been negatively impacted by the properties of a particular environment. To evaluate these, we examine, first, how colonisation 'patchiness' has in several cases been proposed and later modified during the course of Lapita studies, as a result of improved sampling and better understanding of the palaeolandscape. Second, we construct a simple friction model of Lapita colonisation to identify points where Neolithic settlement may have been difficult, and compare these 'friction zones' with those indicated by the known distribution of Lapita sites.

Neolithic colonisation of the Indo-Pacific region is conventionally partitioned into three geographic areas. The oldest movement from mainland Asia is suggested to have spread first through the Philippines and northern Borneo–Sulawesi, with another branch (based on differences in the earliest ceramic assemblages) occupying eastern Indonesia (Bellwood 2005; Spriggs 2007). At some point – palaeoecological opinion suggests human arrival at 4500 BP, while archaeological sites are more recent at 3500 BP – one or more of these groups ventured into the Pacific Ocean and colonised Palau, the Marianas and probably Yap (Dodson and Intoh 1999; Athens *et al.* 2004; Clark 2005). Another movement brought Austronesian speakers, known to archaeologists under the Lapita rubric, to the Bismarck Archipelago by 3400–3300 BP and as far east as Samoa by 2850 BP (Green 2002; Specht 2007).

The Lapita colonisation of the Bismarck Archipelago–Samoa area (Figure 1) is interesting as

its geography includes elements common to both of the other Neolithic colonisation events, with in situ non-Austronesian populations in the large and mostly intervisible islands of the Bismarck Archipelago–Solomon Islands, and uninhabited and generally smaller and increasingly remote landmasses at the eastern extent of Lapita in Fiji–West Polynesia. Archaeologically, Lapita is the best known of the Neolithic migrations and the combination of a comparatively rich material record and a diverse colonisation landscape could provide insight into the structure and pattern of the other prehistoric dispersals.

This is plausible, as Neolithic expansions in island Asia and the Pacific share a punctuated dispersal chronology (Anderson 2001), represented archaeologically by the spread of new types and styles of material culture over large areas. Similarly, the distribution of the three prehistoric expansions in each area is not geographically uniform, and they exhibit colonisation 'patchiness' at large and small scales. For example, the avoidance of small islands within an archipelago is proposed for Palau (Wickler 2001; cf. Clark *et al.* 2006), the avoidance of an archipelago is suggested by Sheppard and Walter (2006, cf. Felgate 2007) for the main Solomon Islands by early Lapita groups, and Austronesian colonisation either failed in, or avoided, Australia and inland New Guinea.

The reality of 'patchiness' in a colonisation distribution is important to evaluate, as the 'gaps', if real, point to the limits of Neolithic demographic, economic and transportation systems, and it informs whether maritime expansion and migration, for instance, proceeded mainly by long-distance leapfrogging, or demic wave-of-advance movement, or some combination of the two (Burley and Dickinson 2001; Anderson 2003; Diamond and Bellwood 2003; Fort 2003).

Lapita gaps: Past and present

Understanding of the geographic distribution of Lapita emerged gradually in the early 20th century with the discovery of distinctive 'dentate' ceramics at Watom in the west (Meyer 1909), New Caledonia in the centre (Piroutet 1917) and Tonga in the east (McKern 1929). The investigation of Lapita sites became an increasing focus of archaeological activity through the 1960s and 1970s, resulting in the discovery of sites in new archipelagos, including Reef/Santa Cruz (Green and Cresswell 1976), and Vanuatu (Hébert 1965; Hedrick and Shutler 1968; Garanger 1971), and additional Lapita deposits in Island New Guinea, New Caledonia and Fiji. The western and eastern margins of Lapita were extended to their current limits by the discovery of Lapita pottery on Aitape (Terrell and Welsch 1997), Manus (Kennedy 1981) and Samoa (Jennings 1974).

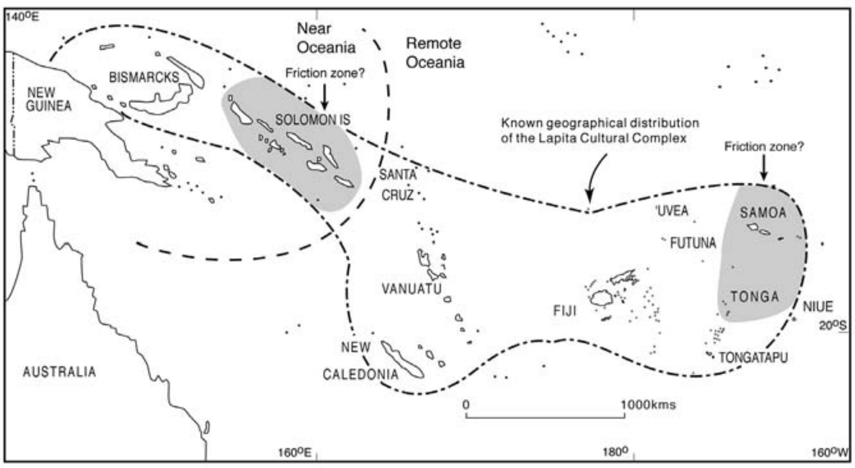

Figure 1. Map of the Lapita distribution and location of potential 'friction zones'.

By the 1980s, Lapita was not only recognised as a widespread cultural complex that stretched from Island New Guinea in the west to Samoa in the east (Golson 1971), but significantly was seen to represent the first population to occupy Remote Oceania (Spriggs 1984). Before the primacy of Lapita was established, there were several other ceramic styles (i.e. paddle impressed and incised and applied relief) that represented potentially different waves of prehistoric migration (Golson 1968:10). With such a crowded field of colonising groups, geographic gaps in the Lapita distribution could be explained by the initial settlement of an area by one of the 'non-Lapita' ceramic cultures. Once the chronological position of Lapita was clarified, such an explanation was no longer tenable. However, the presence of non-Austronesians in Near Oceania (Bismarck Archipelago–Solomon Islands) since the late-Pleistocene presents an analogous situation in which the success of Lapita colonisation might have been controlled by the strength of the indigenous response to incoming migrants.

Nonetheless, ongoing research has tended to diminish the size and extent of gaps in the Lapita distribution, with new sites recorded in Vanuatu (Bedford 2006), the Loyalty Islands (Sand 1995) and the Western Province of the Solomon Islands (Felgate 2003). At the same time, more Lapita sites were also being found in Fiji and Tonga (Burley *et al.* 2001; Clark and Anderson 2001), and the tally of Lapita sites in Island New Guinea has continued to grow (Specht and Torrence 2007; Summerhayes 2007).

A key to much of this success has been the recognition of factors that have transformed palaeolandscapes, particularly tectonic and volcanic activity, along with sea-level change (Dickinson and Burley 2007). The exemplar is Samoa which has a single Lapita site removed by tectonic subsidence 4 m below its original position, so that it is now underwater (Dickinson and Green 1998). Groube (1971:279) had earlier claimed that the absence of Lapita in Samoa after 'thorough archaeological examination' was real, although he did not discuss why Lapita colonisation should have failed to reach Samoa.

The increasing number of Lapita sites, coupled with improved understanding of the palaeolandscape, provides fertile ground for refining models of colonisation, since variability in the size, number and location of sites across an island or archipelago might well result from landscapes that were unfamiliar and difficult to occupy prehistorically (Rockman and Steel 2003). Such 'friction zones' or 'gaps' in the Lapita geography have been recently proposed for the central Solomons and the northern Tonga–Samoa region (Figure 1).

Sheppard and Walter (2006:48) argue that during the earliest phase of Lapita expansion, the main Solomons were entirely leapfrogged, with migrants travelling directly from Island New Guinea to the Reef/Santa Cruz Islands. The 'leapfrogging' pattern of movement of early Lapita colonists is thought to be the result of negative and positive factors. On the one hand, the already established population in the Solomons inhibited early Lapita occupation, and on the other, the discovery that uninhabited islands east of the main Solomons held dense and easily accessible marine and terrestrial resources encouraged long-distance movement and avoidance of the main Solomon Islands.

In northern Tonga and Samoa, the number of recorded Lapita sites is much lower than in southern Tonga (Burley 2007). The western end of 'Upolu has a single Lapita site, Mulifanua, that is submerged from flexural subsidence of the lithosphere under volcanic loading. Active volcanism during the late Holocene has also affected site preservation and visibility on the large islands, as has colluvial infilling of valley floors (Green 2002:132). Subsidence is much less on other islands in the Samoa group (e.g.Tutuila), but except for Mulifanua, no other Lapita settlements have been found, despite large-scale investigations associated with development (Addison and Morrison In press).

Across the 71 islands of Vava'u in northern Tonga, only five Lapita sites have been identified, and all are small and cover no more than 1500 m^2 (Burley 2007). The distribution of late-ceramic plainware sites is also relatively sparse in northern Tonga. This scenario is in striking contrast to central and southern Tonga, where the density of ceramic sites suggests rapid population expansion during Lapita and post-Lapita phases (Burley *et al.* 2001; Burley 2007). Burley (2007:196) notes that the fading Lapita presence in Vava'u, and by extension Samoa, reflects the fact that these islands are the 'frontier periphery' of Lapita colonisation (Burley 2007:196). Addison and Morrison (In press) go further and suggest that colonisation of Samoa was beyond the sustainable limits of Lapita expansion, and the archipelago was not settled permanently until c. 2400 cal. BP.

In the following sections we explore the geographic relationship between islands in the Lapita sphere to identify which island groups might have been 'unfamiliar' friction environments that could have slowed, restricted or redirected migrant movement.

The geography of Lapita expansion

Migrant frequency and volume have been shown to decrease as distance increases (Ravenstein 1882; Lee 1996). Translated to oceanic settings, large islands separated from one another by small water gaps should be colonised more quickly than small and remote islands. This might not happen when the coastal niches of large islands are already occupied by in situ populations, or where landscapes are subject to frequent natural catastrophes (tsunamis, volcanic eruption), or where environments are associated with high mortality from diseases, such as malaria. In such cases, large islands might still be occupied to some extent, settled by colonies in peripheral locations – for instance, on small islands adjacent to the mainland.

As simulation of colonisation indicates that inter-group contact, particularly for non-related marriage partners, was essential to demographic success (Moore 2001), it is important to note that the existence of non-Austronesian groups in the Bismarck Archipelago–Solomons region might well have been a 'positive', rather than a 'negative factor' in the establishment of at least some Lapita colonies. Integration between migrants and indigenous groups would provide both demographic support for the generational growth of migrant communities and access to coastal and inland resources. The almost complete absence of archaeological knowledge about the nature of Lapita and non-Lapita interaction anywhere in the Bismarcks–Solomon Islands means that we cannot yet estimate either the significance or the sign (positive or negative) of prehistoric interaction in relation to Lapita colonisation (Pawley 2007:40–42).

The facility with which prehistoric people could reach new lands is a function, among other factors, of island number, size, height, distance, seafaring skills and technology, and the particular wind, current and seasonal weather patterns around each landmass.

As a first step to modelling Lapita friction zones, a total of eight physical and distance variables were calculated. The definition of 'large island' and small 'water gap' is naturally problematic (e.g. Specht 2007). For the purpose of our analysis, an island area of 250 sq km was considered 'large'. Tongatapu, for example, has an area of 260 sq km and was the focus of an early Lapita occupation (Burley 2007). We know that Lapita groups occupied islands with an area less than 250 sq km, but in the West Pacific, where the earliest Lapita sites are found, many such islands were either close to, or were part of, an archipelago with an island area of 250 sq km or more.

'Large' islands as defined above are common across the known Lapita distribution and its margins, with the area from southeastern New Guinea to Niue having some 52 'large' islands (Table 1). The total includes those where a Lapita presence has not yet been recorded, but

which lie on either the western (Karkar, Umboi, Long) or eastern (Niue) fringes of the current distribution (Table 1).

The latitude and longitude of the 'large' islands was recorded using the Google Earth program using the approximate island centre as a reference point. Land area (square kilometres) and maximum height (metres above sea level) were also recorded (Kennedy 1974; Carter 1984; Douglas and Douglas 1989), as these values correlate approximately with geological and environmental diversity (Table 1). For instance, Rennell, Tongatapu and Niue are in relative terms, small (260–630 sq km) and low (73–154 m asl) limestone islands.

To estimate the degree of landscape 'fragmentation', we counted the total number of 'large' islands within c. 200 nautical miles (370 km) of each of the 52 'large' islands (measured from any point on the coastline of an island using the 'ruler' function in Google Earth), and the number of separate archipelagos with an island of 250 sq km area within 200 nm of a large island. A value of 200 nm for practical Lapita voyaging in the Indo-Pacific is a reasonably conservative figure, based on Neolithic long voyages in excess of 400 nm to reach Palau from the Philippines, and to reach Fiji from southern Vanuatu (440 nm), but it does not take into account specific wind and current conditions, which would require a more detailed analysis (i.e. Irwin 1992; Di Piazza *et al.* 2007). The Mariana Islands are greater than 1000 nm from the Philippines and suggest the possibility of Neolithic voyages much longer than 400 nm, but they may have been settled by island hopping from Palau to Yap (230 nm), and then from Yap to Guam (420 nm), which spans the practical-to-difficult voyaging range suggested here. The 200 nm value is also within the approximate voyaging distance needed to reach Ndende (Santa Cruz) from the Solomon Islands (San Cristobel), and to travel from Ndende to northern Vanuatu.

The success of human colonisation lies ultimately in occupying terrestrial territory, with the great majority of habitable land in the Pacific Ocean contained in archipelago clusters (geologically, island arcs or volcanic hot spots). Locations from which it was feasible to reach several new island groups within a 200 nm zone could represent important migrant dispersal 'nodes'. In contrast, islands that could only be reached by voyages substantially greater than 200 nm are likely to have been harder to colonise in terms of seafaring and its demographic consequence – the transport of adequate numbers of migrants to ensure colony success. Therefore, the shortest distance separating a 'large' island from its closest 'large' neighbour was measured, as was the shortest distance separating each island from the closest distinct archipelago.

Variables were standardised by taking the raw value and subtracting the mean, and dividing the total by the standard deviation. The standardised variables were analysed with multidimensional scaling (MDS) and the results evaluated with hierarchical cluster analysis (HCA) using SPSS 13.0 software. MDS attempts to find the structure in a set of distance measures between cases so that the Euclidean distance between points in an MDS plot reflects the actual dissimilarities between cases. The effectiveness of the procedure in representing the variance of the scaled data against the inter-point distance is measured by the RSQ (squared correlation index) statistic. RSQ values are the proportion of variance in the scaled data that is accounted for by the corresponding distance between cases in the MDS plot. RSQ values ≥ 0.6 are considered acceptable. In short, the distance between islands in the MDS plots reflects their similarity/dissimilarity.

Three MDS analyses were run. The first examined the relationship between location (latitude and longitude), land area and maximum height above sea level to explore island variability. The second MDS examined landmass fragmentation and archipelago accessibility using four variables (number of large islands within 200 nm, number of distinct island groups within 200 nm of a large island, distance from a large island to the nearest 'large' island, and distance from a

Table 1. Islands with an area greater than 250 sq km used in the statistical analysis.

Name	Region	Area (sq km)	Latitude (S)	Longitude (W)	Height (m)
Mussau	Mussau	400	1.257	149.353	650
Manus	Admiralty	1639	2.56	146.582	720
Karkar	PNG-Coast	400	4.381	145.585	1660
Long	PNG-Coast	500	5.209	147.703	1158
Umboi	PNG-Coast	777	5.392	147.563	1655
New Britain	New Britain	37736	5.441	150.431	2500
New Hanover	New Hanover	1190	2.328	150.162	957
New Ireland	New Ireland	9600	3.198	151.598	2150
Fergusson	Entrecasteaux	1437	9.313	150.394	2072
Goodenough	Entrecasteaux	687	9.204	150.146	2566
Normanby	Entrecasteaux	1040	10.126	151.114	1100
Tagula	Entrecasteaux	866	11.310	153.283	806
Trobriand	Entrecasteaux	267	8.366	151.834	55
Woodlark	Entrecasteaux	873	9.743	152.469	225
Bougainville	Solomons	9317	6.115	155.188	2792
Buka	Solomons	682	5.155	154.381	365
Choisel	Solomons	2538	7.456	156.598	1067
Guaudalcanal	Solomons	6475	9.369	160.100	2447
Kolombangara	Solomons	688	7.592	157.446	1768
Malaita	Solomons	3885	9.060	161.051	1433
Maramasike	Solomons	481	9.341	161.281	518
New Georgia	Solomons	3365	8.197	157.396	860
Rendova	Solomons	411	8.330	157.182	1060
Rennell	Solomons	630	11.385	160.169	154
San Cristobel	Solomons	3191	10.358	161.529	1250
Santa Isabel	Solomons	4660	8.036	159.674	1219
Vangunu	Solomons	509	8.383	157.598	1082
Vella Lavella	Solomons	629	7.446	156.391	808
Ndende	Reef/Santa Cruz	506	10.436	165.565	550
Ambrym	Vanuatu	678	16.151	168.711	1270
Aoba	Vanuatu	402	15.236	167.501	1496
Efate	Vanuatu	900	17.406	168.243	647
Epi	Vanuatu	445	16.437	168.137	833
Erromango	Vanuatu	881	18.509	169.869	886
Gaua	Vanuatu	328	14.171	167.316	797
Maewo	Vanuatu	304	15.111	168.810	811
Malakula	Vanuatu	2041	16.223	167.323	879
Pentacost	Vanuatu	491	15.456	168.114	947
Santo	Vanuatu	3885	15.225	166.571	1879
Tanna	Vanuatu	550	19.302	169.199	1084
Vanua Lava	Vanuatu	334	13.505	167.291	946

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Name	Region	Area (sq km)	Latitude (S)	Longitude (W)	Height (m)
Grande Terre	New Caledonia	16750	21.229	165.272	1618
Lifou	New Caledonia	1150	20.582	167.139	85
Mare	New Caledonia	650	21.322	167.592	129
Kandavu	Fiji	407	19.052	178.134	660
Taveuni	Fiji	268	16.508	179.576	1241
Viti Levu	Fiji	5534	16.346	179.133	1032
Vanua Levu	Fiji	10390	17.486	178.088	1224
Tongatapu	Tonga	260	21.111	175.116	82
Upolu	Samoa	1100	13.560	171.448	1143
Savai'i	Samoa	1820	13.377	172.247	1858
Niue	Niue	264	19.403	169.520	73

See text for data sources. Note that the placement of Buka and Bougainville in the Solomons reflects their proximity to the islands of the Solomon group, rather than their contemporary political status.

large island to its closest inter-archipelago neighbour). The third MDS study combined all of the variables to assess which islands might have been particularly resistant to Lapita colonisation.

MDS results

1. Island location, area and height

The first MDS plot (RSQ=0.985) was largely influenced by latitude, longitude and island area, with New Britain as an outlier due to its large size, which is more than twice that of any other island (Figure 2). Islands with an area more than 1800 sq km are located through most of the Lapita distribution, including the Bismarcks, Solomons, Vanuatu, New Caledonia, Fiji and Samoa. The smallest of the 'large' islands in area and height are the uplifted limestone islands of Mare, Lifou, Tongatapu and Niue. Both Vanuatu and the Solomons have numerous islands of more than 250 sq km, including some very large islands such as Santo, Guadalcanal and

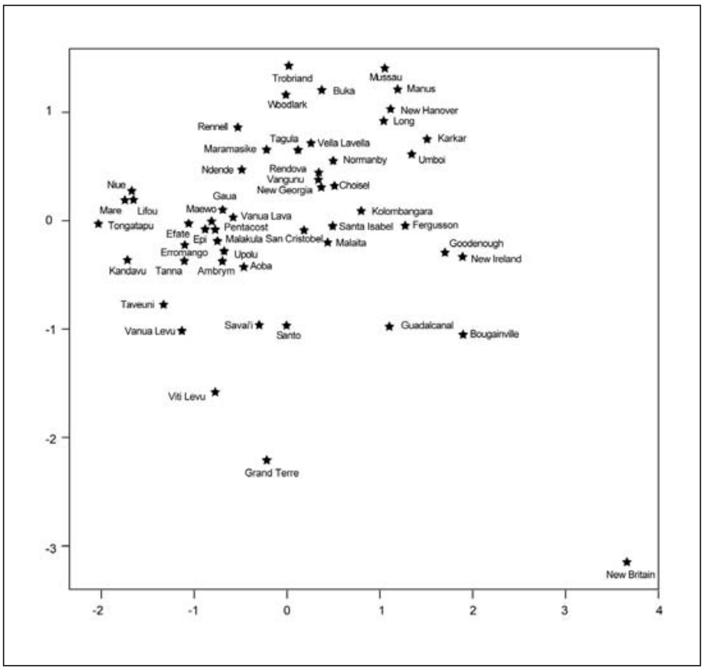

Figure 2. MDS plot of 'large' island location, area and height.

Bougainville (Buka and Bougainville are geographically part of the northern Solomon Islands). These two archipelagos are clearly 'rich' in substantial landmasses and might be expected to have a more complicated history of internal colonisation than islands that are smaller or more remote from neighbouring clusters of large islands.

2. Landscape fragmentation and relative accessibility

The second MDS analysis (RSQ=0.978) considered the fragmentation or accessibility of the different island landscapes encountered by Lapita colonisers by using a value of 200 nm as a nominal voyaging range within which colonisation could have proceeded rapidly given the availability of suitable 'large' islands.

The plot (Figure 3) shows three groups and three outliers (Ndende (Santa Cruz), Tongatapu and Niue). Group 1 is composed of islands within 200 nm of four to eight large islands, and predominantly within 130 nm of another archipelago. These islands should have been reached relatively quickly from adjacent landmasses during Lapita colonisation. Several of the western islands (New Ireland, New Britain, Buka, Woodlark and Manus) are within 200 nm of three different island groups. As these islands are connected potentially to almost as many external large islands as internal, they are likely to have had complicated exogenous migrant sequences.

The second group contains islands that are within 200 nm of nine to 13 other large islands and within 40 nm of another 250 sq km island. The group includes all of Vanuatu and most of the Solomons. These islands are reasonably distant, however, from other island groups (130–330 nm). Once reached, colonists were likely to have had frequent interactions within these two archipelagos and a lower frequency of external movements.

The only island in the 'large' category between the Solomon Islands and Vanuatu is Ndende, which is an outlier in the MDS plot, as it has only four large islands around the 200 nm radius (all are in adjacent island groups). From the Bismarcks to the end of the main Solomon Islands, any large island could be reached by a voyage of 100–150 nm, while the inter-archipelago distance to and from Ndende increases to 200–220 nm. If Ndende and nearby smaller islands were colonisation 'nodes' to which Lapita groups regularly travelled en route to Vanuatu, New Caledonia and islands further east, we should expect to find evidence of numerous large sites with evidence of abundant imports from the west.

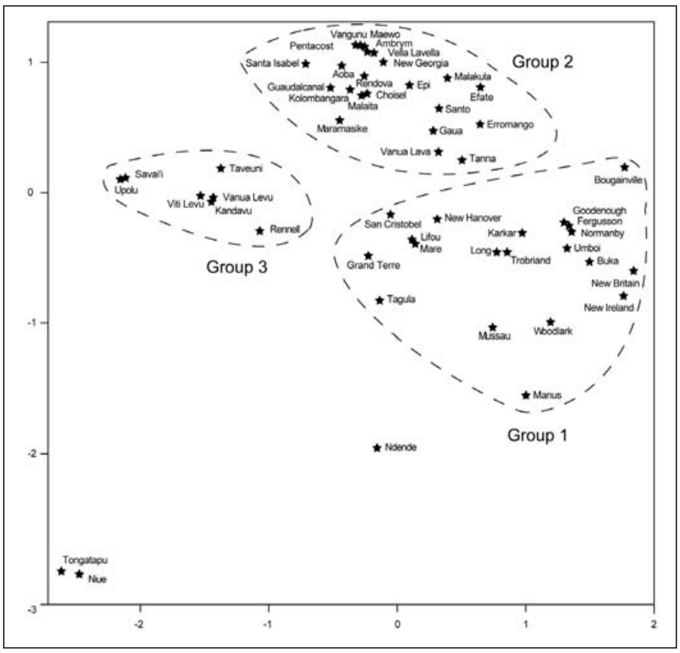

Figure 3. MDS plot of landscape fragmentation and archipelago accessibility. See text for discussion of Group 1, Group 2 and Group 3. Note the outlier position of Tongatapu and Niue.

A test of the argument advanced by Sheppard and Walter (2006) for Lapita avoidance of the Solomons would be a large-scale study of sherd composition from early Lapita assemblages in the Reef/Santa Cruz which demonstrated that imported pottery, like much of the obsidian, was only brought from locations west of the Solomon Islands. However, if a proportion of imported ceramics was found to have been made in the Solomons, that would support the possibility of incremental Lapita movement through the Solomon chain, rather than archipelago avoidance.

The third group consists of Fiji–Samoa and Rennell. These islands are within 100 nm of one to five 'large' islands, but are increasingly distant from any other island group (305–460 nm). Lapita colonists reaching these islands found themselves in an increasingly fragmented environment where there were fewer large islands and greater distances between island groups. Tongatapu and Niue are extreme outliers, as they are, in relative terms, remote from another large island, the closest more than 300 nm away. However, Tongatapu has numerous small islands in its vicinity, including several of volcanic origin, that give the archipelago greater environmental diversity and inter-island accessibility than Niue.

3. Familiar and unfamiliar landscapes

Combining the two sets of variables in the final MDS analysis (RSQ=0.954) shows that in island terms, the large area of New Britain and small dimensions of Niue and Tongatapu are highly anomalous compared with the islands typically encountered by Lapita colonists (Figure 4). A dispersed group (Group 1) contains islands to the west of the Solomons that can be reached from one or more adjacent island groups within 100–130 nm, highlighting the relative continuity of the island landscape for human colonisation. The tighter clustering in Group 2 emphasises the similarity between the Solomon Islands and Vanuatu as island-rich and internally accessible landscapes, the main difference being the sizeable water gap separating the southern Solomons from northern Vanuatu, and the presence of non-Austronesians in the Solomons. After Vanuatu, there are fewer large islands, and the Y-axis in the plot separates landmasses with a large area such as New Caledonia, Viti Levu, Savai'i and Vanua Levu that are nonetheless 'distant' (200 nm or more) from another archipelago.

Small and relatively remote islands include Ndende and the raised limestone islands of Rennell, Lifou and Mare. Niue and Tongatapu are extreme outliers, and they clearly represent

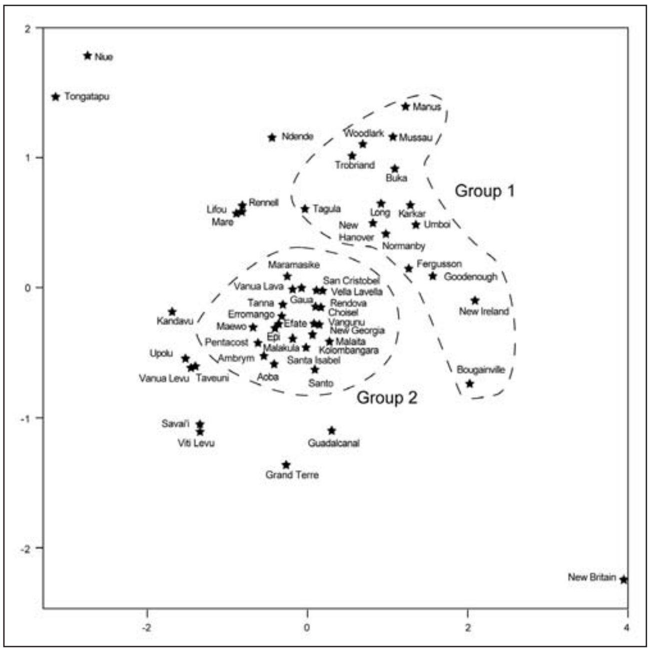

Figure 4. MDS plot of combined variables used in previous analyses. See text for discussion of Group 1 and Group 2. Note the outlier position of Tongatapu, Niue and New Britain.

environments that were in relative terms unfamiliar in their size, geology and level of 'remoteness' compared with islands in the west of the Lapita distribution. Such islands may have been potentially difficult landscapes for Lapita groups to initially colonise.

Discussion and conclusion

The pattern of Lapita colonisation taken from the existing distribution of sites suggests significant gaps in the Solomon Islands and in northern Tonga–Samoa (Figure 1). The absence of early occupation in the Solomon Islands has been taken to mean that poor relations with non-Austronesians were a factor that could not be surmounted by Lapita migrants. Thus, it is proposed that the establishment of Lapita colonists further east was made by leapfrogging the entire Solomon archipelago (Sheppard and Walter 2006) to reach the uninhabited Reef/Santa Cruz (Ndende) islands – a canoe voyage of more than 800 nm. In contrast, the low density of Lapita sites in northern Tonga and their absence, except for Mulifanua, in Samoa suggests demographic exhaustion combined with the difficulties of voyaging in an increasingly fragmented environment.

The assumption of long-distance voyages implied by the avoidance of the Solomons is somewhat at odds with a proposed slowdown in colonisation in northern Tonga–Samoa, as the ability to make maritime journeys of c. 800 nm must to some extent counter the effects of a low population density. An effective maritime reach of c. 400 nm would, for instance, be sufficient to connect colonising groups across the entire Fiji–West Polynesian area.

In view of the uncertainty concerning the reliability of archaeological site distributions, we suggest three criteria be used to further evaluate distribution 'gaps' and 'friction zones'.

First, the reliability of Lapita site distributions should be further tested in archaeological and palaeoenvironmental investigations. Felgate (2007), for instance, has argued strongly against the leapfrogging model for the Solomons, and instead makes the case that the geomorphology of the region, along with an apparent preference for Lapita habitation in the inter-tidal zone, has made the discovery of early sites difficult. In northern Tonga, a pollen record from Avai'o'vuna swamp on Vava'u shows that charcoal from human fires was deposited at 2890–2460 cal. BP (Beta-114012, 2620±80 BP) and continues in the record afterwards (Fall 2005), suggesting a constant and perhaps low-density Lapita presence on Vava'u, about 300 nm from Samoa.

Second, 'anomalous' site distributions can be compared with those of neighbouring areas for consistency. Like the Solomon Islands, the Bismarck Archipelago was already occupied before the arrival of Lapita groups. As Lapita groups were able to co-exist in some manner with non-Austronesians in the Bismarcks, it is unclear why they were unable to do so anywhere in the island-rich Solomons. In the case of Samoa, islands such as Niuatoputapu to the south (140 nm from Samoa) and 'Uvea in the east (200 nm from Samoa) have continuous Lapita-to-post-Lapita records (Kirch 1988; Sand 2000). Why would these small islands be settled, but not the large landmasses of Samoa?

Third, colonisation should be modelled using demographic, environmental and voyaging variables. Computer simulation of canoe voyaging is well established (Irwin 1992; Di Piazza *et al.* 2007), and there have been useful attempts to model the population characteristics and behaviour of colonising groups (e.g. Wobst 1974; Moore 2001) Consideration of the environmental variation encountered by prehistoric colonists (at large and small scales) is less developed, but it has the advantage of identifying locations that were in relative, and perhaps actual, terms 'unfamiliar' and difficult for migrants to initially occupy.

Our model of Lapita geography based on the physical characteristics of islands with a land area greater than 250 sq km does not support the view that the Solomon Islands were

entirely bypassed in early Lapita times, as in the archipelago 'leapfrogging' model (Sheppard and Walter 2006). The Solomons are an island-rich and diverse archipelago similar in many respects to Vanuatu. Analysis indicates that these two island groups are prime environments for internal colonisation, and therefore population mixing, because inter-island distances between the numerous large islands in them are generally much less than the distances required to reach a neighbouring archipelago. The avoidance of the Solomons in early Lapita times, if confirmed, would indicate a negative response to migrants that was both unusually strong and homogeneous across the entire archipelago. As noted above, the analysis of Lapita sites in the Reef/Santa Cruz group – especially the presence/absence of imported pottery sourced to the main Solomon Islands – will provide the key information to resolve the colonisation pattern and voyaging capacity of Lapita groups.

The geography of Fiji–West Polynesia was quickly established by Lapita migrants, as a pot sherd from the Mulifanua site in Samoa indicates transfer from the Udu Peninsula in Fiji, and obsidian from Tafahi in northern Tonga was taken to Lakeba in east Fiji (Best 1984; Dickinson 2006:119). The MDS analysis (Figure 4) adds further support to the idea that Lapita colonisation was slowed or redirected by the fragmented island landscape found when approaching the Andesite line. In comparative terms, Tongatapu, where the majority of Lapita sites in Tonga is found, is small, remote and unfamiliar. When Lapita colonists arrived c. 2900 years ago, sea levels were higher and land area would have been even less that of today (Dickinson and Burley 2007). Tongatapu is composed of limestone and although its soils have been enriched by deposits of volcanic ash, it has low relief, an absence of standing fresh water and depauperate terrestrial resources. Migrants could have responded to Tonga's 'unfamiliar' environment by travelling west to Fiji, or by engaging in long-distance voyages of exploration eastward. However, except for Niue, there are no 'large' islands within 1000 nm east of Tonga, and there is no archaeological evidence that Lapita people ever colonised Niue (c. 220 nm from Tonga). In contrast, return movement from Tonga to east Fiji (c. 200 nm) is archaeologically attested (Best 1984; Clark and Murray 2006).

The diminishing number of Lapita sites in northern Tonga and Samoa might result, then, from the reorganisation of migrant social and economic systems after reaching the 'unfamiliar' large island of Tongatapu – an event that we suggest resulted in a high rate of return movement to the more 'familiar' islands in the Fiji group (Figure 4). The demographic effect of a substantial rate of back migration could be countered by closer settlement spacing on Tongatapu. The numerous Lapita sites present along the old shoreline of the Fanga 'Uta lagoon may be consistent with such a settlement approach. The need for population connectivity during the early phase of Lapita arrival in southern Tonga would discourage, for a time, population fissioning and the permanent occupation of the Vava'u group and Samoa. In terms of material culture, a closer population spacing would facilitate the transmission of art styles, and it is notable that Lapita pottery designs in Tonga display strong continuity from early through to late sites (Burley *et al.* 2002:222). Rather than demographic exhaustion, our scenario favours the short-lived redistribution of migrants to the more 'familiar' environment of Fiji, followed by the gradual growth of permanent colonies on Tongatapu and Ha'apai and their spread to northern Tonga and Samoa. The presence of Lapita and post-Lapita populations on islands near to Samoa, such as 'Uvea, suggests a hiatus of 100–200 years before the permanent colonisation of Samoa. Thus, the relative 'unfamiliarity' of environments does appear to effect colonisation, but not by the 300–400 year interval proposed by Addison and Morrison (In press). Although our model does not directly inform us about the colonisation mode – whether it was by 'leapfrogging' or staged advance – the inference drawn from a delay in the occupation of Samoa is that colony

establishment from Fiji (+400 nm) and southern Tonga (+400 nm) was difficult.

We have assessed the Lapita distribution using the recognised boundary based on site/ceramic locations, but there are important questions about how robust that boundary actually is. If we were to include islands and archipelagos further east than Samoa in our statistical analysis it would confirm their 'unfamiliar' status, and none of these islands has any evidence of Lapita occupation. While the eastern edge of Lapita appears to be firmly set, how secure is the boundary at its western and northern ends, with mainland New Guinea, the Torres Strait, Australia and Island Southeast Asia? The majority of archaeological expeditions in Island Southeast Asia has examined cave and rock-shelter sites, and these locations – if the general experience in the western Pacific is anything to go by – tend not to contain the oldest ceramic deposits. The south coast of New Guinea is thought to be devoid of Lapita sites (Summerhayes and Allen 2007), although 'red slip' pottery about 2500 years old has recently been identified in the Torres Strait (McNiven *et al*. 2006). In simulations of one-way voyages from the Solomons to Australia, Irwin recorded a 100 percent success rate (Irwin 1992:143), and concluded that Lapita sites might be found on the northern Australia coast. Felgate provides tantalising evidence for this in the form of anomalous quartz-calcite temper in late-Lapita sherds from the Solomons that hint at an Australian connection (Felgate and Dickinson 2001; Dickinson 2006:115). It appears likely that the Lapita distribution will be extended in the future, and further geographic and environmental modelling should be applied to understand its complicated colonisation history.

Acknowledgements

GC studied under Atholl at Otago University and did his first fieldwork with him as an undergraduate during the Shag Mouth excavations in 1988–1989. In 1995, when I began a PhD at the ANU supervised by Atholl, academic collaboration and friendship developed. During and after PhD research, I assisted and worked with Atholl on projects in Fiji, Maupiti (Society Islands), Norfolk Island, Palau and Christmas Island (Indian Ocean), enjoying immensely the adventures, work and camaraderie. Like many colleagues, I have only benefited from exposure to an intellect that is relentless (at times remorseless), focussed, crisp and keen. I hope that in his much-deserved retirement the fly rod does not entirely supplant the trowel.

SB first worked with Atholl Anderson in 1984 as a field assistant during mid-winter excavations at Coal Creek in Central Otago, southern New Zealand. There was a large gap before our paths crossed again at the ANU in 1995 when Atholl was roped in as a PhD advisor. His extraordinary capacity for placing regional issues in the wider context shone as he ploughed through, literally overnight, my final draft. My only regret was that I had not consulted with him more often. Collegial fieldwork was planned for more tropical climes in 2000, but was cancelled due to the military coup in Fiji. There is hope yet that other opportunities will arise during his so-called 'retirement'.

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