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Prehistoric maritime migration in the Pacific islands: an hypothesis of ENSO forcing

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Abstract: Long-distance human migration across the Pacific Ocean occurred during the late Holocene and originated almost entirely in the west. As prevailing tradewinds blow from the east, the mechanisms of prehistoric seafaring have been debated since the sixteenth century. Inadequacies in propositions of accidental or opportunistic drifting on occasional westerlies were exposed by early computer simulation. Experimental voyaging in large, fast, weatherly (windward-sailing) double-canoes, together with computer simulation incorporating canoe performance data and modern, averaged, wind conditions, has supported the traditional notion of intentional passage-making in a widely accepted hypothesis of upwind migration by strategic voyaging. The critical assumption that maritime technology and sailing conditions were effectively the same prehistorically as in the historical and modern records is, however, open to question. We propose here that maritime technology during the late-Holocene migrations did not permit windward sailing, and show that the episodic pattern of initial island colonization, which is disclosed in recent archaeological data, matches periods of reversal in wind direction toward westerlies, as inferred from the millennial-scale history of ENSO (El Niño–Southern Oscillation).

Key words: Late Holocene, prehistoric seafaring, colonization pattern, remote Oceania, ENSO (El Niño–Southern Oscillation), wind reversals, Pacific.

Introduction

Initial human settlement of Remote Oceania – the Pacific Islands lying east of New Guinea and South East Asia (Figure 1) – occurred after the late-Holocene advent of the sail (McGrail, 2001). Different regions were colonized initially during the period 3500–600 cal. BP (Figure 1). In shaping this era of the most extensive pre-industrial maritime migrations, many variables were potentially influential, including demographic trends and cultural choices, but the critical, proximate, mechanism of migration was seafaring technology within its operating environment.

We review briefly here some recent arguments about Remote Oceanic sailing technology, and the chronological pattern of initial migration as it is known from radiocarbon dating of colonization sites and palaeoenvironmental sequences. We then propose an hypothesis that relates both of these to periodic changes in the oceanic sailing environment as the consequence of millennial-scale variation in El Niño–Southern Oscillation (ENSO) influences.

Prehistoric seafaring

Prehistoric seafaring depended on a combination of prehistoric navigational skills, vessel performance and sailing conditions. It was assumed traditionally that weatherly (windward-sailing) double canoes, astral navigation and intentional return-voyaging existed during the Remote Oceanic migrations and declined subsequently (Buck, 1938). Reaction to that scenario argued that most passages were one-way drifts and found land by chance (eg, Sharp, 1957), but computer-simulation showed that drifting could not reach marginal East Polynesia (Levison *et al.*, 1973). Modern experimental sailing in weatherly, double-hulled canoes then produced performance data (Finney, 1979; Lewis, 1994) that, in further simulated voyaging (Irwin, 1992), have supported a neotraditional hypothesis of planned seafaring according to a long-term voyaging strategy.

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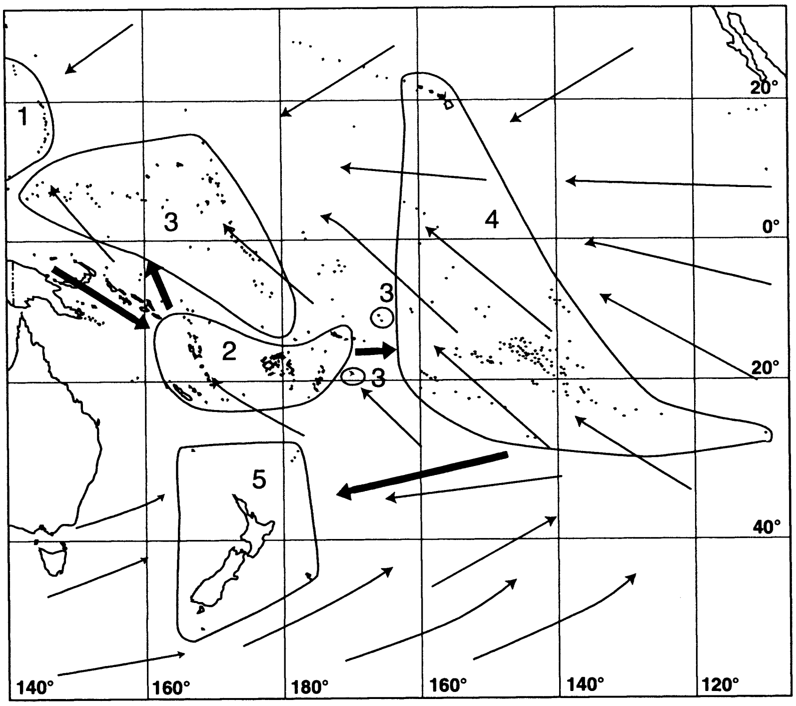

Figure 1 Prevailing (non-El Niño) wind directions (thin arrows), and episodes of migration (thick arrows) in Remote Oceania according to recent archaeological evidence: 1, colonization of West Micronesia at about 3400, or 4800–4500 cal. BP; 2, Lapita colonization in Remote Oceania 3100–3000 cal. BP; 3, colonization of Central and East Micronesia and marginal West Polynesian islands, 2200–2000 cal. BP; 4, colonization of East Polynesia 1250–1000 cal. BP; 5, colonization of South Polynesia 700–600 cal. BP

We accept here that a rudimentary but effective form of astral navigation is technically possible and might have existed prehistorically in Remote Oceania (Finney, 1979; Irwin, 1992), and do not consider that matter any further. It is, rather, the performance parameters of prehistoric voyaging canoes and the conditions in which they facilitated long-distance migrations that are problematical. We acknowledge that in the virtual absence of any direct archaeological evidence of voyaging canoes, none of the performance hypotheses that have been proposed can be ruled out, but to the extent that each of these is consequently reliant upon ethnographic data, we perceive substantial deficiencies in the neotraditional models.

Canoes such as *Hokule'a* (Finney, 1979, 2003) are not East Polynesian replicas, as they are usually described. Instead, they combine favourable elements from diverse Polynesian boatbuilding methods of the early European era and their speed (4–12 kts) and strong windward performance (pointing up to 75°, sailing full-and-by) are achieved by matching powerful synthetic rigging, lashings and other modern technology to working sails of about twice the area relative to waterline of eighteenth century East Polynesian vessels (Anderson, 2000a, 2001). In contrast, early historical observations show that interisland sailing in East Polynesia relied upon fair winds plus auxiliary paddling, the latter reflected in hull form and low freeboard (Sharp, 1957; Finney, 1979; Anderson, 2000a). The lateen sails, high freeboard, enclosed hulls and complex rigging that enabled some Micronesian and West Polynesian vessels to sail well to windward may not have reached Remote Oceania until the twelfth century (McGrail, 2001) although Campbell (1995) prefers local development), and was only arriving in the central Pacific during the European exploration period (Anderson, 2000a).

Linguistic reconstruction indicates that terms for double canoes developed only after settlement of West Polynesia, 3000 cal. BP (Blust, 1997), so earlier Remote Oceanic migrations were probably by outrigger canoe or raft. As there are no central Pacific terms for fixed masts or standing rigging (Pawley and Pawley, 1994), sailing rigs involved in the late-Holocene migrations probably used the simple Oceanic spritsail on spars held erect by running stays and sheets. This, the only rig type recorded initially in New Zealand and probably the Marquesas (Anderson, 2000a, 2003: figure 8), was a safe and flexible design but it offered almost no windward capability and therefore no facility to maintain a more or less continuous impetus to migratory voyaging against the direction of the easterly tradewinds. Some evidence of this constraint may be seen in the scarcity of long-distance interaction. Sourcing studies show that basalt and volcanic glass were moved around the central Polynesian archipelagos, where interisland distances seldom exceeded 400 km, but there is no evidence of interaction with distant islands such as New Zealand, Hawaii or Easter Island.

Migration sequence and climatic variation

Contrary to earlier reviews that emphasized continuity in voyaging, and substantially so in colonization, recent archaeological data show that initial colonization across previously uninhabited regions of Remote Oceania was strongly episodic at a millennial scale. The settlement chronology of West Micronesia extends to 3500–3300 cal. BP on archaeological data (Butler, 1994; Clark, 2004) but some palaeoenvironmental data suggest migration 4800–4500 cal. BP (Wickler, 2001; Athens and Ward, 2001). Initial expansion of the colonizing Lapita culture began 3100 cal. BP in eastern Melanesia (Specht and Gosden, 1997), reaching West Polynesia 100–200 years later (Burley and Dickinson, 2001), while Central Micronesia, and marginal Fiji–West Polynesia were reached 2200–2000 cal. BP (Intoh, 1997, Walter and Anderson, 2002).

In East Polynesia, initial archaeological dates ranged up to 2000 cal. BP, but recent radiocarbon dating of the earliest sites in each archipelago: Hane, Ha'atuatua, Anapua (Marquesas); Vaito'otia-Fa'ahia, Maupiti (Societies); Tangatatau (Cooks); South Point, Bellows Beach (Hawaii); Henderson 5 (Pitcairn group); and Anakena (Easter Island) indicates initial colonization 1250–1000 cal. BP (references in Anderson and Sinoto, 2002; Anderson, 2003). Colonization of South Polynesia (Figure 1) occurred 700–600 cal. BP (Anderson, 2000b, 2003) and reached the Subantarctic islands (Anderson, 2005). Archaeological ages of colonization in East and South Polynesia were challenged by older palaeoenvironmental data but are supported by more recent research (Anderson, 1995, 2002; McGlone and Wilmshurst, 1999; Athens *et al.*, 1999; Burney, 2002).

The recent archaeological and palaeoenvironmental data thus indicate that phases of colonization occurred over several hundred years and at intervals of about 400 to 1500 years apart; an episodic pattern that is also supported by linguistic data (Pawley, 1996). Such an episodic pattern is consistent with the operation of substantial constraints on maritime migration activity or, at any rate, success. If prehistoric voyagers had been able to sail in any direction they chose at almost any time, then it is difficult to see what could have prevented nearly continuous colonization of Remote Oceania, biogeographical differences between regions notwithstanding (Irwin, 1998, 2000). The punctuated pattern therefore appears robust, and it invites consideration of alternative explanatory hypotheses.

ENSO conditions

Two aspects of periodic change in the late-Holocene Pacific environment offer potential explanations of the archaeological pattern that are consistent with downwind sailing. Episodic emergence of atolls during the late Holocene (Kerr, 2003), may have shortened sailing distances or broadened voyaging targets. This was probably important to colonization of Central Micronesia, and of some areas within regions such as the Tuamotus in East Polynesia, but as no atolls emerged in the sea-gaps between the main Solomons and Santa Cruz, or between East and South Polynesia, and none of strategic consequence between West and East Polynesia, it is an explanation of limited utility in the present case.

A potential role of El Niño in migration has been discussed before using modern data (Bridgman, 1983; Finney, 1985), but these do not account for historical patterns in migration success. It is the palaeorecord of ENSO that provides the key to a new hypothesis.

By modern analogy (McPhaden, 1999) and paleoclimatic modeling (Clement *et al.*, 2000; Liu *et al.*, 2000) El Niño conditions during the late Holocene reduced the average strength of easterly tradewinds so that opportunities to sail east on westerly wind reversals increased with El Niño frequency. The plausibility of a migration model based on this proposition depends on showing that there were only infrequent opportunities to cross the main sea-gaps and that those occurred at archaeologically expected periods.

To test this point, we have examined recent wind-stress analyses of surface wind observations in the mid-Pacific (World Ocean Circulation Experiment (WOCE) Special Analysis Center, n.d.), because the West to East Polynesia sea-gap (1200 km), was the most difficult to cross, judging by the long pause (at least 1500 years) involved in colonizing East Polynesia. The data show that around 10–14°S winds are consistently northeast in normal and La Niña years (Figure 2, upper), but in a typical El Niño year the net wind in the same region for January and February is westerly, averaging 3–5 knots (1.5–2.5 m/s) (Figure 2, lower). Assuming no calms or headwinds intervened, conditions of this kind could carry a vessel from West to East Polynesia, at a mean speed of 1.5 knots over the ground, in about 22 days of fair wind sailing.

However, the zonal extent of summer westerlies in El Niño years is variable. They reached the Marquesas in the 1997–98 event (Figure 2, lower), but inspection of results from 1976 to 2003 shows that, on a monthly basis, net westerlies did not reach Tahiti in other strong El Niños (1982–83; 1992–93). This suggests that such events of the scale necessary to cross the West–East Polynesia gap are very infrequent in the wind-stress data, although we acknowledge that these do not extend sufficiently to determine frequencies of suitable events at a centennial scale or beyond.

ENSO periodicity and migration pattern

At a millennial scale, the longest continuous, high-resolution ENSO record comes from Laguna Pallcacocha, Ecuador (Moy *et al.*, 2002). Spectral analysis of laminated clastic deposits from this high-altitude site shows transition to modern periodicities by 5000 cal. BP, and major El Niño phases (Figure 3) that agree with terrestrial and fossil-coral isotope records from the central and western Pacific (Markgraf and Diaz, 2000; Woodroffe *et al.*, 2003; Graham, 2004; McGregor and Gagan, 2004). El Niño occurrence has varied during the last 5000 years from less frequent to over five times more frequent than today (Figure 3). Given that the strongest events occurred when El Niño frequency was highest, we argue that downwind voyaging to the east was most probable at such periods, although not necessarily during all of them. Capital and logistic costs of voyaging were high for small communities and it is probable that decisions to invest in such voyages were only taken after new climatic opportunities had been seen to persist or recur for a substantial period. One pertinent point in this regard is that the spatial extent of tropical drought seems to be correlated with the strength of El Niño (Lyon, 2004), so that difficult growing conditions in the western Pacific, and especially upon smaller islands as shown in modern ENSO events, might have provided some weight to decisions about resumption of voyaging in those conditions.

Comparison of ENSO and archaeological records indicates that migrations into new areas coincided with major El Niño frequency peaks (Figure 3): West Micronesia at either around 3500–3400 cal. BP peak or that at 4900–4600 cal. BP, and Remote Oceanic Lapita at 3100 cal. BP. Synchronized regional changes in pottery styles (Summerhayes, 2000) are correlated plausibly with additional eastward migrations during the 2900–2700 and 2600–2400 cal. BP ENSO frequency peaks. Migrations to East Polynesia occurred during the high-frequency episodes 1600–1100 cal. BP. Downwind voyaging to the west was most probable at low-frequency periods of El Niño activity when tradewind dominance resumed. Initial colonization occurred northwestward to central Micronesia in the interval 2400–2000 cal. BP, perhaps in the 2300–2200 cal. BP frequency trough (Figure 3).

Westward dispersal from East to South Polynesia during high-frequency El Niño conditions, 900–600 cal. BP, is anomalous in terms of the current hypothesis, but it occurred outside the tropical zone and therefore beyond the El Niño wind changes described here. Experimental voyaging has shown that subtropical easterlies in summer provide the best passage from East to South Polynesia (Finney, 1979; Irwin, 1992; Anderson, 2000a) and it is possible that the

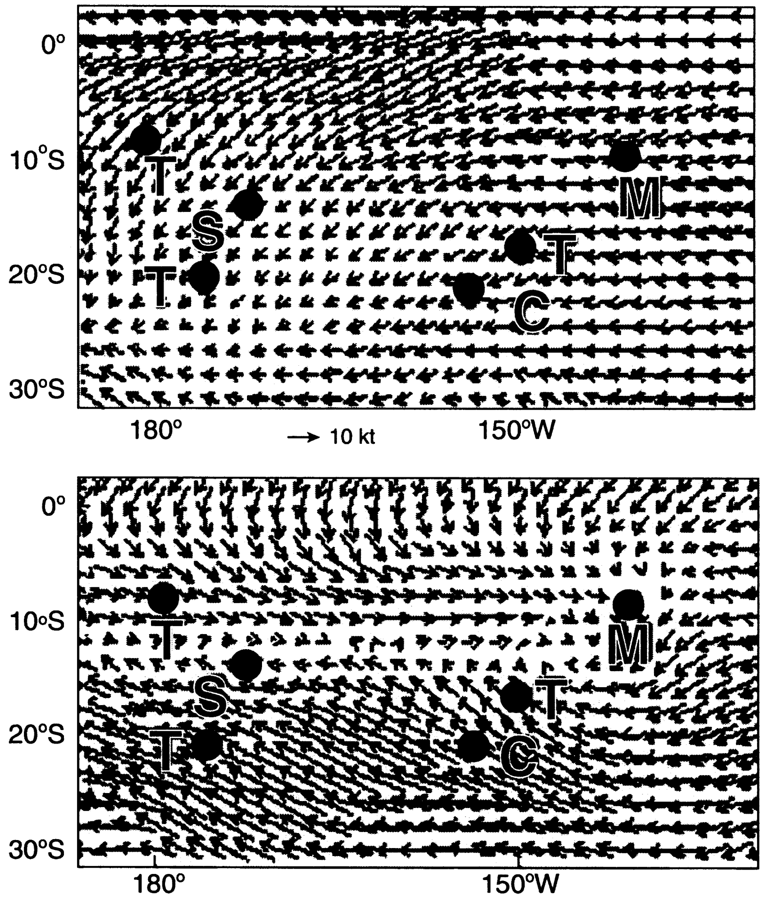

Figure 2 Monthly average wind-stress directions in the central Pacific (WOCE, Special Analysis Center, n.d.) during January of the La Niña year 1999 (above) and El Niño year 1998 (below). The small 10-knot scale-bar indicates approximate average wind speed, based on the stress vectors. Island groups around 180°. Upper: T, Tuvalu; S, Samoa; lower: T, Tonga; around 150° W; M, Marquesas; T, Tahiti; C, Cooks

strengthening of subtropical easterlies which occurs during El Niño episodes (Figure 2, lower), was a factor in the timing.

Discussion and conclusions

We have presented here, in preliminary form, an hypothesis that relates the late-Holocene punctuated pattern of initial migration across Remote Oceania to technical constraints on seafaring that were lifted periodically by ENSO-related variations in wind directions, longitudinal extent and persistence. Clearly, all aspects of this hypothesis require much additional research, not only on the particular databases involved in its formulation, but on the questions it raises.

For example, if our hypothesis is valid then the gap between earliest potential migration and current colonization data in

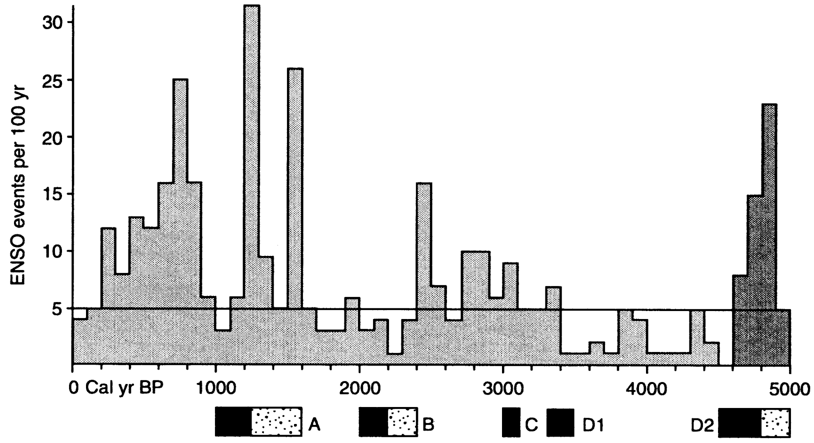

Figure 3 Late Holocene human migration and ENSO frequency. The solid line at 5 indicates threshold frequency to produce ENSO-band variance (data: NOAA/NGDC Paleoclimatology Program web site: http://www.ngdc.noaa.gov/paleo/pubs/moy2002, last accessed 19 October 2005). Migration phases: A, East Polynesia; B, Central Micronesia and marginal West Polynesia; C, Remote Oceanic Lapita; D1 and D2, West Micronesia by archaeological and palaeoenvironmental data, respectively. Migration phase bars show the range of early radiocarbon date medians as solid shading and the possible earlier range of migration (stippled) in the phase if ENSO activity was a major factor

most episodes (Figure 3) requires examination. Does it represent imprecision in dating ENSO frequency at Laguna Pallcacocha (Graham, 2004), and/or archaeological colonization, or a lag in cultural response to climatic change? Might it foreshadow earlier ages of initial colonization that match the major points of change in ENSO frequency (4900, 4600, 3400, 2400, 1600, 1000 cal. BP)? In respect of East Polynesia especially, the age of initial colonization has been a matter of prolonged debate (Kirch and Ellison, 1994; Kirch and Green, 2001; Anderson, 1995, 2003; Irwin, 1998) and although there is a consensus around the second half of the first millennium AD, opinions remain polarized within that span.

Similarly, an argument of technically constrained downwind migration implies both that there was a more limited capability to develop long-distance interaction networks in the Pacific than is commonly assumed (Weisler, 1997; Summerhayes, 2000), and that there was little or no need for change in maritime technology during the late-Holocene dispersal era up to about AD 1200. To what, then, were due the changes in marine architecture and sailing rigs, in progress during the European phase of exploration? If they represent the progressive expansion of Indian Ocean lateen-related technology across the Pacific, then why this innovation rather than other Southeast or East Asian maritime technologies?

Whether the ENSO hypothesis survives extended critical examination, it will serve to re-focus attention on some of the fundamental issues of maritime migration in Holocene prehistory.

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