Journal of Biogeography (*J. Biogeogr.*) (2008) **35**, 1–21

SPECIAL PAPER

Environmental setting of human migrations in the circum-Pacific region

Kevin O. Pope[1]* and John E. Terrell[2]

[1]*Geo Eco Arc Research, PO Box 78, Garrett Park, MD 20896, USA and* [2]*The Field Museum of Natural History, Department of Anthropology, 1400 South Lake Shore Drive, Chicago, IL 60605, USA*

ABSTRACT

Aim To assess the genetic and archaeological evidence for the migration of modern humans out of Africa to the circum-Pacific region and compare the migration patterns with Late Pleistocene and Holocene changes in sea level and climate.

Location Southern and eastern Asia, Australia, and Oceania.

Methods Review of the literature and detailed compilations of data on early human settlements, sea level, and climate change.

Results The expansion of modern humans out of Africa, following a coastal route into southern Asia, was initially thwarted by a series of large and abrupt environmental changes. A period of relatively stable climate and sea level from *c.* 45,000 yr bp to 40,000 yr bp supported a rapid coastal expansion of modern humans throughout much of Southeast Asia, enabling them to reach the coasts of northeast Russia and Japan by 38,000–37,000 yr bp. Further northwards, migrations were delayed by cold northern climates, which began to deteriorate rapidly after 33,000 yr bp. Human migrations along the coast of the Bering Sea into the New World appear to have occurred much later, *c.* 14,000 yr bp, probably by people from central Asia who were better adapted to cold northern climates. Cold, dry climates and rapidly changing sea levels leading into and out of the Last Glacial Maximum inhibited coastal settlement, and many of the sites occupied prior to 33,000 yr bp were abandoned. After 16,000 yr bp, the sea-level rise slowed enough to permit coastal ecosystems to develop and coasts to be re-colonized, but abrupt changes in climate and sea level inhibited this development until after 12,000 yr bp. Between 12,000 yr bp and 7000 yr bp there was a dramatic increase in reef and estuary/lagoon ecosystems, concurrent with a major expansion of coastal settlements. This early Holocene increase in coastal environments and the concomitant expansion of human coastal-resource exploitation were followed by corresponding declines in both phenomena in the mid-Holocene, *c.* 6000–4000 yr bp. This decline in coastal resources is linked to the drop in sea level throughout the Pacific, which may have caused the widespread population dislocations that ultimately led to the human expansion throughout Oceania.

Main conclusions Climate and sea-level changes played a central role in the peopling of the circum-Pacific region.

*Correspondence: Kevin O. Pope, Geo Eco Arc Research, PO Box 78, Garrett Park, MD 20896, USA.
E-mail: kpope@starband.net

Keywords

Archaeology, climate change, Holocene, *Homo sapiens*, human genetics, human migrations, palaeoenvironments, Pleistocene, sea level.

www.blackwellpublishing.com/jbi
doi:10.1111/j.1365-2699.2007.01797.x

INTRODUCTION

Recent advances in the understanding of the nature and timing of modern human (*Homo sapiens*) migrations out of Africa, coupled with new and more detailed insights into Late Quaternary changes in climate and sea level necessitate a reappraisal of the peopling of the Pacific margin from Australia to the Americas. In this paper we examine the environmental setting of human migrations in the circum-Pacific region from the first appearance of modern humans in Asia and Australia *c.* 50,000 yr BP, to the spread of humans to North America and Oceania. Our focus is on changes in climate and sea level and their impact on human adaptations to the coastal zone. The impact of climate and sea-level change on early human migrations in this region is well documented (e.g. Bird *et al.*, 2004; Forster, 2004), but in this paper we attempt a more comprehensive assessment of the environmental data and their integration with the archaeological record.

Throughout this analysis we apply the new radiocarbon 'estimation' curve (NotCal04) for radiocarbon dates in the 20,000–50,000 yr range used by Mellars (2006a) in his study of modern human migrations in Europe. For younger radiocarbon dates, we cite calibrated ages using the CALIB (rev. 5.0.1) program (Stuiver & Reimer, 1993). The NotCal04 curve, as well as other published correction schemes (Fairbanks *et al.*, 2005; Weninger *et al.*, 2005; Turney *et al.*, 2006), indicates that radiocarbon dates of *c.* 30,000–50,000 yr BP have true ages some 4000–5000 years older. The precision of corrected radiocarbon dates in this range is controversial (e.g. Balter, 2006; Ramsey *et al.*, 2006; Turney *et al.*, 2006), and future work will no doubt refine the age estimates used in this paper. Nevertheless, there is a broad consensus that true ages in this time range are significantly older than the radiocarbon ages, and thus corrections are required to correlate environmental and cultural events.

PEOPLING OF THE ASIAN PACIFIC MARGIN

The out of Africa southern coastal hypothesis

Genetic evidence, both mitochondrial DNA and Y-chromosomes, strongly supports the hypothesis that modern humans first migrated out of Africa to Asia < 100,000 yr BP following a southern coastal route (Fig. 1) (e.g. Kivisild *et al.*, 1999, 2003; Quintana-Murci *et al.*, 1999; Cann, 2001; Ke *et al.*, 2001; Underhill *et al.*, 2001; Oppenheimer, 2003; Underhill, 2004). There have been a few critics of this 'Out of Africa Southern Coastal Hypothesis' (Cordaux & Stoneking, 2003), and specifics of the timing and whether or not there was more than one African migration into Asia are still debated, but there is a broad consensus that the southern coastal route played a major role in the dispersal of modern humans.

The more recent genetic studies indicate that the initial migration of modern humans into the Indian subcontinent was as late as 80,000–50,000 yr BP (Barnabas *et al.*, 2005; Macaulay *et al.*, 2005). The African ancestors of these south Asian colonizers may have been the Middle Stone Age coastal inhabitants of the Red Sea (e.g. Stringer, 2000), who first developed an adaptation to marine resources during the Last Interglacial, when seas were near their present level (*c.* 125,000 yr BP) (Walter *et al.*, 2000; Bruggemann *et al.*, 2004). Modern human remains from the nearby Afar region of Ethiopia date to *c.* 160,000 yr BP (Clark *et al.*, 2003), lending support to the hypothesis that these early coastal inhabitants were modern humans, and mitochondrial DNA studies indicate that the source area for the southern coastal migration was Ethiopia (Quintana-Murci *et al.*, 1999).

Firm archaeological evidence for an early migration of modern humans in the period 80,000–50,000 yr BP into southern Asia is lacking. There is evidence for a brief excursion of modern humans out of Africa into Israel (Skhul and Qafzeh caves) near the end of the Last Interglacial at 100,000 yr BP (Stringer *et al.*, 1989; Bar-Yosef, 2000), but this migration was not sustained, leaving a *c.* 50,000 year gap before modern humans returned to the Mediterranean coast. Middle Palaeolithic coastal sites are present on the Arabian side of the Red Sea (Petraglia & Alsharekh, 2003), but little is known of their age, resource exploitation, or affiliation with modern vs. archaic humans. Middle Palaeolithic sites are common in India (James & Petraglia, 2005), and while many have not been dated, most appear to be older than 100,000 yr BP. For example, along the west coast of India, Middle Palaeolithic artefacts are found in fluvial gravels stratified between coastal deposits that have been U-series dated to 50,000–70,000 yr BP and 75,000–115,000 yr BP (Baskaran *et al.*, 1986, 1989). Nevertheless, the re-deposited nature and new dates of *c.* 90,000–126,000 yr BP for the basal unit (Bhatt & Bhonde, 2003) suggest that these artefacts probably date to *c.* 100,000 yr BP or earlier. No *in situ* Middle Palaeolithic sites have been reported from above the 74,000-yr-BP Toba volcanic ash deposits in India (Acharya & Basu, 1993). There is a paucity of archaeological sites in India that have been dated to 100,000–50,000 yr BP, which parallels a similar temporal gap in hominid remains in south and East Asia (Stringer & Andrews, 1988; Jin & Su, 2000).

The earliest Late or Upper Palaeolithic sites in India date to *c.* 45,000–40,000 yr BP and are widely assumed to be from modern humans (James & Petraglia, 2005), although the earliest modern human remains in the region (from Sri Lanka) date to only 36,000 yr BP (Kennedy & Deraniyagala, 1989). A recent study using electrically stimulated luminescence (ESL) dating of faunal remains (teeth) from a multi-component site in Tamil Nadu, India, produced ages of *c.* 45,000–50,000 yr BP (Blackwell *et al.*, 2005), which may date the Upper Palaeolithic or terminal Middle Palaeolithic occupation of the site. Radiocarbon-dated ostrich shells from Upper Palaeolithic archaeological sites in central India produced corrected ages as early as 42,000 yr BP (Kumar *et al.*, 1988). In the upper Ganges Plain of north-central India, optically stimulated luminescence dating of sediments associated with bone and stone tools of a transitional Middle to Upper Palaeolithic type produced ages of *c.* 45,000 yr BP (Singh *et al.*, 1999; Tewari *et al.*, 2002; Srivastava *et al.*, 2003). Further afield, dates of

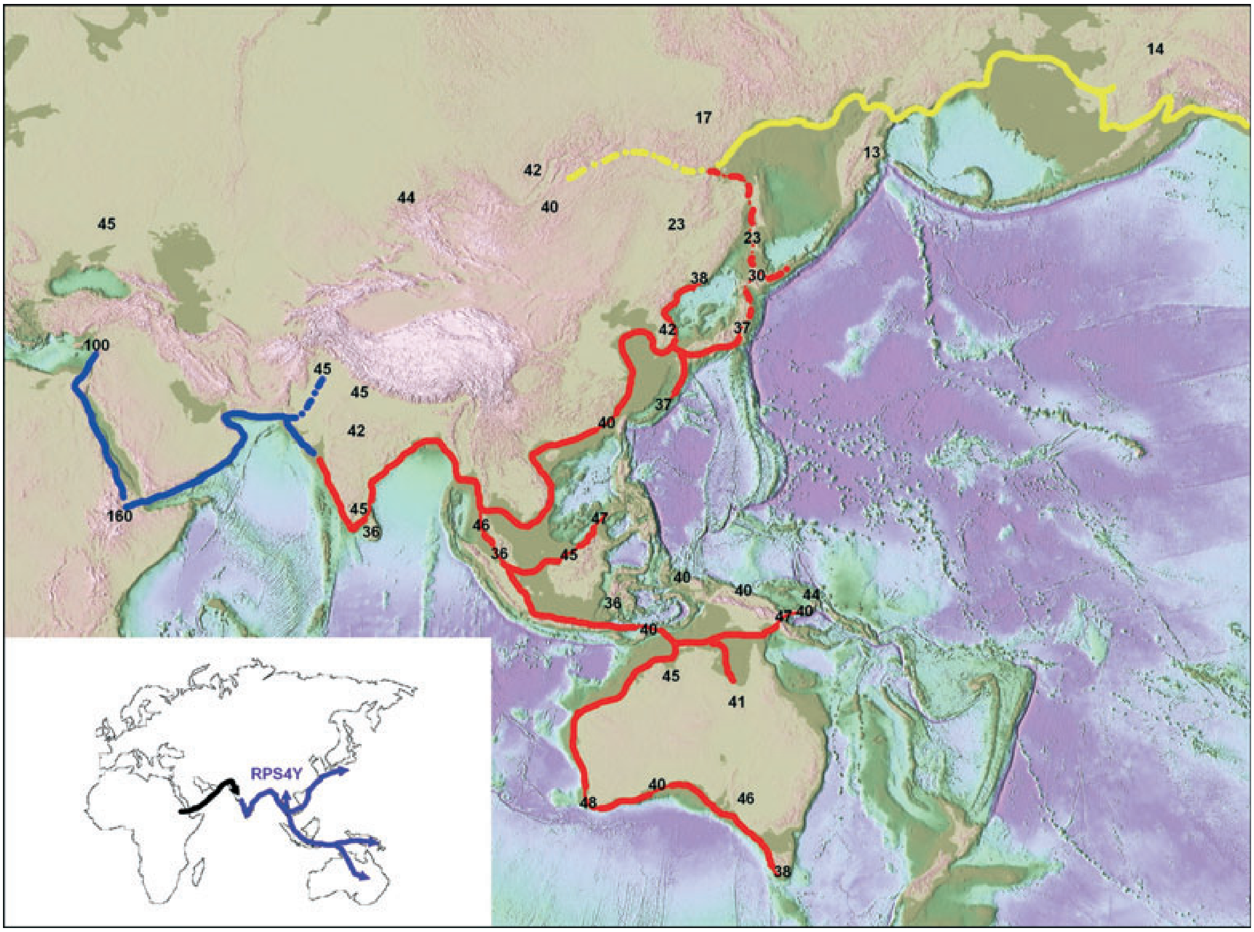

Figure 1 Map showing the early modern human migration route out of Africa into Asia and the New World. Shown are the ages (in thousands of years BP) of early modern human archaeological sites in the region. Initial migration (dark blue line) reached into the eastern Mediterranean and then stalled. A similar early migration into Asia is poorly documented, but may have begun prior to 50,000 yr BP, perhaps splitting into two branches, with the more speculative branch leading into central Asia. The southern migration route (red line) extended eastwards along the coast, splitting into a southern route ending in Tasmania and a northern route ending in Japan and northeast Russia. A later migration (yellow line), possibly originating in Central Asia, extended modern human occupations into eastern Siberia and on into Alaska and the New World. Dates are those cited in the text with others derived from tables in O'Connell & Allen (2004) and Gillespie (2002). The inset shows the migration route based on the distribution of the RPS47C711T genetic marker (M130 mutation), present today among Australians, New Guineans, Southeast Asians, Japanese and central Asians and thought to be a key marker for the early spread of modern humans (adapted from Underhill *et al.*, 2001 and Underhill, 2004).

45,000 yr BP are recorded for sites in northern Pakistan (Dennell *et al.*, 1992) and southern Russia (Anikovich *et al.*, 2007) with distinctly Upper Palaeolithic tool assemblages. It is not clear whether the differences in stone tools from these 45,000-yr-BP sites reflect regional stylistic differences or distinctly different (archaic vs. modern) *Homo sapiens* populations. Studies in Africa have shown that there are no distinct changes in stone-tool typologies that mark the emergence of fully modern humans (e.g. McBrearty & Brooks, 1999), and the flake stone tool assemblages from the earliest, presumed modern human sites in Southeast Asia (e.g., Simanjuntak, 2006) and Australia (e.g. Hiscock & Attenbrow, 2003) do not fit within the Upper or Middle Palaeolithic typology of Europe and western Asia (Mellars, 2006b).

If a migration of modern humans into southern Asia did occur as early as 80,000 yr BP, it too apparently stalled like the migration into the Levant, as there is scant evidence for modern humans in this region prior to 50,000 yr BP, save for some controversial dates of *c.* 60,000 yr BP from Java (van den Bergh *et al.*, 2001) and Australia (Roberts *et al.*, 1994, 2005). Recent DNA studies in India support this view in indicating that the initial migration from Africa was followed by a later eastward expansion *c.* 48,000–44,000 yr BP (Quintana-Murci *et al.*, 1999; Underhill *et al.*, 2000; Barnabas *et al.*, 2005).

The initial migration along the Asian Pacific coast

While the exact timing of the initial migration of modern humans into southern Asia remains uncertain, the archaeological dating of the entry into Thailand, Indonesia, the Philippines, New Guinea, and Australia is more secure (Fig. 1). Abundant archaeological data confirm the colonization of this region by *c.* 47,000 yr BP (Gillespie, 2002; O'Connell & Allen, 2004; Détroit *et al.*, 2004). This date of 47,000 yr BP agrees well with the genetic studies that suggest a late expansion of modern humans after 50,000 yr BP. Evidence for entry into Peninsular Malaysia, East Timor, Suluwasi, Molluccas, the Bismarck Archipelago (West New Britain), and Tasmania is slightly later, at *c.* 40,000–35,000 yr BP (Gillespie, 2002; O'Connell & Allen, 2004).

Analyses of charcoal in sediment cores from Australia (Moss & Kershaw, 2000; Turney *et al.*, 2001), the Banda Sea of Indonesia (van der Kaars *et al.*, 2000), the Sulu Sea in the Philippines (Beaufort *et al.*, 2003), and off the coast of Papua New Guinea (Thevenon *et al.*, 2004) show an abrupt increase in biomass burning in the period *c.* 53,000–40,000 yr BP. The charcoal flux increases in question may be partly the result of climate change, but the increases are remarkably large (two to five times background), abrupt, and do not correlate with other proxies for abrupt aridity, and thus may reflect biomass burning by humans (Moss & Kershaw, 2000; Beaufort *et al.*, 2003; Thevenon *et al.*, 2004). Charcoal peaks in sediment cores are well-known indicators of the first pioneer settlements in the tropics and often appear prior to direct archaeological evidence for such settlements (e.g. Piperno *et al.*, 1990).

Further north, coastal Palaeolithic sites in southern China with probable modern *Homo sapiens* remains are reported from Guangdong, Zhejiang, and Fujian provinces, with the latter finds dated to *c.* 40,000 yr BP (Cheng-Hwa, 2002). A sediment core in the South China Sea, off the coast of Guangdong Province, produced the highest charcoal levels in the basal sediments, dated to *c.* 40,000 yr BP (Sun & Li, 1999). This is reminiscent of the evidence for biomass burning attributed to human colonization of Australia and Southeast Asia noted above. Late Palaeolithic remains are also known from Taiwan, but are poorly dated to < 30,000 yr BP (Cheng-Hwa, 2002). Late Palaeolithic sites are common in the Korean Peninsula, where modern *Homo sapiens* remains (Turubong Hungsugul and Chommal caves) are estimated to date to *c.* 40,000 yr BP, based on associated faunal assemblages and uranium series dates (Norton, 2000). Late Palaeolithic occupation levels at the Korean open-air site of Hahwakeri have been radiocarbon-dated to *c.* 42,000 yr BP (Kim *et al.*, 2004). On the Asian mainland, north of the Korean Peninsula, near Vladivostok, a Late Palaeolithic occupation of Geographic Society Cave has been radiocarbon-dated to *c.* 38,000 yr BP (Kuzmin, 2002).

In Japan, radiocarbon dates from Late Palaeolithic sites in the Kanto region on Honshu Island (Oda *et al.*, 1977; Keally & Izumi, 1987; Kawashima & Onishi, 2004: 309) and on Okinawa (Kobayashi *et al.*, 1971; Trinkaus & Ruff, 1996) place the earliest occupation of Japan at *c.* 37,000 yr BP. Further north, on Hokkaido Island, sites appear to be slightly younger, *c.* 30,000 yr BP (Keally, 1990; Izuho & Keiichi, 2005). North of Hokkaido, Sakalin Island and the Amur drainage of mainland Russia were not colonized until 23,000 yr BP (Kuzmin, 2002). Still further north, colonization of the Kamchatka Peninsula and Alaska occurred even later, at *c.* 14,000–13,000 yr BP (Yesner, 2001; Goebel *et al.*, 2003).

These dates for the entry and spread of modern *Homo sapiens* throughout the islands and coasts of south and East Asia reflect a very short time period, perhaps as little as 5000–10,000 years. This coastal region correlates well with the modern distribution of people with the Y-chromosome biallelic marker M130 (Fig. 1), thought to be a key marker for the initial southern coastal migration from India to Southeast Asia, Australia, New Guinea, and north to Japan (Underhill, 2004).

Whereas many of the dates for the initial colonization of eastern Asia by modern *Homo sapiens* are preliminary and approximate, the pattern is remarkably similar to that for modern humans in Europe, who spread from the Levant to Spain and Germany 47,000–41,000 yr BP (Mellars, 2006a). Spread rates of 0.3–0.4 km yr^{-1} are indicated for the European migration (Mellars, 2006a), whereas even conservative estimates of the spread rate for humans along the Asian Pacific margin are more than twice this rate, ≥1.0 km yr^{-1}, assuming a departure from India *c.* 50,000 yr BP. This rapid spread may in part reflect coastal adaptations and the use of watercraft in the dispersal (e.g. Bednarik, 1999; Stringer, 2000). The East Asia migration reached as far as Korea, Japan and the Pacific coast of Russia by 40,000–37,000 yr BP, but appears to have stalled north of 43° N latitude. The final spread north to Hokkaido and Sakalin Islands, and on to Kamchatka and Alaska, took another 20,000 years or more.

PLEISTOCENE CLIMATES DURING THE EARLY HUMAN MIGRATIONS

Population bottlenecks and environmental change

One of the aspects of the 'Out of Africa' southern coastal hypothesis is that there was a reduction in early human populations (bottleneck) followed by a rapid expansion. This hypothesis is best articulated by Harpending *et al.* (1993) as the 'weak Garden of Eden' hypothesis, whereby there was an early expansion of modern humans at *c.* 100,000 yr BP, followed by a bottleneck and then a later expansion to Eurasia. Recent genetic studies of single-nucleotide polymorphism in Asian populations indicate that this bottleneck occurred 84,000–60,000 yr BP and lasted for 12,000–20,000 years (Marth *et al.*, 2004). If such a bottleneck did occur, what was its cause? A failure of early modern humans to adapt to environmental changes in their newly colonized lands is perhaps the most likely cause for the proposed bottleneck.

Glacial climates of Oxygen Isotope Stage 4 (*c.* 74,000–59,000 yr BP)

Global climates were mostly wet and warm when the first purported expansion of modern humans occurred *c.* 100,000 yr BP, as this expansion roughly correlates with the last interglacial of Oxygen Isotope Stage (OIS) 5 (*c.* 130,000–74,000 yr BP) in the global marine climate record. Speleothem data from Oman indicate especially wet conditions in the periods 135,000–

120,000 yr bp and 82,000–78,000 yr bp, and dry conditions thereafter until the Holocene (Fleitmann *et al.*, 2003). Climate data (oxygen isotopes and weathering indices) from cores in the Arabian Sea (Schulz *et al.*, 1998) and the Bay of Bengal and Andaman Sea (Colin *et al.*, 1999) confirm the presence of warm, productive seas and an active monsoon cycle from 110,000 yr bp to 90,000 yr bp, followed by an abrupt cold/dry cycle from 90,000–85,000 yr bp identified as the global Heinrich Event 7 (H7). Heinrich events were first identified as cold periods with glacier surges and ice-rafted debris in the North Atlantic (e.g. Heinrich, 1988), but in southern Asia these cold events correlate with dry periods of drastically reduced summer monsoon rainfall (Fig. 2).

The climate briefly stabilized in southern Asia after H7, and then deteriorated in a series of steps beginning about 74,000 yr bp into the Last Glacial period of OIS 4. A major cold/dry episode, correlated with H6, occurred in southern Asia from *c.* 64,000 yr bp to 58,000 yr bp (Schulz *et al.*, 1998; Colin *et al.*, 1999). The H6 event was the coldest/driest of the last 110,000 years in the Arabian Sea (Fig. 2) and Bay of Bengal marine records.

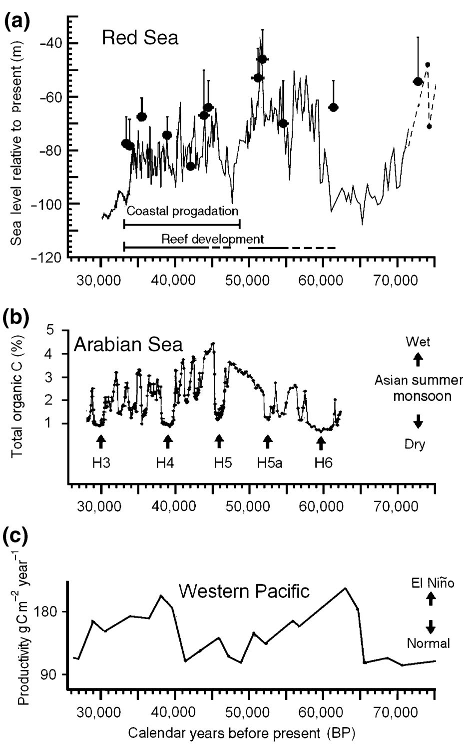

Figure 2 (a) Sea-level proxy based on oxygen isotope data from the Red Sea (Siddall *et al.*, 2003). Also shown are the ages and reconstructed depths (dots with error bars) of coral reefs from Papua New Guinea (Chappell, 2002). Note the period of coastal progradation and reef development between *c.* 50,000 yr bp and 33,000 yr bp. (b) Palaeoclimate proxy for the Indian summer monsoon strength based on total organic carbon in a sediment core from the Arabian Sea (Schulz *et al.*, 1998). (c) Palaeoclimate proxy for the El Niño strength based on coccolithophore abundance in a sediment core from the western Pacific off the coast of Papua New Guinea (Beaufort *et al.*, 2001).

The H6 event is also recorded in marine cores off the coast of East Asia. Sea-surface temperatures (SST) from the southern South China Sea drop abruptly *c.* 65,000 yr bp (Chen *et al.*, 2003), and a high-resolution oxygen isotope climate record from the northern South China Sea (Bühring *et al.*, 2004) shows a pattern of dry conditions after 74,000 yr bp, with an extreme dry episode at *c.* 66,000 yr bp, followed by a fluctuating climate and a return to wet monsoon conditions beginning at 58,000 yr bp. Further north, a detailed climate record from the oxygen isotope analyses of speleothems from Hulu Cave, near the coast east of Nanjing, also indicates a dry climate in OIS 4 punctuated by a few of extreme dry events (*c.* 74,000, 72,000, and 69,000 yr bp) and a return to a wetter monsoon climate about 60,000 yr bp (Wang *et al.*, 2001). Palaeoclimatic records based on diatom analyses from Lake Biwa in south-central Japan also show a dramatic shift towards aridity beginning *c.* 80,000 yr bp (Kuwae *et al.*, 2002). The driest interval in Lake Biwa of the last 130,000 years occurs between *c.* 64,000 and 58,000 yr bp.

Pollen data from the Arabian Sea (Prabhu *et al.*, 2004) also provide a picture of extreme aridity on the Indian subcontinent during OIS 4, with pollen spectra dominated by Chenopodiaceae/Amaranthaceae and *Artemisia*. Pollen from cores from the Banda Sea in Indonesia (van der Kaars *et al.*, 2000) and the east coast of Australia (Moss & Kershaw, 2000) show a similar expansion of grassland and reduction of forest in OIS 4. The Banda Sea data place this arid phase between 74,000 yr bp and 58,000 yr bp. Sediment and pollen data from cores in a fresh-water swamp in western Java indicate warm and wet tropical forest conditions in OIS 5 from 126,000 yr bp to 81,000 yr bp, followed by an abrupt shift to aridity from 81,000 yr bp to 74,000 yr bp (van der Kaars & Dam, 1995). Between 74,000 yr bp and 64,000 yr bp, conditions in western Java became somewhat wetter, but conditions were still much drier and forests were much reduced compared with OIS 5.

Pollen and sediment data from the Leizhou Peninsula near the northwest margin of the South China Sea also indicate extremely dry conditions during OIS 4, with a decrease in forest and a drying out of Tianyang Lake in the period *c.* 74,000–60,000 yr bp (Zheng & Lei, 1999). Pollen records from Japan show a marked decrease in forest and an expansion of herbs (Gramineae, Cyperaceae, Compositae and Chenopodiaceae) in OIS 4, attributed to a reduction in the Asian monsoon (Heusser & Morley, 1997).

The climate histories of the equatorial regions of Southeast Asia compared with the coastal mainland regions are slightly more complex because of competing influences of the Asian Monsoon and El Niño-Southern Oscillation (ENSO) cycles (Fig. 2) (Beaufort *et al.*, 2003). ENSO (El Niño) events are known to be linked to major droughts in the western Pacific region (e.g. Nicholls, 1993; Ayliffe *et al.*, 2004). Although protected somewhat from the Pacific equatorial current, the Sulu Sea experienced a drop in marine productivity *c.* 80,000–70,000 yr bp, possibly reflecting a drop in the Asian winter monsoon and a decrease of the strength of ENSO events (Beaufort *et al.*, 2001, 2003). A marine core off the south coast of Java records an increase in the Southern Equatorial current at 74,000–70,000 yr BP (Gingele *et al.*, 2002), which may also reflect a decrease in ENSO events (Beaufort *et al.*, 2001). Off the north coast of New Guinea there is a major decrease in primary productivity between 80,000 yr BP and 65,000 yr BP (Fig. 2), which is indicative of a decrease in ENSO events and wetter conditions (Beaufort *et al.*, 2001). This same New Guinea record shows an abrupt increase in ENSO events *c.* 65,000 yr BP, extending to 55,000 yr BP (Beaufort *et al.*, 2001), signalling a period of probable large droughts. There is a similar period of reduced circulation off the south coast of Java from 70,000 yr BP to 55,000 yr BP (Gingele *et al.*, 2002), and an abrupt increase in Sulu Sea productivity at the end of OIS 4 with peaks at *c.* 67,000 yr BP and 62,000 yr BP (Beaufort *et al.*, 2003), both of which probably correlate with increases in ENSO events and regional aridity.

In summary, OIS 4 stands out as a period of changing climates punctuated by severe dry episodes in the coastal regions of south and East Asia from India to Japan. The period from 64,000 to 58,000 yr BP, correlating with the Heinrich Event H6 and a major increase in the ENSO cycle (Fig. 2), was especially severe owing to both reduced summer Asian monsoon rains and ENSO-induced droughts. This interval may mark the driest period in this region since modern humans evolved.

Climates in OIS 5 were much warmer and wetter than in OIS 4, and thus more conducive to human migrations. Perhaps of critical importance for the 'Out of Africa' southern migration hypothesis is that the last major Pleistocene wet phase in the Arabian Peninsula occurred at 82,000–78,000 yr BP (Fleitmann *et al.*, 2003). From a climatic perspective, this is the most likely interval for modern humans to have crossed the Arabian Desert into India. Thus, if modern humans did begin their epic migration 80,000 years ago, they were soon faced with a deteriorating climate, as there is ample evidence for severe drought conditions in south and East Asia after 74,000 yr BP, and especially in the interval 64,000–58,000 yr BP. This is precisely the time and place at which the human population bottleneck is proposed to have occurred, suggesting a probable link between harsh climates and human population reductions.

The Toba eruption, *c.* 74,000 yr BP

Another attractive explanation for the population bottleneck is the giant eruption of the Toba volcano in northern Sumatra *c.* 74,000 yr BP (e.g. Ambrose, 1998; Rampino & Ambrose, 2000). Thick ash deposits from the *c.* 74,000-yr-BP eruption are found in cores from the Arabian Sea and the Bay of Bengal (Schulz *et al.*, 1998), from the South China Sea (Song *et al.*, 2000; Bühring *et al.*, 2004), and in mainland India (Acharya & Basu, 1993; Westgate *et al.*, 1998). The Arabian Sea and China Sea records do show a brief, *c.* 1000-yr, cold/dry episode immediately following the Toba ash, but this event appears shorter and less severe than the H6 event noted above, which occurred thousands of years after the eruption and is linked to global climate fluctuations, not the Toba eruption. Nevertheless, the marine core record may not have the resolution to pinpoint the brief climate effects of the ash. Palaeoclimate records from Hulu Cave also record 500–1000 years of cooling and a reduction of the summer monsoon following the Toba eruption (Wang *et al.*, 2001), but in this region the cold/dry event is the most severe event in OIS 3. Whether or not this 73,000–74,000-yr-BP climatic event was caused by the Toba eruption is debated (e.g. Oppenheimer, 2002), and climatic cooling from the Toba eruption is expected to have lasted only about a decade at most (Rampino & Ambrose, 2000). Regardless of the climatic response to the eruption, the direct environmental effects of the ash fall alone may have been severe enough to impact on modern human populations in southern Asia, if they existed.

Interglacial climates of Oxygen Isotope Stage 3 (*c.* 59,000–24,000 yr BP)

Following OIS 4, climates in south and East Asia became significantly wetter in OIS 3, with the return of a vigorous summer monsoon cycle and a reduction in ENSO events after the end of the H6 cold interval *c.* 58,000 yr BP. The major spread of modern humans to Australia and East Asia in the period *c.* 47,000–40,000 yr BP occurred during an especially warm/wet interval in OIS 3. This warm/wet interval falls between the two cold/dry episodes marked by H5 and H4 in marine cores from the Arabian Sea (Schulz *et al.*, 1998) and the Bay of Bengal and Andaman Sea (Colin *et al.*, 1999). The duration of these dry spells, marked by reductions in organic carbon in the Arabian Sea (Fig. 2), are dated to 48,000–46,000 yr BP for H5 and 40,000–37,000 yr BP for H4 (Schulz *et al.*, 1998). One of the wettest periods of the last 100,000 years is recorded in these cores at *c.* 45,000–43,000 yr BP (Fig. 2). Speleothem data from Oman indicate that the H5 dry episode was severe, but brief, with peak aridity *c.* 48,000 yr BP lasting less than 100 years (Burns *et al.*, 2003). There was a brief increase in summer monsoon activity in the Gulf of Aden *c.* 55,000–42,000 yr BP (Almogi-Labin *et al.*, 2000), and in the Red Sea *c.* 42,000 yr BP (Badawi *et al.*, 2005), but otherwise this region is dry and dominated by winter monsoons in OIS 3.

A marine core from the southern South China Sea records warm SST and increased summer monsoons in the interval *c.* 50,000–40,000 yr BP (Chen *et al.*, 2003). SST off the north coast of New Guinea change little in the interval 50,000–40,000 yr BP (Lea *et al.*, 2000), but salinity and primary productively drop significantly (Lea *et al.*, 2000; Beaufort *et al.*, 2001), consistent with a reduced ENSO cycle and wetter conditions. A similar lack of major ENSO events in the interval *c.* 55,000–35,000 yr BP can be inferred from the marine-core data off Java (Gingele *et al.*, 2002). The climate interval between H5 and H4 is also recognized as a warm/wet interval in Hulu Cave (Wang *et al.*, 2001), the northern South China Sea (Bühring *et al.*, 2004; Oppo & Sun, 2005), and the East China Sea (Li *et al.*, 2001). Diatom analyses from Lake Biwa in

Japan show a major increase in temperature and moisture in the interval 50,000–40,000 yr BP, both reaching levels comparable with those of the mid-Holocene (Kuwae *et al.*, 2002). Studies of marine cores off the east coast of Japan place this warm interval slightly earlier, at 53,000–49,000 yr BP (Igarashi & Oba, 2006).

Pollen data from the Arabian Sea (Prabhu *et al.*, 2004) show a dramatic decrease in arid indicators (Chenopodiaceae/ Amaranthaceae and *Artemisia*) and a marked increase in species adapted to moist conditions (Poaceae and Piperaceae) in OIS 3, with a peak in Poaceae at *c.* 42,000 yr BP. Studies of river sedimentation in western India confirm that river discharge in the Pleistocene increased dramatically in the interval *c.* 58,000–54,000 yr BP and then declined rapidly from 39,000 yr BP to 30,000 yr BP (Tandon *et al.*, 1997; Srivastava *et al.*, 2001). Pollen cores from the Banda Sea (van der Kaars *et al.*, 2000) indicate an expansion of tropical forest in OIS 3, peaking at *c.* 42,000 yr BP, after which, evidence for human disturbance becomes prevalent. Pollen data from west Java indicate an increase in precipitation in the interval 62,000–47,000 yr BP, with an expansion of forest (van der Kaars & Dam, 1995). Pollen data from the base of lake cores document humid tropical forest conditions extending back to before 35,000 yr BP in Kalimantan (Anshari *et al.*, 2001) and to before 37,000 yr BP in Sulawesi (Dam *et al.*, 2001). Poorly dated pollen records from New Caledonia (Stevenson & Hope, 2005) and Papua New Guinea (Haberle, 1998) show increases in tropical forests that may correlate with a transition to wetter conditions in OIS 3, but the dating is not certain.

In eastern Australia, Moss & Kershaw (2000) confirm an expansion of tropical forest in OIS 3, peaking at *c.* 50,000–44,000 yr BP, followed by a rapid decline beginning *c.* 45,000–42,000 yr BP. This forest decline is accompanied by an increase in Poaceae and biomass burning and may be linked to human disturbance. The period from 50,000 yr BP to 40,000 yr BP is well documented as an extremely wet period with high lake levels in mainland Australia (e.g. Bowler, 1986; Corrège & De Deckker, 1997; Nanson *et al.*, 1998). Pollen data from the South China Sea (Zheng & Lei, 1999) and Japan (Heusser & Morley, 1997) indicate a slight expansion of temperate forests and moister conditions in OIS 3. An especially warm/wet interval *c.* 39,000–32,000 yr BP is indicated in studies of flora and fauna in northern Japan on Hokkaido Island (Igarashi, 1993; Takahashi *et al.*, 2006).

PLEISTOCENE SEA LEVEL DURING THE EARLY HUMAN MIGRATIONS

Sea level for most of the history of modern humans has been significantly below current levels, as only near the beginning of OIS 5 (*c.* 120,000 yr BP) did levels meet or exceed those of today (Fig. 2). Assuming that modern humans first left Africa *c.* 80,000 yr BP, the sea level would have been *c.* 50 m below present-day levels, meaning that part of the sea bed in the Red Sea and all of the Persian Gulf were exposed. A short water crossing would have been necessary if this initial migration travelled due east from Ethiopia into Arabia, as a narrow water gap of several kilometres remained between the Red Sea and Gulf of Aden. The eastward journey would have traversed a rather narrow coastal plain until the mouth of the Indus River, at which point a broad plain opened up along the west side of the Indian subcontinent. This plain narrowed again along the east side of India (Sri Lanka was connected to the mainland) until the mouth of the Ganges and the Bay of Bengal. After this point, the coastal migration would have soon reached the edge of Sunda, the continental landmass where much of Thailand, Malaysia, Sumatra, Java, and Borneo were merged by an expansive low-lying coastal plain (e.g. Voris, 2000). Significant water crossings (> 100 km) would have been required at this time to reach Sahul, the merged landmasses of New Guinea and Australia. A similar water gap of *c.* 100 km also separated the mainland and the Adaman Islands, which genetic studies indicate may have been settled during the initial coastal migration (Thangaraj *et al.*, 2005).

There is no evidence, however, that modern humans made this journey at 80,000 yr BP, and it is possible that the deserts of Arabia were formidable enough to restrict this initial migration out of Africa northwards to the Levant. Sea levels dropped significantly in OIS 4 and remained at about −100 m before rising again in OIS 3 (Fig. 2). Much later, at 45,000–40,000 yr BP, when the evidence for modern humans in Sunda and Sahul is secure, the sea level averaged about 80 m below current levels (Fig. 2). Despite these lower levels of −80 to −100 m, a water crossing of *c.* 100 km was still required to reach Sahul (Voris, 2000). Most of the small Indonesian islands east of Java, Suluwesi, and the Philippines required short voyages of several kilometres for colonization. Taiwan and Sri Lanka were accessible from the mainland. A water crossing of *c.* 50 km from Korea via Tsushima Island to the merged Japanese islands of Kyushu and Honshu was necessary at *c.* 40,000 yr BP. Colonization of Honshu from the northern islands of Hokkaido and Sakhalin is unlikely, as there is no evidence of human occupation of these northern islands at this early date, even though they were accessible from mainland Russia at this time. Water crossings of *c.* 50 km would also have been required in the island-hopping trek to reach Okinawa from Kyushu at *c.* 40,000 yr BP.

Thus, while the sea level was much lower than it is today when modern humans first colonized south and East Asia, the archaeological record confirms that the southern coastal migration of modern humans involved the use of water craft. The use of such craft may in part explain the rapid dispersal, as long voyages may have been a common practice in the search for optimal coastal environments.

Coastal environments *c.* 75,000–30,000 yr BP

The coastal environments that developed along the southern migration route were largely dependent upon fluctuations in sea level, sediment supply (e.g. proximity to river mouths), and the geometry of the coastal shelf (e.g. Chappell, 1993a; Steinke *et al.*, 2003; Hanebuth & Stattegger, 2004). When the sea level fell rapidly, reefs were exposed, rivers incised their channels, coastal floodplains dried out, and most of the terrigenous sediment bypassed the coastal zone to be deposited in deep water. When sea level rose rapidly, coastal sedimentation could not keep pace, and reefs, estuaries, and floodplains were drowned as the sea rose. Sedimentation rates were higher close to major rivers, and thus coastal ecosystems could more readily adjust to changes. Nevertheless, during either a rapid rise or fall of sea level, coastal ecosystems were disrupted because there was insufficient time for them to prograde seawards (sea-level drop) or aggrade and move inland (sea-level rise).

Such rapid sea-level changes are typically marked in the coastal geological record by depositional hiatuses with erosional surfaces or soil horizons. When the sea level changes more slowly, coastal environments either prograde seawards as the sea level falls (marine regression), or aggrade upwards and migrate inland as the sea level rises (marine transgression). If the sea level remains relatively stable, minor regression and transgression events can occur, depending on changes in sediment supply.

Sea-level data based on oxygen isotopes from the Red Sea (Siddall *et al.*, 2003), augmented with data from uplifted coral terraces in Papua New Guinea (Chappell, 2002), confirm that sea-level changes in OIS 4 and OIS 3 were large and sometimes abrupt (Fig. 2). Chappell (2002) has demonstrated that abrupt sea-level rises occurred at the end of the Heinrich events in OIS 3, perhaps reflecting the rapid melting of coastal glaciers. Between 72,000 yr BP and 65,000 yr BP, the sea level fell 60 m at a rate of 0.7 cm yr^{-1}, followed by a rapid rise of *c.* 2 cm yr^{-1} between 61,000 and 59,000 (H6). Between H6 and H5a, the sea level fluctuated around a depth of −65 m, before rising at a rate of over 2 cm yr^{-1} at the end of H5a (*c.* 51,000 yr BP), reaching −45 m. This highstand was brief, and levels fell (51,000–48,000 yr BP) and then rose again (48,000–46,000 yr BP, H6) at a rate of about 2 cm yr^{-1}. After 46,000 yr BP, sea levels gradually fell, with minor fluctuations of 10 m and one larger oscillation of *c.* 25 m at 40,000 yr BP associated with H4. The sea level remained relatively stable in the interval 40,000–33,000 yr BP, after which it began its rapid drop towards the Last Glacial Maximum (LGM) lowstand of −130 m at *c.* 20,000 yr BP (Lambeck *et al.*, 2002).

The important implication to be drawn from this brief review of sea level is that between 75,000 yr BP and 30,000 yr BP the sea level was mostly rising or falling rapidly, and thus stable coastal ecosystems would have formed only rarely. Support for this conclusion comes from the fact that coastal deposits dating to this interval from south and East Asia are recorded only from *c.* 50,000 yr BP to 33,000 yr BP. Along the west coast of India there is a thick sequence of lagoon and estuarine deposits with abundant mangrove peats dated to 44,000–33,000 yr BP (Kumaran *et al.*, 2005). This period of coastal mangrove development correlates with a humid phase of coastal floodplain aggradation between 54,000 yr BP and 30,000 yr BP (Srivastava *et al.*, 2001). Similar developments are found in eastern India in the Ganges-Brahmaputra drainage (Goodbred & Kuehl, 2000; Srivastava *et al.*, 2003). Cores from the Strait of Malacca record mangrove and brackish water peats dating to 43,000–32,000 yr BP (Geyh *et al.*, 1979).

One of the best records for Southeast Asia comes from studies of the Sunda shelf between peninsular Malaysia and Kalimantan (Hanebuth *et al.*, 2003; Hanebuth & Stattegger, 2004) and the Bonapart Gulf (Yokoyama *et al.*, 2001), where coring in deep- and shallow-water environments documents an extensive buried land surface with coastal swamp and lagoon environments between 50,000 yr BP and 34,000 yr BP. A recent synthesis of radiocarbon dates from Pleistocene coastal sediments in Southeast Asia (Thailand, Malaysia, and Vietnam) reveals a clustering of ages of *c.* 50,000–40,000 yr BP from a prograding coastal environment (Hanebuth *et al.*, 2006). Uplifted Pleistocene deposits along the Sepik-Ramu floodplain in Papua New Guinea contain sago palm swamp and brackish water lagoon deposits that have been radiocarbon-dated to 32,000–40,000 yr BP (Chappell, 1993b). Further north, along the coast of China (Saito *et al.*, 1998; Yim, 1999), Taiwan (Chen *et al.*, 2004), Korea (Yoo *et al.*, 2003) and Japan, a similar assemblage of submerged, prograding coastal environments is dated to between *c.* 50,000 yr BP and 30,000 yr BP.

Concurrent with this period of coastal progradation in OIS 3 was a period of coral reef development in East Asia. Studies of uplifted coral reefs from Papua New Guinea confirm that there was an extensive period of reef formation from *c.* 45,000 yr BP to 33,000 yr BP, a more minor episode from 55,000 yr BP to 53,000 yr BP, and little evidence for reefs in OIS 4 (Fig. 2). Similar records are found in Vanuatu in the southwest Pacific (Cabioch & Ayliffe, 2001), but in the Ryukyu Islands of Japan the record of reef development is somewhat earlier, *c.* 65,000–50,000 yr BP (Sasaki *et al.*, 2004).

Sedimentological data from coastal south and East Asia suggest a lack of extensive coastal swamp, estuary, and lagoon environments prior to *c.* 50,000 yr BP, and most coastal sedimentary sequences display an erosional surface that represents much of OIS 4. In contrast, the interval 49,000–33,000 yr BP stands out as a period when the sea level was relatively stable and lagoons and swamps were actively accreting along the coasts. It should be noted, however, that the dating of these coastal deposits prior to *c.* 50,000 yr BP is difficult given the limitations of radiocarbon dating, and it is possible that some of the coastal deposits described above predate 50,000 yr BP (Yim, 1999; Hanebuth *et al.*, 2006). The dating is more secure for the abrupt end to this coastal deposition after 33,000 yr BP, coeval with the rapid drop of sea level leading into OIS 2 and the LGM at *c.* 30,000–19,000 yr BP. Coral reefs also appear largely to disappear after 33,000 yr BP. Sediment cores from the Bonapart Gulf between Australia and Indonesia record a 50-m drop in sea level to −130 m between 32,000 yr BP and 30,000 yr BP (Lambeck *et al.*, 2002).

LATE GLACIAL AND HOLOCENE COASTAL ENVIRONEMTENTS

Climate conditions in OIS 2, which includes the LGM, were comparable to those in OIS 4, only more severe, especially in the more northern latitudes. Nevertheless, the major changes in the coastal environments for much of south and East Asia at the Pleistocene–Holocene transition were a product of sea-level change, and thus we focus primarily on sea-level change in OIS 2 and OIS 1 (Holocene) after a brief review of climate changes.

LGM and Early Holocene climates

The climate of south and East Asia in OIS 2/LGM was cold and dry, conditions that are well documented in both terrestrial and marine sediments throughout the region (e.g. van der Kaars & Dam, 1995; Schulz *et al.*, 1998; Lea *et al.*, 2000; Takahara *et al.*, 2000; Anshari *et al.*, 2001; Dam *et al.*, 2001; Hope, 2001; van der Kaars *et al.*, 2001; Wang *et al.*, 2001; Nakagawa *et al.*, 2002; Chen *et al.*, 2003; Lim *et al.*, 2004; Prabhu *et al.*, 2004; White *et al.*, 2004; Gong *et al.*, 2005). These cold/dry conditions continued until the abrupt warming known as the Bölling-Alleröd event.

The Bölling-Alleröd warming (*c.* 14,000–12,500 yr BP) was followed by an equally abrupt cooling event known as the Younger Dryas (*c.* 12,500–11,500 yr BP). The Bölling-Alleröd warming and the Younger Dryas cooling events are marked by a respective rapid increase and decrease in the summer monsoon in the Arabian Gulf (Schulz *et al.*, 1998), the South China Sea (Li *et al.*, 2001; Oppo & Sun, 2005), coastal central China (Hulu Cave, Wang *et al.*, 2001), and in the Japan Sea (Koizumi *et al.*, 2006). At the end of the Younger Dryas, *c.* 11,500 yr BP, climates became warmer and wetter throughout the region influenced by the Asian Monsoon. As in OIS 3, the situation in the western Pacific was more complex, as the ENSO cycle peaked again about 12,000–10,000 yr BP (Beaufort *et al.*, 2001), when presumably El Niño-type droughts would have been more prevalent. The brief overlap of the Younger Dryas monsoon minimum and the ENSO cycle at *c.* 12,000 yr BP may have made this period an especially dry period in the Southeast Asian Pacific region. Large charcoal peaks at this time in sediment cores from the western Pacific (Thevenon *et al.*, 2004), Papua New Guinea (Haberle, 2005), and Australia (Moss & Kershaw, 2000) may in part reflect this period of intense drought.

Following this putative period of Younger Dryas/El Niño droughts, warm and wet conditions prevailed throughout south and East Asia, peaking at the mid-Holocene climatic optimum at *c.* 7000–4000 yr BP (e.g. Yu *et al.*, 2005; Koizumi *et al.*, 2006).

LGM and Early Holocene sea-level change

The sea level along the south and East Asian coast reached −140 m by the peak of the LGM at *c.* 22,000–19,000 yr BP (Fig. 3), and vast, dry coastal plains in India, Southeast Asia, and China emerged as rivers and streams incised their channels to meet the receding coast (e.g. Voris, 2000). At 19,000 yr BP post-glacial melting began, and the sea level abruptly rose 15 m in only 500 years (Yokoyama *et al.*, 2001), and then rose more gradually at a rate of 0.3–0.5 cm yr^{-1}, reaching about −95 m at 14,000 yr BP (Fig. 3). At 14,000 yr BP there was another abrupt

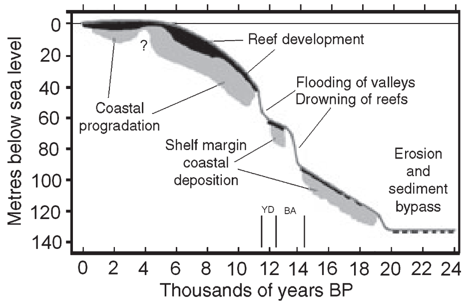

Figure 3 Sea-level curve based on sediment cores and reefs from the Indo-Pacific region (Montaggioni, 2005). Shown are periods of coastal progradation of estuarine and lagoon ecosystems (grey) and of reef development (black). Note the gaps in this development during periods of rapid sea rise, for example during the Bölling-Alleröd (BA) warming and immediately after the Younger Dryas (YD) cooling events.

jump (3.7 cm yr^{-1}) to −75 m, known as glacial melt-water pulse Ia (Fairbanks, 1989; Bard *et al.*, 1990a,b), which correlates with the Bölling-Alleröd global warming event (e.g. Peltier, 2005). Following this rapid-rise event, sea level rose at a rapid rate of 1.5–1.6 cm yr^{-1} until *c.* 8500 yr BP (Fig. 3), except for a brief still stand at 12,500–11,500 yr BP, which correlates with the Younger Dryas global cooling event (Lambeck *et al.*, 2002; Steinke *et al.*, 2003).

Most coastal sediment cores from India to Japan document a deposition hiatus of *c.* 20,000 years, marking the LGM. For example, near the outer edge of the Sunda Shelf, radiocarbon dates for the top of the pre-LGM coastal deposits range from 45,000 yr BP to 29,000 yr BP (mean = 37,800 ± 6900 yr BP, $n = 4$), whereas dates from the base of post-LGM coastal marsh and lagoon deposits range from 19,000 yr BP to 14,000 yr BP (mean = 15,600 ± 2100 yr BP, $n = 8$). A compilation of data from seven locations distributed from India to Japan shows the same trend, with an average gap of *c.* 20,000 years (Table 1). As would be expected, the earlier dates (19,000–14,000 yr BP) for coastal deposition come from well below the current sea level. The detailed record of fossil coral reefs on Papua New Guinea also shows a large gap in the LGM, as no reefs are found between 33,000 yr BP and 15,000 yr BP (Chappell & Polach, 1991; Chappell *et al.*, 1996a). A survey of fossil reefs in the western Pacific and Indian Ocean confirms that reefs in this time period were rare (Montaggioni, 2005).

The sea-level rise between 19,000 yr BP and 14,000 yr BP was slow enough to permit the development of coastal estuaries and lagoons, but they were mostly restricted to the incised valleys near the edge of the continental shelf (Hanebuth & Stattegger, 2004). These valleys were briefly flooded by the melt-water pulse Ia, but coastal accretion resumed afterwards. During the brief still stand at 12,000 yr BP a system of reefs and back-reef lagoons developed along 1300 km of the west Indian coastline (Vora *et al.*, 1996). The Pleistocene drowned reefs on the Sahul Shelf (Edgerly, 1974) may also be of this age. These reefs were subsequently drowned with the rapid raise in sea level after the Younger Dryas (Fig. 3).

Table 1 Radiocarbon ages for coastal deposits pre-dating and post-dating the Late Glacial Maximum (LGM) and the duration of the hiatus in coastal deposition during the LGM. Based on calibrated dates.

Location	Top of pre-LGM, coastal deposits (BP × 1000)	Base of post-LGM, coastal deposits (BP × 1000)	Duration of hiatus (years × 1000)	Source
Japan coast	38	15	23	Yabe *et al.* (2004)
Bohai Sea, China	32	16	16	Marsset *et al.* (1996)
Taiwan coast	37	19	18	Chen *et al.* (2004)
Sunda Shelf	39 (mean)	16 (mean)	23	Hanebuth & Stattegger (2004)
Bonapart Gulf	30	14	16	Yokoyama *et al.* (2001)
Papua New Guinea	40	8	32	Chappell (1993b)
Ganges Delta	33	11	22	Goodbred & Kuehl (2000)
India west coast	30	11	19	Kumaran *et al.* (2005)

Sediment cores further inland and at shallower depths document a later period of coastal sedimentation after the sea had transgressed across much of the LGM coastal plain. For example, radiocarbon dates from sediment cores in the floodplains of the Sepik-Ramu River in Papua New Guinea, the Daly River in northern Australia, and along the west coast of India all show that the post-LGM accretion of estuary and lagoon deposits began between 8000 yr BP and 9000 yr BP (Fig. 4b). A compilation of radiocarbon dates from estuary and lagoon environments from throughout coastal south and East Asia confirms that there was a regional increase in these environments between 10,000 yr BP and 7000 yr BP, followed by a decline between 7000 yr BP and 3000 yr BP (Fig. 4b). A similar compilation of radiocarbon dates from coral reefs reveals a parallel pattern, with a rapid increase in the number of reefs between 10,000 yr BP and 7000 yr BP and a peak in the number of reefs at about 7000–6000 yr BP (Fig. 4a). Reef abundances appear to drop after 7000 yr BP and reach a minimum at about 5000 yr BP, *c.* 1000 years prior to the minimum in estuary/lagoon deposits at *c.* 4000 yr BP.

The peak in coastal estuary/lagoon deposition and reef formation *c.* 7000 yr BP coincides with a slowdown in sea-level rise that occurred as the sea level reached present-day levels. The sea level stabilized at *c.* 1–3 m above current levels *c.* 5000–4000 yr BP in the western Pacific and eastern Indian Ocean (e.g. Pirazzoli, 1991; Dickinson, 2001) and *c.* 6000–5000 yr BP further north in Japan (e.g. Sato *et al.*, 2001), and then fell gradually to present-day levels. The sea level in the western Indian Ocean may not have reached present-day levels until 3000–2000 yr BP, after which it stabilized (Camoin *et al.*, 2004). The brief decline in reefs *c.* 4000 yr BP (Fig. 4a) is probably a direct result of this decline in sea level, which stranded them above the sea. The coeval decline in estuary/lagoon sedimentation *c.* 5000–4000 yr BP (Fig. 4b) is likewise a product of sea-level stabilization and drop, which led to the siltation of lagoons and drying up of swamps. Coastal sediments in nearly all the sites cited in Fig. 4b record a decline in lagoon environments 5000–3000 yr BP. The radiocarbon dating of both reefs and estuary/lagoon deposits hints at a late expansion of these ecosystems after 4000 yr BP, possibly followed by a decline in the last *c.* 1000 years.

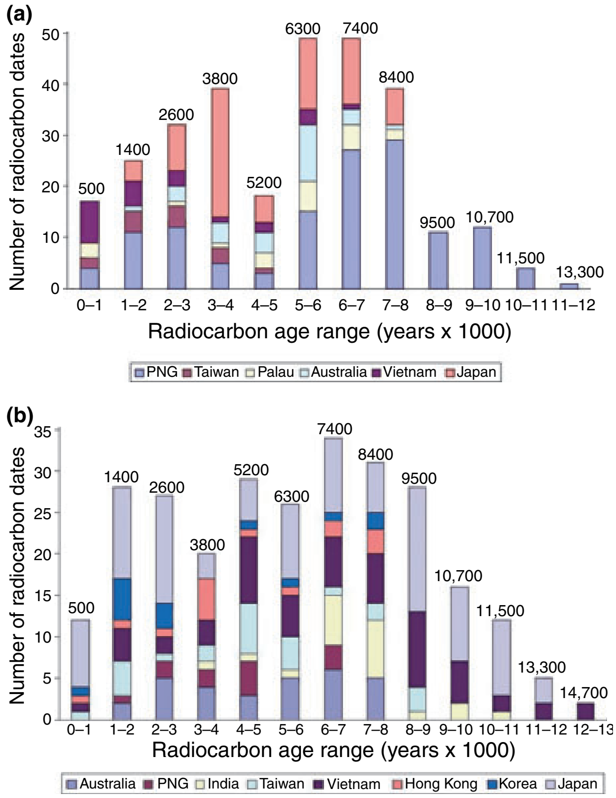

Figure 4 (a) Frequency of radiocarbon dates (uncalibrated) from terminal Pleistocene and Holocene reefs from selected sites in Papua New Guinea (PNG) (Ota *et al.*, 1993; Chappell *et al.*, 1996b; Ota & Chappell, 1999), Taiwan (Yamaguchia & Ota, 2004), Palau (Kayanne *et al.*, 2002), Australia (Woodroffe *et al.*, 2000), Vietnam (Korotky *et al.*, 1995), and Japan (Sugihara *et al.*, 2003; Yasuhara *et al.*, 2004). (b) Frequency of radiocarbon dates (uncalibrated) from terminal Pleistocene and Holocene coastal lagoon and estuary deposits from selected sites in Papua New Guinea (PNG) (Chappell, 1993b), Australia (Chappell, 1993b), India (Kumaran *et al.*, 2005), Taiwan (Chen & Liu, 1996, 2000), Vietnam (Ta *et al.*, 2001, 2002; Tanabe *et al.*, 2003; Hori *et al.*, 2004), Hong Kong (Yim *et al.*, 2004), Korea (Chang & Choi, 2001), and Japan (Tamura & Masuda, 2004; Yasuhara *et al.*, 2004). The dates above the bars give the calibrated age in yr BP for the centre of the age range.

ENVIRONMENTAL CONSTRAINTS ON THE EARLY HUMAN MIGRATIONS

By combining the histories of climate and sea-level changes detailed above, OIS 4 and OIS 2 stand out as times of unstable coastal environments in south and East Asia. Such instabilities may have made living on the coast difficult for extended periods. Some of the major events in OIS 4 were the Toba eruption (*c.* 74,000 yr BP), the peak in ENSO-cycle droughts (65,000–60,000 yr BP), the severe H6 decline in the summer monsoon (62,000–58,000 yr BP), and the rapid fall and subsequent rise in sea level at the beginning and end of OIS 4. Similarly, the major environmental disruptions leading into the LGM were a dramatic drop in sea level 33,000–30,000 yr BP, the cold/dry climates of the LGM, and abrupt fluctuations in both climate and sea level associated with the Bölling-Alleröd warming and the Younger Dryas cooling events. In contrast, climates and sea levels in OIS 3 and OIS 1 were much more stable.

Out of Africa revisited

It is possible that modern humans reached southern Asia by 80,000 yr BP, but the meagre archaeological evidence for these early colonizers suggests that, if they existed, their populations were kept small by the unstable environments prior to *c.* 50,000 yr BP. This view fits well with the population bottleneck indicated by the genetic studies and the 'weak Garden of Eden' hypothesis (Harpending *et al.*, 1993). While environmental conditions improved along the southern migration route in OIS 3, the early part of this interval (*c.* 59,000–45,000 yr BP) was still plagued by large fluctuations in sea level (at 55,000 yr BP and 52,000–48,000 yr BP) and by abrupt declines in the summer monsoon rains (the H5a and H5 events).

The first relatively stable interval in OIS 3 occurred between 45,000 yr BP and 40,000 yr BP, when summer monsoons were strong, ENSO events weak, and the sea level was sufficiently stable to support a prograding system of estuaries and lagoons bordered by extensive coral reefs. It is precisely in this first stable interval that both the archaeological and human genetic data indicate an expansion of modern humans throughout south and East Asia. We propose that the development of productive coastal ecosystems in this interval was a major factor in the rapid spread of modern humans along the southern migration route in the interval 47,000–37,000 yr BP. A markedly improved climate in the interval 43,000–41,000 yr BP has likewise been implicated in the rapid spread of modern humans in Europe (Mellars, 2006a).

A brief period of climatic instability returned in the interval *c.* 40,000–38,000 yr BP, when the summer monsoons declined (H4 event) and the ENSO cycle peaked (Fig. 2), but the sea level remained relatively stable. There is no indication that this event had a significant impact on human populations. It may well be that a critical population mass had been achieved by this time, which was resistant to subsequent brief climate cycles.

Human migrations to the New World

There has been much speculation about the possibility of an early entry of humans into the New World in OIS 3, and a few controversial sites have been reported with possible human occupations > 30,000 yr BP (e.g. Morlan, 2003; Gonzalez *et al.*, 2006). It is plausible that the rapid coastal migration of modern humans along the Pacific margin may have continued northwards into Alaska during the late OIS 3 warm interval of 39,000–32,000 yr BP, which is well documented in northern Japan (Takahashi *et al.*, 2006). However, the data from Northeast Asia suggest otherwise. It is apparent from the distribution of northern Pacific margin sites that the coastal migration stalled north of 43° N latitude after *c.* 38,000–37,000 yr BP (Fig. 1). This northward limit to the early migration coincides with the early LGM limit for temperate forest in Japan (Yasuda *et al.*, 2004) and the Asian mainland (Gotanda *et al.*, 2002). It appears that the first coastal colonizers, originating as they did from tropical regions of southern Asia, could not adapt to the colder climates of northern Asia where they confronted environments dominated by cold waters and steppe/tundra vegetation.

Given the apparent slowdown in the northward coastal migration of early modern humans, it is highly unlikely that they reached Alaska via the Sea of Okhotsk and Bering Sea prior to the LGM. There is one other possibility that should be mentioned here, however, and that is of an oceanic migration to the Americas. Recent simulations indicate that primitive voyagers from Japan floating or paddling rafts east along the warm Kuroshio Current could reach Alaska in 35–105 days and North America proper in 50–85 days (Montenegro *et al.*, 2006). The Kuroshio Current veers off from the coast of Japan at *c.* 38° N (Kawahata & Ohshima, 2002), near the northern limit of the initial early modern human northward migration. Such an oceanic route would explain the lack of early coastal sites along the Sea of Okhotsk and Bering Sea.

The migration of modern humans into the Bering Sea region after 30,000 yr BP is complicated by the fact that modern humans are more likely to have entered this region by a strictly overland route via central Asia (Fig. 1). Genetic studies suggest a central Asian origin for the people who first colonized the New Word via the Bering Sea land bridge, arriving in Alaska either by an overland route or connecting with the coastal route along the Sea of Okhotsk (e.g. Schurr, 2004). Central Asian Late Palaeolithic sites in the upper Ob River dated to 44,000 yr BP (Goebel *et al.*, 1993; Chlachula, 2001), and to 40,000–42,000 yr BP (Goebel, 1999) near Lake Baikal may represent the ancestral homeland of the first Americans. These central Asians were well adapted to glacial climates, but the migration into Alaska *c.* 14,000 yr BP coincides with the Bölling-Alleröd warming, suggesting that LGM climates may have prevented an earlier entry into Alaska. Nevertheless, ice-free coastal environments are well documented along the Canadian coast in the interval *c.* 17,000–

15,000 yr BP (Josenhans *et al.*, 1997; Lacourse *et al.*, 2005), and it is likely that that an ice-free coastal migration route through southern Alaska existed at this time as well (Mann & Peteet, 1994). Thus, if people made it to Alaska by 17,000 yr BP, it appears that the coastal door was open to the New World migration.

LGM and post-glacial environments and human coastal adaptations

The unstable coastal environments of the LGM must have made living on the coast difficult. This view is supported by the observation that there are relatively few Late Palaeolithic sites with occupation levels dating to the LGM compared with earlier periods (e.g. before *c.* 33,000 yr BP), and those sites that do date to the LGM exhibit brief intermittent occupations. For example, most Late Palaeolithic sites in Papua New Guinea and the Bismarck Archipelago date to either before or after the LGM (Gosden, 1995). The few LGM occupation levels at Matenbek on New Ireland show a distinct reliance on imported goods not found in earlier occupation levels, suggesting a need to augment sparse local resources (Gosden, 1995). Buang Merabak Cave, also on New Ireland, was occupied during 44,000–33,000 yr BP and 24,000–20,000 yr BP, and abandoned during the periods of rapid sea-level fall (33,000–24,000 yr BP) and rise (20,000–14,000 yr BP) (Leavesley & Chappell, 2004; Leavesley, 2005). On Timor, modern human occupations occur in two phases, the first *c.* 40,000–34,000 yr BP, and the second beginning at *c.* 16,000 yr BP, but mostly confined to the Holocene (Veth *et al.*, 2005).

Whereas there is some evidence for the exploitation of estuarine and marine resources at south and East Asian coastal sites dating to before 33,000 yr BP (e.g. Rabett, 2005; Veth *et al.*, 2005; Simanjuntak, 2006), marine resources become a focus of many of these sites after 17,000 yr BP, coeval with some of the first evidence for the development of post-LGM coastal reef and lagoon/estuary systems (Figs 3 and 4). For example, coastal-resource exploitation is well documented on the north coast of Papua New Guinea (Gorecki *et al.*, 1991), the island of Nias off the southwest coast of Sumatra (Forestier *et al.*, 2005), and on Timor (Veth *et al.*, 2005), where early shell midden deposits date to 16,600–14,000 yr BP.

Genetic data support this two-phase settlement trajectory in the Pleistocene. Y-chromosome studies confirm the presence of M130 chromosomes in Australian and Melanesian populations (Underhill, 2004), which suggests that the original settlers to this region were part of the initial southern migration *c.* 40,000–50,000 yr BP. Y-chromosome studies also suggest that a population bottleneck occurred after this initial phase of settlement, because for many of the populations in this region the most recent common ancestor of the M130 group dates to *c.* 12,000 yr BP (Kayser *et al.*, 2001).

Between 14,000 yr BP and 7400 yr BP, coastal ecosystems stabilized, and reefs, lagoons, and coastal swamps expanded dramatically (Figs 3 and 4). Following this trajectory, exploitation of coastal estuarine and lagoon resources similarly expanded throughout south and East Asia. A recent survey of mangrove exploitation in Southeast Asia notes sporadic use prior to *c.* 13,000 yr BP, but extensive use thereafter (Rabett, 2005). In southern Thailand there was a rapid increase in the exploitation of shellfish from intertidal and mangrove environments after 13,000 yr BP, which peaked *c.* 8000 yr BP (Anderson, 2005). On Timor, shellfish exploitation increased, beginning *c.* 16,000 yr BP, and peaking *c.* 7000–5000 yr BP (Veth *et al.*, 2005). Along the north coast of Papua New Guinea, shell middens dating to *c.* 5700–7000 yr BP have been found at Vanimo (Gorecki *et al.*, 1991), near Sissano (Hossfeld, 1964, 1965) and in the lower Sepik-Ramu drainage (Swadling *et al.*, 1989, 1991; Swadling & Hope, 1992). All of these north coast sites were abandoned after this brief period of coastal exploitation and were only re-settled in the late Holocene.

Further north, in Japan, the exploitation of marine resources was minimal in the Palaeolithic, but is clearly evident at the beginning of the Jomon culture (Okada, 1998), which dates to *c.* 16,000 yr BP. Nevertheless, extensive use of coastal resources came later, as the first shell midden appears *c.* 10,500 yr BP (Keally, 1986; Kuzmin, 2002). Exploitation of estuary/lagoon resources increased in the Early Jomon period, and marine resource exploitation expanded throughout the islands, peaking in many areas about 6000 yr BP (Keally, 1986; Okada, 1998). Although the earliest dates on shell middens from China and Korea appear to be later than those from Japan (Cheng-Hwa, 2002; Kuzmin, 2002), there is a major expansion of shell midden sites at 8000–7000 yr BP.

This mid-Holocene expansion of settlement throughout Southeast Asia, Australia, and Melanesia is well attested to in the genetics of modern populations. Analyses of Y-chromosome mutations clearly indicate a major population expansion 4000–6000 years ago (Kayser *et al.*, 2001).

Reefs, estuaries, and lagoons expanded again in the late Holocene, but the pattern is more complex (Fig. 4). This complexity probably results from the fact that, after post-glacial melting was complete, local sea-level fluctuations were influenced by a variety of factors, including global eustatic, regional hydro-isostatic, and tectonic influences (e.g. Dickinson, 2001). There is a similarly complex expansion in coastal settlements in the Pacific region in the period from *c.* 4000 yr BP to 1000 yr BP, as most coastal sites abandoned in the mid-Holocene were reoccupied at various times in the late Holocene.

The most notable late Holocene human expansion is the settlement of the numerous islands in Oceania, which began *c.* 3500–3000 yr BP, ultimately reaching Hawaii and Easter Island in the last 1000–2000 years. The initial spread is associated with a distinctive pottery type known as Lapita, found from coastal Papua New Guinea eastwards to Fiji, Tonga, and Samoa (e.g. Green, 1997). Multiple hypotheses have been advanced to explain the origin of the people carrying the Lapita culture, including a migration of Austronesianspeaking agriculturists from Southeast Asia, a more local dispersal of colonists from Melanesia, or a complex process involving multiple interaction spheres extending along the voyaging corridor from New Guinea to Samoa (e.g. Bellwood, 1989; Terrell & Welsch, 1997; Su *et al.*, 2000).

Regardless of the precise origin or nature of the Lapita phenomenon, the following question arises: why did it take some 35,000 years for the spread to take place? Cultural explanations for the late migration of people to eastern Melanesia and Polynesia typically evoke either limited seafaring capabilities prior to 3000 yr BP, or the late development of a well-adapted and 'portable' agricultural technology to support long-range colonization efforts. Alternative explanations focus on environmental factors, for example positing that fluctuating sea levels and unstable coastal environments prior to 6000 yr BP may have limited the potential of coastal settlements (Chappell, 1993a; Gosden, 1995). This environmental explanation has been articulated by Terrell (2002, 2004a,b, 2006) as the 'ancient lagoons hypothesis', which proposes that *c.* 6000 yr BP the sea-level rise slowed down sufficiently to permit the development of coastal lagoon and estuary ecosystems capable of supporting large permanent coastal settlements. This ancient lagoons hypothesis fits well with our analysis, if one assumes that the proper date in calibrated radiocarbon years is closer to 7000 yr BP, but the problem remains as to why was there still a lag of some 4000 years between the period of optimal coastal colonization and the spread of Lapita culture?

Dickinson (2001) has suggested that the Lapita spread to Oceania was linked to the late Holocene drop in sea level, which exposed more readily habitable land along island coastlines. This explanation seems unlikely, as such a drop in sea level is more likely to impact negatively on coastal resources, as once productive reefs emerge and coastal swamps dry out. There is no expansion of mainland coastal sites in this time period, and instead there is an overall trend towards a drop in coastal sites in many regions. The timing of the Lapita expansion does, as Dickinson (2001) notes, coincide with the lowering of sea level in the Pacific region, but it also correlates with the evidence reviewed above showing a decline in reef and estuarine/lagoon environments (Fig. 4). Therefore, we propose that a more likely environmental cause of the Lapita expansion was resource scarcity, which drove people to search for new, more productive habitats.

In summary, major climate and sea-level oscillations in the Late Pleistocene thwarted the initial migration of modern humans into the circum-Pacific region prior to 50,000 yr BP. A period of climatic and sea-level stability correlates with a large expansion in coastal human populations *c.* 45,000–40,000 yr BP, followed by a population decline during the LGM *c.* 33,000–16,000 yr BP. Another expansion in coastal settlements peaked *c.* 8000–6000 yr BP, concurrent with the peak post-glacial expansion of coastal estuaries, lagoons, and coral reefs. Sea-level fluctuations in the mid-Holocene (6,000–4,000 yr BP) disrupted coastal environments and settlements and may have helped to initiate the last stage of human expansion in the Pacific, namely the settling of Oceania *c.* 3500–1000 yr BP.

ACKNOWLEDGEMENTS

This research was supported by The Field Museum with funds from the Regenstein Endowment. We thank Stephen Oppenheimer for comments on an earlier draft of this paper.

REFERENCES

Acharya, S.K. & Basu, P.K. (1993) Toba ash on the Indian subcontinent and its implications for correlations of Late Pleistocene alluvium. *Quaternary Research*, **40,** 10–19.

Almogi-Labin, A., Schmiedl, G., Hemleben, C., Siman-Tov, R., Segl, M. & Meischner, D. (2000) The influence of the NE winter monsoon on productivity changes in the Gulf of Aden, NW Arabian Sea, during the last 530 ka as recorded by foraminifera. *Marine Micropaleontology*, **40,** 295–319.

Ambrose, S.H. (1998) Late Pleistocene human population bottlenecks, volcanic winter, and differentiation of modern humans. *Journal of Human Evolution*, **34,** 623–651.

Anderson, D. (2005) The use of caves in peninsular Thailand in the Late Pleistocene and early and middle Holocene. *Asian Perspectives*, **44,** 137–153.

Anikovich, M.V., Sinitsyn, A.A., Hoffecker, J.F., Holliday, V.T., Popov, V.V., Lisitsyn, S.N., Forman, S.L., Levkovskaya, G.M., Pospelova, G.A., Kuz'mina, I.E., Burova, N.D., Goldberg, P., Macphail, R.I., Giaccio, B. & Praslov, N.D. (2007) Early Upper Paleolithic in eastern Europe and implications for the dispersal of modern humans. *Science*, **315,** 223–226.

Anshari, G., Kershaw, A.P. & van der Kaars, S. (2001) A late Pleistocene and Holocene pollen and charcoal record from peat swamp forest, Lake Sentarum Wildlife Reserve, West Kalimantan, Indonesia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **171,** 213–228.

Ayliffe, L.K., Bird, M.I., Gagan, M.K., Isdale, P.J., Scott-Gagan, H., Parker, B., Griffin, D., Nongkas, M. & McCulloch, M.T. (2004) Geochemistry of coral from Papua New Guinea as a proxy for ENSO ocean–atmosphere interactions in the Pacific Warm Pool. *Continental Shelf Research*, **24,** 2343–2356.

Badawi, A., Schmiedl, G. & Hemleben, C. (2005) Impact of late Quaternary environmental changes on deep-sea benthic foraminiferal faunas of the Red Sea. *Marine Micropaleontology*, **58,** 13–30.

Balter, M. (2006) Radiocarbon dating's final frontier. *Science*, **313,** 1560–1563.

Bard, E., Hamelin, B., Fairbanks, R.G. & Zindler, A. (1990a) Calibration of the ^{14}C timescale over the past 30,000 years using mass spectrometric U–Th ages from Barbados corals. *Nature*, **345,** 405–410.

Bard, E., Hamelin, B. & Fairbanks, R.G. (1990b) U–Th ages obtained by mass spectrometry in corals from Barbados: sea level during the past 130,000 years. *Nature*, **346,** 456–458.

Barnabas, S., Shouche, Y. & Suresh, C.G. (2005) High-resolution mtDNA studies of the Indian population: Implications for Palaeolithic settlement of the Indian subcontinent. *Annals of Human Genetics*, **70,** 42–58.

Bar-Yosef, O. (2000). The Middle and Early Upper Palaeolithic in southwest Asia and neighbouring regions. *The geography of Neandertals and modern humans in Europe and the Greater Mediterranean* (ed. by O. Bar-Yosef and D. Pilbeam), pp. 107–156, Peabody Museum, Harvard University, Bulletin No. 8, Cambridge, MA.

Baskaran, M., Marathe, A.R., Rajaguru, S.N. & Somayajulu, B.L.K. (1986) Geochronology of Palaeolithic cultures in the Hiran Valley, Saurashtra, India. *Journal of Archaeological Science*, **13,** 505–514.

Baskaran, M., Rajagopalan, G. & Somayajulu, B.L.K. (1989) ^{230}Th/^{234}U and ^{14}C dating of the Quaternary carbonate deposits of Saurashtra, India. *Chemical Geology*, **79,** 65–82.

Beaufort, L., de Garidel-Thoron, T., Mix, A.C. & Pisias, N.G. (2001) ENSO-like forcing on oceanic primary production during the Late Pleistocene. *Science*, **293,** 2440–2444.

Beaufort, L., de Garidel-Thoron, T., Linsley, B., Oppo, D. & Buchet, N. (2003) Biomass burning and oceanic primary production estimates in the Sulu Sea area over the last 380 kyr and the East Asian monsoon dynamics. *Marine Geology*, **201,** 53–65.

Bednarik, R.G. (1999) Maritime navigation in the Lower and Middle Paleolithic. *Comptes Rendus de l'Académie des Sciences, Paris, Sciences de la Terre et des Planets*, **328,** 559–563.

Bellwood, P.S. (1989) The colonization of the Pacific: some current hypotheses. *The colonization of the Pacific: a genetic trail* (ed. by A.V.S. Hill and S.W. Serjeantson), pp. 1–59. Oxford University Press, Oxford.

van den Bergh, G.D., de Vos, J. & Sondaar, P.Y. (2001) The Late Quaternary palaeogeography of mammal evolution in the Indonesian Archipelago. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **171,** 385–408.

Bhatt, N. & Bhonde, U.A. (2003) Quaternary fluvial sequences of South Saurashtra, Western India. *Current Science*, **84,** 1065–1071.

Bird, M.I., Hope, G. & Taylor, D. (2004) Populating PEP II: the dispersal of humans and agriculture through Austral-Asia and Oceania. *Quaternary International*, **118–119,** 145–163.

Blackwell, B.B.B., Montoya, A., Blickstein, J.I.B., Skinner, A.R., Pappu, S., Gunnell, Y. & Taieb, M. (2005) ESR analyses of an open-air Paleolithic site: Hints about U uptake, water-table migration, reworking, and paleoenvironmental change at Attirampakkam, India. *Geological Society of America Abstracts with Programs*, **37,** 277. Paper No. 123-9.

Bowler, J.M. (1986) Quaternary landform evolution. *Australia – a geography, Vol. 1, The natural environment* (ed. by D.N. Jeans), pp. 117–147. Sydney University Press, Sydney.

Bruggemann, J.H., Buer, R.T., Guillaume, M.M.M., Walter, R.C., von Cosel, R., Ghebretensae, B.N. & Berhe, S.M. (2004) Stratigraphy, palaeoenvironments and model for the deposition of the Abdur Reef Limestone: context for an important archaeological site from the last interglacial on the Red Sea coast of Eritrea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **203,** 179–206.

Bühring, C., Sarnthein, M. & Erlenkeuser, H. (2004) Toward a high-resolution stable isotope stratigraphy of the last 1.1 m.y.: Site 1144, South China Sea. *Proceedings of the Ocean Drilling Program, Scientific Results*, Vol. 184 (ed. by W.L. Prell, et al.), pp. 1–29. Ocean Drilling Program, College Station, TX.

Burns, S.J., Fleitmann, D., Matter, A., Kramers, J. & Al-Subbary, A.A. (2003) Indian Ocean climate and an absolute chronology over Dansgaard/Oeschger Events 9 to 13. *Science*, **301,** 1365–1367.

Cabioch, G. & Ayliffe, L.K. (2001) Raised coral terraces at Malakula, Vanuatu, Southwest Pacific, indicate high sea level during marine isotope stage 3. *Quaternary Research*, **56,** 357–365.

Camoin, G.F., L.F. Montaggioni, L.F. & Braithwaite, C.J.R. (2004) *Late glacial to post glacial sea levels in the Western Indian Ocean, Marine Geology*, **206,** 119–146.

Cann, R. (2001) Genetic clues to dispersal in human populations: Retracing the past from the present. *Science*, **291,** 1742–1748.

Chang, J.H. & Choi, J.Y. (2001) Tidal-flat sequence controlled by Holocene sea-level rise in Gomso Bay, west coast of Korea. *Estuarine Coastal and Shelf Science*, **52,** 391–399.

Chappell, J. (1993a) Late Pleistocene coasts and human migrations in the Austral region. *A community of culture: the people and prehistory of the Pacific* (ed. by M. Spriggs, D.E. Yen, W. Ambrose, R. Jones, A. Thorne and A. Andrews), pp. 43–48. Australian National University, Canberra.

Chappell, J. (1993b) Contrasting Holocene sedimentary geologies of lower Daly River, northern Australia, and Sepik-Ramu, Papua New Guinea. *Sedimentary Geology*, **83,** 339–358.

Chappell, J. (2002) Sea level changes forced ice breakouts in the last glacial cycle: new results from coral terraces. *Quaternary Science Reviews*, **21,** 1229–1240.

Chappell, J. & Polach, H.A. (1991) Post-glacial sea-level rise from a coral record at Huon Peninsula, Papua New Guinea. *Nature*, **349,** 137–140.

Chappell, J., Omura, A., Esat, A., McCulloch, T., Pandolfi, M. & Pillans, J. (1996a) Reconciliation of late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep sea oxygen isotope records. *Earth and Planetary Science Letters*, **141,** 227–236.

Chappell, J., Ota, Y. & Berryman, K. (1996b) Late Quaternary coseismic uplift history of Huon Peninsula, Papua New Guinea. *Quaternary Science Reviews*, **15,** 7–22.

Chen, Y.-G. & Liu, T.-K. (1996) Sea level changes in the last several thousand years, Penghu Islands, Taiwan Strait. *Quaternary Research*, **45,** 254–262.

Chen, Y.-G. & Liu, T.-K. (2000) Holocene uplift and subsidence along an active tectonic margin southwestern Taiwan. *Quaternary Science Reviews*, **19,** 923–930.

Chen, M.-T., Shiau, L.-J., Yu, P.-S., Chiu, T.-C., Chen, Y.-G. & Wei, K.-Y. (2003) 500 000-Year records of carbonate, organic carbon, and foraminiferal sea-surface temperature from the southeastern South China Sea (near Palawan Island). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **197,** 113–131.

Chen, Y.-G., Liu, J.C.L., Shieh, Y.-N. & Liu, T.-K. (2004) Late Pleistocene to Holocene environmental changes as recorded in the sulfur geochemistry of coastal plain sediments, southwestern Taiwan. *Journal of Asian Earth Sciences*, **24,** 213–224.

Cheng-Hwa, T. (2002) Maritime adaptations in prehistoric southeast China: Implications for the problem of Austronesian expansion. *Journal of East Asian Archaeology*, **3,** 15–45.

Chlachula, J. (2001) Pleistocene climate change, natural environments and palaeolithic occupation of the Angara–Baikal area, east Central Siberia. *Quaternary International*, **80–81,** 69–92.

Clark, J.D., Beyene, Y., Gabrie, G.W., Hart, W.K., Renne, P.R., Gilbert, H., Defleur, A., Suwa, G., Katoh, S., Ludwig, K.R., Boisserie, J.-R., Asfawk, B. & White, T.D. (2003) Stratigraphic, chronological and behavioural contexts of Pleistocene *Homo sapiens* from Middle Awash, Ethiopia. *Nature*, **423,** 747–752.

Colin, C., Turpin, L., Bertaux, J., Desprairies, A. & Kissel, C. (1999) Erosional history of the Himalayan and Burman ranges during the last two glacial–interglacial cycles. *Earth and Planetary Science Letters*, **171,** 647–660.

Cordaux, R. & Stoneking, M. (2003) South Asia, the Andamanese, and the genetic evidence for an "early" human dispersal out of Africa. *The American Journal of Human Genetics*, **72,** 1586–1590.

Corrège, T. & De Deckker, P. (1997) Faunal and geochemical evidence for changes in intermediate water temperature and salinity in the western Coral Sea (northeast Australia) during the Late Quaternary. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **313,** 183–205.

Dam, R.A.C., Fluin, J., Suparan, P. & van der Kaars, S. (2001) Palaeoenvironmental developments in the Lake Tondanao area (N. Sulawesi, Indonesia) since 33,000 yr B.P. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **171,** 147–183.

Dennell, R., Rendell, H., Halim, M. & Moth, E. (1992) A 45,000-year-old open-air Paleolithic site at Riwat, northern Pakistan. *Journal of Field Archaeology*, **19,** 17–33.

Détroit, F., Dizon, E., Falguères, C., Hameau, S., Ronquillo, W. & Sémah, F. (2004) Upper Pleistocene *Homo sapiens* from the Tabon cave (Palawan, The Philippines): description and dating of new discoveries. *Comptes Rendus Palevol*, **3,** 705–712.

Dickinson, W.R. (2001) Paleoshoreline record of relative Holocene sea levels on Pacific islands. *Earth-Science Reviews*, **55,** 191–234.

Edgerly, D.W. (1974) Fossil reef of the Sahul shelf, Timor Sea. *Proceedings 2nd International Coral Reef Symposium*, **2,** 627–638.

Fairbanks, R.G. (1989) A 17,000-year glacio-eustatic sea level record: Influence of glacial melting rates on the Younger-Dryas event and deep ocean circulation. *Nature*, **342,** 637–641.

Fairbanks, R.G., Mortlock, R.A., Chiu, T.-C., Cao, L., Kaplan, A., Guilderson, T.P., Fairbanks, T.W., Bloom, A.L., Grootes, P.M. & Nadeau, M.-J. (2005) Radiocarbon calibration curve spanning 0 to 50,000 years yr BP based on paired $^{230}Th/^{234}U/^{238}U$ and ^{14}C dates on pristine corals. *Quaternary Science Reviews*, **24,** 1781–1796.

Fleitmann, D., Burns, S.J., Neff, U., Mangini, A. & Mattera, A. (2003) Changing moisture sources over the last 330,000 years in Northern Oman from fluid-inclusion evidence in speleothems. *Quaternary Research*, **60,** 223–232.

Forestier, H., Simanjuntak, T., Guillaud, D., Driwantoro, D., Wiradnyana, K., Siregar, D., Awe, R.D. & Budiman (2005) Le site de Tögi Ndrawa île de Nias, Sumatra nord les premières traces d'une occupation hoabinhienne en grotte en Indonésie. *Comptes Rendus Palevol*, **4,** 727–733.

Forster, P. (2004) Ice Ages and the mitochondrial DNA chronology of human dispersals: a review. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **359,** 255–264.

Geyh, M.S., Kudrass, H.R. & Streif, J. (1979) Sea-level changes during the late Pleistocene and Holocene in the Strait of Malacca. *Nature*, **278,** 441–443.

Gillespie, R. (2002) Dating the first Australians. *Radiocarbon*, **44,** 455–472.

Gingele, F.X., De Deckker, P., Girault, A. & Guichard, F. (2002) History of the South Java Current over the past 80 ka. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **183,** 247–260.

Goebel, T. (1999) Pleistocene human colonization of Siberia and peopling of the Americas: An ecological approach. *Evolutionary Anthropology*, **8,** 208–227.

Goebel, T., Derevianko, A.P. & Petrin, V.T. (1993) Dating the Middle-to-Upper-Paleolithic transition at Kara-Bom. *Current Anthropology*, **34,** 452–458.

Goebel, T., Waters, M.R. & Dikova, M. (2003) The archaeology of Ushki Lake, Kamchatka, and the Pleistocene peopling of the Americas. *Science*, **301,** 501–505.

Gong, S.-Y., Mii, H.-S., Wei, K.Y., Horng, C.-S., You, C.-F., Huang, F.-W., Chi, W.-R., Yui, T.-F., Torng, P.-K., Huang, S.-T., Wang, S.-W., Wu, J.-C. & Yang, K.-M. (2005) Dry climate near the Western Pacific Warm Pool: Pleistocene caliches of the Nansha Islands, South China Sea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **226,** 205–213.

Gonzalez, S., Huddart, D., Bennett, M.R. & Gonzalez-Huesca, A. (2006) Human footprints in Central Mexico older than 40,000 years. *Quaternary Science Reviews*, **25,** 201–222.

Goodbred, S.L., Jr & Kuehl, S.A. (2000) The significance of large sediment supply, active tectonism, and eustasy on margin sequence development: Late Quaternary stratigraphy and evolution of the Ganges-Brahmaputra delta. *Sedimentary Geology*, **133,** 227–248.

Gorecki, P., Mabin, M. & Campbell, J. (1991) Archaeology and geomorphology of the Vanimo coast, Papua New Guinea: Preliminary results. *Archaeology in Oceania*, **26,** 119–122.

Gosden, C. (1995) Arboriculture and agriculture in coastal Papua New Guinea. *Antiquity*, **69,** 807–817.

Gotanda, K., Nakagawa, T., Tarasov, P., Kitagawa, J., Inoue, Y. & Yasuda, Y. (2002) Biome classification from Japanese pollen data: application to modern-day and Late Quaternary samples. *Quaternary Science Reviews*, **21,** 647–657.

Green, R.C. (1997) Linguistic, biological, and cultural origins of the initial inhabitants of Remote Oceania. *New Zealand Journal of Archaeology*, **17,** 5–27.

Haberle, S.G. (1998) Late Quaternary vegetation change in the Tari Basin, Papua New Guinea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **137,** 1–24.

Haberle, S.G. (2005) A 23,000-yr pollen record from Lake Euramoo, wet tropics of NE Queensland, Australia. *Quaternary Research*, **64,** 343–356.

Hanebuth, T.J.J. & Stattegger, K. (2004) Depositional sequences on a late Pleistocene–Holocene tropical siliciclastic shelf (Sunda Shelf, southeast Asia). *Journal of Asian Earth Sciences*, **23,** 113–126.

Hanebuth, T.J.J., Stattegger, K., Schimanski, A., Lüdmann, T. & Wong, H.K. (2003) Late Pleistocene forced regressive deposits on the Sunda Shelf (SE Asia). *Marine Geology*, **199,** 139–157.

Hanebuth, T.J.J., Saito, Y., Tanabe, S., Vu, Q.L. & Ngo, Q.T. (2006) Sea levels during late marine isotope stage 3 (or older?) reported from the Red River delta (northern Vietnam) and adjacent regions. *Quaternary International*, **145-146,** 119–134.

Harpending, H.C., Sherry, S.T., Rogers, A.L. & Stoneking, M. (1993) The genetic structure of ancient human populations. *Current Anthropology*, **34,** 483–496.

Heinrich, H. (1988) Origin and consequences of cyclic ice-rafting in the northeast Atlantic Ocean during the past 1,30,000 years. *Quaternary Research*, **29,** 142–152.

Heusser, L.E. & Morley, J.J. (1997) Monsoon fluctuations over the past 350 kyr: high-resolution evidence from Northeast Asia/Northwest Pacific climate proxies (marine pollen and radiolarians). *Quaternary Science Reviews*, **16,** 565–581.

Hiscock, P. & Attenbrow, V. (2003) Early Australian implement variation: a reduction model. *Journal of Archaeological Science*, **30,** 239–249.

Hope, G. (2001) Environmental change in the Late Pleistocene and later Holocene at Wanda site, Soroako, South Sulawesi, Indonesia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **171,** 129–145.

Hori, K., Tanabe, S., Saito, Y., Haruyama, S., Nguyen, V. & Kitamura, A. (2004) Delta initiation and Holocene sea-level change: example from the Song Hong (Red River) delta, Vietnam. *Sedimentary Geology*, **164,** 237–249.

Hossfeld, P.S. (1964) The Aitape calvarium. *Australian Journal of Science*, **27,** 179.

Hossfeld, P.S. (1965) Radiocarbon dating and paleoecology of the Aitape fossil human remains. *Proceedings of the Royal Society of Victoria*, **78,** 161–165.

Igarashi, Y. (1993) History of environmental changes in Hokkaido from the viewpoint of palynological research. *Biodiversity and ecology in the northernmost Japan* (ed. by S. Higashi, A. Osawa and K. Kanagawa), pp. 1–19. Hokkaido University Press, Hokkaido.

Igarashi, Y. & Oba, T. (2006) Fluctuations in the East Asian monsoon over the last 144 ka in the northwest Pacific based on a high-resolution pollen analysis of IMAGES core MD01-2421. *Quaternary Science Reviews*, **25,** 1447–1459.

Izuho, M. & Keiichi, T. (2005) Correlation of Paleolithic industries and palaeoenvironmental change in Hokkaido (Japan). *Current Research in the Pleistocene*, **22,** 19–21.

James, H.V.A. & Petraglia, M.D. (2005) Modern human origins and the evolution of behavior in the later Pleistocene record of South Asia. *Current Anthropology Supplement*, **46,** S3–S27.

Jin, L. & Su, B. (2000) Natives or immigrants: Modern human origin in East Asia. *Nature Reviews Genetics*, **1,** 126–133.

Josenhans, H., Fedje, D., Pienitz, R. & Southon, J. (1997) Early humans and rapidly changing Holocene sea levels in the Queen Charlotte Islands–Hecate Strait, British Columbia, Canada. *Science*, **277,** 71–74.

van der Kaars, W.A. & Dam, M.A.C. (1995) A 135,000-year record of vegetational and climatic change from the Bandung area, West-Java, Indonesia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **117,** 55–72.

van der Kaars, S., Wang, X., Kershawa, P., Guichard, F. & Setiabudi, D.A. (2000) A Late Quaternary palaeoecological record from the Banda Sea, Indonesia: patterns of vegetation, climate and biomass burning in Indonesia and northern Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **155,** 135–153.

van der Kaars, S., Penny, D., Tibby, J., Fluin, J., Dam, R.A.C. & Suparan, P. (2001) Late Quaternary paleoecology, palynology, and palaeolimnology of a tropical lowland swamp: Rawa Danau, West-Java, Indonesia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **171,** 185–212.

Kawahata, H. & Ohshima, H. (2002) Small latitudinal shift in the Kuroshio Extension (Central Pacific) during glacial times: evidence from pollen transport. *Quaternary Science Reviews*, **21,** 1705–1717.

Kawashima, M. & Onishi, M. (2004) Fuchu-shi Musashi Kokubunji Ato Kanren Iseki (Musashidai Nishi Chiku) [Site Associated with the Musashi Provincial Temple Remains (Musashidai West Section)]. Tokyo-to Maizo Bunkazai Senta Chosa Hokoku Dai-149-shu. [*Tokyo Metropolitan Archaeological Research Center Reports*, **149**] (in Japanese).

Kayanne, H., Yamano, H. & Randall, R.H. (2002) Holocene sea-level changes and barrier reef formation on an oceanic island, Palau Islands, western Pacific. *Sedimentary Geology*, **150,** 47–60.

Kayser, M., Brauer, S., Weiss, G., Schiefenhövel, W., Underhill, P. & Stoneking, M. (2001) Independent histories of human Y chromosomes from Melanesia and Australia. *American Journal of Human Genetics*, **68,** 173–190.

Ke, Y., Su, B., Song, X., Lu, D., Chen, L., Li, H., Qi, C., Marzuki, S., Deka, R., Underhill, P., Xiao, C., Shriver, M., Lell, J., Wallace, D., Wells, R.S., Seielstad, M., Oefner, P., Zhu, D., Jin, J., Huang, W., Chakraborty, R., Chen, Z. & Jin, L. (2001) African origin of modern humans in East Asia: a tale of 12,000 Y chromosomes. *Science*, **292,** 1151–1153.

Keally, C.T. (1986) Cultural adaptation at the Pleistocene/Holocene boundary. Paper presented at the World Archaeological Congress, *The 11th Congress of the International Union of Prehistoric and Protohistoric Sciences*, Southampton, UK, 1–6 September 1986. Unpublished conference paper, see http://www.t-net.ne.jp/~keally/index.htm.

Keally, C.T. (1990) Hokkaido Pleistocene archaeology and the earliest Americans: Some comments. *Current Research in the Pleistocene*, **7,** 143–146.

Keally, C.T. & Izumi, H. (1987) The 30,000-year-old lithic components from the Musashidai site, Tokyo, Japan. *Current Research in the Pleistocene*, **4,** 61–64.

Kennedy, K.A.R. & Deraniyagala, S.U. (1989) Fossil remains of 28,000-year-old hominids from Sri Lanka. *Current Anthropology*, **30,** 394–399.

Kim, J.C., Youn, M.Y., Kim, I.C., Park, J.H., Song, Y.M., Kang, J., Choi, H.R., Yum, J.G. & Liu, Y. (2004) Dating paleosols from Paleolithic sites in Korea. *Nuclear Instruments and Methods in Physics Research B*, **223–224,** 723–730.

Kivisild, T., Bamshad, M.J., Kaldema, K., Metspalu, M., Metspalu, E., Reidla, M., Laos, S., Parik, J., Watkins, W.S., Dixon, M.E., Papiha, S.S., Mastana, S.S., Mir, M.R., Ferak, V. & Villems, R. (1999) Deep common ancestry of Indian and western Eurasian mitochondrial lineages. *Current Biology*, **9,** 1331–1334.

Kivisild, T., Rootsi, S., Metspalu, M., Mastana, S., Kaldma, K., Parik, J., Metspalu, E., Adojaan, M., Tolk, H.V., Stepanov, V., Golge, M., Usanga, E., Papiha, S.S., Cinnioglu, C., King, R., Cavalli-Sforza, L., Underhill, P.A. & Villems, R. (2003) The genetic heritage of the earliest settlers persists both in Indian tribal and caste populations. *American Journal of Human Genetics*, **72,** 313–332.

Kobayashi, H., Matsui, Y. & Suzuki, H. (1971) University of Tokyo radiocarbon measurements IV. *Radiocarbon*, **13,** 97–102.

Koizumi, I., Tada, R., Narita, H., Irino, T., Aramaki, T., Oba, T. & Yamamoto, H. (2006) Paleoceanographic history around the Tsugaru Strait between the Japan Sea and the Northwest Pacific Ocean since 30 cal kyr BP. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **232,** 36–52.

Korotky, A.M., Razjigaeva, N.G., Ganzey, L.A., Volkov, V.G., Grebennikova, T.A., Bazarova, V.B. & Kovalukh, N.N. (1995) Late Pleistocene–Holocene coastal development of islands off Vietnam. *Journal of Southeast Asian Earth Sciences*, **11,** 301–308.

Kumar, G., Narvare, G. & Pancholi, R. (1988) Engraved ostrich eggshell objects: New evidence of Upper Palaeolithic art in India. *Rock Art Research*, **5,** 43–53.

Kumaran, K.P.N., Nair, K.M., Shindikar, M., Limaye, R.B. & Padmalal, D. (2005) Stratigraphical and palynological appraisal of the Late Quaternary mangrove deposits of the west coast of India. *Quaternary Research*, **64,** 418–431.

Kuwae, M., Yoshikawa, S. & Yoshio Inouchi, Y. (2002) A diatom record for the past 400 ka from Lake Biwa in Japan correlates with global paleoclimatic trends. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **183,** 261–274.

Kuzmin, Y.K. (2002) Radiocarbon chronology of Paleolithic and Neolithic cultural complexes from the Russian Far East. *Journal of East Asian Archaeology*, **3,** 227–254.

Lacourse, T., Mathewes, R.W. & Fedje, D.W. (2005) Late-glacial vegetation dynamics of the Queen Charlotte Islands and adjacent continental shelf, British Columbia, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **226,** 36–57.

Lambeck, K., Yokoyama, Y. & Purcell, T. (2002) Into and out of the Last Glacial Maximum: sea-level change during Oxygen Isotope Stages 3 and 2. *Quaternary Science Reviews*, **21,** 343–360.

Lea, D.W., Pak, D.K. & Spero, H.J. (2000) Climate impact of Late Quaternary equatorial Pacific, sea surface temperature variations. *Science*, **289,** 1719–1724.

Leavesley, M.G. (2005) Prehistoric hunting strategies in New Ireland, Papua New Guinea: The evidence of the Cuscus (*Phalanger orientalis*) remains from Buang Merabak Cave. *Asian Perspectives*, **44,** 207–218.

Leavesley, M. & Chappell, J. (2004) Buang Merabak: additional early radiocarbon evidence of the colonisation of the Bismarck Archipelago, Papua New Guinea. *Antiquity*, **78,** 0.No. 301.

Li, T., Liu, Z., Hall, M.A., Berne, S., Saito, Y., Cang, S. & Cheng, Z. (2001) Heinrich event imprints in the Okinawa Trough: Evidence from oxygen isotope and planktonic foraminifera. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **176,** 133–146.

Lim, D.I., Jung, H.S., Kim, B.O., Choi, J.Y. & Kim, H.N. (2004) A buried palaeosol and late Pleistocene unconformity in coastal deposits of the eastern Yellow Sea, East Asia. *Quaternary International*, **121,** 109–118.

Macaulay, V., Hill, C., Achilli, A., Rengo, C., Clarke, D., Meehan, W., Blackburn, J., Semino, O., Scozzari, R., Cruciani, F., Taha, A., Shaari, N.K., Raja, J.M., Ismail, P., Zainuddin, Z., Goodwin, W., Bulbeck, D., Bandelt, H.-J., Oppenheimer, S., Torroni, A. & Richards, M. (2005) Single, rapid coastal settlement of Asia revealed by analysis of complete mitochondrial genomes. *Science*, **308,** 1034–1036.

Mann, D.H. & Peteet, D.M. (1994) Extent and timing of the Last Glacial Maximum in southwest Alaska. *Quaternary Research*, **42,** 136–148.

Marsset, T., Xia, D., Berne, S., Liu, Z., Bourillet, J.F. & Wang, K. (1996) Stratigraphy and sedimentary environments during the Late Quaternary, in the Eastern Bohai Sea (North China Platform). *Marine Geology*, **135,** 97–114.

Marth, G.T., Czabarka, E., Murvai, J. & Sherry, S.T. (2004) The allele frequency spectrum in genome-wide human variation data reveals signals of differential demographic history in three large world populations. *Genetics*, **166,** 351–372.

McBrearty, S. & Brooks, A.S. (1999) The revolution that wasn't: a new interpretation of the origin of modern human behavior. *Journal of Human Evolution*, **39,** 453–563.

Mellars, P. (2006a) A new radiocarbon revolution and the dispersal of modern humans in Eurasia. *Nature*, **439,** 931–935.

Mellars, P. (2006b) Going east: New genetic and archaeological perspectives on the modern human colonization of Eurasia. *Science*, **313,** 796–800.

Montaggioni, L.F. (2005) History of Indo-Pacific coral reef systems since the last glaciation: Development patterns and controlling factors. *Earth-Science Reviews*, **71,** 1–75.

Montenegro, A., Hetherington, R., Eby, M. & Weaver, A.J. (2006) Modeling pre-historic transoceanic crossings into the Americas. *Quaternary Science Reviews*, **25,** 1323–1338.

Morlan, R.E. (2003) Current perspectives on the Pleistocene archaeology of eastern Beringia. *Quaternary Research*, **60,** 123–132.

Moss, P.T. & Kershaw, A.P. (2000) The last glacial cycle from the humid tropics of northeastern Australia: comparison of a terrestrial and a marine record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **155,** 155–176.

Nakagawa, T., Tarasov, P.E., Nishida, K., Gotanda, K. & Yasuda, Y. (2002) Quantitative pollen-based climate reconstruction in central Japan: application to surface and Late Quaternary spectra. *Quaternary Science Reviews*, **21,** 2099–2113.

Nanson, G.C., Callen, R.A. & Price, D.M. (1998) Hydroclimatic interpretation of Quaternary shorelines on South Australian playas. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **144,** 281–305.

Nicholls, N. (1993) ENSO, drought and flooding rain in South-east Asia. *South-East Asia's environmental future: the search for sustainability* (ed. by H. Brookfield and Y. Byron), pp. 154–175. Oxford University Press, Singapore.

Norton, C.J. (2000) The current state of Korean paleoanthropology. *Journal of Human Evolution*, **38,** 803–825.

O'Connell, J.F. & Allen, J. (2004) Dating the colonization of Sahul (Pleistocene Australia–New Guinea): a review of recent research. *Journal of Archaeological Science*, **31,** 835–853.

Oda, S., Fujio, I., Kidder, J.E., Keally, C.T. & Yutaka, S. (eds) (1977) *Takaido Higashi Iseki* [*The Takaido Higashi Site*]. Takaido Higashi Iseki Chosakai [Takaido Higashi Excavation Project], Tokyo (in Japanese with English summary).

Okada, A. (1998) Maritime adaptations in Hokkaido. *Arctic Anthropology*, **35,** 340–349.

Oppenheimer, C. (2002) Limited global change due to the largest known Quaternary eruption, Toba ~74 kyr BP? *Quaternary Science Reviews*, **21,** 1593–1609.

Oppenheimer, S. (2003) *Out of Eden: the peopling of the world*. Constable, London.

Oppo, D.W. & Sun, Y. (2005) Amplitude and timing of sea-surface temperature change in the northern South China Sea: Dynamic link to the East Asian monsoon. *Geology*, **33,** 785–788.

Ota, Y. & Chappell, J. (1999) Holocene sea-level rise and coral reef growth on a tectonically rising coast, Huon Peninsula, Papua New Guinea. *Quaternary International*, **55,** 51–59.

Ota, Y., Chappell, J., Kelley, R., Yonekura, N., Matsumoto, E., Nishimura, T. & Head, J. (1993) Holocene coral reef terraces and cosesmic uplift of Huon Peninsula, Papua New Guinea. *Quaternary Research*, **40,** 177–188.

Peltier, W.R. (2005) On the hemispheric origins of meltwater pulse 1a. *Quaternary Science Reviews*, **24,** 1655–1671.

Petraglia, M.D. & Alsharekh, A. (2003) The Middle Palaeolithic of Arabia: Implications for modern human origins, behaviour, and dispersals. *Antiquity*, **77,** 671–684.

Piperno, D.R., Bush, M.B. & Colinvaux, P.A. (1990) Paleoenvironments and human occupation in late-glacial Panama. *Quaternary Research*, **33,** 108–116.

Pirazzoli, P.A. (1991) *World atlas of Holocene sea level changes*, Vol. 58. Elsevier Oceanographic Series, Amsterdam.

Prabhu, C.N., Shankar, R., Anupama, K., Taieb, M., Bonnefille, R., Vidal, L. & Prasad, S. (2004) A 200-ka pollen and oxygen-isotopic record from two sediment cores from the eastern Arabian Sea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **214,** 309–321.

Quintana-Murci, L., Semino, O., Bandelt, H.J., Passarino, G., McElreavey, K. & Santachiara-Benerecetti, A.S. (1999) Genetic evidence of an early exit of *Homo sapiens sapiens* from Africa through eastern Africa. *Nature Genetics*, **23,** 437–441.

Rabett, R.J. (2005) The early exploitation of Southeast Asian mangroves: Bone technology from caves and open sites. *Asian Perspectives*, **44,** 154–179.

Rampino, M.R. & Ambrose, S.H. (2000) Volcanic winter in the Garden of Eden: the Toba super-eruption and the Late Pleistocene human population crash. *Volcanic hazards and disasters in human antiquity* (ed. by F.W. McCoy and G. Heiken). *Geological Society of America Special Paper*, **345,** 71–82.

Ramsey, C.B., Buck, C.E., Manning, S.W., Reimer, P. & Van der Plicht, H. (2006) Developments in radiocarbon calibration for archaeology. *Antiquity*, **80,** 783–798.

Roberts, R.G., Jones, R., Spooner, N.A., Head, M.J., Murray, A.S. & Smith, M.A. (1994) The human colonisation of Australia: Optical dates of 53,000 and 60,000 years bracket human arrival at Deaf Adder Gorge, Northern Territory. *Quaternary Science Reviews*, **13,** 575–583.

Roberts, R.G., Morwood, M.J. & Westaway, K.E. (2005) Illuminating Southeast Asian Prehistory: New archaeological and paleoanthropological frontiers for luminescence dating. *Asian Perspectives*, **44,** 293–319.

Saito, Y., Katayama, H., Ikehara, K., Kato, Y., Matsumoto, E., Oguri, K., Oda, M. & Umoto, M. (1998) Transgressive and highstand systems tracts and post-glacial transgression the East China Sea. *Sedimentary Geology*, **122,** 217–232.

Sasaki, K., Omura, A., Murakami, K., Sagawa, N. & Nakamori, T. (2004) Interstadial coral reef terraces and relative sea-level changes during marine oxygen isotope stages 3–4, Kikai

Island, central Ryukyus, Japan. *Quaternary International*, **120,** 51–64.

Sato, H., Okuno, J., Nakada, M. & Maeda, Y. (2001) Holocene uplift derived from relative sea-level records along the coast of western Kobe, Japan. *Quaternary Science Reviews*, **20,** 1459–1474.

Schulz, H., von Rad, U. & Erlenkeuser, H. (1998) Correlation between Arabian Sea and Greenland climate oscillations of the past 110,000 years. *Nature*, **393,** 54–57.

Schurr, T.G. (2004) The peopling of the New World: Perspectives from molecular anthropology. *Annual Review of Anthropology*, **33,** 551–583.

Siddall, M., Rohling, E.J., Almogi-Labin, A., Hemleben, Ch., Meischner, D., Schmelzer, I. & Smeed, D.A. (2003) Sea-level fluctuations during the last glacial cycle. *Nature*, **423,** 854–858.

Simanjuntak, T. (2006) Indonesia–Southeast Asia: Climates, settlements, and cultures in Late Pleistocene. *Comptes Rendus Palevol*, **5,** 371–379.

Singh, I.B., Sharma, S., Sharma, M., Srivastava, P. & Rajagopalan, G. (1999) Evidence of human occupation and humid climate of 30 ka in the alluvium of southern Ganga Plain. *Current Science*, **76,** 1022–1026.

Song, S.-R., Chen, C.-H., Lee, M.-Y., Yang, T.F., Iizuka, Y. & Wei, K.-Y. (2000) Newly discovered eastern dispersal of the youngest Toba Tuff. *Marine Geology*, **167,** 303–312.

Srivastava, P., Juyal, N., Singhvi, A.K., Wasson, R.J. & Bateman, M.D. (2001) Luminescence chronology of river adjustment and incision of Quaternary sediments in the alluvial plain of the Sabarmati River, north Gujarat, India. *Geomorphology*, **36,** 217–229.

Srivastava, P., Singh, I.B., Sharma, M. & Singhvi, A.K. (2003) Luminescence chronometry and Late Quaternary geomorphic history of the Ganga Plain, India. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **197,** 15–41.

Steinke, S., Kienast, M. & Hanebuth, T.J.J. (2003) On the significance of sea-level variations and shelf paleo-morphology in governing sedimentation in the southern South China Sea during the last deglaciation. *Marine Geology*, **201,** 197–206.

Stevenson, J. & Hope, G. (2005) A comparison of late Quaternary forest changes in New Caledonia and northeastern Australia. *Quaternary Research*, **64,** 372–383.

Stringer, C. (2000) Coasting out of Africa. *Nature*, **405,** 24–27.

Stringer, C.B. & Andrews, P. (1988) Genetic and fossil evidence for the origin of modern humans. *Science*, **239,** 1263–1268.

Stringer, C.B., Grün, R., Schwarcz, H.P. & Goldberg, P. (1989) ESR dates for the hominid burial site of Skhul in Israel. *Nature*, **338,** 756–758.

Stuiver, M. & Reimer, P.J. (1993) Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon*, **35,** 215–230.

Su, B., Jin, L., Underhill, P., Martinson, J., Saha, N., McGarvey, S.T., Shriver, M.D., Chu, J., Oefner, P., Chakraborty, R. & Deka, R. (2000) Polynesian origins Insights from the Y chromosome. *Proceedings of the National Academy of Sciences USA.*, **97,** 8225–8228.

Sugihara, K., Nakamori, T., Iryu, Y., Sasaki, K. & Blanchon, P. (2003) Holocene sea-level change and tectonic uplift deduced from raised reef terraces, Kikai-jima, Ryukyu Islands, Japan. *Sedimentary Geology*, **159,** 5–25.

Sun, X. & Li, X. (1999) A pollen record of the last 37 ka in deep sea core 17,940 from the northern slope of the South China Sea. *Marine Geology*, **156,** 227–244.

Swadling, P. & Hope, G. (1992) Environmental change in New Guinea since human settlement. *The naïve lands: prehistory and environmental change in Australia and the Southwest Pacific* (ed. by J.R. Dodson), pp. 13–42. Longman Cheshire, Melbourne.

Swadling, P., Chappell, J., Francis, G., Araho, N. & Ivuyo, B. (1989) A Late Quaternary inland sea and early pottery in Papua New Guinea. *Archaeologia Oceania*, **24,** 106–109.

Swadling, P., Araho, N. & Ivuyo, B. (1991) Settlements associated with the inland Sepik-Ramu sea. *Indo-Pacific Prehistory Association Bulletin*, **11,** 92–112.

Ta, T.K.O., Nguyen, V.L., Tateishi, M., Kobayashi, I. & Saito, Y. (2001) Sediment facies and diatom and foraminifer assemblages of a late Pleistocene–Holocene incised-valley sequence from the Mekong River delta, Bentre Province, southern Vietnam: the BT2 core. *Journal of Asian Earth Sciences*, **20,** 83–94.

Ta, T.K.O., Nguyen, V.L., Tateishi, M., Kobayashi, I., Tanabe, S. & Saito, Y. (2002) Holocene delta evolution and sediment discharge of the Mekong River, southern Vietnam. *Quaternary Science Reviews*, **21,** 1807–1819.

Takahara, H., Sugita, S., Harrison, S.P., Miyoshi, N., Morita, Y. & Uchiyama, T. (2000) Pollen-based reconstructions of Japanese biomes at 0, 6000 and 18,000 ^{14}C yr BP. *Journal of Biogeography*, **27,** 665–683.

Takahashi, K., Soeda, Y., Izuho, M., Yamada, G., Akamatsu, M. & Chang, C.-H. (2006) The chronological record of the woolly mammoth (*Mammuthus primigenius*) in Japan, and its temporary replacement by *Palaeoloxodon naumanni* during MIS 3 in Hokkaido (northern Japan). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **233,** 1–10.

Tamura, T. & Masuda, F. (2004) Inner shelf to shoreface depositional sequence in the Sendai coastal prism, Pacific coast of northeastern Japan: spatial and temporal growth patterns in relation to Holocene relative sea-level change. *Journal of Asian Earth Sciences*, **23,** 567–576.

Tanabe, S., Hori, K., Saito, Y., Haruyama, S., Doanh, L.Q., Sato, S. & Hiraide, S. (2003) Sedimentary facies and radiocarbon dates of the Nam Dinh-1 core from the Song Hong (Red River) delta, Vietnam. *Journal of Asian Earth Sciences*, **21,** 503–513.

Tandon, S.K., Sareen, B.K., Someshwararao, M. & Singhvi, A.K. (1997) Aggradation history and luminescence chronology of Late Quaternary semi-arid sequences of the Sabarmati basin, Gujarat, western India. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **128,** 339–357.

Terrell, J.E. (2002) Tropical agroforestry, coastal lagoons, and Holocene prehistory in Greater Near Oceania. *Vegeculture in Eastern Asia and Oceania* (ed. by S. Yoshida and P.J. Matthews), pp. 195–216. Monbusho International Symposium, JCAS Symposium Series No. 16. Japan Centre for Area Studies, Osaka.

Terrell, J.E. (2004a) The 'sleeping giant' hypothesis and New Guinea's place in the prehistory of Greater Near Oceania. *World Archaeology*, **36,** 601–609.

Terrell, J.E. (2004b) Island models of reticulate evolution: The 'ancient lagoons' hypothesis. *Voyages of discovery: the archaeology of islands* (ed. by S. Fitzpatrick), pp. 203–222. Greenwood Press, Westport, CT.

Terrell, J.E. (2006) Human biogeography: evidence of our place in nature. *Journal of Biogeography*, **33,** 2088–2098.

Terrell, J.E. & Welsch, R.L. (1997) Lapita and the temporal geography of prehistory. *Antiquity*, **71,** 548–572.

Tewari, R., Pant, P.C., Singh, I.B., Sharma, S., Sharma, M., Srivastava, P., Singhvi, A.K., Mishra, P.K. & Tobschall, H.J. (2002) Middle Palaeolithic human activity and palaeoclimate at Kalpi in Yamuna Valley, Ganga Plain. *Man and Environment*, **27,** 1–13.

Thangaraj, K., Chaubey, G., Kivisild, T., Reddy, A.G., Singh, V.K., Rasalkar, A.A. & Singh, L. (2005) Reconstructing the origin of Andaman Islanders. *Science*, **308,** 996.

Thevenon, F., Bard, E., Williamson, D. & Beaufort, L. (2004) A biomass burning record from the West Equatorial Pacific over the last 360 ky: methodological, climatic and anthropic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **213,** 83–99.

Trinkaus, E. & Ruff, C.B. (1996) Early modern human remains from Eastern Asia: The Yamashitacho I immature postcrania. *Journal of Human Evolution*, **30,** 299–314.

Turney, C.S.M., Bird, M.I., Fifield, L.K., Kershaw, A.P., Cresswell, R.G., Santos, G.M., di Tada, M.L., Hausladen, P.A. & Youping, Z. (2001) Development of a robust ^{14}C chronology for Lynch's Crater (North Queensland, Australia) using different pretreatment strategies. *Radiocarbon*, **43,** 45–54.

Turney, C.S.M., Roberts, R.G. & Jacobs, Z. (2006) Progress and pitfalls in radiocarbon dating. *Nature*, **443,** E3.

Underhill, P.A. (2004) A synopsis of extant Y chromosome diversity in East Asia and Oceania. *The peopling of East Asia: putting together archaeology, linguistics and genetics* (ed. by L. Sagart, R. Blench and A. Sanchez-Mazas), pp. 301–319. Routledge Curzon, London.

Underhill, P.A., Shen, P., Lin, A.A., Jin, L., Passarino, G., Yang, W.H., Kauffman, E., Bonné-Tamir, B., Bertranpetit, J., Francalacci, P., Ibrahim, M., Jenkins, T., Kidd, J.R., Mehdi, S.Q., Seielstad, M.T., Wells, R.S., Piazza, A., Davis, R.W., Feldman, M.W.L., Cavalli-Sforza, L. & Oefner, P.J. (2000) Y chromosome sequence variation and the history of human populations. *Nature Genetics*, **26,** 358–361.

Underhill, P.A., Shen, P., Mirazon Lahr, M., Foley, R.A., Oefner, P.J. & Cavalli-Sforza, L.L. (2001) The phylogeography of Y chromosome binary haplotypes and the origins of modern human populations. *Annals of Human Genetics*, **65,** 43–62.

Veth, P., Spriggs, M. & O'Connor, S. (2005) Continuity in tropical cave use: examples from East Timor and the Aru Islands, Maluku. *Asian Perspectives*, **44,** 180–192.

Vora, K.H., Wagle, B.G., Veerayya, M., Almeida, F. & Karisiddaiah, S.M. (1996) 1300 km long late Pleistocene-Holocene shelf edge barrier reef system along the western continental shelf of India: occurrence and significance. *Marine Geology*, **134,** 145–162.

Voris, H.K. (2000) Maps of Pleistocene sea levels in Southeast Asia: shorelines, river systems and time durations. *Journal of Biogeography*, **27,** 1153–1167.

Walter, R.C., Buffler, R.T., Bruggemann, J.H., Guillaume, M.M.M., Berhe, S.M., Negassi, B., Libsekal, Y., Cheng, H., Edwards, R.L., von Cosel, R., Néraudeau, D. & Gagnon, M. (2000) Early human occupation of the Red Sea coast of Eritrea during the last interglacial. *Nature*, **405,** 65–69.

Wang, Y.J., Cheng, H., Edwards, R.L., An, Z.S., Wu, J.Y., Shen, C.-C. & Dorale, J.A. (2001) A high-resolution absolute-dated late Pleistocene monsoon record from Hulu Cave, China. *Science*, **294,** 2345–2348.

Weninger, B., Jöris, O. & Danzeglocke, U. (2005) *CalPal: Cologne Radiocarbon Calibration and Paleoclimate Research Package*. http://www.calpal-online.de/.

Westgate, J.A., Shane, P.A.R., Pearce, N.J.G., Perkins, W.T., Korisettar, R., Chesner, C.A., Williams, M.A.J. & Acharyya, S.K. (1998) All Toba Tephra occurrences across Peninsular India belong to the 75,000 yr B.P. eruption. *Quaternary Research*, **50,** 107–112.

White, J.C., Penny, D., Kealhofer, L. & Maloney, B. (2004) Vegetation changes from the late Pleistocene through the Holocene from three areas of archaeological significance in Thailand. *Quaternary International*, **113,** 111–132.

Woodroffe, C.D., Kennedy, D.M., Hopley, D., Rasmussen, C.E. & Smithers, S.G. (2000) Holocene reef growth in Torres Strait. *Marine Geology*, **170,** 331–346.

Yabe, H., Yasui, S., Urabe, A. & Takahama, N. (2004) Holocene paleoenvironmental changes inferred from the diatom records of the Echigo Plain, central Japan. *Quaternary International*, **115–116,** 117–130.

Yamaguchia, M. & Ota, Y. (2004) Tectonic interpretations of Holocene marine terraces, east coast of Coastal Range, Taiwan. *Quaternary International*, **115-116,** 71–81.

Yasuda, Y., Yamaguchi, K., Nakagawa, T., Fukusawa, H., Kitagawa, J. & Okamura, M. (2004) Environmental variability and human adaptation during the Lateglacial/Holocene transition in Japan with reference to pollen analysis of the SG4 core from Lake Suigetsu. *Quaternary International*, **123-125,** 11–19.

Yasuhara, M., Irizuki, T., Yoshikawa, S., Nanayama, F. & Mitamura, M. (2004) Holocene ostracode paleobiogeography in Osaka Bay, southwestern Japan. *Marine Micropaleontology*, **53,** 11–36.

Yesner, D.R. (2001) Human dispersal into interior Alaska: antecedent conditions, mode of colonization, and adaptations. *Quaternary Science Reviews*, **20,** 315–327.

Yim, W.W.-S. (1999) Radiocarbon dating and the reconstruction of late Quaternary sea-level changes in Hong Kong. *Quaternary International*, **55,** 77–91.

Yim, W.W.-S., Huang, G. & Chan, L.S. (2004) Magnetic susceptibility study of Late Quaternary inner continental shelf sediments in the Hong Kong SAR, China. *Quaternary International*, **117,** 41–54.

Yokoyama, Y., De Deckker, P., Lambeck, K., Johnston, P. & Fifield, L.K. (2001) Sea-level at the Last Glacial Maximum: evidence from northwestern Australia to constrain ice volumes for oxygen isotope stage 2. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **165,** 281–297.

Yoo, D.-G., Park, S.-C., Sunwoo, D. & Oh, J.-H. (2003) Evolution and chronology of late Pleistocene shelf-perched lowstand wedges in the Korea Strait. *Journal of Asian Earth Sciences*, **22,** 29–39.

Yu, K.-F., Zhao, J.-X., Wei, G.-J., Cheng, X.-R. & Wang, P.-X. (2005) Mid–late Holocene monsoon climate retrieved from seasonal Sr/Ca and d18O records of *Porites lutea* corals at Leizhou Peninsula, northern coast of South China Sea. *Global and Planetary Change*, **47,** 301–316.

Zheng, Z. & Lei, Z.-Q. (1999) A 400,000 year record of vegetational and climatic changes from a volcanic basin, Leizhou Peninsula, southern China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **145,** 339–362.

BIOSKETCHES

Kevin O. Pope is the founder and Chief Scientist at Geo Eco Arc Research, a private company specializing in archaeological, geological, and ecological research. Pope received his PhD in geological archaeology from Stanford University and has broad interests in the intersection of archaeology and the geosciences.

John E. Terrell is the Regenstein Curator of Pacific Anthropology at the Field Museum of Natural History, Chicago, and Adjunct Professor of Anthropology at the University of Illinois, Chicago, and Northwestern University. His research addresses issues related to the genesis and maintenance of human cultural and biological diversity. His primary focus is on the Pacific Islands.

Editor: Sandy Harcourt