

Populating PEP II: the dispersal of humans and agriculture through Austral-Asia and Oceania

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Abstract

This paper examines the history of *Homo erectus* and *Homo sapiens* in the Austral-Asian region bisected by the PEP II (Pole–Equator–Pole) transect, from Siberian Russia, south through Asia, insular Southeast Asia, Australasia and Oceania. Current evidence is reviewed for the timing of the arrival of humans along PEP II, their subsequent expansion through the region and their concurrent development or acquisition of increasingly sophisticated technologies for resource exploitation. Particular emphasis is placed on assessing the role of environmental change in the observed trajectories of human dispersal and technological development. It is concluded that rapid environmental change events may have influenced at least some of these trajectories.

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1. Introduction

The dispersal of humans and their technologies, notably agriculture, through the Austral-Asian region is of interest globally. The region has yielded some of the oldest hominid remains, in the form of Miocene-age fossils from the Potwar Plateau, northern Pakistan. Furthermore, evidence from the PEP II transect has been used to construct contrasting models of the dispersal of humans and technology and suggests that the region included foci for the early domestication of plants, such as rice (*Oryza sativa*) and foxtail millet (*Setaria italica*) and animals, urbanisation, and the world's earliest crossing of a major ocean by humans.

The genus *Homo* boasts a lengthy tenure in the region. For several decades of the 20th Century, the remains of 'Java Man' from Trinil and 'Peking Man' from Zhoukoudian, discovered respectively in 1891 and 1929, both now classified as *Homo erectus*, constituted the best evidence for an ancient 'missing link' between apes and modern humans. *H. erectus* moved into Asia with the ability to fashion simple stone tools, and adapt rapidly to changing environmental conditions.

H. sapiens subsequently displaced *H. erectus*, importing or developing the more sophisticated technologies and social structures that ultimately enabled humans to occupy almost the entire land area of the PEP II transect. In later times, as elsewhere in the world, *H. sapiens* began to domesticate a number of plants and animals indigenous to the region (Lebot, 1999). These and later developments conferred upon *H. sapiens* an increasingly potent capacity to modify the local environment. From humble initial efforts at forest clearance in the late Pleistocene (e.g., Haberle et al., 1991), humans are now capable of clearing 16.9 million hectares of tropical forest per year, a significant portion of this located on the PEP II transect.

The environment and geography of the Austral-Asian region have always presented major challenges to dispersal and some geographic barriers have existed for the full period of hominid evolution. The major fixed geographic barriers are high mountain ranges, such as the Himalayas, and deep-water channels that have served to permanently isolate adjacent landmasses from each other, even during times of lowered glacial sea levels. The biogeographical province of Wallacea marks a series of deep-water channels and islands that divide modern insular Southeast Asia into the distinct Asian and Australasian biogeographic provinces, demonstrating the long-term impermeability of some geographic barriers to many species. In the case of the genus *Homo*,

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the Wallace Line was breached long ago by *H. erectus* (Morwood, 2001). In contrast, the long water crossing and extremely hostile climate at the southernmost end of the PEP II transect has meant that Antarctica was only colonized permanently by *H. sapiens* mere decades ago.

Climatic constraints to dispersal in the past have varied both spatially and temporally. The very large range of environments along the PEP II transect, from polar desert to humid tropics, has resulted in regional variation in the nature and relative significance of different climatic constraints to dispersal. In the broadest possible terms, the most significant climate-dependent constraints to dispersal can be categorized as temperature, sea level and aridity; ice, sea and sand. At the northern end of the PEP II transect, temperature delineates the inhabitable area for humans and domesticates. The position of the boundary between inhabitable and uninhabitable has shifted in the past in response to changing global climate. During glacial times there was the additional physical barrier of an extensive icecap that blocked movement at high latitudes.

In inter-tropical parts of the region, changes in relative sea level (linked to changes in temperature) may have played a major role in modulating dispersal. This is particularly true of insular Southeast Asia, where glacial–interglacial changes in sea level repeatedly exposed and then flooded the ice-age continent of Sundaland. Relative sea level determines whether land bridges are available to assist dispersal between adjacent landmasses without the need for a water crossing. In addition, relative sea level determines whether shallow marine passages such as the Straits of Malacca are open to navigation, allowing direct connections between coastal areas that may be widely separated at times of lowered sea level (Voris, 2000). Once humans surmounted the several deep-water crossings east of Sundaland to make landfall in the Sahul, colonists were faced with a continent where water was in short supply over large areas. The degree and distribution of aridity in Australia has varied in the past and water availability is likely to have exerted a major control on dispersal through much of the Australian portion of the PEP II transect.

Past changes in local and global environmental conditions have therefore offered both opportunities for, and barriers to, dispersal, depending on time and location. The glacial–interglacial changes associated with Milankovitch cycles are characterized by predictable and repeating oscillations in climate while other climatic events, such as the Younger Dryas, have been characterized by rapid, large and comparatively short-lived shifts in climate (Adams et al., 1999). It is also possible that singular events such as volcanic eruptions (Ambrose, 1998), meteorite impacts (Baillie, 1999) or periods of rapid sea level rise (Oppenheimer, 1998) may

have impacted the capacity or desire of human populations to disperse to new areas. Any of these environmental changes may also have partly enabled or catalysed social and technological developments in, for example, maritime technology or herding and agriculture, that enabled further range expansion, even in the face of a subsequent deterioration in environmental conditions.

It is the purpose of this paper to review the complex interactions between environment, geography and the dispersal of humans and agriculture on the PEP II transect. All ages reported in this paper are calendar years ('years ago') unless quoted as 'years BP', in which case the age refers to radiocarbon years before 1950. Radiocarbon years BP are only used for the period beyond the Last Glacial Maximum (LGM) (~20,000 years ago), where calibration to calendar years is currently uncertain.

2. Getting to PEP II

2.1. *H. erectus* in the Austral-Asian region

H. erectus, the earliest hominid whose remains have been found in the area of the PEP II transect, evolved in east equatorial Africa 1.8–1.9 million years ago. It was thought that *H. erectus* moved out of Africa about 1 million years ago, but simple stone tools at Longgupo in southern China attributed to *H. erectus* have now been palaeomagnetically dated to 1.9 million years (Huang et al., 1996). This early expansion, if substantiated, may predate the northward expansion of *H. erectus* into temperate Eurasia, where the earliest remains date to about 1.7 million years at Dmanisi in Georgia (Gabunia et al., 2000).

In their summary of the evidence for early Palaeolithic occupation of China and mainland Southeast Asia, Schepartz et al. (2000) concluded that initial migrations probably took place between 1.5 and 1.0 million years ago, and that upland regions with mixed vegetational zones and river courses were important environments for *H. erectus* in mainland Southeast Asia. Zhu et al. (2001) have recently demonstrated that *H. erectus* had penetrated as far as 40°N in China by 1.36 million years ago; possible *H. erectus* remains have been recovered from Middle Pleistocene-age deposits (younger than 0.73 Ma and older than 74,000 years ago) in the Narmada valley, India (Sonakia and Biswas, 1998) and Barnes and Okita (1999) review the evidence for the arrival of *H. erectus* in Japan some 500,000 years ago, presumably via Sakhalin at a time of low sea level. Roland (2000) considers that *H. erectus* in China developed the ability to manipulate fire about 400,000 years ago, adding a potent tool for environmental modification to the hominid toolkit.

Most of the earliest dates for *H. erectus* from the PEP II region have yet to gain full acceptance, while considerable controversy continues to surround the Narmada remains, which Kennedy (1992) maintains represent an archaic form of *H. sapiens*. In Java, a date of 1.8 million years has been suggested for *H. erectus* at Mojokerto (Swisher et al., 1994), while dates as young as 27,000–53,000 years have been suggested for youngest *H. erectus* remains at Ngandong (Swisher et al., 1996). The reliability of both sets of dates has been questioned (e.g., Grün and Thorne, 1997; Keates, 1998), with some researchers favouring an approximate range of 1.2 million–300,000 years for the tenure of *H. erectus* in island Southeast Asia.

Of particular importance is evidence that *H. erectus* had arrived in Flores by 840,000 years ago, roughly coincident with the earliest dates for their arrival in Europe (Morwood et al., 1998; Morwood, 2001). Unlike other colonizations, the colonization of Flores required at least one major water crossing, even allowing for the possibility that eustatic effects in the mid-Pleistocene may have led to sea levels 20–40 m below the LGM sea level low-stand (Gascoyne et al., 1979; Rohling et al., 1998). That *H. erectus* managed to voyage to Flores suggests that the technological capacity of the species has been underestimated. The complex logistics required to construct watercraft capable of transporting a viable population to Flores suggests the acquisition of language by hominids 800,000 years ago (Morwood et al., 1998; Morwood, 2001).

The human and environmental record of the early and middle Pleistocene in Austral-Asia is too fragmentary for a comparison of environmental controls on dispersal. *H. erectus* on PEP II could manipulate fire and carried a simple tool kit of crude stone choppers, derived from heavily flaked river pebbles and possibly augmented in the humid tropics by wood and bamboo tools. The geochronological evidence for rapid expansion from Africa into the PEP II region is consistent with a progressive latitudinal expansion by the occupation of regions of broadly similar climate. The glacial–interglacial cycles of the Quaternary certainly provided ample opportunity for the colonization of island Southeast Asia from Africa. By broad analogy with more recent times, it seems likely that glacial periods may have been cooler and drier in the tropical parts of the PEP II transect, with reduced moist tropical forest area and expanded areas of dry forest and savanna (e.g., Heaney, 1991; Gathorne-Hardy et al., 2002).

Lower sea level and the more open vegetation of glacial periods may have been conducive to dispersal in the low latitudes. It therefore seems possible that in the tropics, glacial periods and periods of transition between interglacial and glacial conditions may have been times of radiation, while interglacial periods were times of consolidation. Conversely, at extra-tropical latitudes,

the warmer interglacial periods and transitions from glacial to interglacial conditions were conducive to dispersal into new and more northerly ranges, while glacial periods saw consolidation or contractions of range in response to decreasing temperatures. It does seem clear that *H. erectus* lacked the capacity to colonize the highest northern latitudes of PEP II and did not complete the difficult voyages required to reach further east of Wallace's Line than Flores (or possibly Timor).

2.2. *H. sapiens* and colonisation

Lively debate continues as to whether the early *H. erectus* populations of Java and China continued to evolve in partial isolation from populations in other parts of the world, ultimately giving rise to distinct populations of *H. sapiens* in Asia and Australia (the Regional Continuity Model) or whether *H. erectus* was displaced by anatomically modern humans who evolved 100–200,000 years ago in Africa (the Out of Africa Model). Anthropological and genetic evidence in support of either model is summarized in Adcock et al. (2001), Cann (2001), Cooper et al. (2001) and Storm (2001).

Within the Out of Africa family of arguments, debate also continues over whether there was a single migration of modern *H. sapiens* from Africa after 50,000 years ago (e.g., Klein, 1999) or several migrations out of Africa beginning earlier than 50,000 years ago (e.g., Lahr and Foley, 1998). Recent discoveries of engraved ochres in Africa suggest that humans were capable of at least components of modern behaviour by at least 77,000 years ago, and by inference were potentially capable of dispersal from at least this time (Henshilwood et al., 2002).

Ambrose (1998) envisions early populations of *H. sapiens* rising and falling in response to climatic changes over the last 100,000 years, with the most dramatic decrease (to less than 10,000 individuals globally) occurring as the result of a lowering of temperatures following the Mount Toba eruption in Sumatra around 70,000 years ago (Rampino and Self, 1992). This model suggests that the major expansion in the population of *H. sapiens* occurred after 70,000 years ago, with further impetus for dispersal provided by the development of more efficient upper Palaeolithic technologies after ~50,000 years ago.

Stringer (2000) points to the importance of coastal travel during periods of lowered sea level as controlling the trajectory of dispersal of *H. sapiens* from their African homeland, east to the coasts of island Southeast Asia and in the process bypassing existing *H. erectus* populations still living in interior Java. Mannino and Thomas (2002) also point to the importance of easily depleted coastal resources as a driver of early human

dispersal. Unfortunately, uncontested evidence for the early dispersal of *H. sapiens* throughout Austral-Asia with which to test these or any other models is remarkably sparse.

In China, archaic forms of *H. sapiens* date to about 200,000 years ago (Chen et al., 1994), but the earliest date for modern human remains is a uranium series (U-series) age of 67,000 years from Liujiang Cave (Yuan et al., 1986). The association between the dated material and human remains at Liujiang has been questioned (e.g. Brown, 2001) and the oldest radiocarbon dates for anatomically modern *H. sapiens* are about 35,000 BP (Wu, 1992, 1996). Chakrabarti (1999, pp. 74–75) lists the following dates for deposits from the Indian subcontinent believed to be of middle Palaeolithic age: 144,000 and 150,000 years ago (thermoluminescence (TL) dates, western Rajasthan) and 56,000 years ago (U-series, Gujarat). By comparison, the upper Palaeolithic is generally far better dated, with radiocarbon dates ranging from at least 45,000 BP for material from the Potwar plateau to around 10,000 BP for the Son valley. For example, the upper Palaeolithic in the Belan valley, Uttar Pradesh, is dated from 25,000 to around 9000 BP (Williams and Clarke, 1995.) Some overlap between upper and middle palaeolithic cultures is apparent, however. Acharyya and Basu (1993) report middle to upper palaeolithic artefacts in deposits dated to between 40,000 and 100,000 years ago on the basis of the presence of the Youngest Toba Ash, from the Narmada and Son basins. Further north in eastern Russia, while some researchers claim that the D'uktai culture was established north and east of Lake Baikal by 32,000 BP (Larichev et al., 1992), others consider these sites to be no older than 15,000–18,000 BP.

The most significant archaeological find in Sundaland to date has been the 'Deep Skull' in the Great Cave at Niah, Sarawak, in association with charcoal that was originally dated to ca. 40,000 BP (Harrisson, 1958). Recently, further archaeological and geochronological investigations at the site have demonstrated that the skull is indeed of great antiquity, dating to at least 42,000 BP and possibly older (Barker et al., 2001). At Song Gupuh, a cave site on Java, U-series dates on sediments containing stone tools confirm an age of > 70,000 years although the tools are not associated with human skeletal remains and thus the species responsible for making the tools is not clear (Semah and Semah, 1999.). Other evidence of early occupation of the region by *H. sapiens* comes from southern Thailand, where artefacts in the lowest excavation levels of Lang Rongrien cave have been dated to 37,000 BP (Anderson, 1990). In the Philippines the earliest evidence of occupation occurs at Tabon cave in Palawan in sediments dated to 30,000 BP, with modern human skeletal material in the same deposits dated at 20–22,000 BP (Fox, 1970).

2.3. *H. sapiens* east of the Wallace line

Directly east of the Wallace Line, occupation sites with > 30,000-year-old dates are known from southern Sulawesi, Flores, Timor and Aru. Current evidence suggests that the islands of the northern Moluccas were not colonized before 35,000 BP (e.g., Bellwood et al., 1998). Settlement of some eastern islands such as Halmahera may have originated in Irian Jaya, as marsupials including wallabies appear in the sites, becoming extinct in the Holocene. In contrast to the relatively late apparent arrival of people in the oceanic islands, occupation of the northern coast of New Guinea has been dated to 40,000 BP (Groube et al., 1986) and farther east, in New Britain, Leavesley et al. (2002) have reported a similar antiquity for occupation, based on radiocarbon dating of molluscs from the basal layers of the Buang Merebak site. The Aru islands, part of the coastal plain south of New Guinea at times of lower sea level, record occupation by 32,000 BP (O'Connor et al., 2001). Farther into island Melanesia, the currently available evidence suggests that humans had colonized New Ireland by 30,000 BP and the northern Solomons by 28,000 BP (Wickler and Spriggs, 1988). The early spread of *H. sapiens* seems to have halted here, for no Pleistocene sites have been found on Pacific islands further east or southeast, despite a capacity for long-distance voyaging demonstrated by the colonization of Manus (200 km from the nearest landmass) by at least 21,000 years ago (Minol, 2000).

Occupation of the mountainous and heavily forested interior of New Guinea appears to have occurred later than on the coasts, with the first occupation of Kosipe in Papua New Guinea (PNG) at around 30,000 BP (White et al., 1970, Hope and Golson, 1995), and the first evidence of forest clearances in the Baliem Valley at 31,000 BP (Hope, 1998). Haberle (1998) reports on the advent of burning at about 28,000 BP at Tari, PNG, and this continues through the record, suggesting continuous settlement since that time. The extinction of several species of forest dwelling marsupials is still poorly dated, but may have occurred after 40,000 BP, suggesting a possible relationship with colonisation (e.g., Flannery, 1995).

For many years it was thought that humans arrived on the Australian continent at around 40,000 BP, based on radiocarbon dating of remains associated with occupation sites. This would conveniently place the time of arrival of *H. sapiens* in Australia roughly coincident with both the age of the Niah Deep Skull and the earliest ages suggested for the colonization of New Guinea, and also be in accord with hypotheses that favour the rapid expansion of anatomically modern *H. sapiens* from Africa after 50,000 years ago (see O'Connell and Allen, 1998, for discussion). However, results from the application of absolute dating

techniques, such as TL, optically stimulated luminescence (OSL), U-series, electron spin resonance (ESR) and amino acid racemisation, at a number of sites in Australia suggest a considerably earlier landfall by humans on the continent.

The first indication that the human occupation of Australia may have occurred prior to 40,000 BP came from luminescence dating of the Nauwalabila and Malakunanja sites in the northern Territory (Roberts et al., 1990, 1994, 1998). Luminescence dating suggested occupation of the sites by 50–60,000 years ago, although the reliability of the chronologies for these sites was challenged (Allen and Holdaway, 1995; O'Connell and Allen, 1998) and a vigorous debate has been pursued throughout the last decade (e.g., Chappell et al., 1996; Roberts and Jones, 2000). Recent re-investigation of the sedimentary sequence at the Nauwalabila site using the ABOX-SC radiocarbon dating methodology of Bird et al. (1999) found no reason to doubt the veracity of the published luminescence chronology (Bird et al., 2002).

Evidence from radiocarbon dating for human landfall in Australia predating 40,000 BP, supported by OSL and ESR dating, has come from Devil's Lair cave in the extreme southwest of Western Australia, suggesting occupation by 48,000 BP (Turney et al., 2001a). The application of several dating techniques, including ESR, OSL and U-series dating, at Lake Mungo in western New South Wales suggest an age of $62,000 \pm 6000$ years ago for the Lake Mungo 3 skeleton (Thorne et al., 1999), although the reliability of the results was soon questioned (Bowler and Magee, 2000; Gillespie and Roberts, 2000; Grün et al., 2000).

While noting that much of the geochronological evidence for early occupation of Australia is contested to some degree (see Duller, 2001 for a recent review), the balance of evidence currently available therefore points to the arrival of *H. sapiens* in Australia by at least 48,000 BP. Roberts et al. (2001) suggest that the best estimate currently available for human landfall in Australia is $56,000 \pm 4000$ years ago.

A literal reading of the published geochronological evidence for the earliest occupation of the Sahul, Melanesia and northern Wallacea leads to the conclusion that *H. sapiens* arrived on the Australian mainland directly from Timor, subsequently expanding from Australia north into New Guinea and then east into island Melanesia and then back west into the Molluccas (Bellwood et al., 1998). The most likely timing of this initial migration from Timor to Australia, based on an assessment of the timing of opportunities provided by periods of rising sea level, was 59,000–62,000 years ago (Chappell, 2000; O'Connor and Veth, 2000). Sites at the eastern end of Timor have demonstrated that occupation is more than 32,000 years old there (O'Connor et al., 2001), although there is currently no evidence that Timor was colonized prior to this time. A colonization

route from Timor to Australia and then on to New Guinea should find support in genetic similarities between Australian aborigines and at least some New Guinean populations but the genetic evidence remains open to several interpretations (cf. Roberts-Thomson et al., 1996; Redd and Stoneking, 1999; Kayser et al., 2001).

The routes and timing of dispersal through Australia, once landfall was made, have been debated for several decades. Most views fall between the hypotheses of rapid expansion into all environments (Birdsell, 1977) or initial colonization of favoured resource-rich coastal (Bowdler, 1977), or inland savanna woodland regions (Hallam, 1977), followed by subsequent expansion to less favourable environments (Veth, 1989). However, the absence of evidence for the occupation of sites prior to 40,000 BP in locations such as the arid northwest of Western Australia and Cape York suggest that colonization of Australian environments was not indiscriminate (ABOX-SC radiocarbon dates for Carpenter's Gap and Riwi are summarized in Fifield et al., 2002). In addition, the absence of evidence for the early occupation of pivotal coastal locations such as the Northwest Cape in Western Australia does not support preferential dispersal along coasts. This is despite the likelihood that the early voyagers to Australia would have had an affinity with coastal marine environments and also the potential of easily exhausted coastal food resources to drive early human dispersal (Mannino and Thomas, 2002).

The balance of the evidence currently suggests colonization directly from Timor into northern Australia, followed by rapid southward expansion through savanna-woodlands of the continental interior. The speed with which the interior of Australia was penetrated further suggests a period of adaptation in the savanna-covered islands of southern Wallacea, or during dispersal along a corridor of savanna running through the interior of Sundaland of the type envisaged at the LGM (e.g., Heaney, 1991), before arrival in the Sahul.

Expansion into Sahul was facilitated by the wetter conditions that periodically pertained through much of the continental interior between about 40,000 and 60,000 BP (Kershaw and Nanson, 1993; Magee and Miller, 1998; Johnson et al., 1999; Miller et al., 1999). The movement of people into the interior may also have been facilitated by the very large and longitudinally oriented internal drainage system that covers much of northern, central and eastern Australia.

From these favourable riverine and savanna regions, people radiated into more marginal areas after 40,000 BP. Re-dating of the lowest occupation levels of the Punitjarra site in central Australia suggests that the arid core of the continent was occupied by 30,000 BP (Smith et al., 2001), despite the difficulties posed by

increasingly severe aridity over much of the interior of the continent as global climate changed towards the LGM. O'Connor and Veth (2000) conclude that increasing aridity may have catalysed movement back to the coasts and the renewed exploitation of coastal resources. For example, arid coastal sites in Western Australia were occupied from around 34,000 BP (e.g., Morse, 1993).

It seems that changes in water availability, with attendant changes in the distribution of vegetation, may have been the prime driver of dispersal through continental Australia. In possibly the earliest demonstration of humans as an agent of environmental change, *H. sapiens* may have drastically changed vegetation patterns over much of the continent through the sustained use of fire (Kershaw, 1986; Turney et al., 2001b). The demise of the megafauna (Flannery, 1990) in both Australia and New Guinea involved the loss of most terrestrial mammals, reptiles and flightless birds over 40 kg in body weight. This has also been attributed to human predation, probably combined with habitat loss. Until recently the dating of this extinction event was equivocal (Baynes, 1999). However an elegant application of amino acid racemisation dating to eggshells left by an extinct flightless bird (Miller et al., 1999) and a review of dates based on several methods (Roberts et al., 2001) suggests that many taxa may have disappeared around 46,000 BP, within a few thousand years of the arrival of humans on the continent. As with virtually all matters concerning early *H. sapiens* in Australia, the role of humans in megafaunal extinction and vegetation change is contested (e.g., Wroe and Field, 2001). Brook and Bowman (2002) contend that estimates of the duration of overlap between humans and megafauna in Australia are not yet precise enough to substantiate a causal link between the arrival of humans and megafaunal extinction.

One of the last regions of Sahul to be colonized was Tasmania, where the earliest evidence of occupation is from Wareen Cave dated at 35,000 BP (Porch and Allen, 1995). Lambeck and Chappell (2001) have recently demonstrated that the comparatively late colonization of Tasmania was related to sea level in Bass Strait. Until 43,000 BP, Tasmania was completely isolated from the mainland. Thereafter, a tenuous connection was formed with the mainland, with emergence of the entire Bass Strait region complete by about 32,000 BP.

3. Living on PEP II

The nature and dynamics of environmental conditions in Austral-Asia during and since the LGM are foci of other contributions to this volume, and are outlined here to provide a context for human occupation and models of dispersal.

3.1. The LGM: mostly foraging

Glacio-eustatic depression of sea level reached its maximum around the LGM, exposing large areas of continental shelf. In the northern parts of the PEP II transect, Japan, Taiwan and Hainan were joined to mainland Asia. In the centre, the Sunda shelf was fully exposed, joining mainland Asia to Sumatra, Java, Borneo and Palawan, with a narrow strait separating Sunda from the Philippines. This large continent had about double the current land area, but the coalescence of many islands into a single landmass reduced the length of coastline by about 50% (Dunn and Dunn, 1977). In the south, mainland Australia, New Guinea and Tasmania were joined to form the continent of Sahul. Large freshwater or brackish water lakes existed in the Gulf of Thailand, on the shelf north of Java (Lambeck, 2001), in the Gulf of Carpentaria between Australia and New Guinea (Torgerson et al., 1988), in the Bonaparte Gulf in northern Western Australia (Yokoyama et al., 2001a,b) and in the Bass Strait, between mainland Australia and Tasmania (Lambeck and Chappell, 2001).

In the most general terms, climate in much of Austral-Asia was characterized by cooler and drier conditions, although levels of rainfall differed substantially from region to region. At the northern end of the transect, an icecap blocked land east of the Bering land bridge, while vegetation on the land bridge comprised birch-grass and shrub tundra with numerous small ponds (Elias et al., 1996; Hu and Brubaker, 1996). Tundra expanded south to ~50°N, coniferous forests, steppe and temperate grassland covered much of China and the summer monsoon was weakened, leading to increased aridity. Japanese mountains supported numerous small icecaps and taiga dominated much of the lower altitude land.

It is now generally believed that temperatures in the tropics were as much as 6–7°C lower than at present. The altitude of the treeline decreased substantially and glaciers expanded on the highest mountains in Indonesia and New Guinea (Peterson et al., 2002). It is also thought that precipitation on parts of the Sunda Shelf may have been reduced by 30–50% (Kershaw et al., 2001). Despite these major reductions in rainfall levels, the greatly enlarged area of land on the Sunda shelf in the climatically humid core, exposed as a result of lower sea levels, may have led to a larger area of lowland tropical rain and swamp forests than is currently the case.

Sun et al. (2000) conclude that a strengthened winter monsoon, picking up moisture across the South China Sea, led to increased rainfall on the northern coast of Sundaland, in contrast to evidence for increased aridity elsewhere in the region, and this possibly facilitated the establishment of moist tropical forest on the exposed Sunda shelf north of Borneo. The existence of centres of

endemism in northern Borneo suggests that some forest cover was maintained in that region for a very long time, with at least the maintenance of modern moisture levels during the LGM. This is borne out by a study of Lake Sentarum in eastern Borneo (Anshari et al., 2001), where forest was dominant at 19,000 BP.

Away from northern and eastern Borneo, tropical savanna and dry forest expanded farther into tropical Wallacea and Sundaland than is currently the case. It is possible that a north–south savanna corridor bisected the interior of Sundaland during glacial periods (e.g., Heaney, 1991, Gathorne-Hardy et al., 2002), facilitating the movement of some plants and animal species (and people) through the equatorial zone but impeding others (e.g., Brandon Jones, 2001).

Australia was also cooler at the LGM (Miller et al., 1997), and the area of desert in the interior of the continent was considerably larger than at present, with aridity being a response to a weakened Australian summer monsoon. The desert core was bordered to the north by concentric zones of xerophytic shrubland and tropical savannas that extended as far north as southern New Guinea, Sulawesi and Java. Grassland occupied the area of the Gulf of Carpentaria (Chivas et al., 2001) and areas of steppe and temperate forest covered the region south of the Sahul arid zone, with icecaps present on the highest peaks of Australia and New Zealand.

While the details of the timing of the initial colonization of parts of the PEP II transect may remain contentious or obscure (as discussed previously), it is clear that all but the extreme northern and southern parts of the Austral-Asian region and the more remote islands of the Pacific were colonized to some degree by the LGM. In detail, it seems that human occupation may have been patchy in many regions. For example, questions surround the degree to which the arid interior of Australia was permanently occupied during the LGM. Smith (1987) contended that Puritjarra rock shelter in central Australia was permanently occupied through the LGM, but Thorley (1997) has suggested that other sites in the region, away from permanent water holes, were largely if not completely abandoned at the height of glacial aridity. Likewise, the highest alpine areas were likely to have been abandoned at the height of the LGM, although subalpine rock shelters in Tasmania were occasionally inhabited at this time, reflecting the passage of summer hunting parties (Cosgrove, 1995).

There is no evidence that humans practiced systematic agriculture anywhere in the world during the LGM, and in many environments subsistence was possible simply by hunting and foraging *sensu stricto*. In continental Australia, the term fire-stick farming has been used to describe the purposeful use of fire by the earliest inhabitants in support of hunting and foraging activities (Jones, 1969). The widespread use of fire by aborigines

in Australia, dating from 45,000 BP (Turney et al., 2001b), is also thought by some to constitute one of the first recognizable large-scale anthropogenic impacts on vegetation and climate, though this view is contested (see Bird, 1995 for a review). In addition, early clearance of forested valleys in the interior of New Guinea before 26,000 BP may indicate the purposeful and selective promotion of food plants by burning (White et al., 1970; Haberle et al., 1991; Hope and Golson, 1995; Haberle, 1998) while Loy et al. (1992) suggest taro (*Colocasia esculenta*) was utilized from as early as 28,000 BP in the northern Solomons. Tropical rainforest ecosystems are difficult to exploit by foraging alone (Bailey and Headland, 1991) and it has been suggested that, from their earliest occupation, tropical rainforests throughout Austral-Asia and elsewhere may have been exploited by foraging systems and technologies that increasingly resembled horticulture (Groube, 1989; Spriggs, 1993; Pavlides and Gosden, 1994).

3.2. Immediate post-glacial: Bolling-Allerod and Younger Dryas, where applicable

Yokoyama et al. (2000, 2001a) considers that the LGM ended abruptly 19,000 ± 250 years ago with a rapid rise in sea level of around 13.5 m from a maximum glacial drawdown in ice-volume equivalent sea level to –135 m. Thereafter sea level rose continuously, with at least one major period of extremely rapid rise initially estimated as 16 m in 300 years between 14,600 and 14,300 years ago (Hanebuth et al., 2000), but more likely as much as a 25 m rise (Lambeck et al., 2002) between 14,500 and 14,200 years ago (Clark et al., 2002). This meltwater pulse emanated from both the Laurentian and Antarctic icecaps (Clark et al., 2002).

Retreating ice caps and rising relative sea levels rapidly and radically changed the geography of the PEP II transect. At the northern end of the PEP II transect, the Bering land bridge to North America was flooded around 13,000 years ago (Elias et al., 1996). Active tectonism around Korea, Japan and Taiwan complicate the interpretation of land bridges in eastern Asia (see Nakada et al., 1991; Yokoyama et al., 1996; Chen and Liu, 2000; Kim et al., 2000; Park et al., 2000). A rough estimate would be that Japan became separated from mainland Russia 10,500 years ago while Taiwan finally parted from China 9000 years ago.

Major changes occurred in Sundaland, with the rapid flooding of large areas of the shelf. Borneo became isolated from the flooding remnants of Sundaland shortly before 12,000 years ago (Lambeck, 2001) while the Straits of Malacca opened around 10,000 years ago. If the Sunda Strait, separating Java and Sumatra, was not produced recently by an explosive eruption of Krakatau in AD 416 (Judd, 1889), then rising sea levels would have opened this Strait shortly before 10,000

years ago. In the Sahul, Tasmania was separated from mainland Australia 14,000 years ago (Lambeck and Chappell, 2001) and the last connection between Australia and New Guinea, through the Torres Strait, was severed between 10,000 and 11,000 years ago (Chivas et al., 2001; Yokoyama et al., 2001b).

The post-glacial period was marked by several rapid and severe shifts in global climate. Globally, temperate northern latitudes are thought to have warmed abruptly about 14,500 years ago, shortly after Heinrich Event 1, marking the start of the Bolling-Allerod warm phase. Temperatures were similar to modern temperatures for a period of about 2000 years, before dipping rapidly back to conditions approaching those of the glacial maximum for the 1200 years of the Younger Dryas. After 12,300 years ago, temperatures in the northern latitudes again approached modern conditions. Elias et al. (1996) consider that temperatures on the Bering land bridge were briefly higher than at present by as early as 13,000 years ago. This general scheme has recently been augmented in China by detailed speleothem oxygen-isotope records from Hulu cave in Nanjing (Wang et al., 2001) that suggest that Heinrich Event 1 was followed by a rapid and severe, but short lived, cooling. An equally rapid transition to the Bolling-Allerod was terminated abruptly by the Younger Dryas 12,823 ± 60 years ago, which in China, according to Wang et al. (1999, 2001), was characterized by increased aridity rather than by greatly decreased temperatures. The end of the Younger Dryas 11,473 ± 100 years ago marks the beginning of the Holocene.

In Sundaland, following the end of the LGM, temperatures warmed and rainfall increased, leading to an expansion of rainforest into areas previously covered by savanna. While the major late glacial climatic shifts experienced in more northerly regions may have occurred in the tropical regions of the PEP II transect, the evidence remains rather thin (e.g., Maloney, 1995), although Kudrass et al. (1991) have recognized the Younger Dryas in marine isotope records from the Sulu Sea.

In Australia, the nature of post-glacial oscillations in climate, coincident with major Northern Hemisphere events, has also been difficult to substantiate. Temperatures certainly increased following the LGM, but Kershaw and Nanson (1993) have suggested that temperature and precipitation may not have been in phase during stage 2, with the driest conditions actually occurring during the transition from the LGM to the Holocene. The major change in climate in the Australian portion of the PEP II transect may have been related to the re-establishment of the Australian monsoon, 14,000 years ago (Wyrwoll and Miller, 2001). This led to a partial and intermittent return to the comparatively well-watered conditions that pertained in interior Australia when humans first arrived on the continent.

The period of dramatic climatic changes following the LGM would likely make the development of what is now recognized as agriculture difficult, and it has been suggested that the generally hostile climates of the LGM and severe climate instabilities of the post-glacial, coupled with low levels of CO₂, effectively precluded the development of agriculture before the end of the Younger Dryas (e.g. Richerson et al., 2001). Nevertheless, evidence for the early utilization of rice comes from the middle Yangtze region in China, where phytolith evidence suggests that hunter-gatherers occupying Diaotonghuan Cave were eating wild rice by at least 13,000 years ago. During the Younger Dryas, rice phytoliths were not present, but as climate warmed again shortly after the end of the Younger Dryas around 11,000 years ago, the phytoliths of domesticated rice appear, implying active human intervention in sowing and harvesting the seeds (Zhao, 1998).

In northern China, the pollen of beans and green bristlegrass (the progenitor of foxtail millet) occur in sediments in at Nanzhuangtuo dated to 12,000 years ago (Underhill, 1997). The contemporaneity of rice, millet and pottery in the late glacial of China suggest that people were finding it worthwhile to harvest the seeds of these plants for consumption, and to construct simple vessels for storing and cooking long before engaging in what can be recognized in the archaeological record as agriculture. Similarly, in India there is some evidence for a late Pleistocene–Holocene stage in human development, between the upper Palaeolithic and the subsequent occurrence of food production and the establishment of villages, which Chakrabarti (1999) and others have termed the Indian Mesolithic. Micro-liths, animal bones, quern stones and the charred remains of plants found together, in association with rock art at some sites, suggest an economy based on hunting and gathering, possibly supported by the domestication of animals.

In Japan, Jomon people were steaming vegetables in clay pots by 12,500 years ago (Pearson et al., 1986). In Melanesia, the remains of edible *Canarium* (pili nut, Burseraceae), deliberately introduced from mainland New Guinea where it had been cultivated and harvested from at least the terminal Pleistocene at several island sites (discussed in Spriggs, 1993), provide evidence for early horticulture. In Spirit Cave, northeast Thailand, Hoabinhian people were exploiting a wide range of nuts, beans and vegetables according to Gorman (1971), although Bellwood (1997) does not consider the cave inhabitants to have been agriculturalists. Latinis (2000) considers that forms of arboriculture in the late Pleistocene in Wallacea, New Guinea and near Oceania (and elsewhere) developed as part of a punctuated process of subsistence system diversification that evolved opportunistically as people expanded into new and unexploited areas.

Overall, there appears to have been a trend to increasingly systematic tending, transport and utilization of many food plants in the Austral-Asian region, in some cases initiated before the LGM, with this trend intensifying into the post-glacial period. In the northern temperate zone at least, it seems that the Younger Dryas may have temporarily stalled progress toward the development of agriculture, which really only became well established after the beginning of the Holocene.

3.3. The Holocene: agriculture at last

The beginning of the Holocene marked the end of the last major climatic event in the Northern Hemisphere. For many years it was thought that the Holocene globally was characterized by comparatively warm and stable climates. More recently, detailed records in the form of cores of ice and ocean sediments have suggested the persistence of climatic cycles of millennial and centennial scale throughout the Holocene in both northern temperate (Bond et al., 1997) and tropical regions (Sirocko et al., 1993). Melting of the major Pleistocene ice-caps had largely finished by 7000 years ago, and across much of Austral-Asia the lag in isostatic responses to changes in the distribution of water loading led to a period in the mid-Holocene when relative sea level was 1–5 m above current levels. In comparatively flat coastal areas, such as in Southeast Asia and northern Australia, this led to significant transgressions relative to current shorelines, and to the development of extensive mangrove areas in tropical parts of the transect (Woodroffe, 2000). The limestone massif containing Niah Cave, currently over 10 km from the coastline, was essentially an island during the mid-Holocene (Barker et al., 2001), and the extensive swamps in northern Australia have led to the coining of the term ‘Big Swamp phase’ for this period of prehistory in the region (Woodroffe et al., 1985). Following the mid-Holocene highstand, relative sea levels are thought to have slowly declined to current levels (e.g., Lambeck and Chappell, 2001). However, it should be noted that some researchers have recently suggested that the decline may have been episodic, and even included short periods during which sea level rose a few tens of centimetres (Baker and Haworth, 2000; Nunn, 2000; Baker et al., 2001).

Climatic amelioration marking the beginning of the Holocene was rapidly followed by the appearance of agriculture in several parts of the world. Rice, the most important modern crop, was probably first domesticated on the PEP II transect. Opinions on the earliest sites of domestication and cultivation have varied widely from India to China (see Glover and Higham, 1996 for a review), but consensus seems now to favour the middle Yangtze basin in China (Underhill, 1997;

Higham and Lu, 1998), or thereabouts (Zhang and Wang, 1998).

Mc Neish and Libby (1995) have presented evidence for rice cultivation at Xianrendong between 11,200 and 9550 years ago and domestic rice phytoliths dominate the record at Diaotonghuan cave south of the Yangtze Basin from ~9500 years ago, in association with a full range of implements for digging, harvesting and processing rice (Zhao, 1998). By 8500 years ago, rice was an established crop in the middle Yangtze valley, and villages of a hectare or more had sprung up, suggesting the adoption of a more sedentary lifestyle (Higham and Lu, 1998). Further north, at the base of the loess plateau, the remains of over 70 villages, 1–2 hectares in area, have been found dating from about 8,300 years ago (Cohen, 1998). The main crops were both foxtail and broomcorn millet (*Panicum miliaceum*), although evidence was also found for the consumption of Chinese cabbage (*Brassica rapa*), peach (*Prunus persica*), Chinese dates (*Ziziphus jujuba*), walnut (*Juglans* spp.) and hackberry (*Celtis* spp.) (Underhill, 1997).

To the west, Mehrgarh, on the banks of the Bolan river in Baluchistan, has provided the earliest evidence for agriculture on the Indian subcontinent. According to Costantini (1984) and Jarrige (1984), the earliest of the occupation phases at Mehrgarh (Period 1, dated from around 10,000 to around 8350 years ago) was associated with the cultivation of domesticated barley (*Hordeum vulgare*). It is not clear whether these early farmers actually independently domesticated barley, although occupants of the site may have domesticated animals such as cattle, goats and sheep during the later part of Period 1 (Chakrabarti, 1999, pp. 121–122). Similarly, it is unclear whether external forces, such as climate change, were responsible for the adoption of agriculture at Mehrgarh; according to Chakrabarti (1999, p. 119) there is no evidence from the area for significant changes in climate or vegetation during the transition to farming.

Shortly before 5700 years ago the development of copper metallurgy and trade are believed to have partly underpinned the emergence of a distinctive civilization with shared systems of administration and ideology, commonly referred to today as the Indus or Harappan civilization. Although centred upon the Indus and its tributaries, Harappan sites (more than 1000 of which have been discovered to date) ranged from village farming communities to fully developed urban areas accommodating many thousands of people, from Gujarat in the south to north-east Afghanistan in the north (Chakrabarti, 1999). The civilization reached its apogee around 5300 years ago (Weber, 1999), by which time Harappan people occupied a diverse range of environmental settings and were making use of a diverse array of domesticated crops and animals, often in

association with extensive agricultural (eg., irrigation) works.

Higham (1995) argues that climatic deterioration from 8000 years ago spurred the development of systematic cultivation in China. This climatic cooling may have been widely felt; Alley et al. (1997) report cooler and or drier conditions for many parts of the Northern Hemisphere between 8000 and 8400 years ago. In China, a high-resolution record presented by Wang et al. (1999) suggests that 8200 years ago was marked not only by a rapid cooling but also by 'a centennial oscillation from extreme aridity to extreme humidity'. Moreover, Gagan et al. (2001) report a severe short-lived decrease in ocean temperatures around Alor (Sunda Islands, Indonesia) of 3°C beginning 8100 years ago and lasting for less than 500 years.

From the Chinese heartlands of the Yangtze and Huang Ho Basins, rice and millet cultivation spread north and east. The first indications of rice phytoliths on the Korean peninsula date to 6400 years ago and millet appears regularly after 5500 years ago (Nelson, 1993), spreading up into the Russian far east by least 4900 years ago (Kuzmin et al., 1998). In Japan, where Jomon people were probably beginning to practice small-scale horticulture from about 5500 years ago, millet appears from 4500, and rice from 3000 years ago, becoming widespread after 2400 years ago (Crawford, 1992).

The timing of the spread of rice south and east of China has been controversial for many years. Higham and Lu (1998) conclude that rice farming, with its characteristic cultural trappings, including sedentary occupation, arrived in southern Thailand about 4000 years ago but Penny (2001) notes widespread clearance starting around 7000 years ago in central Thailand. The earliest rice remains in Taiwan date from 3,500 to 4000 years ago (Wang, 1984), although new excavations at Nan-kuan-li, near Tainan have revealed carbonised rice grains dating to 5000 years ago (Tsang Cheng-hwa, unpublished; P. Bellwood, personal communication) In the northern Philippines the earliest evidence of rice cultivation is dated to between 3450 and 3700 years ago (Snow, 1986) and the remains of rice from Gua Sireh cave in Sarawak date from 4500 years ago (Sen, 1995) confirmed by the discovery of rice phytoliths in the cave sediments (Beavitt et al., 1996).

Evidence of early agriculture exists at Kuk in the New Guinea highlands in the form of a ditch dug to drain a swamp, presumably for cultivation, possibly about 9000 years ago (Golson, 1977; Denham, personal communication). Clearance was widespread in the main highland valleys by 7500 years ago (Haberle et al., 1991; Haberle, 1998), thus making the development of agriculture approximately contemporaneous with similar developments in China and India. Although no remains have been found that could enable identification of the type of plants being cultivated, it has been

suggested that the first cultigens may have been taro, yams and bananas. Bayliss-Smith (1996, p. 516) reviewed the models proposed for the development of highlands agriculture and concluded 'it is clear we remain in almost total ignorance about the origins of New Guinea agriculture...'.

The evidence for the earliest agriculture remains equivocal (e.g., Spriggs, 1996). But the evidence for more organized horticultural works and extensive forest clearance by 6000 years ago is less so. Bayliss-Smith (1996) suggests that hunting, foraging and cultivation of wild plants persisted until 4500 years ago when the introduction of taro (*Cococasia esculenta*) led to the breaching of an energy threshold. Agriculture intensified after a second energy threshold was crossed around 2500 years ago with the arrival of yams (*Dioscorea* spp.), followed by a third period of revolution accompanying the introduction of sweet potato (*Ipomoea batatas*) around 300 years ago.

Whereas some cultivars such as the fruited screw-palm (*Pandanus*), sugarcane (*Saccharum officinale*) and the fehi-banana (*Australimusa*) have long been viewed as New Guinea domesticates, the Bayliss-Smith (1996) model and others see the major food crops that catalysed agricultural development in highland New Guinea as arriving from elsewhere. Taros, yams and bananas (*Musa* spp.) were thought to have originated in Southeast Asia and the sweet potato in South America (Hather, 1996; Yen, 1998). While the later claim appears robust, research summarized by Lebot (1999) into biomolecular markers now suggests that taro, the greater yam (*Dioscorea alata*), breadfruit (*Artocarpus altilis*) and sago (*Metroxylon sagu*) were domesticated in New Guinea and further east into Melanesia. It therefore seems possible that the components of an agricultural economy based primarily on root crops and arboriculture originated independently and early in New Guinea/Wallacea/Melanesia, due to the existence of a radically different plant resource base available for exploitation east of the Wallace line. The resultant domesticates subsequently radiated west to Southeast Asia and east into the Pacific.

The inhabitants of Australia may have engaged in some of the earliest human experiments in environmental modification known (as discussed earlier) and also developed sophisticated techniques of environmental management and plant husbandry (reviewed by Lourandos and David, 2002) However, sedentary agricultural practices never developed anywhere on the continent. Diamond (1997a) explains this phenomenon plausibly and succinctly as the result of a combination of a generally unfavourable climate coupled with an absence of both plants and animals that are suited to domestication. In short, the transition from a hunter-gatherer to an agricultural economy was never energetically favourable in Australia.

3.4. *The Holocene: moving on*

The development and dispersal of crops and agricultural practice on the PEP II transect is of course intimately linked to the movement of people. Both are also likely to be linked to the Holocene climatic and geographic changes discussed in the preceding section. Separate discussion of Holocene migrations is undertaken here simply because of the complexity and diversity of information and opinion that have been brought to bear on the subject.

It is currently agreed that those islands of the Pacific not already colonized by the Pleistocene were rapidly occupied by long distance voyaging after 3600 years ago (e.g., Anderson, 2001a, b). To the south, New Caledonia was occupied 3100 years ago, New Zealand by 800 years ago and the Chatham Islands by 700 years ago. To the east, Samoa was colonized by 2800–3000 years ago, the Marquesas by 1200 years ago, both Hawaii and Easter Island by 1100 years ago and Pitcairn Island by 1000–950 years ago. It is also generally agreed that some degree of environmental modification attended colonization, in the form of forest clearance, erosion, extinction of endemic species and the introduction of new species of both animals and plants. Prior to this final explosion of people into the Pacific, opinions diverge widely as to the origin, motivation and routes of post-Pleistocene migrations through Austral-Asia.

The idea that the development of agriculture led to the rapid expansion of agriculturalists at the expense of hunter-gatherers is a convincing model for Holocene-migrations (e.g., Renfrew, 1996; Diamond, 1997a, b). It has been argued that population pressure resulting from the development of rice cultivation prompted a migration of Austronesian speaking people from Taiwan shortly after their arrival there 5500 years ago (the Out of Taiwan model). These migrants occupied the northern Philippines by 5000 years ago then moved south into Borneo, Sulawesi and Timor by 4500 years ago, Java and Sumatra by 4000 years ago, largely bypassed New Guinea and arrived on the Bismarck Archipelago by 3400 years ago. From the latter location, humans were well placed to begin the colonization of remote Oceania (Bellwood, 1996, 1997). These intrusive colonists introduced farming as a way of life, displacing or absorbing earlier populations, and some of their practices, as they moved (Spriggs, 1996). The evidence in support of this hypothesis is partly archaeological and partly linguistic (Blust, 1984–1985, 1996, as summarized in Bellwood, 1997; Diamond, 1997b).

Bellwood (2001) appears to view more favourably the possibility that the Austronesian speakers of Oceania were not of ultimate Taiwanese descent, and some recent genetic evidence indicates that wherever the ultimate origin of the Austronesians, they dallied in Melanesia long enough to accumulate a significant genetic legacy

from Melanesians (Kayser et al., 2000) Another set of arguments concerns itself with the origins of the Austronesians, and their movement through Southeast Asia. Alternate readings of the linguistic evidence place the centre of Austronesian dispersal in island Southeast Asia (Meacham, 1984/85; Solheim II, 1996). Such an origin is supported by some genetic and archaeological evidence (Richards et al., 1998; Su et al., 2000; Capelli et al., 2001; Gibbons, 2001; Oppenheimer and Richards, 2001a, b), although the reliability of some of the genetic evidence has been questioned (Diamond, 2001).

In addition, the absence of evidence for rice at many sites in the Philippines, Borneo and Sulawesi at the time the Out of Taiwan model posits Austronesian migration through these regions is unusual for an expansion supposedly driven, by the development of rice cultivation (discussed in Shouse, 2001).

The only model for Austronesian expansion of similar sweep to the 'Out of Taiwan' model has been the 'Eden in the East' model of Oppenheimer (1998). This model posits that the homeland of the Austronesians was island Southeast Asia, and that migration began substantially earlier than suggested by the Out of Taiwan model. The driver of this early migration is envisaged to be environmental rather than cultural change. In particular, Oppenheimer (1998) suggests that rapid flooding of Sundaland may have been the catalyst for a major dispersal of people from the region both to the east and the west, at some time prior to 6000 years ago. He cites archaeological, linguistic, genetic and folkloric evidence in support of this hypothesis and suggests that the final prompt to dispersal was major marine transgression at around 8000 years ago.

The archaeological evidence for the Eden in the East theory has been critiqued in part by Bellwood (2000), and subsequent papers (e.g., Oppenheimer and Richards, 2001a,b) have focused more on the genetic evidence for ancestral Southeast Asian links to modern Polynesians, without directly advocating particular timings or dispersal mechanisms. Nevertheless, a marine transgression around 8000 years ago, possibly linked to more widely occurring events around the same time, is worthy of examination as an example of a natural event potentially capable of affecting human societies in prehistory.

Barber et al. (1999) have linked the changes apparently centred upon 8200 years ago with the catastrophic draining of ice-dammed lakes south of the Laurentide ice sheet 8400 years ago and Teller et al. (2003) have calculated that 163,000 km³ of water was released to the ocean through Hudson Bay at this time, over a period as short as 1 year. The evidence supporting the above interpretation is compelling, and a simple corollary is therefore that sea levels rose globally by 45 cm over a period as short as a year or so at that time. Temperatures over Greenland dropped by up to 4–8°C

for about 300–400 years, conceivably temporarily halting the final melting of the Laurentide icecap over this period.

A rapid rise, followed by short still-stand, or even sea level drop (though gradual thermal contraction) centred upon 8200 years ago has not been conclusively identified in the sedimentary record. This is possibly because of the comparatively large uncertainties associated with determining past sea levels (generally ± 0.5 – 1 m) and because the typical error on a radiocarbon date equivalent to a calendar age of ~ 8000 years ago is ± 70 – 150 years, a considerable fraction of the total 400 year duration of the event. It is possible that a rapid rise, followed by a still-stand over 400 years, amounted to the same vertical rise as would occur if sea level had simply continued to rise at a constant rate over the same period, thus leaving little discernible trace in sea level records. Whether sea level rise associated with the 8200 year event prompted people in Sundaland to get into their boats and paddle away remains to be seen, but it does seem highly likely that a rise in sea level of 0.5 m over a year had a profound effect on all coastal peoples at the time.

At the easternmost end of the Austronesian expansion, the distinctive Polynesian culture that spread eastwards from near Oceania less than 2000 years ago may not have been an extension of an intrusive colonization by Austronesians bearing a new cultural and agricultural package of villages, pottery, yams, taros and pigs as advocated by, for example, Spriggs (1996), but instead may have resulted from a long process of predominantly local innovation (e.g., Gosden, 1992; van Dijk and Thorne, 2002). Evidence discussed by Lebot (1999) that the mainstays of food production in the region, taro and yams, were domesticated locally (or in nearby mainland New Guinea) support his hypothesis, and Latinis (2000) notes that many arboricultural practices predate the putative arrival of Austronesians in near Oceania, and hence were also developed locally.

The adaptations required of seafaring people moving out into the tropical Pacific remained small at first because new islands presented a familiar range of marine resources, soils and vegetation. But as voyagers proceeded eastwards, the drier tropical environments made colonisation riskier. Several island groups (for example Pitcairn, Henderson, and Christmas) seem to have supported only temporary settlement several centuries ago. Easter Island suffered a population crash that may have been resource based (Bahn and Flenley, 1992), but might equally have been caused by an early introduction of European diseases (Rainbird, 2002). The human commensal, *Rattus exulans*, was more successful, colonising many islands and extirpating bird and plant species.

Dispersal still further south meant that many of the tropical crops became non-viable and wholly new

economies had to be invented. New Zealand, a major temperate land, was settled as late as 800 years ago. This late settlement of an isolated group of islands provides a useful laboratory for assessing Holocene environmental change; while fire was rare, shifts from forest to grassland did occur prior to human arrival, which serves as a warning to palaeoecologists not to ascribe all changes to human intervention. Maori economies present a cline of subsistence strategies from plant foods in the north to a dependence on the blubber of marine mammals in the extreme south on Stewart Island (Davidson and Leach, 2001) and the temporarily colonised Auckland Islands (Anderson and O'Regan, 2000). These wind blown fragments of rock at 50°S in the vast Southern Ocean were the furthest attainment of people in the Austral-Asian region by the dawn of the Industrial Age.

4. Conclusion

Considerably more is known about the details of the dispersal of humans and agriculture through land bisected by the PEP II transect now than was the case a decade ago and a cacophony of divergent archaeological, geochronological, linguistic and genetic opinion is currently available on virtually all the topics covered in this review. This is the case whether the subject under discussion is the timing of arrival of *H. erectus* or *H. sapiens* in the region, or the timing of subsequent movements though the region from 1.8 million years ago up to a few hundred years ago. Likewise, the timing, place of origin and routes of dispersal of most food plants, the rise of agriculture (and indeed what constitutes agriculture and evidence for agriculture), the development of trade and the effect of environmental change on humans and the effects of humans on the environment all remain hotly contested subjects.

The last decade has seen shifts in the interpretation of existing data, an example being the interpretation of charcoal in the geologic record of the humid tropics. It was considered that evidence of charcoal in humid tropical environments was evidence of humans (e.g. Haberle et al., 1991), but recent re-interpretations of the same evidence has highlighted the role that ENSO-related droughts may have played in the 'natural' generation of fires in the humid tropics (Haberle et al., 2001). Thus, fire in the humid tropics is not now uniquely equated with human activity. The last decade has also witnessed divergences in opinion, in part resulting from an upsurge in the application of new techniques applied to new materials at a finer scale than previously. Thus, accelerator mass spectrometry and single grain luminescence technologies have enabled the dating of material previously not dateable, at resolutions

not previously achievable. Studies such as those of Wang et al. (1999, 2001) have achieved unprecedented temporal resolution, but the interpretations of the climate records they present are only as good as the link between proxy records and the variable that the proxy is supposedly recording.

In the archaeological realm, geochronology remains only as good as the often-inconclusive association between the material being dated and the event of interest. Adding to the problems are the fact that some commonly used markers of human dispersal, such as artefacts, do not necessarily carry their original makers along with them when they travel, and while genes do carry evidence of their original makers with them, they do so neither completely nor impartially. The fundamental vagaries imposed by instrumentation, interpretation and reputation are unlikely to be resolved any time soon. What is apparent from the results of palaeoclimate research during the last decade, on PEP II and around the world, is the comparatively common occurrence of rapid shifts in climate, forced by a range of processes of variable predictability and severity including episodic catastrophes of considerable magnitude.

The immediate impacts of catastrophic events on humans inhabiting areas bisected by the PEP II transect, and the differing vulnerabilities of communities and ecosystems to these, are the focus of Sidle et al. (2003). As new evidence becomes available and as existing evidence is re-scrutinised, new explanations for well-established diasters are likely. Thus, El Niño has recently been proposed as one of the factors contributing to the severity of major famines and attendant diseases that affected broad sweeps of the Austral-Asian region during the late 19th and early 20th centuries, and in which tens of millions of people died (Davis, 2001). In the more distant past, further research may establish not only dramatic climate and associated environmental (e.g., sea level) changes, such as those possibly centred upon 8200 years ago, but also their place in human history.

At present, one can do little more than speculate on the influence of catastrophes and more gradual forms of environmental change in shaping human history on the PEP II transect. This is partly because of the dearth of adequately dated studies in the region. Thus, improved radiocarbon dating of palaeoclimate evidence from northern India and Pakistan has challenged the orthodox explanation for the abrupt decline of the Harappan civilization—a shift towards climatically drier conditions ca. around 4450–3750 years ago (Singh et al., 1972, 1974, 1990). The evidence suggests that increased aridity occurred earlier than previously thought, around 5700 years ago (Enzel et al., 1999), and therefore a recognisably Harappan civilization continued to flourish along the Indus and its tributaries for at least 1000 years

after the onset of climatically drier conditions. Rather than the reduced availability of moisture, the eventual decline of Harappan civilization was most likely caused by a combination of factors that included environmental changes, such as capture of the River Sarasvati (Valdiya, 1996), as well as the breakdown of trade and an increased emphasis on local resources, all of which led ultimately to overexploitation, environmental degradation and reduced agricultural productivity (Weber, 1999).

In addition to generally poor dating control, it is only possible to speculate on human–environment interrelationships because of the diversity of cultures in the Austral-Asian region and because much remains to be known about how these cultures both perceived and responded to changes in environmental conditions, now and in the past (e.g., see Haberle and David, 2003). A major challenge for the future will therefore be the meshing of archaeological records with the growing number of high-resolution records of palaeoclimate, and the development of theories that link human and environmental changes in ways that biological, physical and social scientists find satisfactory.

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