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THE QUATERNARY is characterised by dramatic changes in climate that relate to the most recent interval of glaciation on the globe. These changes appear to be triggered by small variations in the amount and distribution of solar radiation received by the earth as a result of predictable changes in the earth's orbit relative to the sun, known as Milankovitch cycles (Imbrie et al., 1984). Milankovitch cyclicity is believed to have occurred through the whole of geological time and has been demonstrated to have operated through at least the last 6 Ma (million years) (Shackleton, 1995). The significance of these cycles in the Quaternary is their great amplitude of change which results from the complex relationships between Milankovitch forcing, the distribution of land masses, the growth of mountains and high plateaux, the pattern of ocean circulation, ice sheet growth and decay and substantial changes in carbon dioxide and other ‘Greenhouse’ gases in the atmosphere (Williams et al., 1998).

In the absence of significant changes in the position of, and relationship between, continental masses due to the limited time-span of the Quaternary, natural, terrestrial biogeographic patterns tend to be dominated by these climate changes. However, the movement northwards of Australia by about 100 km over this period may have had some influence on oceanic and atmospheric circulation and biotic migration patterns within the Australian and Asian regions, and episodic lowering of sea level up to 130 m (Ferland et al., 1995) would have had an influence on both terrestrial and marine migration and isolation. During the last glaciation, both Tasmania and New Guinea were joined to the Australian mainland and ocean currents were deflected with the loss of shallow marine environments and no more significantly than in the maritime continent region between northern Australia and mainland Southeast Asia, which holds a central position in regional and perhaps global atmospheric and oceanic circulation patterns. Similar effects would have been felt in New Zealand as islands were joined during low sea level phases and the land area increased by some 150,000 km² with substantial tectonic activity and volcanism.
The short timescale of the Quaternary is significant also for questions related to the evolution of organisms. Evolutionary rates of organisms as directly observed from stratigraphic ranges within the fossil record, indicate that evolutionary change is unlikely to have been a major factor in Quaternary biogeography at least at the species level. This conclusion is supported by an examination of the biological response of biota to Milankovitch forcing (Bennett 1997). He determined that organisms effectively responded to dramatic changes by migrating and extending their ranges, and that there was no notable change in evolutionary rates during the Quaternary period. However, there is likely to have been a significant degree of evolutionary change at the subspecies level, morphologically invisible in many fossil taxa, and in species ecology. Furthermore, one aspect of evolution which is very evident in the Quaternary is extinction and here the role of people has to be taken into account.

The unique feature of the Quaternary is that it embraces the evolution of bipedal, tool-making, fire-using hominids (Williams et al., 1998) who were capable of broad dispersal and also of transporting other components of the biota, as well as inflicting an unprecedented impact on native biota. Although the bulk of human evolution is considered to have occurred in Africa and the African continent, there is strong evidence for the presence of Homo erectus in Southeast Asia by 1.8 Ma. (Swisher et al., 1994) and increasing evidence that individuals had crossed Wallace's line, and hence made sea crossings, to the Lesser Sunda Island of Flores by 800-700 ka (Sondaar et al., 1994; Morwood et al., 1998). However, there is no indication that this migration continued into Australia and New Guinea, probably until between 60 and 50 ka, well after the emergence of Homo sapiens. The subsequent colonisation of most of the Southeast Asian land masses occurred only after 4 ka (Enright & Gosden, 1992) and in New Zealand, after 1ka, and perhaps as late as 700BP (Anderson & McGlone, 1992).

Palaeobiological study of the Quaternary has been dominated by determining and understanding patterns of climate change, and the impact of people, and consequently to assess the relative roles of climate and people on environmental change and the development of the present landscape. There has been a strong focus on the more recent part of this period when human impact has been greatest and where the availability of continuously accumulating sediments, readily datable by methods such as radiocarbon, has allowed the reconstruction of detailed records inter-palatable from present day analogues. This ‘top down’ approach has generally failed to penetrate far into the Quaternary because of lack of interest in older environments, the paucity of dating methods and/or dating precision, the discontinuous nature of the sediment record, and increasing uncertainty about the ecological or environmental meaning of recorded assemblages. On the other hand, the conventional ‘bottom up’ approach of geologically-oriented palaeontologists has generally faltered when it comes to the Quaternary because of low turnover rates relative to the length of the period, and a combination of the above. It is also the case that developing global concern about future climates, has there been a general realisation of the significance of Quaternary patterns of environmental change as a whole.

This review is inevitably biased in its treatment of the Quaternary. We first provide some overview of the status of global stratigraphy, developed independently of Australasian evidence, to provide a context for discussion of regional data. This is followed by an examination of fossil groups which have been studied sufficiently in biostratigraphy and palaeoecology to provide useful palaeogeographic insights or groups which have the potential to do so. Evidence for humans is treated separately because of the distinct influence of this taxon on biostratigraphic patterns of other groups of biota. However, this group is also significant because it initially on the Last Glacial Maximum and Holocene ‘Optimum’ as the best known examples of the environmental extremes which characterised at least the latter part of the Quaternary, followed by a more generalised examination of the whole Quaternary with emphasis on Australasia, and on those few areas where stratigraphical and biological records are most substantial.

GLOBAL QUATERNARY STRATIGRAPHY

Debate over the subdivision of the Quaternary, or even the last 2.6 Ma, continues. A major geological status at all (Berggren et al., 1995), is on-going (P-d’erride, 1997a). However, there is some agreement that the period covered by the Quaternary includes an earlier Pleistocene epoch, which embraces the glacial and interglacial periods which can be subdivided into Early and Late Pleistocene, and the Holocene, the latter defining the period from the end of the last glaciation. The beginning of the Holocene, defined by radiocarbon dating at 10 ka, marks the time when global temperatures achieved approximately 6°C warmer than the present values. Isotopic records indicate that this period is a relatively brief interval of about 15 ka duration. However, there is no sustained change around the formal Pli/ Pleistocene boundary, apparently negating the expectation that this boundary should mark the beginning of late Neoglacimec climatic deterioration. The selection of this boundary was based on the first appearance of the cold water marine mollusc Arctica islandica and the benthic foraminifera Hyalinea balthica in uplifted, and therefore accessible, marine sediments in southern Italy. However, the boundary is not supported by many other marker species and an alternative boundary is being actively considered by the Subcommission on Quaternary Stratigraphy of the International Commission on Stratigraphy (Partridge, 1997b).

The isotope record indicates a significant temperature lowering around 2.6 Ma, with a transition from a dominance of orbital precession (the season of the year when the earth is nearest to the sun) to cycles with a period of about 23 ka, to obliquity cycles, and coincides with the major Gauss/Matuyama magnetic reversal. There is also evidence for the first major incursion of ice-rafted debris into the North Atlantic (Shackleton, 1984), the beginning of major loess deposition in China (Kukla et al., 1990), major changes in mammalian and vegetation communities in Europe (Sue, 1997), and the appearance of the earliest species, Homo rodolfensis, that is currently included in our own genus (Partridge et al., 1995) around this time. These factors, combined with the fact that there is a suitable stratotype marine section exposed in southern Italy showing the appearance of the first true cold indicator planktonic Foraminifera Neogloboquadrina atlantica, together with a variety of other biogeographic markers (Partridge, 1997b) makes it likely that a boundary change will happen in the near future. Consequently, it is apt to acknowledge both a major time of environmental change and anticipate a boundary change. As a result, the Quaternary will be regarded as having begun at 2.6 Ma but, to prevent total confusion, a distinction will be made in this chapter between the conventional Early Pleistocene (Early Pleistocene B, 1.760 to 0.78 Ma) and its temporal extension (Early Pleistocene A, 2.60 to 1.76 Ma) where appropriate.

NATURE AND APPLICATIONS OF FOSSIL EVIDENCE

The perception that the biotas of Australasia have been present for a long period of time, combined with their isolation from the rest of the world and the lack of massive regional disruptions such as those caused by the advances and retreats of ice sheets on northern hemisphere continents, has led to an emphasis on palaeoenvironmental reconstructions of individual sites or small areas rather than on broad palaeogeographic or evolutionary studies. However, the data gathered, although possibly not optimal for palaeo-geographic purposes, are providing a useful basis for examination of patterns of distribution in relation to reconstructions of environmental conditions.
Evidence is provided below from three major environments, marine, terrestrial and non-marine aquatic, each possessing distinct fossil biotas. Fossil terrestrial remains tend to preserve in marine and particularly aquatic environments and evidence from these environments is important to proper taphonomic interpretations of terrestrial assemblages. Coasts provide a fourth environment that is often a complex mixture of the other three but with distinct fossil components such as corals and mangroves. A general indication of the distribution of records from major fossil groups is shown on Fig. 1, while the location of sites and areas mentioned in the text is indicated on Fig. 2.

### Marine fossil groups

For a long time, foraminifera provided the best palaeoenvironmental indicators obtainable from marine sediments but other groups are now making contributions, particularly calcareous nannoplankton, pycnophlanxes and ostracods. Studies in taxonomy of benthic foraminiferal species best define biogeographic provinces along the coastline, but planktonic species can help define them in the open marine environment. Diversity and taxonomy help identify salinity, temperature and depth. Various features of planktonic foraminiferal forms – diversity, coiling ratios, presence or absence of keels – are temperature and, to a lesser extent, depth dependent in the fully marine realm.

Taxonomy of Australian foraminifera, especially modern-forms, has been well addressed by Albani (1979), Collins (1974), Yassini & Jones (1995) for benthic species and Saito et al. (1981) and Kennett & Srivinvasan (1985), for example, for planktonic forms.

Planktonic foraminifera, in particular, are carriers of isotope signals (δ18O, δ13C) which are temperature and primarily ice volume dependent. While studies of these parameters are well advanced in deep sea sections cored by Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP), providing global standards (Tiedemann et al., 1994; Ruddiman & Raymo, 1984, Shackleton et al., 1995) against which all local parameters must be compared, detailed studies of isotopes in Australia have only recently received significant attention. Analyses conducted separately on planktonic and key benthic forms allows differentiation of sea surface and seafloor palaeotemperatures.

Some of the best Quaternary marine sections around Australia have been discovered and sampled during hydrocarbon exploration off northwestern Australia. General results are summarised by Aplotore (1988) and Quilty (1974), and it is likely that a great deal of additional detailed information is stored in company files. Seldom do these studies yield cores spanning the entire Quaternary.

Marine sediments of northwestern Australia are predominantly biogenic carbonates and foraminifera-based biostratigraphy has been described by Quilty (1974) and Aplotore (1988). Quilty (1977) included the Quaternary section in his sedimentation cycle 4 which commenced in the Late Miocene. Aplotore (1988) continued this practice while recognising that it is a very poorly sampled interval. She made very little comment on the post Pliocene sequence other than to state that the Pleistocene contains evidence of sea level lowstand. In North Tryal Rocks No. 1 (Quilty, 1974), the Quaternary section is over 400 m thick and without evidence of any stratigraphic break. *Globorotalia tumida* coiling ratios were interpreted by Quilty (1974) to indicate sea surface temperatures in the earliest Pleistocene were higher than at other times in the Quaternary.

Several research cruises have been conducted in the northwest by national and international programs and have generated a few well cored sections. Where Quaternary sections have been encountered, generally they are thin and carbonate dominated. Elsewhere non-deposition or seafloor erosion is evident. Zobel (1984) examined foraminifera from three cores on the Exmouth Plateau. Benthic species did not provide a useful basis for subdividing the section, suggesting that water depth has constantly been below that at which change manifests itself, but planktonics did. Core KL124 appears to cover most of the Quaternary. The upper 190 cm (approximately the last 380 ka) contains a high proportion of *Globorotalia cultura* (sturdy walled forms) and
other species indicating a subtropical-tropical fauna. From 190-240 cm (380-840 core), the fauna is dominated by *Globorotalia inflata*, indicating somewhat cooler conditions in a 'transitional' fauna. Below that depth (to approximately 1.3 ka), the subtropical-tropical fauna is present and this may coincide with Quilty's (1974) warmer interval.

Although few studies have been undertaken along the southern margin of Australia, relative to the size of the area, enough data are available to indicate that one of the major variables during the Quaternary (and earlier) has been the intensity of activity of the Leeuwin Current (Pearce & Walker, 1991). The effects are felt at least from southern Western Australia to western Victoria. The Leeuwin Current flows mainly in the upper few hundred metres, and not necessarily through the full water column.

Almond et al. (1993) and Li et al. (1997) summarised the variation of foraminiferal faunas with standard Quaternary stratigraphic schemes. Almond et al. (1993) recognised five intervals ([l to V] covering the last 125 ka in core 102G08 taken in the Great Australian Bight. These do not coincide perfectly with the isotope stages of Shackleton & Opdyke (1973) but Interval III appears to be the same as Isotope Stage 5, Interval IV is Isotope Stage 6, and Interval V is the upper part of the Subantarctic Inertial Oscillation (SIO) of Oppo et al. (1990). This suggests that Interval I includes Isotope Stages 2 (lower part only) and 3 and 4. Interval I includes Isotope Stage 1 and the upper part of 2. Intervals I, III and V are the warmer water intervals characterised by high diversity (five planktonic species), dominated by *Globigerinoides* spp., and by some degree of benthic dominance of *Cibicides*, lower productivity. Almond et al. (1993) provide arguments for this interpretation.

This pattern, while having some scope for reinterpretation when longer cores are taken, suggests that during glacial intervals, infralittoral and intertidal zones of the warm-water Leeuwin Current from the west was weaker, but was stronger during interglacials, such as at present. In consequence, warmer water faunas flourish across southern Australia in shallow water during interglacials.

Wells & Okada (1996) used a more comprehensive array of indices on Verna core VI 8-222, offshore from the Victoria-South Australia border. This core contains a record of Stages 1-Stage 2 (last 14 ka), Stage 10 (350 ka) and Stages 12-15 (450 ka). Stage 1 had a temperature maximum at about 8 ka BP with an annual range of 12-22°C, following a cooler Stage 2 (only the last 2 ka preserved). This coincides with high Leeuwin Current activity, low surface productivity and low upwelling. In contrast, Stages 10 and 12 have temperatures near 6°C with higher productivity/higher upwelling and essentially no Leeuwin Current activity. The control on temperature may be oscillation of the Subtropical Convergence over the site. The results are broadly consistent with those of Almond et al. (1993).

There is an increasing emphasis on study of sections of the east coast of Australia. Samples normally are spot samples which lack a full stratigraphic context and, as pointed out by Chaproniere (1991), the foraminiferal stratigraphy within the Quaternary depends on detailed knowledge of local events.

Nees (1997) studied a variety of features, such as infaunal/epifaunal ratios and abundance in benthic foraminiferal faunas from several cores in the Tasman Sea for the interval between Isotope Stage 6 and 7. Abundance increased during glacial stages, except on the Tasman Plateau, and surface productivity varied in relation to the position of the Tasman Front, which was considerably north of its present position during glacial Stage 6 and south of it in Stage 7 with higher productivity at the time over the Tasman Plateau.

In cores from the northern Tasman Sea, Martinez (1997) examined the population size of *Globorotalia troncatulinoides* as an index of productivity of Subantarctic Mode Water (SAMW) at the Antarctic Polar Frontal Zone. The study shows that there has been a decrease in abundance of SAMW generated over the recorded interval.

Chaproniere (1991) and Chaproniere & Pigram (1993) studied Quaternary Foraminifera from offshore Queensland and noted that there appears to be a strong, northward-moving influence of the warm-water Leeuwin Current from the west was weaker, but was stronger during interglacials, such as at present. In consequence, warmer water faunas flourish across southern Australia in shallow water during interglacials.

Ocean Drilling Program Leg 133 conducted a drilling program off central and northeast Queensland and analyses of Foraminifera, magnetic properties, sediment composition, and many other parameters are documented in papers in McKenzie et al. (1993). In contrast with the view of Chaproniere (1991), these studies suggest major changes in the marine environment prior to and during the Quaternary in the Coral Sea region. Oxygen isotopic comparison of the planktonic Foraminifera *Globigerinoides* spp. in ODP Site 111 on the Queensland Plateau has revealed a sea surface temperature record through most of the last 10Ma (Ishii et al., 1996). The age model was constructed from the biostratigraphic datums of Davies et al. (1993) as well as the core from the same site covered by the ODP Site 111 isotope record. Major features include a substantial temperature increase around 2.5 Ma after a Late Pliocene low, and a further systematic increase, of around 4°C, superimposed on glacial/interglacial cyclicity, of 500-700 ka. This more recent increase is recorded in many other cores from the region and, from the most detailed isotopic record, of ODP Site 820 on the continental slope adjacent to the Great Barrier Reef, the timing seems to be closer to 400-250 ka (Peekemann et al., 1996) and at least one section, based on the change in the influence of the southward progression of the East Australian Current.

In contrast with accepted orthodoxy, higher concentrations of foraminifera and carbonate in sediments seem to coincide with glacial intervals, as in *Globorotalia troncatulinoides* (Glab); the high productivity/higher upwelling over the course of this apparent anomaly. Conversely, siliclastic content is higher during warm intervals and this is expressed as higher magnetic susceptibility during intervals of high sea level. Substantial cooling is manifested during glacial intervals.

The Continental Shelf around Tasmania appears to be receiving little sediment at present but the Quaternary sediments known are dominantly carbonates and this gives hope of useful comparative sections which may provide standard sections for much of the Australian margin. Further by regional comparisons, regional correlations (Hodell, 1993; Howard & Prell, 1994). Carbonate content is at a minimum during glacial maxima, and there are grain size trends in the terrigenous content that relate to distance from sediment source.

In New Zealand, the application of foraminiferal studies to Quaternary palaeoenvironmental and stratigraphic reconstructions has had a much longer history than in Australia due to the presence of thick, extensive marine sequences onshore and offshore as exposures and to terrestrial drilling. This facilitated the development of a stratigraphic scheme which has, to some extent, separated it scientifically from the rest of the world, but was of immense value in local terrestrial/marine correlation and in providing a timescale for understanding the biogeographic change in the region. Marine sediments are particularly extensive in the Wanganui and East Coast Basins, in the southern part of the North Island which have been the focus of research. The deep water facies of the East Coast Basin have provided the best records of foraminifera, particularly for the Late Pliocene to Early Pleistocene, but also for the Early and Middle Pleistocene (Hornbrook, 1981). These records have been correlated biostatigraphically with the classic marine sequence for the Late Cainozoic from DSDP Site 284 to the west of the South Island. The oxygen isotope record from this marine core was important in demonstrating Late Miocene expansion of the Antarctic ice sheet and, more significantly for this review, the initiation of northern hemisphere glaciation around 2.5 Ma.

In addition to these regional syntheses of foraminiferal stratigraphy, a number of oxygen isotope records have been produced around Australia covering the last two glacial cycles. Some of these have provided excellent chronologies for palynological records produced from the same cores. These records are considered under terrestrial fossil groups.

Closer to coast, marine and estuarine molluscs become important relative to foraminifera in the establishment of biostatigraphies and palaeoenvironmental conditions. As they are more closely linked with adjacent coastlines, molluscs tend to have more limited geographic distributions (with certain notable exceptions, particularly *Anadara trapezia* [Murray-Wallace et al., 2000]) although, due to their mobility frequently at the larval stage, many are common throughout the south Pacific and Indian Ocean regions. Molluscs are important as an index of temperature, depth and salinity so they provide evidence of changes in the distribution of currents. Water flow characteristics of rivers discharging into the sea, and sea levels. Their value is heightened by variation in the sediment types within which they are found, and by the skewed ranges of dating middle to late Quaternary shells, particularly by amino acid racemisation (e.g. Murray-Wallace, 1995; Murray-Wallace et al., 1989).

Knowledge of the taxonomy and Quaternary palaeoecology of molluscs is substantial for New Zealand, and comparable to studies of foraminifera.
Zealand (e.g. Beu & Maxwell, 1990) and for various parts of Australia, particularly the western seaboard of Western Australia and coastal South Australia (e.g. Kendrick et al., 1991; Ludbrook, 1994). Components of these areas, and especially New Zealand, have experienced uplift allowing the preservation of a variety of coastal landforms, especially those related to past sea level highs.

In New Zealand, molluscs have played a key role, along with foraminifera and nanofossils (minute phytoplankton with calcareous tests) in the development of the Quaternary biostratigraphy. The Plio/Pleistocene boundary has been traditionally located at the time of extinction of type, as with other water molluscs such as *Acanthinaea, Olivea* and *Polinices* and their replacement by cold water arrivals, for example *Zygophamys delicatula* and *Eucamptium nissimius* (Fleming, 1944) while subdivisions have relied heavily on the stratigraphic distribution of pelecypod bivalves (*Sectipecten, Phialopecten, Kapurachlamys, Zygophamys* and *Pecten senso stricto*) (Beu et al., 1987; Beu, 1995) and struthiolariid gastropods (Neef, 1970). Today, and very similar to conditions in the region during the middle Holocene (Kendrick, 1977). A recent review of the historical biogeography of the estuarine mollusc *Anadara trapezium* suggests that warmer seas and interglacial maxima were widespread in the southern Australian and New Zealand regions, dating from isotope stage 11 in New Zealand and at least isotope stage 7 in southern Australia (Murray-Wallace et al., 2000).

At lower latitudes, corals are an important fossil group. The time preserved and present day biogeography are relatively well known, especially for the Indo-Pacific region and they have a low rate of speciation, relative to most other faunal groups (Veron, 1995). A comparison of fossil and modern coral assemblages from the isotope 4 boundary in southern Papua New Guinea with those living today in the region indicated similarity in growth environment and that the majority of species (65) showed no significant differences from extant species (Veron & Kelly, 1988). Only nine species showed taxonomically significant change while only two taxa are now unknown within the region. Scleractinian corals have a well defined ecological ranges, good dispersal ability and can be identified to species level, although there is a great deal of morphological variability within species. These features make them useful for climate reconstruction, although they can also be used to investigate changes in circulation and frontal movements (Sun et al., 1994). Taxa characteristic of warm seas include *Platygyra ridleyi* zoharyi, *Operculodinium israelianum* and *Tuberculodinium vancampae*. Taxa characteristic of cooler seas include *Bietactatodinium tepikiense*, *Dalella chathamense* and *Pyxidinopsis reticulata*. Most Quaternary studies are based on Late Pleistocene and Holocene changes in southeastern Australia. These include *Halimeda*, which can be used in Quaternary palaeo-environments during the Quaternary for near-shore environments. Their value is enhanced by the fact that many species contribute to the formation of reefs whose relative permanence in the landscape allows the reconstruction of environments over long periods of time. Studies on coral assemblages through the last 95 ka in New Guinea have indicated little change in composition, suggesting either that sea surface temperatures have been relatively constant or that corals in the equatorial regions are relatively insensitive to temperature change (Pandolfi, 1996); however, there have been major changes in the distribution and activity of reef growth off eastern Australia, including the Great Barrier Reef (McKenzie & Davies, 1993). The attenuation of coral species with increased latitude has indicated factors such as past glacial sea level changes which extend to Isotope Stage 7, none of the others examined material beyond Isotope Stage 5c.

In an examination of Pliocene to Holocene sequences from foundation test holes associated with the construction of production platforms in the Bass Strait, McMinn (1992b) identified three main environmental and facies development and isolation of the Leeuwu. Current in the Middle Pleistocene. Assemblages from the Last Inter glacial Maximum, dated by Uranium/Thorium (U/Th), suggest that river discharge, and hence climate, was less variable than today, and very similar to conditions in the region during the middle Holocene (Kendrick, 1977). A recent review of the historical biogeography of the estuarine mollusc *Anadara trapezium* suggests that warmer seas and interglacial maxima were widespread in the southern Australian and New Zealand regions, dating from isotope stage 11 in New Zealand and at least isotope stage 7 in southern Australia (Murray-Wallace et al., 2000). Many factors influence coral distributions and caution must be exercised in relating fossil occurrences simply to temperature levels (Veron, 1995), it is up.likely that temperature has not been a major factor in the creation of such large differences in coral assemblages. However, the extinction of *Operculodinium israelianum*, are recognised within the *A. ramulifera* zone. *O. israelianum* is a common warm temperate and tropical species and so it is not possible to recognise this zone much further north.

Neogene and Quaternary sequences have been examined from offshore northeastern (McMinn, 1992d) and northeastern (McMinn, 1994a, b) Australia. The Quaternary samples from northwestern Australia contained evidence for reworking and so no attempt was made to correlate them with the southern assemblages. Some assemblages were typical of tropical environments. The dinoflagellate cysts in the study from the Great Barrier Reef, northeastern Australia, unfortunately showed little systematic variation coinciding with glacial/interglacial events. It is probable that the water temperature varied by too little in this location for changes in the dinoflagellate assemblages to be significant, a conclusion at variance with the interpretation of oxygen isotope records from the area.

**Terrestrial fossil groups**

By far the most important indicator of terrestrial palaeoenvironments is pollen which is preserved in almost all continuously waterlogged sediments including those of marine environments, in many lakes which experience drying particularly if there is a salt crust, and in many cave deposits. All these environments have revealed useful measures of surrounding vegetation due to atmospheric and fluvial transport and mixing of pollen, with the size of the vegetation catchment recorded generally related to the size of the depositional basin. Most onshore records are from more humid environments, particularly New Zealand, southeastern Australia and New Guinea Highlands where cool conditions combined with high precipitation are most conducive to the accumulation of peat deposits and contain sites which are predominantly influenced by terrestrial activity. The clusters of sites in northeast Queensland and in the drier western parts of Victoria reflect the availability of sites produced by volcanic activity. Other records largely within these areas are derived from depressions and karst areas within the river valleys and coasts. The majority of sequences provide evidence for the period since the Last Glacial Maximum and have allowed the construction of regional patterns of vegetation and climate.
environmental, particularly climatic, change for this period. Regional summaries are provided in Dodson (1992), with a more detailed analysis of mainland southeastern Australia undertaken by Kershaw (1993). Other long and substantially longer continuous records from aquatic sites, covering at least the last glacial cycle, are confined to deep volcanic crater lakes such as Lake Taran (D’Costa & Kershaw, 1995) and Lake Wanggango (Edney et al., 1990, Harle et al., 1999) on the Western Plains of Victoria, Lake Keale (Jones-Williams & Dodson, 1975 and Lynch’s Crater and Strenzkeff’s Crater on the Atherton Tableland (Kershaw, 1994), the tectonic basins of Lake George near Canberra (Singh & Geissler, 1985; Kershaw et al., 1991) and Wellington, New Zealand (Mildenhall, 1994, 1995), the spring deposits of Pulbena Swamp in northern Tasmania (Collou et al., 1982), the glaciated basin of Lake Selina in western Tasmania which survived the latest glaciation (Colhou et al., 1999) and the Darwin Crater meteorite impact depression (Colhou, 1988). More discontinuous long records have been constructed from the sites of Egg Lagoon on King Island (D’Costa et al., 1993) and Hidden Lake on Fraser Island (Longmore & Heijin, 1999) inland of coastal dunes.

In the absence of direct, reliable, radiometric dating methods, most of these records have been estimated from pattern matching with the marine isotope record. However, such matching, even if generally reliable, inhibits investigation of lead and lag effects which are important for understanding the causes of climate change and vegetation responses. Analysis of pollen from marine sequences permits comparison of pollen and isotope records. Records produced from the Lombok Ridge (van der Kaars, 1991; Wang et al., 1999) and Banda Sea (van der Kaars et al., 2000) to the north of Australia, provide a regional picture of vegetation and flora in the northern Australia-New Guinea-Indonesian region over the last few glacial cycles; DSDP Site 594 off South Island, New Zealand (Reussur & van de Geer, 1994) and ODSP Site 820 on the northeast Queensland continental slope (Moss & Kershaw, 2000) covering a similar period, and deep sea cores STM8-7 and STM8-10 (van Geer et al., 1994) and E55-6 off the coast of western Victoria (Harle, 1997) covering much or all of the last glacial cycle. Despite the very different environments of deposition, all marine records show patterns of vegetation change similar to more localised records of palaeoenvironments and in the case of the three latter records, the aims of correlation with, and provision of a firmer timescale for, adjacent terrestrial records, were achieved.

Only two records cover a large part of the Quaternary; that from Lake George and a coarse record through the last 1.4Ma from ODP Site 820 (Kershaw et al., 1993). However, the first of these records of Quaternary vegetation and flora, although poorly dated, the second record has provided polliniferous sequences in drillholes and exposures, particularly in the more dynamic landscapes of New Zealand (e.g. Mildenhall, 1978, 1983; Mildenhall & Suggate, 1981) and Tasmania (e.g. Augustinus & Macphail, 1997; Jordan et al., 1995) of the last glacial cycle from Westland on the South Island from about 20 isolated deposits. Summaries of pollen stratigraphy and vegetation are provided for the Last Pliocene (Macphail et al., 1995) and Early-Middle Pleistocene (Macphail et al., 1993) of Tasmania, and for at least parts of the Quaternary and the Tertiary/Quaternary transition in the general region by Mildenhall (1980), Kershaw (1988), Kershaw et al. (1994), Macphail (1997) and Nelson et al. (1988).

There are few continuous pollen records of any length published from semi-arid and arid regions. Two prominent arid regions are confined to deep volcanic crater lakes such as Lake George near Canberra (Singh & Geissler, 1985; Kershaw et al., 1991) and Hidden Lake on Fraser Island (Longmore & Heijn, 1999) inland of coastal dunes.

Also showing potential from these more arid environments is the study of pollen preserved in macrofossils. Traditionally, analysis of the remains of leaves, fruit and seeds has focused on local aquatic plants and contributed to the documentation and understanding of hydroseral succession (Watts, 1978). However, the limited number of macrofossil records, in Australasia, often in association with pollen analysis, has been of greater importance to understanding of evolutionary and distributional patterns in selected terrestrial taxa as well as in refining palaeoclimatic estimates. Advantages of macrofossil remains over pollen, in addition to that of identifying larger and more robust elements of environmental conditions, particularly the size and shape of leaves and their degree of sclerophily, as well as their limited dispersal. The most substantial and systematic studies on Quaternary macrofossils, which have included examination of dispersed or rare elements, have been undertaken in Tasmania (Hill & Macphail, 1985; Jordan, 1995a,b, 1997; Jordan et al., 1991, 1995) and have revealed marked changes in the distribution and ecology of a number of midden taxa.
and sclerophyll taxa over the Quaternary period, including extinctions at the palynologically invisible level. One major conclusion is that caution must be exercised in applying present vegetation patterns to the reconstruction of past climates as both plant/climate relationships and climate itself have been very different from those of today. In studies confined to the late Quaternary, however, the presence of macrofossils in the form of wood of Nothofagus in mainland southeast Australia (McKenzie & Busby, 1992; McKenzie & Kershaw, 1997) and Agathis in North Island, New Zealand (Ogden et al., 1992), has been instrumental in documenting precise changes in the distribution of these taxa which have allowed detailed quantitative estimates of past climatic changes. In one such case, expansion of 30% of the degree of climate change could also be gauged from a comparison of tree rings within modern and fossil wood.

Macrofossil examination is increasingly forming a component of archaeological studies (Beck et al., 1989) and although emphasis is usually placed on collected food and related materials, valuable and detailed data can be obtained on changes in plant distribution and climate. McConnell (1997), for example, provides a credible picture of climate change through the last 40 ka in the Kimberley region, an area which has proved essentially barren for palynological study. In addition, macroremains from stick-nest rat middens in arid areas can provide a useful complement to pollen as has been the case for packrats in the USA, although material is less abundant than in the USA (Hale et al., 1998).

Another form of plant material, which comes in micro- and macro-fossil size ranges, is charcoal. This very resistant product of biomass burning is essential for understanding the biogeography of the component (e.g. Wang et al., 1995), which has generally increased in activity throughout this period, but, despite the important background research of Clark (1982, 1983, 1984), it has not proved possible as yet to quantify vegetation/fire relationships. Concerns about the existence of fire, and hence an indication of the nature of the source vegetation, in the study of the tropical marine core by Wang et al. (1999), this measure approximates the amount of burning in forest relative to that in grassland. Another recent development has been the utilisation of the fine structural detail preserved in macrofossil charcoal to allow identification of source plants (Hope, 1998). In northeast Queensland, the analysis and dating of soil charcoal has allowed a greater spatial assessment of late Quaternary and Holocene fire, and Lynch’s Crater pollen record to be determined (Hopkins et al., 1993, 1996). The identification of the charcoal as *Eucalyptus* demonstrates that eucalypt woodland regionally replaced rainforest during the Last Glacial Maximum and has major applications to the debate over glacial rainforest refugia and the present distribution and floristic stability of rainforest communities. The ongoing examination of charcoal in archaeological sites to the west of the major areas of rainforest in northeast Queensland is providing a further spatial extension of late Quaternary fire chronology in an area where long pollen sequences are lacking (Nie Dolby, pers. comm.). The potential of this method to provide data on vegetation from arid environments has been demonstrated by the analysis of charcoal from an archaeological site in central Australia (Smith et al., 1995). Here, the development of vegetation similar to the present day was deduced from identification of mulga (*Acacia aneura*) charcoal, an identification that would not have been possible from pollen alone.

In contrast to the flora, fauna! groups have played relatively little part in the construction of Quaternary terrestrial sequences and environments; consequently data with which to construct palaeogeographies is limited. This is in marked contrast to other parts of the world where large mammals have traditionally played a major role in the formation of megafaunal extinctions. In Australia, there was mass extinction of an estimated 86% of existing ‘megafauna’ (Martin, 1984) including all 19 species greater than 100kg in mass (Flannery, 1990). Megafaunal extinctions at the end of the Pleistocene were predominantly by three reptiles and one flightless bird (*Genyornis*). The ‘event’ was accompanied by a lower but still significant proportion of extinction in a whole range of smaller terrestrial vertebrates and by dwarfing in some extant species (Flannery, 1990; Murray, 1984). As the megafaunal extinction occurred much earlier in Australia than in New Zealand, within the Late Pleistocene, reconstruction of distribution patterns and habitats of extinct species is more difficult. However, from the examination of all sites containing extinct megafauna (Fig. 2) combined with feeding habits determined from their dentition and assumed vegetation patterns, a substantial attempt has been made by Horton (1984), at least for the marsupials. He determined that there were three major groups of megafaunal species, one adapted to southern grasslands and forests, another to drier forests and woodlands, and a third to cooler and wetter woodlands. On the basis of distribution patterns of surviving fauna, he allocated the megafauna to rainfall zones between 250 and 750 mm mean annual rainfall. He considered that their last known occurrence in the absence of extinctions was in forested and drier environments consistent with biomass estimates and faunal composition globally. An interesting feature of this reconstruction is that the only megafaunal species environments has inhibited the development of useful biostratigraphies or evolutionary trends, with the added impediment that macrofossil studies demand access to a large amount of material. Charcoal from C4 plants has been extracted; largely from erosion products within river systems, swamps, lakes, lunette and sand dunes and loess, and also to caves where the ratio of fossils to matrix is high and where assistance is often provided, for more recent time periods, by archaeologists. Archaeological middens also contribute a source of recent material. Much background on Quaternary faunas is presented, at length, in Vickers-Rich et al. (1991). Throughout the region, there is little information on vertebrate faunas that can be dated to the Late Quaternary and Holocene. One major difficulty of placing sites in even a relative chronology suggests that there was little change in the fauna during the Last Glacial Maximum. Richard (1991) states that ‘As a generality, with unfortunately all too few exceptions, it may be said that Australian terrestrial mammal sites fall into one of two age groups. Either they are younger than 35 ka and capable of being dated by the 14C-technique or they are regarded as Quaternary, beyond the range of 14C. This conclusion is largely echoed for Quaternary avifauna, where Baird (1991) notes only a few elements restricted to this period, while the Early and Middle Pleistocene are almost absent from the New Zealand terrestrial vertebrate record and the few bones from the Pito/Pleistocene are all attributable to taxa recorded at present or within the Holocene (Millener, 1991). However, there are a few sites in Australia which have the potential to provide long stratigraphic records. These include the Wellington Caves complex of New South Wales which may extend back into the *Late Tertiary* (Osborne, 1997), and Naracoorte Caves in South Australia. There is a lack of dating of these sites, now being addressed by *Thermal Ionisation Mass Spectrometry* (TIMS) of speleothems (Ayliffe et al., 1997).

Late Quaternary sites are plentiful, a result of their accessibility, greater likelihood of preservation, archaeological interest and the facilitation of a major role by megafaunal extinctions. To highlight the nature of the extinction event, in New Zealand where there is a close association between extinction and the arrival of people which occurred in the very late Holocene, over 800 sites are known and, in addition, within midden sites, at least 28 of the 33 avian species including all 11 moas, probably representing the last phase of extinctions in New Zealand. In the absence of direct archaeological evidence of the Polynesian period are recorded (Millener, 1991). From these data, recent, more substantial vertebrate records extending back to the very late Pleistocene (eg. Worth, Holdaway, 1993, 1994, 1966; Worth, 1998) and associated palynological research, it has been possible to reconstruct the ecology and distribution of the extinct avifauna, particularly the moa, an important prerequisite for the understanding of the cause(s) of extinction. The original assumption that most moa occupied grassland habitats has proved untenable in light of the substantial late Quaternary vegetation history of the islands (McGlone, 1988) which clearly shows that most of New Zealand was woodland and forested until the last thousand years. The distribution of kill sites and examination of crop contents showing a high proportion of twigs, indicates that the majority of species inhabited open forest and scrubland with several confined to lowland or upland forest, and one species to swamp forest and swamps. There appears to be no pattern in the order of extinction between species and the chronology of sites shows a strong peak around 1300-1250 AD followed by a rapid decline. No sites are reliably dated to later than the 16th century (Anderson & McGlone, 1992) and it is possible that moa disappeared within a hundred years of the arrival of people (Holdaway & Jacomb, 2000).

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of arid areas, the red kangaroo (Macropus rufus), did not become extinct. Horton credits this survival to the lack of stress on an arid-adapted species during the extinction period that he relates to a period of continental drying. He considers that the majority of taxa became extinct at or shortly after about 26 ka, the beginning of oxygen isotope stage 2, with the remainder succumbing to drier conditions around or after the Last Glacial Maximum between about 18 and 15 ka.

Horton’s climatic model is one of a number of hypotheses that have been forwarded in an attempt to explain megaфаunal extinction and, partially due to the overwhelming evidence for extinction by humans in New Zealand, has not been widely accepted. However, it has been difficult to argue the climatic hypothesis either to overkill (Flannery, 1990; 1994) or through habitat change (e.g. Jones, 1973), when radiocarbon ages have persistently suggested that megaфаuna and people co-existed for at least 20 ka (see next section for timing of the arrival of people in Australia). Only recently, with the application of dating techniques additional to radiocarbon, has any confidence been generated in the timing of megaфаunal extinction. The most convincing evidence for the timing of extinction comes from amino acid racemisation dating, supported by amino acid racemometry (AMS) radiocarbon and TIMS CT-series analysis, of some 1200 egg shells of the giant flightless bird, Genyornis, from three arid to semi-arid regions in southern Australia (Miller et al. 1999). Genyornis was continuously present from more than 100 ka until 50 ka when it suddenly disappeared. In a more humid part of southeastern Australia, electron spin resonance dating of extinct diprotodon teeth at Lancefield Swamp, a site critical to climate particularly temperature change (Elias, 1986), is also considered to be a reliable palaeoecological indicator. These respectively, during the late Quaternary, were very different from those of today, limiting their application to the reconstruction of past climates (D’Costa et al., 1987).

Anomalies, which have only recently begun to contribute to an understanding of Quaternary terrestrial environments are land snails and beetles. Land snails are commonly used in the northern hemisphere for providing details of past vegetation communities, and moisture and temperature records (e.g. Jones, 1973). Although they have been limited in their application in Australia because the detailed ecological and systematic background research necessary for full interpretation of fossil records has yet to be undertaken. However, several studies have been successfully completed. Two studies on land snails, from a limestone rock shelf at Chillagoe in north Queensland (David & Stanisic, 1990) and from a limestone cave in southwestern Tasmania (Porch & Allen, in prep.), provide local environmental records for archaeological sites in support of the dating. A third record from Pulbena Swamp in northern Tasmania (Porch, submitted) provides additional and supportive evidence of environmental changes deduced from the analysis of pollen (Colhoun et al., 1982) and ostracods (De Decker, 1982d) at the site. These records have been established recently that in northeast Queensland at least, there is systematic intraspecific variation in mollusc size in relation to rainfall which is providing a basis for reconstruction of past rainfall patterns from fossil sequences (Rowe et al., in press). The beetle, a terrestrial animal, in contrast to the lastualy terrestrial beetles, lies in their sensitivity and rapid response to climatic changes (Eliasi, 1994). It has been demonstrated in the northern hemisphere that beetles provide a much more precise indicator of major climatic changes than do the arid regions of Australia. The bulk of palaeoenvironmental information is derived from the fauna that survived the extinction phase. A number of studies have provided data which complement or question reconstructions derived from pollen and geographic data in southwestern Australia, where Climatic reconstructions are few and somewhat contradictory, faunal sequences have been important in establishing past environmental conditions (Merrilees, 1984). The value of bird remains has been demonstrated by Baird (1989) and Worthy & Holdaway (1993) in detecting the survival of palynologically invisible or uncertain location of small pockets of rainforest in southeastern Australia and Westland, New Zealand. However, it has been difficult to combine palaeoecological indicators which might be useful in extending the single most useful fossil. As with plant fossils, it is frequently revealed that past assemblages, even during the late Quaternary, were very different from those of today, limiting their application to the reconstruction of past climates (D’Costa et al., 1987).

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Aquatic biota

Fossil studies have importance in Australian aquatic environments largely because of a general shortage of water bodies and aquatic organisms. Raft species and their variability and human impact. However, the frequent drying up of lakes on all timescales has inhibited the development of research into many potential indicator fossils including rhizopods, rotifers, sponges, molluscs, insects and fishes, algal and cryptophytes, and have received attention in extinction phases in other parts of the world (De Decker, 1982a). The majority of studies which have been undertaken have intentionally or fortuitously also involved pollen analysis, providing a basis for interpretation in relation to broader catchment areas.

The most widely studied animals are the small crustacean ostracods which occur in lakes throughout much of the Australian continent. These can be identified to species level from shell shapes and ornamentation, which are sensitive to physicochemical conditions in lakes (De Decker, 1982b). They have been used to provide late Quaternary lake level and palaeoclimatic records for a range of sites, especially in southeastern Australia. These sites include volcanic crater lakes on the Western Plains of Victoria (De Decker, 1982b; D’Costa et al., 1989; Edney et al., 1990), Lake George (De Decker, 1982c), and Pulbena Swamp (De Decker, 1982d) where they have provided very valuable complements to other palaeoecological data, particularly pollen. Refinement of lake conditions, namely temperature, ionic composition and salinity has been achieved by the chemical composition of ostracod shells, especially the application of Sr/Ca and Mg/Ca ratios (e.g. Chivas et al., 1986; De Decker et al., 1988). Stable isotopes of carbon and oxygen, analysed from ostracod shells, have also helped reconstruct the origin of waters, their trophic status and salinity levels (Chivas et al., 1986).

The ecology and environmental controls on ostracod distributions in Australia, as well as their biogeography, is being further refined by multivariate analysis on several hundred modern assemblages from southeastern Australia (Lynda Taylor, pers. comm.) and a more general survey of the whole of the continent. Results indicate that a number of ostracod species have very specific requirements with respect to water chemistry and salinity. However, some fossil assemblages, notably in portions of the Lake George core, have no modern analogues and it is thought that these may represent bicarbonate-rich waters which are rarely found on the continent today. There is a characteristic group of ostracods in the northern part of the continent which provide information on the past incursion of summer rainfall conditions into southern Australia attimes in the past. There is no evidence of evolution or extinction in Quaternary ostracods.

Challenging the supremacy of ostracods in Australian environments are diatoms which have been used in the study of Quaternary environments in North America and Europe for several decades and are now the most commonly used palaeolimnological indicators for the reconstruction of palaeolimnological conditions from lake histories in many parts of the world. Diatoms are sensitive to a range of water chemistry parameters including nutrient concentration, salinity, ionic composition and pH: community composition is also influenced by biotic factors such as grazing pressure and the relative proportion of littoral to open water environments. Accordingly, diatom records have been used to provide insights into climate change, land use history, lake successional sequences, catchment processes and atmospheric pollution. Their global application is facilitated by the fact that identical species have been achieved to species level; that most species are cosmopolitan and display consistent optima and ranges for key environmental parameters. Their abundance allows statistical treatment in a similar manner to pollen.

Despite these advantages, the study of diatoms in Australia has been constrained for a long period by the assertion of Joe Richardson (in De Decker, 1982a) that the siliceous frustules of diatoms do not preserve well in sediments of a large number of aquatic environments, although an early study by Tudor (1973) did demonstrate the potential of the method. Recent advances have been made, largely by workers who took the time to learn methodology and taxonomy in foremost laboratories in the UK and France. A realistic appraisal of recent developments in Australia, acknowledging that there is still a need for more work in this area, has been undertaken by Reid et al. (1995).

Following Tudor’s study and one by D’Costa et al. (1989) on volcanic lake sediments of the Western Plains of Victoria, Gell (1998) focussed on similar sites with reconstruction of past salinity conditions based on an extended calibration set derived from over 150 surface samples from western Victoria (Gell, 1997). This approach has been adopted for factors influencing variation in billabongs and other river-related sites in the Murray-Darling Basin (Reid, 1997, Jenny Fluin, AAP Memoir 23 (2000)
ARCHAEOLOGICAL RECORD AND IDSTORY OF HUMAN SETTLEMENT

Although archaeology can be regarded as a distinct area of late Quaternary vertebrate palaeoecology and palaeobiogeography, people have had such an influence on faunal and floral biogeographic patterns that a separation of terrestrial and dryland vegetation (Bothe & Kershaw, 1999). One of the genera identified, Austromyrtus, demonstrates major range contraction as it has an older fossil record in Australia but no longer occurs on the continent.

The earliest undisputed evidence for people in Greater Australia comes from Carpenter’s Gap rockshelter in the Kimberleys (Western Australia), radiocarbon dated to around 40 ka (O’Connor, 1995). Two radiocarbon determinations of 39,700±1000 and 39,220±870 BP, separated vertically by some 20 cm of sediments, were obtained on charcoal firmly associated with cultural materials (McConnell & O’Connor, 1997). The two ages are near the limit of reliable radiocarbon dating and overlap within one standard deviation. This almost certainly indicates that at least the lowermost determination should be treated as a minimum age. How much older the deepest cultural deposits are is open to speculation.

Other early sites dated by radiocarbon means include Ngarrabullgan Cave in north Queensland (originally dated to >37,170 BP, but recently redated to c. 35,000 BP) (David, 1993), Upper Swan terrace in SW Western Australia (37.100+1600-1300 BP to 39.500+2300-1800 BP) (Pearce & Barlow 1995), the Wonnerup Lakes and lower Darling River system in SW New South Wales (including Lake Mungo) (36,000±1100 and older) (e.g. Balme & Hope, 1990; Bowler et al., 1970; Bowler & Thorne, 1976), Warreene Cave in SW Tasmania (Allen, 1997; and Yombina in SW Western Australia 1993; Pavlidis & Gosdon, 1994). The fact that occupation in all of these early sites begins within a short span of time, has led Allen & Holdaway (1995) to suggest that this truly represents the timing of the earliest advent of people in Greater Australia. Furthermore, all early radiocarbon ages were paired with OSL determinations, indicating that radiocarbon and OSL/TL ages are unlikely to differ by more than 2.5 ka. The difference noted above between a 40 ka radiocarbon and an older, 60 ka TL/OSL year chronology (see below) is, therefore, almost certainly not simply due to an employment of two different datant techniques. (Roberts et al., 1997).

The 37-40 ka limit for the antiquity of human presence in Australia, as inferred by radiocarbon dating, is seriously challenged by Roberts et al. (e.g. 1990, 1994), who prefer to interpret the timing of the earliest radiocarbon ages as representing a lower radiocarbon ceiling. They therefore employed TL in the late 1980s, and subsequently OSL, to date a number of sites previously suspected of being very old, but that could not be radiocarbon dated because of an absence of charcoal in the lowermost (i.e. earliest) deposits (Roberts et al., 1990, 1994; Roberts & Jones, 1994). At two sites from Kakadu, central north Australia—Nauwalabila and Malakunanja 2—dates of 53 to 60 ka were obtained for sediments associated with cultural materials. At Malakunanja 2, the earliest cultural deposits were preserved by a series of culturally sterile sediments. This was taken to indicate that people were not in Australia prior to about 60 ka by Roberts et al. (1990). This view is supported by a failure to find cultural materials in sediments (such as lunettes) dated to prior to 60 ka from other parts of Australia many years of searching by both archaeologists and geomorphologists.

There have been other archaeological claims for the presence of people in Australia deeper in antiquity, but none of these has withstood the test of time. The most recent involve suggestions from thermoluminescence dating for human presence as far back as 116 ka and 176 ka (Fullagar et al., 1996) but recent OSL and AMS radiocarbon ages agree that the site is younger than 10 ka (Roberts et al., 1998).

It is commonly accepted by most, if not all, Australian archaeologists that the earliest peoples to arrive in Australia came from Southeast Asia. The exact routes travelled are uncertain, but probably involved one of two possibilities:

1. A northern route from the Sunda shelf eastwards to what now are Sulawesi and Papua New Guinea or the Aru Islands, via smaller islands in the region (e.g. Webb, 1989).
2. A southern route, from Java (then a part of Sunda) through the now what are western Lesser Sunda Islands and Timor, south-eastwards to Greater Australia or eastwards to the eastern Lesser Sunda Islands and then to Greater Australia (Bipell 1977).

In each case, at least one sea crossing of more than 90 km was involved, making the first Australians the earliest known long-distance seafarers in the world. One implication is that cooperative behaviour (including language) of similar complexity to modern humans was involved. This is due more to the requirements of planning and boat/craft construction than to navigational skills. Some authors have argued that such behavioural implications would rule out early hominids such as Homo erectus (Davidson & Noble, 1992; but see Bednarik, 1997). This is consistent with the radiocarbon and TL/OSL chronologies, both of which firmly within the timeframe of Homo sapiens sapiens.

Considering the debate over the time of arrival, it is uncertain whether it took place during times of low sea levels, when sea crossings were shortest, or during times of rising seas, when population movements would have created social, political and/or economic pressures in the homelands. Resolution of this question depends on our ability to determine the timing of population movements and, consequently, of their arrival in Greater Australia. In either case, the first peoples were almost certainly Homo sapiens, and probably Homo sapiens sapiens, biologically akin to modern peoples (the earliest remains, including those of Lake Mungo, are fully modern) (e.g. Webb, 1989).

By 32 ka, the Huon Peninsula, New Britain, northern Australia, Tasmania, western New South Wales and southwestern Australia were all occupied. The only two major landscapes currently without occupational evidence by this early time are the arid core and the Southeastern Highlands. However, active sedimentation regimes in the former at least would render the discovery of such early sites very difficult; we do not therefore, know whether or not absence of evidence should be taken as evidence of absence. By 22 Ma, the Last Glacial Maximum, all major Australian environments were occupied, including the arid zone, the Southeastern Highlands, and the areas of highest bioclimatic diversity (Lourandos & Hope, 1976), although it is uncertain whether people actually lived in tropical rainforest until about 5 ka BP (Horsfall & Hall, 1990).

Most Australian archaeologists have concentrated on researching early sites, either in search for the ‘oldest’, or so as to obtain long temporal sequences by which cultural trends and trajectories can be investigated. Despite this, it is only in some parts of Australia that Pleistocene sites are commonly found: the tropical north (the Kimberleys, Arnhem Land and Cape York Peninsula) and the temperate coastal zone, the dry lakes of western New South Wales, and southwestern Tasmania. In the tropical north, more than half of the 58 excavated and dated rockshelters have revealed Pleistocene cultural materials in each of the three regions (Lourandos & David, in press). Such high proportions of early
sites are very unusual in the context of the rest of Australia, where Pleistocene rockshelters usually account for considerably less than 10% of known sites. This northern distinction probably indicates demographic circumstances peculiar to northern Australia, including higher Pleistocene human populations in the warm, humid regions north of the tropic of Capricorn.

It was once thought that the first Australian settlers colonised the continent following the coast, where both water and marine resources familiar to seafaring peoples could be found (Bowdler, 1977). However, the numerous early archaeological sites subsequently found in inland regions implies that this is unlikely to have been the case (see also White & O’Connell, 1982). Indeed, Birdsell (e.g. 1957) had earlier argued that colonisation followed inland routes, via the once well-watered lakes and rivers of the arid and semi-arid core. This problem is heightened by uncertainty over the problem of reconstruction with any confidence. This is in part made possible by the beginnings of systematic seed grinding (Lourandos & David, in press). After c. 5 ka, however, cultural trends diverge with occupational intensities increasing throughout the Holocene (but see Hiscock, 1986). David & Lourandos (1998) have recently argued that this divergence probably began during the early Holocene, when conditions became reglobalsed (see also McNiven, in press).

Together, these factors imply both a significant economic and politico-territorial networks. This established a demographic momentum that continued well after the end of the early Holocene ‘optimum’.

Intensification of occupation in Australia from about 5 ka is paralleled by an explosive human colonisation of the Southwest Pacific Islands from Melanesia (it is not known if these two processes were related), terminating in the eventual peopling of New Zealand (Enright & Gosden, 1992). The environmental impact on these islands was severe as a result of the introduction of new plants and animals, clearance of the native vegetation for agriculture, often using fire, and hunting of native fauna. Results included widespread species extinction and accelerated soil erosion on hill slopes and deposition on adjacent lowlands (Enright & Gosden, 1992). Although these events are geologically recent, there is still a great deal of debate on actual times of arrival of people on individual islands and subsequent timing and specific causes of various impacts. Debate is nowhere more heated than in New Zealand where three occupation chronologies have been proposed: ‘long’ (>1.5 ka), intermediate (c. 1 ka) and short (<0.6 ) (McGlone & Wilmshurst, 1999).

Fig. 3. Generalised reconstruction of features of the Australasian region at the height of the present (Holocene) interglacial, centred on 6 ka.

Details from Table 3. Table 3.细 Marcel values for dates of occupation for Off-shore Islands.

6 ka

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contact, if not settlement as per the long chronology, has been boost by AMS dating of bone collagen. The introduced Pacific rat (Rattus exulans) which have provided dates as old as 1.8 ka (Holdaway, 1996), although, predictably, these early dates have been questioned (Anderson, 1996). Biogeographically, this debate is important for determination of pattern and rates of faunal extinction. It also has a major bearing on causes of extinction as cats could have had a marked impact on the biota perhaps before the major phases of human colonisation and establishment.

EXIREMESOFTHELASTGLACIALCYCLE

The detail available for the mid Holocene ‘optimum’ and the Last Glacial Maximum (LGM) provides some indication of the degree of environmental change which has characterised much of the Quaternary period as well as biogeographic responses to it. These periods provide, in many ways, recent analogues for the less well known earlier part of the Quaternary although they differ in that people were present and the megafauna had become extinct. Although the focus here is placed on the response of organisms, it must be emphasised that estimates of environmental change are based on biological data, generally supplemented by complementary information derived from the physical sciences.

The mid Holocene ‘optimum’ occurred within the range 7 to 5 ka (Fig. 3). For most of Australasia, palynological data suggest that conditions were wetter, perhaps by up to 25% warmer, by about 1°C than present with reduced seasonal variation or inter-annual variability (Dodson & Harrison, 1993; Kershaw, 1995; McGlone et al., 1993). The period though does not necessarily incorporate either the highest temperatures or the most effective precipitation for all areas. In northeastern Queensland, for example, analyses on pollen data indicate that highest values were achieved after 5 ka - although in concert with increased variability (Kershaw & Nix, 1988) — while similar analyses in southeastern Australia (Lloyd & Kershaw, 1997; Markgraf et al., 1991) suggest that maximum winter temperatures occurred earlier, around 9 ka. However, these estimates are derived from wetter areas where high and more continuous cloud cover may have effectively reduced incoming radiation during the ‘optimum’ period. Sea surface temperatures are also considered to have been slightly higher, and have been demonstrated to have been along the western and southern coasts of Australia with a more intense Leeuwin current (Kendrick, 1977; Murray-Wallace et al., 2000). Sea levels reached their present day levels by about 6.5-6 ka (uncorrected 14C years) and may have exceeded them by up to a metre in some places towards the end of the period. Overall, climate controls on the environment were similar to those of today with the exception of the El Niño-Southern Oscillation (ENSO) whose activity is likely to have been lower until the very end of this period (McGlone et al., 1992). Biogeographic patterns were not significantly different to those of today at the broad regional level. Rainforest had a marginally expanded distribution but essentially retained a similar fragmented and remnant distribution as it does today in Australia. In New Guinea and New Zealand, rainforest had expanded to cover most of these islands, replacing grassland and open forest in drier areas and grassland and subalpine vegetation at higher altitudes. In southeast Australia at least there was also a greater coverage of both wet and dry sclerophyll forest. Mangroves, which had flourished during the marine transgression, retained a much greater abundance than today although there is little evidence for a greater spatial distribution. There is little information from the arid and semi-arid parts of Australia, but greater water availability in what are now ephemeral lake systems would have markedly altered aquatic assemblages. It is interesting to note though that the major playa lakes only filled partially during this interglacial period (eg. Magee et al., 1994). It is possible that even the small difference between this period and today has been augmented by the impact of Aboriginal people as intensity of occupation substantially increased throughout the Australian continent shortly after 5 ka. This event may have been triggered by the loss of environmental ability at this time or, as suggested by David & Lourandos (1998), environmental patchiness was created by a fragmentation of the political landscape after the mid Holocene, resulting in patch burning and use of accessible landscapes.

Condition(s) during the Last Glacial Maximum, centred on 20-18 ka (Fig. 4), were very different to those experienced by the first European colonists. In line with the retreat of world temperatures, most were cooler but, from available estimates, the degree of temperature lowering is uncertain. In southeastern Australia, New Zealand and the New Guinea highlands, evidence from the extent of glaciers and position of the treeline suggest that mean annual temperatures were in the order of 6°C lower at higher altitudes and perhaps 4-6°C lower in the lowlands. The application of bioclimatic profiles of rainforest taxa to fossil assemblages in the Otway Ranges of Victoria suggest that temperatures were no more than 6°C lower (McKenzie & Kershaw, 1997), while mapping of the extent of periglacial activity in southeastern Australia indicated a depression of up to 9°C (Barrows, 1995). A similar surprisingly extreme estimate has been proposed from amino-acid racemisation of eggshells preserved in the central part of Australia (Miller et al., 1999). These estimates of temperature lowering for terrestrial environments are generally larger than those predicted from global climatic modelling (Harrison & Dodson, 1993; McGlone et al., 1993) and from sea surface temperatures based on distributional changes in foraminifera (Barrows et al., 1995; Wright et al., 1993), which do not exceed 3-4°C. Greater debate is over the extent of temperature lowering in the tropics. There is little evidence of temperature change from the terrestrial lowlands within the region but temperature lowering in pollen records in the Indonesian region immediately to the north suggest reductions in the order of 6°C, similar to those at higher tropical altitudes and to higher latitudes (van der Kaars, 1998). Sea surface temperature estimates vary from 0-2°C based on foraminiferal assemblages (Barrows et al., 1996; Thunell et al., 1994) to about 5°C from tropical corals (Guilderson et al., 1994) lower than today.

During the Last Glacial Maximum, both absolute and effective precipitation was reduced. Estimates from biological and geomorphic data suggest a reduction up to 50% of those of today. These differences are much greater than those suggested from global model results (Wright et al., 1993). One major influence was the temperature lowering which reduced the ability of the atmosphere to take up moisture and which, in the tropics, caused a reduction in cyclogenesis. The situation was exacerbated by substantially reduced sea levels, down about 130 m, with the build up of ice in the northern hemisphere. Low sea levels resulted in greater continentality and moisture reduction within present terrestrial landscapes due to the loss of extensive continental shelves and coastal mountains. Evidence from corals, molluscs and marine plankton suggests that transport of warm water to higher latitudes along the western and southern Australian coast was...
substantially lowered by the switching off of the Leeuwen current. Despite reduced temperatures, evaporation rates may have been high due to higher winds associated with the compression of pressure belts towards the equator, although there is uncertainty as to whether the critical boundary between the westerly winds and subtropical high pressure belt across central Australia was located to the north or south of its present position (Bowler et al., 1976; Harrison & Dodson, 1993). Marine evidence suggests strongly that frontal zones were north of their present positions during the last glacial period. Although conditions were generally dryer, the Last Glacial Maximum was wetter than the period succeeding it, from about 15,000 to 12,000 BP when rising temperatures on an essentially glacial landscape reduced effective precipitation to lowest levels within the last glacial cycle (Kershaw & Nanson, 1993).

One major regional response to glacial conditions was a reduction in the extent of mesic communities, particularly rainforest and mangroves. The only recorded areas of substantial rainforest were in New Guinea and Northland, New Zealand, although records from coastal and marine records during the Holocene transgression, continuing to some degree through the Holocene period, but there is little evidence for mangroves at the Last Glacial Maximum. Reduced precipitation and temperatures would have had some influence, but the most important factor would have been the loss of shallow water habitats with the retreat of the sea to the continental margins. Survival would have been limited to narrow patches along the continental slope.

Rainforest vegetation and other mesic communities, particularly the eucalypt dominated wet and dry sclerophyll forests in southern and eastern Australia, were regionally replaced by more open eucalypt woodlands in Australia including some lowland parts of New Guinea, grassland steppe and low shrubland vegetation. It is considered that the almost total replacement of trees by steppe would require conditions more extreme than those accountable by reduced temperatures, rainfall and stronger winds, and McGlone (1988) postulates also the occurrence of frequent incursions of cold southerly winds and regular frosts for this period. There is little direct evidence of Vud land vegetation except that the cover must have been reduced to allow extensive mobilisation of sands over a large portion of Australia. The occurrence of red kangaroo bones though, outside of the present natural range of the species, indicates expansion of arid zone ecosystems (Horton, 1984).
Although it is possible to define the gross floristic and structural features of major communities, many assemblages were different to those of today. This is not unexpected as the range of climates was different to those at present. There is no identified modern analogue for the extensive grassland steppe vegetation (Kershaw, 1998) and components must be hidden in a variety of alpine, subalpine and cool woodland communities (Hope, 1994). One major component, a type of Podocarpus, which produced a distinctive type of pollen characterised as ‘spikes’. Given the form name of Tabulifloridites has been recorded only rarely in the Holocene. pleistocenicus by Martin (1973), it may relate to several pollen taxa including Calomelania and Cassinia arcuata (Macphail & Khan, 1991), but it is also possible that at least some component taxa have become extinct. In extinct Queensland, a rainforest genus, Dacrydium, appears to be have become extinct within the Last Glacial Maximum (Kershaw, 1994). Within the fauna, Hope et al. (1978) record an otherwise mixed faunal assemblage on Kangaroo Island, South Australia, than is present today including rodents from dense scrubs to open shrublands and pygmy possums now restricted to Tasmania.

In terms of general biogeographic responses to the environment extremes, the majority of taxa, although responding in an individualistic manner, generally appear to have expanded and contracted within particular ranges rather than undertaking wholesale migration as is characteristic of organisms in glaciated parts of the world. In an examination of regional patterns of change in the Victorian region, rainforest expanded only marginally in the Holocene from retreats occupied during the glacial period (Kershaw, 1998). Greater expansion was probably inhibited by limited dispersal and by a sensitivity to fire in exposed situations. There is no indication that areas of rainforest separated by more than a few kilometres coalesced during the Holocene ‘optimum’.

**PATTERNS OF CHANGE THROUGH THE PLEISTOCENE**

Discussion is focused on three major areas where a combination of suitable sedimentary sequences and interest in analysis of a range of palaeoecological indicators has provided at least some picture of changing environments and biotic responses through much of the Quaternary period. Summaries of sequences from these areas are shown on Figures 5 to 7 in relation to the global marine oxygen isotope stratigraphy of Shackleton et al. (1995) and to the New Zealand biostratigraphy of Naish et al. (1996) and the New Zealand biostratigraphy (Naish et al. 1996; and astronomical timescale of Lourens et al. (1996) and Jordan et al. (1996). Time ranges only of first and last appearances of major biotic indicators are included but the inferred time ranges of terrestrial floral sequences providing largely continuous and quantitative data are also discussed.

The most complete sequence is centred on the Wanganui Basin of New Zealand where a record of marine cyclicity dating back to 3.6 Ma has been identified and correlated with the astronomically-tuned marine isotope record, from palaeomagnetism, oxygen isotope ratios, biostratigraphy, cyclostratigraphy and tephra-chronostratigraphy (Naish et al., 1998). Evidence is provided of changes in foraminiferal, mollusc and pollen assemblages from this area and the broader region of the North Island (Fig. 5). Southeastern Australia has been the centre of Cainozoic pollen and plant macrofossil studies, but chronostratigraphical control is poor for the uneconomic Quaternary part of the record (Fig. 6). By contrast, a great deal of recent effort has been put into the establishment of the offshore stratigraphy of northeastern Australia, particularly to assist in the dating and understanding of environments associated with the development and history of coral reefs (McKenzie et al., 1993). The onshore and offshore records have also been tied together by palynological studies of isotopically and biostratigraphically dated offshore core (Fig. 7).

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to 2.2 Ma is suggested, although this is likely to be an artefact of representation of discontinuous sequences and uncertain dating as well as geographical spread of sites rather than a series of abrupt events. Again there is little response at or around 1.8 Ma, with only Microstrobos disappearing slightly after this time.

In southeastern Australia, the only firmly dated pollen record which transcends the Plio-Pleistocene boundary is that from Lake George, which, from the pollen evidence, indicates the abrupt decline of a number of essentially cool temperate forest taxa at some time within the latter part of the Gauss palaeomagnetic chron, that ended about 2.6 Ma. There is little vegetation response around 1.8 Ma although one recent taxon - Podocarpaceae - is regionally present to about 2.2 Ma. Records from Tasmania and the offshore Gipsland Basin, reviewed by Macphail (1997), show similar marked declines in rainforest or wet heath taxa around the Plio-Pleistocene boundary, and it is likely that in future, more continuous and better dated sequences will indicate some synchrony of change about or slightly after 2.6 Ma.

In northeastern Australia, there is a coarse but almost continuous record through the late Cenozoic and little evidence of floral turnover relating to either definition of the Plio-Pleistocene boundary. The only possible disappearance of a taxon at a palynologically visible level is Nothofagus subsection Brassospora but many other recognisable taxa which became extinct in southeastern Australia, and also New Zealand, survived in the northeast.

The most obvious explanation for the changes in New Zealand is a reduction in temperature indicated by marine indicators and suggested from pollen data by the loss of a number of taxa, including Sapotaceae, Cupanae and Beaucrata, which are now restricted to moist environments at lower latitudes. However, the loss also of taxa which are characteristic of cool temperate forests, such as Microcachrys and species of Nothofagus subsection Brassospora, suggest the influence of other factors of which increased climatic variability, particularly in the case of Nothofagus subsection Brassospora, presently restricted to montane environments in New Guinea and New Caledonia, is likely to have been important. Some increase in taxa of more open environments suggest also that somewhat drier conditions may have accompanied this variability.

In southeastern Australia, almost all identifiable taxa which became extinct have representatives in cool temperate rainforests or have extant relatives whose predicted temperature ranges in cool temperate forests, or around 1.8 Ma.

**Plio-Pleistocene boundary**

There are few areas where it has been possible to address the position and significance of the Plio-Pleistocene boundary. One of these is New Zealand where there has long been interest in relating the local biostratigraphic scheme to the global Quaternary stratigraphy. Evidence for cooling, noted as early as the 1940s, resulted in the base of the Nukwranuan being correlated with the Plio-Pleistocene boundary (Fleming, 1953). Subsequent dating of this stage produced contradictory results and uncertainty about its global relationships. However, the weight of evidence, including that from Wanganui, indicates an age close to the Gauss/Matuyama boundary and adds weight to the proposal to move the Plio-Pleistocene boundary to around 2.6 Ma (Naish et al., 1998). A concentration of last occurrences of typical Pliocene warm water bivalve molluscs and the first representation of a number of cool water taxa, including foraminifera, coccoliths and bivalves around 2.5 Ma and the lack of any real assemblage changes around 1.8 Ma, is a good illustration of the significance of the proposed boundary.

On land, changes in the pollen flora of North Island are even more dramatic, although extinctions far outweigh first appearances and include a variety of arboreal or shrub taxa, with rainforest affinities. A stepwise elimination from about 2.5 Ma is suggested, although this is likely to be an artefact of representation of discontinuous sequences and uncertain dating as well as geographical spread of sites rather than a series of abrupt events. Again there is little response at or around 1.8 Ma, with only Microstrobos disappearing slightly after this time.

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In southeastern Australia, almost all identifiable taxa which became extinct have representatives in cool temperate rainforests or have extant relatives whose predicted temperature ranges should allow them to survive at these high latitudes (Kershaw, 1997). Consequently any decrease in local influence. One possible influence is suggested by Bowler (1982) who, in an attempt to explain sedimentological sequences in southeastern Australia including that of Lake George, postulated that the steepening of the latitudinal gradient with the development of the Antarctic ice sheet resulted in the formation, expansion and movement northwards of the mid latitude high pressure belt. This contributed to continental drying in the Pliocene and to a switch from summer to winter rainfall in southeastern Australia around 2.5 Ma as this region, for the first time, came under the influence of the westerly wind belt. Such a change in seasonality have had a more dramatic impact on rainforest taxa than any reduction in temperature and rainfall and its influence is likely to have extended to New Zealand.

The lack of any substantial response in the flora of northeastern Australia at the Plio-Pleistocene boundary is consistent with the Bowler hypothesis in that no major change in atmospheric circulation is predicted for this part of the world and also with a reduced impact of any steepening of the temperature gradient in these tropical latitudes. The major oscillation in sea surface temperatures postulated for the Coral Sea in the Late Pliocene, culminating in a sharp rise in temperature around 2.5 Ma, appears not to have had any long term effect on the vegetation, although the period itself is notable for a lack of preserved fossil evidence in offshore cores analysed to date (Kershaw et al., in press).

**Early Pleistocene**

This interval covers at least two-thirds of the Quaternary period, yet, because of a sparsity of evidence or at least dated evidence, is virtually ignored in any reconstruction of Quaternary environments. Its potential role in the development and understanding of present day environments and biogeography.

The substantial changes at the Plio-Pleistocene boundary in southeastern mainland Australia resulted in a landscape dominated by vegetation that has no recognisable modern analogue.
Asteraceae, including high values of the distinctive morphological type Tricolporites pleistocenicus, dominated the herbaceous component of the vegetation, while Casuarinaceae composed the major arboreal element, during the recorded period from Lake George (c. 2.5-1.3 Ma) (Kershaw et al., 1993). From the earliest part of the period in the Hapuku-1 core, offshore Gippsland Basin (Macphail, 1997). This combination continued as important through much of the Quaternary from Gippsland Basin evidence (Alan Partridge, pers. comm.). A dominance of Asteraceae is indicated around a TL age of about 1 Ma in a short sequence from a sand quarry bordering Port Phillip Bay (Pearson, 1996). In the western plains of Victoria, a 70 m core from the volcanic crater of Pejark Marsh provides a semi-continuous, fossiliferous, time-dated, pollen record from about 0.7 to 1 Ma (Wegstaff et al., in press). Poaceae shares dominance with Asteraceae in this record, probably because the heavy basaltic soils favoured grasses as they do today, while trees are relatively limited in their representation, with again Casuarinaceae as the most conspicuous component. A further problematic element is the frequent occurrence of Cyathea spores suggesting the representation of separate tree fern communities.

The general impression from the vegetation is that, although climate cyclicity is evident, it was not the biogeographic force that is seen in the later part of the Quaternary, with climate not achieving extremes of temperature or precipitation. From the modern pollen data set in southeastern Australia, the closest matches are with some semi-arid spectra where Casuarinaceae woodlands are most conspicuous and the dry conditions are conducive to proliferation of opportunistic Asteraceae. However, conditions appear to have been cooler than present as T. pleistocenicus values are much reduced during later interglacials. This reconstruction accords well with interpretations of the marine isotope record which suggests that conditions should have been as warm as today. Consequently it is likely that other factors were important in determining the vegetation cover of this period. One possibility is that at some time in the past, the parts of the pre-existing vegetation were unable to adapt to the proposed switch from summer to winter rainfall and that cosmopolitan elements like the daisies filled this void. Major casualties were the Araucariaceae, indicative of forests which expanded over much of the eastern part of Australia as wetter rainforests declined during the Late Tertiary, and also the eucalypts and related Myrtaceae which, in the eastern part of the Murray Basin at least (Kershaw et al., 1994; Martin, 1991), appear to have formed a kind of wet sclerophyll forest in association with high levels of burning. Casuarinaceae maintained or increased its representation and it is not known whether this represents species survival from sclerophyll communities previously present or the evolution of new species in response to changed environmental conditions (Jones et al., 1999).

Visualising the landscape for this period in southeastern Australia is more difficult than for any other time during the Late Cainozoic. A mosaic of Casuarinaceae forest and more open vegetation with Asteraceae small trees and shrubs, and some eucalypts dominant above a heathy or grassy understorey may have existed with rainforest still prevalent in Tasmania and slightly more extensive and diverse than today in wetter parts of the mainland. The relative importance of these vegetation type communities oscillated in relation to the global climate forcing. In addition, there is evidence of survival through much of the period, particularly from Pejark Marsh, of many more small patches of rainforest, particularly Araucariaceae, presumably in more protected environments on higher nutrient status soils. The recent discovery of several sites in the east of the Blue Mountains of New South Wales, a taxon not recorded palynologically in the Pliocene period, provides a demonstration of the ability of rainforest to survive in small patches through long periods of geological time (Jones et al., 1995).

The flora of New Zealand and southeastern Australia, particularly Tasmania, was more similar to that of today than during the Early Pleistocene. Although there was some differential extinction at Pleistocene boundary, for instance Microcachrys in New Zealand and Dacrydium cupressinum type in Australia which could have been stochastic or due to different levels of productivity (Kershaw & McGlone, 1995). New Zealand had a mix of sclerophyll taxa including Acacia, Casuarinaceae and probably Eucalyptus with the potential of developing a landscape similar to that of Australia (Kershaw, 1988). In northeastern Australia, and probably along most of the eastern seaboard, the vegetation continued to be dominated by drier araucarian forest with wetter rainforest patches in coastal and montane areas probably little more extensive than at the time of arrival of European people (Kershaw et al., 1993). It might be inferred that the gradient of rainforest-related vegetation extended well inland with extensive areas of deciduous and semi-evergreen vine thickets, sensu Webb (1968), replacing araucarian forest, in semi-arid environments with rainfall as low as about 600 mm per annum.

There is virtually no evidence of conditions within the more arid centre of Australia, but a low resolution marine record from the similarly arid northwestern margin indicates a dominance of open vegetation including hummock grassland with an Acacia canopy and savanna grassland, probably with a Casuarinaceae-dominated canopy (McDonald et al., 1992). Significant vegetation changes such as Gyrotemonaceae could suggest also a regional presence of rainforest-related thicket vegetation. These communities had been developing from the Late Miocene, presumably under increasing aridity, but there is no evidence of eucalypt woodlands.

Overall, the vegetation component of the landscape appears to have been relatively stable through this long Early Pleistocene period, allowing the evolution of a characteristic Quaternary fauna. Grasslands were extensive in northern Australia and possibly also in the centre of the Australian continent providing suitable environments for grazers. But with more extensive drier rainforest and thicket and Casuarinaceae woodlands and forests, and perhaps also woody Asteraceae communities, browsers would have been at an advantage over much of the continent.

Early-Middle Pleistocene transition

After a long period of relative stability, there is evidence of development of offshore reefs from the Early-Middle Pleistocene boundary although the boundary itself is not clearly indicated in any available sequences. There are a group of extinctions, mainly bivalves, in the Wanganui sequence around 1.3 Ma, suggesting a further decrease in sea surface temperature. This coincides, approximately, with the beginning of the gradual temperature decline in the marine isotope record (Fig. 5) which continues to at least the Early-Middle Pleistocene boundary. Other extinctions and also first appearances of taxa, both mammal faunas and bivalves, occur through this period in the Wanganui sequence. A reduction in sea surface temperatures around the boundary is also suggested from northwestern Australia (Quilty, 1974; Zobel, 1984), but the evidence from northern Australia is more contradictory with Chaproniere (1991) and Chaproniere & Pigram (1993) suggesting little change in planktonic foraminifera and no evidence of cooling (as is the case for the whole of the Quaternary), and oxygen isotope records indicating surface temperatures (Lem et al., 1996; Peerdeman, 1997). By contrast to the marine records, terrestrial palaeobotanical changes appear to be more closely related to the Early-Middle Pleistocene boundary, although the degree of reliability is lower because of the discontinuous nature of the records. In New Zealand there are both last and first appearances, but little evidence of extinction. The dated record from Lake George (Singh & Geissler, 1991) suggests that the oceanic core may provide a valuable check on the terrestrial record in the pollen record. This input of macrofossil data is important in demonstrating that the plant landscape has probably been more dynamic than previously appreciated from a consideration of dominant pollen data. The mix of rainforest and sclerophyll taxa makes it difficult to determine the environmental causes of extinction, though it is probable from the loss of taxa such as Dacrycarpus and Symlocos that a further increase in climatic variability was important and, from the latter taxon, that temperatures may also have decreased.

The generalised pollen record from ODP 820 (Kershaw et al., 1993) suggested that marked changes in components of north Queensland vegetation may have occurred around the Early-Middle Pleistocene boundary, consistent with the evident transition in the local and global isotope records from glacial to interglacial cycle dominance. Detailed examination of the pollen record between about 1 and 0.9 Ma (Russell Wild, pers. comm.) has confirmed the suggested increase in importance of Casuarina and Campionemion, indicative of a shift from riverine to estuarine sources. One explanation is that the development of offshore reefs provided more sheltered estuarine environments for mangrove establishment and maintenance. However, there is no evidence for the existence of mangroves in eastern Australia during this period, although the beginnings of mangrove establishment, perhaps in the Wanganui sequence. A reduction in sea surface temperatures around the boundary is also suggested from northwestern Australia (Quilty, 1974; Zobel, 1984), but the evidence from northern Australia is more contradictory with Chaproniere (1991) and Chaproniere & Pigram (1993) suggesting little change in planktonic foraminifera and no evidence of cooling (as is the case for the whole of the Quaternary), and oxygen isotope records indicating surface temperatures (Lem et al., 1996; Peerdeman, 1997). By contrast to the marine records, terrestrial palaeobotanical changes appear to be more closely related to the Early-Middle Pleistocene boundary, although the degree of reliability is lower because of the discontinuous nature of the records. In New Zealand there are both last and first appearances, but little evidence of extinction. The dated record from Lake George (Singh & Geissler, 1991) suggests that the oceanic core may provide a valuable check on the terrestrial record in the pollen record. This input of macrofossil data is important in demonstrating that the plant landscape has probably been more dynamic than previously appreciated from a consideration of dominant pollen data. The mix of rainforest and sclerophyll taxa makes it difficult to determine the environmental causes of extinction, though it is probable from the loss of taxa such as Dacrycarpus and Symlocos that a further increase in climatic variability was important and, from the latter taxon, that temperatures may also have decreased.

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Darwin Crater in Tasmania and Lake Terang in the western plains of Victoria which are both considered to extend to at least isotope stage 12. All records display marked fluctuations reflecting the high amplitude in interglacial stages. General correlation between marine and terrestrial records is possible and has been demonstrated for areas where comparisons between marine and terrestrial pollen records have been made, including northeastern and southeastern mainland Australia and New Zealand. Glacials were substantially drier, and in most cases demonstrably cooler than interglacials, with expansions of more open vegetation and reductions in lake levels. Geomorphic studies on riverine, lake and dune sediments from more arid parts of Australia (Kershaw & Nanson, 1993; Magee et al., 1995; Wasson, 1989) and dust deposited in the Tasman Sea (Hesse, 1994) confirm that glacial was much drier than interglacials throughout the region. There is a suggestion also that precipitation levels were frequently higher within interglacials of the Middle-tate Pleistocene than had been achieved during much of the Early Pleistocene (Wagstaff, in press). In the western plains of Victoria, interglacial peaks in rainfall are generally more substantial than during the Early Pleistocene and suggest not only the attainment of higher rainfall but that the rainforest had the capacity to respond to climate change after existing for over a million years in small isolated patches. In the marine records, it is clear that glacial/interglacial alternations led to significant changes in oceanic conditions around Australia. Frontal zones moved north during times of expanded glaciation. The Leeuwin Current changed in importance while that the rainforest had the capacity to respond during the Holocene. 

However, cyclical variation can not readily be used to explain the degree of sustained environmental change in the late Quaternary which includes regional and continental level plant extinctions and the almost total loss of terrestrial megafauna. The most substantial landscape change is recorded in northeastern Australia where previously dominant moist araucarian forest was progressively replaced at study sites by open eucalypt vegetation. Perhaps the earliest evidence is from Fraser Island in southeastern Queensland where most of the landscape process, accompanied by a substantial and sustained increase in Poaceae is suggested about 37,000 years ago and perhaps debatable uranium/thorium dates, to have taken place from before 350 ka to around 200 ka (Longmore & Heijnis, 1998). The last significant representation of Araucaria though did occur within the last interglacial period and, like other records mentioned, failed, along with other rainforest taxa, to respond during the Holocene.

The ODP 820 record from northeastern Queensland provides a more detailed and continuous record through the last 250 ka. Here, Araucaria shows a clear two-tiered decline around 130 ka and 38 ka, the latter decline also recorded in the adjacent terrestrial record of Lynch's Crater. At both these sites the declines are accompanied by peaks in both eucalypts and charcoal with a general increase in both components through the record. The sites also demonstrate that the Laing Dacrydium guillauminii, now present only in New Caledonia, around 20 ka, and when combined with the loss of Austromyrtus from the Lynch's Crater record during the last glacial period, probably indicates a substantial reduction in the occurrence of Eucalyptus because the last interglacial is the only recorded extinction. This is in contrast to the number of extinctions evident in the New Zealand marine record over the last 500 ka. However, the data sets are not easily compared as the marine evidence is at species level and that of pollen at genus level. As indicated from Tasmanian macrofossil data, there may have been significant plant extinction at species level.

Since the publication of Singh et al. (1981), environmental changes in faunal assemblages from Australasian Quaternary sediments –from Lynch’s Crater and Lake George—there has been a tendency for environmentalists to accept the proposition that vegetation change in association with increased burning of the landscape was caused by Aboriginal activities and hence the Australian landscape is a cultural phenomenon (Flannery, 1994). Concern expressed about the dating of the major vegetation change at Lake George around 130 ka (e.g., Wright, 1986) was lessened by a similar age assigned to the increase in burning and sustained vegetation change in the initial ODP 820 record. Archaeologists have rejected or remain very sceptical about an inference for the presence of people some 70 to 90 ka before any artefactual evidence or have even rejected the suggestion that People altered pre-existing burning patterns (Horton, 1982).

Any alternative explanation for sustained vegetation change and increased burning had always faltered due to the lack of an obvious mechanism. The suggestion that recorded events were simply a continuation of a process of change initiated during the Oligocene, when northern Australia was in the central part of the continent by the drying trend in the late Tertiary (Kershaw, 1994), is shown here not to be viable. Most of the Quaternary experienced relatively stable conditions, despite the presence of fire-promoting eucalypt and grass vegetation with fire as a well-established environmental component. However, there is evidence from marine cores taken off the northern part of the continent of a regional increase in sea surface temperatures within the Middle Pleistocene. As mentioned, sedimentary records from the Coral Sea region suggest a systematic increase of about 4°C between about 500 and 250 ka (Isern et al., 1996; Pe德rdek, 1993), estimates supported by sedimentary evidence for the development of the Great Barrier Reef within the last 500 ka (Ferry et al., 1991). Off southern Australia, the increase in sea surface temperature, about 380 °C, was determined from foraminiferal assemblages (Zobel, 1984), while expansions of the bivalve Anadara trapezia (Murray-Wallace et al., 2000) during interglacials within the last 400 to 250 ka may indicate a re-evaporative effect (Isern et al., 1996). However, an increase in the temperature increase may have related to the development of a Coral Sea Warm Pool, a possible extension of the Western Pacific Warm Pool. The cause of this temperature...
increase has not been determined but could well relate to changing land-sea configurations and accompanying volcanic activity within the maritime continent, as Australia continued its movement northwards.

An increase in sea surface temperatures may have resulted in reduced moisture and precipitation which may help explain higher representation of rainforest relative to the Early Pleistocene in some pollen records, but could hardly explain the degree of instability which led to the expansion of sclerophyll vegetation and demise of fire-sensitive communities and taxa. However, if the evidence does relate to the development of the West Pacific Warm Pool, this would provide the Pacific temperature gradient required for the operation of El Niño-Southern Oscillation variability and, despite increased precipitation, the drought conditions necessary for increased fire activity and sclerophyll expansion.

A further question that needs to be addressed in consideration of the climate model is why do landscape changes appear to fall into discrete time periods? The change around 130 ka is clearly related to a significant glacial transition, but other sustained changes around 170 and 40 ka show no such correspondence with climatic events. One suggestion is that ENSO has not operated constantly or that its intensity has varied through time. Evidence of an increase in variability within the last 5 ka or so, which has been attributed to the latest onset of ENSO (McGloone et al., 1992; Shulmeister & Lees, 1995) provides support for this view. Consequently, change would be concentrated within those periods when ENSO was most active. Under these circumstances, any impact of people might simply have been an acceleration of a natural process.

Habitat change due to Aboriginal burning is also unlikely to have been the predominant cause of megafaunal extinctions. Evidence of an increase in variability within the last 5 ka or so, which has been attributed to the latest onset of ENSO (McGloone et al., 1992; Shulmeister & Lees, 1995) provides support for this view. Consequently, change would be concentrated within those periods when ENSO was most active. Under these circumstances, any impact of people might simply have been an acceleration of a natural process of the formation of community types that are not represented today, and these fall within the general category of grassland/steppe. The degree to which these two periods can be considered representative of extremes of glacial cycles over a longer period may be questioned in Australia and New Guinea, because of the presence of megafaunal extinctions. However, similarities in the nature and degree of change to New Zealand, that had yet to experience human settlement and megafauna extinction, suggest that these influences on other components of the biota were not substantial in comparison with the impact of climate change.

Three areas, southeastern Australia, northeastern Australia and New Zealand (primarily the Wanganui Basin), contain the most substantial records of change through the Quaternary in general, and comparisons between them are made, largely on the pollen data. Records are generally of low resolution and little information is provided on cyclicity, at least prior to the last 1 Ma. New Zealand and southeastern Australia show significant extinction of previously important taxa, particularly megafauna, during the Late Pleistocene boundary, around 2.5 Ma, reflecting the importance of global cooling perhaps augmented by the initiation of a winter rainfall regime at these latitudes. By contrast, northeastern Australia shows no clear response to the onset of the extinction period, although there is local evidence for a Cenozoic global drying trend is evident. Further floral extinctions and some sustained changes in taxon abundance are recorded around the Early-Middle Pleistocene transition, probably in response to heightened precipitation and temperature contrasts between glacial and interglacial periods. In contrast to New Zealand, and most of the globe, northeastern and southeastern Australia show trends towards more open vegetation with extinctions in some wetter elements and increased burning within the last few hundred thousand years, with megafaunal extinctions. This trend toward a slightly more extensive and, in Australia and New Guinea, the impact of people was probably significantly lower than today. During the Late Glacial Maximum, temperatures were probably at least 4°C and up to 8-9°C lower than today and substantial temperature lowering in the lowland tropics is debated. These lower temperatures combined with more regional influences, particularly substantial expansions in continental shelves, resulted in precipitation levels lower than those of an increased ice volume, with sea surface temperatures off northeastern Queensland between 500 and 250 ka. It is hypothesised that this temperature increase is related to the development of the West Pacific Warm Pool and associated ENSO activity that a substantial increase in the availability of water to fire. It is likely that Aboriginal burning accelerated Late Quaternary vegetation changes but did not initiate them.

In relation to megafauna, this environmental change is important because it suggests that either climate or habitat change was the primary cause of Late Pleistocene extinctions. Consequently, we consider that the most likely explanation is direct killing by people, a
conclusion supported by the evidence for the demise of megalaula in the late Holocene of New Zealand.

ACKNOWLEDGEMENTS
We thank Patrick De Deckker, Matt McGlone and Colin Murray-Wallace for their incisive comments and attempts to incorporate some consistency and balance into this review. Mike Macphail, Dallas Mildenhall and Alan Partridge, for valuable comments on Quaternary pollen stratigraphy, Nick Porch and Michael Reid for input on specific fossil groups, John Tibby for help with referencing and Gary Swinton for drafting the text figures. We apologise for the scant attention paid to some groups of biota. In the case of molluscs and corals, we thank Alan Beu and Charlie Veron respectively for their very valuable input and appreciate that heavy commitments prevented them making the contributions to this paper that they would have liked.

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