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Subdividing the Pleistocene using the Matuyama–Brunhes boundary (MBB): an Australasian perspective

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Abstract

The last major reversal of the Earth's magnetic field, the Matuyama–Brunhes boundary (MBB), dated at 0.78 Ma, is widely identified in Australian and New Zealand Pleistocene deposits. In New Zealand, the MBB is precisely located in shallow marine sediments of Wanganui Basin, where it corresponds with the base of the New Zealand Putikian Substage. A combination of marine biostratigraphy, sequence stratigraphy and tephrostratigraphy permit correlation from Wanganui Basin to other on-land sections and deep-sea cores. In Australia, the MBB is identified in many continental sequences, particularly saline lake basins. However, chemical weathering has resulted in variable Brunhes-age normal overprints that are sometimes difficult to remove. Australasian tektites are a potential lithostratigraphic marker just prior to the MBB, but have yet to be identified in the same on-land section as the MBB in Australia. Identification of reverse polarity magnetisation in weathered deposits, including soils, provides a minimum age of 0.78 Ma for these materials. A widespread arid shift in paleoclimate succeeded the MBB in Australia. Placement of the Lower–Middle Pleistocene boundary at the MBB would constitute the most recognisable chronostratigraphic marker in weathered continental deposits.

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1. Introduction

The last major polarity reversal of the Earth's magnetic field, known as the Matuyama–Brunhes polarity transition or reversal, has long been used a chronostratigraphic marker in Quaternary studies. The Matuyama–Brunhes boundary (MBB) is dated at about 0.78 Ma (Shackleton et al., 1990; Spell and McDougall, 1992; Tauxe et al., 1996), and occurred during Marine Oxygen Isotope stage (MOIS) 19 (Zhou and Shackleton, 1999). The MBB has been widely identified in both marine and continental sequences (see Tauxe et al., 1996; Zhou and Shackleton, 1999, and references therein) and is also a key time marker for the chronology of human evolution and migration.

Participants at the Burg Wartenstein Symposium “Stratigraphy and Patterns of Cultural Change in the Middle Pleistocene”, held in Austria in 1973, recommended that “The beginning of the Middle Pleistocene should be so defined as to either coincide with or be

linked to the boundary between the Matuyama Reversed Epoch and the Brunhes Normal Epoch of paleomagnetic chronology” (Butzer and Isaac 1975, Appendix 2). A similar recommendation was made by the INQUA Working Group on Major Subdivision of the Pleistocene at the XII INQUA Congress in Ottawa in 1987 (Richmond, 1996). Indeed, by the time of the XIV INQUA Congress in Berlin in 1995, the search for a suitable boundary stratotype section was focussed on three sections in Japan (Aida et al., 1995), New Zealand (Pillans, 1995), and Italy (Ciaranfi and Marino, 1995).

There appears to be a widespread use of the MBB in defining the Lower–Middle Pleistocene boundary (e.g. Bowen, 1988, Tables 10.1 and 11.1; Berggren et al., 1995, Fig. 4). The purpose of this paper is not so much to recommend a particular stratotype, but rather to reinforce the acceptance of the MBB in defining the beginning of the Middle Pleistocene, particularly in the extreme range of stratigraphic settings that occur in Australia and New Zealand (see Fig. 1 for locations of sites mentioned in text).

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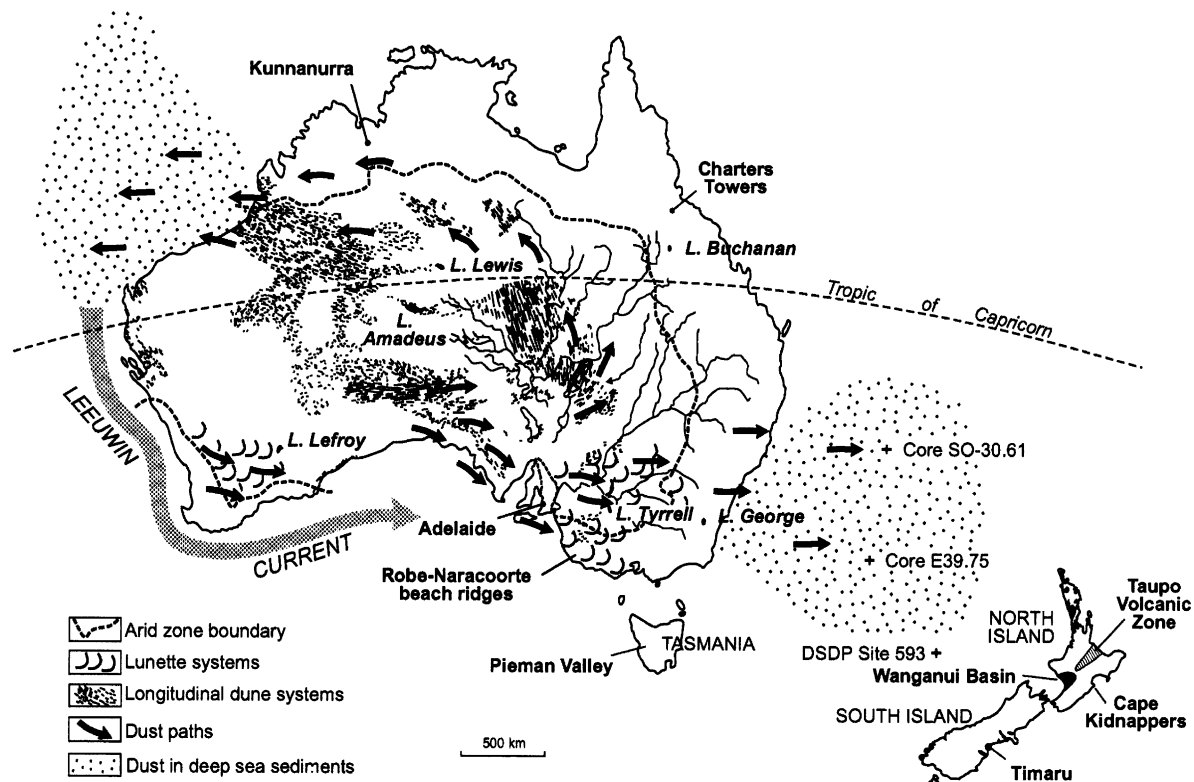


Fig. 1. Location map showing sites mentioned in the text.

2. New Zealand

2.1. Wanganui Basin

The Wanganui Basin contains one of the most complete on-land stratigraphic records of the Quaternary known anywhere in the world (Naish et al., 1998). The basin contains an emergent sequence of minimally deformed, shallow marine sediments, as a result of regional uplift in a back-arc setting. The marine sediments are richly fossiliferous (e.g. Fleming, 1953; Abbott and Carter, 1997) and contain the stratotypes for the New Zealand Plio–Pleistocene Nukumaruan and Castlecliffian Stages (Beu, 2001).

As a consequence of its location, adjacent to the Taupo Volcanic Zone, possibly the most active Quaternary rhyolitic volcanic area in the world, the basin contains many rhyolitic tephra that are useful for correlation and dating (Seward, 1976; Pillans et al., 1994; Shane et al., 1996b).

The MBB was first identified in the basin at the Castlecliffian stratotype coastal section by Turner and Kamp (1990), and subsequently confirmed at three other inland localities by Pillans et al. (1994). Interpretation of the natural remanent magnetisation (NRM) of the sediments is often difficult because of weak intensities, strong secondary overprints, and thermal instability of clay minerals (Roberts and Pillans, 1993; Turner, 2001).

However, careful thermal demagnetisation allows identification of the primary detrital magnetisation. The polarity transition occurs over a 10 m interval in marine strata of Cycle 6 (Fig. 2), comprising the Kaikokopu Formation, (Transgressive Systems Tract), Upper Westmere Shellbed (Mid-Cycle Shellbed), and Upper Westmere Siltstone (Highstand Systems Tract) (see Abbott and Carter, 1997). The MBB is located between the Kaukatea Tephra (0.87 ± 0.05 Ma) and the Kupe Tephra (0.64 ± 0.08 Ma), at a level that is coincident with the base of the New Zealand Putikian Substage, and which marks the first appearance of the genus *Pecten* in Wanganui Basin (Pillans, 1994). Three important microfossil datums occur in close proximity to the MBB in Wanganui Basin—the last occurrence (LO) of the coccolith *Reticulofenestra asanoi*, the LO of the radiolarian *Ptericanium trilobium*, and the first occurrence (FO) of the coccolith *Geophyrocapsa omega* (Edwards et al., 1995; Bowen et al., 1998; Naish et al., 1998).

The marine sequence is unconformably overlain by a flight of marine terraces, up to ca 0.68 Ma in age (Pillans, 1983). Paleomagnetic results from loess beds overlying the terraces indicate normal polarities correlated with the Brunhes Chron (Pillans and Wright, 1990). Loess beds are labelled L1–L12 (youngest to oldest), and include the widespread tephra marker, Rangitawa Tephra (0.34 Ma), near the top of loess L10

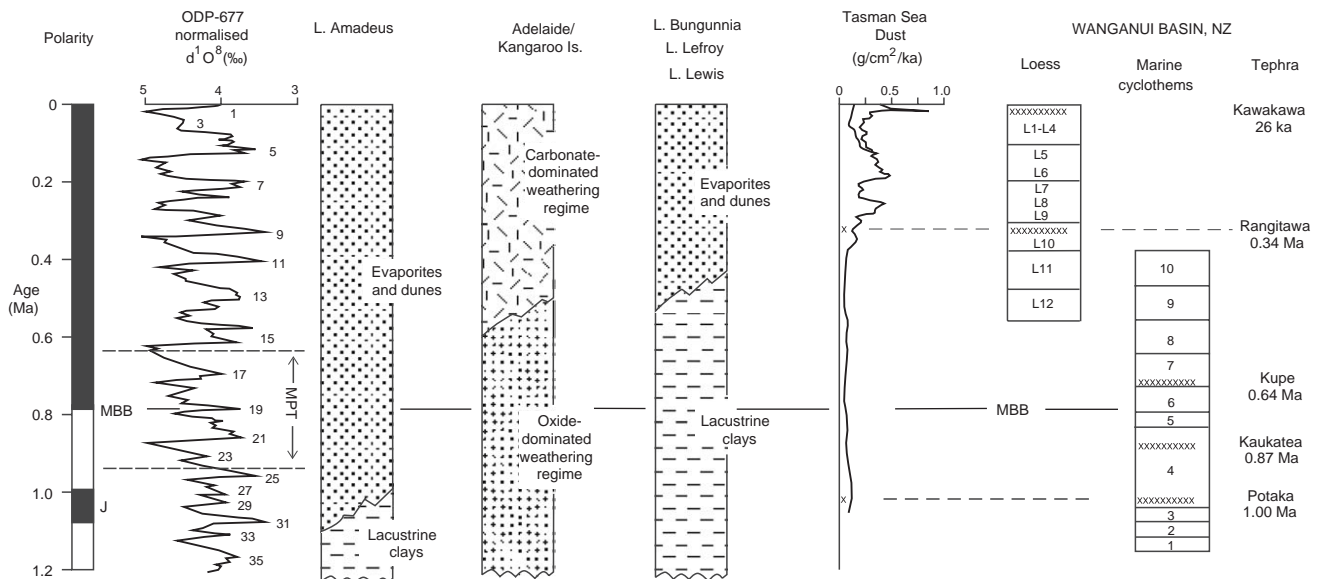


Fig. 2. Summary stratigraphic and correlation diagram showing Geomagnetic Polarity Time Scale and marine oxygen isotope record (Shackleton et al., 1990) and summary paleoclimate records from Lake Amadeus (Chen and Barton, 1991), Adelaide/Kangaroo Island (Pillans and Bourman, 1996, 2001), Lake Bungunnia (An et al., 1986), Lake Lefroy (Zheng et al., 1998) and Lake Lewis (English et al., 2001). Tasman Sea dust record is from core E39-75 (Hesse, 1994). Wanganui Basin data from Pillans (1994), Pillans et al. (1994) and Abbott and Carter (1997). MBB—Matuyama–Brunhes boundary; MPT—mid-Pleistocene transition.

(Pillans et al., 1996). The oldest loess layer (L12), not described in previous publications, underlies ca 0.5 Ma dunesand at the Rangitatau East site of Pillans and Wright (1990), and is correlated with MOIS 14 (Fig. 2).

2.2. Cape Kidnappers

The MBB was reported by Black (1992) to be in a sequence of alternating marine and terrestrial sediments at Cape Kidnappers on the east coast of the North Island. Subsequently, dating of interbedded tephra beds in the interpreted Brunhes Chron yielded fission track ages of 0.79 ± 0.06 and 0.86 ± 0.05 Ma, and an Ar/Ar age of 0.88 ± 0.04 Ma, suggesting that the sequence was affected by normal overprinting, and that the true position of the MBB was higher (Shane et al., 1996a). The alternating field demagnetisation procedures, used by Black (1992), appear to have been unsuccessful in isolating the primary remanences.

2.3. Timaru loess

The thickest New Zealand Pleistocene loess–paleosol sequences occur on the east coast of the South Island. Near Timaru, up to 20 m of loess overlies the 2.5 Ma Timaru Basalt. Six main loess units have been recognised (Runge et al., 1974), the youngest of which contains the 26 ka Kawakawa Tephra layer. Luminescence ages from the youngest three layers are somewhat problematic (Berger et al., 2001), but broadly indicate correlation with MOIS 2, 6, and 8. The older three layers are tentatively correlated with MOIS 10, 12 and

14 (or 16). Paleomagnetic results (Berger et al., 2001; Pillans, unpublished data) indicate normal polarity throughout. Thus, the entire loess column is assigned to the Brunhes Chron, despite the fact that it is directly underlain by 2.5 Ma basalt. Either older loess was deposited and subsequently eroded or loess production did not occur prior to MOIS 16.

2.4. Taupo Volcanic Zone and western North Island

The Taupo Volcanic Zone in the central North Island contains a complex stratigraphic sequence of dominantly rhyolitic ignimbrites and airfall tephra layers, the distal equivalents of which are identified in surrounding sedimentary basins and in deep-sea cores. A combination of paleomagnetic data and $^{40}\text{Ar}/^{39}\text{Ar}$ dating (Houghton et al., 1995), demonstrates that the sequence extends to at least 1.6 Ma, with the MBB bracketed by Rahoeka (normal polarity; $^{40}\text{Ar}/^{39}\text{Ar}$ age 0.77 ± 0.03 Ma) and Tikorangi Ignimbrites (reversed polarity; $^{40}\text{Ar}/^{39}\text{Ar}$ age 0.89 ± 0.04 Ma).

A 15 m thick section, comprising strongly weathered tephra beds in the western North Island, has a basal fission-track age of 2.24 ± 0.29 Ma (Lowe et al., 2001). The MBB is interpreted to lie within an unconformity at a depth of 1.4 m, directly overlain by 0.34 Ma Rangitawa Tephra.

2.5. South Island glacial deposits

Stratigraphic studies in the north and west of the South Island have identified four major Pleistocene and

two major Pliocene glaciations (Suggate, 1990). Paleomagnetic results (Fitzsimons et al., 1996) show that the Pliocene deposits are dominantly reversed polarity, as well as deposits at one site previously thought to be Middle Pleistocene in age. In discontinuous sequences such as these, reversed polarity remanence indicates a minimum age of 0.78 Ma.

3. Australia

3.1. Robe-Naracoorte beach ridges

The first published paper to specifically identify the MBB in Australia was by Idnurm and Cook (1980), who reported paleomagnetic results from the Robe-Naracoorte beach ridge sequence in southeast South Australia. Eight major ridge systems were sampled for paleomagnetism, with the youngest seven yielding normal polarity remanences, and the oldest ridge (the East Naracoorte ridge, some 100 km inland) yielding reversed polarity remanence. Idnurm and Cook (1980) concluded that the magnetic remanence, isolated by thermal demagnetisation, was a chemical remanent magnetisation (CRM) acquired during weathering up to perhaps 30,000 years after deposition of the beach ridge sediments. Subsequent luminescence dating of the normally magnetised beach ridges yielded ages up to 500 ka (Huntley et al., 1993, 1994), consistent with the position of the MBB in the sequence, and confirmed that the ridge sequence represents high sea-level stands from each of the odd numbered marine isotope stages back to the MBB.

3.2. Lake Bungunnia

In the Lake Tyrell region of southern Australia, An et al. (1986) showed that a major hydrologic transition from lacustrine clays to saline clays and dunes occurred soon after the MBB. The Olduvai Subchron and Gauss–Matuyama boundary were also identified. Both thermal and AF demagnetisation were employed, depending on degree of weathering.

3.3. Lake George

The MBB was identified by Singh et al. (1981), at a depth of 17.4 m in sediment cores from Lake George. Older magnetostratigraphic units identified included the Jaramillo and Olduvai Subchrons and the Gauss–Matuyama boundary. The sediments represent a mixture of lacustrine and slopewash facies, variably overprinted by pedogenesis including secondary oxidation and colour mottling. Only AF demagnetisation procedures appear to have been used, whereas other authors (e.g. An et al., 1986; Chen and Barton, 1991) have

concluded that thermal cleaning is required to adequately demagnetise weathered samples.

3.4. Lake Amadeus

Chen and Barton (1991) identified the MBB at shallow depths (1–2 m) in cores from Lake Amadeus, a groundwater discharge playa in Central Australia. A combination of alternating field and thermal demagnetisation procedures was used to isolate the primary magnetisation, depending on the degree of secondary weathering; thermal demagnetisation was preferentially used on reddish (hematitic) samples. A major change from fluvial-lacustrine to playa sedimentation was identified prior to the MBB, at about the time of the Jaramillo Subchron (Fig. 2).

3.5. Lake Buchanan

Chivas et al. (1986) reported paleomagnetic results from Lake Buchanan, an intermontane playa located astride the Great Dividing Range in central Queensland. The MBB was located at a depth of 5.05 m, in a core that penetrated some 15 m of uniform, non-laminated sandy clays. The Jaramillo and Olduvai Subchrons were also tentatively identified, but the paleomagnetic results were unreliable for some core sections owing to intense iron-staining and pedogenesis. Demagnetisation was by AF methods only. Four major wet episodes were identified in the Brunhes Chron, but Chivas et al. (1986) were uncertain whether this reflected low climatic/hydrologic variability of the lake, or if the sedimentary record was incomplete because of deflation episodes.

3.6. Lake Lefroy

A paleomagnetic study of sediment cores from Lake Lefroy, in Western Australia, by Zheng et al. (1998), identified the MBB, Olduvai Subchron, and the Gauss/Matuyama boundary. The Jaramillo Subchron was also tentatively identified but poorly resolved. The magnetic remanence carrier was interpreted to be magnetite, with a minor contribution from other minerals such as hematite and goethite. AF demagnetisation was used for the majority of samples. A significant hydrologic transition, as inferred from a change from freshwater clays to evaporitic gypsum-dominated sediments, occurred above the MBB, about 500 ka as extrapolated from sedimentation rates (Fig. 2).

3.7. Lake Lewis

Lake Lewis is a salt lake in Central Australia, at the southern edge of influence of the Australian summer monsoon system. English et al. (2001) identified the

MBB at a depth of 9 m in a thick, uniform sequence of lacustrine clays, representing a long period of generally wetter conditions than at present. These clays are overlain by more heterogeneous lake sediments indicative of greater aridity, expressed through fluctuating lake levels and increased levels of salinity. Paleomagnetic methods, detailed by English (2001), included both AF and thermal demagnetisation procedures to isolate the characteristic remanent magnetisation (ChRM).

3.8. Sellicks Beach, Adelaide

Coastal cliffs near Adelaide, and on nearby Kangaroo Island, expose a sequence of weathered dune sands, colluvium and aeolian clays overlying a thin marine layer that contains the Plio–Pleistocene index fossil *Hartungia*. Paleomagnetic results allow identification of the MBB, and underlying Jaramillo Subchron (Pillans and Bourman 1996, 2001). The MBB occurs in oxide-mottled colluvium of the Ochre Cove Formation, which is unconformably overlain by calcareous Ngalinga Clay. The change from oxide- to carbonate-dominated weathering is interpreted to represent a major arid shift in climate (Fig. 2). In the original study by Pillans and Bourman (1996), only AF demagnetisation of samples was undertaken. Subsequent resampling and paleomagnetic measurements have utilised thermal demagnetisation (Pillans, unpublished), to show that the upper part of the oxide-mottled Ochre Cove Formation is of reversed polarity with a strong normal overprint. The MBB is thus placed at the unconformity between the Ochre Cove Formation and the overlying Ngalinga Clay.

3.9. North Queensland soils chronosequence

A 6 Ma soils chronosequence developed on basaltic lava flowing in north Queensland was described by Pillans (1997). Paleomagnetic sampling of the soil profiles indicates the presence of reverse polarity magnetisation in the lower B-horizons (below 60–80 cm depth) that must have been acquired prior to the MBB. Preservation of reverse polarity implies that the lower B-horizons have been largely unaffected by chemical weathering and/or physical disturbance (e.g. bioturbation) for at least 0.78 Ma. Pillans (1997) speculated that prior to the MBB, soil weathering may have occurred to a greater depth because summer rainfall was significantly higher than present.

3.10. Tasmanian glacial deposits

The Pieman River valley in western Tasmania preserves the most complete record of Pleistocene glacial advances yet documented in Australia, where four pre-Last Glaciation ice-advances are recognised.

Paleomagnetic results from interbedded glaciolacustrine sediments show that the oldest, and most extensive glacial deposits (Bulobac Glaciation) are of reversed polarity (Augustinus et al., 1995). Pollen data indicate a Late Pliocene to Early Pleistocene age, i.e. within the Matuyama Chron (Augustinus and Macphail, 1997).

3.11. Australasian tektites

About 790 ka (Schneider et al., 1992), an asteroid or comet impacted somewhere in southeast Asia, producing tektites, microtektites and impact debris which are found over more than 10% of the Earth's surface (Schnetzler and McHone, 1996), including much of Australia and surrounding oceans. Although there has been considerable debate concerning the age of the Australasian tektites, their age is now firmly established through magnetostratigraphy of deep-sea cores in which microtektites occur just prior to the MBB (Schneider et al., 1992), as well as direct laser fusion $^{40}\text{Ar}/^{39}\text{Ar}$ dating of tektite glass (Izett and Obradovich, 1992). Previously, a number of field studies supported a Late Pleistocene age in the range 5–25 ka (e.g. Gill, 1970; Lovering et al., 1972), but these occurrences are now considered to represent reworking into younger sediments (e.g. Fudali, 1993; Shoemaker and Uhlherr, 1999). Even in regolith deposits where reworking is suspected, the presence of tektites provides a maximum age of 790 ka for the enclosing sediment. For example, waterworn tektites have been found in diamond-bearing alluvial gravel terraces some 25 km downstream of the Argyle diamond mine near Kunnanurra in northwestern Australia (Fudali et al., 1991; Fudali, 1993), indicating a maximum age of 790 ka for the terraces. Australasian microtektites are also present in Chinese loess sequences, where their presence as a discrete layer has been used to correct the misleading position of the MBB (Zhou and Shackleton, 1999). Australasian tektites associated with Acheulean-like stone tools in South China yield an $^{40}\text{Ar}/^{39}\text{Ar}$ age of 803 ± 3 ka, thus making them the oldest known large cutting tools in East Asia (Hou et al., 2000).

4. Tasman Sea cores

Hesse (1994) measured the flux of aeolian dust from Australia in cores from the Tasman Sea. In core E39.75 the MBB was identified at a depth of 888 cm, and oxygen isotope analyses enabled identification of all marine isotope stages down to MOIS 16 (ca 620 ka). A marked increase in dust fluxes is observed from MOIS 10 (ca 350 ka) upwards, with highest fluxes occurring during even numbered (glacial) stages (Fig. 2). Also of interest is the identification, at a depth of 878 cm in core E39.75, of Potaka Tephra, a widespread tephra marker

layer in New Zealand sequences, including Wanganui Basin (Fig. 2). Another widespread New Zealand tephra layer, Rangitawa Tephra (0.34 Ma), is present in core SO-36.61 (Hesse, 1994; Pillans et al., 1996), but this core did not penetrate into the MBB.

The MBB and the Potaka Tephra are also identified at DSDP Site 593 (Nelson et al., 1985; Barton and Bloemendal, 1986), where revised oxygen isotope measurements (Nelson et al., 1993) show that the Potaka Tephra was erupted during MOIS 28.

5. Discussion

The MBB is a widely identifiable chronostratigraphic marker in Pleistocene deposits in Australia and New Zealand. It is of particular significance in correlation and dating in Australia, because of the generally strongly weathered, unfossiliferous nature of Pleistocene sedimentary sequences. However, as cautioned by Chen and Barton (1991) there are two significant problems to be overcome:

1. The primary component of magnetic remanence is variably affected by chemical weathering, which results in a secondary weathering-induced remanence that may completely obliterate the primary component. Thus, downward displacement of the apparent position of the MBB is to be expected as a result of Brunhes normal overprinting.
2. Sedimentation rates can be highly irregular, including possible erosional hiatuses. Thus it can be difficult to establish definitive correlations of the local magnetostratigraphy with the Geomagnetic Polarity Time Scale (GPTS).

Despite such problems, the MBB is often the only (or one of only a few) chronological control point(s) in Australian Lower to Middle Pleistocene stratigraphic sequences. In the time range 0.5–2.5 Ma, and in the absence of tephra layers, few other dating techniques are applicable. Furthermore, where strata are strongly weathered, and secondary magnetic overprints are suspected, the presence of reversed polarity remanence provides a minimum age of 0.78 Ma (Pillans and Bourman, 1996). However, the Australian continent has a long history of subaerial exposure dating back hundreds of millions of years in many regions, and weathered regolith with reversed polarity may be as old as Early Tertiary in some instances (e.g. Idnurm and Senior, 1978). Fortunately, comparison of paleomagnetic poles with the Australian Apparent Polar Wander Path can readily distinguish Plio–Pleistocene weathering imprints from those more ancient (Idnurm, 1985).

Major paleoclimatic changes occurred across much of the Australian continent during the Quaternary. The

Last Glacial is known to have been significantly drier (and colder) than present (e.g. Bowler, 1976), and the same appears to be broadly true for earlier glacials. A major Mid-Pleistocene arid shift is identified at many sites as post-dating the MBB, possibly in the time range 600–400 ka (Pillans and Bourman, 2001), and also represented by increased aeolian dust content of cores from the Tasman Sea over the last 350 ka (Hesse, 1994). The MBB is the critical chronostratigraphic marker that links these records.

Pillans and Bourman (2001) suggested that the Mid-Pleistocene arid shift in Australian continental records might be linked to the change from 40 to 100 ka frequencies in astronomical parameters that occurred around 620 ka, and its subsequent effects on the strength of the Leeuwin Current, a major moisture source in western and southern Australia (Fig. 2). In their study of the oxygen isotope record from ODP Hole 806B in the western equatorial Pacific, Berger et al. (1994) referred to the last 620 ka, showing strong 100 ka cycles as the Milankovitch orbital chron, but pointed out that the transition from 40 to 100 ka cyclicity is obvious from about 900 ka. Heslop et al. (2002) referred to the interval from 920 to 640 ka, over which the change occurred in Chinese loess sequences as the Mid-Pleistocene transition (MPT). However, while the timing of the MPT is broadly similar in Chinese loess sequences and deep-sea cores, its differing expression in the two realms is indicative of non-linear relationships with global ice volume (Heslop et al., 2002).

In contrast to other Australian lacustrine records, the evidence from Lake Amadeus (Chen and Barton, 1991) suggests that the major arid shift at that site occurred prior to the MBB, probably around the time of the Jaramillo Subchron and the beginning of the MPT. However, Lake Amadeus is one of the least responsive hydrologic systems in Australia because of its arid climate and low catchment/lake area (Bowler, 1981). Thus, differing hydrologic thresholds at lake Amadeus are expected to produce a differing environmental history from other lake basins. Such differences serve as a clear reminder that paleoenvironmental changes may be time transgressive across the continental landscape, and therefore do not constitute reliable chronostratigraphic horizons.

6. Conclusions

Fine stratigraphic subdivision, correlation and dating of Pleistocene marine sediments has progressed in leaps and bounds, in the past 30 years, particularly utilising a combination of astronomical tuning of oxygen isotope stratigraphy, magnetostratigraphy and biostratigraphy in deep-sea cores. In shallow marine sequences, such as Wanganui Basin, sequence stratigraphy and

tephrostratigraphy are also important. Thus, in general, in marine strata there are multiple criteria for definition of chronostratigraphic units, as illustrated by the definition of the Plio/Pleistocene boundary at the Vrica stratotype section (Aguirre and Passini, 1985). However, whilst not wishing to deny the value of such multiple criteria in marine sequences, the greater challenge remains to correlate to, and between, Pleistocene continental deposits.

In continental sequences, particularly those lacking tephra layers, such as in Australia, the MBB is the most easily recognised chronostratigraphic marker. Although the MBB and Australasian tektites have yet to be located in a single section, the latter have considerable potential for confirmation of the position of the MBB where secondary overprinting is present or suspected.

In my opinion, the MBB, rather than the Jaramillo Subchron, provides the most reliable and most practical magnetostratigraphic datum for major subdivision of the Pleistocene for the following reasons:

1. The MBB is the first major polarity change before the present, making it easy to identify in sediment cores and other relatively continuous sedimentary records. Episodes of reversed polarity are reported from the Brunhes Chron, but these are of short duration (up to a few thousand years), and may not be global in extent.
2. The Jaramillo Subchron is of relatively short duration (0.99–1.07 Ma), which means that it is not always recognised or preserved.
3. At sites where independent age control is lacking, the identification of reversed polarity remanence allows a minimum age assignment of 0.78 Ma. Such minimum age data are extremely useful in weathered Australian continental deposits. If the Lower–Middle Pleistocene boundary were placed at the MBB, then reversed polarity magnetisation would be a diagnostic criterion for distinguishing between Middle and Lower Pleistocene.
4. Definition of the Lower–Middle Pleistocene boundary should avoid over-emphasising supposed global paleoclimatic events associated with the change from 40 to 100 ka orbital frequencies, because such events are inevitably expressed in complex (and time-transgressive) ways.

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