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# The emergence of an agricultural landscape in the highlands of New Guinea

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## Abstract

That pollen and sedimentological evidence can make a significant contribution to our understanding of the nature and antiquity of agricultural development in the highlands of New Guinea has long been recognised and promoted by Jack Golson. Detecting the beginnings of agriculture and subsequent impact on landscape and vegetation is, however, not straightforward. A conceptual model for the identification of human impact in palaeoecological records is constructed to distinguish between the impact of hunter-gatherer and agricultural activity. Five palaeoecological sites from highland valleys (1400–1890 m altitude) that cover the period from the last glacial maximum (22 000 cal BP) to the present are reviewed and the implications of the rate and direction of environmental changes are evaluated. Using Rate of Change analysis as a means of identifying deviations in the rate of vegetation change from that which would be expected under natural climate change, the earliest indications of agricultural impact in the vegetation record can be identified at around 7800 cal BP. Subsequent vegetation change reflects an increase in anthropogenic impact that is punctuated by peak episodes of vegetation change towards a more open landscape. The emergence of an agricultural landscape in New Guinea is seen as a result of gradual indigenous development punctuated by external influences such as introduced domestic plants and climate change and variability.

## Introduction

Pollen and sediment evidence has long been at the forefront of attempts to understand the timing and nature of the transition to an agricultural landscape in the highlands[1] of New Guinea (Golson 1977, 1991; Golson and Hughes 1980; Hope and Golson 1995). From the outset of Jack Golson's research in the highlands of Papua New Guinea, he adopted an integrated palaeoecological and archaeological approach to reconstruct the environmental context of past human societies. This approach continues to be a major influence today, and has yielded persuasive evidence for human impact on the environment that dates back to before the last glacial maximum (Haberle 1998a; Hope 1998).

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But what was the nature of the Pleistocene impact on the environment and how does it differ, if at all, from later Holocene impacts commonly associated with agriculture? Evidence that early human occupants of the highlands were not only hunting and gathering but were actively manipulating the environment to enhance food procurement, at least with the aid of fire, continues to fuel the debate over agricultural origins in New Guinea. The discovery of large distinctive flaked blades, otherwise known as waisted axes, in a number of Pleistocene highland New Guinea sites, including Kosipe (open site, White *et al.* 1970) and Nombe (rockshelter, Gillieson and Mountain 1983) at around 26,000 BP,[2] puts an alternative perspective on possible mechanisms for Pleistocene subsistence. Groube (1989) suggests that these artefacts represent the existence of a technological capability for forest clearance and that through trimming, canopy-thinning, ring-barking and with the use of fire, restricted natural stands of useful understorey plants might be promoted. In a review of pre-agricultural hunter-gatherer strategies for subsistence in tropical rainforest, Mountain (1991:62) proposes a model of environmental management in which 'zones which receive greater light were expanded at the forest edges and in naturally thinner zones such as swamps and clearings, using the technique of burning to assist in clearance of vegetation'.

Palaeoecological studies in New Guinea rely on a series of criteria to distinguish human impact from natural processes in a record of vegetation history. These primarily include the identification of processes that are unprecedented in the palaeoecological record such as indications of forest decline and burning, and increases in secondary forest and herbs (Haberle 1994; Walker and Singh 1994). This certainly includes the impact of agriculture as defined by the cultivation of domesticated crops and establishment of agroecosystems (Harris 1989). However, in the absence of direct archaeobotanical evidence for domesticated plants in the highlands of

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1. 1 In this case the term 'highlands' refers to the inland regions of New Guinea above an altitude of about 1000 m and not exclusively to the present day Highlands provinces of Papua New Guinea.
2. Ages based on the radiocarbon method are given as calibrated radiocarbon years before AD 1950 (cal BP) calculated using CALIB v3.1 (Stuiver and Reimer 1993). Ages over 19260 radiocarbon years before present have not been calibrated and are reported as radiocarbon years before present (BP).

| | Hunting and Gathering | Cultivation-Agriculture | |
|---|---|---|---|
| | | *Evolution* | *Revolution* |
| **Subsistence behaviour** | | | |
| i) environmental manipulation | quiescent | dynamic | dynamic |
| ii) new plants/animals | none | few | many |
| iii) population growth | low | gradual | rapid |
| **Palaeoecological indicators** | | | |
| i) forest trees | ± loss | gradual loss | rapid loss |
| ii) disturbance adapted plants | little change | gradual increase | rapid increase |
| iii) charcoal | increased | increased | increased |
| iv) rate of change | minimal | gradual increase | rapid increase |
| **Landscape history** | | | |
| i) divergence from natural variability | low | moderate, increasing | high, rapid |
| ii) regional visibility | problematic | stochastic | time-transgressive |

Table 1. The imprint of anthropogenic activity on the landscape.

New Guinea these criteria may also apply to a range of subsistence activities that span wild and domesticated plant cultivation practices through to the establishment of intensive agroecosystems. In order to distinguish between the impact of hunter-gatherer and cultivation or agricultural activities on the landscape it is necessary to focus on the process of landscape change. This can be categorised into several broadly divergent possibilities each with different outcomes for the palaeoecological record (Table 1).

The impact of hunting and gathering may be characterised by *quiescent impact* in which natural processes of environmental change are enhanced and utilised by the indigenous population for subsistence gains. This is exemplified by the record of Pleistocene human impact in the Australian tropics, where the use of fire to accelerate or enhance the impact of existing climate trends within the vegetation communities first became evident (Kershaw 1986). Recent regional comparisons between long pollen records from tropical Australia and Indonesia show that sustained disruption of rainforest and expansion of more open vegetation under the influence of increased burning occurs several times during the late Quaternary at intervals that relate to Milankovitch and sub-Milankovitch climate cyclicity or periodic increased influence of El Niño-related climate variability (Kershaw *et al.* 2002). The most significant of these events occurs between 32,000–34,000 BP, at a time when the archaeological record for human colonisation begins and, while human impact is the best explanation, the relative role of climate change remains problematic (Kershaw *et al.* 2002; Moss and Kershaw 2000). At around the same time in the highlands of New Guinea, montane rainforest is replaced by open grasslands in some sites under the influence of increased burning, though there is little discernible change in forest composition (Haberle *et al.* 1991; Hope 1998), and no evidence for sustained enhancement of secondary forest or understorey plants. While these changes are most parsimoniously assigned to human colonisation and subsequent impact, any divergence in the rate and direction of vegetation change from that which would be expected under the influence of natural climate variability alone is likely to remain low.

In contrast, the emergence of an agricultural landscape may be characterised by *dynamic impact* in which natural processes of environmental change are not only enhanced but are overcome or outpaced by human activity. The impact on the landscape is one not only of loss of forest but also of a change in forest composition favouring plants adapted to sustained disturbance and fire. The appearance of open vegetation incorporating herbaceous plants associated with gardens may also be apparent. The rate and direction of this change relative to the natural environmental variability is the critical factor. On the one hand an 'evolutionary' model for the emergence of an agricultural landscape, while requiring active manipulation of the environment, is characterised by a gradual intensification of human influence, which is most likely the result of *in situ* transformations in plant management strategies. Under this model there is divergence in vegetation change from natural climate variability, though this appears as a series of localised and stochastic events in the palaeoecological record. On the other hand the 'revolutionary' model for the emergence of an agricultural landscape is characterised by a rapid and perhaps time-transgressive change in vegetation across the landscape that is highly divergent from trends in natural variability. This model is reminiscent of the classic 'Neolithic transition' seen in the European pollen record during the early to mid Holocene (Willis and Bennett 1994), resulting from the introduction of domesticated plants and agricultural techniques from an external source.

In this paper I attempt to identify human impacts, based on the criteria set out in Table 1, at palaeoecological sites associated with five major highland basins between 1400 m and 1890 m altitude (Fig. 1), where

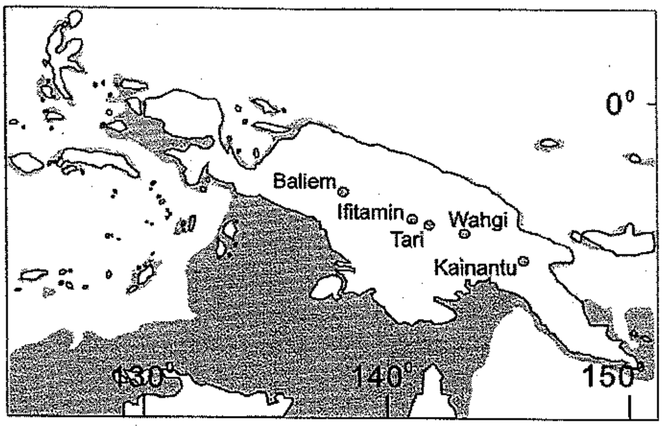

Figure 1. Map of main highland valley sites in New Guinea mentioned in the text.

agricultural populations are most densely concentrated and deforestation has been most complete. The evidence presented will focus on the key indicators of human impact and the rates at which these changes occur relative to natural climate change during the late glacial and Holocene periods. The spatial and temporal implications of this evidence will be discussed in the light of the models for human impact outlined above and conclusions drawn about the nature and antiquity of the emergence of an agricultural landscape in highland New Guinea.

## Rate of Change Analysis

In order to investigate the rate at which different variables change through time, an analysis of the dissimilarities between these variables is performed on both climate and pollen data. Rate of Change Analysis was first developed by Jacobson and Grimm (1988) and involves measuring the dissimilarity between adjacent pairs of samples and then relating that to the temporal difference between these samples. Due to the non-linear properties of this measure the analysis works best with samples that are separated by a similar time distance (e.g. 100 year sampling interval). This is rarely achieved when sampling for pollen analysis due to changes in sediment accumulation rates and pollen deposition rates. In this analysis the data chosen from Papua New Guinea do not have a constant interval between each sample so an interpolation of the data has been performed to approximate a constant sampling interval of 500 years. Palaeoclimate data reflecting regional and global climate dynamics that are likely to influence the climate of the highlands of Papua New Guinea, and palaeoecological data from sites that have 3 or more chronological control points (radiocarbon analysis or tephra markers) have been selected for this analysis. To facilitate inter-site comparisons only pollen taxa common to all sites were selected for the analysis, including *Nothofagus*, *Castanopsis/Lithocarpus*, *Phyllocladus*, Myrtaceae, *Macaranga*, *Trema*, *Dodonaea*, *Casuarina*, and Gramineae. While the addition of further taxa to the pollen data set or new climate proxy data to the palaeoclimate data set may change the outcome of this analysis, it must be emphasised that the current selections are considered to reflect robust changes in the environment.

An indication of the rate at which vegetation changes across the highlands of New Guinea is then arrived at by producing a cumulative rate of vegetation change (i.e. sum of rate of change values in Fig. 3A–E divided by the number of sites). All numerical analysis has been implemented within PSIMPOLL, a C program for plotting and analysing pollen data, developed by Bennett (1994).

## Climate change and variability in New Guinea

The island of New Guinea lies within the humid tropics and is strongly influenced by seasonal fluctuations of the major equatorial circulation patterns. During the austral winter, New Guinea is under the influence of deep tropical easterly air flow (south east trade winds) while, during the austral summer monsoon, equatorial north westerlies dominate. Throughout the year the region is a locus of airstream convergence known as the Intertropical Convergence Zone (ITCZ) and, as a result, is one of the most persistently cloudy regions around the equator (McAlpine *et al.* 1983). Circulation patterns over the region are strongly affected by the Southern Oscillation, though the influence is strongest during the pre-monsoon from September to November (McBride 1999). The severity of the 1997–98 El Niño event was brought about by an anomalous eastwards displacement of the ITCZ from over the maritime continent towards the central Pacific and a subsequent failure of the austral summer monsoon (Webster *et al.* 1998). In the highlands, localised circulation patterns and orographic effects are also important (Brookfield and Hart 1966). During the austral winter the eastern highlands of Papua New Guinea and the central ranges of West Papua experience drier conditions. Where the highland ranges narrow, as in the central part of the island, it is almost uniformly wet in all months.

The equatorial circulation patterns have experienced major changes over the last 20,000 years since the end of the Last Glacial Maximum (LGM, 20,000–24,000 cal BP). The regional climate mechanisms that are most likely to have influenced local climate variability, and therefore vegetation change, over this time period in the highlands of New Guinea include; (i) relative position and intensity of the ITCZ (Fig.2A), (ii) solar insolation (Fig. 2B), (iii) sea surface temperature (Fig. 2C), (iv) sea level and its influence on continentality (Fig. 2C), (v) relative influence of polar air from the northern and southern hemispheres (Fig. 2D), and (vi) levels of atmospheric $CO_2$ (Fig. 2D). Rate of Change analysis was performed on these variables at 500 year intervals in order to observe the relative rate at which climate changes from just after the LGM through to the present (Fig. 2E).

Sea surface tempertures, sea level and atmospheric

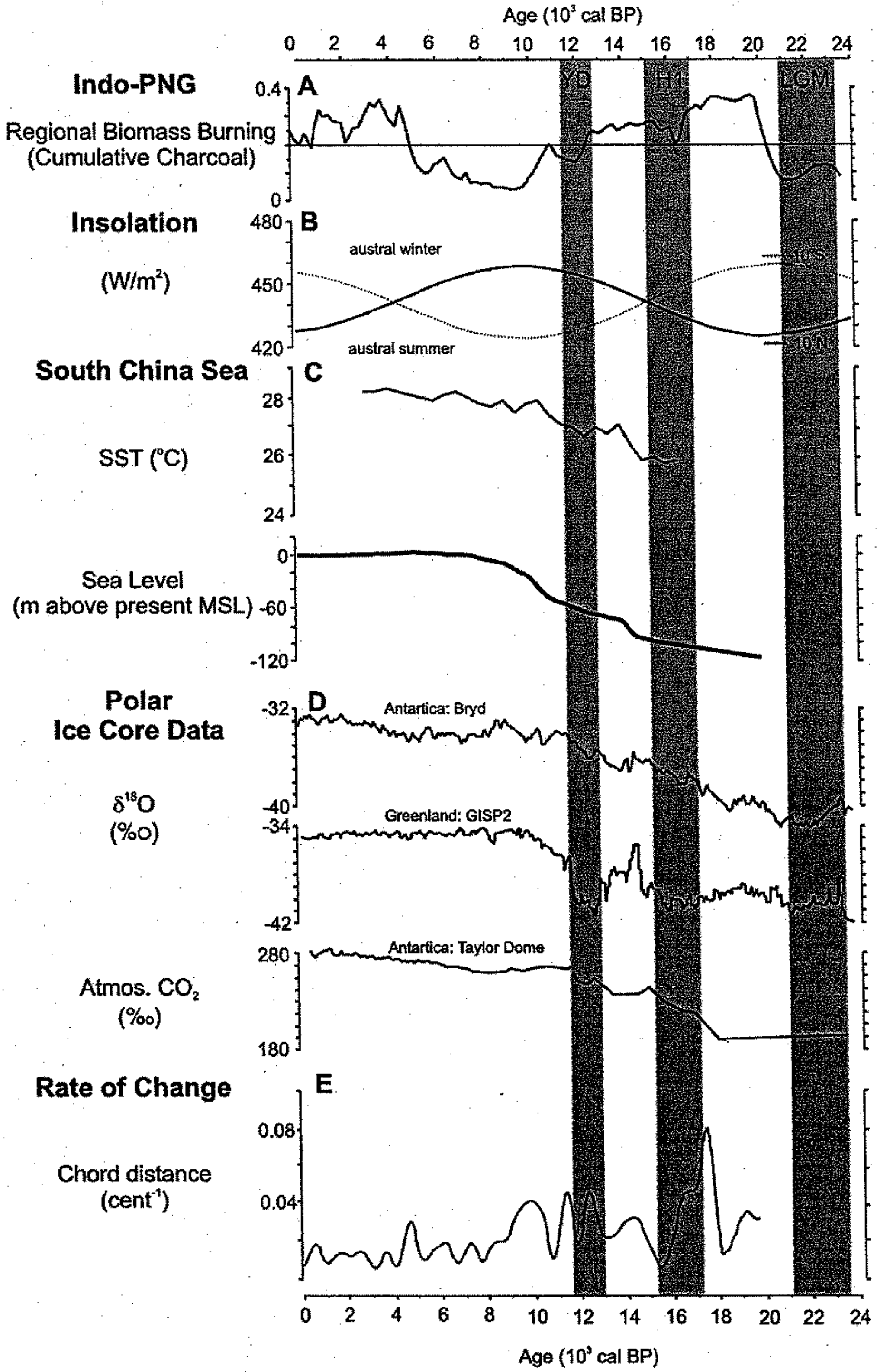

Figure 2. Comparison between regional and global climate proxies. (A) regional biomass burning derived from a cumulative charcoal record from Papua New Guinea and Indonesia (Haberle and Ledru 2001) (B) South China Sea sea surface temperature and sea level record (after Steinke *et al.* 2001) (C) ice-core data from northern hemisphere ($\delta^{18}O$, GISP2; Grootes *et al.* 1993) and southern hemisphere ($\delta^{18}O$, Byrd, Broecker 1998; Atmospheric $CO_2$, Taylor Dome, Indermühle *et al.* 1999 and Smith *et al.* 1999). (D) summer insolation at low latitudes (10°S and 10°N; Berger and Loutre 1991), and (E) Rate of Change analysis (Jacobson and Grimm 1988) based on interpolated values (500 yr intervals) for the parameters represented in (A), (B), and (C).

$CO_2$ reached minima during the LGM. Pollen records (Haberle 1998a) and changes recorded in equatorial glaciers (Hope and Peterson 1976) indicate that this period was at least 5ºC cooler and somewhat drier than present in the highlands of New Guinea. Sea level, sea surface temperatures and atmospheric $CO_2$ gradually increased during the period of deglaciation, between 20,000–10,000 cal BP, though these trends were punctuated by two major and very rapid climate fluctuations known as Heinrich events (Bond *et al.* 1997). The Younger Dryas, or H0, occurred between 11,700 and 13,000 cal BP and H1 occurred between 15,000 and 17,000 cal BP. A rapid shift to relatively cool conditions may have occurred at these times in New Guinea as reflected in the regional fire (Fig. 2A) and sea surface temperature (Fig. 2C) record, though the climate mechanism for this to occur remains unclear. One possibility is that while temperatures were reduced by up to 2ºC in the northern Hemisphere (Peteet 1995), the increased differentiation between northern and southern hemisphere polar ice volumes (Taylor Dome and GISP2 $\delta^{18}O$ records, Fig. 2D) at these times may have enhanced polar air incursions to tropical latitudes and shifted the ITCZ northward of New Guinea, resulting in cooler and possibly drier climate in the highlands. The rate of climate change as depicted in Fig. 2E reveals that the late glacial period was a period of rapid climate change up until around 10,000 cal BP when Holocene rates of climate change were reduced by up to 10 times those recorded during the late glacial period.

The early Holocene (10,000–7000 cal BP) witnessed increased convection over New Guinea with the development of a strong austral summer monsoon and the build up of warm waters to the north of the region, producing warmer and somewhat wetter conditions. Seasonality may also have been reduced at that time due to a relative increase in solar insolation during the austral winter and decrease during austral summer (Fig. 2B). In general the rate of climate change remains subdued during the Holocene with the exception of a shift to more frequent and intense El Niño-related events that occurs at around 5000 cal BP (Haberle and Ledru 2001; McGlone *et al.* 1992).

## Palaeoecological indicators of the emergence of agriculture

The broad changes in vegetation since the arrival of humans in the lower montane forests of New Guinea around 26,000 BP have been established from 19 swamp and lake sites (Haberle 1994; Haberle 1998b). The late glacial records show that vegetation, at least within montane and alpine regions, has a remarkable ability to track climate change (Hope 1976). This is also the case in lower montane highland valleys where human settlement and deforestation are most complete (Haberle 1998a; Walker and Flenley 1979). However, many palaeoecological sites within the highland valleys are not continuous, perhaps due to anthropogenic-related disturbance, and lack detailed chronological control. Despite these problems five sites have been selected from highland valleys extending from the central ranges of Irian Jaya to the eastern highlands of Papua New Guinea, representing the most suitable records for an analysis of the rate of vegetation change. A summary diagram (Fig. 3) is presented for each site that includes the relative proportions of forest trees, trees indicative of disturbance (*Macaranga*, *Trema*, *Dodonaea*, and *Casuarina*) and herbaceous plants (mainly grass), charcoal particle concentration and rate of change analysis.

### *Baliem Valley (Fig. 3A)*

Kelela Swamp at 1400 m altitude (Haberle *et al.* 1991) has a long, possibly discontinuous, pollen record dating back to some time before 7800 cal BP. In the earliest phase regional forest cover was dominanted by mixed *Castanopsis/Lithocarpus* forest in the valley, possibly reflecting late glacial to early Holocene climatic warming. Accession of clay and silty sediment to the site was followed by evidence for widespread forest disturbance, burning and myrtaceous swamp forest clearance at around 7800 cal BP. The rate of vegetation change reaches a peak between 6500 and 4500 cal BP. After this, forest clearance and burning continued with only minor reversals through to 3000 cal BP, when extensive grassland areas were established. A second phase of high rate of vegetation change is recorded between 2000 and 1000 cal BP. There is a marked rise in *Casuarina* pollen around 1100 cal BP, suggesting that silvicultural practices may have become important.

### *Ifitaman Valley (Fig. 3B)*

The township of Telefomin lies in the Ifitaman Valley at an altitude of around 1500 m. In contrast to the Baliem Valley, *Nothofagus*-rich forest remains a relatively important forest element throughout the 20 000 year pollen record, despite the relatively low elevation (Hope 1983). Around 14,000 cal BP regional warming produced a shift in forest composition to a more mixed *Nothofagus* forest, with only a slight rise in *Castanopsis/Lithocarpus*. The Telefomin pollen record shows two major disturbance events between 18,500–19600 cal BP and 13,500–9100 cal BP (inferred from Hope 1983:Fig. 3), which are interpreted as anthropogenic burning and local forest disturbance followed by abandonment and re-establishment of primary forest. The rate of vegetation change during this period is generally low with a single peak around 11,000 cal BP. A hiatus in sedimentation is believed to occur between 8000 and 4500 cal BP (Hope 1983). The final period of disturbance occurs only after 4500 cal BP, when grassland expands rapidly to its present extent and forest and swamp forest are cleared from the site. The rate of vegetation change in the late Holocene is around 2 times higher than in the late glacial period, peaking at around

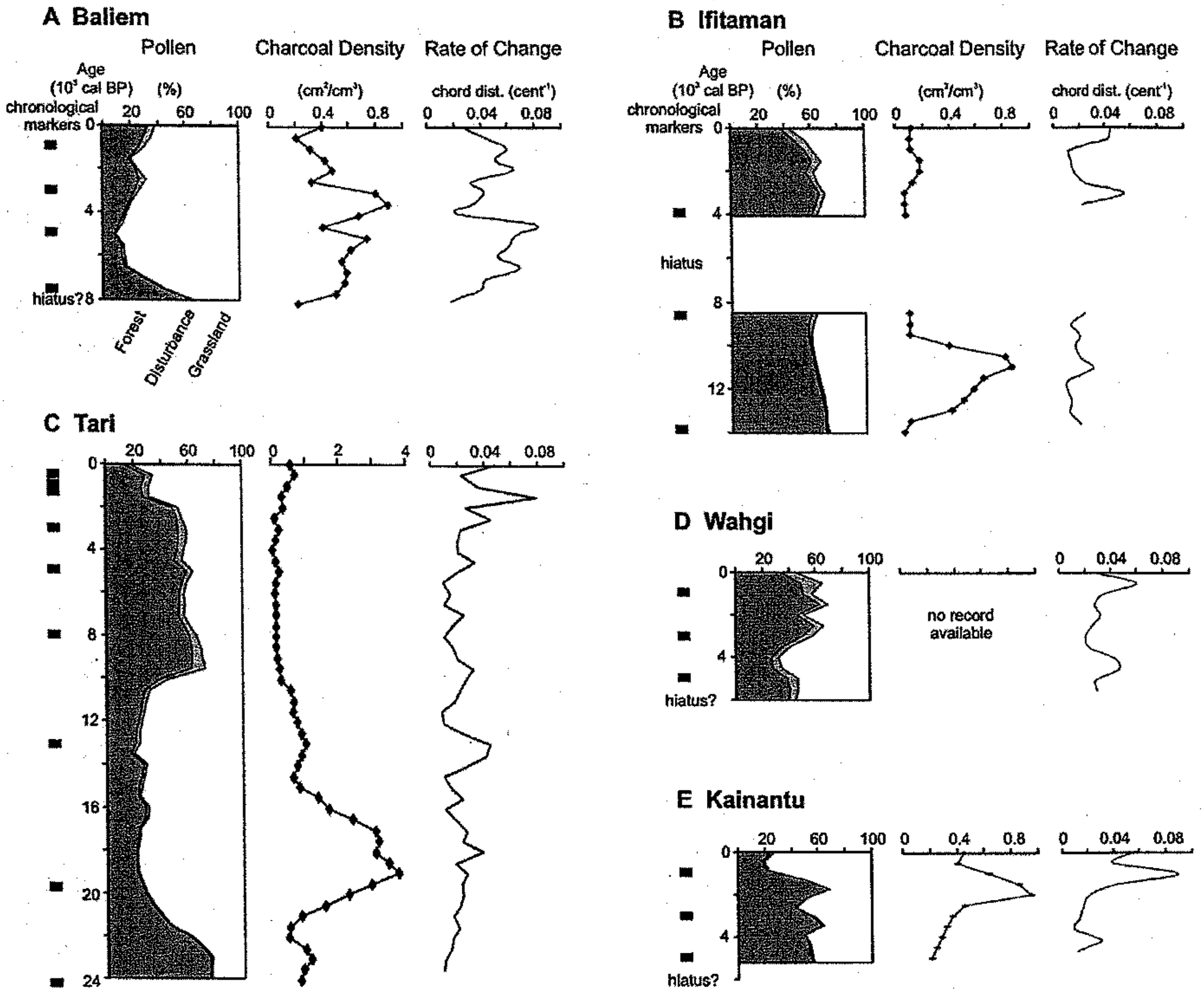

Figure 3. Relative changes in pollen, charcoal and rate of change analysis along a west to east transect of highland valleys (1400m–1890m) in New Guinea; (A) Baliem (Kelela Swamp, 1400 m altitude, Haberle *et al.* 1991); (B) Ifitaman (Telefomin, 1500 m altitude, Hope 1983); (C) Tari (Haeapugua, 1650 m altitude, Haberle 1998a); (D) Wahgi (Draepi-Minjigina, 1890 m altitude, Powell 1982); (E) Kainantu (Norikori Swamp, 1750 m altitude, Haberle 1996). Summary pollen diagram showing the relative representation of forest, disturbance-related trees, and herbaceous taxa at each site. Rate of Change analysis is based on interpolated pollen percentages at 500 yr intervals for major taxa common to all sites (*Nothofagus*, *Castanopsis*/*Lithocarpus*, *Phyllocladus*, Myrtaceae, *Macaranga*, *Trema*, *Dodonaea*, *Casuarina*, and Gramineae).

3000 and 500 cal BP. *Casuarina* appears to be grown in the valley only after 1000 cal BP, in line with the evidence from the Tari Basin and the Baliem Valley. However, unlike these two regions, the extensive grasslands around Telefomin today are rarely used for agricultural purposes and are infrequently burnt.

### *Tari Basin (Fig. 3C)*

Haeapugua (1650 m altitude) is the only published continuous pollen record from the highlands of New Guinea that spans at least 27,000 BP to the present (Haberle 1998a). The montane tree *Nothofagus* is important throughout the record, though other trees, including *Castanopsis*/*Lithocarpus*, Myrtaceae, *Dacrydium* and *Pandanus* attain dominance at different times. The study shows that the basin floor is forested until just prior to the LGM when the establishment of grassland is considered to be the consequence of climate change as well as the arrival of humans in the region. Between 20,000–10,000 cal BP, burning is sufficient to maintain grasslands in the valley floors. The rate of vegetation change peaks at around 17,000, 13,000 and 10,000 cal

BP during the late glacial period. The early Holocene is marked by the development of swamp forest vegetation. The rate of vegetation change is relatively low during the early Holocene, though rises to levels comparable to the late glacial after 5000 cal BP. There are also indications of forest disturbance beginning around 5000 cal BP, with swamp forest clearance and a peak in the rate of change commencing around 1600 cal BP.

### *Wahgi Valley (Fig. 3D)*

The Wahgi Valley has been the focus of extensive palynological research over the last 30 years (Powell 1970, 1982; Powell *et al.* 1975) with palynological sites from 1590 to 1890 m altitude. As in the other major montane valleys, *Nothofagus* forest occupied much of the valley floor prior to the LGM. There is no pollen data from the Wahgi Valley from the LGM until around 6000 cal BP, as the sediment sections are truncated or disturbed. The pollen diagrams covering the mid to late Holocene in the Wahgi Valley all show that clearance had occurred by the beginning of the records at 6000 cal BP and that the initial forest clearance event may have been much earlier. A thick clay fan which began to be deposited around 9000 BP in the Kuk swamp is considered to represent a period of slope sediment mobilisation that followed initial clearance (Golson 1977; Hughes *et al.* 1991), though we have no pollen evidence to substantiate this claim. The Draepi-Minjigina pollen record (Fig. 3D) shows the presence of grasslands since 6000 cal BP and a rate of vegetation change comparable to the other Holocene records. A phase of increased rate of vegetation change associated with forest disturbance and grassland expansion occurs around 4000 cal BP, which is not evident in other Wahgi Valley records (Powell 1982). At other sites in the Wahgi Valley, such as Kindeng Swamp and Lake Ambra, a major expansion of grasslands at the expense of forest and regrowth occurs after 1900 cal BP. A similar development is recorded at Draepi-Minjigina around 1400 cal BP. This phase has been linked to the intensified use of the lower slopes for gardening after the development of tillage practices (Golson 1977; Powell 1982). A second phase of increased vegetation disturbance belongs to the last 1100 years of vegetation history in the Wahgi Valley and is characterised by an increase in *Casuarina* and a high rate of vegetation change similar to that recorded in other highland sites.

### *Kainantu Valley (Fig. 3E)*

Norikori Swamp (Haberle 1996) lies at an altitude of 1750m in the eastern highlands and shows that a

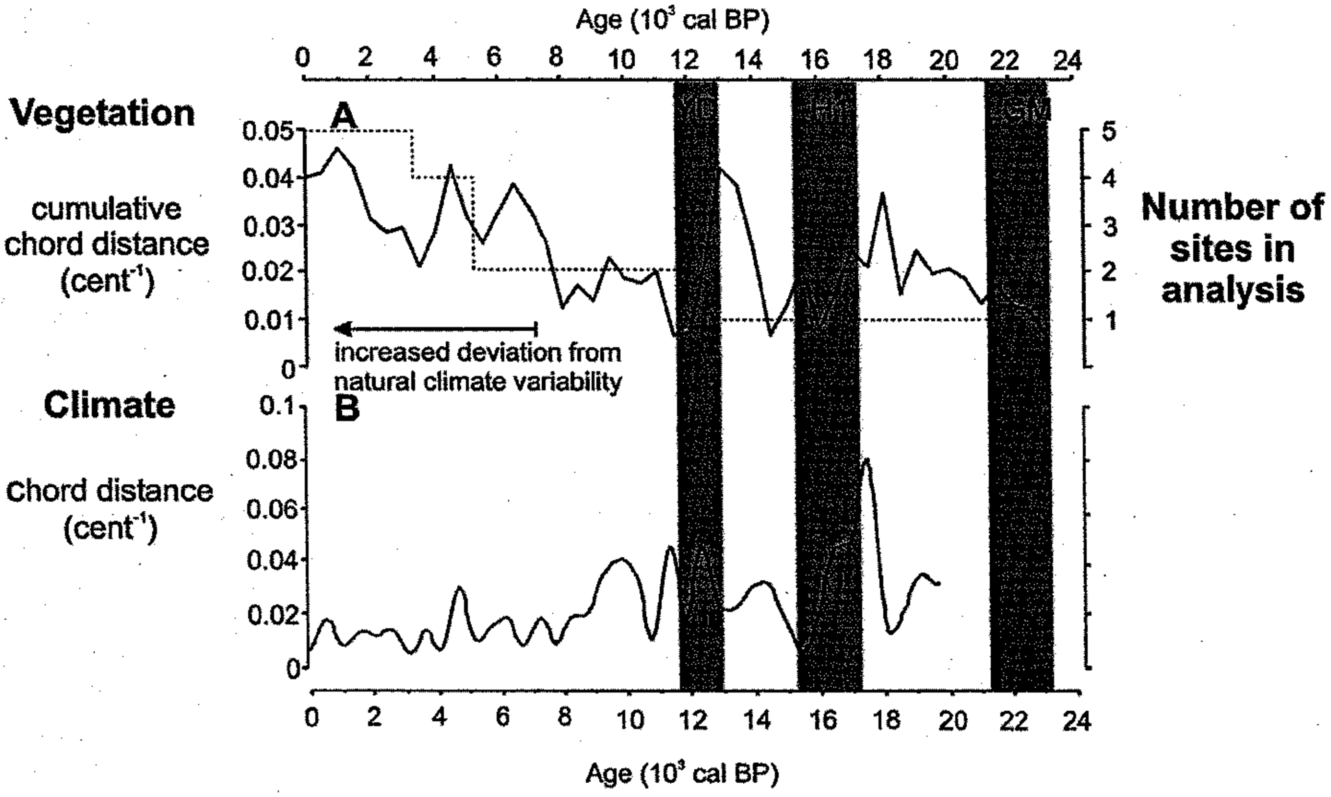

Figure 4. Comparison between (A) cumulative rate of vegetation change (sum of rate of change values in Fig. 3A–E divided by the number of sites with number of sites shown by dashed line) and (B) rate of climate change (Fig. 2E), from 24,000 cal BP to the present.

Myrtaceous/*Pandanus* swamp forest existed on the site for an undetermined time before 5000 cal BP. Disturbance of forest and clearance is already evident by the time Holocene sedimentation begins around 5000 cal BP. Features purported to be fossil agricultural structures in the nearby Arona Valley are dated to around 4500 cal BP and are associated with pollen assemblages representing deforested conditions (Golson and Gardner 1990; Haberle 1996). Forest clearance and burning continue gradually until 1500 cal BP when rapid vegetation change towards an extensive grassland landscape, similar to the present, occurs. *Casuarina* begins to increase around 600 cal BP, suggesting that silvicultural practices were developed somewhat later in the eastern highlands region than in the central and western parts of highland New Guinea (Haberle 1998b).

## Discussion

Regional changes in vegetation are identified through the analysis of palaeoecological data from multiple sites across the highlands. Figure 4 illustrates the cumulative rate of vegetation change time series from available highland pollen records compared to the global and regional palaeoclimate proxies (500 year interpolated sample interval for both data sets). The comparison shows synchrony between peaks in the rate of vegetation and climate change during the late glacial. The response of tropical montane vegetation to climate change is particularly marked at the time of early deglaciation beginning around 18,000 cal BP. The forest limit rises and montane forests invade valley floor grasslands in response to warmer temperatures and rising atmospheric $CO_2$ (Hope 1976; Walker and Flenley 1979). There are a number of inconsistencies in the progression of forest expansion after this time. At Komanimambuno (2750 m altitude, Hope 1976), in the central highlands of Papua New Guinea, forests are established above the site by 12,500 cal BP. At Sirunki (2500 m altitude, Walker and Flenley 1979) and Haeapugua (1650 m altitude, Haberle 1998a) the pollen evidence points to retardation in the establishment of forest until 10,000 cal BP. The sporadic development of montane forest in highland valleys between 1600–2800 m altitude at the end of the last glacial indicates that conditions were not uniformly suitable for forest development until after 10,000 BP. These inconsistencies reinforce the suggestion that fire, of either natural or anthropogenic origin, may have played a significant role in reducing the suitability of new forest habitats that were liberated from cold temperatures and low atmospheric $CO_2$.

After 10,000 cal BP there is a consistent reduction in the rate of climate change to rates that are *as much as* 10 times lower than experienced during the late glacial period. Rates of vegetation change are also low for a brief period during the early Holocene. However a deviation from the trend seen in the climate change record is evident after 7800 cal BP in the vegetation change record. While it is not possible to identify the beginnings of this process due to sediment discontinuities, forest clearance is evident more than 1000 years earlier in the Baliem and Wahgi Valleys relative to the Tari Basin, which lies between the other two valleys. All sites show that the mid–late Holocene period is characterised by increasingly higher rates of vegetation change through to the present. The regional trend towards an increasing rate of vegetation change is punctuated by peaks at 6500, 4500 and 1500–1000 cal BP. With the possible exception of the peak at 4500 cal BP, which coincides with the onset of modern El Niño-related climate variability (Haberle 2000), the gradually increasing rate of vegetation change recorded from 7800 cal BP is at odds with the trends evident in the climate change record. Following the criteria for identifying the nature of anthropogenic impact on the highland environment of New Guinea outlined in Table 1, it is evident that the mid–late Holocene deviation from expected natural variability in vegetation dynamics is indicative of anthropogenic influence associated with agricultural activity. This is in contrast to the late glacial and early Holocene period in which the major peaks in vegetation change are consistent with peaks in the rate of climate change.

What does this mean in terms of the nature and origin of agriculture in highland New Guinea? The palaeoecological records from highland valleys point to a sustained and gradual intensification of forest clearance and burning from at least 7800 cal BP. This is neither strictly time-transgressive nor is it synchronous along a longitudinal transect as might be expected under a 'Neolithic Transition' model where diffusion of agricultural techniques and crops may have been rapid and the impacts widespread. If agriculture was being practiced around 10,000 cal BP in the Wahgi Valley, as suggested from the archaeological evidence at Kuk Swamp (Golson 1991), then this does not register in the regional palaeoecological record until 2200 years later. This suggests that either the agricultural activity was very localised for a long period of time and not registered in regional pollen records or that the antiquity of early agriculture in New Guinea requires re-assessment. A number of critical lines of evidence from the Kuk Tea Station excavations have been challenged by Denham (in press, and this issue) that suggest that the basal features at the site are not necessarily associated with agricultural practices.

A more complex model of landscape history is suggested by the palaeoecological results which suggest a trend from a *quiescent impact* (late glacial to early Holocene) towards an increasingly *dynamic impact* (mid–late Holocene) of human activity that is punctuated by peak episodes of vegetation change towards a more open landscape (6500, 4500, and 1500–1000 cal BP). Whether these latter episodes of rapid vegetation change are directly associated with the introduction of cultigens (e.g. a hypothesised introduction of taro 4500 years ago, Bayliss-Smith 1996), or indigenous developments in agricultural techniques in the face of increased land degradation or climate change (e.g. a hypothesised prolonged drought forcing the development of *Casuarina* silvicultural techniques around 1200 years ago, Haberle and Chepstow-Lusty 2000), is not yet known for certain. Despite these uncertainties the nature of landscape change in the highlands can at least be partially explained in terms of 'a series of energy thresholds that mark important steps in an increasing intensity of control over the social landscape' (Bayliss-Smith 1996:519). While the timing and nature of these changes can be identified we are yet to understand the reason for these changes.

## Conclusion

The introduction of Rate of Change analysis to the study of human impacts on the environment provides an opportunity to reassess landscape history in New Guinea. However, it is important to emphasise that the analysis is limited by the quality and number of the palaeoecological and palaeoclimatological records, and that the addition of new records with improved chronological control may influence the outcome of future syntheses. Also, while the analysis of rates of vegetation change provides an additional dimension to palaeoecological interpretation, it does not provide an explanation for the emergence of agriculture in New Guinea. Recent assessments of the possible origins of agriculture have emphasised the possibility of both *in situ* adaptations and invention, overlain by diffusion of domestic plant and animals from lower altitudes in New Guinea or from sources further afield. However, further palaeoecological work is needed to assess more fully the nature and antiquity of the emergence of agricultural landscapes across different environments and the relative influence of internal versus external forces on indigenous agricultural development. While the addition of high-resolution vegetation history records with detailed chronological control will be essential to this endeavour, a continued emphasis on integrating archaeological and palaeoecological investigations will provide the social dimension to constructing landscape history required to advance our understanding of the context for the emergence of agricultural landscapes through time.

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