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Reports on findings that Gunditjmara responded technologically to climate change during both early and late Holocene

Builth's 2008 paper, asserts pre-1788 Aboriginal communities devised technological solutions to address climate change

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Environmental and cultural change on the Mt Eccles lava-flow landscapes of southwest Victoria, Australia

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Abstract: The Gunditjmara people developed a socio-economic system based on the modification of wetland ecosystems associated with the Mt Eccles lava flow primarily for sustainable production and management of the highly nutritious shortfin eel (*Anguilla australis*). This paper examines the environmental history of these landscapes since their inception about 30 000 years ago, through palaeoecological analysis of sediment cores from associated lakes and swamps, in order to contribute to an understanding of the causes and timing of cultural transformation. Two records cover the whole of the 30 000 year history of the landscape while two others provide evidence of change within the Holocene. A great deal of variation within the landscape is revealed, both temporally and spatially, with opportunities for human exploitation through the whole recorded period. Although most features of the records can be explained by natural landscape development and climate change, some human modification can be suggested from around the Pleistocene–Holocene transition while more obvious indications of management relating to eel aquaculture are evident from about 4000 cal. yr BP that appear to include adaptations to the onset of a drier and more variable climate. The study has implications for the explanation of intensification of settlement in Australia more generally within the mid to late Holocene.

Key words: Aboriginal land management, eel aquaculture, volcanic landscape, Budj Bim, palynology, vegetation history, human–environment relationships, Holocene, Victoria, Australia.

Introduction

Australian Indigenous people are often characterized as having little or no impact on the environment or having achieved a harmonious state of equilibrium with it. However, the established perception of a materially bereft Aboriginal family group on the move for water and other necessities is challenged by the findings from archaeological research in southwest Victoria. Archaeological landscape analysis undertaken on the weathered basalt lava flow from the Mt Eccles volcano has demonstrated that the Gunditjmara people developed technology that manipulated prevailing ecosystems resulting in an enhanced resource base with the means to establish resource surplus (Presland, 1976; Coutts *et al.,* 1978; Williams, 1988; Builth, 2002a, 2004). Landscape and ecological transformation inevitably directed the socio-economic and cultural development of Gunditjmara society (Builth, 2006). This is a landscape that demonstrates the co-evolution of humans and their environment.

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In this landscape, known to Gunditjmara as *Budj Bim*, archaeology documents physical remains, as opposed to cultural knowledge and memory, of the historical interconnectivity of the Gunditjmara with their environment. All the characteristics and attributes of the environment together form the ingredients for their particular economic, social and spiritual development. The challenge for science is how to extricate data from both the cultural remains and their ecological milieu in order to reveal anthropogenic influences and modifications to the natural landscape during its history. We know that the archaeology of the eel aquacultural system represents environmental manipulation and its subsequent management. What we are searching for, via multiproxy core analyses, is the signature of this occurrence and its possible relationship to climatic or other environmental stimuli.

Questions arise as to the timing of the land modifications. Did they occur over the long or short term? Could part or all of this technology be a dynamic response to climate fluctuations? Could the technology be a response to regional social dynamics including the development of exchange systems (Lourandos, 1980, 1991, 1997)?

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Social determinism: cause or effect?

The research undertaken by Lourandos (1980: 387) during the 1970s demonstrated that in southwest Victoria a former economic expansion had taken place via environmental control and specialized technology aimed at taking maximum advantage of the ecological traits of the shortfin eel. The eels' predictable migration patterns and habitat preference make these activities highly profitable, with low energy invested for high calorific, protein and fat return. Lourandos hypothesizes that local demographic pressures and population interaction in the late Holocene were the incentive and, therefore, motivation leading to mechanisms of economic control and thence to prestige and status (Lourandos, 1980: 400–403). Further, the extensive networks and intergroup festivities, ceremonies and exchange helped regulate the relationships between the high density competing clan groups. In summary, Lourandos considers population increases and changes in social organization to have been the motivating factor behind environmental manipulation. Following on from Lourandos (1980, 1983, 1997), McNiven (1998), Lourandos and David (2002) and David *et al*. (2006) have argued for a socially driven determinant as explanation for the regional social dynamic documented by Lourandos as occurring from approximately 4000 years ago.

An alternative hypothesis is that the changed social dynamics are the effect and not the cause of social and cultural developments. This hypothesis proposes a 'theoretical approach that regards past (and present) cultures as somehow functions of, or shaped by, environmental pressures' (Gaffney and van Leusen, 1995). It is aimed at deciphering 'the motivating factor behind environmental manipulation' and therefore the reasons for the late-Holocene cultural 'intensification' process as described by Lourandos (1983). Investigations on the lava flow are therefore aimed at identifying environmental change and discriminating between the human/social and/or climatic origins of these events.

Budj Bim cultural landscape

The Mount Eccles lava flow, or *Budj Bim* (Figure 1), is one of the longest, most spectacular and recent lava flows in Victoria, estimated to be 30 000 years old (Head *et al*., 1991)**.** The landform, some 165 km^2 in extent, supports wetlands and other types of water bodies within a mosaic of *Eucalyptus viminalis* woodland and basalt terracing with extensive surrounding wetlands resulting from disruption of the pre-existing drainage system. The area experiences a temperate winter rainfall regime. Climate parameter estimates derived from the predictive program BIOCLIM (Busby, 1991) indicate a mean annual rainfall of 746 mm with 256 mm falling in the winter and 112 mm in the summer, a mean annual temperature of 13ºC, a mean summer temperature of 17ºC and mean winter temperature of 9ºC.

The area incorporates Lake Condah (see Figure 2), which has long been known to have been associated with numerous fish traps and stone house remains (Worsnop, 1897; Coutts *et al.,* 1978). The archaeological remains at Lake Condah were integral to the claim that southwest Victoria was the locus of 'complex' Aboriginal occupation within Australia (Lourandos, 1976; Presland, 1976; Coutts *et al.,* 1978; Williams, 1988). However, the larger *Budj Bim* landform*,* as a cultural and socio-economic landscape, was not investigated archaeologically until the late 1990s, when field survey techniques and interpretation using GIS demonstrated that the areas where groundwater surfaced, that is, the periphery of the lava flow plus its entire western arm from Lake Condah south to the sea, had been subject to landscape-scale anthropogenic modification for the purpose of eel aquaculture (Builth, 1996, 2002a, b). Biomolecular analysis confirmed that eels had been smoked in the hollows of culturally modified trees (Builth, 2002a). These systematic modifications ensured the long-term availability and continued growth of large numbers of eels plus the means to process and preserve numerous migrating mature eels (Builth, 2002a, b, 2004, 2006).

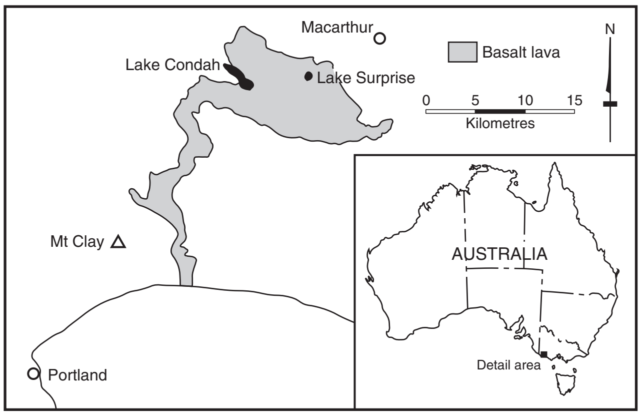

Figure 1 Location of *Budj Bim* (the Mt Eccles lava flow) and pollen sites of Lake Surprise and Lake Condah

The design of the aquaculture system allows immigrant elvers from the Pacific Ocean the physical means to reach suitable wetlands in which they will thrive and grow for up to 20 years, and, upon their maturity, the means to return to the ocean to spawn. In order for the Aboriginal wetland managers to make this possible, all the wetlands on the flow were joined with both an inlet and outlet channel, making a contiguous series of separate but integral parts that formed the whole system. Along the channels weirs were constructed to ensure successive but sustainable trapping of eels during their outward migration. The archaeology shows that a large investment of effort was directed towards the trapping of the seasonal migrating silver eels. This occurred at the particular time in their 7- to 20-yr life cycle when fat and protein content was highest (Malainey *et al*., 1999; Leach and Davidson, 2001). The subsequent processing of these eels by smoking in culturally modified *Eucalyptus ovata* or *viminalis* trees*,* resulted in the preservation of this highly nutritious and valuable resource (Builth, 2002). Preserving mature eels by smoking at this time enabled the collection, storage and trading of their high yielding, highly valued oil. An increased flow of water stimulates eel migration (Gooley *et al*., 1999), and eels are more easily trapped in flowing than still water (Moriarty, 1978). Thus a network of channels, linking marshes to the permanent swamps, and constructed in order to produce a flow between them, would guarantee a seasonal high return of eels. The result is an increase in the 'natural' eel biomass for the area and the infrastructure for an efficient trapping and processing enterprise.

The preservation and storage of a seasonally abundant highly nutritious species combined with the perennial availability of younger eels, and other wetland resources including tubers and corms as staple vegetable foods, is considered to have resulted in sedentism and a resilient society. In addition to functioning as eel growing and processing infrastructure, the system of channels would have countered rainfall variability by facilitating controlled drainage in periods of heavy rainfall and retaining water during dry periods. The system would have therefore contributed to the stability of the economy and population.

To date, the chronology of the cultural modifications to the Budj Bim landscape has not been determined, in the main because of the lack of sediment accumulation in association with the archaeological remains. Determining this chronology may assist in relating the development of the aquaculture system with either the regional exchange system and/or environmental stimuli.

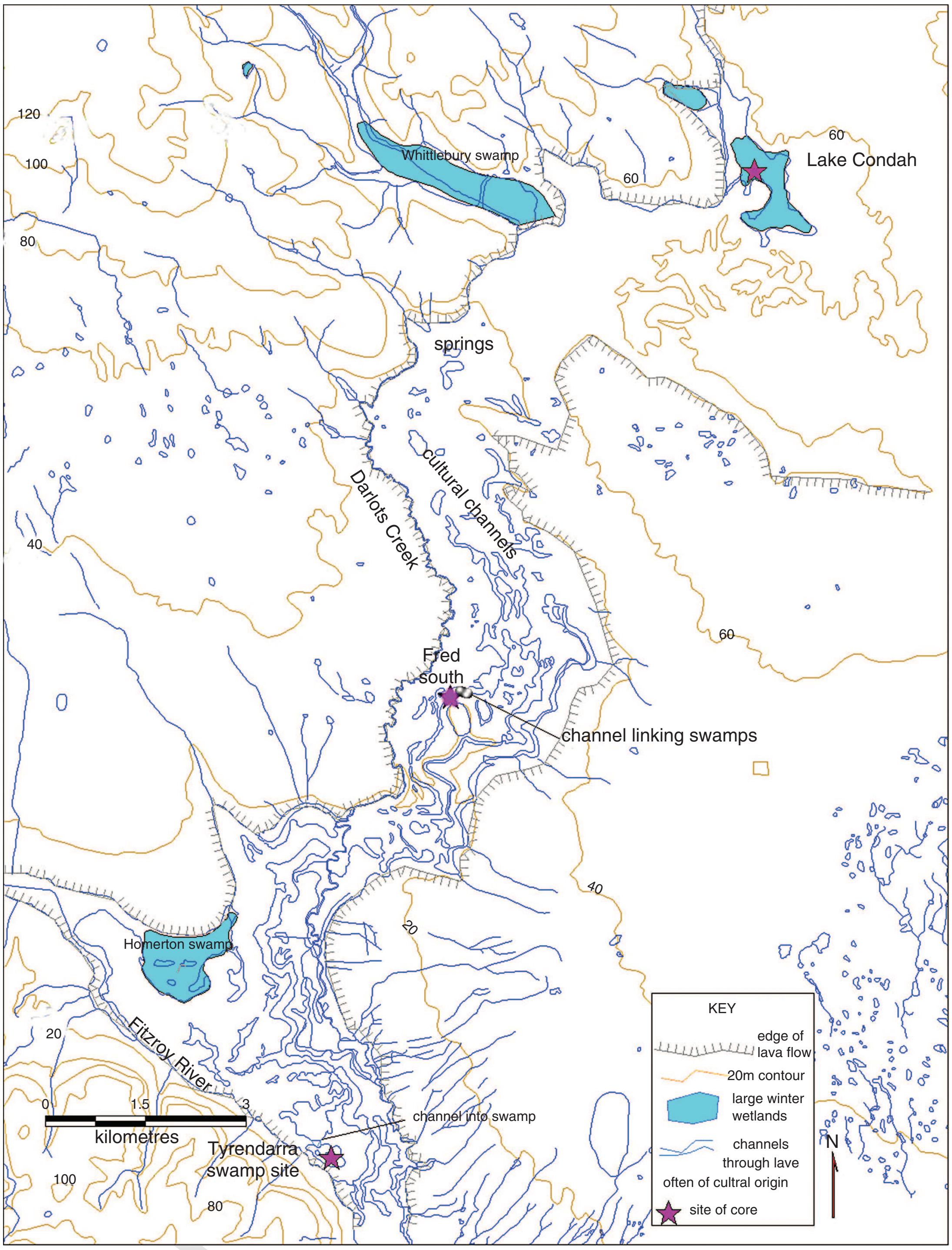

Figure 2 Location of pollen sites at Lake Condah, Fred South Swamp and Tyrendarra Swamp in relation to features of the Budj Bim landscape

Palaeoecological records

Study sites

Four palaeoecological records have been produced that cover different environmental settings associated with the Budj Bim landscape. Lake Surprise (Figure 1) formed within the vent of the Mt Eccles volcano. Owing to its relatively small size (*c*. 700 m long and up to 180 m wide), substantial depth (12 m at the time of sampling), a catchment limited to surrounding steep slopes and a lack of inflow or outflow streams, it could provide a continuous record of surrounding vegetation since the formation of the Eccles landscape, and one that that could be interpreted in regional climate terms. The lake is fringed by a narrow and discontinuous band of swamp vegetation and the surrounding vegetation is dominated by an open forest of *Eucalyptus viminalis* with a second storey of *Acacia melanoxylon* and understorey of mainly Poaceae, Asteraceae, *Pteridium esculentum* and *Banksia marginata,* although the vegetation is more open on precipitous slopes.

Lake Condah (Figure 2) was selected because of its association with eel traps around the margin of the lava flow that, as previously mentioned, have received substantial archaeological attention and current interest in the lake's restoration after installation of drainage systems by Europeans. It is one of a number of such swamps and shallow lakes that are considered to have formed as a result of disruption to the pre-existing river drainage system with lava outflow although, unlike some other such swamps that date back to the time of formation of the flow, the swamp sediments of Lake Condah had been dated to only 9000 years ago (Head *et al*., 1991). Lake Condah is much larger than Lake Surprise (*c*. 3 km long by 600 m wide when full), and also much shallower, being dry at the time of sampling. Consequently, the record, as well as being shorter than that of Lake Surprise, is likely to be discontinuous. When combined with a likely input of pollen from a broader and poorly defined catchment, the record will also be more difficult to interpret in vegetation and climate terms than Lake Surprise. The fact that much of the vegetation surrounding the Eccles lava flow has been removed for agriculture does not help definition of this catchment, although it was likely dominated by eucalypt woodland with *Leptospermum* scrub common in swamp areas. Lake Condah itself, when dry, supports a variety of small dryland to aquatic herbs and particularly grasses, which are grazed by cattle.

Fred South and Tyrendarra swamps are located on the Tyrendarra basalt flow that filled the former valley system leading to the coast (Figure 2). Fred Swamp is a component of the 'northern' modified drainage system analysed by Builth (2002a). It receives its inflow of water through an 80 m long channel that has been excavated through basalt. This same channel passes through a large number of swamps and small water bodies. These include some 'natural' swamps but the majority are considered to have been culturally modified to serve as permanent eel habitat. The channel joins the Darlots Creek 5 km downstream, and features a large number of weirs for the seasonal trapping of eels. The location of this particular swamp makes it an integral part of the aquacultural system, and it features culturally modified trees and stone house remains around its periphery.

The swamp is narrow, about 60 m at its widest point, but reaches a length of 200 m before the next weir downstream. At the time of sampling it contained about 1 m of water but does dry out during drought conditions. Much of the water surface is currently covered by a floating mass of *Azolla* and *Lemna* above submerged *Myriophyllum* and *Triglochin* with *Carex* tussocks lining the margins and, in places, emergent within the swamp. Frequent flooding of the landscape has probably inhibited tree growth and there is only a sparse cover of *Eucalyptus viminalis* and *Acacia melanoxylon* above a predominantly Poaceae and *Pteridium* ground cover. Although water-borne pollen may be a component of the influx to the site, the density of the local vegetation and the fact that stream flow emanates from springs on the Tyrendarra lava flow to the north, means that any water-borne contribution from beyond this landscape is small.

Tyrendarra Swamp is substantially larger than Fred South, approximately 400 m by 300 m, and lies within the Tyrendarra Indigenous Protected Area immediately to the west of another archaeological study area of Builth (2002a), and adjacent to the Fitzroy River that borders the western edge of the flow (Figure 2). The swamp appears to alternate between dry and shallow water (about 30 cm) with water level currently constrained by a European drain. This drain is considered to have been constructed over the top of a former Gunditjmara outlet channel to the Fitzroy used by migrating eels. This large swamp also has a culturally constructed inlet channel, of unknown date, which enabled a flow-through of water (and eels) from a much larger swamp to its north. This swamp, in turn, was fed via a cultural channel with waters from the Darlots Creek to its north (see Figure 2). Much of the Tyrendarra swamp is covered by a continuous cover of shallow water aquatics including the emergent sedge *Eleocharis,* floating leaved *Villarsia* and submerged or stranded *Myriophyllum* mixed in with wetland grasses. Eucalypt and *Acacia* trees are dense within a band from the northwest to the southeast along the Fitzroy, but sparse within the surrounding grass dominated vegetation.

Field and laboratory methods

A complete lake sediment sequence from the deepest point in Lake Surprise was collected by a combination of a frozen spade sampler that provided a slab of the topmost metre of unconsolidated sediment, a hand-operated Livingstone Sampler which recovered a core from 1 to 13 m and a piston sampler operated with a winch and pulley system that extended core retrieval to the sediment base around 18.5 m. The record presented here excludes the frozen slab material that is the focus of ongoing high resolution analysis. The much heavier, predominantly organic clay sediments of Lake Condah required a portable percussion-drilling rig with a petrol driven jack-hammer to collect a 2.8 m core.

A hand operated D-section sampler (Jowsey, 1966) was sufficient to collect most sediment from the predominantly peaty sediments of Fred South and Tyrendarra. However, the protruding nose of this sampler prevented collection of basal sediments. At Tyrendarra, an 80 cm PVC tube pushed into the sediment and extracted using a hydraulic system was used to collect additional sediment for analysis of macrofossils and succeeded in retrieving basal sediments. The 200 cm core from Fred South was taken from close to the centre of the basin but the 330 cm core from Tyrendarra was taken from close to the margin, where sediment depth was much greater than that recorded by probing over most of the swamp. The location coincided with evidence for a European drain that is considered to have followed an Indigenous channel. The top part of the sequence was taken just beyond the influence of the drain and stratigraphically correlated within the main core.

Samples of 1cm^3 were extracted for pollen and charcoal analysis at 10 or 20 cm intervals from the uncontaminated centre of 1 cm slices from each core and, after addition of *Lycopodium* spore tablets to allow calculation of concentrations, were prepared by a modification of the system of van der Kaars *et al*. (2000). The remainder of each slice was used for determination of moisture content, organic and carbonate contents using the loss on ignition method and, in the case of the top 13 m of the Lake Surprise core, diatom analysis (Tibby *et al*., 2006).

Pollen was counted on slides under a microscope until at least a count of 150 grains of common southeast Australian dryland taxa (that include *Eucalyptus,* Casuarinaceae, Poaceae and Asteraceae) had been achieved (D'Costa and Kershaw, 1997), and these formed the basis of the sum against which all taxa were percentaged on pollen diagrams. Charcoal particles greater than 15 μm maximum diameter were counted along four slide transects per sample.

Material for radiocarbon dating was taken initially as a guide to the age of sequences and subsequently for major pollen or stratigraphic boundaries. Apart from a few exploratory ages determined by conventional radiocarbon dating on bulk sediments, ages were determined using AMS either on cleaned plant macrofossils or on pollen concentrates after preparation using the pollen preparation method without the potentially contaminating step, acetolysis. Samples were analysed mainly at the Australian Nuclear Scientific and Engineering Organisation (ANSTO), Sydney, with a few samples at the Waikato Radiocarbon Laboratory in New Zealand. Radiocarbon ages, with an interhemispheric offset of 40±13 years (Hogg *et al*., 2002), have been calibrated using INTCAL04 (for samples <20 ka BP) (Reimer *et al*., 2004) and Cariaco Basin/Hulu Cave (for samples >20 ka BP) in OxCal (Hughen *et al*., 2006).

Pollen diagrams

Selected, salient features generally including sediment characteristics, pollen and charcoal concentrations and ratios as well as

Table 1 Radiocarbon ages from pollen sites, calibrated to calendar ages using INTCAL04 (for samples <20 ka BP) ((Reimer *et al*., 2004) and Cariaco Basin/Hulu Cave (for samples >20 ka BP) in OxCal (Hughen *et al*., 2006). All ages are expressed with an uncertainty of ± 1 standard deviation

Depth (cm)	Lab. no.	Material dated	^{14}C age + 1σ	Cal. age + 1σ
Lake Surprise				
220	OZH380	Pollen fraction	2150 ± 50	2160 ± 100
360	OZG890	Pollen fraction	2900 ± 50	3060 ± 60
798	OZJ032	Pollen fraction	6910	7170 ± 80
940	OZH381	Pollen fraction	9020 ± 70	10 060 ± 120
1069	OZG892	Pollen fraction	11 480 ± 80	13 360 ± 130
1120	OZH382	Pollen fraction	13 310 ± 110	16 400 ± 540
1210	OZH383	Pollen fraction.	9600 ± 60	10 930 ± 140
1335	OZH384	Pollen fraction	14 570 ± 80	17 930 ± 250
1435	OZH385	Pollen fraction	16 100 ± 100	19 290 ± 210
1535	OZH386	Pollen fraction	22 000 ± 140	26 590 ± 440
1727	OZH387	Pollen fraction	23 910 ± 180	28 840 ± 370
Lake Condah				
152	OZI227	Pollen fraction	4150 ± 50	4670 ± 110
292	OZI228	Pollen fraction	9860 ± 250	11 400 ± 440
Fred South				
58–61	Wk11416	Bulk sediment	7796 ± 77	8600 ± 110
116	OZH923	Pollen fraction	10 790 ± 80	12 780 ± 70
155	OZH924	Pollen fraction	11 310 ± 160	13 220 ± 190
150–198	Wk11417	Bulk sediment	13 388 ± 115	16 500 ± 540
Tyrendarra				
148	OZH716	Pollen fraction	21 160 ± 150	25 360 ± 370
303	OZH039	Macrofossil	29 950 ± 280	35 260 ± 340
332	OZH717	Pollen fraction	26 560 ± 220	31 420 ± 180
343	OZI038	Macrofossil	27 490 ± 270	31 950 ± 280

percentages of individual taxa are shown on TILIA constructed diagrams that have been zoned with the aid of CONISS stratigraphically constrained classification of spectra using pollen sum taxa (Grimm, 1987). Chronological control is provided by the ages listed in Table 1.

Lake Surprise

Few attributes are required to illustrate patterns of change from the Lake Surprise record (Figure 3). Radiocarbon ages support existing evidence for development of the landscape about 30 000 years ago and a full record since this time is represented. The basal half of the record, covering the latter part of the last glacial period (zones LS11–6), is dominated by the herbaceous family Asteraceae, suggesting an open herbaceous vegetation and substantially lower temperatures than today. High Asteraceae values are characteristic of glacial assemblages throughout southeastern Australia but are generally associated with equally high Poaceae percentages (Kershaw, 1998). The fact that Poaceae values remain low could be due to the unweathered nature of the basaltic substrate that inhibited colonization by grasses, which prefer heavy clay soils. Rainfall and the groundwater-table were clearly adequate to maintain a lake environment but relatively high values for Chenopodiaceae, probably derived from semi-arid shrublands, suggest that rainfall was lower than today. Drier conditions are also indicated by high values for *Myriophyllum* spp. and *Botryococcus* that inhabit shallow water. Significant peaks in *Myriophyllum muelleri*, which is tolerant of brackish water, indicate a higher concentration of salts than at present. Associated with these drier conditions are relatively high levels of charcoal. Although this suggests significant burning of the vegetation, charcoal-pollen ratios do not, on average, vary substantially through the record suggesting that the charcoal concentrations are largely an artefact of changing sediment accumulation rates that are lower within the earlier part of the record.

There is variation in glacial assemblages, the most notable being periods of increased representation of Casuarinaceae or *Eucalyptus.* Highest values of tree pollen, mainly *Eucalyptus*, are centred on the last glacial maximum (about 21 000 years ago).

There are sharp and sustained changes around the zone LD6–5 boundary with a marked increase in Casuarinaceae and concomitant declines in Asteraceae and Chenopodiaceae. The age for this event is 13 360 ± 130 cal. yr. BP that corresponds well with the age of a similar change in another western plains record, Tower Hill (about 13 700 cal. yr. BP), which has been intensively dated through the Lateglacial period (Turney *et al*., 2006). Together, they provide a firm date for this glacial–interglacial transition. The reversed underlying ages of 16 400 ± 540 cal. yr. BP and 10 930 ± 140 cal. yr. BP are problematic, especially as the latter coincides with an isolated peak in Casuarinaceae, There is evidence for both changes in the pattern of burning and aquatic vegetation prior to the zone LS6–5 boundary, suggesting that the change in dryland vegetation may have been delayed, perhaps because of the time taken for longer-lived trees to respond to climate.

Casuarinaceae woodland or forest dominated the landscape until about 8000 years ago with all indications, including marked reductions in Asteraceae, Chenopodiaceae, *Myriophyllum muelleri* and *Botryococcus*, that both temperature and precipitation were much higher than during the glacial period. *Eucalyptus* values, though, were generally lower and only increase after an event (zone LS4) that resulted in the sharp and sustained decline in Casuarinaceae and a temporary resurgence in Asteraceae. This event may indicate a short-term reduction in temperature or a disturbance feature that facilitated the partial replacement of Casuarinaceae by *Eucalyptus.* From both an examination of modern pollen spectra in southeastern Australia (D'Costa and Kershaw, 1997) and lake level studies on crater sites on the western plains (Jones *et al*., 1998), the expansion of eucalypts relative

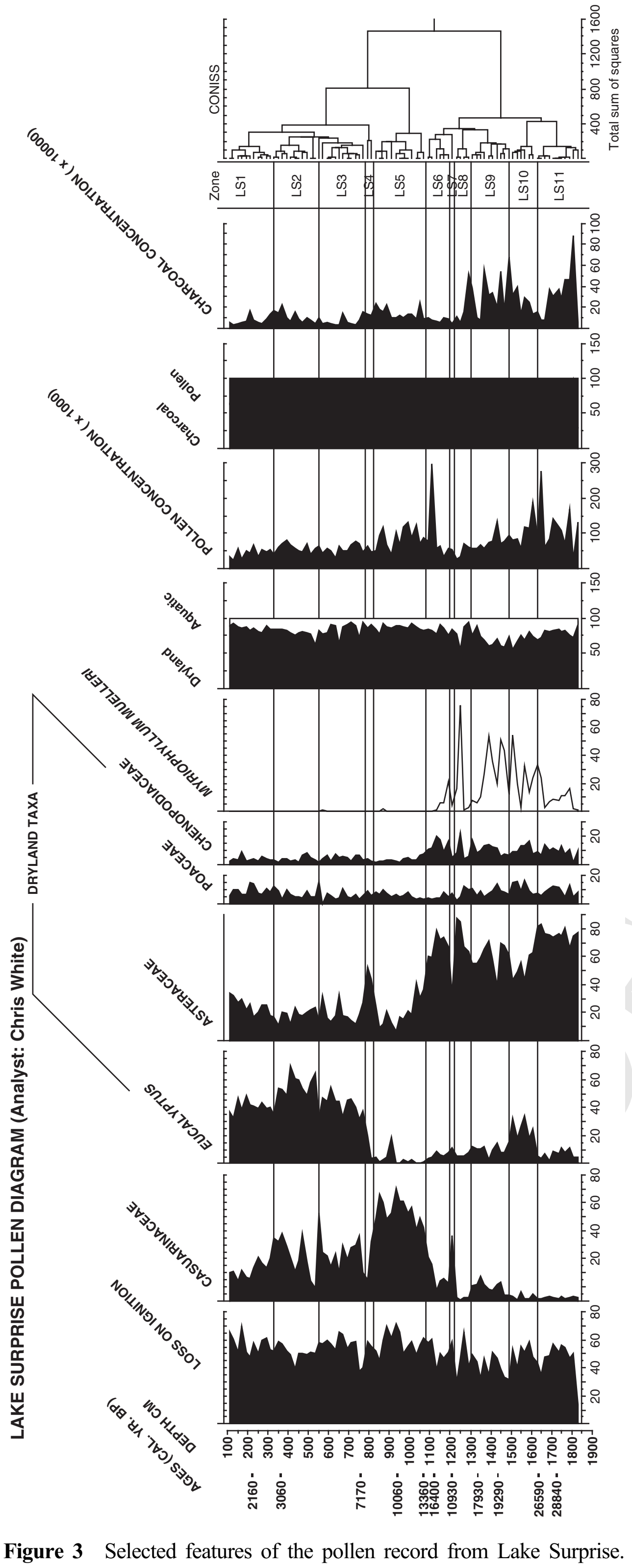

Figure 3 Selected features of the pollen record from Lake Surprise. Values for taxa are expressed as percentages of the dryland common taxon sum for individual spectra. Dryland taxon percentages shown as silouette graphs while that of the aquatic taxa are displayed as line graphs

to Casuarinaceae can be related to a regional increase in effective precipitation.

There appears to be little consistent change in vegetation and lake conditions through the remainder of the record that terminates just prior to evidence for the impact of Europeans. Rates of change analysis on both the pollen and diatom assemblages conducted on the top 13 m of this record, however, indicate an increase in variability in the record and, from diatoms, some overall decline in lake level from about 3750 years ago (Tibby *et al.,* 2006).

Lake Condah

The core collected from Lake Condah extends the existing record of Head (1989) from about 9000 to over 11 000 cal. yr. BP (Figure 4). The accumulation of only 2.8 m in this period is very slow compared with Lake Surprise and may be discontinuous. There is little doubt that the organic component of the sediments would have largely oxidized within this shallow lake basin, as indicated by the low loss on ignition values, but input of allochthonous sediment per unit area would also have been low owing to the large extent of the lake. The record appears to commence at the glacial–interglacial transition with a sharp reduction in Asteraceae and charcoal particles and a rise in Casuarinaceae. Regionally, this is comparable with the record from Lake Surprise. The lack of a longer glacial record at Lake Condah suggests that moisture levels were too low to allow sediment accumulation. The age of the transition of about 11,000 cal. yr. BP is somewhat younger than that at Lake Surprise, perhaps related to the dating of basal sediments in a shallow system with the opportunity of root penetration from aquatic plants or mobilization of carbon with water-level fluctuations around the sediment surface.

The subsequent peak in Casuarinaceae, marking zone LC4, is muted in comparison with that at Lake Surprise, suggesting that this taxon was closely associated with Mt Eccles itself. Such a distribution would be consistent with the ecology of the most likely contributor, *Allocasuarina verticillata,* that is best represented on well-drained volcanic structures, such as Mt Eccles, on the western plains today and its inferred past distribution in pollen records from Tower Hill (Edney *et al*., 1990). The low values of *Eucalyptus* and Poaceae in the Lake Condah record suggest that, regionally, *Eucalyptus* woodland and grassland had a very restricted distribution. By contrast, Chenopodiaceae peaks within the zone, suggesting incursion of saltmarsh onto Lake Condah. This is consistent with the presence of *Myriophyllum muelleri* that, in combination with *Botryococcus,* suggests a shallow and perhaps brackish and ephemeral lake environment.

The sharp fall in Casuarinaceae values and increase in *Eucalyptus* percentages at the zone LC4–3 boundary can be equated with similar changes at Lake Surprise around 8000 years ago. The change marks more clearly an increase in moisture availability with associated declines in Chenopodiaceae, *Myriophyllum muelleri* and *Botryococcus* and their replacement with freshwater taxa including another species of *Myriphyllum, M. integrifolium* type according to Head (1989). Although still shallow, the basin was probably more permanent. Unlike Lake Surprise, the surrounding eucalypt vegetation, predominantly divorced from Mt Eccles, had a substantial ground layer of grasses that most likely extended onto the margins of the basin.

A change at around 4700 years ago is indicated by CONISS but may be artificial in that the major feature is a temporary fluctuation in the ratio between *Eucalyptus* and Casuarinaceae, although it does mark a general trend towards reduced values of Casuarinaceae*,* Asteraceae, Chenopodiaceae and higher values of *Eucalyptus* and Poaceae in zone LC2. A similar change is recorded in the record of Head (1989), dated to around 4400 years ago. The general impression is of a further increase in moisture levels, especially if the increase in Poaceae is interpreted as an expansion of waterlogging in the region. There is also a substantial increase in one-third *Myriophyllum* sp. in zone LC2 that can be equated with a group of species identified by Head as indicative of higher water levels.

A reduction in flooding of the lake is recorded in zone LC1 with increased representation of the swamp taxa Cyperaceae and *Triglochin.* As this change corresponds with the presence of *Pinus,* the best indicator of European presence within the region, it can

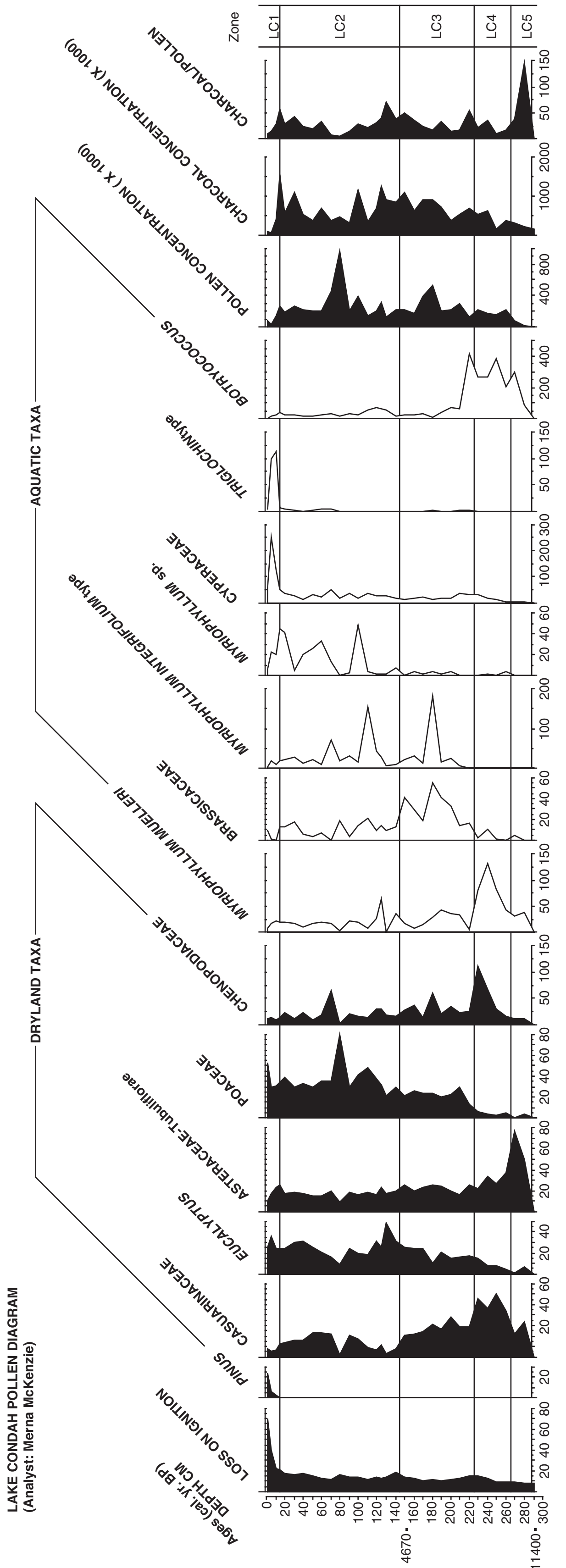

Figure 4 Selected features of the pollen record from Lake Condah. Values for taxa are expressed as percentages of the dryland common taxon sum for individual spectra. Dryland taxon percentages shown as sillouette graphs while those of aquatic taxa are displayed as line graphs

most parsimoniously be attributed to drainage of the system by European settlers.

Fred South Swamp

A very different pattern of sediment accumulation and pollen representation to either of the previous sites is provided by Fred South Swamp (Figure 5). There is little consistent variation in values of dryland taxa throughout the sequence that covers at least the last 16 000 years. The record is dominated mainly by *Eucalyptus,* Asteraceae and Poaceae. Exceptions include the basal zone where only *Eucalyptus* achieves high values and the European period where *Pinus* also emerges as a major taxon. Casuarinaceae and Chenopodiaceae percentages are at background levels. By contrast, there is marked systematic variation in the generally substantial aquatic pollen component with a number of taxa achieving dominance at different times. High swamp productivity is reflected in the consistently high loss on ignition values.

The beginning of the sequence, around the end of the last glacial maximum (zone FS 5), is marked by high values of submerged *Myriophyllum* that, together with the floating taxon, *Azolla*, suggest shallow open water. The dominance of *Eucalyptus* pollen at this time may be more related to a lack of other plants growing on the basalt flow than having a significant local presence as the high charcoal-pollen ratio in contrast with low charcoal concentrations indicates very low dryland pollen influx. However, the eucalypt values still indicate a surprisingly large tree abundance for this period.

The surface of Fred South Swamp underwent a sequence of changes during the Lateglacial period and early Holocene, from about 15 000 cal. yr. BP to 8000 cal. yr. BP. *Myriophyllum* gives way to *Rumex*, subsequently associated with *Typha*, which are then replaced by Cyperaceae followed by *Triglochin* and then by *Leptospermum.* This gives the impression of autogenic succession from open water to swamp that is eventually colonized, to some degree, by woody vegetation. However, the sequence of changes is likely to have been effected by rising water levels with increased precipitation and changing influence of running water derived from springs. It is probable that this water source also facilitated colonization of the lava landscape by grasses and provided the moisture necessary for survival of eucalypts throughout this Lateglacial period. It appears that the water was fresh as there is no indication of brackish conditions on the swamp or of Chenopodiaceae colonizing the lava flow.

From the beginning of the Holocene, about 11 000 years ago, there is a major reduction in aquatic pollen, possibly suggesting that increasing water levels in the basin drowned the swamp vegetation, or that the swamp vegetation was substantially disturbed. Subsequently, around 8000 years ago, the local environment changed dramatically with a replacement of fibrous peat (coarse detritus) by greasy decomposed peat (humus), and Brassicaceae became the only major aquatic pollen type, apart from spores of the floating fern *Azolla.* It is possible that further increased water flow was the disrupting influence that also, through the provision of oxygen, caused the decomposition of accumulating plant material. This influence probably extended to removal of sediment, because the accumulation through most of the Holocene is relatively low, and to the higher inorganic component, resulting from either greater influx of allochthonous sediment or the decomposition of organics generated within the basin.

Some reversion to the pre-Holocene basin state is recorded within the European period, zone FS 1, by increased values for *Myriophyllum*, Cyperaceae*, Triglochin*, aquatic pollen generally and loss on ignition*,* the decline in Brassicaceae, and re-establishment of peat sedimentation. Drainage by Europeans may have had some impact on water levels but, unlike Lake Condah, this influence was

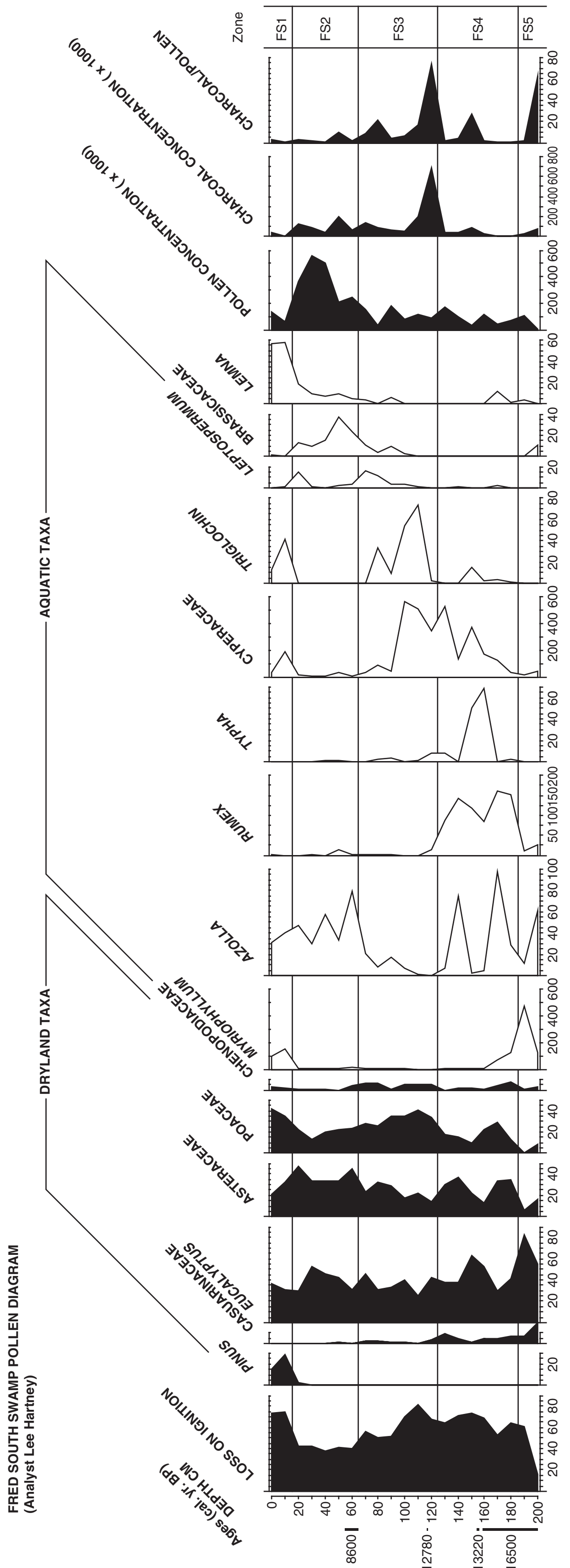

Figure 5 Selected features of the pollen record from Fred South Swamp. Values for taxa are expressed as percentages of the dryland common taxon sum for individual spectra. Dryland taxon percentages shown as sillouette graphs while those of aquatic taxa are displayed as line graphs

not direct, and it is difficult to imagine an immediate or significant response of regional disturbances to the spring water feeding Darlot's Creek, the channel, or the ecology of Fred South Swamp.

Charcoal concentrations are generally low throughout the record apart from a marked peak around 13 000 years ago and, except at the base of the sequence, a similar pattern is shown in the charcoal-pollen ratio. Consequently, fire is unlikely to have exerted any major ecological control over changes in the vegetation.

Tyrendarra Swamp

The 330 cm record from Tyrendarra Swamp appears to cover the whole of the period since formation of the lava flow with the three radiocarbon ages near the base of the sequence being in excess of 30 000 years (Figure 6). The oldest date, in excess of 34 000 cal. yr. BP, is clearly too old and could indicate contamination from plant material from the pre-existing plant landscape having been mixed into the lava flow. The longer record from here, in comparison with Fred South Swamp, may relate to the fact that this part of the flow is in close proximity to the Fitzroy River and Darlot's Creek, which could have been permanent water courses. It is also likely that the coring site happened to be in a localized deep depression able to tap a lower water-table. Most of the remainder of Tyrendarra swamp is probably much younger, as probing failed to penetrate more than about 100 cm. Like the Fred South record, there is limited systematic variation in representation of major dryland taxa, with a dominance of Poaceae and relatively constant percentages of *Eucalyptus* and Asteraceae throughout, while the aquatic pollen record displays marked changes. The dominance of Poaceae and relatively low *Eucalyptus* percentages may have been a function of the poorly drained landscape, including much of the present Tyrendarra swamp, for much of the period. Charcoal values are generally low, although peaks in both the concentration and charcoal/pollen ratio are registered in zone TS6.

The basal sediment of the sequence is composed of 'gyttja' or rubbery algal ooze that suggests there was little organic matter other than being produced by algae, presumably because weathering had not yet provided a suitable substrate for colonization of the new landscape by higher plants. This 'desertic' picture is supported by the extremely low pollen concentrations. It is likely that the water was shallow, perhaps restricted to cracks in the basalt-flow depression. The 'pools' were then sequentially colonized by *Myriophyllum*, *M. muelleri*, *Lemna*, *Typha*, *Rumex*, Cyperaceae and *Eleocharis* through zones TS1 and 2. Assuming that the age of around 25 000 yr. BP is correct, this sequence of changes took place well before a similar sequence at Fred South Swamp. It would suggest, in combination with the lack of evidence regionally for major climate change at this time, that it is a true primary aquatic succession. This 'succession' appears to have taken place before any substantial development of vegetation on the basalt landscape as dryland pollen concentrations remain very low through this period.

There are further changes in aquatic vegetation within zones TS5 and TS4 that show both similarities with, and differences from, those at Fred South. Both *Triglochin* and Brassicaceae increase, with the latter maintaining a significant presence through much of the remainder of the diagram. They are accompanied by the floating leaved aquatic *Villarsia* and by the return of *Myriophyllum.* Together Brassicaceae, *Villarsia* and *Myriophyllum* suggest shallow open water that dried periodically. As with Fred South Swamp, there are increases in the decomposition of the peat and in the inorganic component of the sediment within this relatively stable phase of aquatic pollen representation, but as they appear to have been initiated at different times (ie, the beginning of zone FS2 (*c*. 9000 cal. yr BP) and zone TS3 (*c*. 25 000 cal. yr BP))

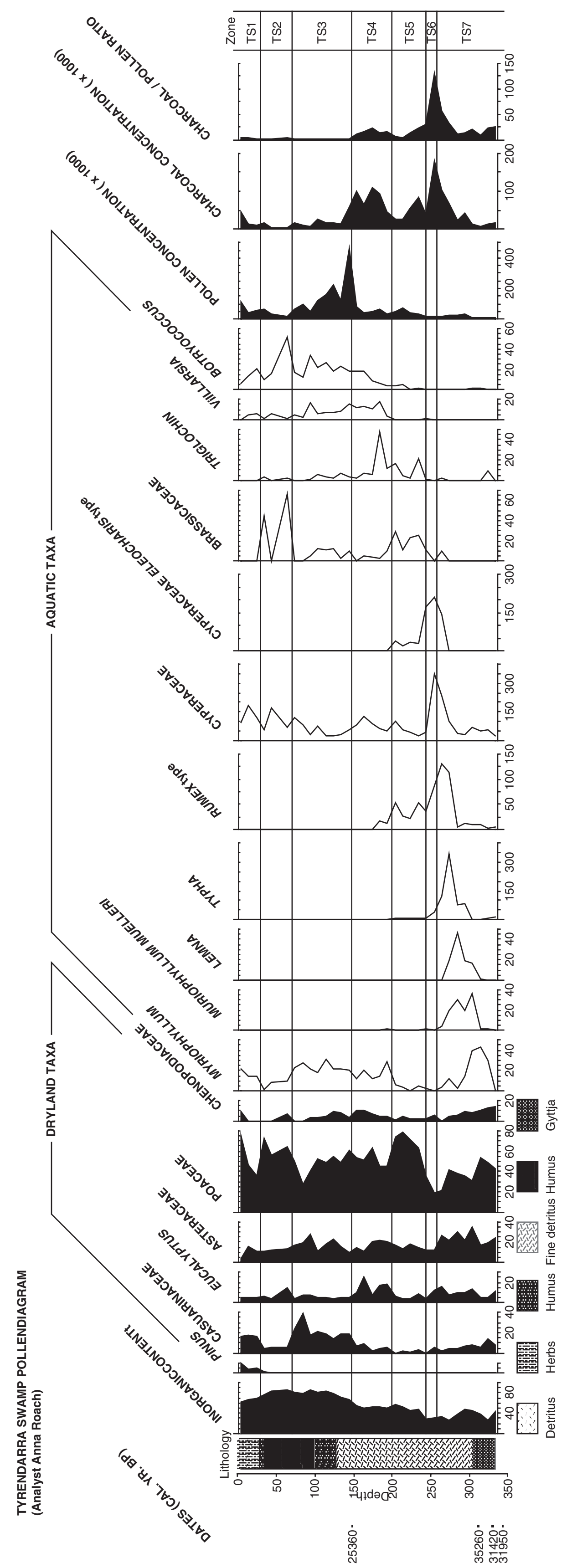

Figure 6 Selected features of the pollen record from Tyrendarra Swamp. Values for taxa are expressed as percentages of the dryland common taxon sum for individual spectra. Dryland taxon percentages shown as sillouette graphs while those of aquatic taxa are displayed as line graphs

they may not have a similar cause. The postulated reason for these changes at Fred South was an increase in water flow within the Holocene but, with a radiocarbon age some 16 000 years older, such a hypothesis is difficult to sustain for Tyrendarra. It could be that sediment accumulated to the level of the permanent water-table resulting in frequent surface drying and, eventually, decomposition of accumulating organic sediments without any increase in water flow. Alternative explanations are that the date of 25 360 ± 370 cal. yr BP is either incorrect and the whole record, from about the base of zone TS3, is Holocene in age or that there is a major hiatus within the record perhaps extending from about 25 000 to about 8000 years ago. There is a substantial peak in pollen concentrations at this point, adding some weight to the proposal of a still-stand in swamp growth.

The dryland pollen record from Tyrendarra Swamp does little to resolve the question of chronology. There is some evidence of partial replacement of Asteraceae by Poaceae at the zone TS2 boundary, which marks the transition between 'glacial' and 'interglacial' environments at Lake Surprise, about 13 000 years ago, supporting a late chronology. However, this is not accompanied by a rise in Casuarinaceae, which occurs much later at Tyrendarra Swamp. Considering the lack of a major response of Casuarinaceae at this time at Fred South Swamp, a signal at Tyrendarra Swamp, more remote from Mt Eccles, would not be expected. It could be that this TS3 Casuarinaceae peak is reflecting the vegetation of the coastal dunes that were widely colonized by the same species of Casuarinaceae, *Allocasuarina verticillata*, from about 8000 years ago (Crowley, 1994). Although there is minimal evidence of a subsequent decline in Casuarinaceae from pollen sites to the west of this region (Head, 1988), it is a feature of a number of records from coastal southeastern Australia, occurring between about 5000 and 4000 years ago (Crowley, 1994). Consequently, this pattern may also support a later chronology for much of the record.

In contrast to other records providing evidence of the European settlement phase, Tyrendarra shows little sign of European impact, even though there is evidence of attempted drainage. The only major change on the swamp is the disappearance of Brassicaceae, a feature in common with Fred South. The re-emergence of Casuarinaceae may result from a relaxation of burning within coastal vegetation.

Human–environment relationships

The timing of the arrival of people in Australia, although debated, occurred at least 45 000 years ago (Roberts and Jones, 2001; Gillespie, 2002; Bowler *et al.,* 2003) and occupation has been continuous throughout most of the continent over at least the last 35 000 years (Cosgrove *et al*., 1990; Lourandos and David, 2002). Consequently, people were likely to have been present in the region at the time of formation of Mt Eccles and the Budj Bim landscape. Support for this assumption is provided by oral accounts by Gunditjmara people of volcanic activity in the study area (Dawson, 1881; Kerley, 1981: 144; Builth, 2002a: 18).

The Eccles lava flow would, through the disruption of the pre-existing drainage, have rapidly created resource-rich aquatic environments around the flow, as evidenced by the early dates on Condah and Whittlebury swamps (Head *et al*., 1989). It is uncertain as to whether eels were part of this resource, as sea levels were much lower than today, providing some inhibition to colonization by elvers from the ocean. The increased width of the continental shelf, some 50 km to the continental slope, would not, in itself, have provided any barrier, as eels today are abundant at sites such as Lake Bolac, presently some 100 km from the coast. In addition, the evidence for swamp environments as well as open water in Lake Surprise and Tyrendarra Swamp suggests that water availability was sufficient to maintain river flow to the sea. However, the steepness of the continental slope during lowest sea levels at the last glacial maximum may have had some impact. There must also be some question over climatic conditions at this time.

The Lake Surprise record suggests that the LGM climate was not homogeneous. The early part, dating from about 26 000 years ago, appears, from the strong peak in eucalypt pollen, to have been relatively wet, while the shift to low eucalypt percentages combined with low organic matter within the sediment and an increase in *Myriophyllum* pollen indicates much lower moisture levels. The peak in pollen concentration above the date of 25 000 cal. yr BP in the Tyrendarra record, that can be interpreted as a period of little swamp growth, may also suggest dry conditions in the latter part of the LGM, although the chronology of this record is of some concern. It is possible, therefore, that swamp environments were restricted during at least part of the LGM but there is no indication that low moisture levels would have inhibited river flow that could have resulted in human abandonment of the landscape.

Although fresh water was clearly present on the lava flow from shortly after the time of its formation, as indicated by basal dates at Tyrendarra, this landscape may have been unsuitable for occupation for many thousands of years. The evidence indicates that, apart from a shallow, brackish Lake Surprise, wetlands were restricted to small ponds that contained only algae and submerged aquatics, with an absence of Aboriginal food plants. Low pollen concentrations suggest that the basalt surfaces were largely devoid of vegetation. Subsequent aquatic succession was marked by a switch from algal ooze to peat incorporating a number of plants, including *Typha*, *Eleocharis* and, eventually, *Triglochin* that could have been exploited. However, there is little evidence of similar developments in dryland vegetation, presumably because of the time taken for liberation of nutrients from the basalt and soil formation, especially under cooler and drier climatic conditions than those of today. In fact, the apparent abundance of aquatic resources is exaggerated as a result of taxa being expressed as percentages against a very low dryland pollen sum. Limitations to dating inhibit clear correlation between Fred South and Tyrendarra Swamps and, consequently, the degree of landscape amelioration for plant growth prior to the Lateglacial, but it is likely that a variety of aquatic resources, although limited in their distribution, were available for exploitation.

Variability, then, characterizes the records during the glacial–Holocene transition, with establishment of widespread freshwater swamp and lake environments on and around the lava flow by at least 13 000–12 000 years ago, and maximum Holocene water levels and/or water flow on the lava flow by about 6000 years ago. Although there is a reduction in pollen of economically useful aquatic plants within the lava-flow records, it is likely that, as is the case at present, they would have flourished within the shallow swamp environments away from the major depressions. The high level of water availability from reliable rainfall, river flow and groundwater, in combination with much closer proximity to the coast as sea levels rose towards present-day levels, would have provided the ideal environment for eels and the harvesting of them.

The change from peat to organic mud at Fred South Swamp, and possibly also at Tyrendarra Swamp, is considered to have been a response to greater water flow, but it is perhaps uncertain whether this would have occurred naturally without enhancement of flow into these depressions by artificial channelling; from spring activity into Fred Swamp and, in the case of Tyrendarra, through channelling flows south through the Tyrendarra swamps from Darlots Creek to the Fitzroy River. It is also possible that eel capture, impoundment and growth would have been facilitated by maintenance of open water that could have been assisted by the extraction of peat which was known to be used for covering the structural framework of the stone-based dwellings (Builth, 2002a: 69–80), or by sediment disturbance. The presence of islands of *Carex* hummocks within Fred South Swamp could represent conscious maintenance of late successional vegetation as platforms from which eels could be speared. Some support for Gunditjmara involvement in the lava flow swamp systems may be provided by the fact that the sediment reverted to peat around the time of commencement of European settlement, possibly a result of the abandonment of Indigenous eel management. A third alternative, that decomposition of the acrotelm or biological active surface layer could result in decomposition of the peat to organic mud in time, is thought unlikely with a peat thickness of some 25–35 cm.

Of greatest interest to an assessment of human–environment relationships is the mid to late Holocene period. Here, there is conflicting evidence between the Lake Surprise and Lake Condah records for the direction of change in moisture availability centred on about 4000 years ago. Although there is no clear signal in the summary pollen diagram presented here, an increase in rates of change was demonstrated in both pollen and diatom components of the Lake Surprise record from an estimated 3750 cal. yr BP, with the diatom plankton record indicating also an overall reduction in lake level (Tibby *et al*., 2006). This pattern of reduced and more variable effective moisture, associated with an increase in burning, is consistent with that from the western plains generally, as already mentioned, but also from much of eastern Australia and in other parts of the globe. The variability component has been attributed predominantly to a well-documented increase in the activity of the El Niño–Southern Oscillation (ENSO) (eg, McGlone *et al*., 1992; Schulmeister and Lees, 1995), a feature that is demonstrated to impact this region (Drosdowsky and Williams, 1991) and considered to have been initiated in the Pacific region about 5000 years ago (Turney and Hobbs, 2006). A recent detailed comparison of reconstructed mid- to late-Holocene ENSO patterns and dates from archaeological sites in Queensland concluded that human activity was closely tied to ENSO activity (Turney and Hobbs, 2006). Tibby *et al*. (2006) considered that, as the rates of change in pollen and diatoms came into phase around 3750 years ago for the first time within the Lake Surprise record, human impact could also have come into the equation. However, because the site is divorced from the eel management system, and it is difficult to conceive of a major human influence on diatoms through changes in water quality within a deep lake, ENSO was the most likely environmental trigger.

A different picture is presented from the Lake Condah record where water depth is considered to have increased around 4600 cal. yr BP and, according to Head (1989), was to double the previous depth. She considered that the cause was a natural change in moisture availability and that only at this time did the water level allow the eel traps on the adjacent lava flow to become operational.

However, a different scenario can be proposed from an examination of the archaeological landscape. Lake Condah shows archaeological evidence of having been modified, resulting in an enhanced capacity to hold water via the damming of its deeper southwest section. The modified section of the lake edge is situated directly adjacent to the lake's well-documented fish trap systems. It is an accepted belief that the functioning of the traps and ponds is directly connected to the lake level, that is, as the lake level rises the adjacent ponds are filled via the channels and the spatially associated traps work to hold back water and fish can be collected then or as the level recedes. Thus, as the lake rises higher, the more distant and elevated trap systems can come into operation (Coutts *et al*., 1978; Head, 1989; van Waarden and Simmons, 1992; van Waarden and Wilson, 1994; Scabe, 2002).

While this is no doubt a natural consequence of rising lake levels, analysis of the hydrological regime and topography suggest a more complex relationship between the lake and the adjacent trapping systems. It is suggested here that the infrastructure functioned as eel collection, growing and trapping systems, but was designed to be fed by local catchment water from the stoney rises to the south and southwest in the first instance. The trapping systems are therefore a buffer and prevent direct run-off into the lake from these directions. There are numerous sink holes to the south and southwest of the lake and it has been observed that during rain events these overflow through channels into the remnant ponds, unlike to the west, north and east where the local catchment feeds directly into the lake. The mature eels eventually need to return to the lake to have access to the migration corridor, Darlots Creek, and this occurs during autumn when the lake first overflows via the cultural channels into the trapping and pond systems. The running water stimulates the mature eels to migrate and they are subsequently trapped during their short journey to the lake and then along the river. Thus, the culturally engineered separation of the ponds from the lake was integral to growing and trapping the shortfin eel here.

The spatial extent of the modified Lake Condah was ultimately controlled by a strategically located cultural weir at the southwestern extreme of the lake. This is where the overflow during autumn and winter used to form the seasonal northern section of the Darlots Creek (Ingram, 1883). Using GIS, the position of this weir has now been demonstrated to control the levels of water in Lake Condah and even Condah Swamp (Gippel *et al*., 2006). It is here suggested that damming of the lake and construction of the associated weir was undertaken about 4600 years ago to guarantee permanent water in the lake despite the onset of more variable climatic conditions. This feasibly dates the present Lake Condah trap systems and the initial construction of an overflow weir to this time.

There is little indication of changes in the records from the Tyrendarra flow in the mid to late Holocene, although the high values in Brassicaceae within zone TS2 may suggest some alteration of swamp conditions. It is quite feasible that the damming of the water bodies along the length of the flow occurred at this time as a technological response to the onset of climatic variability in order to maintain water levels and continuation or enhancement of the established, aquaculture based, socio-economic system.

Conclusions

The formation of Mt Eccles lava flow, about 30 000 years ago, resulted in the development of a diverse, resource-rich landscape that, from at least the end of the last glacial maximum, could be progressively utilised by Indigenous people. The potential for landscape exploitation was facilitated by the range of freshwater sources and associated useful plants and faunal species gradually inhabiting the landform; in particular, the abundance of shortfin eel that could be manipulated by modification of the stoney rise landscape. The creation of a cultural landscape could have been gradual over a long period of time but evidence suggests that it accelerated within the last 5000 to 4000 years.

The most likely reason for this acceleration in the cultural transformation of the landscape was the onset of more variable climatic conditions associated with an intensification in ENSO activity, combined with generally lower rainfall. Consequently, the sophisticated Gunditjmara society that developed from an economic base of eel aquaculture is considered to have been mainly a response to external environmental stimuli rather than being purely socially driven that has been the prevailing paradigm. Production of more refined and better dated palaeoecological records, together with more intensive archaeological and hydrological analysis of the landscape is needed to test this conclusion. This will provide a clearer picture of landscape evolution and exploitation throughout the history of the lava flow.

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