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Cyclic floral succession and fire in a Cenozoic wetland/peatland system

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ABSTRACT

The cyclic succession of brown coals in the Latrobe Valley, Gippsland Basin, Australia, records an exceptional floral and charcoal record from the Late Oligocene to Middle Miocene. New palynological, geological and charcoal data are consistent with existing colourimetry, carbon isotope, and organic geochemical and palaeobotanical data, indicating that the repeated lithotype cycles represent relative drying (terrestrialization). Based on this detailed palynological study, the vegetation succession within the Latrobe Valley peatlands is interpreted to have begun with a fire-prone emergent marsh of bulrushes (Typhaceae), which grades landward into a fire-prone meadow marsh of rushes (Restionaceae), heaths (Ericaceae) and coral-ferns (Gleicheniaceae). This marsh environment then developed into a forested bog, with gymnosperms (e.g. the Podocarpaceae *Dacrycarpus* and *Dacrydium*) as the dominant trees, until an ombrogenous forest bog developed, predominantly consisting of angiosperms (e.g. *Nothofagus*, *Quintinia*).

The similarity between vegetation successions in New Zealand and the lightening-upwards cycles from the Latrobe Valley coals suggests that New Zealand's modern vegetation communities represent a floral analogue for the successions preserved in the Latrobe Valley coals. High abundances of micro and macro charcoal recorded in the darker lithotypes, within the lithotype cycles of the M1B and M2A seams, suggest that the Latrobe Valley peatlands were subject to repeated fires during the Late Oligocene to Early Miocene.

1. Introduction

Repeated floral successions with abundant charcoal are preserved in the lithotype cycles of the Latrobe Valley brown coals. However, the origin of these lithotype cycles remains controversial with studies from different disciplines producing contradictory models termed the dry-dark and dry-light models (Holdgate et al., 2014). The same two contradictory models have also been proposed for the German brown coals. The dry-dark model proposed that dark lithotypes were produced in the driest facies, while light lithotypes were deposited in either very wet or open water environments (Teichmüller, 1958; Teichmüller, 1989; Luly et al., 1980; Kershaw and Sluiter, 1982; Sluiter and Kershaw, 1982; Finotello and Johns, 1986; Blackburn and Sluiter, 1994). In contrast, the dry-light model proposed that light lithotypes were deposited in the driest facies, while dark lithotypes were deposited in the wettest facies (Hagemann and Hollerbach, 1980; Hagemann and Wolf, 1987; Anderson and Mackay, 1990; Holdgate et al., 1995; Holdgate et al., 2014). These lithotypes are arranged in cycles, which are generally attributed to being caused by terrestrialization (drying-upwards cycles) (e.g. Muller et al., 2003; Frank and Bend, 2004).

This paper presents a more detailed depositional model for the Morwell 1B seam of the Latrobe Valley based on new palynological, geological and charcoal data, in conjunction with a re-analysis of pre-existing colourimetry, carbon isotope, geochemical and palaeobotanical (macrofossils and palynology) data. Comparisons are also drawn from studies undertaken on modern vegetation successions in New Zealand, which appear to be similar, in terms of floral composition (at genera level), to the Latrobe Valley floras and successions.

The flora and charcoal records from the Late Oligocene to Early Miocene also provide insights into the fire history of Australia's vegetation (Scott et al., 2000).

2. Geological setting

The Gippsland Basin, in south-eastern Australia, records a sedimentary record from the Cretaceous to Recent and is unique with regard to the scale and size of its contained brown coal and petroleum energy resources (Smith, 1982). The Cenozoic onshore segment of the basin is dominated by terrestrial sediments of the Latrobe Valley Group (Figs. 1,2). The main coal-bearing sequences in the Latrobe Valley Group, of the onshore Gippsland Basin are, in stratigraphic order, the Traralgon

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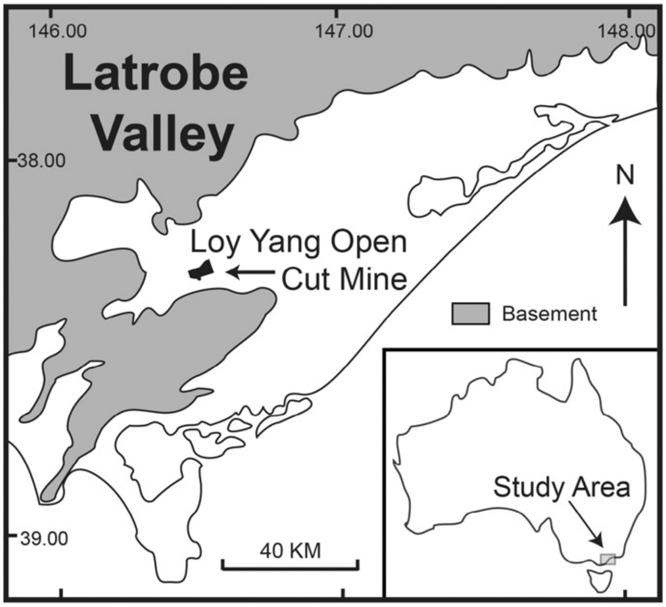

Fig. 1. Location of the Gippsland Basin and Latrobe Valley.
Modified from Holdgate et al. (2014).

Formation, the Morwell Formation and the Yallourn Formation. The Morwell Formation, the focus of this paper, is divided into two major coal seams – the Morwell 1 (M1) and Morwell 2 (M2) seams, which in the eastern half of the Latrobe Valley Depression are further subdivided into the M1A, M1B, M2A, M2B and M2C seams. The coal-bearing Latrobe Valley Depression hosts several coal seams >100 m thick, constituting in total, the thickest brown coal succession in the world (Holdgate, 2003).

3. Lithotypes in the Latrobe Valley and lithotype models

Lithotypes in the Latrobe Valley brown coals are defined on dry coal surfaces by colour, texture, gelification and weathering (George and Mackay, 1991). Lithotypes become more defined on older and more weathered surfaces. Darker lithotypes in outcrop are characterized by high degrees of gelification, intense cracking and recessive weathering, relative to lighter lithotypes. Lighter lithotypes are characterized by resistant weathering, producing prominent beds with little or no cracking. George and Mackay (1991) defined 5 lithotypes: dark, medium dark, medium light, light and pale. Holdgate et al. (1995) defined a sixth lithotype, the laminated dark, characterized by the darkest colour and prominent lamination.

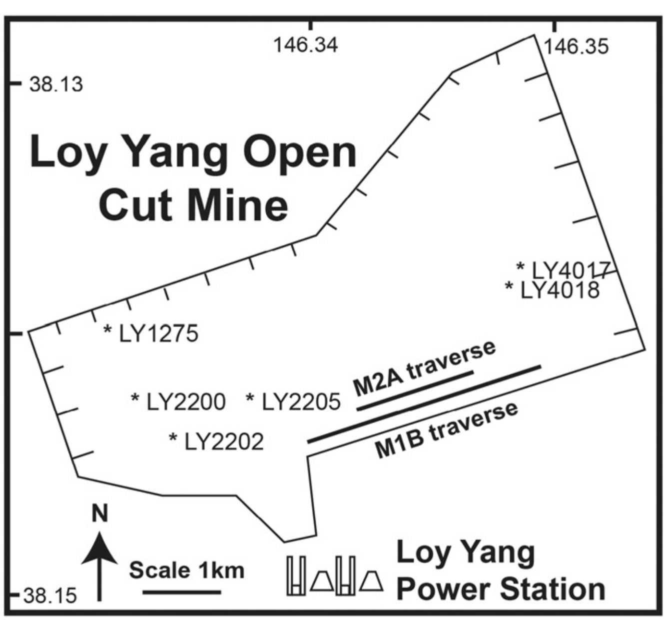

Fig. 2. Map of Loy Yang Open Cut Mine and the location of the M1B and M2A stratigraphic sections and bores (prefix LY).
Modified from Holdgate et al. (2014)

Lithotypes occur as a series of cycles, the cycles ranging from 10 to 30 m in thickness and characterized by lightening-upward trends with prominent banding at a 1–3 m scale (Mackay et al., 1985; Holdgate et al., 2014). Cycle tops are commonly characterised by abrupt and unconformable boundaries with the overlying cycle (Mackay et al., 1985; Holdgate et al., 2014).

Various models have been proposed to explain the formation of the lithotype cycles. Based on the soft (brown) coals of West Germany, Teichmüller (1958) first suggested a series of palaeoenvironments ranging from open water to dry forest, in a regular hydroseral series. Based on Teichmüller's (1958) model, Luly et al. (1980) proposed that the lithotypes in the brown coals of the Latrobe Valley ranged from open water (represented by the light lithotype), to increasingly drier swamp substrates (the darker lithotypes). Likewise, Kershaw et al. (1991) proposed that the darker lithotypes were deposited under the driest, most terrestrial conditions, and that the lighter lithotypes were formed in open water conditions. This model of darkening-up cycles is at odds with the observed lightening-upwards cycles first statistically documented by Mackay et al. (1985).

Anderson and Mackay (1990) later contradicted these models and instead proposed that the dark lithotypes represented the wettest facies while the light lithotypes represented the driest. Anderson and Mackay (1990) suggested that the formation of the lithotypes took place in a series of ombrogenous peat bogs. These authors further suggested that peat dome development controlled the nature and extent of degradation and hence the nature of the lithotypes within the dome. Lighter lithotypes are suggested to form in the more oxic and drier (dry-light model), upper portions of the peat dome, while darker lithotypes form in the lower more anoxic, wetter facies (Anderson and Mackay, 1990). Holdgate et al. (2014) proposed a dry-light model with the lightening-upwards cycles representing relative drying (terrestrialization) upward for the Oligocene-Miocene brown coals in the Latrobe Valley. Holdgate et al. (2014) also integrated geological, geochemical and palynological data in order to interpret the major floral/ecological characteristics of the coal facies. More recently, Holdgate et al. (in press) have also applied this model to the German brown coals. In the Latrobe Valley, the cycles begin with a laminated dark or dark coal, the base of which can have high organic sulphur contents suggesting a marine-influence (Holdgate et al., 1995; Holdgate et al., 2014).

4. Methods

Stratigraphic sections from the M1B and the M2A seams were measured on the southeastern face of Loy Yang Open Cut (Fig. 2). Coal samples were collected at 25 cm intervals based on the stratigraphic heights measured using a Jacob's staff. These samples were dried at 40 °C for 3 days and crushed to a grain size of 0.5–1 mm before quantitative colourimetry was performed using a Konica Minolta Chromameter CR-410 chromameter with the Hunter L, a, b colour scale. The three colour outputs – L (lightness), a (red) and b (yellow) were combined to produce a colour index using the formula as stated in Holdgate et al. (2014):

$$\text{Colour index} = 10(L' + a' + b') + 100, \text{ where } L' = (L-16.966)/2.050,\ a' = (a-2.534)/0.604 \text{ and } b' = (b-4.421)/1.304.$$