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Constraints on carbon accumulation rate and net primary production in the Lopingian (Late Permian) tropical peatland in SW China

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ABSTRACT

During the Permian, peatland, as represented in extensive coal deposits, was a major component of the global carbon cycle. Carbon storage in peatland is a balance between decay and net primary production (NPP), which in turn are sensitive to variations in the concentration of atmospheric CO_2 and O_2. To evaluate peatland carbon storage and NPP during the Lopingian, a period thought to be characterised by higher atmospheric O_2 and CO_2 than modern levels, spectral analyses of geophysical data from a 15.1 m thick Lopingian (Upper Permian) coal in southwestern China were conducted to define the time frame of temporal carbon accumulation in tropical peatland. The result shows that the mineral matter content (ash yield) of the coal was possibly influenced by 123 ka (eccentricity), 35.6 ka (obliquity) and 21.2 ka (precession) Milankovitch periodicities. Using this timeframe and an understanding of carbon loss during coalification, the Lopingian tropical peatland carbon accumulation rate is calculated to be 61.1–73.0 g C/m^2/yr which is expected to correspond to a NPP of 611–1460 g C/m^2/yr respectively. A comparison between the predicted Pennsylvanian (Late Carboniferous) NPP and modern values indicates that the Permian NPP calculated is consistent with geochemical and paleobotanical models, supporting a proposal that productivity was mainly controlled by temporal atmospheric O_2 and CO_2 levels.

1. Introduction

With the exception of the Early Triassic 'coal gap' (Retallack et al., 1996), peat deposits and peatland ecosystems have been important components of the global carbon cycle since the Late Devonian (Greb et al., 2006; Han and Yang, 1980); during this interval peat has accumulated under a wide range of atmospheric compositions (Berner, 2006). Differences in atmospheric chemistry, in particular the concentration of O_2 and CO_2 are predicted to influence the rate at which peatland accumulates carbon and will, in turn, influence the significance of the peatland carbon reservoir in the global carbon cycle (Beerling and Woodward, 2001). As we move towards a warmer, CO_2 rich state of the Earth's climate, understanding the response of peatland to a wide range of atmospheric conditions becomes ever more important, and it is the aim of this paper to evaluate the carbon accumulation pattern and its controls in the Lopingian tropical peatland developed under markedly different atmosphere, which contained ca. 25% O_2 and 0.1% CO_2 according to recent model outputs (Berner, 2006, 2009).

Although efforts have been made to understand carbon accumulation rates in Cenozoic lignite and coal deposits (e.g. Large, 2007; Large et al., 2003, 2004), carbon accumulation in pre-Cenozoic peatland has not been well investigated because estimates of carbon accumulation rates require a method of constraining time. In conjunction with associated uncertainties, methods like radiogenic dating may lack the precision required to constrain time in even relatively thick coal seams (Allègre, 2008); alternative methods are required. If the coal is sufficiently thick, one feasible way to tackle this problem is to identify Milankovitch cycles in geochemical or geophysical data (Schwarzacher, 1993; Weedon, 2003), and this has been applied to Cenozoic coal and lignite (Briggs et al., 2007; Large, 2007; Large et al., 2003; 2004). An additional and complementary approach to the application of orbital cycles is to use the Holocene peat record to estimate reasonable upper and lower limits of peat accumulation rate to help further define the likely range of carbon accumulation rates (Large, 2007). However, this method assumes a degree of uniformitarianism and requires understanding of carbon loss during coalification. Although these approaches have distinct drawbacks, in combination they have the potential to provide reasonable constraints that can be considered in the context of expected trends in productivity and decay. Ultimately they are one of the few, perhaps the only means to evaluate this type of information prior to the Cenozoic.

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In this paper, spectral analysis has been conducted on the geophysical logs from a thick Lopingian coal seam in southwestern China. The results are used in conjunction with an understanding of peat accumulation and coalification to constrain temporal equatorial carbon accumulation rates as well as the local productivity. These results are then considered in the context of the Lopingian atmospheric chemistry.

2. Geological settings

The geology of southwestern China provides an excellent opportunity to investigate the terrestrial ecosystem of the Late Paleozoic to Early Mesozoic (e.g. Peng and Shi, 2009; Yin et al., 2007; Yu et al., 2007), thanks to its well preserved stratigraphic record, especially the abundant coal resources, which are the unique coal records from the Lopingian tropics (e.g. Cleal and Thomas, 2005; Li and Wu, 1996).

For the purpose of this research, samples were obtained from one thick and locally wide spread Lopingian coal seam in Nuodong, Pu'an County in western Guizhou Province (Fig. 1A), which was located in an intra-cratonic basin within the Late Paleozoic South China Plate (Liu et al., 1993). With a palaeolatitude of 2.6°–4.5°S (Wang and Li, 1998; Fig. 1B) the area probably had a warm and wet tropical climate in the Lopingian (Fluteau et al., 2001; Li and Wu, 1996). The Middle–Upper Permian coal succession consists of the Emeishan Basalt Formation (Sun et al., 2010), the terrestrial Xuanwei Formation, and the Longtan and Changxing Formation formed in paralic settings (Shao et al., 1998). During coal deposition, this region experienced a regional transgression, which occurred at the end of the Wuchiapingian and persisted into the Triassic (Shao et al., 1999; Shen and Shao, 1995; Wang et al., 2011).

The specific coal investigated is the 15.1 m thick Nuodong 17# coal seam (Nuodong coal for short). This coal occurs in the upper member of the Longtan Formation (Fig. 2), which is dominated by fine

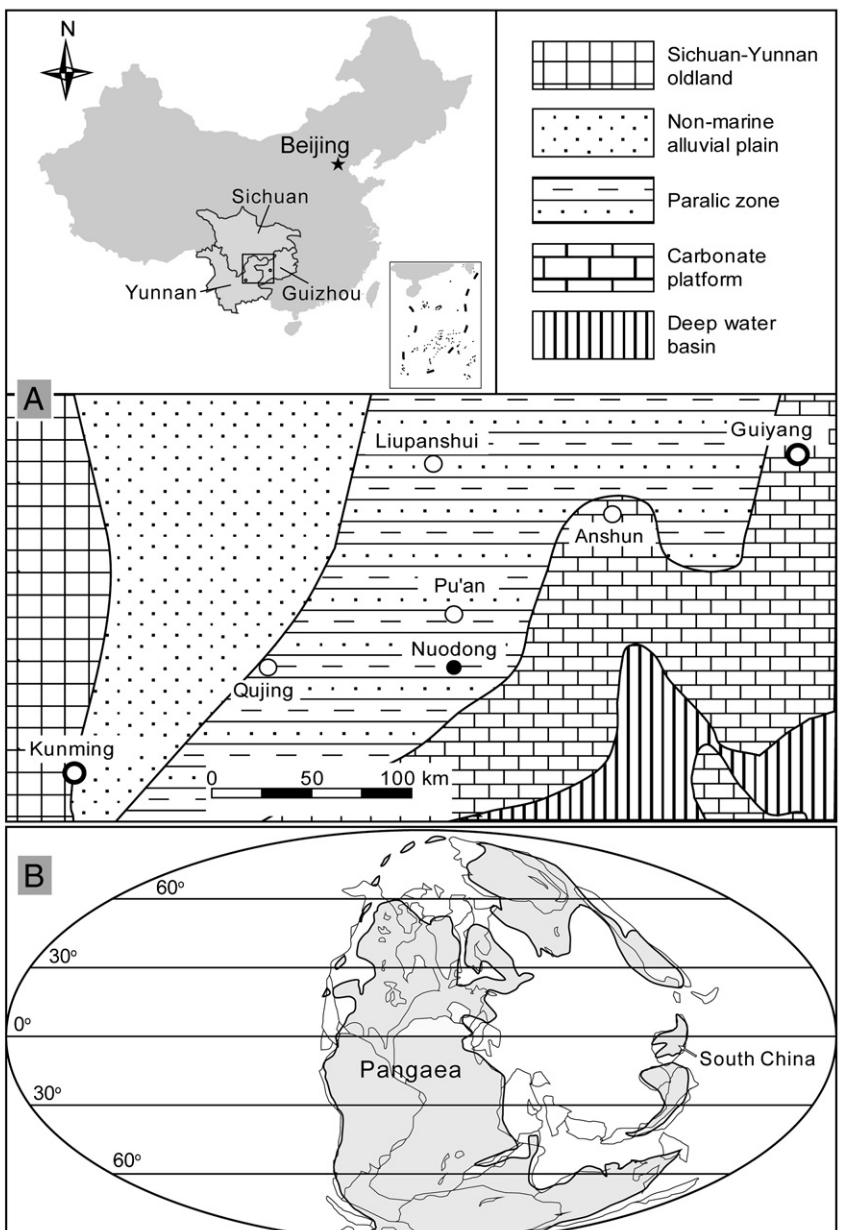

Fig. 1. A) Location of the study area in western Guizhou and eastern Yunnan, China, and its palaeogeographical outline in the Lopingian (Late Permian) (modified from Shao et al., 1999; Wang et al., 2011). Filled circle designates the studied section, bold open circles are provincial capitals and normal open circles are county centers; B) Palaeogeographical reconstruction of the Lopingian and the location of South China Plate (modified from Ziegler et al., 1997).