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TECTONICS, TROPICAL FOREST DESTRUCTION AND GLOBAL WARMING IN THE LATE PALAEOZOIC

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ABSTRACT. The Late Palaeozoic tropical wetland forests of Europe and North America largely disappeared in the early Stephanian, coinciding with a phase of Variscan tectonic activity. This removal of a major carbon sink seems to have coincided with the onset of global climatic warming, recognisable in both northern and southern high latitudes.

KEY WORDS: Carboniferous, coal forests, tectonics, climate change, atmospheric CO_2

INTRODUCTION

During the Carboniferous Period, wetland forests extended over large parts of the tropics. Arborescent lycophytes typically dominated these forests (Phillips & DiMichele 1992) and their remains produced major coalfields. In China, these coal forests survived until the end of the Permian (Li *et al.* 1995) eventually succumbing to the global Permian-Triassic extinction event. However, the western coal forests of Europe and North America disappeared earlier; the youngest lycophyte-dominated coals here being earliest Stephanian (Cleal 1997, Wagner & Lyons 1997).

Climate change has been evoked to explain the disruption to the western coal forests because the changes occurred more or less synchronously over an extensive area (Phillips & Peppers 1984). In this model, the approximate symmetry of land north and south of the equator, resulting from the assembly of the Pangea supercontinent, caused a monsoonal circulation to develop. This shifted rainfall away from the tropics, making conditions unsuitable for supporting lycophyte-dominated forests (DiMichele *et al.* 1985). However, most of the component plates of Pangea were already assembled by the Namurian (Scotese & McKerrow 1990) when the wetlands were only just starting to develop.

To overcome this anomaly, it has been suggested that tectonic activity caused the growth of Himalayan-scale mountains in the tropical belt and that these delayed the onset of the monsoonal system until the very late Carboniferous (Phillips & Peppers 1984). There is, however, little evidence of mountains of this scale during the early Westphalian; most major Late Carbonferous tectonic activity having been very late Westphalian and early Stephanian in age. In our view, tectonics is a major factor in explaining the fate of the western coal forests, but in a different way to these previous models (see Fig. 1).

VARISCAN TECTONICS AND THE COAL FORESTS

Variscan tectonics were the result of the collision of the Euramerica and Gondwana continental plates along a line through North America and Europe. There were several phases of tectonic movement from the middle Westphalian to the late Stephanian, but the most significant one resulted in the uplift of the main area of coal formation (the Variscan Foreland), which changed into an area of net erosion. The youngest European coals of the Variscan Foreland are earliest Cantabrian (e.g., Cleal 1997) and obviously must post-date the tectonic movement. This tectonic movement was also responsible for the rifting of the mainly Precambrian basement of the French Massif Central, which resulted in the formation of numerous intra-montane coal basins (Vetter 1986) whose oldest deposits are Late Cantabrian (Bouroz *et al.* 1970). The tectonic activity must, therefore, have been sometime between the very early and late Cantabrian.

Until recently, the situation in North America was thought to be different, with coal formation continuing through the Late Pennsylvanian (roughly equivalent to the Stephanian). However, Wagner & Lyons (1997) have demonstrated a significant non-sequence between the Middle and Upper Pennsylvanian in North America and

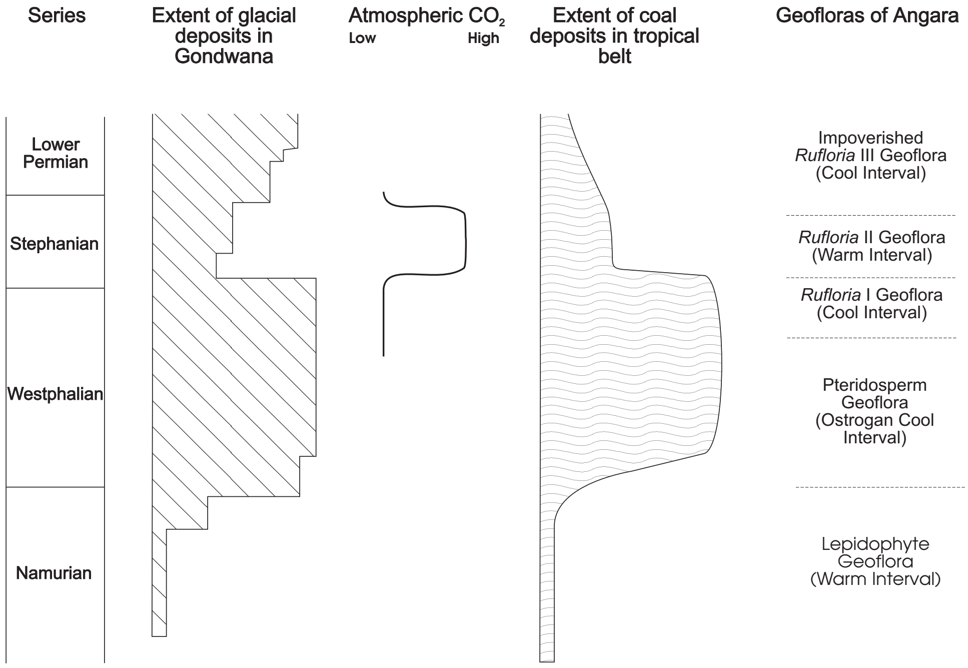

Fig. 1. Proposed correlation of the extent of polar ice, atmospheric CO_2 levels, coal deposits and Angaran geofloras in the Late Carboniferous and Early Permian. Ice distribution is based on Frakes *et al.* (1992). Atmospheric CO_2 levels and the area of coal deposits in the palaeoequatorial belt is based on Cleal *et al.* (1999). The stratigraphical distribution of the Angaran geofloras is based on Meyen (1982) and Durante (1995)

that, as in the European part of the Variscan foreland, most of the Stephanian is absent.

The uplift of the Variscan Foreland caused the lowland swamps that covered most of the area to be drained. The arborescent lycophytes, which dominated these swamps, were highly adapted to the water-logged substrates (Phillips & DiMichele 1992). The uplift and draining of the Variscan Foreland therefore caused the coal forests to be wiped-out here. They were replaced by mesophytic vegetation dominated by smaller and/or slower growing plants such as conifers, cycads and peltasperms (DiMichele & Aronson 1992). These newer forests would have been far less productive in both vegetational growth and peat formation.

The Upper Pennsylvanian coals of the Appalachians represent a temporary return of the coal forests in the late Stephanian C and Autunian. However, these forests were fundamentally different, ferns and medullosalean pteridosperms being the dominant plants (Phillips & Peppers 1984). These later forests were also relatively short lived and disappeared early in the Permian. No similar coal forests occurred at this time in the European part of the Variscan foreland, although there were small patches of forest throughout the Stephanian in intra-montane basins (e.g. Vetter 1986).

Invoking tectonics as the underlying mechanism for the early Stephanian changes in the tropical vegetation explains why the eastern coal forests did not also disappear. As China was not part of the Variscan belt, it was not subjected to the same tectonically-driven geomorphological changes as occurred in the west. Wetland habitats continued with minimal disruption and thus the lycophyte-dominated forests could survive here.

CONSEQUENCES OF THE DISAPPEARANCE OF THE COAL FORESTS

The coal forests must have represented a significant sink in the Late Carbonferous carbon budget. Our preliminary calculations suggest that, at their height, the European and North American forests alone would have been responsible for a carbon drawdown of 13–16 megatonnes per annum. Changing the nature of the tropical lowland vegetation in Europe and North America from highly productive lycophyte-dominated forests to mesophytic forests of much lower productivity must have had a significant impact on the global carbon cycle. The most immediate impact would have been a rise in atmospheric CO_2 of *c.* 50–60 megatonnes per annum. Although this may seem small compared with the total atmospheric CO_2 content (730,000 megatonnes assuming Carboniferous levels were approximately similar to today's – Berner 1993), if the increase continued for tens of thousands of years, the impact on the atmosphere would have been significant. Some of this CO_2 would have been absorbed by the oceans and the increased higher latitude vegetation, such as the *Nothorhacopteris-Botrychiopsis-Ginkgophyllum* flora of Gondwana (Wagner *et al.* 1985). Nevertheless, a net increase in atmospheric CO_2 would be expected and this seems to be borne out by a reported fall in stomatal densities in the early Stephanian (Cleal *et al.* 1999). It also coincides with evidence of marked global warming during the Stephanian, such as the Tupe Formation interglacial of Argentina (González 1990), and the Alykaevo Climatic Optimum in Angara (Meyen 1982, Durante 1995).

It thus seems that climate change did not cause the range of the coal forests to fluctuate, but rather that the dynamics of the forest caused the climate change. The inception of the Gondwana ice-cap coincided with the development of the coal forests, the Stephanian interglacial occurred when the forests contracted due to Variscan tectonics, and the ice-cap returned with the temporary resurgence of the forests. Unlike the earlier proposed models, this provides a mechanism (tectonics) for explaining all of the observed geological data.

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