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Fossil Focus: Coal Swamps

by Ben Slater*[1]

Introduction:

Coal swamps are the classical terrestrial (land-based) ecosystems of the Carboniferous and Permian periods. They are forests that grew during the Palaeozoic Era (encompassing the Carboniferous and Permian) in which the volume of plant biomass dying and being deposited in the ground was greater than the volume of clastic (grains of pre-existing rock) material, resulting in a build-up of peat. This was subsequently buried, and eventually turned into coal over geological time. These swamps gave rise to most of the major, industrial-grade coal reserves that are mined today. The palaeontology of these coal-forming ecosystems is well known from the Carboniferous rocks of Euramerica (modern day Europe and North America), owing to the history of coal exploitation in these regions. However, extensive swamp areas that produced thick coal reserves have also formed at other times in the Earth's history, most notably in the Permian. During the Early Permian, the coal swamps of Euramerica continued to flourish in Cathaysia (the tectonic blocks that formed modern day China), and throughout the Permian, coal swamps dominated by seed plants called glossopterids were found on the Southern Hemisphere supercontinent Gondwana (formed from modern day India, Australia, Antarctica, Africa, Madagascar and South America). The coal swamps of the Carboniferous (Fig. 1) and Early Permian formed primarily in tropical regions, whereas the Gondwanan coal swamps of the later Permian formed in higher-latitude temperate regions. Coal forests developed primarily in lowland areas such as river deltas, but there is a bias in the plant fossil record because fossilization is most likely to occur in these waterlogged habitats, meaning that fossils of drier, upland plant communities are much less common, so little is known of the plants that grew there.

Figure 1 - Reconstruction of a Carboniferous coal swamp with stands of Lepidodendron and Calamites on a lake margin (John Watson © The Open University).

Formation of coal:

Coal is currently the foremost source of electricity in the world, and one of the largest sources of anthropogenic carbon dioxide. It is formed largely through the accumulation of dead plant matter, which builds up in layers of peat. If the peat accumulates in anoxic conditions (that is, in places in which it is not exposed to oxygen) such as at the base of a lake or swamp, or if a forest is flooded by rising seas, the carbon-rich plant material does not biodegrade. This peat is then buried by sediments deposited on top of it, and is subject to increasing pressure and temperature. Eventually, the peats are lithified, or compacted into solid rock, and form coal.

Coal balls:

Much of the information that we have on coal-swamp plants comes from the detailed investigation of coal balls: plant matter that has been turned into fossils through permineralization, a process in which minerals, in this case calcium carbonate, seep into organic matter and form an internal cast of it. Coal balls often form in acidic peats, or when seawater permeates the compressed plant matter. The carbonate forms a hardened ball that resists compression throughout burial, thereby preserving the plant remains in exceptional detail; even cellular details can be retained. Such structures can be studied using a range of techniques. One of the most successful is the production of acetate peels, which involves cutting the coal ball using a high-powered saw, then dipping the cut surface in a bath of hydrofluoric acid to dissolve the silica and carbonate surrounding the fossil, leaving the organic remains standing just proud of the cut surface. Acetone is poured onto this surface and a sheet of acetate is laid on it, then peeled away. This reveals a cross-section through the coal ball that shows the exceptional detail within (Fig. 2), which can be observed under a microscope.

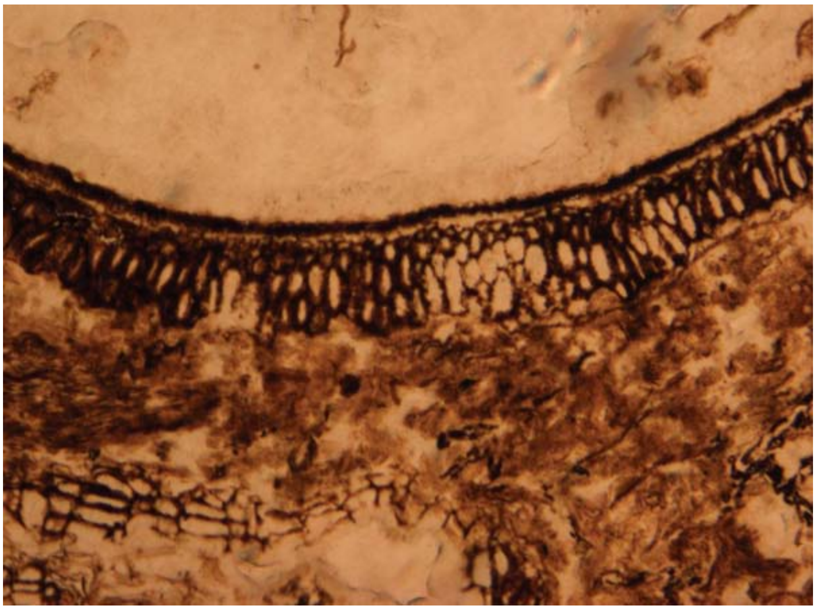

Figure 2 - Microscope image of plant material seen in an acetate peel. Part of a seed wall is visible.

Plants of the coal swamps:

Lepidodendron

The name ***Lepidodendron*** was originally assigned to scaly trunk fossils found commonly in Carboniferous coal measures (Fig. 3b), but it now refers to the whole plant, which has been reconstructed as an enormous tree-sized organism. ***Lepidodendron*** dominated the Carboniferous coal swamps, and is thought to have reached heights of 40 metres. It is not closely related to the trees of today; instead, ***Lepidodendron*** is a lycopsid, more closely related to modern club mosses and quillworts. The thick trunk formed a pole, which had no branches, apart from the crown at the very top of the mature plant. The scale-like pattern on the trunk was produced by leaf scars (cushions where leaflets fell away). It was probably green in life because, unlike in modern trees, the trunk was composed of photosynthesizing tissues. The branches at the crown of the mature ***Lepidodendron*** terminated in reproductive structures that look similar to cones (Fig. 3a). Reproduction was via spores as in modern lycopsids, rather than seeds as in most modern plants. It has been deduced from comparisons with modern lycopsids that many species of ***Lepidodendron*** reproduced only once, at the end of their lives. It has also been estimated that the plant may have grown to its full height in just 10–15 years. ***Lepidodendron*** grew in dense stands, as we know from assemblages of fossilized stumps, but the canopies of these forests would have been much more open than those of modern rainforests. Because ***Lepidodendron*** only branched to form a crown when mature, many of the tree-like plants in a forest would have been juvenile poles blocking out only a small amount of light.

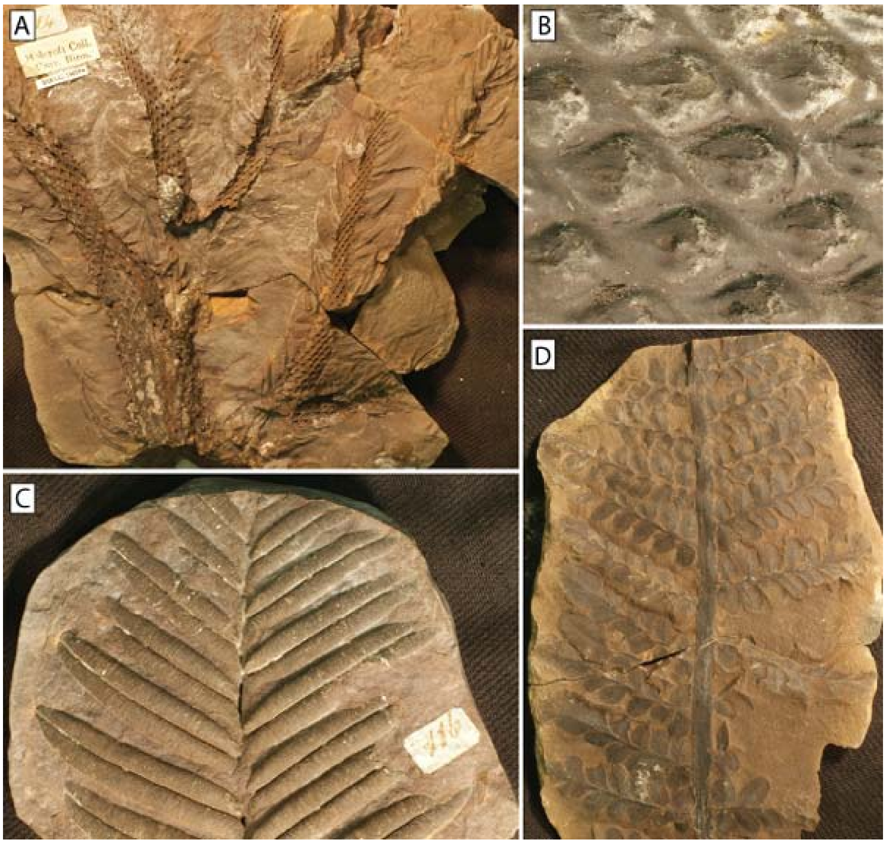

Figure 3 - a, Parts of Lepidodendron crown. b, Leaf cushions on stem of Lepidodendron. c, d, Fern-like fronds of Carboniferous age (images taken by Andrew Storey).

The roots of ***Lepidodendron*** are common fossils in their own right, and are given the name ***Stigmaria***.

<u>Calamites</u>

Calamites are commonly found stem fossils of the coal measures (Fig. 4a,b). These stems are ridged with divided segments, some reaching 60 centimetres across, and wide enough to suggest that in life the plants might have reached up to 20 m in height. The plants that formed these stems are close relatives of modern horsetails. The leaves were arranged in circular whorls and the plants grew in the wettest areas of the coal swamp, around lakes and river margins.

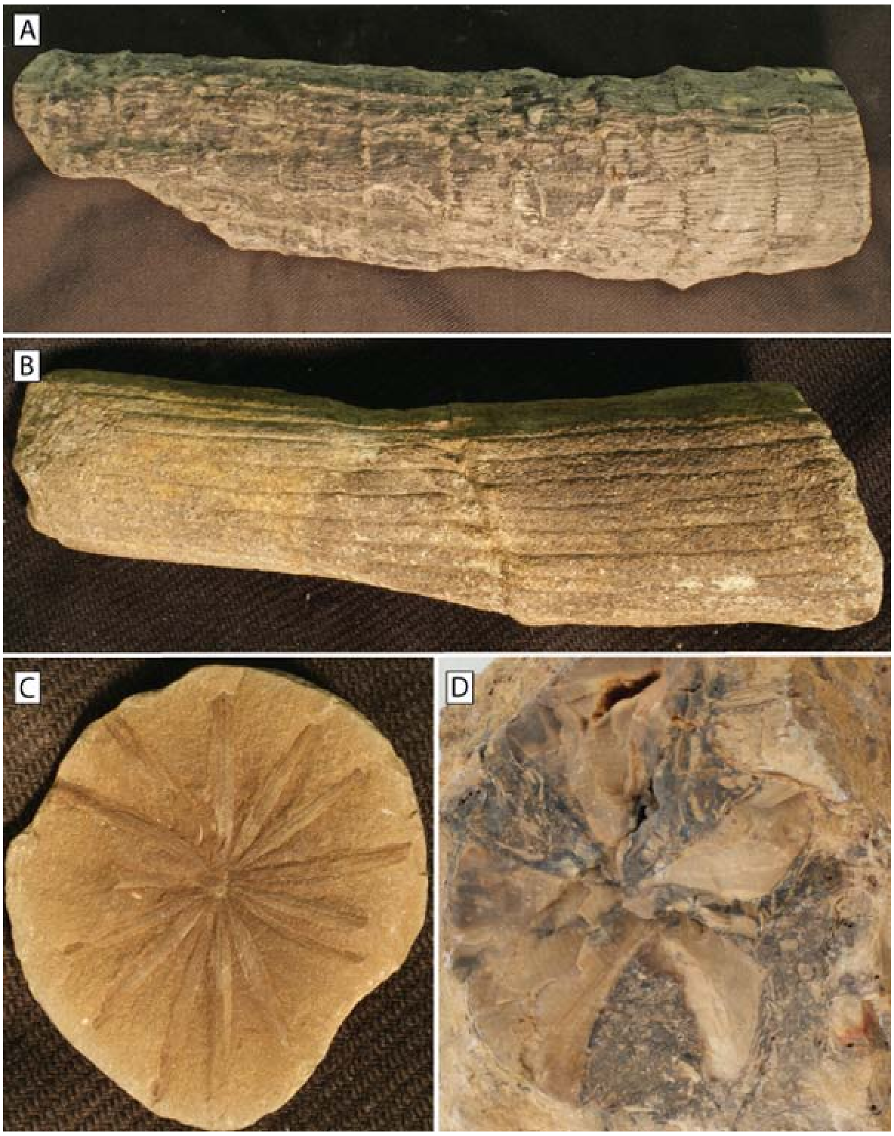

Figure 4 - - a, b, Examples of Calamites stem cast fossils. c, Annularia leaf whorl. d, Cross section through chambered Vertebraria root of Permian age (images taken by Andrew Storey).

Sphenopsids

The sphenopsids are similar in appearance to ***Calamites***, to which they are closely related, but are thought to have been much smaller plants with a range of heights. Some were vine-like scramblers. The leaves grew on the stems in whorls, termed ***Annularia*** (Fig. 4c).

Ferns

Ferns were a common component of coal-forming ecosystems from the Carboniferous and Permian periods, just as in many environments today. They vary from small shrub-sized plants to large tree-ferns. Tree-sized ferns of the order Marattiales are common fossils of the British Carboniferous Coal Measures, occurring in coal balls and as flattened adpression fossils (formed of both a compression and an impression).

Pteridosperms

This diverse group of plants is known informally as the 'seed-ferns' because their leaf fronds superficially resemble those of true ferns, but unlike true ferns the pteridosperms reproduced via large seeds at the base of their leaves. The group is now thought to be paraphyletic, meaning that it includes several groups of plants that are only distantly related to each other. Plants termed pteridosperms were common in both Carboniferous and Permian wetland ecosystems.

Glossopterids

The glossopterids dominated the higher-latitude coal swamps of the Southern Hemisphere during the Middle and Late Permian. The name of the group comes from the common leaf fossil ***Glossopteris***, a name that is now used for the entire reconstructed plant. ***Glossopteris*** was tree-sized and bore large tongue-shaped leaves, which were possibly shed during the autumn at higher latitudes. The roots of ***Glossopteris*** are known as ***Vertebraria*** (Fig. 4d), named because they look like backbones when viewed lengthways. The ***Vertebraria*** roots were filled with air chambers, which may have been an adaptation to the boggy, waterlogged soils in which they grew. Large quantities of ***Glossopteris*** fossils were found among the remains of Captain Robert Falcon Scott and his four companions after the British Terra Nova Expedition to Antarctica (1910–13), which ended in disaster, with the death of all members of the expedition. The distribution of ***Glossopteris*** across the now dispersed southern continents (Fig. 5) was cited as early evidence in support of the theory of continental drift proposed by Alfred Wegener (1880–1930).

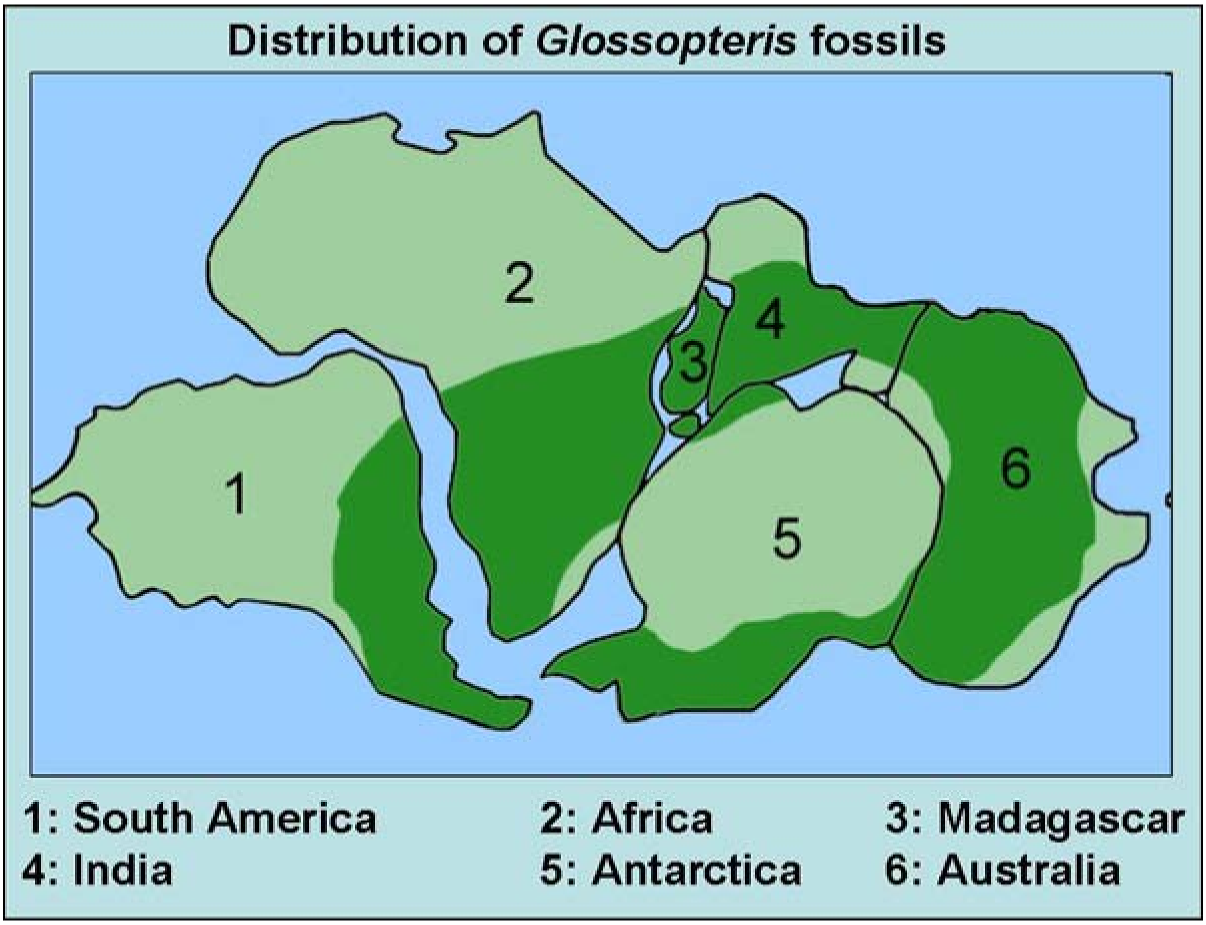

Figure 5 - Distribution of Glossopteris fossils across the southern continents.

Animals of the coal swamps:

The rich habitats provided by the coal swamps were home to a diverse array of animal life, chiefly invertebrate arthropods. Arachnids such as scorpions and trigonotarbids (Fig. 6a) were among the dominant predators of the Carboniferous forests. Trigonotarbids are extinct arachnids similar to modern spiders, but lacking the ability to spin silk webs. Myriapods (centipedes, millipedes and two smaller groups) were also present in these coal-forming terrestrial ecosystems. Millipedes (Fig. 6b) were among the first animals to have colonized the terrestrial environment, and were abundant as detritivores (feeding on decomposing organic matter) in Carboniferous forests. Some Carboniferous and Early Permian millipedes grew very large; one genus, ***Arthropleura***, reached lengths of up to 3 m.

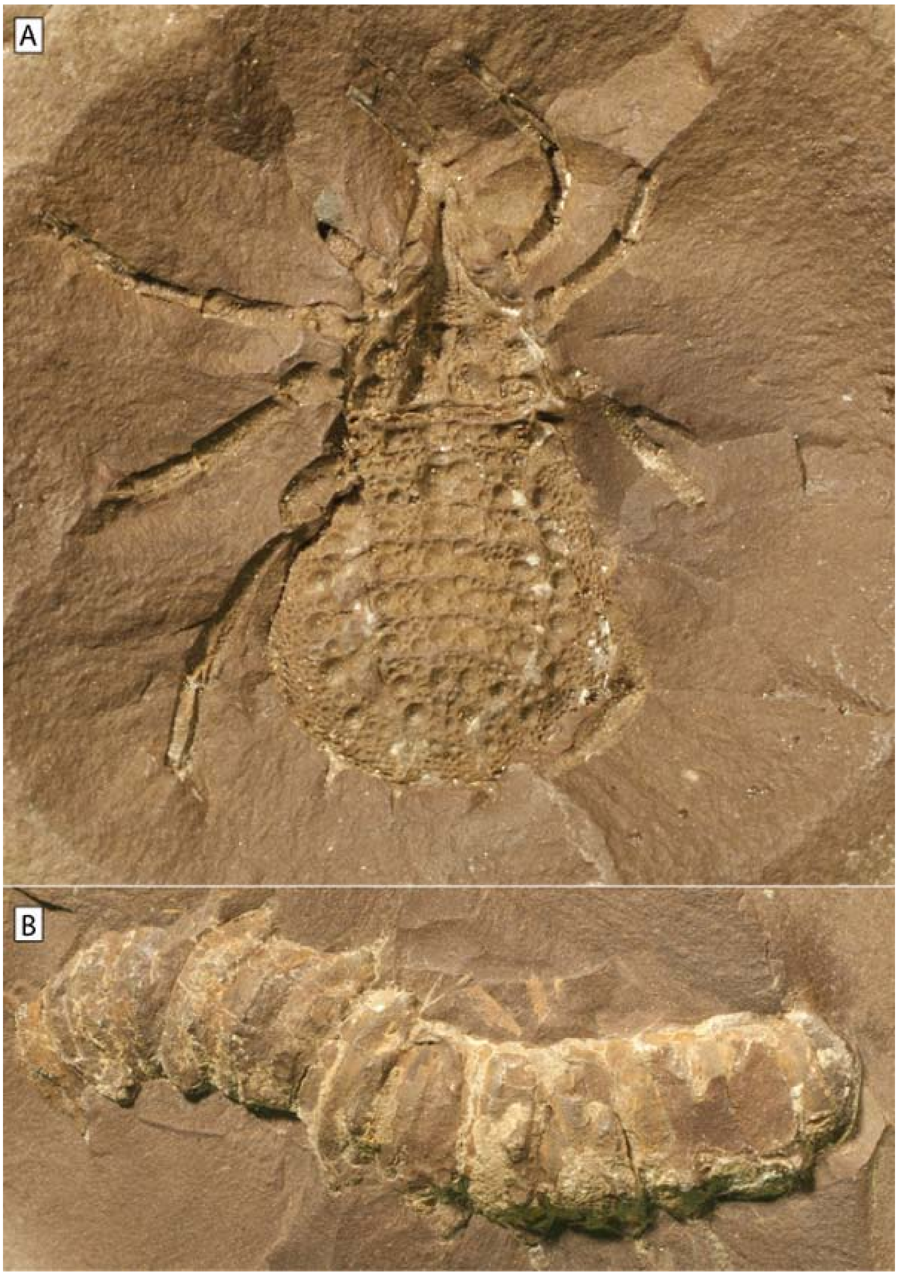

Figure 6 - a, Trigonotarbid arthropod from a Carboniferous coal ball. b, Millipede from a Carboniferous coal ball.

Other giants of the Palaeozoic coal swamps included the relatives of modern dragonflies, from the genus ***Meganeura*** (Fig. 7) in the Carboniferous and ***Meganeuropsis*** in the Permian, which attained wingspans of up to 75 cm. These would have been top predators, certainly in the air during maturity and probably in the water during their nymph stage. Other arthropods found commonly in the coal-forest ecosystems are early relatives of cockroaches and mites. Vertebrates that lived in the Carboniferous forests included early relatives of the amphibians and the first reptiles. Fossil remains of some of the oldest true amniotic (egg-laying) reptiles, such as ***Hylonomus lyelli***, are found inside the hollowed stumps of large plants of the Pennsylvanian (Upper Carboniferous) coal deposits of Joggins in Nova Scotia, Canada. It has been suggested that the reptiles either lived inside these broken stumps or sheltered there from forest fires, given that some of the remains are rich in charcoal. Alongside the terrestrial creatures, many aquatic animals lived in the lakes, pools and waterways of the coal swamps. These included crustaceans, bivalves, horseshoe crabs adapted to live in fresh or brackish waters, and fish including freshwater sharks.

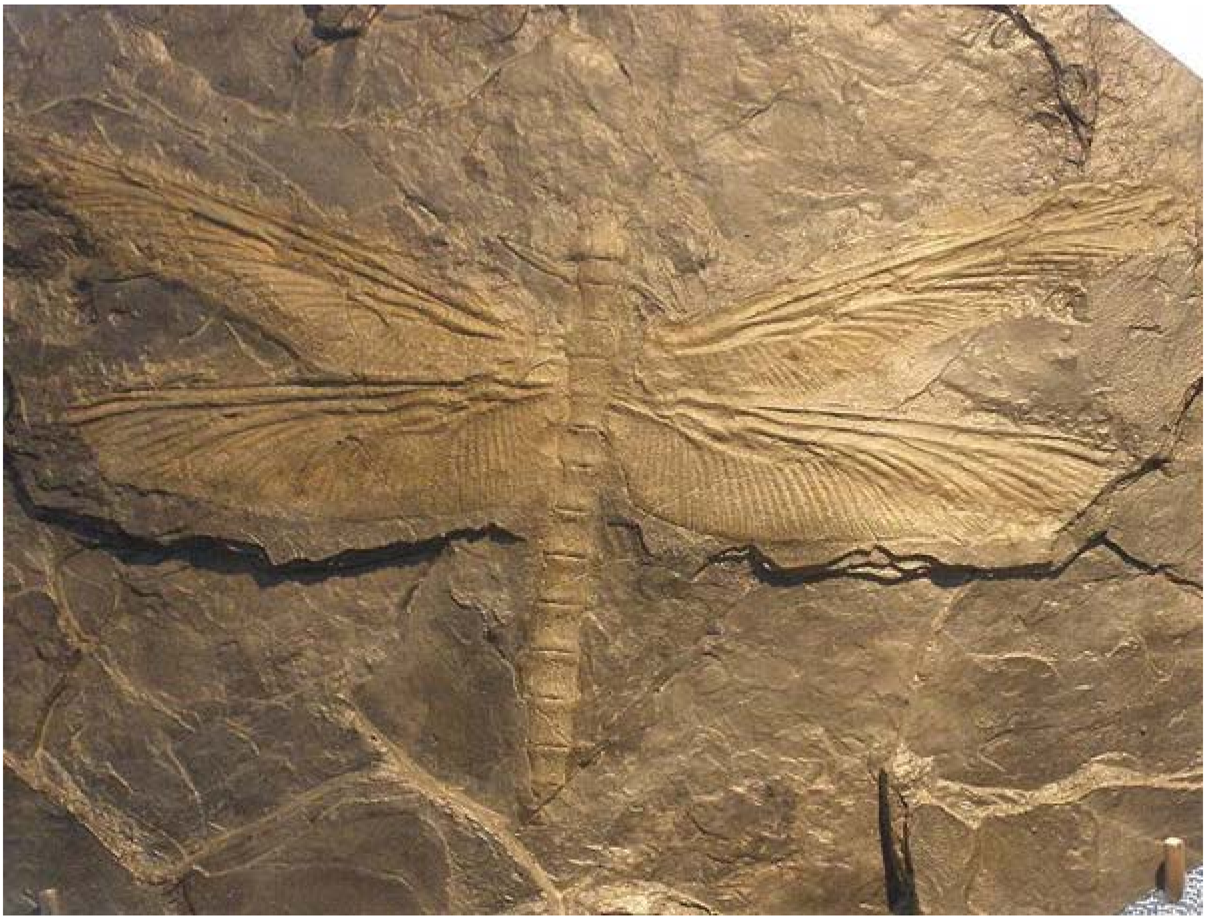

Figure 7 - Meganeura, Carboniferous relative of modern dragonflies.

Fate of the coal swamps:

The coal swamps of tropical Euramerica gradually shrank towards the end of the Carboniferous, owing to a change in climate and because the lowlands that they occupied were being destroyed by mountain uplift. However, in wetter regions such as Cathaysia, the Carboniferous rainforests continued to flourish well into the Permian. Throughout the Permian the climate became increasingly warmer, leading to the reduction of the Southern Hemisphere ice cap. This favoured hardier, seed-bearing plants such as the glossopterids. The end of the Permian Period, 251 million years ago, saw the largest mass extinction known in the history of life, with an estimated 95% of all species on Earth dying out. The glossopterid-dominated coal swamps of Gondwana were among the casualties of this mass extinction. No coal deposits are known from the rocks of the Early Triassic. Thin coals of limited extent only return in Middle Triassic rocks, some ten million years later, after what is known to geologists and palaeontologists as the coal gap. It is thought that this reflects the extinction of coal-forming ecosystems, and that it took many millions of years before new groups of plants adapted to create wetland peat-forming habitats.

Suggestions for further reading:

Cleal, C. J. & Thomas, B. A. 1994. *Plant Fossils of the British Coal Measures.* Dorchester: The Palaeontological Association. ISBN 0901702536

Cleal, C. J. & Thomas, B. A. 2009. *An Introduction to Plant Fossils.* Cambridge: Cambridge University Press. ISBN 978052188715.1

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