

Timing of angiosperm evolution - the key role of stratigraphy

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The most profound change in terrestrial in Mesozoic ecosystems was induced by the advent of flowering plants during mid Cretaceous times, heralding great pulses in the evolution of other groups of organism, including insects, birds and mammals.

A wealth of information concerning fossil angiosperms has been accumulated during the past decades, changing fundamentally our view of the evolution of this group (Friis et al., 2006). However, since macro- and mesofossil records of flowering plants originate mostly from terrestrial sequences, direct dating is lacking for most important sites. Recent stratigraphic studies of marginal marine sections in Portugal provided the so far most complete and most reliably dated record of angiosperm pollen grains (Heimhofer et al., 2006). The new dating is based on biostratigraphy - mostly dinoflagellate cysts - and chemostratigraphy ($\delta^{13}\text{C}$ and Sr isotopes) (Heimhofer et al., 2003; Burla et al., submitted).

Based on these data it is possible to date the classical mid-latitudinal key sections, e.g. Potomac Group of eastern USA (Doyle and Hickey, 1976) and Western Portuguese basin (Friis et al., 2000), which contain important angiosperm meso- and macrofossil records. These new calibrations reveal a so far undocumented early phase of angiosperm evolution, including a first radiation of the magnoliids and monocots during the Aptian, preceding the radiation of the eudicots by at least 10 million years (Hochuli et al., 2006). Until recently a Barremian origin of the eudicots was inferred from poorly dated sections. According to the new stratigraphic data this group appears during the late Aptian and consistent occurrences are found from the early Albian onwards.

Flowering plants diversified and spread very rapidly during middle and late Albian times. Climate is thought to have a major impact on the evolution, the rapid radiation and the spreading of angiosperms. Climatic variations in the Aptian probably induced the first important radiation of the magnoliids and monocots as well as the evolution of eudicots. Unstable ecological conditions are thought to have favoured the spread of the small shrubby and herbaceous early angiosperms, which certainly had shorter life cycles than the dominating gymnosperms. Stable climatic condition seemed to have favoured the great radiation of the entire group during the Albian (Heimhofer et al. 2005). The major role of climate in the radiation of angiosperms is suggested by gradients in their lateral distribution as well as by their more recent – Cainozoic - radiations in specific areas (e.g. Linder 2003).

By the end of the Turonian flowering plants dominated most of plant assemblages. Thus, their radiation, especially the one of the eudicots, was even faster than previously thought. This leaves us with the “abominable mystery” for the rapid development of flowering plants as Darwin expressed it in 1879 (Darwin & Seward, 1903).

The new timing has a considerable impact on the calibration of molecular clocks, for which reliable paleontological calibration points are indispensable. Presently, the

fossil records are too scanty for most groups; consequently molecular clocks are bound to be unreliable.

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