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Changing CO2 and the evolution of terrestrial and marine photosynthetic organisms during the terrestrialization process in the Palaeozoic.

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The comparative analysis, at the scale of the entire Phanerozoic, of the curves of modelled variation in atmospheric CO2, of global phytoplankton diversity, and of the major steps in land plant evolution, shows interesting and somewhat unexpected correlations that can be explained in a coherent conceptual model linking the terrestrialization process, the global carbon cycle, and the evolution of the large oceanic phytoplankton.

A simple model for the evolution of land plants can be proposed which subdivides the terrestrialization process into a sequence of four successive terrestrial autotrophic biomes: a cyanobacterial-dominated microbial landscape (microbial mats: 2.2 Gy), a bryophyte-dominated subaerial biome similar to posterlands, sensu Retallack (1993) (thalloid bryophytes: 523-513 My), a polysporangiophytic biome that includes both rhyniophytoids and tracheophytes which do not possess secondary xylem (tracheophyes: 426-423 My), and a forested biome composed of plants that possessed secondary xylem (lignophytes: 385-375 My). These stages represent successive incremental increases levels of biomass (thus of sequestration of carbon), and of weathering of parent rock (depth of the rhizosphere). Apart from the microbial mats biome, each of the three successive stages corresponds to a subsequent drop in paleo-CO2 levels as established in the GEOCARB III model. This was not an expected result of our analysis, because the primary effect of terrestrialization should not have been felt until the rise of the forested (Lignophyte) biome during the Late Devonian. Nevertheless, it seems a remarkable coincidence that each of three periods of the most significant drops in the CO2 model begins exactly at the time of the origin of each successive vegetative biome. It is therefore proposed that the cumulative increase in biomass retention (which corresponds to the successive establishment of terrestrial biomes) contributed significantly to a drawdown of pCO2 due to the sequestration of Corg in organic matter trapped in plant biomass, litter, soils, and buried in sediments, adding up to the better known effect of increased weathering due to the evolution of deep rooting systems during late Devonian time onwards.

In this study, we also examined the potential perturbations to the phytoplankton of the mid-Palaeozoic marine realm as CO2(aq) declined and as POM and DOM delivery to the shallow shelf increased nutrient flux to the oceans. We used the fossil record of acritarchs as a proxy for the large phytoplankton of the Palaeozoic. Our data show that the standing diversity of acritarchs (genus-level taxon richness) is highly correlated with the decline in Palaeozoic pCO2 as modelled by Berner and Kothavala (2001); the two curves show the same trends, the acritarch diversity curve being offset, on average, by a -10 my time lag. We propose that the gradual (and not catastrophic as previously assumed) decline in acritarch diversity observed during late Silurian – late Devonian times was causally linked to the decline in dissolved CO2 in the oceans and the associated increase in oceanic pH, which were in turn caused by the falling pCO2 in the atmosphere.

These observations appear to link the decline of the acritarchs to the rise of the terrestrial biota through the effect of terrestrialization on pCO2.