PROTEROZOIC ACRITARCHS AND DIVERGENCES OF GREEN MICROALGAE

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The morphology of microfossils with resistant cell walls, their ornamentation and functionally identifiable structures are the first source of information used to assess their biological affinities. Difficulties in relying on morphology alone due to the problem of convergent morphology may be resolved by the ultrastructure of the cell wall and its biochemistry.

The cell walls of microfossils, which are acid-resistant and thus extractable by chemical processing from the host rocks, are composed of biopolymers that show the properties of the sporopollenin/algaenan classes of biomolecules synthesized by green algae, the green lineages of dinoflagellates, and the reproductive cells of higher plants (spores and pollen). These biota share primary biochemical pathways of organic synthesis of biopolymers for constructing cell walls, and show a common early lineage in their phylogeny. The geochronologic sequence of appearance of microfossils with diagnostic traits of phycoma-like cysts, zygotic cysts with ornamentation, pylomes, double-walled vesicles and endocysts, and spheroidal vegetative cells and/or aplanospores with trilaminar sheath structure (TLS), which are interpreted to be green microalgae, is aligned on the phylogenetic tree of the Viridiplantae. The radiometric datings of the first appearance datum of these taxa provide the minimum age of the origin of the classes to which they are assigned. According to the affinities of microfossils inferred herein, the sequence of evolutionary events is as it follows.

The stem-group of the Viridiplantae extends in time prior to c. 1800 Ma, and the major branching nodes in a common lineage are at c. 1800 Ma for the Chlorophytes, c. 1650 Ma for the Prasinophyceae, and at c. 1450 Ma for the Chlorophyceae-Ulvophyceae lineage. The divergence of the Ulvophyceae might have occurred before c. 950 Ma. The origin of the Chlorophytes is constrained by the earliest record of the *Leiosphaeridia*-type microfossils from the Changzhougou Formation. The “leiosphaerid” morphology, which is recognized among the prasinophyceaeen or chlorophyceaeen microalgae, has deep roots in their common ancestral group and it is not only the result of a convergent morphology expressed later on.

The prasinophyceaeen lineage is recognized by *Tasmanites rifejicus*, and co-occurring species with phycoma-like, double-walled cysts: *Simia*, *Pterospermopsimorpha*, and *Pterospermella*, and striated *Valeria*. *Valeria* appears at c. 1650 Ma in the Mallapunyah Formation, and it marks the minimum age at which the Prasinophyceae lineage split from the
basal Chlorophytes. Phycoma-like microfossils are subsequently recorded at c. 950 Ma \((Octoedryxium)\), c. 580 Ma \((Tasmanites, Simia, Octoedryxium, Pterospermopsimorpha)\), and since c. 540 Ma through the Cambrian \((Tasmanites, Granomarginata, Pterospermella, Cymatiosphaera)\).

The chlorophycean lineage is recognized by various species of \textit{Leiosphaeridia} showing the TLS in their cell walls, which are likely the early members of the orders Volvocales and/or Chlorococcales. Leiosphaerids with such traits are present at c. 1450 Ma, 650 Ma and 520 Ma. The divergence of the Ulvophyceae prior to c. 950 Ma is suggested by the dasycladacean \textit{Archaeoclada} and \textit{Variaclada} in the Lakhanda Group, and the siphonocladacean \textit{Proterocladus} from the c. 700-750 Ma Svanbergfjellet Formation.

The presented minimum ages of the origin of the Viridiplantae and the divergence of the major microalgal clades differ from the molecular clocks estimates. They also suggest that previously inferred time of the origin of Chlorophytes at c. 1 Ga or 1.5 Ga is too young. The molecular clocks estimates of these events are in conflict with microfossil records, and the interpretation of some of them as being photosynthesizing biota, and seem to be delayed in time.

Following the Great Oxygenation Event at c. 2.2 Ga, the oxygen pressure in the ocean-atmosphere system has been apparently increasing although with significant fluctuations through time. This was due to the variation in carbon cycles and carbonate formation, assembly and breaking off the supercontinents and weathering rate change, and hydrological cycle and stratification of the oceans. The Palaeo-Mesoproterozoic oceans were stratified with deep layers anoxic and only the surface layer oxygenated by photosynthesis within the photic zone. The late Neoproterozoic oxygenation event resulted in full oxygenation of the oceans and deep currents circulation.

The increasing pressure of oxygen in marine environments is argued to have played a decisive role in the evolution of metazoans in the Ediacaran and Cambrian, yet the cause-effect relationships may be in reverse as it comes to photosynthetic organisms diversification and growing abundance observed through the Proterozoic. The recorded diversification of green microalgae (acritarchs) must have enhanced the rates of primary productivity in the surface ocean layers and organic carbon burial in shelf sediments. Photosynthesis most profoundly increased the oxygen pressure in the global ocean. Precise correlation in time of the geochemical signatures and radiations of photosynthetic biota may reveal critical relationships between biotic and environmental evolution.