

TIMING OF THE ORIGIN OF PLASTID AND EVOLUTIONARY HISTORY OF THE CHLOROPHYTA BY MICROFOSSIL RECORD

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The origin of plastid in eukaryotes and the minimum age of this event based on microfossil record is indirectly inferred by recognizing green algae among organically preserved, unicellular microfossils other than cyanobacteria. Single primary symbiosis of cyanobacterium established algae and led to divergence of Archaeplastida, including Chlorophyta. The reproductive cysts of extant microalgae share characters derived from their early green algal ancestors. The genetic inheritance and eventually its phenotypic expression is universally shared. Similarly, the enzymes binding specific compounds in photosynthesis evolved from cyanobacteria and are present in all photosynthesising organisms since the Archean. Molecular clock analyses suggest that primary plastid was established by c. 1.5 Ga, whereas by fossil record c.1.8 Ga (*Leiosphaeridia*) or 2.1 Ga (*Grypania*). The fossil record of stem group eukaryotes without assignment to living groups is at 2.1 Ga by carbonaceous compressions (*Grypania*), however, the recognition as an alga is not excluded, and it would provide the minimum age of the origin of plastid. Spheroidal microfossils (*Leiosphaeridia*) with multilayered cell-wall and trilaminar sheath structure that is the algal character of Chlorophyceae are documented throughout the Proterozoic into Cambrian. Because of the presence of this character and interpreted as algal cysts, some leiosphaerids show record of chlorophyceans persistently since 1.8 Ga. Microfossils with phycoma-like morphology suggesting prasinophycean affinity are known at minimum age of 1.4–1.2 Ga (*Pterospermopsimorpha*, *Pterospermella*, *Simia*, *Tasmanites*). Microfossils of the Proterozoic to Cambrian ages assessed by body plan, ornamentation, excystment structure, cell wall resistance and ultrastructure, and internal bodies defined by their own walls, are recognized as algal zygotic cysts and phycomata by comparison with extant green algae. Internal bodies are a part of reproductive cysts, resembling those known in Chlorophyta. They are inferred to be endocysts containing zygote, if single, or offspring cells, if multiple, in sexual and asexual generations of ancient taxa of the classes Chlorophyceae and Prasinophyceae. Based on the earliest occurrence of microfossils with morphologic characteristic of a zygotic cyst, multilayered cell-wall structure indicative of the primary and secondary wall, and with an internal body in the *Dictyosphaera-Shuiyousphaeridium* plexus, the sexual reproduction is evident at c. 1.4-1.2 Ga. It became common in the Neoproterozoic (*Cymatiosphaeroides*, *Trachyhystrichosphaera*, *Vandalosphaeridium*, *Tanarium*, *Asterocapsoides*, *Ancorosphaeridium*, *Densisphaera*), and the Cambrian (*Skiagia*, *Polygonium*). The divergence of Chlorophyta from the lineage of Chloroplastida occurred at the minimum age of 1.8 Ga, and the origin of primary plastid prior to this time.

