Tertiary *Metasequoia* leaves: A case example of paralleled preservation at biomolecular and morphological levels

QIN LENG[1] AND HONG YANG[2]

[1]Nanjing Institute of Geology & Palaeontology, CAS, Nanjing 210008, China (qin.leng@nigpas.ac.cn)
[2]Department of science and technology, college of science and arts, bryant university, smithfield, RI 02917, USA (hyang@bryant.edu)

Metasequoia is an evolutionary conservative conifer genus with a continued fossil record widely reported in the Northern Hemisphere since Late Cretaceous. Three deposits, the late Paleocene-early Eocene Ellesmere Island deposit of Canada (~60Ma), the middle Eocene Axel Heiberg Island deposit of Canada (~45Ma), and the Miocene Clarkia deposit of the US (~15Ma) yield exceptionally preserved *Metasequoia* fossil leaves, offering a rare opportunity for a comparative and combined study at the morphological and biomolecular levels.

A sequence of biomolecular preservation is detected by Py-GC-MS analysis on solvent-extracted residues. Total ironic chromatographs show that the ~60Ma old material produces large amounts of polysaccharide moieties and detectable fatty acids, showing the best quality of preservation. The ~45Ma old material yields mainly lignin products but with lesser amounts of polysaccharide moieties. Fatty acids are hardly detected. The pyrolysis products of the ~15Ma old material are dominated by lignin products and a few polysaccharide products with very low quantity are detected, indicating the lowest quality of biomolecular preservation.

SEM observation also exhibits a similar sequence of preservation at the morphological level. The ~60Ma old material is the best preserved with almost intact 3-dimensional epidermal cells and with distinct and continuous cuticular membrane layers. The cuticular membranes covering collapsed epidermal cells of the ~45Ma old material are still layered but layers are not readily recognizable. The ~15Ma old material is of the lowest quality of preservation with cuticle as the only structurally preserved part.

Such a comparative and combined SEM and geochemical approach makes it possible to detect the source of preserved structural labile biopolymers. These molecules might have played a significant role in the fossilization and preservation of exceptionally preserved fossil leaves.

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The preservation of cytoplasm in fossil plant cells

XIN WANG[1] AND DAVID L. DILCHER[2]

[1]Nanjing Institute of Geology and Paleontology, 39 Beijing Dong Road, Nanjing 210008, P. R. China (wangxin@flmnh.ufl.edu)
[2]Florida Museum of Natural History, Gainesville, FL32611-7800, USA (dilcher@flmnh.ufl.edu)

Cytoplasm has been an object of paleobiological research only rarely because cytoplasm is labile in death of an organism and thus not incorporated into the fossil record. The plant cell walls that are relatively inert as well as plant parts covered with waxes, cutin or sporopollinin such as epidermal cells and spores or pollen are most often preserved. These are relatively stable and physiologically inactive parts of the plants and remain for some time after death of the plant while the cytoplasm in most extant plants usually is decayed shortly after death and certainly before fossilization. However, this decay process needs to be re-examined in light of new data that demonstrates the potential for the preservation of cytoplasm in fossil plants and the actual preservation of cytoplasmic cellular contents. Recent work on the ultrastructure of fossil plant cells suggests that the assumption of the rarity of the occurrence of cytoplasm in some fossil plant cells may be mistaken. The decay of cytoplasm is an organic reaction that needs time and the action of enzymes that are very sensitive to environment changes and only function at particular temperatures. Wildfires, that usually produce high temperatures that bake or burn original plant material, are not rare at all in modern or geological history. High temperatures of forest fires can stop the decay of cytoplasm and the right combination of temperature and occurrence of the fire can charcoalify plant bodies, preserving cytoplasm within the plant cells. Charcoalified material is an inert material frequently seen in the sediments. Based on the above long-existing knowledge, it is conceivable that cytoplasm fossils should be more common objects for research than previously thought. In this paper, we will demonstrate the fine preservation and subcellular ultrastructures of cytoplasm never seen in fossil plants before. The fossil materials are charcoalified plant debris from the early Cretaceous (the late Albian, about 100 m.a.) in Kansas, USA. Different preservation patterns suggest that at least lightning and wildfires are related to the production of fossil cytoplasm. Our conclusion is also favored by our experiments with the fixation of cytoplasmic contents of plant cells in modern plant materials by high temperatures.