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Exploration of Phytogeographic and Evolutionary Trends of the Plants Growing in Salkhan Area During Pre Fossilization Period

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ABSTRACT: During pre fossilization period the plants growing in Salkan area, evolution has resulted in a wide range of complexity, from the earliest algal mats, through multicellular marine and freshwater green algae, terrestrial bryophytes, lycopods and ferns, to the complex gymnosperms and angiosperms (flowering plants) of today. While many of the earliest groups continue to thrive, as exemplified by red and green algae in marine environments, more recently derived groups have displaced previously ecologically dominant ones; for example, the ascendance of flowering plants over gymnosperms in terrestrial environments.^{[1]:498}

There is evidence that cyanobacteria and multicellular photosynthetic eukaryotes lived in freshwater communities on land as early as 1 billion years ago,^[2] and that communities of complex, multicellular photosynthesizing organisms existed on land in the late Precambrian, around 850 million years ago.^[3]

Evidence of the emergence of embryophyte land plants first occurs in the mid-Ordovician (~470 million years ago), and by the middle of the Devonian (~390 million years ago), many of the features recognised in land plants today were present, including roots and leaves. By the late Devonian (~370 million years ago) some free-sporing plants such as *Archaeopteris* had secondary vascular tissue that produced wood and had formed forests of tall trees. Also by the late Devonian, *Elkinsia*, an early seed fern, had evolved seeds.^[4] Evolutionary innovation continued throughout the rest of the Phanerozoic eon and still continues today. Most plant groups were relatively unscathed by the Permo-Triassic extinction event, although the structures of communities changed. This may have set the scene for the appearance of the flowering plants in the Triassic (~200 million years ago), and their later diversification in the Cretaceous and Paleogene. The latest major group of plants to evolve were the grasses, which became important in the mid-Paleogene, from around 40 million years ago. The grasses, as well as many other groups, evolved new mechanisms of metabolism to survive the low CO₂ and warm, dry conditions of the tropics over the last 10 million years.

KEYWORDS: pre fossilization, Salkan, evolution, phytogeographic, evolutionary, trends, exploration

I.INTRODUCTION

During pre fossilization period the plants growing in Salkan area, evolved from a group of green algae, perhaps as early as 850 mya,^[3] but algae-like plants might have evolved as early as 1 billion years ago.^[2] The closest living relatives of land plants are the charophytes, specifically Charales; assuming that the habit of the Charales has changed little since the divergence of lineages, this means that the land plants evolved from a branched, filamentous alga dwelling in shallow fresh water,^[5] perhaps at the edge of seasonally desiccating pools.^[6] However, some recent evidence suggests that land plants might have originated from unicellular terrestrial charophytes similar to extant Klebsormidiophyceae.^[7] The alga would have had a haplontic life cycle. It would only very briefly have had paired chromosomes (the diploid condition) when the egg and sperm first fused to form a zygote that would have immediately divided by meiosis to produce cells with half the number of unpaired chromosomes (the haploid condition). Co-operative interactions with fungi may have helped early plants adapt to the stresses of the terrestrial realm.^[8]

Plants were not the first photosynthesisers on land. Weathering rates suggest that organisms capable of photosynthesis were already living on the land 1,200 million years ago,^[6] and microbial fossils have been found in freshwater lake deposits from 1,000 million years ago,^[9] but the carbon isotope record suggests that they were too scarce to impact the atmospheric composition until around 850 million years ago.^[3] These organisms, although phylogenetically diverse,^[10] were probably small and simple, forming little more than an algal scum.^[6]

Evidence of the earliest land plants occurs much later at about 470Ma, in lower middle Ordovician rocks from Saudi Arabia^[11] and Gondwana^[12] in the form of spores with decay-resistant walls. These spores, known as cryptospores, were produced either singly (monads), in pairs (dyads) or groups of four (tetrads), and their microstructure resembles that of modern liverwort spores, suggesting they share an equivalent grade of organisation.^[13] Their walls contain sporopollenin – further evidence of an embryophytic affinity.^[14] It could be that atmospheric 'poisoning'



prevented eukaryotes from colonising the land prior to this,^[15] or it could simply have taken a great time for the necessary complexity to evolve.^[16]

Trilete spores similar to those of vascular plants appear soon afterwards, in Upper Ordovician rocks about 455 million years ago.^{[17][18]} Depending exactly when the tetrad splits, each of the four spores may bear a "trilete mark", a Y-shape, reflecting the points at which each cell squashed up against its neighbours.^[19] However, this requires that the spore walls be sturdy and resistant at an early stage. This resistance is closely associated with having a desiccation-resistant outer wall—a trait only of use when spores must survive out of water. Indeed, even those embryophytes that have returned to the water lack a resistant wall, thus don't bear trilete marks.^[19] A close examination of algal spores shows that none have trilete spores, either because their walls are not resistant enough, or, in those rare cases where they are, because the spores disperse before they are compressed enough to develop the mark or do not fit into a tetrahedral tetrad.^[19]

The earliest megafossils of land plants were thalloid organisms, which dwelt in fluvial wetlands and are found to have covered most of an early Silurian flood plain. They could only survive when the land was waterlogged.^[20] There were also microbial mats.^[21]

Once plants had reached the land, there were two approaches to dealing with desiccation. Modern bryophytes either avoid it or give in to it, restricting their ranges to moist settings or drying out and putting their metabolism "on hold" until more water arrives, as in the liverwort genus *Targionia*. Tracheophytes resist desiccation by controlling the rate of water loss. They all bear a waterproof outer cuticle layer wherever they are exposed to air (as do some bryophytes), to reduce water loss, but since a total covering would cut them off from CO₂ in the atmosphere tracheophytes use variable openings, the stomata, to regulate the rate of gas exchange. Tracheophytes also developed vascular tissue to aid in the movement of water within the organisms (see below), and moved away from a gametophyte dominated life cycle (see below). Vascular tissue ultimately also facilitated upright growth without the support of water and paved the way for the evolution of larger plants on land.

A snowball earth, from around 720-635 mya in the Cryogenian period, is believed to have been caused by early photosynthetic organisms, which reduced the concentration of carbon dioxide and increased the amount of oxygen in the atmosphere.^[22] Based on molecular clock studies of the previous decade or so, a 2022 study observed that the estimated time for the origin of the *multicellular* streptophytes (all except the unicellular basal clade Mesostigmatophyceae) fell in the cool Cryogenian while that of the subsequent separation of streptophytes fell in the warm Ediacaran, which they interpreted as an indication of selective pressure by the glacial period to the photosynthesizing organisms, a group of which succeeded in surviving in relatively warmer edaphic refugia, subsequently flourishing in the later Ediacaran and Phanerozoic on land as embryophytes. The study also theorized that the unicellular morphology and other unique features of the Zygnematophyceae may reflect further adaptations to a cryophilic life.^[23] The establishment of a land-based flora increased the rate of accumulation of oxygen in the atmosphere, as the land plants produced oxygen as a waste product. When this concentration rose above 13%, around 0.45 billion years ago,^[24] wildfires became possible, evident from charcoal in the fossil record.^[25] Apart from a controversial gap in the Late Devonian, charcoal has been present ever since.

Charcoalification is an important taphonomic mode. Wildfire or burial in hot volcanic ash drives off the volatile compounds, leaving only a residue of pure carbon. This is not a viable food source for fungi, herbivores or detritivores, so it is prone to preservation. It is also robust and can withstand pressure, displaying exquisite, sometimes sub-cellular, detail in remains.

II.DISCUSSION

During pre fossilization period the plants growing in Salkan area , all multicellular plants have a life cycle comprising two generations or phases. The gametophyte phase has a single set of chromosomes (denoted $1n$) and produces gametes (sperm and eggs). The sporophyte phase has paired chromosomes (denoted $2n$) and produces spores. The gametophyte and sporophyte phases may be homomorphic, appearing identical in some algae, such as *Ulva lactuca*, but are very different in all modern land plants, a condition known as heteromorphy.

The pattern in plant evolution has been a shift from homomorphy to heteromorphy. The algal ancestors of land plants were almost certainly haplobiontic, being haploid for all their life cycles, with a unicellular zygote providing the $2N$ stage. All land plants (i.e. embryophytes) are diplobiontic – that is, both the haploid and diploid stages are multicellular.^[1] Two trends are apparent: bryophytes (liverworts, mosses and hornworts) have developed the gametophyte as the dominant phase of the life cycle, with the sporophyte becoming almost entirely dependent on it; vascular plants have developed the sporophyte as the dominant phase, with the gametophytes being particularly reduced in the seed plants.



It has been proposed as the basis for the emergence of the diploid phase of the life cycle as the dominant phase that diploidy allows masking of the expression of deleterious mutations through genetic complementation.^{[26][27]} Thus if one of the parental genomes in the diploid cells contains mutations leading to defects in one or more gene products, these deficiencies could be compensated for by the other parental genome (which nevertheless may have its own defects in other genes). As the diploid phase was becoming predominant, the masking effect likely allowed genome size, and hence information content, to increase without the constraint of having to improve accuracy of replication. The opportunity to increase information content at low cost is advantageous because it permits new adaptations to be encoded. This view has been challenged, with evidence showing that selection is no more effective in the haploid than in the diploid phases of the lifecycle of mosses and angiosperms.^[28]

There are two competing theories to explain the appearance of a diplobiontic lifecycle.

The interpolation theory (also known as the antithetic or intercalary theory)^[29] holds that the interpolation of a multicellular sporophyte phase between two successive gametophyte generations was an innovation caused by preceding meiosis in a freshly germinated zygote with one or more rounds of mitotic division, thereby producing some diploid multicellular tissue before finally meiosis produced spores. This theory implies that the first sporophytes bore a very different and simpler morphology to the gametophyte they depended on.^[29] This seems to fit well with what is known of the bryophytes, in which a vegetative thalloid gametophyte nurtures a simple sporophyte, which consists of little more than an unbranched sporangium on a stalk. Increasing complexity of the ancestrally simple sporophyte, including the eventual acquisition of photosynthetic cells, would free it from its dependence on a gametophyte, as seen in some hornworts (*Anthoceros*), and eventually result in the sporophyte developing organs and vascular tissue, and becoming the dominant phase, as in the tracheophytes (vascular plants).^[1] This theory may be supported by observations that smaller *Cooksonia* individuals must have been supported by a gametophyte generation. The observed appearance of larger axial sizes, with room for photosynthetic tissue and thus self-sustainability, provides a possible route for the development of a self-sufficient sporophyte phase.^[29]

The alternative hypothesis, called the transformation theory (or homologous theory), posits that the sporophyte might have appeared suddenly by delaying the occurrence of meiosis until a fully developed multicellular sporophyte had formed. Since the same genetic material would be employed by both the haploid and diploid phases, they would look the same. This explains the behavior of some algae, such as *Ulva lactuca*, which produce alternating phases of identical sporophytes and gametophytes. Subsequent adaption to the desiccating land environment, which makes sexual reproduction difficult, might have resulted in the simplification of the sexually active gametophyte, and elaboration of the sporophyte phase to better disperse the waterproof spores.^[1] The tissue of sporophytes and gametophytes of vascular plants such as *Rhynia* preserved in the Rhynie chert is of similar complexity, which is taken to support this hypothesis.^{[29][30][31]} By contrast, modern vascular plants, with the exception of *Psilotum*, have heteromorphic sporophytes and gametophytes in which the gametophytes rarely have any vascular tissue.^[32]

III.RESULTS

During pre fossilization period the plants growing in Salkan area , there is no evidence that early land plants of the Silurian and early Devonian had roots, although fossil evidence of rhizoids occurs for several species, such as *Horneophyton*. The earliest land plants did not have vascular systems for transport of water and nutrients either. *Aglaophyton*, a rootless vascular plant known from Devonian fossils in the Rhynie chert^[33] was the first land plant discovered to have had a symbiotic relationship with fungi^[34] which formed arbuscular mycorrhizas, literally "tree-like fungal roots", in a well-defined cylinder of cells (ring in cross section) in the cortex of its stems. The fungi fed on the plant's sugars, in exchange for nutrients generated or extracted from the soil (especially phosphate), to which the plant would otherwise have had no access. Like other rootless land plants of the Silurian and early Devonian *Aglaophyton* may have relied on arbuscular mycorrhizal fungi for acquisition of water and nutrients from the soil.

The fungi were of the phylum Glomeromycota,^[35] a group that probably first appeared 1 billion years ago and still forms arbuscular mycorrhizal associations today with all major land plant groups from bryophytes to pteridophytes, gymnosperms and angiosperms and with more than 80% of vascular plants.^[36]

Evidence from DNA sequence analysis indicates that the arbuscular mycorrhizal mutualism arose in the common ancestor of these land plant groups during their transition to land^[37] and it may even have been the critical step that enabled them to colonise the land.^[38] Appearing as they did before these plants had evolved roots, mycorrhizal fungi would have assisted plants in the acquisition of water and mineral nutrients such as phosphorus, in exchange for organic compounds which they could not synthesize themselves.^[36] Such fungi increase the productivity even of simple plants such as liverworts.^{[39][40]}



To photosynthesise, plants must absorb CO₂ from the atmosphere. However, making the tissues available for CO₂ to enter allows water to evaporate, so this comes at a price.^[41] Water is lost much faster than CO₂ is absorbed, so plants need to replace it. Early land plants transported water apoplastically, within the porous walls of their cells. Later, they evolved three anatomical features that provided the ability to control the inevitable water loss that accompanied CO₂ acquisition. First, a waterproof outer covering or cuticle evolved that reduced water loss. Secondly, variable apertures, the stomata that could open and close to regulate the amount of water lost by evaporation during CO₂ uptake and thirdly intercellular space between photosynthetic parenchyma cells that allowed improved internal distribution of the CO₂ to the chloroplasts. This three-part system provided improved homoiohydricity, the regulation of water content of the tissues, providing a particular advantage when water supply is not constant.^[42] The high CO₂ concentrations of the Silurian and early Devonian, when plants were first colonising land, meant that they used water relatively efficiently. As CO₂ was withdrawn from the atmosphere by plants, more water was lost in its capture, and more elegant water acquisition and transport mechanisms evolved.^[41] Plants growing upwards into the air needed a system for transporting water from the soil to all the different parts of the above-soil plant, especially to photosynthesising parts. By the end of the Carboniferous, when CO₂ concentrations had been reduced to something approaching that of today, around 17 times more water was lost per unit of CO₂ uptake.^[41] However, even in the "easy" early days, water was always at a premium, and had to be transported to parts of the plant from the wet soil to avoid desiccation.^[42]

Water can be wicked by capillary action along a fabric with small spaces. In narrow columns of water, such as those within the plant cell walls or in tracheids, when molecules evaporate from one end, they pull the molecules behind them along the channels. Therefore, evaporation alone provides the driving force for water transport in plants.^[41] However, without specialized transport vessels, this cohesion-tension mechanism can cause negative pressures sufficient to collapse water conducting cells, limiting the transport water to no more than a few cm, and therefore limiting the size of the earliest plants.^[41]

IV. CONCLUSIONS

The early Devonian landscape was devoid of vegetation taller than waist height. Greater height provided a competitive advantage in the harvesting of sunlight for photosynthesis, overshadowing of competitors and in spore distribution, as spores (and later, seeds) could be blown for greater distances if they started higher. An effective vascular system was required in order to achieve greater heights. To attain arborescence, plants had to develop woody tissue that provided both support and water transport, and thus needed to evolve the capacity for secondary growth. The stele of plants undergoing secondary growth is surrounded by a vascular cambium, a ring of meristematic cells which produces more xylem on the inside and phloem on the outside. Since xylem cells comprise dead, lignified tissue, subsequent rings of xylem are added to those already present, forming wood. Fossils of plants from the early Devonian show that a simple form of wood first appeared at least 400 million years ago, at a time when all land plants were small and herbaceous.^[84] Because wood evolved long before shrubs and trees, it is likely that its original purpose was for water transport, and that it was only used for mechanical support later.^[85]

The first plants to develop secondary growth and a woody habit, were apparently the ferns, and as early as the Middle Devonian one species, *Wattieza*, had already reached heights of 8 m and a tree-like habit.^[86]

Other clades did not take long to develop a tree-like stature. The Late Devonian *Archaeopteris*, a precursor to gymnosperms which evolved from the trimerophytes,^[87] reached 30 m in height. The progymnosperms were the first plants to develop true wood, grown from a bifacial cambium. The first appearance of one of them, *Rellimia*, was in the Middle Devonian.^[88] True wood is only thought to have evolved once, giving rise to the concept of a "lignophyte" clade.

Archaeopteris forests were soon supplemented by arborescent lycopods, in the form of *Lepidodendrales*, which exceeded 50m in height and 2m across at the base. These arborescent lycopods rose to dominate Late Devonian and Carboniferous forests that gave rise to coal deposits.^[89] *Lepidodendrales* differ from modern trees in exhibiting determinate growth: after building up a reserve of nutrients at a lower height, the plants would "bolt" as a single trunk to a genetically determined height, branch at that level, spread their spores and die.^[90] They consisted of "cheap" wood to allow their rapid growth, with at least half of their stems comprising a pith-filled cavity.^[11] Their wood was also generated by a unifacial vascular cambium – it did not produce new phloem, meaning that the trunks could not grow wider over time.

The horsetail *Calamites* appeared in the Carboniferous. Unlike the modern horsetail *Equisetum*, *Calamites* had a unifacial vascular cambium, allowing them to develop wood and grow to heights in excess of 10 m and to branch repeatedly.

While the form of early trees was similar to that of today's, the Spermatophytes or seed plants, the group that contain all modern trees, had yet to evolve. The dominant tree groups today are all seed plants, the gymnosperms, which include



the coniferous trees, and the angiosperms, which contain all fruiting and flowering trees. No free-sporing trees like *Archaeopteris* exist in the extant flora. It was long thought that the angiosperms arose from within the gymnosperms, but recent molecular evidence suggests that their living representatives form two distinct groups.^{[91][92][93]} The molecular data has yet to be fully reconciled with morphological data,^{[94][95][96]} but it is becoming accepted that the morphological support for paraphyly is not especially strong.^[97] This would lead to the conclusion that both groups arose from within the pteridosperms, probably as early as the Permian.^[97]

The angiosperms and their ancestors played a very small role until they diversified during the Cretaceous. They started out as small, damp-loving organisms in the understorey, and have been diversifying ever since the Cretaceous,^[98] to become the dominant member of non-boreal forests today.

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