Quest for early land plants

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ABSTRACT

Singh R. S., Kar R. & Agarwal A. 2010. Quest for early land plants. Geophytology 39(1-2): 101-103.

The oldest (Middle Ordovician) land plants are known by the spores. The morphological features of these spores do not suggest aquatic habitat. It is assumed that the earth primarily has two states, the Icehouse state and the Greenhouse state, the former favours the animals and the latter the plants. Based on the prevalence of Greenhouse state, it is surmised that unaltered continental Early Ordovician sedimentary rocks (500 Ma) may also yield remains of the early land plants. A Late Cambrian rock (510 Ma) laden with land plant remains is also not ruled out.

Key-words: Ordovician, land plants, Greenhouse state, Icehouse state.

INTRODUCTION

Prior to the advent of land plants (embryophytes), life was confined to water bodies. The emergence of embryophytes led to marked changes in climate, biogeochemical processes, evolution and food chain, leading gradually to the present day continental environments. The earliest palynologial indications of land plants are known by the spores (tetrads) recorded from Middle Ordovician (475 MA) sediments from Saudi Arabia and slightly younger sediments from Oman, which have been related with the liverworts. Recently, from Argentina, five distinct cryptospores (liverwort spores) were recorded from the sediments of similar chronology. Megafossils of presumably land plants, few centimetres in size with bifurcation, are recorded from Middle Silurian (425 Ma) sediments of Ireland. It was only during Late Silurian that the definite land plants, known as *Cooksonia,* appeared. These were simple stems, bifurcated several times, having some spherical sporangia at apices, without true roots but only root hairs from the creeping stems that became extinct during Early Devonian.

During Early Devonian (415-400 Ma), several other land plants with spines and leaves in some forms appeared. Well known plant megafossils from the Rhynie Chert of Scotland provide a good sketch of plant adaptation on land. During the Middle Devonian, further diversification of species with development of leaf-like structures took place and during the Late Devonian the oldest seed plants, the gymnosperms, appeared. The Early Cretaceous saw the advent and proliferation of angiosperms, which eventually became the dominant life form on earth. The climatic response which led to the evolution of land plants from the aquatic habitat is mainly attributed to the alternating two states of the earth, the hot and cold climatic regimes. In the former Greenhouse state plants are favoured, while in the Icehouse state animals flourish. Keeping in view the past episode of prolonged Greenhouse state in between the Varanger and Permo-Carboniferous glaciations, the possibility of the emergence of land plants, earlier than the present records is discussed here.

OBSERVATIONS AND COMMENTS

The rupture of the super continent, Rodinia, and the formation of mega continent Gondwana during the Neoproterozoic glaciation (0.73-0.58Ga) was followed by extreme Greenhouse state in association with sea-level rise and intensive volcanism. These phenomena caused freeing of ice from the earth crust and widespread precipitation, providing new ecological conditions and a unique opportunity for plants to evolve on land. The oldest record of the land plants is inferred from the discovery of obligate tetrads, dyads and sporangia from the Middle Ordovician (475 Ma) of Saudi Arabia and Oman, which has opened a new frontier for the search of early land plants (Strother et al. 1996, Wellman et al. 2003). Recently, five cryptospores (spores of liverworts) have also been reported from the Middle Ordovician sediments of Argentina (Rubinstein et al. 2010). Some of these fossils exhibit large numbers of spores within sporangia, leading to the supposition of authentic land plants. Investigation on the wall ultra structure of these spores points towards a bryophytic affinity. Others, however, profess caution to this conclusion because they assume that these plants could very well be affiliated to some aquatic algae (Banks 1975, Chaloner 1988). The adherence of four or two spores together, without any floating mechanism, stands against the assumption of their aquatic habitat. The smooth (unspongy) wall structure of the spores should also not encourage a watery environment. The acritarchs with elaborate grapnel like processes evolved at the terminal Neoproterozoic (570 Ma) and therefore, if the concerned spores were of aquatic nature, they should reflect it in their morphology (Zhang et al. 1988). The Middle-Late Devonian (380 Ma) aquatic pteridophytes developed bifid processes, apical prominence (acrolamella) and spongy spore wall structure in response to their environment (Dilcher et al. 1992, Kar & Dilcher 2002).

DISCUSSION

In between the Varanger (570-560 Ma) and Permo-Carboniferous (285-280 Ma) glaciations, an intense Greenhouse state prevailed. The increase of carbon dioxide and other gases in the atmosphere coupled with sea-level rise, active volcanism and subsequent rise in temperature, witnessed the development of bryophytes in Middle-Late Ordovician; pteridophytes, lycopsida, psilopsida etc. during Middle Silurian-Early Devonian and gymnosperms in the Late Devonian. It is assumed that the earth has only two states - the Icehouse state and the Greenhouse state, the former favours the animals and the latter the plants (Hoffman & Schrag 2002, Kar & Kar 2004). The origin of flowering plants was also ushered in the last Greenhouse state in between the Late Jurassic and Early Cretaceous, approximately 145 Ma ago (Sun et al. 1998, 2002). Early Cretaceous atmospheric warming in India was principally due to volcanism (Rajmahal and Sylhet volcanism), which favoured establishment and diversification of angiosperms. During the Late Cretaceous, because of extensive Deccan volcanism, warmer conditions reappeared, eliminating some plants including a few angiosperm groups and introducing new and more diverse species. This period also witnessed diversification and evolution of insects and mammals which established co-association with the angiosperms for the process of pollination. Many of the angiosperms modified their floral structures to facilitate pollination by specific insects and thus a co-evolution of insects and the angiosperms was facilitated. This Late Cretaceous proliferation is the more recent and well studied example of the relationship of the Greenhouse state and the development of land plants.

Widespread low latitude glaciation took place at the beginning of the Palaeoproterozoic (2.45-2.22 Ga) and at the end of Neoproterozoic (0.73-0.58 Ga) eras covering almost the whole earth. The later 'Snowball Era' was also a time for continental break up of the supercontinent Rodinia and the formation of megacontinent Gondwana by means of subduction and accretion (Hoffman et al. 1998, Kirschvink 1998). There was hardly any chance for terrestrial plant life on the perennial ice cover. The movement of the enormous glaciers eroded the rock to turn it into soil during the later phase of glaciation. The abrupt ending of the Neoproterozoic glaciation, perhaps due to outgassing by extreme volcanism, was followed by a rise in sea-level as evidenced by the deposition of dolostone or limestone in wide geographical regions, just above the glaciogenes (Kennedy 1996, Corkeron 2001). The atmospheric oxygen level, which was very low (pO_2 0.03 bar) between the Palaeoproterozoic and Neoproterozoic Greenhouse state, raised considerably (pO_2 0.2 bar) in the post Neoproterozoic Greenhouse state (Rye & Holland 1998). The volcanic dust finally settled on the ice-free earth to provide additional cover to the soil. All these factors were conducive to flourish life on land. The eukaryotes, which had a precarious existence during the Neoproterozoic glacials, exhibit an abrupt abundance, morphological diversity and taxonomic complexity (Grey & Corkeron 1998, Walter et al. 2000, Knoll 1994). The Ediacaran megafossils were also at their zenith occurring profusely in the post glacial sequences in many parts of the world (Fedonkin 1992, Martin et al. 2000).

The Greenhouse state between the Varanger and Permo-Carboniferous glaciations prevailed roughly for 300 Ma. The terrestrial plants with bryophytic affinity are recorded approximately after 100 Ma (475 Ma). This period, by any standard, is a long time. When the climate was favourable and sufficient atmospheric oxygen available, the record of plants on land should start earlier. A patient search on the unaltered continental Lower Ordovician sedimentary rocks (500 Ma) would perhaps be rewarded with the remains of the early land plants. A Late Cambrian rock (510 Ma) laden with land plant remains is also not ruled out. Apart from routine maceration, these rocks should also be investigated on SEM by random fracturing. The delicate tissues that could be dissolved during chemical processing may be observed in this manner. Besides, one should also be mentally prepared to see some hitherto unknown forms, which trod on the virgin land as a pioneer.

ACKNOWLEDGEMENT

The authors are grateful to the Director, Birbal Sahni Institute of Palaeobotany, Lucknow for permission to publish this paper.

REFERENCES

Banks H. P. 1975. The oldest vascular plants: a note of caution. Rev. Palaeobot. Palynol. 20: 13-25.

Chaloner W. G. 1988. Early land plants - the saga of a great conquest. In: Greuter W. & Zimmer B. (Editors), Proc. XIV Int. Bot. Cong.: 301-316.

Corkeron M. L. & George A. D. 2001. Glacial incursion on a Neoproterozoic carbonate platform in the Kimberley region, Australia. Bull. Geol. Soc. Am. 113: 1121-1132.

Dilcher D. L., Kar R. K. & Dettmann M. E. 1992. The functional biology of Devonian spores with bifurcate processes – a hypothesis. Palaeobotanist 41: 67-74.

Fedonkin M. A. 1992. Origin and early evolution of the Metazoans. In: Lipps J. H. & Signor P. W. (Editors), Plenum Press, New York, London: 87-129.

Grey K. & Corkeron M. 1998. Late Neoproterozoic stromatolites in glacigenic successions of the Kimberley region, Western Australia: evidence for a younger Marinoan glaciation. Precambrian Res. 92: 65-87.

Hoffman P. F., Kaufman A. J., Halverson G. P. & Schrag D. P. 1998. A Neoproterozoic Snowball Earth. Science 281:1342-1346.

Hoffman P. F. & Schrag D. P. 2002. The Snowball Earth hypothesis: Testing the limits of global change. Terra Nova 14: 129–155.

Kar R. K. & Dilcher D. L. 2002. An argument for the origins of heterospory in aquatic environments. Palaeobotanist 51: 1-10.

Kar R. K. & Kar R. 2004. Greenhouse effect of the past and plant evolution. Curr. Sci. 86 (2): 267.

Kennedy M. J. 1996. Stratigraphy, sedimentology, and isotopic geochemistry of Australian Neoproterozoic postglacial cap dolostones: deglaciation, delta ^{13}C excursions and carbonate precipitation. J. Sed. Res. 66(6): 1050-1064.

Kirschvink J. L. 1998. The Proterozoic Biosphere: A Multidisciplinary Study. In: Schopf, J.W. & Klein C. (Editors), Cambridge University Press, Cambridge: 51-52.

Knoll A. H. 1994. Proterozoic and Early Cambrian protists: Evidence for accelerating evolutionary tempo (Proterozoic/Cambrian/Eukaryotes). Proc. Natn. Acad. Sci. U.S.A. 91: 6743-6750.

Martin M. W., Grazhdankin D.V., Bowring S. A., Evans D. A. D., Fedonkin M. A. & Kirschvink J. L. 2000. Age of Neoproterozoic bilatarian body and trace fossils, White Sea, Russia: Implications for Metazoan Evolution. Science 288: 841 – 845.

Rye R. & Holland H. D. 1998. Paleosols and the evolution of atmospheric oxygen: a critical review. Am. J. Sci. 298: 621-672.

Rubinstein C. V., Gerrienne P., de la Puente G. S., Astini R. A. & Steemans P. 2010. Early Middle Ordovician evidence for land plants in Argentina (eastern Gondwana). New Phytologist, 188: 365-369.

Strother P. K., Al-Hajri S. & Traverse A. 1996. New evidence for land plants from the lower Middle Ordovician of Saudi Arabia. Geology 24: 55-58.

Sun G., Dilcher D. L., Zheng S. & Zhou Z. 1998. In Search of the First Flower: A Jurassic Angiosperm, *Archaefructus*, from Northeast China. Science 282: 1692 -1695

Sun G., Ji Q., Dilcher D. L., Zheng S., Nixon K. C. & Wang X. 2002. Archaefructaceae, a new basal angiosperm family. Science 296: 899-904.

Walter M. R., Veevers J. J., Calver C. R., Gorjan P. & Hill A. C. 2000. Dating the 840-544 Ma Neoproterozoic interval by isotopes of strontium, carbon and sulfur in seawater, and some interpretative models. Precambrian Res. 100: 371-433.

Wellman C. H., Osterloff P. L. & Mohiuddin U. 2003. Fragments of the earliest land plants. Nature 425: 282–85.

Zhang Y., Yin L., Xiao S. & Knoll A.H. 1988. Permineralized fossils from the Terminal Proterozoic Doushantuo Formation, South China. J. Paleont. 72: 1–52.