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Geobiology and paleobiogeography: tracking the coevolution of the Earth and its biota

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Abstract

Paleobiogeographic research is an important area of geobiology that involves the study of the coevolution of the Earth and its biota by considering how tectonic and climatic changes have affected the evolution and distribution of organisms. The intellectual heritage of the discipline stretches back well before Darwin. Phylogenetic approaches to paleobiogeography have played an important part in the expansion of the field, and recent analyses have incorporated Geographic Information Systems (GIS). Each of these approaches, by enhancing the precision of paleobiogeography, helps make the discipline more relevant to geobiology.

The interaction occurring between the geological and biological sciences in paleobiogeography is apparent in several areas. First, there is the emergence of new techniques such as the ability to analyze ancient DNA sequences. Also, paleobiogeographers and biogeographers have realized that geo-dispersal, a biogeographic process first identified through studies of the fossil record, can powerfully influence the evolution and distribution of biotas. Finally, biogeographers have recognized that paleontological incompleteness and extinction constrain our ability to reconstruct biogeographic patterns in the fossil record and the extant biota, respectively. Each of these developments suggests that further growth in paleobiogeography will involve important interactions between studies involving the fossil record and the extant biota, and this, along with the discipline's commitment to studying how tectonic and climatic changes have influenced evolution, reaffirms the validity of the synthetic field that is geobiology.

Keywords: Paleobiogeography; Geobiology; Phylogenetics; Extinction; Geographic Information Systems (GIS)

1. Introduction

Geobiology is that unifying discipline that seeks to span and link the geological and biological sciences. Paleobiogeography is an important research area within geobiology because it is aimed at tracing the

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coevolution of the Earth and its biota. Its neontological cousin, biogeography, has the same aims but generally omits data from the fossil record. Paleobiogeography and biogeography focus on where and why groups of organisms are distributed over the face of the Earth. The Earth system is important to the biological system because it controls, through a variety of processes, many aspects of organismal distribution and evolution. A major research area within paleobiogeography is relating evolutionary patterns in clades of organisms to tectonic and climatic changes. This area of research has a long intellectual heritage extending back well before Darwin's (1859) publication of *On the Origin of Species* (Mayr, 1982; Browne, 1983; Lieberman, 2000), and a brief reprise of this heritage helps illustrate the future prospects for synthesis between the geo- and biosciences. Paleobiogeography also contributed crucial evidence to the development of theories of continental drift and plate tectonics (Hallam, 1981).

More recently, the discipline has shown renewed interest and growth for several reasons, including the use of phylogenetic approaches and Geographic Information Systems (GIS) to analyze paleobiogeographic patterns; these techniques enhance the quantitative nature of the discipline, increasing precision in testing hypotheses. Other exciting and important recent advances include the application of ancient DNA to paleobiogeography; the extension of techniques to the fossil record that were once restricted to the modern biota further blurs the line between geology and biology. Also important is that although some biologists have claimed that phylogenetic biogeography should be based solely on the search for congruent patterns of speciation linked to vicariance, paleontologists have recognized that there is another type of congruent biogeographic process that can be studied: geo-dispersal. Vicariance is the process whereby geographic barriers form within the range of one or more species due to geological or climatic changes, and the formation of these barriers causes populations to become geographically isolated; the populations then diverge and eventually speciate. It is a type of allopatric speciation. Geo-dispersal is the process whereby geographic barriers fall, again due to geological or climatic changes, and then several species can subsequently and congruently expand their geographic ranges (Lieberman and Eldredge, 1996; Lieberman, 1997). If geo-dispersal is not considered in biogeographic studies, the resulting biogeographic patterns may be incomplete or inaccurate. Finally, paleobiogeographers have come to recognize that extinction is an important mechanism which effects a biologists' ability to study biogeographic patterns when only the modern biota is considered. This means that biologists must more fully utilize paleontological data, again offering another important bridge between the geo- and biosciences.

The increasingly quantitative nature of paleobiogeography, the interdigitation of biogeographic and paleobiogeographic analyses through the touchstone of ancient DNA, documenting the effects extinction has on the modern biota, and the importance of biogeographic processes first uncovered in the fossil record, like geo-dispersal, signals that paleobiogeography is an area of geobiology where the links between the geo- and biosciences continue to grow.

2. The history of biogeography and the move towards a geobiologically centered science

2.1. Early approaches to biogeography

Buffon may have been the first to realize the powerful affect the Earth system had on its biota; for example, he argued "the Earth makes the plants; the Earth and the plants make the animals" (Buffon, 1749–1804 in Mayr, 1982, p. 441). Although operating in a pre-Darwinian framework, many of Buffon's writings indicate that he believed that life showed a pattern akin to evolutionary descent from a common ancestor, and then if different regions have similar species, at one time, they must have been connected (Lieberman, 2000). Buffon's view on the control the Earth exerted on life was refined by Augustin de Candolle (1817, 1820), who recognized a difference between factors that control organismal distribution on the small and large scales. Factors that operate on the small scale include temperature, light, and ecology, while factors at the large scale were related to geology (Nelson, 1978; Browne, 1983). Lyell (1832), building on de Candolle's work, recognized that the geographic ranges of species and