Historical Perspectives on Biodiversity and Geodiversity

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Introduction

The concept of geodiversity has come to recent attention largely due to the work and publications of geologist Murray Gray. In his book, *Geodiversity: Valuing and Conserving Abiotic Nature,* Gray presents a comprehensive thesis assessing the role and significance of abiotic resources upon biotic resources (Gray 2004).

A basic premise of the geodiversity concept recognizes that there is an intrinsic relationship between biological diversity and geological diversity. In principle, the geologic bedrock is viewed as the foundation of the ecosystem. Geologic resources and processes sustain much greater relationships with biotic resources and biosystems than is commonly recognized. These relationships are integrated at the ecosystem, community, species, organism, cellular, and genetic levels.

The relationship between biodiversity and geodiversity can be evaluated in modern environments or past environments (paleoenvironments). Gray's book presents a multitude of examples from around the world demonstrating the inherent relationships and patterns between modern biotic and abiotic resources. Similarly, the fossil record preserves excellent examples of relationships between ancient organisms and paleoenvironments. Research focused on paleoecological changes or trends over time may enable greater understanding of the influences that geologic resources may have exerted over biotic resources in the past.

Modern relationships

In recent decades the relationships between biodiversity and geodiversity have become more recognized by modern ecologists and natural resource specialists. An increasing number of research publications and conferences focus on the integration of modern "bio-geo systems." The relationships can be examined at the microscopic through the global levels of resolution. Below are a number of examples of how geologic resources and geodiversity influence biotic resources.

Climate. Climate can be influenced locally by geologic features and processes. Mountain ranges can impact wind speeds and directions, as well as form rain shadows. Volcanic eruptions generating large volumes of ash may be transported great distances and influence regional climatic conditions.

Hydrology. Hydrology is largely controlled by geology and geomorphology. The distribution of drainages, watersheds, aquifers, seeps, and springs are linked to lithologic and stratigraphic contacts and geomorphic features. Lakes form within calderas, karst topography, periglacial zones, and where landslides or basalt flows dam river valleys. Additionally, water chemistry, salinity, and other variables influencing biodiversity are directly associated with geologic resources.

Soils. Soils are the link between the abiotic and biotic worlds. Soil composition and chemistry are directly related to the underlying bedrock. Consequently, the distribution of many plant taxa is dependent upon the mineralogical and chemical composition of the soil. Resource management staff at Capitol Reef National Park have been able to use geologic maps and soils maps to locate rare and endangered species of cacti which grow directly and sometimes exclusively within soils developed in the Jurassic Morrison Formation.

Habitat. The diversity of geologic features and processes provides an almost infinite array of habitat types to sustain life. Changes in elevation between intermontane basins and mountain ranges typically transcend multiple life zones; geothermal springs sustain nutrients and temperatures required by certain forms of cyanobacteria (Figure 1); caves fissures, talus slopes, and gypsum sands support species adapted to survive in these geologic environments.

Biogeographic distribution. The geographic distribution of fauna and flora is well studied. Range maps for modern species are typically illustrated in natural history field guides. Geographic ranges and migration routes are often influenced by surficial geomorphology. Mountain ranges, canyons, deserts, water bodies, and other geologic features may either represent corridors or barriers to migration. Paleontological records show that historic ranges for taxa may change over time, often related to geologic factors. Continental drift and changes in sea level can result in the connection or separation of land masses, in turn resulting in either the direct competition or geographic isolation of biota.

Historical geologic and biological views

Geologists are trained to assess the past through evidence and information preserved within rock units. Discernable characteristics such as mineral composition, sediment textures, morphology, and bedding often yield detailed information regarding ancient depositional environments.

Not all paleontologists spend their careers hunting for dinosaurs. Scores of specialists have dedicated their careers in order to establish scientific credibility in the fields of paleoecology, paleogeography, paleoclimatology, and related disciplines. The opportunity to assess both geologic and paleontologic data over long spans of geologic time is powerful. Historic biological and historic geologic data discernable in the stratigraphic record may be of great benefit to the modern ecologist.

Geologic time scale. The division of geologic time is not arbitrary, but has been based upon significant geologic and paleobiologic events. Major boundaries established in the geologic time scale often represent mass extinction and speciation events. Research from around the world, which has been incorporated into the geologic time scale, consistently support the concept of changes in past biodiversity are often tied to changes in geodiversity.

Extinction. Extinction has been comprehensively examined by both modern biologists and paleobiologists (Raup and Sepkoski 1982, 1986). Despite the hopes and efforts to establish a simple explanation for extinction, such as a meteor impact, our understanding of extinction remains limited. Certainly mass extinctions, which transcend taxonomic boundaries, are somehow linked to large-scale change in abiotic resources.

Speciation. Just as biodiversity is dependent upon geodiversity, biodiversity is a function of genetic diversity. Questions pertaining to systematics and evolution are typically better addressed by way of paleontological resources than by modern species. The fossil record contains an abundance of evidence to derive phylogenetic relationships and evolutionary trends (Raup 1981).

Figure 1. Cyanobacteria in a thermal pool at Yellowstone National Park. *Photo courtesy of the author*

Origin of life. The adaptability of life is well demonstrated in the geothermal pools of Yellowstone National Park. Cyanobacteria thrive within the high-temperature, mineral-rich hot springs, demonstrating an interesting example of a close relationship between biotic and abiotic resources. The existence of high-temperature cyanobacteria in Yellowstone hot springs is considered important in research associated with the origin of life on earth and the existence of life on other planets (Reysenbach, in press).

Early biodiversity / Ediacara fauna. One of the most interesting and important paleontological discoveries occurred in a series of very old rocks in the Ediacara Hills of Australia (McMenamin 1998). Fine-grained Precambrian sedimentary rocks, deposited in a low-energy environment, preserve beautiful and delicate remains of soft-bodied organisms (Figure 2). These rare and unusual life forms provide an exceptional view of early biodiversity on earth.

The rich Ediacaran fauna overturned the long-held misconception that biological diversity during the Precambrian was low. In fact, since the discovery at Ediacara, fieldwork in Precambrian rocks has yielded numerous other localities around the world preserving these mysterious soft-bodied organisms—experiments in the early evolution of life.

Cambrian explosion. The beginning of the Paleozoic, referred to as the Cambrian, is defined by the almost sudden, worldwide explosion of life forms, in terms of both diversity and abundance. This perceived biotic explosion is more directly tied to the chemical evolution of the atmosphere

Figure 2. An Ediacaran fossil. *Photo courtesy of the author*

with sufficient concentrations of oxygen available for organisms to precipitate calcium carbonate exoskeletons. Over the past 4 billion years, life has continued to evolve, diversify, and become integrated into communities and ecosystems.

Plate tectonics / continental drift. Modern geologic theory is based upon an understanding that the Earth's crust consists of plates. These plates are dynamic and mobile. Geologists believe that the continental landmasses of today were once part of a single landmass referred to as *Pangaea.* The distribution of identical fossil genera from Permian rock units, exposed across four widely separated continents, provides strong evidence for the original proximity of these organisms and landmasses.

Mountain building / orogeny. The geographic range and migration routes of species can be defined by geologic and geomorphic features. The uplift of mountain chains, development of canyons, and expansion of lakes are examples of geologic processes which may influence the distribution and movement of biotic resources.

Visitors to Grand Canyon National Park may learn about the story of the tassel-eared squirrels. The Abert's squirrel and Kaibab squirrel are believed to be descendents of a common ancestor. With the development of the Grand Canyon, two populations of the squirrel were geographically isolated. Eventually the isolated populations evolved into distinct taxa (Figure 3).

Sea-level changes. The geologic record preserves abundant evidence of changes in worldwide sea level. Transgressive and regressive sequences, representing eustatic sea-level changes, punctuate the Paleozoic era. During the Cretaceous period, a shallow inland sea extended from the Gulf of Mexico to the Arctic Ocean. This Cretaceous sea existed for millions of years, geographically isolating populations of terrestrial plants and animals.

Continental glaciation. Four cycles of glacial advance and retreat are documented during the Pleistocene. Continental ice sheets expanded and withdrew in northern latitudes. During periods of glacial advance, a worldwide drop in sea level was experienced. The drop in sea level, combined with the expanded ice sheet, resulted in a direct connection between Alaska and Russia, referred to as the *Bering Land Bridge.*

Megafaunal migration. Changes in sea level, expansion of continental ice sheets, and the development of land bridges enabled terrestrial species to migrate into adjacent land masses. During the Pleistocene, large mammals and humans were able to migrate across the Bering Land Bridge. In turn, these mammals came into direct competition with existing species.

Pleistocene cave deposits. Pleistocene / Holocene climate changes can be docu-

Figure 3. An example of geomorphically induced reproductive isolation: the distinctive Abert's (A) and Kaibab (b) squirrel. *Photo courtesy of the author*

mented through analysis of packrat middens and fossiliferous cave deposits (Santucci et al. 2001). In classic studies undertaken by the paleontologist John Guilday, fossil-rich sequences of Pleistocene strata were excavated from sinkholes and caves of the Appalachian states (Guilday and Hamilton 1978). The stratified cave sediments yielded fossil mammal remains alternating between southern warm-weather species and northern cold-weather species. Through independent lines of evidence, it was determined that this biostratigraphic pattern was due to the displacement south of the northern boreal species during glacial advance, and the return of the southern temperate species during glacial retreat.

Great Smoky Mountains refugia. Great Smoky Mountains National Park is renowned for its rich biodiversity. This fact has been confirmed through comprehensive biological resource inventories in recent years. Part of the historic biological story at the park is tied to the expansion of the continental ice sheets during the Pleistocene. During glacial advance, the more northern boreal and temperate species were pushed south and were eventually established themselves within Pleistocene refugia in the southern Appalachians.

The Darwinian approach

In consideration of this geodiverse perspective, perhaps it is worth reflecting on Charles Darwin's contributions to natural science. Darwin proposed new ideas put forth in *On the Origin of Species* and other publications based upon observations and data accumulated on a global scale. Over the past half-century, natural science has shifted its focus in education, research, and funding away from the Darwin-style big-picture approach, to an emphasis on the cellular, genetic, and molecular levels of biology.

Unquestionably, we have benefited from the scientific understandings gained through this microscopic and submicroscopic trend in natural science. However, the cost has been a diminished ability for many scholars and students to take on the multidisciplinary, big-picture questions. In turn, we have migrated toward anthropocentric and biocentric strategies for natural science.

Odds are that one would more likely recognize the influence of geodiversity on biodiversity if one lives in the shadow of a volcano, along an active fault line, or in the path of an advancing glacier.

As we continue to integrate biotic and abiotic components of the natural world into our conscience and routinely recognize that geology is the foundation of the ecosystem, then we may come to fully understand that "Earth and its inhabitants have evolved together."

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