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FOR MY FAMILY

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geologic environments

The history of organisms runs parallel with, is environmentally contained in, and continuously interacts with the physical history of the Earth. (George G. Simpson, 1963)

Scientific explanation is often expressed in "if . . ., then . . ." statements. That is, "if" certain necessary and sufficient conditions exist, "then" particular events will occur. For a simple example: If water is cooled to 0°C at one atmosphere of pressure, then it will undergo a change in state from liquid to solid. Similarly, the study of the Earth's environments is concerned with establishing if–then relationships by determining the necessary and sufficient conditions required for diverse geologic phenomena.

There is a broad range of geologic environments that demands inquiry or definition. What are the pressures and temperatures deep in the Earth's crust? What assemblages of silicate minerals will be at equilibrium under these temperatures and pressures? What are the states of stress and strain in active mountain belts or in stable continental blocks? What conditions of climate and habitat favored the invasion of land by the first amphibians? The investigation of these and many other geologic environments is being actively pursued by Earth scientists today.

Although research in recent and ancient geologic environments and their associated geologic processes has proliferated lately, the foundations of environmental analysis are as old as the science of geology itself.

One of the earliest controversies in geology, almost two centuries ago, concerned the geologic environment responsible for the formation of basalt, a dark, fine-grained rock composed of various silicate minerals. Abraham G. Werner, a German mineralogist of the eighteenth century, insisted that basalt, like all other rocks, was deposited from a "universal ocean" that once covered the earth. Werner denied that rocks could form in any way except as chemical precipitates from this universal ocean. Two of Werner's students, D'Aubuisson de Voissins and Leopold von Buch, influenced by the work of a French geologist, Nicholas Desmarest, realized that some rocks, basalt in particular, had an igneous origin—that is, they had crystallized with the cooling of a molten rock mass. For many years the young science of geology was divided into two bitterly opposed camps: the "Neptunists" who argued that all rocks were water-laid, and the "Plutonists" who maintained that certain rocks owed their origin to the eruption of hot masses of molten rock to the surface from below the Earth's crust. The issue, of course, was the correct geologic environment for different kinds of rocks found at the Earth's surface.

Modern interest in analyzing geologic environments has been spurred on by the development of new investigative tools, like the electron microscope; by the formulation of fresh theories, like plate tectonics; and by the extensive observations of active geologic processes as they occur naturally in the field or experimentally in the laboratory.

PALEOECOLOGY AND ENVIRONMENTAL STRATIGRAPHY

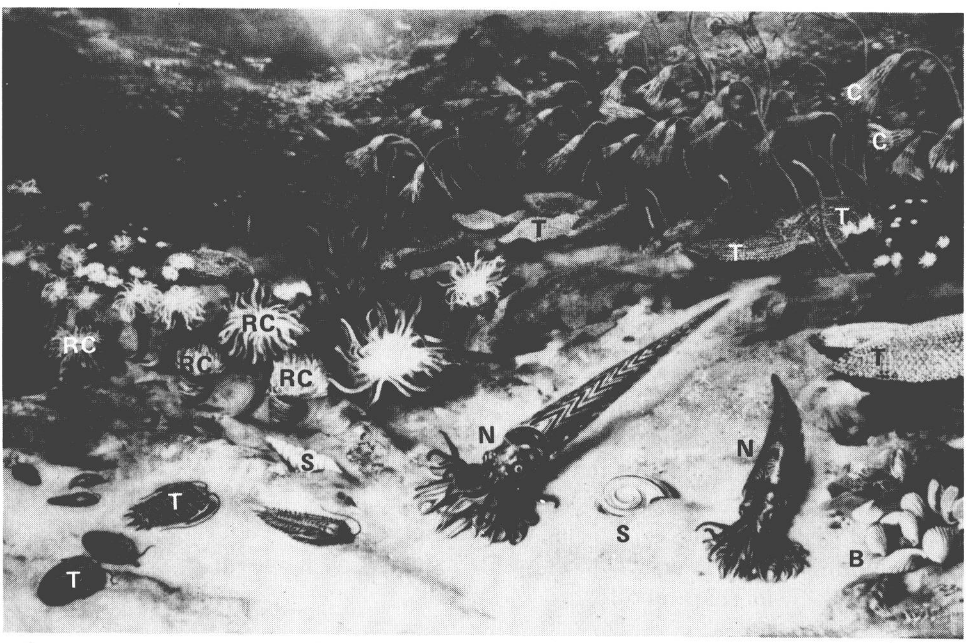
This volume considers one part of the broad spectrum of geologic environments, that of recent and ancient sedimentary environments and their associated organic remains. The goal of these investigations is to understand the complex interrelationships between ancient organisms and their habitats. This area of Earth science is called *paleoecology*. It is related to the field of *ecology*, which is concerned with explaining the interaction of *living* animals and plants with their physical, chemical, and biological environment. Ecology is an established science with its own body of data, concepts, and principles.

Ecology itself is subdivided into two areas: *synecology* and *autecology*. Synecology attempts to relate the abundance and distribution of *whole faunas and floras* to particular environmental regimes. Autecology seeks to explain the interactions of a *specific group* of organisms within the fauna and flora with local environmental conditions. For example, the synecology of organisms in a Pacific coral atoll describes which organisms feed on other organisms, how the animals and plants cope with the strong surf, and the role that sunlight and nutrients play in supporting the reef dwellers. The autecology of a particular species of sea urchin, on the other hand, will describe in what protected part of the reef the animal lives, how it feeds, and other relevant facts that distinguish it from other species in the atoll.

In one sense, then, paleoecology is simply ecology projected backward in time. Thus the paleoecologic study of a Paleozoic coral reef in Illinois will interpret the particular marine conditions that favored the proliferation of rugose and tabulate corals, pentamerid brachiopods, massive bryozoans, delicate crinoids, and robust trilobites; how the organisms interacted with each other and tolerated the physical and chemical factors present in the environment; and how individual species gathered food and occupied living space on the sea floor (Fig. 1-1).

But paleoecology, having a significant time dimension, can add another level of inquiry not usually found in most ecological studies. The analysis of how a given fauna and flora, whether a community of organisms in a coral reef, desert, or the deep sea, came to have the structure or organization it has. In other words, how the community evolved through geologic time. For example, has the basic ecologic structure of a modern coral reef been the same since the first appearance of coralline organisms, or have coral reefs evolved not only in terms of their constituent species but also in terms of how those species interacted with each other? It is this level of paleoecological inquiry, usually called *community evolution*, that intrigues many students and specialists today.

FIG. 1-1 This reconstruction of a Silurian coral reef community shows the inferred life habits of colonial tabulate corals (TC), solitary rugose corals (RC), crinoids (C), nautiloid cephalopods (N), trilobites (T), brachiopods (B), and snails (S) some 400 million years ago. Such a reconstruction represents graphically what the science of paleoecology seeks in part to describe and explain.



But there is another sense in which paleoecology is not merely ecology projected backward in time, owing to sparse preservation of many ancient organisms. Those organisms that are preserved as fossils are often extinct, so that we have no direct way of knowing what their vital needs were. Moreover, various environmental factors in the ancient habitat, such as temperature, salinity, and humidity, are not directly recorded in the existing sedimentary rock. Consequently, paleoecologists have been forced to develop their own techniques and procedures for inferring from the enclosing rock matrix what the original environmental conditions may have been, as well as for estimating numbers of individuals and kinds of organisms in the ancient environment. This leads us to the notion of *environmental stratigraphy*.

The intimate association of fossil organisms with sedimentary rocks demands that paleoecologists interpret the origin of the rock matrix as well as the presence of the included fossils. In fact, by using composition and size of sedimentary grains, primary structures, and other internal evidence contained in a sedimentary rock, paleoecologists can reconstruct the depositional environment of the rock. Such a reconstruction gives us information, independent of the fossils themselves, about the conditions under which the ancient organisms presumably lived and died or, at least, certainly were buried.

Because organisms have evolved throughout geologic history, we cannot uncritically interpret the past ecology of fossils by comparison to their living descendants. Even worse, many fossils are extinct without present-day close relatives. Fortunately, however, the kinds of rocks that form in a great variety of sedimentary environments have not become extinct. Hence, we can readily apply knowledge of recent environments to ancient rocks, and thereby define the boundary conditions, as it were, under which the fossils buried in the rocks probably lived.

ENVIRONMENTAL RECONSTRUCTION AND THE EARTH SCIENCES

Although it is intrinsically interesting to discover the kinds of environments in which various ancient fossil organisms flourished, paleoecology makes other important contributions to related geological fields of inquiry.

Paleoecology contributes most directly to *paleontology*, which is concerned with the history and evolution of life and therefore is a natural part of that science. For paleontologists seek more than merely a description of the various kinds of animals and plants that have lived in the past. They also wish to know why particular groups of organisms have evolved as they did and what environmental pressures the organisms were adapting to. To understand organic evolution, it is just as critical to know the habitats and habits of an organism as it is to know its shape and form.

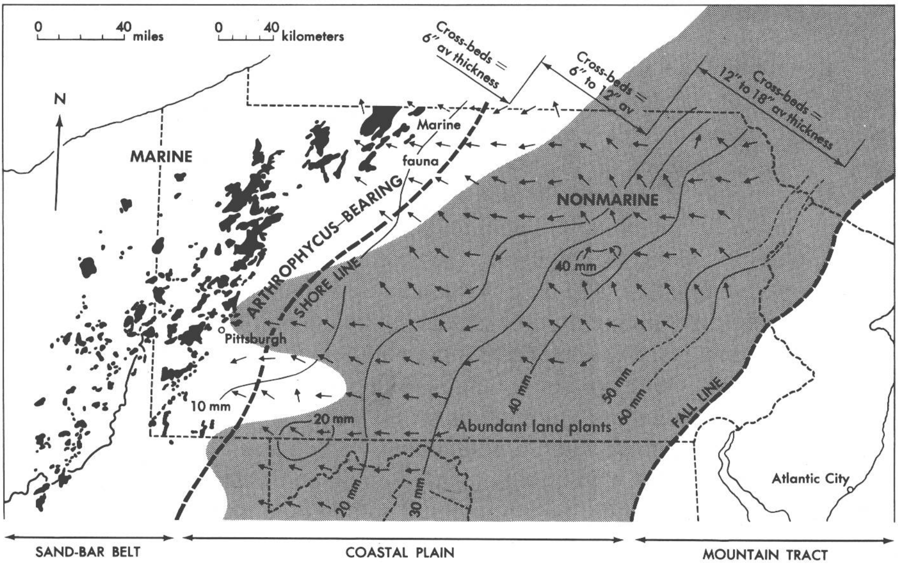


FIG. 1-2 Detailed analysis of the Pocono Formation, Mississippian Period, of the central Appalachians. This study by B. Pelletier included many aspects of this sedimentary rock, including grain size and composition, orientation of cross-stratification and plant remains, maximum size of quartz pebbles, sand/shale ratios, and fossil content. Pelletier was able to demonstrate that the Pocono Formation was a nonmarine, coastal-plain sediment derived from sedimentary rocks and low-grade metamorphic rocks in a source area located near Atlantic City, New Jersey. Sediment transport was to the west and northwest; the ancient shoreline trended northeast across Pennsylvania and was located some 25 miles east of Pittsburgh. Offshore the Pocono Formation is a marine shale and sandstone that contains abundant burrows ("Arthrophycus"), occasional brachiopods, and a few clams and snails. Sand/shale ratio greater than two is shaded; maximum pebble diameters in millimeters are shown by contours; current directions are shown by small arrows. Note relation of oil pools (black) to the sand bar belt. (After B. Pelletier, 1958.)

Paleoecology provides information not only regarding the distribution of ancient lands and seas, but also about what sorts of terrestrial and marine environments these might have been. Thus, besides indicating the position of former shorelines, paleoecology can help determine past climates, what kinds of landscapes existed where, and the prior location of ancient marine habitats like deltas, lagoons, and continental shelves. Such information is valuable to geologists attempting to describe and explain the long course of Earth history. In more practical ways, paleoecology contributes to the exploration for oil and gas trapped in marine sedimentary rocks. These fossil fuels accumulate from the decomposed remains of microscopic marine plants in certain types of porous and permeable rocks, often sand-bar deposits and coral reefs. Prediction of just where such deposits might occur depends on correct interpretation of the paleoecology and environmental stratigraphy of sedimentary strata lying deeply buried within the Earth's crust (Fig. 1-2).

ENVIRONMENTAL CLASSIFICATION

In defining and reconstructing ancient sedimentary environments and the paleoecology of the fossils that lived there, we have to consider the kinds of sedimentary environments found on the Earth today. The classification presented here is essentially based on physical criteria, although by implication chemical factors are involved as well. Moreover, since virtually all environments are populated by a variety of species adapted to the particular demands imposed by different environments, by extension, these environments will also presuppose certain biological factors. The classification of environments must be, of course, somewhat arbitrary, because the boundaries of one environment are not clear-cut from another. Nevertheless, certain environmental settings are quite distinctive, and these major categories are indicated below.

For each sedimentary environment it is useful to identify the *medium* of deposition (marine, freshwater, or subaerial), the *process* that deposits the sediments (waves, tides, rivers, wind, and so on), and the *place* of deposition (beach, deep-sea floor, tidal flat, lake bottom, desert, and so on). Keep these parameters in mind during our discussion of particular sedimentary environments.

Marine Environments

The environments that begin at the sea's edge can be broadly subdivided into two major realms: the *pelagic*, which refers to the water mass itself, and the *benthic*, which refers to the substrate of sediments at the bottom. The pelagic realm can in turn be subdivided into the water that lies over the continental shelves (*neritic* environment) and the water mass that lies beyond the continental shelves in the deeper ocean basins (*oceanic* environment). The oceanic water mass can be still further differentiated into various other subenvironments according to depth of water.

The benthic realm has subdivisions, too, which correlate more or less with the pelagic subdivisions. Thus, the *sublittoral* environment includes the sea bottom on the continental shelves, and hence is overlain by the neritic pelagic environment. The sea floor beyond the continental shelves includes the *bathyal*, *abyssal*, and *hadal* regions, which correspond more or less to the continental slope, the deep-ocean floor, and the deep-sea trenches, respectively.

That part of the sea floor that lies within the range of high and low tides is referred to as the *littoral* or *intertidal* environment. The narrow fringe of land that lies above the normal high water mark but is still within range of the sea's influence (salt spray, storm waves, or unusual high tides) is defined as the *supralittoral* environment. These various marine environments are illustrated in Fig. 1-3.

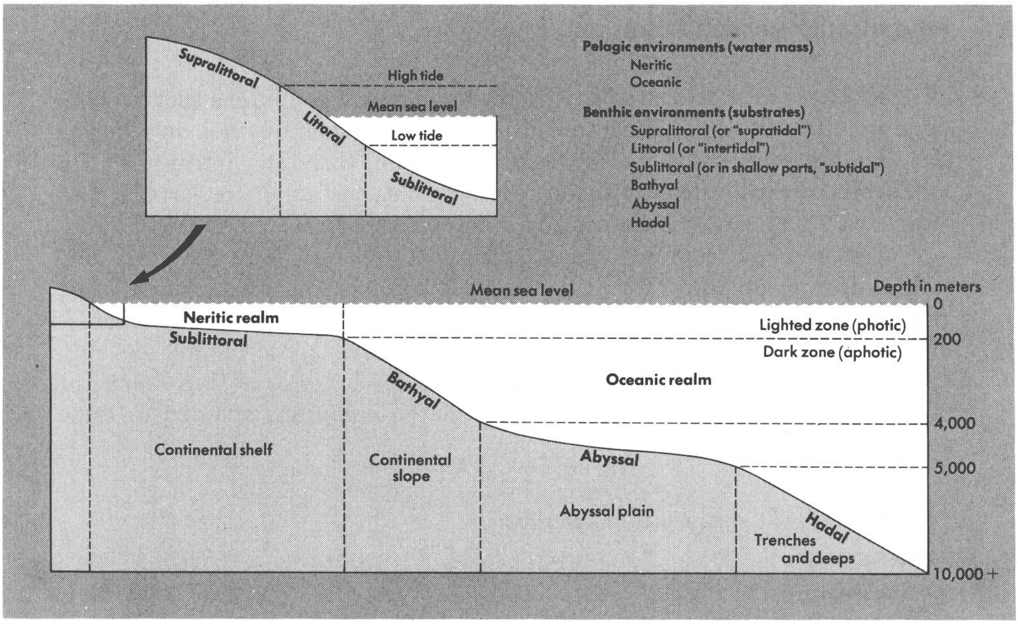


FIG. 1-3 Major marine environments as commonly defined. Although boundaries are not precise, note the general correspondence of sublittoral, bathyal, abyssal, and hadal environments with continental shelf, slope, abyssal plain, and trench. The penetration of sunlight decreases with water depth, being virtually absent in waters deeper than 200 meters, where it is always dark.

Terrestrial Environments

Terrestrial environments lying away from the sea's margin are considerably more diverse and individually more variable than marine environments. For example, except for very shallow and isolated bodies of the sea, marine environments do not have the great fluctuations of temperature that occur on land.

On the land surface itself there are various aquatic environments, such as the *lacustrine* (lakes and ponds) and the *fluvial* (streams and rivers) as well as *swamps* and *marshes*. Two particularly important ecologic factors in these aquatic environments are the amount of water movement and the ratio of water surface area to water depth. Water movement, or current, influences the circulation of oxygen and nutrients. Where the currents are especially strong, the local inhabitants may have special adaptations that enable them to move upstream or that prevent their being swept downstream and eventually even out to sea. The ratio of water surface area to water depth influences the amount and distribution of dissolved oxygen within the water mass. In shallow streams and ponds there is usually sufficient oxygen distributed throughout the water to support a rich flora and fauna. Deep lakes, by contrast, may have inadequate quantities of dissolved oxygen because of a relatively small water surface area in contact with the atmosphere and a slow rate of circulation of the water mass as a whole. Consequently, many deep lakes will have bottom waters so low in oxygen that few, if any, organisms will be able to live there.

In nonaquatic terrestrial environments, physical conditions such as temperature, humidity, wind, and sunlight fluctuate considerably not only during the year but even daily. These environments are, therefore, intrinsically far more variable than terrestrial aquatic environments and still more variable than marine environments where ecological conditions are generally more constant.

Besides these temporal variations in physical conditions, there are also rather rapid geographic differences related to changes in topography, latitude, proximity to the oceans, and so on. The result is a number of widely different dry-land habitats, including deserts, semiarid plateaus, arctic tundra, and rain forests. These various habitats can be characterized in terms of their dominant physical conditions together with the associated organisms adapted to these conditions.

Table 1-1 Major Environments of Deposition

- TERRESTRIAL
  - Subaerial
    - Landslide and talus
    - Dunes and desert pavement
  - Lacustrine
    - Lakes and ponds
    - Swamps
  - Fluvial
    - Alluvial fans
    - Rivers and streams
    - Flood plains
    - Deltas
- MARINE
  - Nearshore (subaerial to subaqueous)
    - Marshes
    - Dunes
    - Tidal flats
    - Beaches
    - Deltas
    - Lagoons
    - Estuaries
  - Offshore
    - Shallow subtidal (inner continental shelf)
    - Deep subtidal (outer continental shelf)
    - Continental slope
    - Deep sea
  - Organic buildups
    - Wave-built (e.g. shell mounds)
    - Organism-built (e.g. coral reefs)