The Making of Paleogeographic Maps.

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The writer has often been asked what the principles are that guide him in the making of paleogeographic maps, and he has frequently answered this question in lectures to his graduate students and others. Teachers of Historical Geology, however, have expressed a desire to have such information placed before them in printed form, and this paper has been written to meet their wishes.

Geography and paleogeography. — The geography of to-day can only be understood in the light of the geologic past, and on the other hand, paleogeography can only be deciphered when guided by a knowledge of the causation of the changes in the geography of the present. Geography has been defined as the science which describes the earth's surface, including the distribution of the living things upon it at the present time, and more especially of man and his cultural works. Paleogeography, on the contrary, treats of the succession of geographies of the past, i. e., the prehistoric geographies as known to Paleontology and Geology. It seeks not only to describe and picture the shapes and interrelations of the various marine areas and the lands, but as well to discern, on the latter, the leading physiographic forms; the volcanic, desert, and glacial areas; the major drainage lines; and, throughout time, the paleoclimatology. For the seas and oceans, the connections are worked out on the basis of the fossils entombed in the sediments (paleobiogeography), which likewise indicate something about the temperature, depth, and salinity of the water. In other words, paleogeography is the synthesis of the several earth sciences based on the record of the rocks of the earth's surface.

The geographer's methods of observation are direct, for he measures and describes what he sees, but the geographic and organic relations of any given geologic time are discerned by the paleogeographer mainly by indirect methods; he sees no actual seas and oceans, no hills, valleys, mountains, or rivers, no actual living things of any past time, yet the paleogeographic record of all these is hidden in the rocks and fossils, and can be read by him as easily as the antiquarian or archeologist deciphers, in his unearthed relics, forgotten civilizations and languages, or wholly unknown human cultures.

Since it has taken the geographers more than two thousand years to bring their science to its present high stand as depicted on modern maps and described in modern books, it follows naturally that the present knowledge of paleogeographers must be sketchy rather than detailed, and in a way comparable to the geography of the ancients. This conclusion becomes all the more apparent when we realize that the sciences of Geology and Paleontology began as such but a little more than a century ago, and that large parts of some of the continents still remain almost unknown geologically. The paleogeographers therefore picture to us only what geologists and paleontologists know. As yet the geographies of the past are all much generalized and must long remain more or less inaccurate; nevertheless we are learning rapidly how to picture on maps the paleogeographic values ascertained by the geologists and paleontologists.

It was natural that the term "paleogeography" should be readily suggested by such older usages as "ancient geography" and "geologic geography", and so we find T. Sterry Hunt coining the word for the first time in 1872 in his article entitled "The Paleogeography of the North American Continent" (Jour. Amer. Geog., New York, IV, p. 416). He says:

"The student of organic fossils constructs from their history the sciences of *paleophytology* and *paleozoology;* and we may also, from the records of the attendant physical changes, construct what may be appropriately named *paleogeography*, or, the geographical history of these ancient geological periods."

The term, however, did not come into wide usage until subsequent to 1896.

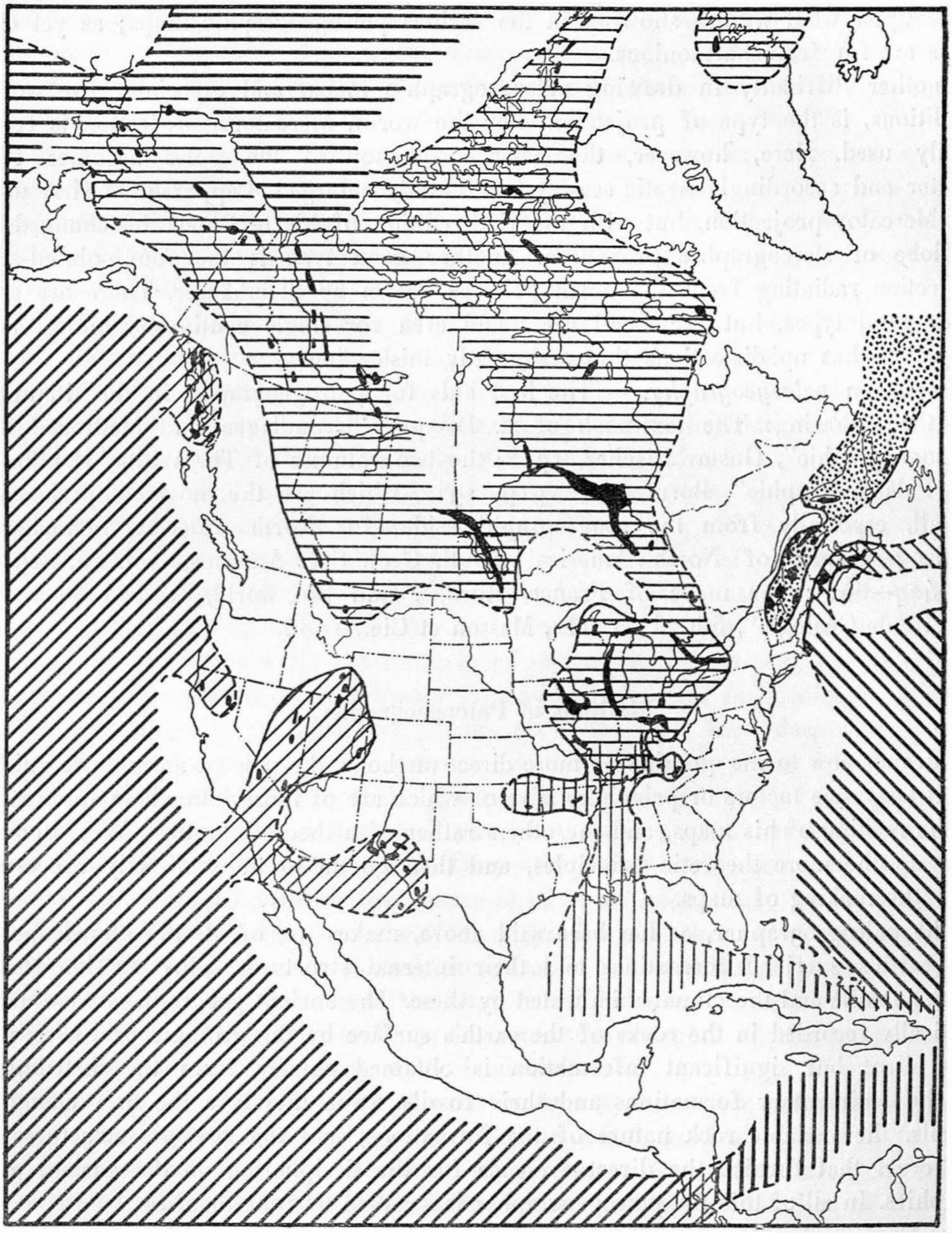
History. — Now let us look a little into the history of paleogeography. It appears that the French geologists were the first to take up this study, and De Lapparent the first to disseminate it widely. Élie de Beaumont, in his geologic lectures at the College of France, used to outline to his students, as early as 1829, the relation of the lands and seas as shown by certain of the better known formations in the center of Europe. His first published map appeared in 1833, but it was mainly his students who spread the knowledge in printed maps. In America, the first to show paleogeographic maps was the Swiss geologist, Arnold Guyot, in his Lowell lectures of 1848, but apparently the first such maps to be published in this country were the three included in James Dwight Dana's epochal work of 1863, the "Manual of Geology". Of world paleogeography, Jules Marcou published the first map in France in 1866, but it appears to have attracted little attention, the most celebrated of the early attempts along world lines being the widely known map published by the Viennese paleontologist Neumayr in 1883, and based on ammonite distribution. In 1894 Karpinsky issued seventeen maps relating to the historical geology of western Russia, which proved, as had nothing before, the periodicity of continental flooding by the oceans. Even earlier, Jukes-Browne in his "Building of the British Isles", 1888, showed fifteen maps, and Canu in 1896 put out an atlas with fifty-seven maps relating to France and Belgium. Then in 1910 Schuchert in his "Paleogeography of North America" published fifty maps. The book that has had the greatest influence in this branch of Geology, however, is De Lapparent's text-book, "Traité de Géologie", the fourth edition of which (1900) had twenty-one maps of France, thirty of Europe, and twenty-two of the world; the fifth edition, of 1906, had twenty-five of France, thirty-four of Europe, and twenty-three of the world, besides ten from other authors.

Since 1833 there have appeared something like 1000 different paleogeographic maps, and of this number about 450 relate to North America. Nevertheless, paleogeography is still in its infancy; practically all of the maps embrace too much geologic time, the ancient shore lines are much generalized and are drawn in sweeping curves unlike modern strands with their islands, bays, and headlands, the ancient lands are usually drawn as almost featureless, and only rarely do the maps indicate the areas of probable mountains, the volcanoes, and the drainage. Moreover, no one has attempted to picture the geographies back of the Cambrian — a vast time almost devoid of fossils. This means that all of our attempts are limited to the shorter latter half of geologic time, which alone has an abundance of fossils in its formations.

Paleogeographic difficulties. — It was stated above that all paleogeographic maps embrace too much geologic time. Hence none can give an exact geographic picture of any one time in the sense that maps showing the present geography do, since the latter embrace the conditions of our time as seen during the life of an individual. To get at the significance of these statements, however, we must analyze them still further.

Geology used to say that the age of the earth is of the order of about one hundred million years, but ever since the rate of disintegration of radium-bearing minerals became known, it has been clear that geologic time is ten to fifteen times longer. As more than one half of this time lies back of the Cambrian, we have at least five hundred million years of geologic time since this period, with an abundance of fossils to help us to decipher the succession of paleogeographies. Accordingly, if we make one map for each million years, we should eventually have five hundred, and yet of no continent are there at hand as many as seventy-five successive maps, while of the world there are fewer than thirty-five for all the time since the beginning of the Cambrian. Even one million years is surely too long a time to give a true picture of the paleogeographic conditions of a given time, and it seems safe to predict that some day paleontologists will aim at making more than five hundred maps for all North America and two or three times as many more depicting the spread of faunules over limited areas.

All paleogeography is drawn over the geographic base of the present, a method of illustration started by the first paleogeographer, Élie de Beaumont, and followed by everyone since. At present it is the only correct method, because we can not understand the ancient, but tentative geographies except on the base of the present one; maps drawn by plotting the present position of the fossils and then taking away the present continental outlines, as the writer has done on more than one occasion, become meaningless. And yet, as everyone knows, the modern base of the continental areas is a greatly foreshortened one in all the places where the roots of the ancient mountains and the peaks of the modern ones occur, and consequently the geography of the present gives a more or less erroneous picture of the actual size and shape of the ancient seas in the areas older than the times of mountain making. These crushed areas are variably wide, in the Appalachians now around 150 miles, while the Cordilleras of western North America are usually not less than 500 and not more than 1000 miles across. Previous to the Permian,



however, the Appalachian area must have been between 100 and 200 miles wider, while that of the Cordilleras must have shrunk something like 300 to 500 miles since the Devonian. It is these folded and overthrust areas that eventually will have to be smoothed out in order to give true areal relationships to the paleogeographies older than the times of orogeny. This matter is discussed at greater length by Dacqué (1915, pp. 370—375). For the present, however, this need not be done excepting for special cases, since now it is more important that we first agree upon what we are showing in the various paleogeographic maps; as yet our maps are far from harmonious.

Another difficulty in drawing paleogeographic maps, and especially for world conditions, is the type of projection. For the world, Mercator's projection is commonly used. Here, however, the enlargement toward the poles becomes ever greater and accordingly Arctic seaways are unduly enlarged. Lapparent at first used the Mercator projection, but with the fifth edition of his text-book he changed to a globe or stereographic projection. Another good type is the four-pointed-star projection radiating from the north pole, as drawn by Steinhäuser. There are still other good types, but for small areas and even for single continents, almost any projection has no distortions that are greatly misleading.

Books on paleogeography. — The best aids for paleogeography in the literature are the following: The text-book of E. Dacqué, "Grundlagen und Methoden der Paläogeographie", Gustav Fischer, 1915; the two volumes of Th. Arldt, "Handbuch der Paläogeographie", Bornträger, 1919—1922, which are the most comprehensive of all, especially from the zoogeographic side; for North America, Schuchert's "Paleogeography of North America" (Bull. Geol. Soc. America, vol. 20, 1910, pp. 427—606); for maps of France, Europe, and the world, A. de Lapparent's "Traité de Géologie", 5th ed., 3 vols., Masson et Cie., 1906.

Methods of Paleogeography.

Turning now to the question of more direct methods, the paleogeographer is guided by at least nine factors or principles, five of which are of more immediate application in the making of his maps, and the others rather of a theoretic nature. We will first take up the more theoretic principles, and then go on to those directly concerned with the making of maps.

The paleogeographer, as has been said above, makes use of all the knowledge of the earth's surficial formations and their internal structures, plus the knowledge of the fossils and the climates indicated by these. The ancient geographies were automatically recorded in the rocks of the earth's surface by the geologic processes, and this silent but significant information is obtained chiefly from the distribution of the sedimentary formations and their fossils. It is therefore the ever changing fossils, the variable rock nature of the formations, and the geologic structures of the crust that furnish the direct evidence for the deciphering of the ancient geographies. In all of this the paleogeographer is steadied by four theories:

1. *Uniformitarianism.* — The laws of nature have always operated more or less as we see them doing now, although not necessarily with their present intensity; hence in our work of deciphering we are guided by the results we see to-day. In other words, paleogeographers, like geologists, are conformists or uniformitarians, followers

of a doctrine first propounded by Hutton more than a century ago, and later put into working order by Lyell.

2. *Permanency of the Earth's Greater Facial Features.* — The first question that a paleogeographer asks himself is: Have the continental masses and the oceanic basins always been as we see them to-day, and have they always held their present relations to one another? This question is fundamental in paleogeography, for if there has been a repeated or irregular interchange of these areas, the discerning of the ancient geographies would be most difficult if not impossible. By "repeated interchange" is meant the changing of oceanic basins to dry land and the sinking of continents at different times to below two miles of depth and their rising again into dry land. If, on the other hand, there has been more or less permanency in the position of the continents and oceanic basins, then the work of the paleogeographer is much simplified.

Because most of the continents are deeply buried beneath strata laid down by marine waters, the older geologists naturally came to the conclusion that the deep oceans had often interchanged places with the continents. They did not then know that the fossils first, and then the sediments, would also indicate depth of water, and temperature as well. Accordingly, Sir Charles Lyell, whose text-books had wide influence, taught that "every part of the land had once been beneath the sea, and every part of the oceans had once been land". We agree with Lyell that, at one time or another, every part of the lands has been beneath *shallow* seas, but as for the rest of his dictum, all geologists now hold that there is not the slightest evidence present on the lands to show that the continents have ever been submerged beneath great depths of oceanic water. And that every part of the oceans once has been land, there is not the slightest direct evidence to prove. Geophysical and geological studies, on the contrary, all show that the oceans of to-day have been deep-water basins almost since their origin, or at least since before Cambrian time, that they have always remained in essentially their present places, and finally that they have apparently grown somewhat deeper, and somewhat larger as well, at the expense of the continents during the geologic ages. These conclusions are at once demonstrated by the fact that the crust beneath the oceans is of rocks about three per cent heavier than those of the continents, and therefore on the basis of the law of isostasy which has to do with the balance of masses, there can be no interchange between them as to their relief. On the other hand, the lands rarely have any abyssal or oceanic deposits, and even those known to be present near the margins of the continents do not cover more than one per cent of the land surfaces.

In regard to the possibility that the continents may have been displaced, or have slid about horizontally, Geology appears to be coming to hold that this may be true to a limited extent; and that something of a compensatory nature has gone on is demonstrated by the fold-mountains. On the other hand, the distribution of the best known faunas of the Paleozoic and Mesozoic shows clearly that the continents since at least the Cambrian must have been about the present distances apart, for if they had been much nearer together the number of species common to two continents would be far greater than it is known to be, i. e., rarely exceeding five per cent.

We now know that the North American continent has been more or less widely flooded by the oceans at least seventeen times, and that these shallow-water floods varied in extent between 154,000 and 4,000,000 square miles. At times there were vast inland seas, many of them far greater in areal extent than the present Hudson Bay. These facts show how constantly the geography of the geologic past has been changing. To-day we are living in the first phase of a new cycle and a new era, and the oceans have already begun their spread over the continents, as seen in Hudson Bay, the North and Baltic seas, and the more or less wide extension of the shallow seas over the shelves that border all continents.

Here we may digress a little to say that by *seas* is meant those oceanic waters that spread with limited depths over the continents. These waters in paleogeography are called *epicontinental seas;* when such are restricted to the margins of the continents, they are called *shelf seas;* when they spill more or less widely over the interior basin areas, they are *epeiric seas;* while the long and narrow ones immediately on the inner side of the borderlands are the *geosynclinal seas*. All of these basins are thought to have had shallow waters, as a rule under 500 feet of depth. Therefore their deposits are *littoral* when near shore, and farther away are *neritic;* both series of deposits are, accordingly, within the zone of wave action and sunlight penetration, with greatest abundance of bottom life. It is the rarest exception that the epicontinental seas have deeper waters approaching those of the bathyal regions of the oceans.

Finally, it should be said that the epicontinental seas do not necessarily everywhere deposit sediments continuously, because in certain areas the currents and wave action are so strong as not to permit the silt and muds to accumulate and become cemented. Where tidal action is strong, as in the littoral regions and over the submerged "ridges", and in certain places in the oceanic depths, the bottoms are swept clean of all the finer sediments and these are piled up elsewhere, on the "banks" or in the deeper offshore waters where the currents and wave actions cease.

3. *Cyclic Nature of Geologic Phenomena.* — It is now a demonstrated fact that the oceans have repeatedly transgressed the continents and as often have left these areas. Usually, one such completed movement takes place in the duration of a single period, but some of the periods, as now delimited, have two and possibly three floodings. Again, minor mountain makings (= disturbances) often appear during the latter half or last third of the periods, with greater ones (revolutions) closing the eras. In all of this we see that crustal compensation takes place periodically in all continents, with the result that the geologic processes of the lands proceed from rejuvenated youth to maturity, from high lands to low lands, and in many continents from small to greater areas of dry lands, and from small to vast floodings.

4. *Increase in Volume of Water with Time.* — We now postulate that the volume of water on the surface of the earth has increased with geologic time. This modern view is opposed to that of the older geologists, who held that there was at first a universal ocean over the earth's surface, and that it originally had far more water than is now visible, since great quantities had soaked into the cooling earth subsequent to its astral condition. This last conclusion is only partially true, the amount

so absorbed being relatively small. It is known, through deep mining and oil well borings, that the stratified rocks tend to become drier with depth. Furthermore, we know that most volcanos, when in action, are delivering to the earth's surface new waters (juvenile waters), which have become freed by the rock differentiations and chemical changes deep within the crust. The volcanoes were most active in the earliest history of the earth, and therefore the oceanic waters increased in volume then far more quickly than subsequently. The writer believes that probably three fourths of the present oceanic waters were in existence at the close of the first half of the earth's history (Proterozoic), and that the remaining twenty-five per cent has been added since. However, this postulate of an increasing hydrosphere is not known to have markedly affected the ancient geographies.

5. *Diastrophism.* — Now we must consider another condition of the earth's surface that has an important bearing on the making of paleogeographic maps, namely, diastrophism. Under diastrophism are comprehended all the movements of the earth's surface, and this means that the oceanic bottoms, as well as the dry lands, have moved; in consequence, the oceanic level in relation to the lands must have been in repeated movement up and down. Geologists now clearly understand that the stratigraphic record is discontinuous, that it is much interrupted by "breaks", and that the local sequences are very variable. What any geologist sees is therefore the local records, and these fragments Historical Geology pieces together to make one more or less continuous story. Everywhere the geologic sequence is full of these "breaks" or "intervals" of time, when no local record was being made other than that of erosion, which of course means removal of record. These breaks or intervals are as a rule not general and the fossils show that the recording goes on now here and now elsewhere, and that it is continuous probably only in the ocean basins that are forever inaccessible to geologists.

The continents are spoken of as the positive or rising elements of the earth's surface, because the sum of their crustal movements is positive or upward. It is well known, however, that parts of them are more positive than others, i. e. certain areas have a local tendency to rise more or less frequently and to variable heights. The most striking of these positive regions are the marginal areas of the continents, called *borderlands*. These have for long times a decided, but pulsatory, tendency to rise and renew their highland form, and are therefore among the most striking of the geanticlines. On the other hand, the interiors of the continents have far less dominant, smaller, and lower subpositive areas, which reappear time and again as domes and depressed geanticlines. For these periodically rising areas the paleogeographer should ever be on the lookout, since they indicate to him the position of the dry lands, hence also the locations of shore lines and the sources of sediments.

It is, however, not an easy matter to locate with exactness the actual positions of the shore lines; in paleogeographic maps in which the scale is small, and especially those seen in octavo books, the solidly drawn lines, which indicate the best known shore lines, are probably nearly always in error anywhere from 5 to 25 miles, and where the lines are broken they may be 50 miles out of place or altogether wrong. The presence of sandstones passing into conglomerates and the thinning out of formations against the positive areas are among the surest indications of nearness to shore lines.

Geology now affirms that geosynclinal areas, once uplifted into fold-mountains, have a tendency to be re-elevated time and again, and therefore to remain as continuous lands. It is rare to find places where the oceans have spread completely across the site of a Paleozoic mountain range, or one of younger age, but it is not so rare to find that Paleozoic or younger seas have spread completely across mountains of Proterozoic or Archeozoic time. A most wonderful transgression of this nature is recorded in the Grand Canyon of the Colorado River, where Cambrian seas have spread horizontal strata across the upturned and worn-down roots of mountains that were uplifted at different times during the Archeozoic and Proterozoic.

In all the continents there are more or less large areas that have the most ancient rocks known to geologists, and upon whose flanks lie younger and younger strata as one proceeds away from them. These are known as the nuclei or shields of the continents, the parts that were elevated earliest into mountainous areas and welded into very resistant masses. Since their final folding and peneplanation, they have been rarely transgressed by the seas, and hence are the longest enduring lands, which guide the paleogeographer in his mapping of the seaways about them.

6. *Areal Stratigraphy.* — The units in paleogeography are the geologic formations and faunal zones, and as the first essential in mapping is to determine the places of the transgressing seas, it follows that this cartography is most concerned with the sediments of marine deposition. Accordingly, the "continental deposits" must be clearly distinguished from those of the seas, and this is done chiefly through the entombed fossils, though fresh-water deposits are often devoid of such life records and they are usually lacking in those made by desert conditions. The present geographic distribution of the formations is the first basis for deciphering the geographies of the past. These formations are masses of rock, either stratified or unstratified, of one kind or of various kinds, formed in the seas and oceans or on the lands, with or without fossils, and composed either of sediments or igneous materials. Just how many formations there are in North America since the beginning of the Cambrian is unknown, but the well known and more or less widely spread ones probably exceed several hundred. Some day there will be more than 500 faunal zones, but so far the writer has been able to gather material for only about 125 maps covering the whole of North America.

One of the greatest drawbacks in making paleogeographic maps is the areas where the formations at the surface go beneath younger ones and do not reappear on the other side of the basin of deposition. Even more deterrent are the great lava fields, as for instance those of the Columbia and Snake rivers, which cover at least 150,000 square miles of older strata; or the regions of great bathyliths, such as the one of the Coast Range of British Columbia, where the older formations have been swallowed up by the igneous masses or have been eroded away since their rising. In all these areas one is dependent in his studies upon the distribution of the formations in adjacent regions with synchronous faunas.

7. *Superposition.* — The geologic age of a formation is determined first through

superposition. It naturally follows, if in a given area there are several superposed formations which have not been disturbed through crustal deformation, that the lowest one must be older than those above. Also that when they are cut by igneous rocks these crystalline masses must be younger than the formations through which they rose when molten.

8. *Petrology.* — The petrologic factor, or the nature of the stratified rocks, tells whether they were formed in water or by the winds, in seas and oceans or in rivers and lakes, or on dry lands under pluvial or arid climates. Also the probable depth of water in the seas, the amount of agitation, and whether the rocks were formed near to, or far from, the shores. The environment automatically impresses itself to a considerable extent upon the accumulating sediments, just as it brings about most of the evolution of all living things.

9. *Paleontology.* — Fossils are the basis of most geologic chronology, because all life is in the constant state of change comprehended under the term organic evolution. The individuals change into different species or even genera, and the forms of an assemblage die out or migrate elsewhere or are added to by the introduction of new ones of local origin or by immigrants. In other words, the organic assemblages constitute a series of vital records automatically made by nature, and the order of their appearance in time is checked by the law of stratigraphic superposition. Therefore any fauna or flora indicates more or less accurately the geologic time of its existence.

Fossils, furthermore, tell much about the environment in which they lived, whether in the seas or oceans, on lowlands or highlands, in swamps, rivers, or lakes, and whether the climates were cold, temperate, or tropical. As examples may be cited, for normally marine seas, an abundance of bryozoans, brachiopods, echinoids, crinoids, and cephalopods; warm seas have the greatest variety of invertebrates, along with reef-building corals and thick-shelled and cemented bivalves (Chamacea and especially Rudistacea), large foraminifers and an abundance of shelled cephalopods; near-shore seas have Ostracea and barnacles; cold marine waters lack reef corals, large foraminifers, cemented bivalves, oysters, and have small faunas though the individuals are very abundant. In all of this, however, the paleontologist is guided by the distribution of life as it is at present, and by the Hutton-Lyell principle that at all times the laws of nature have operated uniformly and about as we see them to-day.

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