Earth history at the century mark of the U.S. Geological Survey*

(paleontology/stratigraphy/paleoecology/paleogeography/geochronology)

GEORGE GAYLORD SIMPSON

Professor of Geosciences, University of Arizona, Tucson, Arizona 85721, and President, Simroe Foundation

Contributed by George Gaylord Simpson, June 14, 1979

ABSTRACT Earth history involves all aspects of geological and biological evolution, especially paleontology and stratigraphy. Early paleontological exploration of the western United States by and before the U.S. Geological Survey featured the dramatic discoveries and rivalries of the great vertebrate paleontologists Leidy, Cope, Marsh, and Osborn. Invertebrate paleontology and paleobotany in the U.S. Geological Survey blossomed with emphasis on practical missions. The most illuminating and useful earth history, nevertheless, emerges where there is a high degree of interaction with academic scholars. Despite a good knowledge of its broad features, the drama of earth history remains obscure in detail. Whereas it speaks conclusively for the reality of organic evolution, it is less conclusive about mechanisms and many important transitions. Current investigations, however, especially in pre-Phanerozoic, mammalian, and human paleontology, promise improved insights. New techniques in collecting, sample preparation, and research are revealing previously unknown kinds of fossils and exquisite details of preservation. Plate tectonic theory provides a new framework for historical geography and biogeography. Emerging techniques in geochronology—matching paleopolarity sequences, for example—promise to resolve old problems of the synchronicity or heterochronicity of different biotic provinces. As it splits into subfields, the teaching and practice of paleontology expand to cover all of them. The fossils themselves, however, remain the basic objective evidence. All hypotheses about them must answer to this court of appeal. But nature rarely responds in an either-or way. The most probable hypotheses are those that have repeatedly confronted objective reality and survived all opportunity for disproof.

SCOPE OF EARTH HISTORY

The classic disciplines of earth history are paleontology and stratigraphy, and they are the subjects of a branch of the present U.S. Geological Survey (the USGS). The orientation of that branch, styled “P. and S.,” is primarily paleontological but stratigraphy in a broader sense overlaps widely with other disciplines of the earth sciences, notably sedimentary lithology and structure and geological mapping. As involved in earth history, paleontology also has a broader meaning than the description and classification of fossils. It also involves faunal succession and correlation, paleoecology, and other aspects of historical biology. Earth history also includes paleogeography and geochronology, which again broadly overlap other earth sciences, here notably tectonics and geophysics. In still wider ramifications, earth history extends beyond the earth sciences, strictly speaking, and has contacts with virtually all the life sciences and physical sciences.

Thus, earth history is not only a complex subject in itself. It also is central as an interdisciplinary science that has almost boundless scope and possibilities. I emphasize this at the outset

because in this short essay I cannot even mention more than a small selection of topics.

RETROSPECT

As this is a historical occasion, the centenary of the founding of one of the world's greatest geological organizations, it is appropriate to take a brief look at an aspect of the human history of that organization itself. I do so from the particular point of view of a paleontologist and, specifically, a vertebrate paleontologist. The USGS was formed by a consolidation and extension of four earlier 19th century surveys of the Western Territories, those known as the Hayden, King, Wheeler, and Powell Surveys after their directors. Those surveys supported and published paleontological researches that are historic classics. Joseph Leidy's *Contributions to the Extinct Vertebrate Fauna of the Western Territories* was a great pioneering effort, published by the Hayden Survey in 1873. The tremendous volume known affectionately as “Cope's Bible” was based on his work (in part) for the Hayden Survey and was published in 1885, in fact after the Hayden Survey no longer existed as such. It was titled *The Vertebrata of the Tertiary Formations of the West. Book I.* (There never was a Book II.) In 1876 the Hayden Survey also published a classic of invertebrate paleontology: *A Report on the Invertebrate Cretaceous and Tertiary Fossils of the Upper Missouri Country* by F. B. Meek.

The third of the great 19th century vertebrate paleontologists, O. C. Marsh, was associated with King, although not in the field. In 1880 the government, continuing to support publication for the pre-USGS territorial surveys, published as part of the report of the King Survey Marsh's *Odontornithes: A Monograph on the Extinct Toothed Birds of North America*. In 1879 Marsh was president of the National Academy of Sciences which at that time recommended that the four territorial surveys be ended and a single national geological survey, the USGS, be established. King, Marsh's friend, was made the first director but soon retired and was replaced by Powell, a friend of both King and Marsh. Hayden was out, and with him Cope, embroiled with Marsh. Understandably, Marsh continued to have USGS support, and in 1884 the USGS published another large monograph by him: *Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals*. Marsh also planned a monograph on the horned dinosaurs and had many illustrations for it prepared, but this was not published by the USGS until 1909, long after his death, with the posthumous collaboration of J. B. Hatcher and R. S. Lull, Marsh's successor at Yale University. Marsh also had many lithographic plates of the bones of other dinosaurs prepared while he was officially the Vertebrate Paleontologist of the USGS and at the then great cost to the USGS of more than \$45,000. These were finally published in 1966 by Yale University Press with explanatory material by J. H. Ostrom, the present successor of Marsh at Yale, and J. S. McIntosh.

* Presented at the symposium “Earth Science and Earth Resources—A Centenary Salute to the U.S. Geological Survey,” 23 April 1979, at the Annual Meeting of the National Academy of Sciences of the United States of America.

Cope, too, had many figures prepared for the Hayden Survey that were never published by it. Under the editorship of W. D. Matthew, these were finally published in 1915 by the American Museum of Natural History aided by the USGS. Somewhat ironically, Henry Fairfield Osborn, no friend of Marsh, succeeded the latter in 1900 as Vertebrate Paleontologist of the USGS by appointment of the then Director Charles D. Walcott, a friend of Osborn's, and was made a Senior Geologist of the Survey by Walcott's successor, George Otis Smith, another friend of Osborn's. The most obvious result of that association was the publication by the USGS in 1929 of the sumptuous two volumes of Osborn's monograph on the titanotheres. (It will interest some present-day writers of monographs that Osborn's monograph was in press for 10 years after its completion in manuscript.)

Vertebrate paleontologists also remember with gratitude that the first bibliography and catalogue of North American fossil vertebrates, by O. P. Hay, was published by the USGS in 1901. In paleobotany a pioneering classic was L. Lesquereux's *Catalogue of the Cretaceous and Tertiary Plants of North America with References to the Descriptions*, published by the Hayden Survey in 1878 and followed by the USGS in 1898 and 1919 with F. H. Knowlton's catalogues of Cretaceous and Tertiary North American plants.

THE USGS MORE RECENTLY

The USGS no longer issues comparably invaluable paleontological reference works or monographs of quite such splendor as these earlier ones. Nevertheless, its paleontological staff has expanded greatly and now is perhaps the largest group of career and part-time professional paleontologists of any single organization in the world. In 1977, the last year for which fairly complete figures were available when I wrote this essay, the USGS issued about 25 publications devoted definitely to paleontology, and about 90 others by USGS staff members were published elsewhere. Many were abstracts, reviews, or brief notes, but substantial results of original research were included.

The USGS is mission-centered and its missions are primarily those of applied geology. The work of the USGS as a whole has strong emphasis on assisting exploration for metals and organic fuels, on water resources and control, and on engineering geology. Its work on earth history must be directed in large part toward services useful in those applications. For example, the very extensive and intensive program of geologic mapping depends heavily on stratigraphic paleontology. Paleontology in a more general sense benefits greatly from this application of it. I believe that the orientation toward applied geology is right and proper for a national organization of this sort. At the same time, and without intending to be rude on a birthday, it does seem to an outsider that such a bureau is almost inevitably impeded by bureaucracy and that science can often be more innovative and inspiring under other auspices.

One example of what might have been is appropriate here. The USGS initiated a project to summarize paleogeographic, paleoecological, and paleotectonic aspects of earth history in maps, tables, charts, and text for each period from the Cambrian onward. That would seem an ideal project for which a large national organization could provide teamwork and resources not practicable in more academic circumstances. The first results indeed gave promise of becoming remarkably innovative and inspiring for any historical geologist, but the project dragged on for some 25 years, produced publications for only four geological periods, and has now been abandoned.

It is also distressing to learn that publication of the *Journal*

of Research of the United States Geological Survey, which has been the USGS in-house medium for much of its basic research, will be stopped at the end of this year.

Earth history is livelier and is more widely pursued in academia than elsewhere, including the USGS which is so much larger than any one academic geological department. The USGS has contributed markedly to the more academic institutions by a sort of symbiosis. An example is the system of part-time (WAE, "when actually employed") appointments which have included support for field work by academic geologists outside of teaching terms. That was especially significant when less (although now still inadequate) support was available for studies of earth history from the National Science Foundation and some other sources.

Here I must point out that academic institutions (universities and museums) are finding it increasingly difficult, and sometimes virtually impossible, to support field and other research and publication from their own resources. Even with the National Science Foundation, support for studies of earth history from sources in governments, societies, and foundations is becoming less, not more, adequate. An example close to home for me is that the Carnegie Institution of Washington, which provided for two volumes of the Hay bibliography and catalogue of fossil vertebrates, and the Geological Society of America, which provided for nine successive volumes of the Camp bibliographies and for the two volumes of the Romer bibliography, have stopped support of this continuing effort and have reduced or eliminated other contributions to the study of earth history. It is greatly to be desired that the USGS be enabled to expand its contacts with and support of aspects of the study of earth history more basic than those of direct economic interest and yet fundamental also for the latter.

WHAT NOW AND NEXT?

Here I propose to stop centering attention on the birthday of the USGS and to consider a few of the many other aspects of the present situation and future prospects of the study of earth history.

What first comes to mind is the known fossil record—that is, the fossils actually in hand and published or currently under study. One point of view, decidedly a minority one, is that the presently known fossil record is complete enough to be taken at its face value. That is both vague and untenable as a generalization. The record is adequate for some purposes, such as the demonstration that organic evolution is a fact of earth history, but is still inadequate for others and useless for some. It reveals broad features of the history of life, the most tremendous and exciting of all dramas. It also exemplifies many details here and there, but for others, although it does put broader or narrower restraints on interpretations and hypotheses, it is not conclusive.

The continuing incompleteness of the record and the rewards of pursuing it further are demonstrated by the fact that important paleontological discoveries are now being made at a faster rate than ever. Discoveries of fossils in early Precambrian rocks, long thought to be devoid of clearly identifiable fossils, are now being made with some frequency.

Even in Europe and North America, where fossil collecting has been going on longer and more intensively than on other continents, new discoveries are still accumulating rapidly also in the long span since the beginning of the Cambrian, the so-called Phanerozoic, eras of "visible animal life." The remarkable discoveries of vertebrates and other fossils made early in this century in Asia by American and Swedish expeditions are currently being exceeded by those of Mongolian expeditions under Polish and Russian joint auspices in central Asia and by

the very active and productive work of Chinese paleontologists in the Peoples Republic of China. The latter include further discoveries of the earliest known mammals and also a whole series of hitherto unknown early Cenozoic vertebrate faunas. Field and laboratory studies on the later Cenozoic in Africa, long publicized because of the light they throw on the origin of man, continue as actively and as productively as ever. Paleontological work in South America has a long history but continues to be richly rewarding. In my own field, fairly recent discoveries include, for example, the oldest identifiable mammals yet known from that continent and a whole series of mammalian faunas in Bolivia that begin to rival the hitherto incomparable sequence in Argentina. Australian paleontology is so active that a new journal devoted entirely to it has completed its second volume of publication and is continuing. (The interesting name of the journal, *Alcheringa*, is a central Australian aboriginal word meaning "in the beginning" and is also the technical name of one of the oldest Precambrian fossils.) Many fossils have now been found in Antarctica but none of land mammals, although some land mammals almost certainly were there at some time. Anyone who discovers them will become famous overnight.

Other aspects of current fossil collecting and its prospects for the future involve field and laboratory methods. Included, for instance, are methods that find and recover large numbers of small to microscopic fossils, both invertebrate and vertebrate. These result in discovery of species and other taxa that would otherwise be overlooked. They also often provide larger samples of known species, which permit more precise statistical studies of population variation and dynamics. Another example is the increasing precision of field records. For some fossils collected in the 19th century the field data for geological horizon and geographic position are "Tertiary east of the Rocky Mountains." Modern standards increasingly require both horizontal position on a map, photograph, or plan and vertical position in a stratigraphic section within 1 m or less. Other data commonly relevant involve the nature of the matrix and of the sedimentation that produced it and the attitude of individual fossils within it.

As all geologists know, the most important development in recent years bearing on paleogeography is the theory of plate tectonics and the consequent general acceptance of the reality of continental drift. This gives a new framework for the geographic aspects of earth history. It has been recognized ever since geology began to be studied in a truly scientific way that tectonic events have changed geography throughout geological history in various ways such as the origin of mountain ranges and the spread and withdrawal of epicontinental seas. It has also been clear to paleontologists for a century or more that there have been times of formerly closer relationships between faunal regions now isolated from each other—for example, between the marine faunas of the Caribbean and the eastern Pacific—and of previous isolation of regional faunas now closely connected—for instance, land faunas of Europe and of northeastern Asia. Plate tectonics adds another feature to these changes: the actual movements of whole continents or considerable parts of them.

Paleogeographic maps now taking these plate movements into account differ considerably from those made on the hypothesis of continental stability. Thus, the scenes in which earth history has occurred are being viewed somewhat differently. In some cases this explains more clearly what was already known. For example, it was long known that the early Eocene mammals of North America and Europe were more alike than in later faunas. That indicated some sort of connection. The plate tectonic explanation is that these two continents were then

parts of the same continent. The recent and not yet fully studied discovery of a considerable fauna of early land mammals on Ellesmere Island in what is now the far north will throw further light on this.

Another example is an early belief that Australia had long been connected by land to Asia. Geophysical plate tectonic evidence suggests that this was not so and that the Australian plate was near, if not fully connected with, East Antarctica until well into the Cenozoic and then moved to its present position. Spread of plants and animals one way or the other between South America and Australia can thus be explained as having occurred by way of Antarctica. However, present evidence indicates that this spread was highly incomplete and selective, which strongly suggests that the connection of the South American, Antarctic, and Australian plates was interrupted by marine barriers, either between the plates or on them. Thus, biogeography, both paleo- and neo-, adds to and emends the results of tectonic paleogeography.

Our geography is not static but is something that changes, and changes radically, through time. This study might be called historical geography, a dynamic process, rather than simply paleogeography, which might still be seen as a static condition. It is clearly dependent on chronology, and in the relevant aspects of geochronology there has been a great increase in the methods available and the accuracy of their results. The sequential method tells us not when things occurred but the order in which they occurred. This system was devised early in the 19th century and although it has been greatly modified in detail it is still the conceptual basis of much of earth history. Nineteenth century attempts to put the sequence in a framework of "real time" (whatever that term is taken to mean) were premature and have turned out to be far off the mark. It was the discovery of radioactivity that changed all that, and now we have an almost bewildering number of different approaches to geochronology based essentially on that discovery and its direct sequels. Yet students of earth history are still more likely to speak of an event or a fauna as occurring in, say, the early Eocene than to speak of it as occurring, say, 50 Myr before the present.

It is also true that paleontological correlation, the earliest method of placing Phanerozoic sedimentary rocks in the sequence, is still usual for that purpose. This, too, has become increasingly refined and complicated and doubtless will continue to do so. I will here take time only to mention one major problem and steps now under way to solve it. Correlation of fossil faunas or floras from separate localities of course depends on their having groups of organisms—taxa—in common. That works well enough under many circumstances, but it may fail when the faunas or floras being compared evolved in isolation and came to have little or no clear resemblance to each other. That is true, for example, of the terrestrial vertebrates in the Tertiary rocks of Australia or of South America as compared with faunas in Europe, where sequential dating was first standardized, or in North America or Asia. Correlation by radioactivity methods is also of limited use in these examples because many of the sediments do not contain suitable minerals. It has been found, however, that many of them do have remanent (residual) magnetism by which the polarity of the Earth at the time when the rock was deposited can be determined. This polarity has changed from time to time, being called "normal" when as now the so-called north end of a compass needle does point north and "reversed" when that end would have pointed to what we call south. Presumably these reversals affected the whole earth at the same time. Thus, a reversal episode in South America, for instance, can be dated if it coincided with one in North America or elsewhere. There is a fairly obvious catch:

the polarity in itself does not give a date; it only gives an off-on signal. To place it in time, one must tie into a polarity sequence a date obtained preferably from radioactivity and also from paleontological association. That is often possible, and this is a very active ongoing program at present.

Such a program requires close cooperation between different specialists within the broad field of geology. It is likewise interdisciplinary between the physical and the biological sciences, which is true of all aspects of biostratigraphy. It is also true of paleoecology, although that discipline is less readily separable from its nongeological analogue, the ecology of the present time. That is evident in the now classical work that may be said to have set paleoecology up as a distinct science: *Treatise on Marine Ecology and Paleoecology* published by the Geological Society of America in 1957. The first volume, 1296 pages, is on recent or neoecology; the second, 1077 pages, is on paleoecology. The first volume was edited by Hedgpeth, a biologist, and the second by Ladd, a USGS geologist. Since then, several books, both technical and popular, have been devoted specifically to paleoecology, including the study of ancient environments which involves sedimentation as well as the makeup of fossil communities. There is a trend now to teach and study the principles of paleontology in general rather than, or in addition to, its study in terms of systematics, anatomy, and identification. That trend is evident not only in refreshingly new texts on general paleontology in which paleoecology figures extensively but also in a successful new journal, *Paleobiology*, of which four volumes have been completed.

The biological study of fossils has interesting and sometimes surprising results concerning nonbiological aspects of earth history. An example is the study of growth bands in recent and fossil corals, bivalves, and other organisms. Among other results is evidence that the number of days per solar year has probably

decreased rather steadily since the early Cambrian and that the number of days per lunar month may also have decreased but not so steadily. This is one of the innumerable subjects on which the last word has not been said.

The fossil record is the record of the history of life. It therefore is the objective evidence for the processes and principles of long-range evolution, another subject on which the last word decidedly has not been said. Here again the objective evidence puts definite restraints on the inferences that can be drawn from it: the principles of evolution cannot be contrary to any item of that evidence. Nevertheless, not all of the restraints are absolute. More than one hypothesis or theory about the mechanisms of organic evolution may be consistent with what is now definitely known. It must also be noted, however, that one such hypothesis or theory may be definitely more probable than another. Moreover, nature does not necessarily deal in an either-or or absolutely polarized way. One example of current discussions of such hypotheses is the supposed conflict between what have been labeled, somewhat obscurely, as "punctuated equilibrium" and "gradualism." The question involved in present controversy is whether the origin of distinctively new sorts (taxa) of organisms takes place at rates that are instantaneous in terms of measurable geological time or gradually over geologically appreciable stretches of time. The restraints of the fossil record as now known indicate that this is the wrong question to ask, but more judicious questions about the rates and ways of evolution are being and will continue to be asked as a legitimate and important part of earth history. This is not the proper place to discuss this particular subject any further. It is brought up here just as another example of the fascinating ramifications of earth history and of the present great activity and future even greater promise of the study of this subject.