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ON UNDERSTANDING GEOCHRONOLOGICAL TIME[1]

By

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ABSTRACT

Current estimates of the age of the Earth are based on the radioactive isotope dating of materials in the oldest known rocks and the extrapolated "history" of that material prior to its time of consolidation into those selfsame rocks. The problem of chronological time is discussed in terms of this history, particularly as it relates to geological and biological processes and the geologic column.

Various geochronological methods are employed to study the ages of materials and events, depending on the nature of the material or the relation between the event and the datable material. Results from each technique give certain information that can be interpreted in terms of ages; all dating is based on interpretation of age determinations. Interpretations of these data are strengthened if the material is studied to (1) determine exactly what is the material being studied, (2) learn the complete "life history" of the material analyzed, and (3) learn the precise association between the material analyzed and the phenomenon being "dated."

INTRODUCTION

Until recently, estimates on the age of the Earth and the length of geochronological time making up the history of this planet have fluctuated between periods of time ranging from thousands of years to those amounting to billions of years. The present-day estimates are given as being in the general magnitude of 5×10^9 (5 billion) years. One can well question how these estimates have been derived, what is their total meaning, and exactly how valid we believe them to be. Also, one may question the value of knowing or the need of having accurate answers to this age problem. These questions, simple in wording and intent, require careful analysis before attempts to give answers can be made.

The topic of geochronological time, or geological time as it is sometimes called, under discussion here is in itself something of an enigma. In 1941, Adolph Knoph remarked in a James Arthur Foundation lecture at New

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York University that if he were ever asked, as a geologist, ". . . . what is the single greatest contribution of the science of geology to modern civilized thought?" the answer could be "the realization of the immense length of time. So vast is the span of time recorded in the history of the Earth, that it is generally distinguished from the more modest kinds of time by being called 'geologic time.'"

Geologic processes have been operating through this 5-billion year history, and biological processes have been in operation at least 3 billion years. Mountains have been pushed high above the surrounding plains only to be worn back to their base levels through erosion and the eroded materials carried away to be deposited in basins where later mountain-building processes thrust these rocks high above their base levels to form new mountains. Certain ocean bottom levels have been thrust upward until they emerged from the sea and became continental areas, and certain continental areas have sunk beneath the oceans where they were covered with marine sediments only to later be raised once again. Ore bodies have been formed, eroded, or carried away in solution form and these materials used in the reconstitution of new ore bodies. Volcanoes have time and again raised their bombastic voices and coughed up materials from deep inside the earth. When plant and animal life did appear, the biological forms lived and died, and the material from their bodies enriched the ocean bottom ooze and the continental soils from which later forms of life could thrive. The crust of the earth has never been completely quiescent, nor is it today; rather in places it has constantly been raised, lowered, and shifted. If we had had a time-lapse rate camera focused on the Earth since its beginning, we would be able to see and study these processes in dynamic operation, similar to the way cloud formations are now photographed.

Before we can understand such a history, we must examine the basis on which our premises are built, one of the most basic of which is time itself. There is probably no English word as commonly used and as little understood as is the word time. Interpretations of the word are as varied as the countless people who use it. To a large extent this is probably because it has never been satisfactorily defined for many fields of science and remains mainly as a concept for most of us in spite of all that has been said and written on it. If each of us were to take pencil and paper to write a personal concept of time, the probability would be small that any two of these concepts would be exactly the same. For some reason we generally refuse to come to grips with the problem of a definition and slough off any concern with it by the feeling that the concept is "too immense" or "too complex" to hold our attention in more than a cursory way.

In the theoretical and philosophical books and articles on time—such as Schlegel's "Time and the physical world," Blum's "Time's arrow and evolution," Richenbach's "The direction of time," Whitrow's "The natural philosophy of time," and Grunbaum's "Time and entropy"—the major problem involved centers around entropy and how the direction of time is affected by "reversible time" when working with isolated particles on the subatomic level.

The trend of modern science dictates that we must set up some common working definition of time. We must have some basis for understanding it at least to a point where we can work with results achieved by research in our own laboratories and by colleagues in other fields who are also concerned with temporal problems. We cannot advance far without this type of cooperative and understanding effort.

I believe that to be effective a definition of time should encompass biological and radioactive matter if it is to be used in such fields as geochronology, geology, and archaeology. The definition I use ignores, having little bearing on our particular problem, the Lorentz transformation equation as illustrated by the clock paradox problem and the time-invariant Clausius process. Also, it assumes that there is some "loss" of usable energy in the universe, and I'll put the word loss in parenthesis, because unless we look upon it as a perfect perpetual-motion machine, the universe has to be moving toward some increased degree of entropy. With these exceptions in mind, I would define time as the direction and continuance taken by all matter in the universe as it moves toward higher entropy.

This definition includes all matter ranging in size from submolecular particles to megascopic plant and animal life. The original source of this matter, or particles making up this matter, is a complex study and not our concern in this discussion. Our interest centers around the particles from the moment they became part of this planet. We must not, however, attempt to treat these particles as isolated matter else we come back to the problems bothering the theorists working with the reversible direction of time and with entropy. Using this definition of time, we should have no great difficulty fitting into the total time continuum the life history of the Earth, including the minutia making up this history, such as the dating of rocks formed during certain periods or when certain events occurred.

The geochronological time scale as we know it today is, in brief, the geologic column containing interpreted "dates" on the various divisions of the column that have been derived by applying radioactivity dating and other techniques to particular rock types, and it represents the composite work of many people through the last two centuries.

The geologic column is a descriptive outline of time-rock units, which enables students of the earth sciences to properly categorize and order historical materials in their proper position on a relative time basis. These time-rock units are practical divisions representing sediments deposited in a given area somewhere within the total corresponding time unit. In almost all cases, as will be explained later, identifications of these units are based on the remains of plants and animals that lived in that general area at that time.

In the column, for example, the Paleozoic Era refers to "early" life forms, the Mesozoic Era refers to "middle" life forms, and the Cenozoic Era refers to "recent or late" life forms. So few fossils have been found in pre-Paleozoic or Precambrian rocks that, coupled with the external similarities of the rocks, it has been virtually impossible to set up worldwide time-rock units for this vast span of time comprising approximately 85 to 90 percent of the Earth's history. Some fossils have been found, however, in these ancient rock types, such as those studied and described by Tyler and Barghoorn for the Gunflint Formation in southern Ontario that are dated at approximately 2 billion years of age and those described by Glaessener stratigraphically located deep in Precambrian rocks in southern Australia.

Cambrian rocks are distinguished, or characterized, by the first abundant records of fossil life of which trilobites are the most famous. In general, the Cambrian Period rocks contain such a diversity of types that we can be certain of a long period of Precambrian development that has not been reflected in the fossil record; most of the major phyla at least of the invertebrates were already in existence by this time. One might say that perhaps in the life forms the major development in the Cambrian was that of "hard parts" or "bony" material that could be more easily fossilized. The Ordovician Period contains abundant remains of fishlike vertebrates and more highly developed trilobites. The Silurian Period is based on the presence of reef-corals and abundant brachiopods. The Devonian contains numerous remains of fish and primitive land plants. And so the story goes, each *Era*, *Period*, and *Epoch* having its own characteristic forms. It must be kept in mind that, although each subdivision has its own characteristic forms, these do not represent sudden changes in life forms; rather, as the fossil record is studied, described, and as additional material makes it more complete, we can see a continuous sequence of life evolving and diversifying, and finally we subdivide the total history, as based on faunal succession, on a more or less arbitrary basis.

The first written record on fossils, to my knowledge, is that reported by the Greek philosopher Anaximander in the sixth century B.C., who wrote that the peculiar forms of rocklike materials within the rocks in the Nile Valley were actually remains of fish; therefore, at one time these rocks had to have been on the bottom of the sea. Aside from rather sporadic and scanty references written during intervening centuries, it was not until the time of Nicolaus Steno in the A.D. 1600's and Linnaeus in the 1700's that serious consideration was given to fossil remains.

These "early-day" people, such as the Englishman William (Strata) Smith, studied fossil remains primarily in England and France. They learned to recognize particular groups or assemblages of fossils, and they began correlating these fossil assemblages over wider and wider areas. They found that the best material for correlation was the "guide" types, which had a limited time span but were of widespread distribution. In this correlation work, they were aided by generalizations, such as the one first formally presented by Steno in approximately 1669 and called the "Law of Superposition" in which it is stated that in an undisturbed sequence of sedimentary rocks, the youngest strata are on the top.

After considerable study, Conybeare and Phillips described in 1822 the rocks of the Carboniferous Period. They were followed in the 1830's by Sedgwick, Murchison, Lyell, and Alberti who described still other periods.

Prior to the development and use of radioactivity dating methods, numerous theories were advanced by various individuals concerning the age of the Earth and the total span of time for the geologic column. Certain people concerned themselves with measuring the increasing salt content of the oceans, and, extrapolating that data back in time to a period when the oceans were free of salt, they calculated figures on the minimum age of the Earth. Other people worked with the rates of sedimentation of various deposits, then, compiling all the data they could locate on the thickness of *all* deposits, they came forth with minimum ages on the Earth. Still other techniques were applied with so-so results.

No matter what techniques were employed to determine the time span in actual years, the "elastic" geologic column could be stretched or shrunk according to the latest estimates. This was made possible because the major division of the column was and still is, as previously stated, based on fossil life forms found imbedded in the sediments. Paleontologists paid little attention to time in finite years, and it was only when some theorist shrunk the scale to such a ridiculously low figure that even the fossils squirmed did they come forth with personal ideas on "rates" of evolution and other paleontological processes that sometimes needed to be taken with almost as much salt as the salinity of the oceans theories demanded.

Nevertheless, it was the paleontologists who developed the first sound approaches to the problem of finite years for the geologic column, although they did this by a round-about means while studying the origin and development of faunal life forms. These characteristic forms were used to correlate "time" units within the limits set by crustal disturbances and unconformities of varying importance that mark the boundaries of the *Eras*. With more refined taxonomic classification and procedures, they have learned to identify types marking the divisions of lesser importance, such as the *Periods*, the *Epochs*, the *Ages*, and the *Stages*.

Such divisions were, and are, easy to recognize where unconformities and (or) other rock "breaks" occur. In areas where no lithologic breaks are discernible, deep-seated problems arose, and still arise, on whether or not the particular rocks belong to this or that time period. Only a few of these problems have as yet been solved to everyone's satisfaction. The more minutely the uplift of mountains and crustal movements are studied and dated by radioactivity techniques, the more drawn out and complex the tectonic processes become, until at present it seems that these processes are always in operation in some degree in some locality, although certain major events may have occurred in a comparatively short span of years. Thus, crustal movements and unconformities are losing some of their importance as universal boundary markers.

The stratigraphic paleontologist has had to concern himself with problems such as those encountered in working out the biostratigraphy of an area where a particular rock unit is based on the assemblage of fossils. In this usage, time is relative because the major problems center around the relationship of one unit to another.

In February 1896, I believe it was, Henri Bacquerel, while waiting for the skies to clear in order to conduct an X-ray experiment on fluorescing substances in sunlight, left a photographic plate and a piece of uranium salt in a desk drawer. Several days later the sun was shining, and when he went to remove the plate to continue his study, he found it had been exposed to some unknown radiation. This rather fortuitous incident led to new investigations and ultimately into radioactive disintegration, nuclear fusion and fusion, and to other such studies. Shortly after this incident, the Curies began their search for sources of radioactivity.

In 1909, John Holy, in his book "Radioactivity in Geology," discussed radioactivity in rocks and the energy needed for the mountain-building processes. Thus, for the first time the "radioactive" clock gave us our very first technique for measuring in actual years the long expanses of time involved in the Earth's history. Discovery after discovery followed, and by 1931 "The Age of the Earth" was published by the National Research Council. This work was based on the lead-ratio techniques and traced an orderly succession of geologic events back over 2 billion years. With the development of mass spectrometry in the late 1930's still other and more accurate methods were made available. All these depend, however, on the concept of the statistically derived invariant rate of radioactive disintegration. Investigations into better instrumentation and new methods continue to the present time, and refinements are constantly being made in the framework of the history of the Earth.

METHODS

There are today many techniques being used to study the Earth's history and processes that have operated during this history. These various techniques and methods being used give results we can classify into three broad categories. These are:

1. Relative placement methods or those that are concerned with relating particular materials or events to other materials or events to the extent that one is previous to, contemporaneous with, or follows the other. Time cannot be considered here in terms of years or even as a theoretical unit of measurement. In this category are such methods as:

Paleontology (invertebrate and vertebrate)
Stratigraphy
Geomorphology
Palynology
Thermoluminescence
Thephrochronology
Fluorine analysis
Etc.

2. Time placement methods that include those that attempt to place definite dates in terms of calendar years on events or items, but because these methods incorporate within that temporal placement a certain statistical error, the results are given in intervals (or globs) of time rather than in points in time. All the actual age determinations used in the geochronological time scale have been derived by these methods with the exception of that covering the last several thousand years in which tree-ring "dating" can be employed. In this group are such methods as:

Radiocarbon
Potassium-argon
Lead ratio techniques
Rubidium-strontium
Laminations, including glacial and nonglacial varves
Ionium
Etc.

3. Absolute placement methods. In this category are those methods that attempt to place in terms of a single year various materials or events. The only entry in this group is:

Dendrochronology (tree-ring dating)

There is no method known that yields "dates," rather they yield such information as ratios between parent and daughter materials, or they tell us when a certain annual lamination was deposited, or when a particular ring was formed on a particular tree.

Without going into the details on how radioactive techniques such as potassium-argon are carried out, let me say that all these involve laboratory analyses of materials composed of small particles that were part of still older materials during the first part of their stay on this planet, excluding, of course, recent arrived extraterrestrial material such as meteorites and cosmic dust. We do not "date" the particles, rather we derive the elapsed time since their assemblage into a particular type of matter or the elapsed time since they were metamorphosed into their present form. The better our techniques can pinpoint the elapsed time of this assemblage or metamorphosis, the smaller will be the "glob" of time concerning this transformation. This glob represents the period of time during which these materials *could have been* assembled.

It is not possible to walk into the field and simply remove a chunk of rock from an outcrop and take it into the laboratory for dating. In the first place, we cannot take a piece of innocuous material, place it in a magical black box, close the door, twist a few dials, make a few adjustments then turn on the power and, after lights have flashed, bells have rung, and puffs of white smoke have cleared, read off the age of the object on a dial attached to the box. As magical as some of the laboratory apparatus might seem to be, it can only do tasks for which it was designed, constructed, and programmed to do. The results yielded in these analyses are so much analytical gibberish until the data are translated into understandable terms.

Our laboratory methods or techniques are designed to give to us information we can use for age determinations. What do we mean by the term *aging* of rocks and how is this aging accomplished? If you can pardon my loose usage of common expressions and terms, I might say that *aging* is the result of the wear and tear on materials caused by the operation of life processes with the passage of *time*. When the term *aging* is voiced, most of us immediately think of it in terms of "life" and "biological life" at that. Without going into the philosophy of life and the causes that brought it about, or bring it about, let me simplify this by stating that in an analogous way, "life" exists on a submolecular or submicroscopic level as well as on the megascopic one. By submolecular or submicroscopic level, I mean the levels on which are the molecules, the atoms, and the subatomic particles that make up the material we see when looking through an optical microscope. These materials constitute all matter in the Universe, and this matter has "life." To be certain, it is not the same life on the biological microscopic or megascopic level, and it is called *molecular* or *atomic* life to differentiate it from the biological type.

As this matter "ages" through time, it undergoes changes in its structure as energy and matter are assimilated and dispensed. Those we normally consider as biological aging processes, similar to our life processes, are on a different level from those processes on subatomic or submolecular levels. Rocks and minerals are comprised of the same type of minute particles as those in our bodies and from which our bodies derive their building materials and their energies. If we could look deeply enough into our own or other biological life, we would see that the same aging processes are in operation within the minute particles making up these biological forms. I should say perhaps, for the sake of accuracy, that our bodies are simultaneously aging on several levels, which are the submolecular, the molecular, and the megascopic levels of assemblages of matter.

Rocks are *born*, that is the particles are assembled into a particular matter, or they are metamorphosed from one type into a new type of matter through external pressures, temperatures, and the disintegration process common to radioactive isotopes. Rocks *age*, because with the passing of time, there are changes brought about in their internal structures because of various "life" processes; and rocks *die*, either through disintegration by mechanical and chemical weathering or metamorphosis into different materials.

Thus, the passage of time brings on changes in the inanimate as well as the animate material. Such common expressions as "the eternal hills" or the "everlasting rocks" may give a connotation of no change, but the various processes in operation do, with the passage of enough time, cause mountains to be worn down; even the particles making up the rocks and mountains are subject to aging and change. Our laboratory methods simply measure some of these changes, mainly radioactive decay, and from these age-determination studies we can go on to calculate *dates* in the Earth's history.

Providing the total time span of the Earth is anywhere near the estimates now being given, we have very little if any definite knowledge of the matter making up this planet during the first half of its stay. Earth scientists now consider this age to be in the general magnitude of 5 billion years; some astronomers are thinking of the age of the Universe as being in the magnitude of 8 to 10 billion years.

Most of our knowledge extends back only through the Cambrian Era, but the aging of materials taken from the oldest rocks thus far located and studied takes us back to a period approximately 3 billion years ago. These materials are undoubtedly reconstituted from earlier materials; thus, all we can say is that this age represents the beginning of the present life cycle of this particular material. As more and more studies are done, there is some possibility that still older rocks will be located, and eventually we may learn something of this earlier part of the Earth's history.

PROBLEMS

The second major division of this portion of the discussion is concerned with *problems* in age determinations, and of these I will only touch on what I consider to be a few highlights. In the Geochronology Laboratories, for example, only a small percentage of the staff's time is devoted to the so-called age determinations. Approximately 75 to 80 percent of our time is concerned with understanding the material being analyzed and interpreting the results yielded by such analyses.

All *dating* is a matter of interpretation no matter whether it is a *date* on a structure in an archaeological site, or the *date* of a glacial recession, or the *date* of a particular rock formation. In my own experience, I believe that interpretation can be strengthened and made more accurate by following three steps, which need not necessarily be undertaken in the order given here. These are: (1) to determine exactly *what is the material* being analyzed for its age, (2) the determination of the complete "life history" of the material being studied, and (3) learn the precise association between the material studied and the phenomenon being "dated."

The physical properties of the material being analyzed must be minutely examined if we are to know what we are studying. The inside rings of a thousand-year old tree will, for example, give a radiocarbon age of 1,000 years, although the tree was a live growing entity when cut for our study.

Not all materials can be so analyzed that we can obtain their age even if they may seem to be of the proper type. Of these so-called "datable" materials, some yield such data and some do not. I can best compare this to what would happen if I were to walk out on the University campus and, considering all coeds to be "datable," ask the precise age of each one I met. The answers would fall into three general categories, I believe. Most of them would tell me it was none of my business how old they are. A smaller number would give me some sort of vague reply, such as that they are over 16 (and obviously under 75). Only a very few would give me a straightforward answer. Our "datable" materials are much like this; most of them ignore all that we can do to obtain clear-cut *aging* data, a few specimens give us evasive or vague information, and only a very few yield definite quantitative data.

We need to study the materials to the extent that we rather fully understand what they tell us when we make an analysis. To illustrate this point, let me again use radiocarbon work as an example. Every radiocarbon analysis coming out of the laboratory is as accurate as can be determined by modern science. In other words, every radiocarbon age determination has an extremely high degree of probability of being correct. This does not mean, however, that the application of that age determination in terms of calendar years to an archaeological or geological event can be done with any high degree of accuracy. All that any radiocarbon analysis does is to simply determine the ratio in a given amount of material between the existing nonradioactive carbon 12 and 13, and the radioactive carbon 14 isotopes, and plugging this ratio information into an equation based on the disintegration processes, we calculate the time when the material was a live substance. This ratio may have subsequently been altered or disturbed through either a natural or an artificial cause, and this cannot be determined on the basis of the laboratory analysis alone. We cannot simply assume that all such analyses are valid for the dating of a prehistoric event.

The second major problem is the determination of the complete "life history" of the material being studied. Aside from dendrochronology, all our dating techniques are based on the disintegration of radioactive materials. The analyses of these materials yield results based on the ratio between the amount of parent material still remaining in our sample and the amount of daughter products given off during disintegration. Any disturbance in this ratio leads to an "erroneous" figure as far as the true age relationship is concerned. Recognition of this problem causes us to carefully study field and laboratory conditions to determine whether or not exogenic or endogenic processes may have disturbed the natural ratio. Samples are discarded if there is much doubt that we must have contamination that cannot be overcome or for which we cannot correct.

In radiocarbon work many samples submitted for study are comprised of small bits of charcoal because there is no single piece large enough to analyze by itself. The small bits may represent many individual shrubs, trees, or other types of organic matter that may have had a long life or a short one. What are we dating? It is not *a* piece of homogeneous material, but rather we are obtaining *an average age of all the material making up the total sample*. Some of these materials may be reliable and some may not; we have no way to know exactly how much contamination may be in the sample, thus, the "date" can be erroneous.

We have found in potassium-argon work that we need to study the source locality in detail to determine the field conditions that controlled the geologic structure of the area and the exogenic and endogenic processes that may have had some effect on the sample. These latter would include nearby volcanic activity, long exposure to the atmosphere, hydrothermal conditions, and other such phenomena. We must know, as an added example, if the sample studied is an indigenous part of the parent rock or if it is a bit of residue from an older rock that was carried in during sedimentation. If we understand the complete life history of the sample, this problem will not be of extreme importance when proper steps are taken to counteract such conditions, or it will tell us that we cannot expect reliable results from the laboratory analyses.

In tree-ring dating we know that the tree was a live growing botanical entity at the time when the last seasonal growth was formed. It stands to reason that the use of the tree in the construction of a house or some other architectural or functional feature could not have occurred until after the tree died. The investigator must determine the length of time after such a terminal date before the tree was used in construction. This means that he needs to reconstruct the story of that particular specimen from the time it was a living tree until it was found in the site in question. To do this, he must determine how the tree was used, under what conditions it was used, when it was used, and, unless it is an integral part of a wall or some other architectural feature, how did the specimen come to be where it was found.

The third major problem concerns the precise association between the material studied and the event or item we want dated. Solutions to this problem are based in part on answers derived from the preceding problem concerning the life history of the sample.

We cannot assume that simply because an object or a bit of material has been found in a certain stratum that its history is exactly the same as that for the stratum. We know that certain minerals migrate from the country rock into the particular samples we are studying and that there is cross migration from the sample materials into the country rocks. The entire processes of erosion and sedimentation are concerned with the tearing down of rocks and the transportation of that material into another environment where it is used to create new types of rocks. Under these conditions, we can have older materials being incorporated into younger sediments.

We must also realize that to "date" material from a lava does not, necessarily, date the eruption of a particular volcano. We have to determine the association between the lava, in this case, and the particular volcano—they may or may not be related. In such problems there must be close coordination between the laboratory and fieldwork. Further, the researcher should test several different types of material from the same horizon to learn what has happened in the field in regard to the material being studied. Such analyses may indicate that two seemingly contemporaneous materials were actually not contemporaneous or that two apparently unrelated events might actually be the result of a common event and so on.

Each particle of material studied has its own history, but each particle has never been completely isolated from all other matter. In this same sense, no event in the Earth's history was ever a complete entity in itself; thus, we must study the total chain of related events if we are to understand the one with which we are working. The investigator must assume responsibility for these field observations, and to do this he must be cognizant of the total conditions of the particular temporal problem and its relationship to other events in the history of that specific area. "Sloppy" fieldwork is no more excusable than "sloppy" laboratory work.

The literature on earth sciences contains numerous "dates" on rocks and events. What is meant when such a "date" reads, for example, 2.3×10^9

years? Geochronologists or geologists do not have the same definition for the word date as do physicists, historians, or other scientists. The common dictionary definition of the word date is that it is a point in space-time. We must modify this definition because we cannot be nearly precise enough to pick out a point in space-time. As stated earlier, what comes from the various aging methods are "globs" of time during which the material we are studying could have been "born." When geologists speak of an "absolute" date they mean that this is a "date" in terms of calendar years, whereas they had been using dates based on guesswork and estimations or on the relative time relationship of one rock type to another or of one event to another. While they strive for accuracy and precision, they are not using the term "absolute" in its normal dictionary definition.

The "date" of 2.3×10^9 years, then, simply means that the material was assembled into its present form somewhere around 2 billion 300 million years ago. There is the strong tendency to forget the standard deviation that is a part of this "age." Thus, although this is a statistical calculation, we feel that this date is very precise, as far as our present-day instruments go, and its accuracy is somewhere in the proper magnitude.

In tree-ring studies, when the term date is used it refers to the year in which a particular ring was formed on a particular specimen. When this tree was cut and used to help construct a house, or put to some other use, is a different matter. All we know is that it could not have been so used until after the year in which the last ring was formed.

Our love for pigeonholes and our consuming desire to place each piece of data in a labeled box has led us into some false assumptions regarding the use of the units making up the divisions or the column. In probably no single locality can we be absolutely certain that the deposit represents the total time span of a single division of the time scale. All we can do is work with one segment and extrapolate from that segment into the others.

Although few believe, I hope, in the catastrophic theory on the periodic extinction of whole groups of animals and plants, as first advanced by the early-day French paleontologist Curvier, I fear that we try to read into the column such breaks as these even though none exist. Unless we have unconformities marking the boundaries, we become confused in relating materials to one time unit or another.

I want to close here by stating that in discussing these problems I am always reminded of an analogy that has been used many times but is still pertinent. You perhaps recall the scene in Carroll's story of Alice in Wonderland where she is talking to the Mad Hatter about many things, and they finally come around to the topic of time. The Mad Hatter remarked, "I dare say you never even spoke to Time." "Perhaps not," Alice cautiously replied, "but I know I have to beat time when I learn music." "Ah, that accounts for it," said the Mad Hatter, "He won't stand beating. Now if you only kept on good terms with him, he'd do almost anything you like with the clock."

Any investigator working with temporal problems also has to keep on good terms with time because it is capricious and undependable unless mastered to a point where it can serve the purpose that we need for these problems. I am afraid, however, that many of us only think in terms of beating time rather than understanding it and putting it to its proper usage.

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