# Time — and Earth's History

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Since the time of Charles Lyell and Charles Darwin in the past century, the study of geology has been dominated by the concepts of uniformitarianism in nature and evolution of living forms [1]. These two concepts are incompatible with a literal interpretation of the first part of Genesis. Consequently, conservative Christians, including Seventh-day Adventists, have refused to accept them as commonly applicable to Earth's history.

Physical geology (that part of geology dealing with the inorganic materials of the earth) is becoming a more exact science in the sense of dealing quantitatively with experimental data by the application of relatively simple and well understood physical and chemical principles to the study of the earth. No adequate presentation of these aspects of geology and their religious significance exists in Adventist literature. In this paper, therefore, I attempt to present in as objective a manner as possible some of the critical evidence that bears on the question of the duration of Earth's history on the basis of quantitative physical and chemical principles.

Although the subject matter is technical, the significance of the conclusions warrants as technical and precise a presentation as is possible to a general audience. I have tried to make the presentation understandable, therefore, to a reader with at least a general acquaintance with basic scientific concepts. Some allusions not basic to the central argument have been left unexplained in the interest of brevity and unity of thought, but the important mathematical equations are presented in graphic form for those not familiar with algebra and calculus.

## I

The actual meaning of *uniformitarianism* has remained a source of discussion and controversy among geologists. Some have attempted to limit rates and magnitudes of geological processes in former times to those rates and processes we observe today. But evidence has steadily accumulated that many parts of the geological record were formed under conditions that do not exist on the earth today. The great successive floods of lava up to 10,000 feet in accumulated thickness and 200,000 square miles in extent in India, northwestern United States, and other areas; the extensive continental glaciers that covered high-latitude land areas; and the shallow sea deposits that underlie large areas of central United States are just a few examples of former conditions with no modern counterpart. Consequently, to many geologists uniformitarianism means that the physical and chemical "laws" that scientists demonstrate as operating in our present environment simply explain the evidence about the history of the earth that we find in the rocks beneath our feet [2].



This concept arose from an attempt to explain certain geological data and therefore has a degree of support from geological evidence. In fact, some degree of uniformity is necessary to investigate the history of the earth in any consistent manner. How can one say that a fossil represents the remains of former life or that a particular sediment was laid down by running water unless one assumes the basic historical continuity of biological processes or the same interactions of water with suspended sediment that we observe today? The traditional argument between conventional "uniformitarian" geologists and defenders of the Genesis story has been over (*a*) the rates and magnitudes of former geological processes and (*b*) the possible intervention by God in the normal operation of nature to produce non-normal results (i.e., the Genesis Flood).

Most of the large-scale processes that act on our environment and that are discerned in the geological record give no indication of the absolute time period involved, although some give an idea of the approximate time (for example, fossil mudcracks imply fairly rapid sedimentation). Rates of many geological processes — such as erosion, transportation, and deposition of sediments by water and wind, and eruption of volcanic materials from the earth's crust — depend on the amount of energy and material available. Therefore the question of time can be answered only after the rate at which energy and material were supplied has been determined. In many processes like those mentioned above, these rates are difficult and sometimes impossible to determine from the evidence available.

The increasing application of physics and chemistry to the study of geology has introduced the possibility of measuring time in an absolute, quantitative manner. Most basic physical and chemical processes — like planetary motions, radioactive decay, and vibration of molecules — are quantitatively time-dependent. For example, a certain molecule will always vibrate the same number of times during a given time interval if other physical conditions are constant. Therefore, if certain geological data can be related to these basic processes, elapsed physical time can be determined theoretically.

There are certain questions that involve the validity of any such attempt: (*a*) Do we understand sufficiently all of the processes involved, or are we neglecting some important factor? (*b*) Is the available evidence sufficient to formulate definite conclusions? (*c*) Did the same processes operate in previous times as operate today, and at the same rates? The first two questions must be answered for each case investigated. But the third question is of a more general nature and concerns the success or failure of the attempt to use known physical and chemical processes to explain earth history.



The approach to this last question has been essentially the common working hypothesis of responsible science, namely, that theories and ideas are dropped or modified as evidence accumulates that they cannot explain. As it applies to geology this concept can be stated as follows: If physical processes have changed, or if observed geological evidence is the result of laws not at present understood or of direct divine intervention, then our attempt to explain geological history by current scientific knowledge should fail. (I am using the word *science* here and elsewhere in this article as "a rational and systematic approach" to understanding our universe (*a*) that is based on experimental evidence, (*b*) that uses as few a priori assumptions as possible, and (*c*) that is willing to accept its own reasonable conclusions.)

This is the position that any geologist, be he uniformitarian or Flood geologist, should start from. Neither the Bible nor the writings of Ellen G. White give a scientific account of Creation and the Flood in any modern sense of the word, and the most obvious characteristics of the geological record indicate continuity with present physical processes. Therefore the uniformitarian hypothesis should be the starting point for our investigation of geology, even if it only serves to delimit its own range of validity and point to the existence of other processes or of an incomprehensible divine intervention in earth history.

Modern science provides strong evidence that physical processes as we know them have remained essentially the same in space and time accessible to our observation. Astronomy has shown that the physical processes observable to us that operate elsewhere in the universe conform to the same physical "laws" as do those of the earth and the solar system. Recently discovered quasi-stellar objects (QSOs) seem to indicate the existence of physical conditions in the universe very different from those in our tiny speck of space; but they present no more compelling evidence for new basic "laws" or processes, especially ones that are inherently foreign to better understood parts of the universe, than does any new area of knowledge. The light from the most distant observable galaxies appears to have taken about 4 billion years to reach us, yet indicates that the physical processes involving electromagnetic radiation at the time and place of its origin were the same processes operating here today.

The highly complex processes of biological life are intimately and directly related to very specific physical and chemical properties of matter and its interaction with energy. A minor change in the properties of any number of elements on which the life process depends would result in extinction of life in its present form [3]. Since the specific properties of elements are directly related to the fundamental "laws" of matter and energy (whether we clearly understand these laws or not), these laws could not have changed significantly since life has existed on earth, without a corresponding change of fundamental biological processes. But no evidence for such change exists in the geological record. Consequently we should be careful about postulating the existence of processes in the past that cannot be observed today unless the evidence suggests that this is so.



## II

I will now examine some of the critical scientific evidence derived from the geological record concerning the time involved in the history of the earth. Of major importance is the phenomenon of radioactive decay. A comprehensive description here of the methods involved and the data accumulated on the subject of radiometric dating is impossible. Only the briefest account of methods is given. The conclusions and interpretations then presented are the result of a sincere attempt to understand and evaluate the existing evidence. The reader is encouraged to consult the references given, and others, to see if these things be so.

Perhaps a brief comment should be made about the accuracy of the data on which the following section is based. In general, the analytical methods and instruments used have been developed in the sciences of physics and chemistry. Slipshod analytical results or unwarranted interpretations in the geological literature are usually evident to a careful reader or are shown up by later publications. I have tried to keep these factors in mind and to deal with data that are well substantiated, or else to indicate the present state of certainty.

Certain atomic nuclei that are unstable disintegrate spontaneously to other nuclei with the emission of matter and energy. The types of disintegration of geological interest are (*a*) the emission of an alpha particle (helium nucleus, (*b*) the emission of a beta particle (positive or negative electron), (*c*) orbital electron capture by the decaying nucleus (same final result as positive beta emission), (*d*) nuclear fission (splitting of a nucleus into two smaller nuclei).



The decay of an individual nucleus cannot be accurately predicted; only the probability of its decay within a certain period of time can be determined. But the average behavior of a large number of such nuclei can be accurately predicted. The following equation represents the behavior of such a large number of like nuclei.

$$-dN/dt = \lambda N$$

This equation means that the number of nuclei decaying in a short period of time ($-dN/dt$) is proportional to the number of nuclei (N) existing at that time. The disintegration constant ( $\lambda$ ) indicates the rate at which a given nuclear type decays.

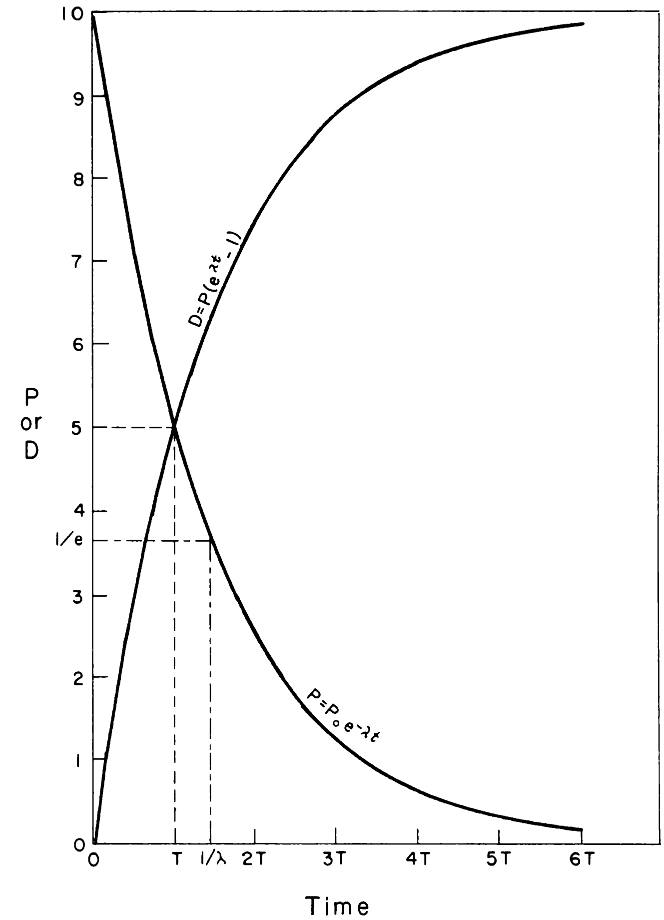
Another expression indicating decay rate is the *half-life.* This expression denotes that time during which one-half of the nuclei initially present will decay. The rate at which a given nucleus decays is a consequence of the basic forces on which the existence and behavior of matter depend. Therefore, in the absence of evidence to the contrary, it is logical to consider the decay rate to be constant.

There is no known way to alter significantly the rate of decay of a naturally unstable nucleus by changing its physical or chemical environment except in the case of electron capture [4]. This decay rate has been changed slightly in light elements with few electrons surrounding the nucleus, but such effects are not significant in any of the elements used in radiometric dating [5]. Mathematical manipulation of the foregoing equation leads to the following:

$$N = N_0 e^{-\lambda t}$$

N is the number of nuclei at any time t, and $N_0$ is the number present at time $t = 0$ (before any of the nuclei under consideration have decayed). N decreases exponentially with time (FIGURE 1). This equation can be used to indicate elapsed geological time if N and $N_0$ can be related to observable properties of rocks and minerals containing radioactive elements. In gen-

FIGURE 1. The decay of the parent (P) and the growth of the daughter (D) nuclei as a function of time in units of the half-life (T) of the parent.




eral, this involves measuring the abundance of a radioactive nucleus present (P, parent) and the abundance of its decay product (D, daughter). Then in the above equation $N = P$ and $N_0 = D + P$ or

$$P = (P + D)\ e^{-\lambda t}$$

Rearranging leads to

$$D = P\ (e^{\lambda t} - 1) \qquad \text{(Eq. 1)}$$

This is the basic equation used in radiometric dating (FIGURE 1).

There are three main assumptions involved in using equation 1. (*a*) Either there has been no gain or loss of parent or daughter from the material investigated during the time involved, or such changes can be determined and corrected for. (*b*) Either no daughter was present at time t = 0, or the amount can be determined and used to correct D for the initial daughter present. (*c*) The decay rate has remained constant during the time involved.

The four main dating techniques that have been used, and their results, are discussed separately in the following sections.

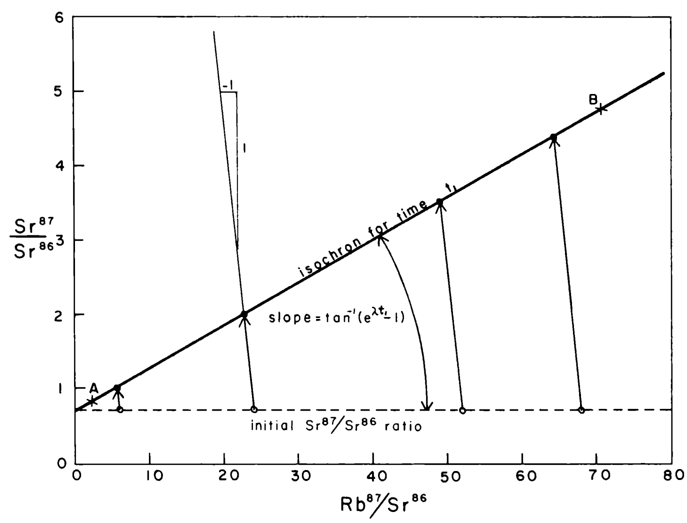
1. RUBIDIUM-STRONTIUM SYSTEM [6]

The isotope rubidium-87 ($Rb^{87}$) decays by negative beta emission to strontium-87 ($Sr^{87}$) with a half-life of about 47 billion years. (Isotopes are chemically similar atoms with different nuclear structure). Since the average abundance of strontium in the rocks usually dated by this method is similar to that of rubidium, the assumption of no initial $Sr^{87}$ would be clearly invalid. Consequently a method must be found to
35 determine the initial $Sr^{87}$ present when the radiogenic time clock started. This can be done by measuring isotope ratios. Equation 1 is divided by the abundance of $Sr^{86}$, another isotope of strontium that is not involved in a decay process and therefore should have constant abundance with time, and a term is added to represent the initial isotope ratio.

$$Sr^{87}/Sr^{86} = (Sr^{87}/Sr^{86})_0 + (Rb^{87}/Sr^{86})\ (e^{\lambda t} - 1)$$

This equation is in the form y = b + mx, which is the equation of a straight line. If rocks and minerals formed at the same time and place, but with different $Rb^{87}/Sr^{87}$

FIGURE 2. A Rb/Sr isochron diagram showing the undisturbed growth of four minerals with different Rb/Sr ratios, but with the same initial $Sr^{87}/Sr^{86}$ ratio. At any time t, the composition of the four minerals plots on a straight isochron line. The isochron could also be generated by mixing two compositions A and B in varying amounts.



ratios, can be analyzed and the measured ratios are the result of radioactive decay, the values when plotted on a graph of $Sr^{87}/Sr^{86}$ versus $Rb^{87}/Sr^{86}$ should form a straight line whose slope is related to the age of the samples and whose y intercept represents the initially common $Sr^{87}/Sr^{86}$ ratio of the analyzed samples (FIGURE 2).

An alternative explanation of such a straight line would be that the plotted points represent different amounts of mixing between two different magma compositions, say A and B in FIGURE 2. If the plotted points represent different rock samples that are separated by a large enough distance to represent parts of a nonhomogenous liquid, this explanation could be geologically valid. But if minerals from the same small rock sample form such a line, then the decay explanation is the only possible one, since the liquid magma in a small area will be homogenous in $Sr^{87}/Sr^{86}$ ratio because of mixing [7].



If the analytical values do not form a straight line but scatter, the assumptions underlying the use of the above equation are not valid in that particular case. Many studies have shown that the mixture hypothesis is rarely valid and that different rock samples that originated in the same geological event usually plot on a straight line, indicating homogenous initial $Sr^{87}/Sr^{86}$ ratios sometimes over many square miles. In rocks that have been altered by heat or pressure after initial formation, the individual mineral samples often do not fall on a straight line, whereas the whole individual rock samples do. This indicates redistribution of isotopes over small areas (usually fractions of inches) [8].

All available evidence that I am aware of appears to support the validity of the method as a geochronological tool when proper and careful use is made of it.

### 2. POTASSIUM-ARGON SYSTEM [9]

A natural isotope of potassium ($K^{40}$) disintegrates by negative beta emission to calcium-40 ($Ca^{40}$) and by electron capture to argon-40 ($Ar^{40}$) with a total half-life of 1.26 billion years. The ratio of the two types of decay is constant; so only one decay product needs to be measured to determine radiometric time. Calcium-40 is very abundant in nature, whereas $K^{40}$ is a rare isotope (0.02 percent of naturally occurring potassium); therefore, trying to measure any radiogenic calcium would be difficult, if not impossible in most cases.

On the other hand, $Ar^{40}$ is a chemically inert gas whose only significant source in the rocks of the earth is the decay of $K^{40}$. Since it is chemically inert, it tends to be excluded from the orderly lattice structure of crystallizing minerals; but after the mineral has formed and cooled, the subsequently produced $K^{40}$ will be trapped in the tight crystal structure. The assumption of no initial $Ar^{40}$ is therefore a geochemically reasonable first approximation that can be modified as data accumulate. Other isotopes of potassium are measured to determine and correct for the presence of $Ar^{40}$ not due to radioactive decay.

Experiments have shown that some rock materials are more suitable for potassium-argon dating than others. The best minerals have high potassium contents, high resistance to diffusive loss of argon, and low initial excess $Ar^{40}$ relative to that produced by decay during the dated time interval. When minerals with these properties are selected, good agreement with other dating methods, especially Rb-Sr and recently fission-track dating, has been obtained [10].

Of course violations of the dating assumptions have also been found. In rocks that have been subjected to rapid cooling (determined by independent evidence) [11] or that crystallized far below the earth's surface, where magmatic $Ar^{40}$ may have attained relatively high pressures [12], excess $Ar^{40}$ has been found. These effects are not usually significant for carefully selected samples, and the general agreement with other dating methods which are not subject to the same difficulties shows the general validity of the potassium-argon method. Recently developed analytical techniques may permit the use of the method even in less than ideal situations [13].

3. URANIUM-THORIUM-LEAD SYSTEM [14]

The three natural heavy isotopes — uranium-238 and -235 and thorium-232 ($U^{238}$, $U^{235}$, $Th^{232}$) — decay by alpha emission with half-lives of 4.5, 0.71, and 13.9 bil-
37 lion years respectively through a series of intermediate unstable isotopes to the stable end products, lead-206, -207, and -208 ($Pb^{206}$, etc.). These chemically and geologically associated nuclei allow four different age calculations to be made on suitable minerals. The mineral zircon is usually used because of its widespread availability, though low abundance, and relatively high uranium and thorium content. Equations similar to the Rb-Sr equation can be used for each parent-daughter pair, such as:

$$Pb^{206}/Pb^{204} = (Pb^{206}/Pb^{204})_0 + (U^{238}/Pb^{204})\ (e^{\lambda t} - 1)$$

where $Pb^{204}$ is another naturally occurring lead isotope. In addition to the parent-daughter relationships, the ratio $Pb^{206}/Pb^{207}$ can be used for dating, since this ratio varies with time, because of the different decay rates of $U^{238}$ and $U^{235}$. The initial abundance of lead in zircons is usually so low that the $(Pb^{206}/Pb^{204})_0$ correction term is relatively minor [15].

Zircon is a very resistant mineral and often physically survives when other minerals in rock are altered because of physical or chemical changes in the environment. In such cases the U-Th-Pb system is usually affected by diffusion of these elements in the zircons, and ages calculated from the four different methods are not the same. Techniques have been developed to analyze these discordant ages. But since an adequate description is too involved for this article, the reader should consult the references given for details. The resistance of zircon and the availability of four independent age equations sometimes makes this system the only method available for dating the original time of formation of rocks where alteration subsequent to the original formation has invalidated other radiometric dating systems.

4. FISSION-TRACK DATING [16]

Although most $U^{238}$ decays by alpha emission, about one in every two million atoms decays instead by spontaneous fission. This slow rate is fast enough to use the method for dating if the record of fission decay can be observed. The daughter nuclei recoil from the decay site and leave a damage trail in the surrounding crystal before they are stopped. These minute imperfections in the crystal can be chemically etched, observed, and counted under a microscope.

If the amount of parent uranium and the number of fission tracks present are known, a radiometric age can be calculated. This age does not depend on assumptions concerning initial daughter present, because there will be no fission tracks when the mineral first forms. Any age calculated is most likely to be less than the real radiometric age, because of track healing in the crystal with time.

Comparison of fission-track dating methods with the previously discussed systems shows good agreement to about 1 billion radiometric years, with a tendency for older materials to show a slightly lower age, probably because of track healing.

The great abundance of data available on the above dating methods has shown that, when suitable materials are analyzed, the different methods give concordant results within reasonable limits of geological and physical accuracy. Furthermore, discrepancies can be explained by known natural geochemical and geophysical processes (like alteration by heat or pressure) that act on the materials of the earth. It appears that radioactive decay is the only possible known mechanism that can account for the observed results.



Some apologists have used the "gap" theory of Genesis (chapter one, verse one) to reconcile radiometric dating with the seven-day creation record, but this explanation clearly does not fit the evidence of the geological record. The foregoing dating procedures do not measure the time that matter has been in existence, but the time since it has been in its present state in particular rocks and minerals (since solidification of a liquid magma or major alteration).

There are many of these once molten (igneous) rocks that have intruded fossiliferous sedimentary strata from below or have spilled out as lavas above them, in both cases clearly showing a genetically younger age than the associated fossils. In addition there are minerals such as glauconite that form by chemical precipitation from solution within the actual fossiliferous sediments that can be dated [17]. These are without doubt younger than the associated fossils. What appear to be the remains of bacteria and algae are associated with some of the oldest radiometrically dated rocks on earth, over 3 billion radiometric years [18]. Much effort has been made to date these rocks that can be related to fossils. The relative time scale of geological events that had previously been developed, on the assumption that the sequence of life forms has changed through time, has been substantiated in major details by the radiometric dating methods [19]. In fact, the extension of both radiometric dating and fossil correlation procedures often leads to very good agreement with the radiometric time scale developed in other areas of the world [20].

CONSTANCY OF DECAY RATE

There still remains to be answered the question of the constancy of the decay rate. This cannot be determined in an absolute manner, although there exists evidence from which an inductive answer can be derived. Previous mention has been made of the firm basis of a constant decay rate in basic physical theory, but experimental evidence can also be investigated.

The isotope ratios of most important elements on earth have been investigated. Some of these ratios have also been determined for meteorites that strike the earth and recently for the lunar samples. The ratios of stable isotopes that are not affected by decay processes or nuclear reactions have been shown to be the same in these three sources (some of the elements involved are potassium, strontium, silver, carbon, nitrogen, and sulphur) — strongly suggesting that the material in these bodies had a common origin and that at the time of formation the radioactive isotopes also had similar abundances.

If this is true and if the decay rate has been the same on earth, meteorites, and the moon, the present ratios of the radioactive isotopes in relation to the stable isotopes of the same elements should be the same in the three sources. $U^{238}/U^{235}$ should also be the same, since this ratio changes with time because of the different decay rates of the two isotopes. The uranium ratio is identical within experimental error in these three sources, and potassium and rubidium ratios are the same on earth and meteorites. (I am not aware of these ratios having been determined on lunar samples yet.) This would strongly suggest that the decay rate has been the same in all materials available for our study [21].

Another phenomenon that has been investigated in relation to the constancy of the decay rate is the pleochroic halo. The alpha particle emitted by a particular radioactive isotope has a definite kinetic energy and the variation in range (distance traveled before being stopped because of collisions) of mono-energetic alpha particles is small. The range is related to the energy of the particle. In addition, the energy of an emitted alpha-particle is related to the stability of the parent nucleus and to the decay rate — the less stable the nucleus, the faster the decay rate and the more energetic the emitted alpha particle. Physicists have developed equations that can approximately predict these quantities from basic nuclear properties of elements [22].

Quite often minute grains of highly radioactive minerals such as zircon are included in larger crystals of more common rock-forming minerals. As the alpha particles from the decay of radioactive nuclei in the inclusion are emitted in all directions into the surrounding crystal, spherical halos of radiation damage are formed that can be detected as a discoloration of the crystal after a certain threshold track density has been reached. These halos have definite radii. Once the relation between alpha-particle range and energy in the host crystal is established, then the energy of the alpha particles that created the halo can be determined. The parent nucleus can be identified from a knowledge of radioactive isotopes and their corresponding decay energies. Multiple ring halos with radii corresponding to the decay products of the uranium and thorium series have been identified in rocks [23].



The foregoing relationship of decay rate and alpha-particle range can lead one to conclude that if a change has occurred in the stability and decay rate of alpha emitting isotopes, then this change would be reflected in variations of alpha-particle range and consequently of halo radii with time. Pleochroic halos produced by uranium and thorium in rocks of various ages have been investigated, and no significant change has been found. A slight change in the halo radius because of the parent uranium decay was reported [24], but this effect was explained later by the change in $U^{238}/U^{235}$ ratio with time and corresponding decrease in intensity of the $U^{235}$ halo, which is only slightly larger than the $U^{238}$ halo. Strictly speaking, this just indicates that the apparent range-energy relationships of alpha particles have remained constant, but neither is there any physical evidence to say that the decay rate has not remained constant during the time involved.

In addition to the uranium and thorium series halos, other "anomalous" halos have been described, some of which can be identified with separately occurring short-lived uranium and thorium series isotopes [25]; others have not been identified with certainty and may belong to short-lived, now extinct, isotopes [26]. Some observers have suggested that these anomalous halos may be evidence of a short time elapsing between the creation of matter and its existence in its present form in rocks, because any separately occurring, unsupported, short half-life isotopes would have decayed if a long time had elapsed between these two events. The anomalous halos associated with the uranium and thorium decay series show geological and physical characteristics that suggest they originated by the chemical separation of the different elements in the series from chemically active solutions migrating through the enclosing rocks [27].

Such an explanation is geologically and geochemically plausible. The geological and geochemical conditions which are important to an understanding of the origin of the recently investigated anomalous halos have not been reported. Until these important details about the origin of pleochroic halos are more thoroughly investigated and understood, conclusions about the nature of geological time based on them are very tenuous. In other words, this is an active area of investigation in which premature judgments are unwarranted, inasmuch as there is a basic lack of understanding of what phenomena are involved. Some details of the available evidence indicate that physical and chemical phenomena in addition to radioactive decay, such as alteration of minerals and diffusion of radioactive nuclei, may be involved in the genesis of these anomalous halos.

### COOLING RATE DATING

Other aspects of physical geology also have a bearing on the duration of time. One of these is heat conduction. The small size of objects that we see heating and cooling every day does not readily bring to mind the long periods of time required for large objects to cool. Large bodies of rock the size of those we see in the cores of mountains today may require thousands of years to cool from their initially molten state.

I have made a calculation based on a simplified physical model [28]. A laterally extensive sheet of solid rock 6,500 feet in thickness with the upper surface kept at 0° C would require 100,000 years to cool from an initial uniform temperature of 700° C to a final maximum temperature of 70° C. Some areas of the world, especially areas of former mountain building, give evidence of many such large intrusions of hot magma related to each other in a time sequence. The large size of mineral crystals found in these rocks, which depends on slow rates of diffusion of chemical elements in liquid magmas, supports the long cooling periods determined by thermal conduction theory.

### CARBON-14 AND THE ATMOSPHERE

I have left the discussion of carbon-14 dating until now, because it must be considered in relation to former conditions in the earth's atmosphere. Carbon-14 is produced mostly in the stratosphere (upper atmosphere) by nuclear reactions between neutrons generated by cosmic rays and nitrogen-14, the main constituent of the atmosphere. This $C^{14}$ is incorporated into atmospheric carbon dioxide and mixed with the stable isotopes ($C^{12}$, $C^{13}$) of carbon in the systems that exchange carbon dioxide with the atmosphere (organic life and terrestrial waters).

When an organism dies, it stops exchanging carbon with its environment and either decays or is preserved. The $C^{14}$ present in the dead material disintegrates with a characteristic half-life of 5,730 years. The remains of a dead organism can theoretically be dated by measuring the present $C^{14}/C^{12}$ ratio in the remains. The original $C^{14}/C^{12}$ ratio is assumed to have been similar to the ratio found in modern organisms in a similar environment. This consideration of environment is important, since the $C^{14}/C^{12}$ ratio varies in modern carbon exchange reservoirs. This dating method is normally useful for ages up to several half-lives of $C^{14}$, although techniques of isotope enrichment can theoretically extend the time limit considerably if problems of contamination with modern carbon can be reduced. For details, complications, and discussion of results, the reader is referred to other sources [29].

It has been postulated that the nature of the preflood atmosphere prevented the formation of appreciable $C^{14}$ at that time. Therefore, apparently old $C^{14}$ dates just indicate preflood, flood, or early postflood conditions. Two possible mechanisms proposed for this shielding effect are (*a*) a stronger geomagnetic field which effectively deflected most cosmic rays from the earth and (*b*) a water vapor canopy existing above most of the present atmosphere that absorbed cosmic rays and shielded the atmospheric nitrogen.



The possible nature of a preflood atmosphere could be the subject of another paper. Any postulated effects on the $C^{14}$ system can be tested independently of hypothetical atmospheric conditions by comparison of $C^{14}$ dates with some other dating system that does not depend on atmospheric conditions. The half-lives of the radioactive parents previously discussed are very much greater than those of $C^{14}$; so a direct comparison in the short time period useful in $C^{14}$ dating is difficult. With considerable technical and geological difficulties, K-Ar dating has been extended to such short time periods. In cases where these difficulties appear to be overcome, there is good agreement between the two methods [30].

Under certain circumstances, chemical separation of the different elements in the uranium and thorium decay series occurs in nature. When the series are physically undisturbed, an equilibrium is reached where the rate of decay of any short-lived member is equal to its rate of production. If elements are separated, this equilibrium is disturbed and the return to equilibrium over a period of time can be used as a dating method.

Marine corals are greatly enriched in uranium isotopes, in comparison with thorium isotopes. In addition, $U^{238}$ and its daughter $U^{234}$ are not in equilibrium in sea water (activity ratio = 1.15) because of preferential removal of $U^{234}$ from weathering rocks. Both the decay of excess $U^{234}$ and the growth of $Th^{230}$ (daughter of $U^{234}$) in old corals can be used as dating techniques. The calculated ages of old coral reefs by the use of these two methods agree satisfactorily with each other and also with available $C^{14}$ dates on geologically related samples [31].

Sediments that accumulate on the ocean floor are initially enriched in the relatively insoluble thorium and protactinium isotopes with respect to their parent uranium. The decay of these unsupported daughters has been used to measure accumulation rates of ocean sediments. The conditions needed for valid ages are not always found (migration of isotopes in the sediments and mixing of sediment occurs); but when the appropriate conditions appear to be met, the measured disequilibrium ages agree with $C^{14}$ ages on the same sediment cores [32]. Moreover, when large age discrepancies occur, the $C^{14}$ age is always less than the disequilibrium age, indicating possibly more, not less, $C^{14}$ in the past atmosphere [33].

## III

For the benefit of those who followed the foregoing presentation with difficulty, I will summarize the main points.

1. The radioactive isotope abundance pattern in rocks can be scientifically explained at present only by radioactive decay processes.

2. The decay rates have been the same in all solar system material available to us. (Meteorites are thought to come from the asteroid belt between the orbits of Mars and Jupiter, about 2.8 times farther from the sun than Earth is.)

3. Other well documented and understood physical processes either support or do not contradict the evidence of radiometric dating.

4. Fossil organisms are definitely found in rocks at least 600 million radiometric years old and probably in the oldest known sedimentary rocks on earth.

5. Carbon-14 dating is in general agreement with other dating procedures, suggesting a fairly constant $C^{14}$ level in the atmosphere in geologically recent times.

6. There is no well documented evidence suggesting that physical "laws" or processes operating in the inorganic world, at least during the time interval involved in this paper (about 3 billion years), are not those we can see and investigate today.

7. Many of the evidences used to argue for a short time scale of earth history (rapid sedimentation in certain areas, etc.) cannot determine absolute durations of physical time over large areas. Moreover, this characteristic of fluctuating rates of buildup of the geological record is inherent in the

operation of nature and is found on all scales — from the very thinly deposited laminae of shaly sediments (indicating alternating periods of fast and slow deposition) to explosive volcanic violence, earthquakes, and landslides, followed by little or no activity.

One can ask, of course, why the present isotope abundance pattern could not have been created instantaneously as we find it today, but this solution is not as satisfactory as it may appear at first. This would not be at all similar to the instantaneous creation of a tree with growth rings, because the isotope abundance patterns have no necessary relationship to the structure of rocks and minerals as growth rings do to the structure of a tree. Furthermore, this would not explain the existence of radiation damage, like fission tracks, associated only with radioactive minerals and in quantitative agreement with radiometric ages based on isotope abundances or the existence of radiometrically old rocks and minerals in various degrees of demonstrable genetic relationship to preserved fossils.



Again, one might postulate an abnormal disruption of nuclei during an episode such as the Genesis Flood. Since there is no intrinsic difference between radioactive and nonradioactive nuclei, one should expect that some nonradioactive isotopes would be affected by such an event, but available evidence gives a negative answer to this expectation. In short, if the events narrated in Genesis took place within the recent past, then this interpretation should find abundant support at the center of physical geology. Instead, when viewed from a broad perspective, the testimony of this field is uniformly against such an interpretation.

The conclusions reached here are admittedly incompatible with some of the literal interpretations of the beginnings of the book of Genesis. However, I believe there is sufficient justification for careful and objective examination of our position on the literalness of the biblical Creation and Flood stories and for careful consideration of the biblical and literary-historical evidence pointing to a figurative and theological interpretation of this material that has been presented by responsible, conservative biblical scholars [34].

It is most important that the church tolerate, and even encourage, constructive thought and necessary differences of opinion that will arise before a solution to these problems is clear. It is my sincere conviction that a realistic and objective attitude toward geological evidence will be found to be in harmony with the same attitude toward the Bible and will reinforce faith and confidence in an inspired Word, the writings of Ellen White, and the soundness of basic Adventist doctrine [35].

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35 I hope that no one concludes that I am supporting the theory of biological evolution. Although acceptance of a long time scale opens the possibility of evolution, this is an independent theory and must be evaluated on the basis of its own supporting evidence. Recent denominational publications have presented the problems of evolutionary theory adequately in a general manner (see Harold G. Coffin, *Creation — Accident or Design?,* Washington, D. C.: Review and Herald Publishing Association 1969), although a detailed examination of the geological evidence concerning the origin and history of life on earth is not available at present.