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The Pentateuch and Joshua

The three questions which closed the last chapter are actually closely interrelated. For if Moses wrote the Pentateuch, then he certainly would have had access to the correct information concerning the Exodus, and it is reasonably probable that his information on Creation and the Flood are accurate as well. Also, if the information on Creation and the Flood and the Exodus are accurate, there is no good reason to deny the Mosaic authorship of the vast bulk of the Pentateuch. On the other hand, if the Pentateuch and Joshua were written late, there is little reason to expect them to be accurate, and if they are inaccurate, it is virtually certain that they were written late.

It may surprise some, but I think the easiest approach for now is to deal with the question of the historicity of Genesis 1-9 and its relation to the theory of evolution.

Evolution, Creation, and the Flood

Numerous attempts have been made to relate the early Genesis account to the theory of evolution. These can be divided into four groups. First, there is *mechanistic evolution.* This theory holds that the universe and life in it evolved by purely naturalistic means, without any outside interference. In this view the geologic column represents millions of years of time (currently felt to be 4.3 to 4.5 billion years total, of which 550 to 600 million years, called the Phanerozoic, have undisputed traces of life). The adherents of this theory commonly hold that the early Genesis account is entirely mythical and thus unreliable.

Second, there is *theistic evolution.* This theory holds that mechanistic evolution is essentially correct except that at certain points (or perhaps continually) God helped the process along a little. This theory usually deals with the early Genesis account in a manner similar to, but not usually quite as harsh as, mechanistic evolution.

Third, there is the theory of *multiple creations*, sometimes called *progressive creation*, which holds that there was a creation, or multiple creations, over a period of millions of years. These successive creations are usually thought of as being destroyed catastrophically, creating the geologic column. Then a few thousand years ago, there was a special creation and a fall, whose details more or less fit those of Genesis 1-3. From the multiple creations viewpoint the Flood is usually interpreted as a local phenomenon that did not leave any unequivocal traces.

Finally there is *special creationism,*[1] which holds that God created a chaotic world and then created life on it for the first time a few thousand years ago. In this view the geologic column (more properly the Phanerozoic to at least the Cretaceous and possibly to the Pleistocene) is the result of the Biblical Flood. What happened before creation week is not completely agreed upon. Our planet may have been created on the first day, or it may have been in a chaotic state for millions of years before creation week. The same holds true for the stars outside our solar

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[1]The term originally came from the idea that God created each individual species as it is today, but by now has evolved (pardon the expression) into the definition given in the text, with the term "special" becoming less technical and more an expression of a specific unique supernatural intervention.

system. From the point of view of modern physics, this distinction may not matter, as the aging of the universe without observers is in one sense irrelevant.[2]

The first alternative, mechanistic evolution, appears at this point highly unlikely to be correct. As we have noted in chapter 2, mechanistic evolution has no explanation for the origin of life. The evidence we have indicates that this problem is becoming more acute rather than less so.

There are a number of other criticisms of "evolution" which are actually criticisms of mechanistic evolution. For example, there is the problem of the "missing link". For almost all phyla the problem is actually a missing chain—all the links are missing. Stephen Jay Gould's "hopeful monsters" might as well be relabeled "miracles". One of the few testable predictions Darwin made was that intermediate forms would be found as the geologic record was more fully examined. At present this prediction appears to be dead wrong. Then there is the problem of evolving complex structures like the eye—and not just once, but twice (squids, octopi, etc., and vertebrates). Such problems make it reasonable to discontinue consideration of mechanistic evolution until more evidence compels its re-evaluation. This is in spite of the fact that it and special creationism are the two most satisfying positions from a theoretical point of view (the most elegant).

But none of the foregoing objections touch either theistic evolution or multiple creations. For if God was there to help the process, in whatever way He did it, then the fact that it was a miracle would not prove theistic evolution or multiple creations wrong, and in fact is not unexpected. Hence the above arguments fall well short of proving special creation. Therefore we must use

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[2] As a logical option, the day-age theory can be ignored. It is neither Biblical (the days in Genesis 1 had an evening and a morning) nor is it adequate to explain the geologic column (for example, the reptiles of the 6th day precede the birds and whales of the 5th day in the geologic column). It is a hybrid born of desperation.

All of the above theories accept minor evolutionary changes (sometimes called microevolution) today. Only mechanistic evolution and one brand of theistic evolution wholeheartedly accept large evolutionary changes (macroevolution). Nobody knows the precise line to draw between microevolution and macroevolution, except that macroevolution would bridge the gap between the phyla and between the classes, and between other animals and humans, while microevolution does not. Therefore differentiation between these theories on the basis of macroevolution is not as useful as it would seem at first.

another approach to decide which scenario is most likely.

We should now note the major advantages and disadvantages of the three remaining groups of theories relative to each other. Theistic evolution has the advantage of not having to challenge the scientific evidence for long ages of earth's history. It is also able to incorporate any evidence for macroevolution, and yet is not mechanically dependent on macroevolution. However, it must deny the historicity of the Genesis creation and flood accounts (and thus must assume that Jesus' theology was incorrect, which is difficult if Jesus was really the Messiah). It is also basically an *ad hoc* theory. It can accommodate almost any evidence, which from a theoretical point of view is a disadvantage. One would prefer a theory which had more predictive power.

On the other hand, special creation has a great deal of predictive power, and allows for the historicity of the Genesis creation and flood accounts, making it an elegant theory, on a par with mechanistic evolution. However, it must deny the validity of the standard arguments for the existence of life on the earth for millions of years (it bears repeating that special creation may allow for our planet, and the stars, to be in this age range. It is only when unmistakable fossils exist, usually believed to be in the Cambrian, that the difficulties become acute).

The multiple creations model is a compromise. It allows life on the earth to be as old as usually believed, while at the same time being more or less faithful to the Genesis creation account. This has some theological advantages; it can allow Jesus' theology, and Paul's theology, to be more accurate than can theistic evolution, as Jesus' theology makes use of the Genesis account of creation, and Paul's theology depends on the Fall.

However, the multiple creations model is unable to find any traces of a Flood in the geologic record. It is thus in the awkward position of insisting on the basic historicity of Creation and the basic nonhistoricity of the Flood.[3] The multiple creations model therefore does not completely exonerate Jesus' theology, as Jesus also makes use of the Flood as a parallel to the time of His second

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[3] Remember that according to the Genesis account the flood is supposed to have lasted for a year. Noah is supposed to have built a large boat in preparation and supported a veritable zoo. Perhaps most striking, the boat is said to have landed in the mountains of Ararat. This implies an event of global scale. If there are not obvious geological evidences of such an event, then it is wildly exaggerated if not fictitious. Theology based on a non-existent event is baseless.

coming. The insistence on a Creation and a Fall for what are essentially theological reasons while denying another theologically significant event in the same document because this time it is scientifically testable seems incongruous to me. Thus I see the multiple creations model as theoretically the least satisfying option, an option to be used only if we must eliminate both theistic evolution and special creation from the competition.

So for now we can attempt to choose between theistic evolution and special creation. It should be noted that with the disappearance of mechanistic evolution[4] this is no longer a choice between science and religion (it does, of course, have scientific and religious repercussions). Both theories postulate a God Who intervenes. Both theories claim that they can explain the scientific evidence if given enough research. What this dispute is actually

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[4] In fact, even mechanistic evolution may not fit some of the more important qualifications of a scientific theory. Karl Popper had trouble with the scientific aspect of mechanistic evolution as noted in the following passages:

". . . I intend to argue that the theory of natural selection is not a testable scientific theory, but a metaphysical research program; and although it is no doubt the best at present available, it can perhaps be slightly improved." (Popper KR: *Unended Quest: An Intellectual Autobiography.* Glasgow: William Collins Sons & Co. Ltd., 1976, p. 151)

"It is metaphysical because it is not testable." (p.171)

". . . it suggests the existence of a mechanism of adaptation, and allows us even to study in detail the mechanism at work. And it is the only theory so far which does this.

"This is, of course, the reason why Darwinism has been almost universally accepted. Its theory of adaptation was the first nontheistic one that was convincing; and theism was worse than an open admission of failure, for it created the impression that an ultimate explanation had been reached.

"Now to the degree that Darwinism created the same impression, it is not so much better than the theistic view of adaptation; it is therefore important to show that Darwinism is not a scientific theory, but metaphysical. . . ." (p. 172)

Popper did see one prediction, and therefore a possible scientific test of evolution: "Gradualness is thus, from a logical point of view the central prediction of the theory. (It seems to me that it is its only prediction.)" (p. 172)

Thomas Kuhn also noted that it is difficult to derive testable conclusions from mechanistic evolution. When discussing his differences with Karl Popper, he noted that a modified Popperian approach might be that "For a field to be a science its conclusions must be *logically derivable* from *shared premises. . . .* But in this form, at least, it is not even quite a sufficient condition [for a field to be a science], and it is surely not a necessary one. It would, for example, admit surveying and navigation as sciences, and it would bar taxonomy, historical geology, and the theory of evolution. The conclusions of a science may be both precise and binding without being fully derivable by logic from accepted premises." *(The Essential Tension,* Chicago, University of Chicago Press, 1977, p. 250, n 21, italics his)

over is history. What matters is not what **should** happen, or what **could** happen, but what **did** happen.

Once the dispute is seen in this way, two considerations come to the fore. First, the early Genesis account taken at face value purports to be historical, and therefore should not be ignored until it has been shown to be false. Special creation gains an edge (possibly a slight edge, but an edge) in the discussion, since there are no early historical documents supporting theistic evolution. Second, chronology is the backbone of history. And the essential difference between the two theories (other than their theological implications) is time. In this case absolute physical and chemical dating methods (primarily radiometric dating) are the backbone of chronology from a theistic evolutionary point of view (or any other point of view espousing a long age of life on earth). So it becomes incumbent on us to examine the reliability of these physical and chemical dating methods. We may wish to avoid getting into nitpicking details, but if we are to be honest and careful we really have little choice.

There are several books on dating methods. Perhaps one of the better ones for an initial survey is *Absolute Dating Methods* by Mebus A. Geyh and Helmut Schleicher.[5] This book lists 76 physical and chemical methods used to date the earth, the moon, meteorites, or fragments thereof. The list at first seems overwhelming. But we are not looking for pat answers. And so perhaps the best way to begin is at the beginning. Potassium/argon dating is listed first, and is often considered the most reliable dating method demonstrating a long chronology, so we will begin there.

Potassium/argon dating

Potassium/Argon dating is one kind of radiometric dating (dating using radioactive material). Radioactive materials, like the starting materials of many other physical and chemical processes, transform in proportion to time and the amount present at the beginning.[6]

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[5] Berlin: Springer-Verlag, 1990, hereinafter cited as Geyh and Schleicher. This book has an excellent bibliography in the back.

[6] Some readers may find this introductory discussion unnecessary. Others, however, will find it too brief. Those who do may consult standard physics,

If you start with an amount, say 10 kilograms or 22 pounds, of an unstable substance (we will call it substance A), at the end of a specified time, say 1 year, you would have only part of it left, for example 8 kilograms. In this case, if you started out with 5 kilograms instead of 10, you would have 4 kilograms at the end of 1 year. The general formula would be $A_{1 \text{ year}} = A_{\text{Beginning}} \times 0.8$, for 1 year's wait (in line with conventional usage we will use A_0 for $A_{\text{Beginning}}$). But if you started with 10 kilograms and waited 2 years, you would not have 6 kilograms. At the end of the first year you would have 8 kilograms. This 8 kilograms becomes your starting point for the second year, and the amount at the end of the second year is 8×0.8, or 6.4 kilograms. By the same token at the end of 1/2 year, the amount will not be 9 kilograms but slightly less than 9 kilograms. This makes the formula $A_{1 \text{ year}} = A_0 \times 0.8$ awkward to use.

A more convenient set of formulas are $\ln(A_0/A) = kt$ and (essentially the same formula) $A = A_0 e^{-kt}$. (For those whose eyes glaze over at the mere mention of calculus, it may be of some help to note that only standard formulas are used in this text. These formulas are included for the benefit of readers who want to go into the subject more thoroughly).[7]

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chemistry, and calculus texts and/or the introduction to a geochronology text. Two good geochronology texts are Dalrymple GB, Lanphere MA: *Potassium-Argon Dating: Principles, Techniques, and Applications to Geochronology.* San Francisco: W. H. Freeman, 1969, hereinafter cited as Dalrymple and Lanphere, and Faure G: *Principles of Isotope Geology* (2nd ed). New York: John Wiley and Sons, 1986, hereinafter cited as Faure.

[7] These formulas can be derived by using a very small time interval (theoretically infinitely small) dt and writing $-dA/dt = k \times A$ or kA. That is, the amount lost in a very small amount of time (therefore the minus sign) is directly proportional to (= a constant k times) the amount at that time (in our original example k would be 0.22314/year. This means that during a very small amount of time, say 1/100,000 of a year or 5.259 minutes, our 10 kilograms would lose 0.000022314 kilograms). This can be rewritten $dA/A = -k\,dt$. This formula can be integrated to yield $\log_e A - \log_e A_0 = -k(t - t_0) = -kt$ (we will define $t_0 = 0$), or $\ln(A_0/A) = kt$ (t is now the time from the beginning of the period). Taking the exponential of both sides we have $A_0/A = e^{kt}$ or $A/A_0 = e^{-kt}$ or $A = A_0 e^{-kt}$. Many texts use the Greek letter λ instead of k for the time constant. Most readers are acquainted with logarithms to base 10. Some may not be familiar with logarithms to base *e*. Logarithms to base *e*

($e = 1 + 1/1 + 1/[1{\times}2] + 1/[1{\times}2{\times}3] + 1/[1{\times}2{\times}3{\times}4] + \ldots = 2.718281\ldots$)

are slightly more difficult for common usage, but the natural result of calculus (thus the name natural logarithm and the abbreviation ln), simpler theoretically, and much easier for computers. We may compute

We will see these formulas and variants again and again. They can be graphically represented by the following:
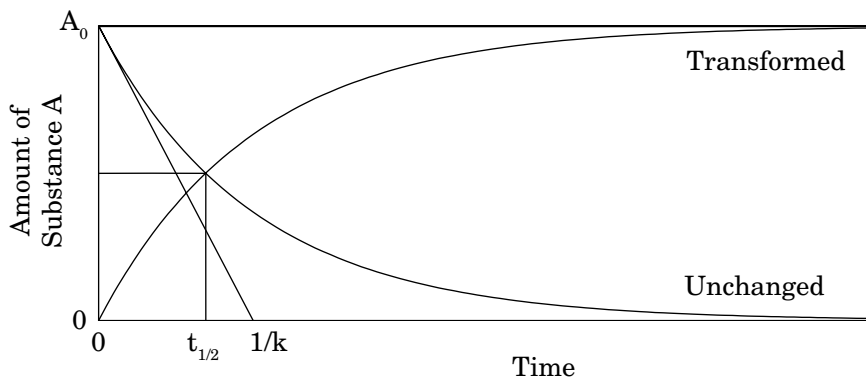
Note that the inverse of the constant k gives the time at which all of the substance would have transformed if it had kept up its initial rate of transformation. This is sometimes called the mean life. There is another constant, the half life (or $t_{1/2}$), which is the time at which half of the material is gone. It is equal to ln 2 (= 0.693147 . . .) times $1/k$. Also note that the amount of material transformed at a given time (the daughter product D) can be found by the formula $D = A_0(1 - e^{-kt})$. If one knows the starting amount A_0 one can find the time needed to leave only a given amount of unchanged A by the formula $t = (\ln [A_0/AT]/k$. If A_0 is not known one can calculate it by the formula $A_0 = A + D$. But this is only valid if there was no D present at the beginning and there has been no D or A gained or lost since the beginning (other than by spontaneous transformation of A to D). If there has been D present at the beginning (D_0), or if D has been added (D_A) or lost (D_L) since the beginning, then the formula for finding the D formed from A, D*, is $D^* = D - D_0 - D_A + D_L$, and $A_0 = A + D^*$. If there has been gain or loss of A (other than spontaneous transformation) since the beginning, there is no easy universal formula for correcting the time estimate for such gains or losses. We shall find these conditions particularly important.

$e^x = 1 + x/1 + x^2/[1{\times}2] + x^3/[1{\times}2{\times}3] + x^4/[1{\times}2{\times}3{\times}4] + \ldots$
If $0 < x < 2$ we may compute $\ln x$ (= $\log_e x$) = $(x-1) - (x-1)^2/2 + (x-1)^3/3 - (x-1)^4/4 + \ldots$, whereas if $x > 1$ we may find $\ln x$ by using $\ln x = -\ln (1/x)$. There is no such simple formula for $\log_{10} x$ or 10^x. The two systems are related by the formulas $\log_{10} x = \ln (x) / \ln (10)$ and $10^x = e^{x \ln 10}$.

We will now review the theory behind radioactivity. Atoms are nearly digital entities. That is, each atom has a whole number of protons, neutrons, and electrons, and its weight (or more properly, mass) is equal to their combined masses minus a very small mass called the binding energy. An electron has very small mass compared to a proton or a neutron (which have roughly equal mass), and for most purposes its mass can be ignored. This means that the mass of each atom is a nearly perfect function of the number of protons and neutrons in its nucleus. The number of protons in an atom determines the number of electrons it has when electrically neutral, and thus almost all of its chemical properties. All atoms of a particular element have the same number of protons. Thus even though technically it would be proper to write $_1$H for hydrogen and $_2$He for helium, the abbreviations H and He already contain the information in the subscript and it is not necessary to do so. However, the number of neutrons in hydrogen is not specified by the symbol H, and so to distinguish the different kinds of hydrogen we write their digital mass (protons + neutrons, nucleons) either in the upper left or the upper right corner. Thus deuterium, hydrogen with one neutron and one proton (two nucleons), is written ^{2}H or H^2 (the former is more common). Hydrogen without any neutrons is written ^{1}H, and hydrogen with two neutrons (tritium) is ^{3}H.

Some isotopes are unstable and spontaneously break down, or transform, into other elements. Thus ^{3}H will eject an electron and turn into ^{3}He (with two protons and a neutron). This transformation process is called radioactivity. There are 4 different major (for our purposes) kinds of radioactivity. First, a nucleus can eject an alpha particle, or ^{4}He nucleus, and thus lose 2 neutrons and 2 protons. This happens mainly with nuclei that are too big to be stable. Second, it can eject an electron, as ^{3}H does, and turn a neutron into a proton. This happens mainly with nuclei that have too high a proportion of neutrons. Third, it can eject a positron (a positive electron) which then annihilates an electron, sending 2 gamma rays (an electromagnetic radiation, related to light but more energetic than x-rays) in opposite directions. In what gives the same final result, except for a different kind and amount of gamma rays (or x-rays), it can capture one of the electrons orbiting it. This is called K-capture. Both of these processes turn a proton into a neutron, and happen to nuclei which have too high a proportion of protons. Fourth, certain nuclei which

are too heavy will spontaneously split into 2 comparable (usually not equal) halves, along with usually a few leftover neutrons. This is called fission. (In addition, a nucleus can be made in an excited state which emits a gamma ray, or in some cases gamma rays, and thereby loses a very small amount of mass. This does not affect the number of protons or neutrons and so will not be further considered here.) In all these cases the mass of the end products is slightly less than that of the starting material. The excess energy is transformed either into gamma rays or into motion of the end products. For example, ^{3}H weighs slightly more than ^{3}He.

What governs which atoms are stable and which are unstable (and how unstable they are) is not completely understood, and the part that is understood is complicated to explain. Perhaps the only additional observation we should make here is that nuclei seem to prefer to have an even number of protons and an even number of neutrons. Thus potassium-40, or ^{40}K,[8] is unstable, even though it has a good balance of neutrons (21) and protons (19), because there are odd numbers of both. It will decay to either ^{40}Ca (calcium) or ^{40}Ar (argon).

One of the unusual things about radioactivity is that except for K-capture, which is very slightly influenced by the chemical environment and pressure,[9] the rate of decay (the constant k) is not measurably influenced by any known environmental factor. Neither temperature, electric or magnetic field strength, light, x-rays, nor any other variable is known to influence the rate of decay. This makes radioactive decay the best physical or chemical method of measuring time.

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[8] The abbreviation is for Kalium.

[9] Apparently because pressure creates a higher density of electrons, particularly K-electrons, near (actually in) the nucleus. The deviation in the half-life is 0.6% for ^{7}Be at 270 kbar (Hensley WK, Bassett WA, Huizenga JR: "Pressure dependence of the radioactive decay constant of beryllium-7." *Science* 1973;181:1164-5). This is far too small to account for the discrepancy between the time frames under discussion. A change in chemical environment makes an even smaller difference in the half-life (<0.2% in the case of beryllium-7, the most highly influenced isotope). There are theoretical reasons for expecting a slight effect of chemical environnment on other isotopes, but the expected effect is so small that if it exists we are unable to measure it. See Dalrymple GB: *The Age of the Earth.* Stanford: Stanford University Press, 1991, pp. 86-90 for a good summary of the available experimental evidence and theory.

Potassium has at present a uniform mixture of ^{39}K (93.2581%) and ^{41}K (6.7032%), both of which are stable, and ^{40}K (0.01167%). This ratio has been the same wherever it has been measured. As noted before, ^{40}K is radioactive. Its decay constant is 5.543×10^{-10} /year, which corresponds to a half life of 1.250×10^9 years. It decays to either ^{40}Ca (88.8%) via beta decay, or to ^{40}Ar (11.2%).[10] The ratio of production of ^{40}Ar to ^{40}Ca is called the branching ratio. The radiogenic ^{40}Ca is hard to distinguish from ^{40}Ca already in the environment. (The distinction can sometimes be made. We will come to that later.) But radiogenic ^{40}Ar can be distinguished from atmospheric argon (about 1% of air is argon) by the presence of ^{36}Ar (0.337%) and ^{38}Ar (0.063%) in atmospheric argon (which leaves ^{40}Ar at 99.600% and a ^{40}Ar/^{36}Ar ratio of 295.5 to 1). This makes it possible to devise a dating method which is valid if the following assumptions are satisfied:

1. The rate of decay, and the branching ratio, of ^{40}K have not changed.
2. The material in question lost all its argon at an identifiable time t_0.
3. No argon has been lost since time t_0.
4. No argon except atmospheric argon, with today's ^{40}Ar/^{36}Ar ratio, has been gained since time t_0.
5. No potassium has been gained or lost since time t_0, except by decay.
6. The ratio of ^{40}K to total K is constant.
7. The total K, ^{40}Ar, and ^{36}Ar in the material in question can all be measured accurately.

For situations in which these assumptions are satisfied, we may derive a standard formula for potassium/argon dating:

$$t = \ln (^{40}K_0/^{40}K) / k \qquad \text{(Assumptions 1a,5)}$$
$$= \ln [(^{40}K + {}^{40}Ar^* + {}^{40}Ca^*) / {}^{40}K] / k \qquad \text{(Decay products)}$$
$$= \ln [1 + (^{40}Ar^* + {}^{40}Ca^*) / {}^{40}K] / k \qquad \text{(Algebra)}$$
$$= \ln [1 + (^{40}Ar^* / 0.112) / {}^{40}K] / k \qquad \text{(Assumption 1b)}$$
$$= \ln [1 + ([^{40}Ar - (^{36}Ar \times 295.5)] / [0.112 \times {}^{40}K])] / k$$
$$\text{(Assumptions 2,3,4)}$$

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[10] Via K-electron capture with a gamma ray (11.0%), K-capture without a gamma ray (0.16%), or positron emission (0.001%). The mechanism does not really matter for our purposes.

$$t = \frac{\ln\left(1 + \frac{^{40}Ar - (^{36}Ar \times 295.5)}{0.112 \times K \times 0.0001167}\right)}{5.543 \times 10^{-10}} \text{ years} \quad \text{(Assumptions 1a,6)}$$

According to assumption 7 we can measure total K, ^{40}Ar, and ^{36}Ar. This formula uses units of moles per gram of sample. A slight correction is necessary if units of weight (mass) are to be used.

Potassium/argon dating has been used extensively, so there is a large amount of evidence regarding its fit with evolution-ary[11] theory. It actually fits fairly well. Some studies give the impression that it fits perfectly, but such studies often use fil-tered data (that is, the data that fit best).[12] The boundaries of the geological time periods have been moved to fit potassium/argon dating.[13] And many minerals are not felt to be suitable for analysis; they do not give the expected dates. For these reasons the fit is not quite as good as might be thought. However, for

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[11] We will use the term evolution, rather than theistic evolution. This is for brevity, to avoid awkward phrases, and because the time scale is common to all theories of evolution. We will also use the term creationist instead of special creationist for brevity and to avoid awkward phrases, even though theistic evo-lutionists are technically creationists.

[12] For example, Evernden JF, Savage DE, Curtis GH, James GT: "Potas-sium-argon dating and the Cenozoic mammalian chronology of North America." Am J Sci 1964;22:145-98. For evidence of their selectivity, see their discussion on pp. 171-4 of why all but one potassium/argon date for the Rusinga Island biotites was discarded. Then note their continued apparently uncritical use of biotite in other areas where the dates obtained matched their expectations. Note also that "Unfortunately many of the samples that passed field inspection for suitability and were laboriously collected, later proved unsuitable for dat-ing. . . . Thus, of some 65 samples collected by M. Skinner only 10 could be used." (p. 174) It might have been interesting to know why such samples proved unsuitable for dating, and what their potassium/argon dates were.

It is interesting to speculate what would happen if an article in chemistry or medicine were submitted with perhaps 1/6 of the data reported. It is difficult for me to believe that the article in question would have become a classic, as the article by Evernden et al. apparently has.

In point of fact, the selectivity in this article may be even greater than noted above. Sometimes the whole rock basalt date is reported, and sometimes a mineral fraction from the basalt is dated instead, such as biotite or sanidine. Why one type of date is used at one time and not at another is not specified. If there are 3 mineral fractions per basalt sample, there are 4 different possible dates for that sample. Thus one could pick the dates that fit one's expectations and create a very impressive list of dates with close agreement without there being more than a general correlation of most dates with one's expectations.

[13] See Geyh and Schleicher, p. 374 chart.

certain minerals the fit is quite good. Any creationist explanation of potassium/argon dating must account for its relatively good accord with the evolutionary time frame.

From an evolutionary perspective biotite and hornblende give the best dates. Dates on hornblende are most often in accord with the evolutionary time scale, but biotite is more widespread and retains its potassium/argon age under fairly severe weathering conditions. Many other minerals such as sanidine, anorthoclase, plagioclase, leucite, nepheline, muscovite, phlogopite, and lepidolite (all igneous and/or metamorphic minerals) can be dated by the potassium/argon method. Whole rock basalt (lava) can also be used. Only one sedimentary rock, glauconite, can be dated by this method and the results are not always considered to be reliable. Several sedimentary rocks which contain large amounts of potassium, particularly sylvite (KCl), which is over 50% potassium by weight, are not considered satisfactory

The extensive use of potassium/argon dating also provides a fair amount of evidence bearing on the underlying assumptions. We should turn our attention to those assumptions now. In doing so, we should keep in mind several considerations. First, when we read any statement, we should ask, "How does the author know?" Statements without adequate evidence should not be determinative in our inquiry.[14] There is a place for a certain kind of scientific skepticism. Second, we should not assume the evolutionary time scale when evaluating potassium/argon dating. Since the explicit purpose of our inquiry is to evaluate whether potassium/argon dating supports the evolutionary time scale, it would be circular reasoning to assume the evolutionary time scale at the outset of our inquiry. On the other hand, we will not assume a creationist time scale either (However, we may use evolutionist or creationist assumptions as limiting cases). Finally, we cannot use another dating method to calibrate potassium/argon dating until we have examined the other method and established

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[14] This does not mean that all statements are presumed false until proven true. Statements whose basis can reasonably be believed to be experimental have some weight. Statements which are based on theory which is not being challenged have some weight. But statements which depend on the theories which are being evaluated cannot themselves support those same theories. That would be circular reasoning. These statements can only be used to help determine the internal consistency of a theory, or to suggest plausibility to the one who made the statement.

its validity. At present we have not done so for any radiometric dating methods. For now, correlations with other methods will not be used unless both evolutionists and creationists agree on their validity.

We now turn our attention to the underlying assumptions. The last assumption, number 7, is one of the safest. Measurements of potassium that have been made in different laboratories, and with different methods, are repeatedly in agreement to within experimental error. The isotope dilution method of measuring argon has a firm theoretical basis, and in appropriate specimens it yields results which match those obtained from volumetric and neutron activation analyses. The limitations in the accuracy of the various methods of measurement are fairly well-understood. We can accept the the "raw" data as basically accurate.

Assumption 6 is similarly secure. The isotopic composition of potassium from many sources has been measured, and the results are always essentially the same. Natural isotopic enrichment effects can be safely ignored.

Assumption 5 is fairly safe. In most situations where potassium has been either gained or lost from a mineral, the mineral has been noticeably altered (it would be difficult to do this without affecting the argon to an even greater extent). Replacement of the potassium in a rock with potassium from other sources, so long as the isotopic concentration is not significantly altered, would have no effect on the apparent age derived by the above formula. And if there were a problem of this nature, to effect the changes needed to explain the time difference between evolutionary and creationist models (up to 5 orders of magnitude), a creationist would need up to 5 orders of magnitude increase in the initial potassium content of our specimens, a physical impossibility (it would require more than 100% potassium). Nor can isotopic enrichment and then depletion effects bridge this gap in any reasonable manner.

Assumption 4 is probably satisfied for most samples. It would only be incorrect for materials which are heated in the presence of argon from the earth's mantle, which apparently contains almost entirely ^{40}Ar, or perhaps in primordial argon, which may have had a higher concentration of ^{36}Ar than the present atmosphere. We will tentatively accept it, keeping in mind that it may be challenged.

Assumption 3 is fairly commonly violated, according to most texts on potassium/argon dating. That is, according to the standard interpretation of potassium/argon dating, many rocks lose argon. Specifically, most sedimentary rocks are supposed to lose argon because their crystal structure cannot retain it. Glauconites appear to be the only sedimentary minerals from which an appropriate age (from the evolutionary perspective) can (sometimes) be obtained. Certain minerals such as sylvite appear to lose argon in recrystallization (or perhaps cannot retain argon); at least their ages are consistently much too young for the evolutionary time scale. Rocks that have been heated after formation can be demonstrated to have younger potassium/argon ages than similar rocks from the same formation which have not been heated. Several processes are listed in standard texts as explanations for this argon loss, such as metamorphism, weathering, and reheating. We will return to this assumption later. We will only note for now that the violation of this assumption would cause the rock to date younger than its age of formation. Depending on the loss of argon, this date could be as low as recent (< 5000 years).

Assumption 1 is often challenged by some creationists. They reason that radioactivity could have speeded up during the Flood, possibly providing a contributory cause of the Flood, and producing erroneously high apparent ages. For every order of magnitude that one increases the decay rate, one increases the apparent age of the rock by the same order of magnitude. The relationship is mathematically perfect. The only way to tell that anything unusual took place is to note whether daughter products have escaped as expected. There is some evidence which can be interpreted as a disequilibrium of helium and of argon.

The major problem with this creationist view is the absence of a mechanism to explain or predict the change in the half life. Theoretically radioactive decay could be caused by some mechanism such as neutrinos, rather than being random from the point of view of the atom, but no evidence of a decrease in any half life has been noted during recent supernova explosions, for instance.[15]

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[15] A minor problem is determining which radioactive decay processes are affected. Presumably it would have to be all of them, or all of one kind, or one particular isotope, or else this creationist hypothesis is just another *ad hoc* hypothesis.

A systematic change in radioactive time constants is still a theoretical possibility, but until there is direct evidence for it we will use it as a last resort, only if radiometric dating is otherwise secure, but compelling non-radiometric evidence requires a short span for the history of life on this earth.

Assumption 2 sounds logical at first, and is usually stated in texts as self-evident.[16] But it is one of the few testable assumptions (along with assumption 6 and 7), and so it should be checked.

I am aware of very few direct experiments in which rocks are heated to see if the argon is all driven off under realistic geologic conditions to reset the potassium/argon clock. Of course, rocks are heated routinely in a vacuum to drive off their argon for measurement. But no one would argue that the rocks in an igneous intrusion, for example, were intruded under vacuum conditions.

In one series of experiments, muscovite was heated to 740° to 860° C under high argon pressures (2,800 to 5,000 atmospheres) for periods of 3 to 10.5 hours. The muscovite absorbed significant quantities of argon (producing potassium/argon ages of up to 5 billion years), and the absorbed argon appeared like ordinary "radiogenic" argon.[17] In another series of experiments, muscovite was synthesized from a colloidal gel under similar argon pressures and temperatures. The muscovite synthesized in this way contained up to 0.5% argon by weight![18] These experiments show that under

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[16] For example, Geyh and Schleicher, p. 56: "What is special about the K-Ar method is that the daughter nuclide is a noble gas, which is normally not incorporated into minerals and is not bound in the mineral in which it is found." Dalrymple and Lanphere state on p. 46: ". . . a silicate melt will not usually retain the ^{40}Ar that is produced, and thus the potassium-argon clock is not "set" until the mineral solidifies and cools sufficiently to allow the ^{40}Ar to accumulate in the mineral lattice." Dalrymple (see note 9) states on p. 91, "The K-Ar method is the only decay scheme that can be used with little or no concern for the initial presence of the daughter isotope. This is because ^{40}Ar is an inert gas that does not combine chemically with any other element and so escapes easily from rocks when they are heated. Thus, while a rock is molten the ^{40}Ar formed by the decay of escapes from the liquid."

[17] Karpinskaya TB, Ostrovskiy IA, Shanin LL: "Synthetic introduction of argon into mica at high pressures and temperatures." *Isv Akad Nauk S. S. S. R. Geol Ser* 1961;8:87-9.

[18] Karpinskaya TB: Synthesis of argon muscovite." *Internat Geol Rev* 1967;9:1493-5. This is approximately 2,500 times as much argon as is naturally found in the usual muscovite, and it is mostly liberated again at over 300° C. A linear interpolation would seem to indicate that the usual potassium/argon dates

certain conditions argon can be incorporated into rocks that we are told are supposed to exclude argon when they crystallize. This makes me uncomfortable accepting assumption 2 without further evidence. One might even argue that minerals should not lose argon without someplace for it to go. But such conditions are not likely to be realistic geologic conditions either.

Perhaps the best way to test assumption 2 is to find formations that everyone can agree were formed within the last 5 to 10 thousand years, date them, and see if they date to essentially zero. This has been done by Dalrymple.[19] He dated several lava flows which are known to have erupted in modern times. Most of the lava flows had essentially zero potassium/argon ages. However, about 1/5 of the flows had excess ages. The flows that dated oldest all had ultramafic xenoliths and xenocrysts (small rocks and crystals of foreign material) mixed into the lava. The excess argon, and the extra apparent age, was attributed to these foreign materials, which themselves could date over 1 billion years old.[20] Doubt was also expressed about the resetting of phenocrysts (crystals which apparently crystallized from the lava itself), although all the lavas dated had phenocrysts, and some phenocrysts had only argon whose isotopic composition matched that of air.[21] From this Dalrymple concluded that basalt can have its

could be obtained with ^{40}Ar partial pressures of as little as 2 atmospheres.

I have found one reference on the introduction of argon into glass, Roy DM, Faile SP, Tuttle OF: "Effect of large concentrations of dissolved gas on properties of glasses." *Phys and Chem of Glasses* 1964;5:176-7. The argon introduced (under 1/2 to 10 kbar) was not quantified, but was noted to be dissolved rather than in bubbles.

The alert reader may wonder why I have not cited data for biotite or hornblende. The reason is because I am not aware of any such data. All the experiments on potassium-bearing minerals I have found in the literature are cited in this and the previous note.

[19] Dalrymple GB: "^{40}Ar/^{36}Ar analysis of historic lava flows." *Earth Planet Sci Lett* 1969;6:47-55.

[20] Dalrymple, see note 19, citing Funkhouser JG: "The determination of a series of ages of a Hawaiian volcano by the potassium-argon method". Univ of Hawaii Ph.D. thesis, 1966. Dalrymple's citation is accurate. For those who are going into the subject in depth I recommend the thesis.

[21] A plagioclase phenocryst from Surtsey that was 1 cm in diameter gave an ^{40}Ar/^{36}Ar ratio of 298.9, which was not statistically different from the value of 296.1 which Dalrymple' mass spectrometer gave for air. However the Mt. Etna 1792 basalt and the Mt. Lassen plagioclase both dated high, and both had large phenocrysts but no xenocrysts. In addition, Dalrymple cited the work of Damon *et al.* (Damon PE, Laughlin AW, Percious JK: "Problem of excess argon-

potassium/argon clock reset, but this is reliable only if there are no xenocrysts or xenoliths in the basalt. The xenocrysts apparently can retain most of their argon even when heated to the temperature of molten lava. Furthermore, tests on basalt which flowed into the ocean showed that although the lava which hardened above the water dated to essentially zero age, basalt which cooled under the water could date as high as 43 million years old.[22] This would of course be relevant for a creationist who believes that the world was covered with water, ocean water to be specific, during much of the Flood. Certainly if one is to avoid obviously erroneous dates in basalt, one will avoid pillow lava.

But there was another phenomenon which was noted in Dalrymple's article. Some modern lavas had $^{40}Ar/^{36}Ar$ ratios of less than 295.5. According to a straightforward interpretation of potassium/argon dating, this should be impossible. Dalrymple was not willing to write these ratios off to experimental error. Thus the straightforward interpretation has to at least be modified.

Dalrymple suggested two possible explanations for the excess ^{36}Ar (He rejected the possibility of significant ^{36}Ar formation *in situ* from nuclear reactions). The kinder one (from an evolutionary point of view) was that when argon from the air diffused back into the lava,[23] ^{36}Ar diffused in preferentially. But this would mean that the "zero age" lavas actually had an apparent age, and that most lavas do not degas upon eruption. In fact, depending on how strong is the preference for ^{36}Ar diffusion, it could even be that all lavas do not completely degas.

40 in volcanic rocks." In: *Radioactive dating methods and Low-level counting,* Vienna: IAEA, 1967, pp. 463-481). Damon *et al.* cited several instances of phenocrysts with potassium/argon ages of 1 to 7 million years over that of the whole rock, and one potassium/argon date on olivine phenocrysts of greater than 110 million years in a recent (<13,000 year old) basalt. They also state that "Coarse [phenocryst] minerals (x > 1 mm) may take more than 100 years to completely degas at lava temperatures." (p. 478) Unfortunately, they do not give the evidence for this statement.

[22] Dalrymple GB, Moore JG: "Argon 40: Excess in submarine pillow basalts from Kilauea Volcano, Hawaii." *Science* 1968;161:1132-5. These basalts were 60-90% glass, with phenocrysts. See also Noble CS, Naughton JJ: "Deep-ocean basalts: Inert gas content and uncertainties in age dating." *Science* 1968;162:265-7, where the basalts dated up to 21 million years old, and also retained helium.

[23] There was 1.7-123 million years' worth of ^{40}Ar found in the lava if one ignores the ^{36}Ar.

His other explanation was that the lavas with the anomalously high ^{36}Ar actually came from an area of the mantle that had primordial argon which had not been diluted with radiogenic ^{40}Ar and had not completely degassed. But this means that there is no reason to assume that lava whose argon matches that of the air has degassed either. It may have simply started with argon which matched air argon.

Thus the evidence is that lava does not completely degas on eruption. The precise amount of gas lost cannot be easily quantified using the data we have on hand. It would be very helpful to expose hot lava with a known argon content to ^{38}Ar or ^{39}Ar to see how much argon actually is lost and/or gained and how fast, and what its isotopic composition is.

When we turn to how basalt is dated in the geologic column, we find statements like "basaltic glass, in contrast to acid glass, has a very poor argon retentivity and is unsuitable for K/Ar dating."[24] Mankinen and Dalrymple[25] noted that two basalts containing glass dated much younger than expected whereas the phenocrysts in one of those basalts gave the expected dates. They concluded that basalts containing glass should be rejected and in the latter case accepted the phenocryst age. This would seem to indicate that the workers in the field trust old samples that they would be reluctant to trust if they were recent, and vice versa. This is particularly striking in view of the experimental evidence that argon diffusion in glass is negligible under ordinary geological conditions.[26]

It would seem that at least the data tends to undermine the validity of the potassium/argon dating of basalt. It could even suggest that the conventional time scale is incorrect. Perhaps these basaltic glasses don't lose argon. Perhaps they simply were

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[24] Geyh and Schleicher, p. 61.

[25] Mankinen EA, Dalrymple GB: "Electron microprobe evaluation of terrestial basalts for whole-rock K-Ar dating." *Earth Planet Sci Lett* 1972;17:89-94. In one case the glass in question was unaltered, and still gave a potassium/argon age of 1.6 million years rather than 7.4 million years. These are still not creationist dates, but if lava does not routinely degas, they are easily explainable from a creationist perspective.

[26] Fechtig H, Kalbitzer S: "The diffusion of argon in potassium-bearing solids." In Schaeffer GA, Zähringer J (eds): *Potassium-Argon Dating.* New York: Springer-Verlag, 1966, pp. 68-103. It is worth quoting p. 101: "This section concludes that diffusion at room temperature is always so small that no appreciable argon losses occur.

more completely degassed at the time of the eruption and the basalt is really as young as or younger than the indicated age. Certainly no potassium/argon date for basalt should be accepted as secure until we know whether the basalt matches the characteristics of recent basalt that is consistently dated at zero by the potassium/argon method.

It might be revealing to date recent and geologically old basaltic lava, glass, phenocrysts, and xenocrysts blinded to their geological horizon, and report all the results. This is the procedure that would be done in, for example, a controversial medical research area.

(Some may object to this comparison. However, there are parallels between geology and medicine. Both are not exact sciences in the sense that physics and chemistry are. They both deal with situations with many variables, not all of which can be precisely controlled. Both have a practical aspect—finding oil, and helping patients. And both make use of multiple branches of "basic" sciences.)

Perhaps we can place greater trust in granitic intrusions. There are unfortunately no historically witnessed granitic intrusions which can be used for a baseline. So we really don't know whether or not granitic intrusions reset their potassium/argon clocks. One hint comes from a granitic xenolith from a pleistocene basalt (conventional age 60,000 years). This xenolith was estimated to have been at $1,100°$ C during the basaltic lava eruption, and yet its sanidine had a potassium/argon age of 2 million years (the biotite age was not given).[27] Its original "age" was estimated at 40-92 million years, so it was estimated to have retained 2-5% of its argon. Other xenoliths may have potassium/argon ages of over 1 billion years.[28] And a report from Olduvai Gorge indicates that individual biotite crystals in tuff could retain 400-800 million years' worth of ^{40}Ar.[29] Apparently the clocks in granitic xe-

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[27] Dalrymple and Lanphere, p. 143, citing Dalrymple GB: "Argon retention in a granitic xenolith from a pleistocene basalt, Sierra Nevada, California." *Nature* 1964;201:282. The granite was 10 cm in diameter and 3 m below the surface of the lava.

[28] See note 20.

[29] Walter RC, Manega PC, Hay RL, Drake RE, Curtis GH: "Laser-fusion $^{40}Ar/^{39}Ar$ dating of bed I, Olduvai Gorge, Tanzania." *Nature* 1991;354:145-9. The $^{40}Ar/^{39}Ar$ dating method is a variant of the potassium/argon dating method which uses neutron irradiation of the sample to produce ^{39}Ar from ^{39}K. Note that these results would appear to invalidate tuff dates.

noliths can be only partially reset by heating that has usually been assumed to completely reset them.

Several examples of multiple minerals including hornblende and biotite which even evolutionists admit have excess argon can be found in Dalrymple and Lanphere.[30] Another particularly obvious example is a biotite cited by Faure[31] whose potassium/argon age exceeds the traditional age of the earth!

So we can't be sure that the clock is fully reset for biotite or other granitic minerals either, and the evidence that does not depend on evolutionary presuppositions is in favor of it not being reset.

Is there a mineral that someone who does not start with evolutionary presuppositions might believe to be completely reset at the time of formation? Yes, there is. Potassium minerals in evaporite deposits should have equilibrated their argon with the atmosphere when they crystallized. One would expect that any argon incorporated into the mineral should have the same isotopic composition as that in air. Sylvite in particular is over 50% potassium by weight, which would make the potassium and argon easier than usual to measure, and can form crystals up to an inch across or larger, which would seem to make it a good candidate for argon retention.

But evolutionists do not use sylvite and similar evaporites, because of the "poor retentivity" of salt minerals, and because they recrystallize below 100° C.[32] How do we know this? Is it because someone has measured the diffusion of argon in sylvite? Or has someone tried to mildly heat or deform the crystals to see if the argon is released? Has someone irradiated sylvite with neutrons to see if ^{39}Ar will diffuse out of the crystal? No, experimental evidence is not the basis for these assertions about retentivity and recrystallization. In fact, the experimental evidence is actually against these assertions.[33] The reason these assertions

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[30] Pp. 121-144, especially pp. 126-8 table.

[31] P. 105, citing Ashkinadze GS, Gorokhovskiy BM, ShukolyakovYA: "^{40}Ar/^{39}Ar dating of biotite containing excess ^{40}Ar" *Geochem Int* 1977;14(3):172-6.

[32] Geyh and Schleicher, pp. 61-2. The difficulty with sylvite has been noted since the very first use of potassium/argon dating. See Aldrich LT, Nier AO: "Argon-40 in potassium minerals." *Phys Rev* 1948;74:876-7.

[33] The diffusion of argon from sylvite has actually been measured by some of these methods, and it has turned out to be negligible under geological conditions. See Fechtig and Kalbitzer, note 26.

are made is because sylvite crystals in particular, and evaporite salts in general, give potassium/argon dates much younger than their evolutionary ages, so they must have lost argon somehow. That is a logical deduction as long as one knows that the evolutionary time scale is largely correct. However, if one is not irreversibly wedded to that time scale, another explanation presents itself. Perhaps the minerals are not really that old. Perhaps there is something wrong with the evolutionary time scale.

And on second thought, the theory that argon diffuses out of sylvite crystals seems contrived. If argon does not diffuse out of biotite, with its loose cleavage planes, why should argon diffuse out of sylvite, which has a close-packed crystal structure? It is of interest that several other minerals "lose argon", and yet we are told that in another mineral (this time igneous), sanidine, "diffusion of argon is several orders of magnitude faster at low temperatures than extrapolation from high temperature data would indicate."[34] And we read that

> Initially, it was hoped that these experiments [determining argon diffusion characteristics of minerals] would lead to a classification of these minerals according to their ability to retain argon. In addition, it was thought that experimentally determined diffusion coefficients might provide a way to correct "apparent" ages for argon loss and to provide a basis for using argon loss to determine the exact geologic conditions (heating, burial, and so forth) that caused the loss. Unfortunately, these goals have not been reached. Although the relative ability of most common minerals to retain argon is known, this knowledge has come largely from geologic studies rather than from diffusion experiments.[35]

In other words, the experimental evidence is against the diffusion which must have happened if the evolutionary time scale is correct, and so the standard approach has been to ignore the experimental evidence and try to create a scenario compatible with the evolutionary time scale. Now that is fine if you know

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[34] Geyh and Schleicher, p. 62, citing Marshall BD, Woodard HH, DePaolo DJ: "K-Ca-Ar systematics of authigenic sanidine from Waukau, Wisconsin, and the diffusivity of argon." *Geology* 1986;14:936-8. The potassium/argon age in this paper was up to 75 million years less than the stratigraphic age (>454 million years).

[35] Dalrymple and Lanphere, p.151.

that the evolutionary time scale is correct. But if we are trying to make an unbiased effort to determine the validity of the evolutionary time scale, the evidence does not appear to support that scale.

I have seen no independent evidence to support the suggestion that mild heating accounts for low potassium/argon dates in sylvite. The best evolutionary theory to explain the evaporite data would seem to be that which has also been advanced to explain the "anomalously" young $^{87}Rb/^{87}Sr$ and $^{40}K/^{40}Ca$ ages of the same minerals. The sylvite periodically re-dissolves in water. This does not seem unreasonable. It might be interesting to re-examine these deposits to see whether there is other evidence for recrystallization that would support this repeated solution theory.

From a creationist standpoint the evaporite deposits still present a problem. For if they are truly simple evaporite deposits, the potassium/argon dates would be predicted to be zero, and yet Devonian sylvite deposits (conventionally dated ca. 350 million years old) have potassium/argon dates of around 200 million years. So the question remains, why don't the deposits date at zero?

I can think of two possible explanations which would allow a creationist time frame. First, it is possible that sylvite absorbs argon underground, either directly or as a result of recrystallization. It is of interest that if there is recrystallization, buried sylvite and carnallite can apparently incorporate argon, and radiogenic argon at that, on recrystallization.[36] It would be interesting to

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[36] This is because rubidium/strontium and potassium/calcium dates give a maximum age of 2-100 million years for (Permian) sylvite that dates 200 million years old by the potassium/argon method (Baadsgaard H: "Rb-Sr and K-Ca isotope systematics in minerals from potassium horizons in the Prairie Evaporite Formation, Saskatchewan, Canada." *Chem Geol (Isot Geosci Sect)* 1987;66:1-15). Thus even by evolutionary criteria this sylvite occluded over 100 million years' worth of argon on (re?)crystallization.

Incidentally, this discussion illustrates one of the problems in comparing two general scientific theories (or research programs, as Lakatos would call them). There is often no single piece of evidence that conclusively proves one theory superior to the other. The judgment more often has to be made on the basis of which theory fits the relevant facts best, and that depends on which facts are considered most important and well-established, and how hard we search for facts and theoretical predictions. In this case should we close our investigation on hearing that published potassium-argon dates often match the evolutionary time scale, or on hearing that sylvite dates too low for the evolutionary time scale, or on hearing that sylvite dates do not neatly fit a creation-

crystallize evaporites under high argon pressures to see how much argon is actually incorporated.

Second, these deposits may not be evaporite deposits at all. It has been strongly (and persuasively) argued[37] that whatever else they are, they are not seawater evaporites. The puzzle of their formation has not been solved, and it would seem premature to use them as proof of an old earth until their formation is better understood, although they may be given due weight.

One final point deserves consideration. It is still proper for an evolutionist to point out that potassium/argon dating as currently used matches the evolutionary time scale. A creationist explanation of potassium/argon dating must state not only why the current usage is incorrect but also why the dates at present line up with the evolutionary time scale as well as they do. A start can be made by noting that many dates do not fit, as noted above, and that there is some selectivity in the kinds of samples and specific samples that are dated.[38] There is also selectivity in which samples are submitted for publication (no one likes to submit ambiguous or chaotic data), and which are published (review-

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ist model, or on hearing that the rubidium-strontium dating evidence suggests the possibility of sylvite occluding argon? In theory, of course, even this is not enough. We shall have to test that possibility experimentally, and the exploration goes on forever. In practice we have to stop at least for now with the observations that have been done and make the best tentative judgment we can on the basis of the available data.

However, I do not think that the process is totally subjective. Eventually we should reach the place where one theory continually runs into problems and the other continually points to new correct observations. When this happens, we can provisionally accept the latter theory, and insist that the former explain parsimoniously the difficulties presented to it before we reconsider our judgment.

This means that we may be required to do a good deal of gruntwork in order to establish whether multiple pieces of evidence fit obviously better into one theory, or whether the evidence is truly equivocal. We may not like it, but intellectual honesty requires a fair treatment of all the evidence.

[37] Hardie LA: "The roles of rifting and hydrothermal $CaCl_2$ brines in the origin of potash evaporites: An hypothesis." *Am J Science* 1990;290:43-106. Hardie argued for most of the evaporite deposits being the result of the evaporation of $CaCl_2$ brines in rift and other extensional fault basins. He cited no modern examples of extensive KCl deposits.

[38] For example, see the recommendation to get a geochronologist to select pilot samples, which then guide the selection of final samples, in Geyh and Schleicher, p. 7.

ers do not like to approve publication of these data, and editors do not like to publish them). Incidentally, these distortions of the data are for the most part done innocently. The same thing happens, for example, in medicine. Positive results are always easier to publish than negative results, and both are easier to publish than chaotic results. However, this selectivity may be somewhat offset by a reverse selectivity which can happen in the publishing of textbooks. That is, the textbooks I have cited may collect the problem dates more than the usual ones (and most of my data is obtained from literature cited by various textbooks).[39] There is still a real order to most of the potassium/argon dates which needs explanation.

There are three explanations from a creationist perspective for a gradation of potassium/argon dates from older to younger for rocks without significant differences in real age. First, there may have been gradually decreasing argon concentrations and pressures as time during a Flood passed, perhaps because of gradual degassing of the mantle. Second, rocks later during the Flood may have formed under less (hydrostatic) pressure than those formed earlier. This would allow them to be more thoroughly degassed for the same temperature. Finally, the later rocks may have been more thoroughly melted, and for a longer time period, allowing more inherited argon to escape from the later rocks. Perhaps all three mechanisms were operative to some extent. All these explanations seem plausible, and there is evidence for the first one.[40] So it would seem that there is a creationist model which is believable, and which has supporting evidence for its explanation of the general trend of potassium/argon dates in the geological column.

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[39] That is my feeling on reading the texts cited above. However, it is not the usual case in textbooks. Most texts simplify experiments and emphasize the positive, often glossing over problems. The possibility remains that the texts I have cited are also biased in favor of the approved theories, in which case the evolutionary interpretation of potassium/argon dating is in even worse trouble than here portrayed.

[40] Beryl and cordierite contain essentially no potassium, yet *"It may be stated that the helium and argon content of beryl and cordierite increases with the age of the mineral and there is no relationship between this phenomenon and the alpha emission, potassium content, chemical composition or mineralogical environment of the mineral."* (Damon PE, Kulp JL: "Excess helium and argon in beryl and other minerals." *Am Min* 1958;43:433-59. The quote is from p. 445, italics theirs) This is true especially of ^{40}Ar. This observation would be predicted by a creationist, but I have not seen a good explanation of this from an evolutionary standpoint.

To summarize, modern basaltic lava potassium/argon dates indicate that the current use of potassium/argon dating is probably invalid, and the glass dates at least suggest a shorter chronology. Biotite and other plutonic minerals are consistent with this position, although the supporting data there is not as complete as we would like. The data on sylvite and other evaporite minerals are problematic for both a short chronology and a long chronology, although the problems for a long chronology appear to me to be as great or greater in spite of the greater research effort to solve them from that chronology's point of view. With the data examined so far, a (special) creationist model for the age of life on the earth provides a more straightforward approach than an evolutionary one.

Other Dating Methods

If potassium/argon dating is actually slightly in favor of the creationist position, perhaps we should re-examine the other dating methods to see if they really do dovetail with evolutionary theory as well as it is claimed. So we turn again to Geyh and Schleicher and look at those 75 other methods. Some of them, such as ^{138}La/^{138}Ce, ^{176}Lu/^{176}Ha, and ^{207}Pb/^{206}Pb, are used only for Precambrian material, and thus are irrelevant for dating life. They may be valid, or they may be invalid, but it doesn't really matter for our purposes. Some, such as ^{3}H, ^{210}Pb, and ^{228}Th excess/^{232}Th, are used only for recent (< 3000 year old) samples, and thus again irrelevant for the question at hand. Some are considered highly experimental, such as the ^{10}Be/^{36}Cl method (if evolutionists do not have confidence in a method or its assumptions, it would seem difficult to use it to disprove a creationist time scale). Some are essentially variations on other methods, such as the ^{39}Ar/^{40}Ar method.[41] Some are only relative dating methods, such as paleomagnetism and stable oxygen isotopes. Some are used on only meteorites or lunar rocks and are mostly irrelevant for dating life on the earth (all except for the terrestrial ages of meteorites).

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[41] Which is a variation on ^{40}K/^{40}Ar dating and subject to the same criticisms. The only apparent advantage of the ^{39}Ar/^{40}Ar method, the plateau effect, is not always present, and it is sometimes grossly wrong by anyone's standards when it is present. See Ashkenadze *et al.* in note 31.

And some are obsolete, like the chemical lead method. Some, of course, suffer from more than one drawback for our purposes. When all these extraneous methods are removed from consideration, we are left with the following methods: ^{87}Rb/^{87}Sr, ^{40}K/^{40}Ca, ^{147}Sm/^{143}Nd, uranium/thorium/lead and lead/alpha, krypton/krypton, uranium/xenon and xenon/xenon, ^{14}C, ^{36}C1, ^{53}Mn, ^{81}Kr, ^{129}I, ^{26}Al, ^{10}Be, most of the U and Th disequilibrium series, U/He, Thermoluminscence and relatives, Fission tracks, Pleochroic haloes, terrestrial exposure ages of meteorites, Amino acid racemization, Nitrogen content of bones, and Obsidian hydration. This is still an impressive list, but a far cry from the 76 methods we started with. And this list can be whittled down still further. Three little-used methods are similar enough to ^{40}K/^{40}Ar dating that they are subject to the same criticisms and can be safely ignored, one is grossly inaccurate by anyone's standards, and one is a combination of other dating methods.

The krypton / krypton method utilizes the fact that ^{238}U spontaneously fissions at a very slow rate, producing krypton in some fission events. This krypton from spontaneous fission is compared to the krypton produced by the neutron-induced fission of ^{235}U, which is used in this method to measure the ^{235}U concentration. Because there is a constant ratio of ^{235}U to ^{238}U, the concentration of ^{238}U is known if the concentration of ^{235}U has been determined. The resetting of the krypton/krypton clock requires elimination of all previously accumulated or acquired krypton. Krypton is a noble gas like argon. Since krypton atoms have a larger radius than argon, they are more easily trapped by minerals, and would be less likely to be eliminated than argon. As another parallel with potassium/argon dating, we find it suggested that krypton is lost, to account for younger ages than the "real" (evolutionary) age.[42] I have been unable to find any reports of attempted krypton/krypton dating of recent (zero age) samples.[43] Krypton/krypton dating is not a significant support to an evolutionist arguing against a young earth.

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[42] For example, Geyh and Schleicher, p. 151.

[43] An additional complication is that the samples are irradiated with neutrons, and since the neutron flux (amount of neutrons of the proper energy passing through a given area) is hard to measure, sometimes the krypton ratios are compared with those of a rock of "known" age. This procedure is justified if the reference rock is dated with either the krypton/krypton method or another reliable method, but if it is dated by the potassium/argon method, our discussion above makes the date obtained worthless as evidence for the evolutionary time scale.

The uranium/xenon method and its derivative, *the xenon/ xenon method,* use xenon produced by spontaneous ^{238}U fission. In the uranium/xenon method the uranium (and therefore the ^{238}U) is measured directly. In the xenon/xenon method the uranium is measured by measuring the fission products of ^{235}U, analogous to the krypton/krypton method. The clock for these methods is reset when all the xenon is driven off. Xenon is another noble gas, with atoms larger than krypton and therefore larger than argon. Again there is reference to the loss of xenon,[44] meaning ages that are too young (although not young enough for a creationist model; only 30-70% less than required by the evolutionary time scale). And again no data has been published for "zero age" samples.[45] The data from uranium/xenon and xenon/xenon dating are not a significant support for either an evolutionist or a creationist model.

The uranium/helium method depends on the fact that for each ^{238}U that decays to lead 8 ^{4}He atoms are produced. This is complicated by the fact that uranium commonly contains ^{235}U (producing 7 ^{4}He atoms), ^{234}U (a decay product of ^{238}U producing 7 ^{4}He atoms), and ^{232}Th (thorium, producing 6 ^{4}He atoms). Thus if one knows the composition and amount of uranium and thorium present at the beginning, has a closed system (no U or Th moving in or out and especially no He moving in or out), and knows the amount of ^{4}He present at the beginning, one can estimate the time. It turns out that one cannot calculate the time straightforwardly, but one can find it graphically. Again we read of the loss of helium,[46] but this time it is a little more believable because the helium atom is so small. However, with this method there is some evidence regarding whether the clock is consistently reset. The evidence is negative. Helium is found in minerals which have no uranium or thorium, and is found in recently heated lava cooled under the sea.[47] Here is another example of retention of a noble gas. It would be helpful to find minerals that are reset when formed experimentally, and are impervious to helium diffusion,

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[44] For example, Geyh and Schleicher, p. 153.

[45] For the xenon/xenon method, the same method of comparing the rock to be dated with a rock of "known" age is used as was used for the krypton/krypton method. Again this makes the method dependent not only on the hypothesis of zero xenon initially, but also on the accuracy of the date of the "known" age rock.

[46] Geyh and Schleicher, pp. 248,250.

[47] Damon and Kulp, see note 40, and Noble and Naughton, see note 22.

and use these minerals to date ancient rocks. But without such data, it is inappropriate to use uranium/helium dating in support of either time scale.

Terrestrial ages of meteorites in our age range are primarily found using ^{53}Mn, ^{36}C1, ^{81}Kr, and ^{129}I, and possibly thermoluminescence. These ages may be considered under the respective methods and need not be considered independently.

The nitrogen or collagen content of bones is a very rough method. It has nearly 2 orders of magnitude of demonstrated spread, and is influenced by such factors as temperature, moisture, pH, and bacterial environment. It is not nearly reliable enough to be of much use in differentiating between evolutionary deposits and Flood deposits.

Rubidium/strontium dating. We will now discuss the first method on our revised list. The ^{87}Rb/^{87}Sr method is dependent on the observation that rubidium is widely distributed with potassium (which it closely resembles chemically), and that about 1/4 (27.8346%) of the rubidium is ^{87}Rb, which is radioactive and decays by electron emission to ^{87}Sr. Its decay constant is 1.42×10^{-11}/year, which corresponds to a half life of 4.88×10^{10} years. This would make an excellent dating method if all the ^{87}Sr were eliminated at time zero. Unfortunately it is not, and so instead it is assumed that at time zero all the strontium is thoroughly mixed so that the strontium isotopes are homogeneously distributed. Strontium has three other isotopes ^{84}Sr, ^{86}Sr, and ^{88}Sr, which are present in constant ratios relative to each other.[48] One can presume that initially the isotopic strontium composition was the same throughout a (presumably melted) rock. Then the rock crystallized so that the rubidium was partially separated from the strontium. If there is strontium in some mineral without rubidium, then this mineral can be used to determine the original ^{87}Sr/^{86}Sr ratio.[49] If this was 0.710, and a given rubidium-containing mineral had a ^{87}Sr/^{86}Sr ratio of 0.720, then for every 1000 atoms of ^{86}Sr, 10 atoms of ^{87}Sr would have been produced by ra-

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[48] So that ^{84}Sr/^{86}Sr = 0.056584 and ^{86}Sr/^{88}Sr = 0.1194, which gives percentages in usual rock of 82.52% ^{88}Sr, 7.00% ^{87}Sr, 9.86% ^{86}Sr, and 0.56% ^{84}Sr. The percentage of ^{87}Sr varies between 6.9% and 7.4%+, depending apparently on the past and/or present rubidium content of the rock.

[49] One could use the ^{87}Sr/^{88}Sr ratio or the ^{87}Sr/^{84}Sr ratio but the ^{87}Sr/^{86}Sr ratio is closer to 1, easier to work with, and the traditional one.

dioactivity. If in this mineral the $^{87}Rb/^{86}Sr$ ratio was 0.40, then for every 1000 atoms of ^{86}Sr there would be 400 atoms of ^{87}Rb. Thus the original ^{87}Rb concentration would have been 400 + 10, or 410 / 1000 atoms of ^{86}Sr. The formula for the age of the mineral would be t = ln (410/400) years/(1.42 x 10^{-11}), or 1.74 billion years. If $^{87}Sr/^{86}Sr$ is the ratio in the rubidium-containing rock, and $(^{87}Sr/^{86}Sr)_0$ is the ratio of the rock with no rubidium and therefore the ratio at the time of homogenization, and $^{87}Rb/^{86}Sr$ is the ratio in the rubidium-containing rock, then the general formula for the age is

$t = ln ([^{87}Rb/^{86}Sr + {}^{87}Sr/^{86}Sr - ({}^{87}Sr/^{86}Sr)_0] / [^{87}Rb/^{86}Sr]) / k.$

The problem with using this formula is that we rarely have a mineral with essentially no rubidium but enough strontium to determine the initial $^{87}Sr/^{86}Sr$ ratio. So what is usually done is to obtain several minerals with different degrees of rubidium enrichment so that they have different $^{87}Rb/^{86}Sr$ ratios. Then the $^{87}Rb/^{86}Sr$ ratios are plotted against the $^{87}Sr/^{86}Sr$ ratios. Several assumptions are made:

1. The radioactive decay constant of rubidium has been invariant.

2. The strontium isotopes were evenly distributed at time t.

3. No net rubidium migration has occurred since time t.

4. No net migration of strontium isotopes has occurred since time t.

5. We can accurately measure the $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios in a given set of minerals.

If these assumptions are correct, we will find our plot giving a straight line:[50] $^{87}Sr/^{86}Sr = ({}^{87}Sr/^{86}Sr)_0 + (e^{kt} - 1) {}^{87}Rb/^{86}Sr$. This is in the form of y = a + bx. The value a gives the intercept, and b gives the slope, which in this case is $(e^{kt} - 1)$. Thus picking some ideal example numbers, we might see a graph like this:

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[50] The derivation of the formula is as follows:

$^{87}Rb = {}^{87}Rb_0 \, e^{-kt}; \quad {}^{87}Rb_0 = {}^{87}Rb \, e^{kt}$	Assumptions 1,3
$^{87}Sr^* + {}^{87}Rb = {}^{87}Rb_0 ; \quad {}^{87}Sr^* = {}^{87}Rb_0 - {}^{87}Rb = {}^{87}Rb \, e^{kt} - {}^{87}Rb = {}^{87}Rb \, (e^{kt} - 1)$	
	Decay products
$^{87}Sr = {}^{87}Sr_0 + {}^{87}Sr^* = {}^{87}Sr_0 + {}^{87}Rb \, (e^{kt} - 1)$	Assumption 4
$^{87}Sr/^{86}Sr = ({}^{87}Sr/^{86}Sr)_0 + {}^{87}Rb/^{86}Sr \, (e^{kt} - 1)$	Assumption 2

By assumption 5 we can measure the appropriate ratios.
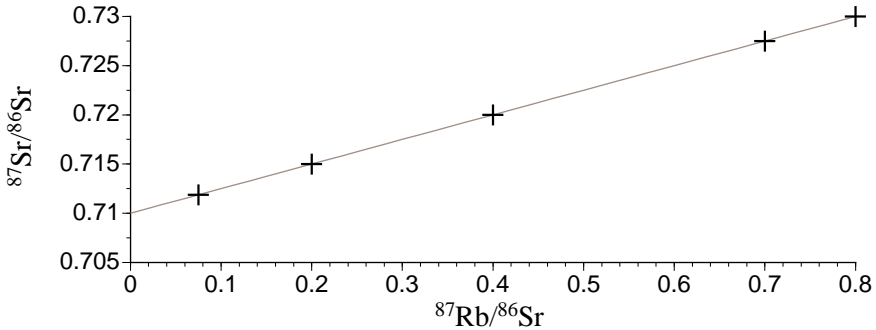
Note that where the line crosses the zero line for the ^{87}Rb/^{86}Sr ratio gives the original ^{87}Sr/^{86}Sr ratio. Any strontium that originally had no rubidium with it would have to have that ^{87}Sr/^{86}Sr ratio still. Even if there is no such sample, we can predict its composition using our straight line. The apparent age is found by taking the slope,[51] which in this case is 0.010/0.40 or 0.025. So $e^{kt} - 1 = 0.025$, $e^{kt} = 1.025$, and $t = \ln(1.025)/k$. The general formula is $t = \ln(1 + \text{slope})/k$. We only need 2 points to determine the straight line and thus the slope, but if there are more than 2 points, and all our assumptions are correct, the points should all lie on the same straight line. It is commonly felt that if all the points lie on a straight line, this is a good indication that the above assumptions are correct. Besides, scientists like a straight line, and there are nifty little computer programs for calculating the slope and intercept of the best straight line (the one that passes closest to the most points).

We now turn to how these dates are used in practice. The first paragraph of Faure (whose area of expertise is strontium geochemistry) dealing with experimental results is a shock:

> Igneous rocks of granitic composition may contain both mica minerals and K-feldspar, all of which can be dated by the Rb-Sr method. Ideally, all minerals of an igneous rock should indicate the same date which can then be regarded as the age of the rock. When mineral dates obtained from one rock specimen or from a suite of cogenetic igneous rocks are in agreement, they are said to be "concordant." Unfortunately, "discordance" of mineral dates is more common than "concordance." The reason is that the constituent minerals of a rock may gain or lose radiogenic ^{87}Sr as a result of

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[51] Which is the change in the ^{87}Sr/^{86}Sr ratio divided by the change in the ^{87}Rb/^{86}Sr ratio.

reheating during regional or contact metamorphism after crystallization from a magma. In such cases, the mineral dates generally are not reliable indicators of the age of the rock. We must therefore turn to the rocks themselves if we want to determine their ages.[52]

I thought this was supposed to be a good dating method for minerals. Now we are told that Sr^{++} migrates. Furthermore it does not just re-equilibrate during metamorphism—"(sometimes K-feldspar actually gains ^{87}Sr.)"[53] I have a hard time swallowing that. Isotopic fractionation seems unlikely to be significant with two isotopes as close as ^{87}Sr and ^{86}Sr, and no experimental evidence is alleged to account for this.[54]

But maybe the rubidium/strontium ages of minerals can be explained by metamorphism, and what we really need is whole-rock suites. Surely strontium can't migrate a matter of feet (or meters) in rock that was not melted and stirred. But we are told that ". . . dated by the whole-rock Rb-Sr method . . . The date indicated by the isochron may be the time of crystallization of the igneous rocks or it may reflect the metamorphic event. . . . The latter is preferred in this case."[55] Also "Whole rock isochrons may *likewise* indicate the age of the metamorphic event during which the sediment was recrystallized."[56] In fact, as Geyh and Schleicher frankly admit, "Although it does not fit the conventional model for Rb/Sr isochron dating, resetting of Rb/Sr whole-rock isochrons by high-grade metamorphism (granulite facies) has been reported (e.g., Burwash et al. 1985)."[57] Furthermore, this migration of strontium "may also occur for rocks that

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[52] Faure, pp. 120-1.

[53] Faure, p. 124.

[54] In fact, the evidence was contrary in 1967, according to Hanson GN, Gast PW: "Kinetic studies in contact metamorphic zones." *Geochim et Cosmochim Acta* 1967;31:1119-53. On p. 1120 Hanson and Gast state, "It is significant that no one has so far been able to thermally induce radiogenic strontium-87 to leave its host mineral in quantities commensurate to the loss of argon under geologically reasonable conditions even though it is not uncommon to find biotites in nature which have lost both radiogenic argon-40 and strontium-87 due to a thermal event." I have not seen any data which would challenge their conclusion.

[55] Faure, pp. 127-8.

[56] Faure, p. 128, italics his.

[57] P. 84, citing Burwash RA, Krupicka J, Basu AR, Wagner PA: "Resetting of Nd and Sr whole-rock isochrons from polymetamorphic granulites, northeastern Alberta." *Canad J Earth Sci* 1985;22:992-1000.

macroscopically appear unaltered. Without an age determination with another method for comparison, it is often not possible to recognize such an isochron as false."[58] So there is at least sometimes massive migration of strontium and possibly rubidium with elevated temperature and/or fluid, which cannot be detected by the usual signs of metamorphism.

But there is evidence against this proposed migration. For example, pyroclastic rocks can be dated "only by their phenocryst minerals (e.g., biotite, muscovite, sanidine). This is a proven procedure for assigning radiometric ages . . ." Notice that tuffs do not equilibrate the strontium in their phenocrysts after deposition. Here, strontium apparently does not migrate even in minerals. In fact, sedimentary rocks, deposited under water, do not homogenize their strontium if the grain size, at least of illite clay, is 2 microns or larger.[60] If strontium doesn't migrate enough to equilibrate in aqueous suspension except possibly with small grain size, why should it have migrated enough to equilibrate across macroscopic collections of whole rock, some of which are presumably much more coarse-grained? (If the strontium moves at all, it has to equilibrate or else it would take incredible luck to avoid ruining the straight line of the isochron.)

Why strontium should easily migrate is not obvious to me anyway. Strontium is doubly charged in minerals, and is poorly soluble in water; generally much less so than (singly charged) potassium or rubidium. Theoretically it should be hard to get strontium to migrate. In fact, one might ask, if argon (a neutral gas) has been retained in a mineral (so that the potassium/argon

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[58] Geyh and Schleicher p. 87, citing Schleicher H, Lippolt HJ, Raczek I: "Rb-Sr systematics of Permian volcanites in the Schwartzwald (SW Germany). Part II: Age of eruption and the mechanism of Rb-Sr whole rock age distortions." *Contrib Mineral Petrol* 1983;84:251-91. Note that "The Rb-Sr system in these rocks is often disturbed in such a way that the linearity of the sample points is retained in the isochron graph, thus producing apparent isochrons with reduced age values ("rotated isochrons", ...)".

[59] Geyh and Schleicher, p. 85.

[60] Faure, p. 130, citing Clauer N: "A new approach to Rb-Sr dating of sedimentary rocks." In Jager E, Hunziker JC (eds): Lectures in Isotope Geology. Berlin: Springer-Verlag, 1979, pp. 30-51; Clauer N: "Rb-Sr and K-Ar dating of Precambrian clays and glauconies." Precambrian Res 1981;15:331-52; and Bonhomme MG: "The use of Rb-Sr and K-Ar dating methods as a stratigraphic tool applied to sedimentary rocks and minerals." *Precambrian Res* 1982;1S:5-25.

age is believable by an evolutionist), why should strontium ions migrate to reduce the rubidium/strontium age?

The explanations for low rubidium/strontium dates seem lame to me. In fact, there seems to be a certain apriorism in their interpretation. For dates that fit the evolutionary time scale, even if the "assumptions are probably not strictly satisfied by any of the common detrital minerals", still, "useful information" is presumed to have been obtained.[61] But if the dates do not fit, even if the rocks appear unaltered, it is because "even a modest increase in temperature of 100 to 200° C or so may have drastic effects on the parent-daughter relationships of natural decay schemes without necessarily being reflected in the usual mineralogical or textural criteria for metamorphism."[62] One might as well say what Dalrymple and Lanphere said regarding potassium/argon dating, that the evolutionary time scale is the ultimate arbiter for radiometric dates.[63] And Faure comes close to making such a statement: "The final test of the validity of dates obtained from clay minerals is that they must *decrease* up-section in a stratigraphic succession of sedimentary rocks."[64] In that case there is no logical reason to regard such biased interpretations as evidence for the evolutionary time scale.

The more logical interpretation is that the rocks are not as old as the conventional ages would make them. But can one then explain those beautiful straight line "isochrons" from the standpoint of a short chronology? It turns out that one can. Suppose that instead of mixing our rock to homogenize the strontium isotopes, allowing the rock to crystallize with partial separation of rubidium from strontium, and then letting the rubidium decay in place, we let the rubidium decay in one rock before mixing it with a rock containing strontium but little or no rubidium. If we do not completely homogenize the two rocks, components will be

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[61] Faure, p. 134.

[62] Faure, p. 123.

[63] Pp. 196-7. The four tests they give are: 1. Direct comparison with other radiometric ages, 2. Direct comparison with fossils, 3. Stratigraphic sequence, and 4. Inference. Note that all but the first test reduce to whether the date fits with the evolutionary time scale, and if the other radiometric methods are chosen on the basis of their "reliability" (how well those methods fit the evolutionary time scale), the first test also reduces to a fit with that scale.

[64] P. 131, italics his. Note the absence of the possibility that to within the limits of the measurement the strata were laid down contemporaneously.

mixed in varying proportions, and the "mixing line" produced is mathematically indistinguishable from an isochron.[65] So a straight line need not imply an accurate age. A mixing line will explain the data just as well (in fact, all 2-component mixing lines are straight lines). All that is required is that ^{87}Rb and ^{87}Sr are initially found together, that is, the $^{87}Sr/^{86}Sr$ and the $^{87}Rb/^{86}Sr$ ratios are both higher in the same rock.

This way of explaining rubidium/strontium dates naturally accounts for systems like the theoretical example given in the figure on p. 85 of Geyh and Schleicher. Whole-rock dating gives a relatively unaltered mixing line. But if there was a certain amount of equilibration between the minerals in a single rock followed by re-separation of rubidium and strontium before it cooled, the slope of the mixing line could be reduced.

Is it realistic to believe that granitic intrusions, for example, do not mix completely? Apparently so. At least Geyh and Schleicher think so; "For example, there are indications that the condition of isotopic homogeniety of a magmatic body at time t_0,

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[65] The mathematical derivation in the simplest case is as follows: In rock A let us suppose there is r rubidium per gram, and s_1 strontium-87 per gram. In rock B let us suppose there is s_2 strontium-87 and t strontium-86 per gram. Then in a mixture of a proportion a of rock A and a proportion b of rock B (a + b = 1) there would be $ar + as_1 + bs_2 + bt$ per gram. The $^{87}Sr/^{86}Sr$ ratio would be $(as_1 + bs_2) / bt$ and the $^{87}Rb/^{86}Sr$ ratio would be ar / bt. Thus for a given mixture $^{87}Sr/^{86}Sr = bs_2/bt + (s_1/r)(ar/bt) = (^{87}Sr/^{86}Sr)b + (^{87}Sr/^{87}Rb)a\,^{87}Rb/^{86}Sr$. Notice that the plot of $^{87}Sr/^{86}Sr$ versus $^{87}Rb/^{86}Sr$ is a straight line with intercept $(^{87}Sr/^{86}Sr)b$ and slope $(^{87}Sr/^{87}Rb)a$, precisely analogous to the isochron plot shown above.

A more complicated but analogous equation giving a straight line can be obtained for impure sources. Given rock A with r_1 ^{87}Rb s_1 ^{87}Sr, and t_1 ^{86}Sr, and rock B with r_2 ^{87}Rb, s_2 ^{87}Sr, and t_2 ^{86}Sr, we have in any given mixture $^{87}Rb/^{86}Sr = r/t = (ar_1 + br_2)/(at_1 + bt_2)$ and $^{87}Sr/^{86}Sr$ $s/t = (as_1 + bs_2)/(at_1 + bt_2)$, assuming $t_1 > 0$ and $t_2 > 0$ (both rocks have some ordinary strontium) and a is the proportion of rock A and b is that of rock B (so a + b = 1). Then (assuming $r_1/t_1 \neq r_2/t_2$, that is, the two rocks do not have the same ratio of rubidium to ordinary strontium),

$s/t = (as_1 + bs_2)(r_1t_2 - r_2t_1) / [(at_1 + bt_2)(r_1t_2 - r_2t_1)]$

$\quad = (ar_1s_1t_2 - ar_2s_1t_1 + br_1s_2t_2 - br_2s_2t_1) / [(at_1 + bt_2)(r_1t_2 - r_2t_1)]$

$\quad = \dfrac{ar_1s_2t_1 - ar_2s_1t_1 + br_1s_2t_2 - br_2s_2t_1 + ar_1s_1t_2 - ar_1s_2t_1 + br_2s_1t_2 - br_2s_2t_1}{(at_1 + bt_2)(r_1t_2 - r_2t_1)}$

$\quad = [(at_1 + bt_2)(r_1s_2 - r_2s_1) + (ar_1 + br_2)(s_1t_2 - s_2t_1)] / [(at_1 + bt_2)(r_1t_2 - r_2t_1)]$

$\quad = (r_1s_2 - r_2s_1)/(r_1t_2 - r_2t_1) + [(ar_1 + br_2)(s_1t_2 - s_2t_1)1/[(at_1 + bt_2)(r_1t_2 - r_2t_1)]$

$\quad = (r_1s_2 - r_2s_1)/(r_1t_2 - r_2t_1) + (r/t)[(s_1t_2 - s_2t_1)/(r_1t_2 - r_2t_1)],$

which again is a straight line.

prerequisite for isochron dating of magmatic rock, is not always fulfilled. But for the Rb/Sr system, for example, initial heterogeniety would place the determination of a whole-rock isochron age in doubt, if not make it impossible."[66] For example, "Some granites formed from crustal material by anatectic melting [melting of a previously solidified rock] have yielded only poorly defined isochrons. In some cases it has been shown that the scatter is not caused by secondary post-magmatic disturbances, but by incomplete homogenization of the anatectic melt . . ."[67] But if incomplete mixing can also give straight "isochrons", there is no reason to suppose that any "isochron" necessarily shows true age. The isochron method of rubidium/strontium dating is not "self-checking".[68]

In fact, when faced with "isochron" lines that are grossly too old even by the evolutionary time scale, geochronologists have no trouble ascribing them to mixing lines. Several examples are given in Faure.[69] One can even have a backward "isochron" (giving a negative "date"), which is universally conceded to be a mixing line.[70] Thus a creationist explanation of other "isochrons" as mixing lines is not out of order.

It may be pertinent to note that in order to completely reset

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[66] Pp. 12-13.

[67] Geyh and Schleicher, p. 87.

[68] Contrary to the claim of Dalrymple, see note 9, p. 109.

[69] Pp. 145-7. His examples follow: Pleistocene to Recent (<1.6 million years old) lava with a Rb/Sr age of 773 million years (Bell K, Powell JL: "Strontium isotopic studies of alkalic rocks: The potassium-rich lavas of the Birunga and Toro-Ankole Regions, east and central Africa." *J Petrol* 1969;1O:536-72); upper Miocene to Pliocene (5-9 million years old by K/Ar dating) lava with a Rb/Sr age of 31-39 million years (Dickinson DR, Dodson Mn, Gass IG, Rex DC: "Correlation of initial $^{87}Sr/^{86}Sr$ with Rb/Sr in some late Tertiary volcanic rocks of south Arabia." *Earth Planet Sci Lett* 1969;6:84-90); Pliocene to Holocene (<5.3 million years old) lava giving Rb/Sr ages of 570 and 870 million years (the 570 million year "isochron" is apparently from <3000 year old lava. Leeman WP, Manton WI: "Strontium isotopic composition of basaltic lavas from the Snake River Plain, southern Idaho." *Earth Planet Sci Lett* 1971;11:420-34); and Miocene to Holocene (<24 million years old) volcanic rock with a Rb/Sr age of 1.2 billion years (Duncan RA, Compston W: "Sr-isotopic evidence for an old mantle source region for French Polynesian vulcanism." *Geology* 1976;4:728-32). An additional report has been made of Pliocene to Holocene (<5.3 million years old) lava with a Rb/Sr age of 1.5 billion years (Leeman WP: "Late Cenozoic alkalirich basalt from the western Grand Canyon area, Utah and Arizona: Isotopic composition of strontium." *Bull Geol Soc Am* 1974;85: 1691-6).

[70] For an example, see Dasch EJ, Green DH: "Strontium isotope geochemistry of lherzolite inclusions and host basaltic rocks, Victoria, Australia." *Am J Sci* 1975;275:461-9.

an isochron, strontium isotopes must completely homogenize, to the nearest part per 10,000 or so, without homogenizing rubidium, or at least with subsequent refractionation of rubidium. If one simply mixes rubidium along with strontium, one has a mixing line with the same slope as the original isochron. This would make it more difficult to assume re-equilibration.

What about the apparent order in rubidium/strontium dates? Some of it is more apparent than real, due to the biases we noted under potassium/argon dating. But there is a real order as well. This might be accounted for by more complete mixing of the starting components for mixing lines as the Flood went on, with flatter "isochrons" as a result. And what about the matching of rubidium/strontium dates with potassium/argon dates? Some of the dates do not match.[71] This fact is not as generally appreciated as it should be. But even matched dates do not necessarily correspond with real time. Dalrymple and Lanphere[72] note some nearly parallel potassium/argon and rubidium/strontium dates which no one would say represented real time. Whether the data were somehow biased or whether there is some non-chronological relationship between the two systems I cannot say for sure, but certainly the relationship does not have to be chronological to give concordant "dates".

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[71] For example, see Odin GS (ed): *Numerical Dating in Stratigraphy.* Chinchester, UK: John Wiley and Sons, 1982. Chapter 12 (Keppens E, Pasteels P: "A comparison of rubidium-strontium and potassium-argon apparent ages on glauconies." Pp. 225-44) is full of examples of disagreement, and also has examples where the two methods agree but both differ from the accepted age. One may argue that glauconies are not always reliable, but examples of "incorrect" dates from other minerals such as biotite and whole rock granite may be found in chapter 24 (De Souza HAF: "Age data from Scotland and the Carboniferous time scale." Pp. 455-66), for example. Also see Lanphere MA, Wasserburg GJF, Albee AL, Tilton GR: "Redistribution of strontium and rubidium isotopes during metamorphism, World Beater Complex, Panamint Range, California." In: Craig H, Miller SL, Wasserburg GJ (eds): *Isotopic and Cosmic Chemistry.* Amsterdam: North-Holland Publishing Company, 1964, pp. 269-320. This fascinating study also demonstrates whole-rock (separated by, in some cases, miles) dates 200 million years younger than the presumed age of the formation (1.8 billion years), as well as up to 50% disparity between potassium/argon and rubidium/strontium mineral ages, in spite of minimal to no mineralogical evidence of metamorphism at this time (presumably 115 million years ago).

[72] Pp. 160-1, citing Hart SR: "The petrology and isotopic-mineral age relations of a contact zone in the Front Range, Colorado." *J Geol* 1964;72:493-525, and especially Hanson and Gast, see note 54.

Is there some mineral or rock that one might reasonably assume had complete initial homogenization of its strontium isotopes so that we can get a minimum rubidium-strontium age for deposition? Yes, there is. Evaporite minerals would be expected to have had all their strontium either in solution or equilibrium with solution at the time of deposition. But evaporites turn out to be a real can of worms. For it is not certain whether so-called evaporites are actually formed by evaporation. It is certain that most of them are not formed by the evaporation of seawater.[73] Their minerals do not always lie on a straight "isochron" line,[74] implying either an unusual recrystallization history or a complex mixing line. And their dates, although quite low, are mostly not in harmony with a creationist model.[75] The problems for a creationist would be neatly solved if some of the crystals were transported in, or even if the minerals were crystallized in different stages. From an evolutionary perspective, migration of strontium seems implausible, but re-solution is much more plausible. In conclusion, the evidence from rubidium/strontium dating, as well as that from potassium/argon dating, points in the direction of a short chronology for life on the earth. The difficulties of interpretation within an evolutionary time scale are far worse than those within a creationist time scale.

Two other methods are analogous to rubidium/strontium dating and stand or fall with it. *Potassium / calcium dating* is strictly analogous. The only change in the formulas is the addition of a factor for the branched decay of ^{40}K.[76] In fact, the chemistry is

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[73] See Hardie in note 37.

[74] See Baadsgaard in note 36.

[75] Lippolt HJ, Raczek I: "Rinneite-dating of episodic events in potash salt deposits." *J Geophys* 1979;46:225-8 (Rinneite [NaK_3FeCl_6] of Permian [250-300 million years old] age gave dates of 30-85 million years old by "model age" [the initial $^{87}Sr/^{86}Sr$ was estimated] and another sample gave 20 million years by actual isochron, but carnallite [$KCl \cdot MgCl_2 \cdot 6H_2O$] found with the rinneite did not fall on the isochron, dating instead to 8.5 million years); Lippolt HJ, Raczek I: "Cretaceous Rb-Sr total rock ages of Permian salt rocks." *Naturwissenschaften* 1979;66:422-3 (two samples of these Permian potassium minerals gave ages of 82 ± 1 and 96 ± 1 million years within 10 feet of each other on the same horizon); and Baadsgaard in note 36.

[76] The equation being $^{40}Ca/^{42}Ca = (^{40}Ca/^{42}Ca)_0 + (^{40}K/^{42}Ca) \times 0.888 \times (e^{kt} - 1)$ for the isochron line. The equation can also use ^{44}Ca or some other isotope as its reference instead of ^{42}Ca.

similar. Potassium and rubidium are nearly interchangeable and are found together, and the same is true for calcium and strontium. It is therefore not surprising that the few potassium/calcium ages that have been determined matched the rubidium/strontium ages for the same rocks. It is of interest that evaporites, for which one can be the most comfortable that isotopic homogenization has occurred, again usually date low.[77] Potassium/calcium dating, like rubidium/strontium dating, is actually more compatible with a short than a long chronology.

The ^{147}Sm / ^{143}Nd method depends on the decay of ^{147}Sm to ^{143}Nd by the ejection of an alpha particle, with a decay constant of 6.539×10^{-12}/year (and therefore a half life of 106 billion years). The isochron method is again used.[78] The same criticisms apply to this method as to the rubidium/strontium method, but this method has the additional disadvantage for our purposes of being hard to reset by anyone's standards.[79] Finally, the long half-life of ^{147}Sm means that most samarium/neodymium dates are Precambrian. Samarium/neodymium dating can be safely ignored in the present discussion.

Uranium / Thorium/Lead methods. These are three interrelated methods that all depend on the decay of a long-lived isotope (^{238}U, half life 4.468×10^9 years, ^{235}U, half life 7.038×10^8 years,

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[77] Some studies (for example, Wilhelm HG, Ackerman W: "Altersbestimmung nach der K-Ca-Methode an Sylvin des Oberen Zechsteines des Werragebietes." *Z Naturforsch* 1972;27a:1256-9; and Heumann KG, Kubassek E, Schwabenbauer W, Stadler I: "Analytisches Verfahren zur K/Ca-Altersbestimmung geologischer Proben." *Fresenius Z Anal Chem* 1979;297:35-43) use model ages instead of isochrons. Heumann *et al.* dated langbeinite (potassium magnesium sulfate) with a potassium/argon age of 147 million years and a rubidium/strontium age of 152 million years, to 154 million years (the geological age was not given). The sylvite of Wilhelm and Ackerman, with a geological age of 200 million years, dated 133 million and 40.5 million years. Wilhelm and Ackerman attributed this to metamorphosis and recrystallization, without citing any other evidence for these processes.

It is fascinating to note Baadsgaard's data (see note 36), especially on the Alwinsal Willowbrook core. With rubidium-strontium dating the sylvite gives 20-60 million years, and the carnallite gives 2-20 million years, whereas the potassium-calcium dates are 4-85 million years and 85-125 million years, respectively. Notice the reversal of the (apparent) relative ages (the conventional age is 350 million years and the potassium/argon age is 200 million years).

[78] The formula is $^{143}Nd/^{144}Nd = (^{143}Nd/^{144}Nd)_0 + (^{147}Sm/^{144}Nd)(e^{kt} - 1)$

[79] For example, see Geyh and Schleicher, p. 103: "This example clearly shows the high resistence [*sic*] of the Sm-Nd system to metamorphic resetting."

and ^{232}Th, half life 1.4010×10^{10} years), through several steps, to lead. Each isotope listed above produces a different isotope of lead[80] (^{238}U yields ^{206}Pb, ^{235}U yields ^{207}Pb, and ^{232}Th yields ^{208}Pb) through several steps of alpha and beta decay. For now we will not worry about the intermediate steps.[81] For our purposes, once the uranium or thorium decays, it can be considered to have produced the proper isotope of lead immediately as a good approximation, if the evolutionary time scale is close to accurate.

These are essentially isochron methods. One can assume an invariant decay constant, initial homogenization of lead, and no migration of uranium, thorium, any of their daughter products, or lead, and no removal of ^{235}U by neutron-induced fission.[82] One then makes isochron plots as in rubidium/strontium dating,[83] and in theory obtains three different dates which should all be concordant if the above assumptions are correct. If the dates are concordant, the conclusion is usually drawn that the calculated age represents real age.

Two criticisms of these methods can be made. First, even concordant dates can be precisely duplicated by mixing lines, just as in rubidium/strontium dating. Concordance may suggest that a deposit was last separated into uranium (and thorium) and lead fractions at a given time, but it does not prove that the last time it was made into a hot slurry was that long ago. This is particularly true for whole-rock dating, but is true for mineral dating as

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[80] Abbreviated Pb, from the Latin plumbum, from which we get the English word plumbing.

[81] This is because the methods under discussion are only used to date materials 1 million years old or older. The longest-lived intermediate is ^{234}U with a 245,000 year half life. The other mean lives added together are less than 120,000 years for any series.

[82] There is one place in Africa where this assumption is probably not true, the Oklo uranium deposit. About half the ^{235}U has probably been fissioned.

[83] The equations are:

$$^{206}\text{Pb}/^{204}\text{Pb} = (^{206}\text{Pb}/^{204}\text{Pb})_0 + (^{238}\text{U}/^{204}\text{Pb})\,(e^{kt} - 1)$$
$$\text{where k } 1.55125 \times 10^{-10}/\text{year,}$$
$$^{207}\text{Pb}/^{204}\text{Pb} = (^{207}\text{Pb}/^{204}\text{Pb})_0 + (^{235}\text{U}/^{204}\text{Pb})\,(e^{kt} - 1)$$
$$\text{where k} = 9.8485 \times 10^{-10}/\text{year, and}$$
$$^{208}\text{Pb}/^{204}\text{Pb} = (^{208}\text{Pb}/^{204}\text{Pb})_0 + (^{232}\text{Th}/^{204}\text{Pb})\,(e^{kt} - 1)$$
$$\text{where k } 4.9475 \times 10^{-11}/\text{year.}$$

There is also a ^{207}Pb/^{206}Pb age which is obviously mathematically interrelated with the uranium/lead methods, and as noted above, is only considered valid on precambrian age material anyway, and will not be given separate consideration here.

well, since zircon is especially resistant to melting.[84]

Secondly, in practice "The ages obtained with the above equations are almost always discordant."[85] This would imply that almost none of the deposits which are dated by the uranium/thorium/lead methods have been undisturbed since the last time the uranium/thorium/lead clocks were completely reset. This would invalidate the dating methods unless there is some way of mathematically correcting for the age discrepancies.

These considerations have led to the concordia method of uranium/lead dating. It is difficult to determine the relative movement of uranium and thorium into or out of a rock or mineral if movement has taken place after formation. Therefore, it is difficult to relate thorium/lead dating to uranium/lead dating in a specimen which is assumed to have been disturbed. But the two uranium isotopes should migrate together, as should the different lead isotopes, and so the ^{238}U/^{206}Pb age and the ^{235}U/^{207}Pb age can be related to each other. If we assume that the uranium in the sample was initially lead-free (or if we correct for primordial lead based either on the isotope ratios of nearby lead without uranium or on the use of isochron methods), the ^{238}U/^{206}Pb ratio will give an age and the ^{235}U/^{207}Pb ratio will give an age. Where the ratios give the same age is called the concordia line (this is not a *straight* line). If a sample has aged (for example, 3 billion years) and then loses lead[86] or gains uranium, its uranium/lead ratios move from where it is on the concordia line along a straight line, called the discordia line, toward the origin. If the uranium/lead clocks are not completely reset (the lead is not completely removed and does not have its isotopic composition completely homogenized), the various rocks will have their uranium/

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[84] See Gale NH: "The dating of plutonic events." In Odin GS (ed), see note 71, pp. 441-50: "Even though, [*sic*] a zircon suite may be well-dated by the U-Pb discordia method . . . , there can still be doubt whether this date is that of the rock formation itself or whether the zircons are detrital or have inherited radiogenic lead, resulting in the U-Pb result giving an 'age' older than the rock formation. (This danger is also inherent in fission track ages of zircons from bentonites.)" (pp 446-7).

[85] Geyh and Schleicher; p. 117.

[86] This movement of lead can occur in zircons exposed to seawater under high pressure and temperature in a relatively short time (up to 61% lead loss at 13 d in 2M NaCl at 1Mbar and 500° C) according to Pidgeon RT, O'Neil JR, Silver LT: "Uranium and lead isotopic stability in a metamict zircon under experimental hydrothermal conditions." *Science* 1966; 154:1538-40.

lead ages "stuck" at varying distances down the discordia line. Then as more uranium decays and more lead accumulates the discordia line gradually moves, but remains a straight line. At a later time one can not only date the original age of the sample (the "upper concordia age") but also the time of the disturbance (the "lower concordia age"). From the standpoint of our discussion the meaning of the upper concordia age is not terribly important, as these dates are almost always Precambrian. But the lower concordia age often falls into the Phanerozoic, so the meaning of this age is quite germane to our discussion.
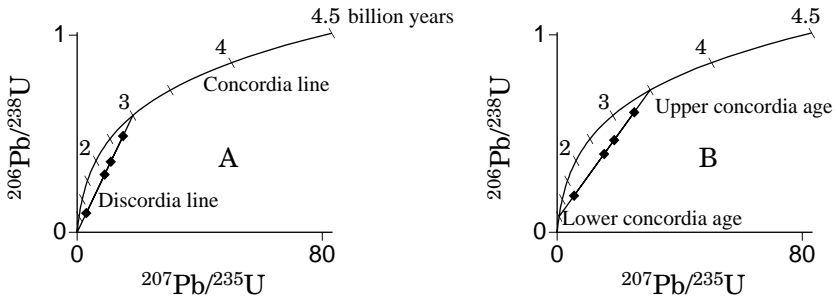
Discordia lines: A. Initial B. after 500 million years

There is an elaborate discussion of discordia lines in both Geyh and Schleicher[87] and Faure[88] which I will not repeat here. In some cases a discordia line can make a certain amount of sense from an evolutionary geological perspective. However, "In many Archaean areas the lower intercept gives an age value that cannot be assigned to any known geological event. This secondary value is then viewed as meaningless."[89] So some lower concordia

[87] Pp. 117-27.

[88] Pp. 291-9.

[89] Geyh and Schleicher, p. 121. See also p. 124: "A multi-stage history of detrital zircon or monazite can produce a pseudo-linear plot with intercepts between discrete metamorphic events, which are then without geological meaning." What is a "pseudo-linear plot"? It would seem to be a linear plot which we do not like. In that case how do we know that an ordinary "linear plot" has geological meaning except that we want to believe it?

Some examples of lower concordia ages which are not realistic from anyone's perspective are given in Tilton GR: 'Volume diffusion as a mechanism for discordant lead ages." *J Geophys Res* 1960;65:2933-45. Another example is given in Kuovo O, Tilton GR: "Mineral ages from the Finnish Precambrian." *J Geol* 1966;74:421-42.

ages are difficult to explain from an evolutionary perspective using standard theory.[90]

Is there another way to get those straight lines? Yes, a discordia line can be precisely reproduced by a mixing line (in fact, the original discordia line to the origin is just a special case of such a mixing line).[91] Mixing lines would seem to be the easi-

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[90] This problem has been felt so acutely that several diffusion models have been developed to explain "invalid" lower concordia dates. The most prominent of these have been the constant diffusion model (Tilton GR, see note 89) and the radiation damage-induced diffusion model (Wasserburg GJ: "Diffusion processes in lead-uranium systems." *J Geophys Res* 1963;68:4823-46). However, these models would be expected to be universal, or at least universal given certain parameters, and there are multiple examples of discordia lines which cannot reasonably be made to fit diffusion models (See, for example, Catanzaro EJ: "The interpretation of zircon ages." In Hamilton EI, Farquhar RM (eds): *Radiometric Dating for Geologists.* London: Interscience Publishers, 1968; and Ludwig KR, Stuckless JS: "Uranium-lead isotope systematics and apparent ages of zircons and other minerals in Precambrian granitic rocks, Granite Mountains, Wyoming." *Contrib Mineral Petrol* 1978;65:243-54). But note that even if the diffusion model were correct, it would still invalidate lower concordia ages as representing real time.

[91] This solution to the problem was noted in Steiger RH, Wasserburg GJ: "Comparative U-Th-Pb systematics in 2.7×10^9 yr plutons of different geologic histories." *Geochim Cosmochim Acta* 1969;33:1213-32. The derivation is as follows: We will take two rocks, Rock 1 with P_1 ^{206}Pb, U_1 ^{238}U, Q_1 ^{207}Pb, and V_1 ^{225}U, and Rock 2 with P_2 ^{206}Pb, U_2 ^{238}U, Q_2 ^{207}Pb, and V_2 ^{225}U. We will define for any rock $P/U = R$ and $Q/V = S$. The concordia plot is then R versus S, and the discordia line becomes $R = aS + b$. We note that for any rock U/V is a constant, so that $U_1/V_1 = U_2/V_2$ and $U_1V_2 = U_2V_1$. We will assume that there is some uranium in both rocks, so that $U_1 > 0 < U_2$ (and $V_1 > 0 < V_2$).

In a given mixture with x amount of Rock 1 and (1–x) amount of Rock 2 we have

$R = P/U = (xP_1 + (1-x)P_2) / (xU_1 + (1-x)U_2) = (P_2 + x(P_1-P_2)) / (U_2 + x(U_1-U_2)$

$RU_2 + Rx(U_1-U_2) = P_2 + x(P_1-P_2)$, and $x(R(U_1-U_2) - (P_1-P_2)) = P_2 - RU_2$.

By a precisely analogous derivation we have

$$Q_2 - SV_2 = x(S(V_1-V_2) - (Q_1-Q_2)).$$

Multiplying the equations by each other and dividing by x, we have

$$(R(U_1-U_2) - (P_1-P_2)) (Q_2-SV_2) = (S(V_1-V_2) - (Q_1-Q_2)) (P_2 - RU_2).$$

(This equation is valid even if x = 0, for in that case

$$R = R_2 = P_2/U_2 \text{ and } P_2 - RU_2 = P_2 - P_2 = 0,$$

and similarly $Q_2 - SV_2 = 0$, so that the above equation reduces to 0 = 0 and is still correct.)

Multiplying out, we have

$RQ_2U_1 - RSU_1V_2 - RQ_2U_2 + RSU_2V_2 - P_1Q_2 + SP_1V_2 + P_2Q_2 - SP_2V_2$
$= SP_2V_1 - RSU_2V_1 - SP_2V_2 + RSU_2V_2 - P_2Q_1 + RQ_1U2 + P_2Q2 - RQ_2U_2.$

Collecting terms,

$RS(U_2V_1 - U_1V_2) + R(Q_2U_1 - Q_1U_2) = S(P_2V_1 - P_1V_2) + (P_1Q_2 - P_2Q_1)$

est explanation for the "meaningless" age values for lower concordia ages noted above. If that is the case, then mixing lines might also explain ages which were previously presumed to have geological meaning. Lower concordia ages would then no longer have the persuasive power that has usually been assumed for establishing a date for a Phanerozoic deposit. A straight line does not require an accurate lower concordia age. The discordia method is not "self-checking".[92]

Is a mixing line a believable mechanism for discordia lines? Certainly for whole-rock dating a mixing line makes sense (and much of the dating that is done is whole-rock dating). For collections of zircons extracted from whole rock it also makes sense. Even if the dating is done on individual zircon crystals it would make sense unless uranium is consistently incorporated into zircon without lead. This would seem to require the uranium to be incorporated one atom at a time as an integral part of the zircon crystal structure.

The only requirement left of a creationist theory would be to explain the trend of dates to roughly match evolutionary theory. A general trend from older dates in earlier (i. e., lower) rocks to younger dates in later rocks could be explained by the gradually more thorough melting and mixing of the minerals in question as the Flood progressed. And of course there is some natural selectivity in what is published.

However, before we leave uranium/lead dating, attention should be drawn to a fascinating set of observations published in 1976.[93] Some uranium-rich water percolated through Mesozoic coal (conventional dates over 100 million years old), depositing uranium and its daughter products. From pleochroic haloes of ^{210}Po found in the coal it was reasonably shown that the uranium solution infiltrated the coal before coalification was com-

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.Since $U_1V_2 = U_2V_1$, $RS(U_2V_1 - U_1V_2) = 0$, and

$R(Q_2U_1 - Q_1U_2) = S(P_2V_1 - P_1V_2) + (P_1Q_2 - P_2Q_1)$, or (if $Q_2U_1 - Q_1U_2 \neq 0$)

$R = S(P_2V_1 - P_1V_2) / (Q_2U_1 - Q_1U_2) + (P_1Q_2 - P_2Q_1) / (Q_2U_1 - Q_1U_2)$,

which is a straight line. If $Q_2U_1 - Q_1U_2 = 0$, then $S(P_2V_1 - P_1V_2) = (P_2Q_1 - P_1Q_2)$, which gives a vertical straight line. Thus *a mixing line of any two uranium-bearing rocks will always give a straight line on a concordia plot.*

[92] Contrary to the claim of Dalrymple, see note 9, p. 119.

[93] Gentry RV, Christie WH, Smith DH, Emery JF, Reynolds SA, Walker R, Cristy SS, Gentry PA: "Radiohalos in coalified wood: New evidence relating to the time of uranium introduction and coalification." *Science* 1976;194:315-8.

plete, and that coalification was completed roughly 1-10 years from the time polonium (and therefore probably uranium) deposition began.

The uranium did not deposit evenly. Instead, it formed small inclusions which had haloes, mostly without the outer, last-stage haloes. Uranium/lead ratios were measured in several of these inclusions. The ratios ranged from 2,230:1 to 27,300:1 and even higher (unmeasurable lead content). This would appear to give a date of less than 300,000 years—how much less is anyone's guess. Movement of lead would seem to be unlikely when lead inclusions 50 microns away seemed intact, and it would take massive movement of uranium to explain these dates on an evolutionary basis.

To my knowledge the raw data has not been challenged. Attempts to explain the data by impugning the analytical methods would seem to apply equally to evolutionary dates. And since there is radiogenic lead in these samples not associated with uranium, the experimental results suggest that whole rock dating is not valid unless, as a minimum requirement, the lead can be demonstrated to be microscopically in the same place as the uranium.

Lead/alpha dating is just a watered-down and much less sophisticated version of uranium/thorium/lead dating. It is done by counting the alpha activity in the sample, measuring the lead content, and assuming no initial lead.[94] It is not able to take primordial lead into account, as uranium/thorium/lead dating does, and should date rocks to a somewhat older age than the average of uranium/thorium/lead dates. It is not worthy of independent consideration.

Uranium series disequilibrium methods: The uranium series disequilibrium methods include several methods which utilize the daughter products of ^{238}U and ^{235}U. The methods that concern us are the ^{230}Th/^{234}U method, the ^{231}Pa/^{235}U method, the ^{231}Pa/^{230}Th method, the ^{234}U/^{238}U method, the ^{230}Th$_{excess}$ method, the ^{231}Pa$_{excess}$ method, the ^{230}Th$_{excess}$/^{232}Th method, the ^{231}Pa$_{excess}$/^{230}Th$_{excess}$ method, and the ^{226}Ra$_{supported}$ and ^{226}Ra$_{unsupported}$ methods. The principles for each of them are similar, so they will be considered together, starting with the best-documented. The reliability of these methods is currently assessed

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[94] The lead/alpha method is nearly equivalent to the chemical lead method, which is obsolete.

on the basis of several criteria:

-The sample must have a uranium content of >10 ppb, >1 ppm is better.
-Terrestrial carbonates should have contained no ^{232}Th at the time of formation.
-Coral (aragonite, less than 1% calcite), mollusc shells, speleothem, and travertine should be compact, impervious to water, and may show no signs of weathering. They must have formed a closed system (Schwarcz 1980).
-There may be no signs of diagenetic recrystallization, which could have mobilized uranium or subsequent disintegration products (Geyh and Henning [*sic*] 1986). Thus, for example, primary aragonite samples (e.g., mollusc shells or coral) may not contain any calcite.
-The proportion of acid-insoluble residue must be <5% and the ^{230}Th/^{232}Th activity ratio of terrestrial carbonate should be >20.
-The ^{226}Ra/^{230}Th and ^{234}U/^{238}U activity ratios of marine samples older than 70 ka should be in the range of 1.0 ± 0.1 and 1.14 ± 0.02, respectively.
-The radiometric age should be consistent with the stratigraphic data.
-Dates obtained using different methods, e.g., ^{230}Th/^{234}U (Sect. 6.3.1), ^{231}Pa/^{235}U (Sect. 6.3.2), ^{230}Th-excess (Sect. 6.3.5), ^{231}Pa-excess (Sect. 6.3.6), U/He (Sect. 6.3.14), and ^{14}C (Sect. 6.2.1), should agree.

    If even one of these criteria is not fulfilled, the results cannot be expected to be reliable.[95]

This means that if authors and editors adhere to these criteria (especially the last two), no dates will ever be published that disagree with either the evolutionary time scale ("the stratigraphic data") or with the standard interpretation of ^{14}C dating.[96] Therefore we can expect to see biased data. If the evolutionary time

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[95] Geyh and Schleicher, p. 213, citing Thurber DL, Broecker WS, Blanchard RL, Potratz HA: "Uranium-series ages of Pacific Atoll coral." *Science* 1965;149:55-S.

[96] That it is intended to be applied this way can be inferred from Geyh and Schleicher, p. 222. Discussing methods for the "correction" of data, and noting their limitations, the authors state, "However, as none of these methods is entirely satisfactory, samples should be selected that will yield reliable ages with a high probability." Reliable in what way? Giving the desired ages, or theoretically uncomplicated? If the former, then gross bias is introduced.

scale is correct, then the data will be biased in the proper direction; but for the question as to the validity of that scale, the published data are nearly worthless. Thus even impressive data like that of Bard *et al.*[97] are not that helpful, since we have no way of knowing how many studies with different results never got completed, or wound up unpublished.[98]

But on to the methods themselves. They are dependent on having known initial amounts (or concentrations) of a parent and a corresponding daughter nuclide (or two independent nuclides) which have presumably been immobilized in the past, and measuring the state of progression of the relevant nuclides toward equilibrium.

The ^{230}Th/^{234}U method, considered the most reliable, starts by assuming that no ^{230}Th is found in a sample at the time of closure of the system. The ^{234}U initially in the system decays to ^{230}Th with a half life of 248,000 years. The ^{230}Th itself decays with a half life of 75,200 years. With appropriate measurements of the ^{238}U/^{234}U and ^{230}Th/^{234}U ratios, a formula relating the age and the above ratios may be derived.[99] The age itself is found by

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[97] Bard E, Hamelin B, Fairbanks RG, Zindler A: "Calibration of the ^{14}C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals." *Nature* 1990;345:405-10. It should perhaps be noted that they cited disagreements between the presumed original ^{14}C/C ratios of previously dated varved sediments, U-Th dating, and ice cores of up to 100% (p. 406).

[98] Because of this bias, the situation is a little like arguing that the economy in a Marxist country is doing well because the news reports are always good. If one believes in Marxism then they are reassuring evidence. But if one is trying to decide whether Marxist doctrine is correct, then the systematic bias makes the data unimpressive.

This analogy should not be pushed too far. There is a major difference between scientific and Marxist reports. Science values truth, honesty, and trustworthiness, whereas Marxism is quite willing to dispense with them if it suits its purposes. Thus, although science has its Piltdown men, their perpetrators are disapproved even by evolutionists. Most of the time one can at least trust the raw data, whereas this is not true at all for Marxist propaganda. Reports of violent students at Tiannenmen Square are quite likely to be simply fabricated.

[99] The equation is

$$\frac{[^{230}\text{Th}]}{[^{234}\text{U}]} = \frac{k_{230}}{k_{230} - k_{234}}(1 - \frac{[^{238}\text{U}]}{[^{234}\text{U}]})(1 - e^{-(k_{234} - k_{230})t}) + \frac{[^{238}\text{U}]}{[^{234}\text{U}]}(1 - e^{-k_{230}t})$$

(the brackets indicate alpha activity ratios rather than atomic ratios). One is tempted to think that for practical purposes the alpha activity of ^{234}U should be equal to that of ^{238}U. However, it turns out that the uranium in water is relatively enriched in ^{234}U, so that in groundwater the decay of ^{234}U is greater than that of ^{238}U by a factor of as much as 10 or more. Seawater today usually has an activity ratio of 1.15. If it were not for this the equation would be much simpler.

interpolation as the formula cannot be solved explicitly for time.

The method depends on four assumptions:

1. The decay constants have been invariant.
2. The initial ^{230}Th concentration was zero
3. There has been no net migration of ^{238}U, ^{234}Th, ^{234}Pa, or ^{234}U.
4. There has been no net migration of ^{230}Th.

For the purposes of our discussion we will grant assumption 1. The chief complaint of evolutionists concerns the acquisition of uranium by the specimen. If additional uranium is introduced, the radiometric ages will be too low. This apparently happens quite commonly.[100] (This would be viewed differently by a creationist.) There is also evidence that thorium may not be retained by some specimens. Because thorium is not supposed to be soluble in seawater, this seems theoretically improbable, but since thorium loss is apparently required to make some ages fit an evolutionary model, it is assumed to have occurred.[101] Apparently leaching of uranium also occurs, giving ages too old even for evolutionists.[102] Whether this effect is absent for dates which agree with the evolutionary time scale would appear to be a matter of opinion. Also adding of ^{230}Th apparently can occur sometimes without any physical indication of a problem.[103]

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[100] For example, see Geyh and Schleicher, p. 225: "Even when all of the rules are observed, incorrect data are sometimes obtained. A frequent reason is the presence of an open system, which is often the case with bones, teeth, marine phosphorites (Burnett and Kim 1986), and marine mollusc shells (Kaufman et al. 1971; Ivanovich et al. 1983), all of which acquire uranium in complex, episodic processes." The references cited are Burnett WC, Kim KH: "Comparison of radiocarbon and uranium-series dating methods as applied to marine apatite." *Quat Res* 1956;25:369-79; Kaufman A, Broecker WS, Ku T-L, Thurber DL: "The status of U-series methods of mollusk dating." *Geochim Cosmochim Acta* 1971;35:1155-83 (a thorough and devastating review); and Ivanovich M, Vita-Finzi C, Hennig Gd: "Uranium-series dating of molluscs from uplifted Holocene beaches in the Persian Gulf." *Nature* 1953;302:405-10.

[101] See Geyh and Schleicher p. 225: "In addition, Rae and Hedges (1989) have demonstrated that under certain circumstances not only uranium but also thorium may become mobile. Cross sampling often yields significantly lower ages than the burial age." They are citing Rae A, Hedges REM: "Further studies for uranium-series dating of fossil bone." *Appl Geochem* 1959;4:331-7. The results of Rae and Hedges seemed to indicate that bone took up thorium in groundwater experimentally. This would invalidate the whole dating procedure for bone, and suggest its invalidity elsewhere. It would be fascinating to see whether coral, for example, also can take up thorium from seawater.

[102] Geyh and Schleicher, pp 225-6.

[103] "In spite of this correction for detritus, U/Th ages obtained for Holocene

Perhaps most devastating for the validity of the dating method, one can have "unknown, non-zero initial specific activities of the ^{230}Th in samples taken from different cores."[104] If one cannot be assured of initially zero ^{230}Th activity, the basis of the method falls apart. Apparently this initial ^{230}Th is felt to come partly from seawater and partly from terrestrial detrital particles. Of course the concentration of the latter would be expected to have been much higher during and shortly after a Flood, almost *ex hypothesi.* Therefore the method would appear to be theoretically incapable of proving the validity of the evolutionary time scale (by the same token, it would be very unlikely that it could prove a creationist time scale). We might conclude by saying that ^{230}Th/^{234}U dating is not very helpful in our quest. The significance of ^{230}Th/^{234}U ages is greatly limited.

The ^{231}Pa/^{235}U method is closely analogous to the ^{230}Th/^{234}U method. It uses the assumption that ^{235}U is transported into a material without any ^{231}Pa. The ^{235}U then decays (via short-lived ^{231}Th) to ^{231}Pa.[105] The same criticisms that apply to the ^{230}Th/^{234}U method apply to this method. In addition, ^{231}Pa is acknowledged to be more mobile than ^{230}Th (although the inference usually drawn is that it may be lost, rather than that it may be gained).[196] The literature contains frequent estimates of ^{231}Pa loss and prolonged ^{235}U gain, to account for ages younger than expected using an evolutionary time scale. This method does not present a serious challenge to a creationist time scale.

The ^{231}Pa/^{230}Th method utilizes a mathematical division of the equation for the ^{231}Pa/^{235}U method by the equation for the ^{230}Th/^{234}U method. It is not really an independent method, and does not need further consideration in this discussion.

The ^{234}U/^{238}U method is based on the observation that minerals formed in equilibrium with water contain an excess of ^{234}U with respect to ^{238}U (excess decays per minute, not excess at-

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stalagmites are often too large by several thousand years with no suggestion of any detrital component indicated by the presence of ^{232}Th (Geyh and Hennig 1986)." Geyh and Schleicher, p 226, citing Geyh MA, Hennig GJ: "Multiple dating of a long flowstone profile." *Radiocarbon* 1986;25(2A):503-9.

[104] Geyh and Schleicher, p. 221.

[105] The formula for ^{231}Pa activity is closely approximated by $[^{281}Pa/^{235}U] = 1 - e^{-kt}$, where k is the decay constant of protactinium-231, 2.021 $\times 10^{-5}$/year, corresponding to a half life of 34,300 years.

[106] Geyh and Schleicher, p. 230.

oms). This excess (or disequilibrium) is presumably because minerals containing uranium are damaged at the sites where ^{238}U has partially decayed, so the resultant ^{234}U is therefore more available for solution than undecayed ^{238}U. Seawater is enriched in ^{234}U compared to uranium ore, and groundwater is still more enriched. If one knows the original ^{234}U/^{238}U activity ratio one can closely approximate the time by $t = \ln ([^{234}U/^{238}U - 1]_0 / [^{234}U/^{238}U - 1]) / k$, where $[^{234}U/^{238}U]$ is the activity ratio rather than the molar or weight ratio. However, without knowledge of $[^{234}U/^{238}U]_0$, time cannot be calculated. And there are no reliable estimates for this initial ratio.[107] Thus this method is not helpful in deciding our question.

[107] See Geyh and Schleicher, p. 232: "The main problem in applying this method to the dating of terrestrial samples is the lack of exact knowledge of the initial ^{234}U/^{238}U activity ratio, which is known only for marine samples." For marine samples, of course, a Flood might be expected to have had a major impact. And indeed there are evidences which could suggest that the initial ^{234}U/^{238}U activity ratio has varied. Ivanovich *et al.* in note 100 state on p. 410, "Furthermore, the ^{234}U/^{238}U activity ratios in modern marine shells are close to 1.15, the accepted value for oceanic water[3] [Kaufmann *et al.* in note 100], whereas the uranium isotope activity ratios in fossil shells are commonly greater than 1.15 indicating assimilation and uptake of uranium isotopes at least partly from sources other than oceanic waters[4,7]. [Veeh HH, Burnett WC: "Carbonate and phosphate sediments." In Ivanovich M, Harmon RS (eds): *Uranium Series Disequilibrium: Application to Enviornmmental Problems.* Oxford: Clarendon press, 1982, pp. 459-80; and Rosholt JN: "Open System model for uranium-series dating of Pleistocene samples." In: *Radioactive dating methods and Low-level counting,* Vienna: IAEA, 1967, pp. 299-3 11.]"

The dating of corals by the ^{234}U/^{238}U and ^{230}Th/^{234}U methods appears to be the place in radiometric dating where the data are most consistently supportive of the evolutionary hypothesis. There are still minor glitches, such as the occasional inconsistency with ^{14}C dates, but the evolutionary time scale does explain the vast majority of the published data with simple and plausible assumptions (but see Bar-Matthews M, Wasserburg GJ, Chen JH: "Diagenesis of fossil coral skeletons: Correlation between trace elements, textures, and ^{234}U/^{238}U." *Geochim Cosmochim Acta* 1993;57:257-76). So it is only fair to ask for a creationist model that will perform as well.

A creationist model would have to start by saying that the ^{234}U/^{238}U ratio in seawater at the end of the Flood was close to 1.10, instead of the 1.15 ratio at present. With massive leaching of the continents and the input to the oceans of water with an average value of perhaps 1.5-4 (fairly typical of groundwater), the value of seawater would have risen fairly quickly to its present level and then moved little for the last several (4-20+ depending on the model) thousand years. The detrital content of the oceans, and therefore the thorium available for direct incorporation, would be decreasing during this time, giving decreasing ^{230}Th/^{234}U ratios and therefore decreasing "ages". Thus it seems that if thorium can be incorporated directly into corals (and this should be tested as it has

The ^{230}Th-excess method is used to date ocean sediments and manganese nodules. It is based on the theory that in present-day oceans uranium (including ^{238}U and ^{234}U) stays in solution for approximately 250,000 years,[108] whereas thorium is adsorbed onto plankton or sediment particles within decades. The excess thorium decays away by the equation

$$\ln ([^{230}\text{Th}_{\text{excess}}]_0 / [^{230}\text{Th}_{\text{excess}}]) = kt.$$

If the sediment is deposited at a constant rate, and the $[^{230}\text{Th}_{\text{excess}}]$ is constant, then

$$\ln [^{230}\text{Th}_{\text{excess}}] = \ln [^{230}\text{Th}_{\text{excess}}]_0 - kd/r,$$

where d is the depth and r is the sedimentation rate or the manganese nodule growth rate. Of course, the sedimentation rate and the thorium content of the oceans would be expected to have been greater in the past if a Flood occurred, making it difficult to make a straightforward interpretation of results. But an evolutionary interpretation is difficult also, as noted by Geyh and Schleicher:[109] "The application of this method to pelagic sediments has been successful [has given the expected dates] in only a few cases because A_0 [the initial excess thorium specific activity] apparently often changes with the rate of sedimentation . . .". "In manganese nodules, in addition to changes in A_0, ^{230}Th can migrate by diffusion . . . causing apparent ages that are too small by up to a factor of 3." So the ^{230}Th-excess method must be classified among

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been in bone; see Rae and Hedges in note 101), there is a simple creationist model which can also explain the data.

It is fascinating at this point to speculate concerning the two models. The creationist model suggests that Pleistocene corals near large land masses should be less reliable than mid-ocean corals, particularly having a ^{234}U/^{238}U ratio of greater than 1.15, while their ^{230}Th/^{234}U ratios should be higher than predicted by a straightforward evolutionary model. Furthermore, it suggests that there should be an unusual profile to pre-Flood corals. Their ^{234}U/^{238}U ratio should be less than 1.10, perhaps even approximating 1.00, which matches the evolutionary prediction of great apparent age, but their ^{230}Th content should be quite low, comparable with that of modern corals, giving ^{230}Th/^{234}U dates near zero. I have not yet run across any data in the literature which would appear to corroborate or refute these predictions. These predictions should be tested, but it is doubtful that any evolutionist would attempt to date Paleozoic or Mesozoic coral unless he considers a creationist model at least a possibility.

[105] Mean life? No supporting data are given by Geyh and Schleicher (p. 216).

[109] P. 236. An example of a sedimentary profile with a profile of excess ^{230}Th that is actually reversed can be found in Somayajulu BLK: "Analysis of the causes of variation of ^{10}Be in marine sediments." *Geochim CosmochimActa* 1977;41:909-13. No other evidence is cited for the hypothesis that this is a disturbed sediment.

the methods which do not aid in choosing between evolutionary and creationist time scales.

The ^{231}Pa-excess method is very similar to the ^{230}Th-excess method, and suffers from the additional drawback that ^{231}Pa is more soluble in water. It need not be further considered here.

The ^{230}Th-excess/^{232}Th method is similar to the ^{230}Th-excess method, but attempts to compensate for the variability of ^{230}Th concentration during sedimentation using the assumption that the input of ^{230}Th correlates "with the input of detrital ^{232}Th, which, of course, is not always the case."[110] For use in volcanic rocks, complete homogenization is assumed and an "isochron" plot is made. After the rubidium/strontium isochron discussion above we need not comment further. This method is not enough of an improvement to merit a change in our evaluation of the ^{230}Th-excess method.

The ^{231}Pa-excess/^{230}Th-excess method assumes that all the ^{230}Th excess and all the ^{231}Pa excess in ocean sediments came from precipitation out of seawater with ^{234}U, ^{235}U, and ^{238}U in present-day concentrations. The method is not as clear-cut as one might wish.[111] But more importantly, this method would be expected to have been drastically affected by detrital components of Flood waters.

The supported ^{226}Ra and unsupported ^{226}Ra methods are "only of historical significance with respect to.. . application for oceanographic studies."[112] The other applications seem to deal with recent dates and are not relevant to our discussion.

Of the dating methods which have been discussed, potassium/argon dating of basalts is slightly in favor of a short chronology, rubidium/strontium dating is against a long chronology, and the others are not much help in either direction, with the exception of uranium/lead dating, in which the data reported by Gentry *et al.* strongly support a creationist position. This leaves us with thermoluminescence dating and its relatives (optically stimulated luminescence and electron spin resonance dating), fission-track dating, pleochroic haloes, amino acid dating, obsidian hydration, and the cosmic ray nuclides to consider.

Thermoluminescence dating depends on the fact that natural crystals have tiny imperfections which can hold electrons. When

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[110] Geyh and Schleicher, p. 238.
[111] Geyh and Schleicher, p. 240.
[112] Geyh and Schleicher, p. 243.

a crystal is irradiated, the radiation sometimes knocks electrons into these "holes". They then remain trapped until the material is heated, whereupon they jump back where they belong with the emission of a photon per electron. The method depends on knowing the dose of radiation (uranium, cosmic ray, potassium, etc.), the characteristics of the crystal, and the association of heating with the event to be dated (and no heating since). It is also technically demanding. Finally, there seems to be a plateau effect (when all the defects are filled with electrons, no further "aging" can occur), which would tend to blur the difference between an evolutionary and a creationist time scale. This method is primarily used in archaeology and is not much help with our problem. Interestingly, from an evolutionary standpoint, "the interrelation of the TL signals from meteorites in terms of radiation ages or terrestrial ages has not yet been solved."[113] A creationist explanation of these data is perfectly straightforward.

Optically stimulated luminescence dating and *electron spin resonance dating* are simply two more ways to measure the displaced electrons that are measured by thermoluminescence dating. They give us no additional information at this time.[114]

Fission track dating is based on the spontaneous fission of ^{238}U. The constant for this decay is around 7 to 8×10^{-17}/year (there is some uncertainty in the measurements and more uncertainty in the method of measurement), which is much less than the alpha decay constant (most ^{238}U atoms decay by alpha decay). When a ^{238}U atom fissions, the two major fragments fly in opposite directions with enough force to disrupt the crystalline or polymeric structure over a track of about 10 to 20 microns. These tracks can be seen if the mineral is ground and polished, then etched with a chemical solution such as hydrofluoric acid or

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[113] Geyh and Schleicher, p. 270, citing Sears DWG, Hasan FA: "Thermoluminescence and Antarctic meteorites." In Annextad JO, Schultz L, Wanke H (eds): *International Workshop on Antarctic Meteorites.* LPI Tech Rep 86-01. Houston: Lunar and Planetary Institute, 1986, pp. 83-100. Sears and Hasan give Antarctic meteorite thermoluminescence values which are scattered over two orders of magnitude and are all within the range of values for modern (witnessed) meteorites. It is fascinating that the heat of entry into the earth's atmosphere is not supposed to reset the thermoluminence that the meteorites acquired from cosmic rays in space.

[114] It is of interest that electron spin resonance dating of the flowstone reported by Geyh and Hennig in note 103 was too high by up to an order of magnitude, especially in the recent material.

potassium hydroxide. It should then be simple to measure the ^{238}U concentration, count the tracks, and relate the two by a formula. But there are several complications.

First, it seems that ^{238}U is not always (in fact, is usually not) distributed uniformly in the crystal. In some cases starburst tracks can be seen apparently originating from ^{238}U nodules. Secondly, the volume in which a given number of fission tracks is located is hard to determine (it is easy to measure the area but not the effective depth). So a surrogate for the ^{238}U concentration is used which gets around both of these problems. With ^{238}U, ^{235}U is found in the standard ratio. The ^{235}U can be caused to fission by irradiation with neutrons (this neutron-induced fission is the principle behind the atomic bomb). This reaction produces independent fission tracks which can be compared with the ^{238}U fission tracks. With a relatively simple formula, the age can be determined from the two counts.[115]

But this approach is not without problems. The decay constant for the spontaneous fission of ^{238}U is uncertain, and makes the derived time imprecise. More importantly, the neutron flux is hard to determine, and varies from place to place in a reactor. So the preferred procedure at present is to compare the spontaneous and induced fission track densities on the sample rocks to those on several reference (monitor) rocks whose age is known. The age of the sample is found by $t = t_m \, (\rho_{sf}/\rho_{if}) / (\rho_{msf}/\rho_{mif})$.[116] Of course, if the zeta correlation, as it is called, is used, it makes the age of the sample depend entirely on the age of the monitor. This means that fission tracks when interpreted this way give only relative dates.

In addition, there are problems with annealing (track fading). Often there are not enough visible tracks to match the presumed age. To correct for track fading, samples are heated and

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[115] The formula is $t = \ln (1 + \dfrac{\rho_{sf} k_{238} \sigma_{235} \phi}{\rho_i k_{sf\,238}} \dfrac{^{235}U}{^{238}U}) \Big/ (k_{238} + k_{sf\,238})$, where ρ is the density of fission tracks, k_{238} is the alpha decay constant of ^{235}U, $k_{sf\,238}$ is the decay constant for the spontaneous fission of ^{238}U, σ_{235} is the cross-section of ^{235}U for thermal neutrons (5.802×10^{-22} cm^2), and ϕ is the neutron flux in neutrons/cm^2.

[116] Where ρ is the track density, m is the monitor, sf is spontaneous fission, and if is induced fission. Strictly speaking, the formula given in Faure, p. 346, col. 1 (20.13 and 20.14) is more accurate.

the spontaneous to induced fission track ratio is measured for various temperatures (or the same temperature for various times). The induced tracks, and the spontaneous tracks that have not faded, begin fading promptly at a critical temperature. Tracks that have been partially annealed do not begin increased fading until a higher temperature is reached, so the spontaneous tracks reach a higher ratio to the induced tracks before starting to fade. This gives a plateau age which can be correlated with other radiometric ages (for example, potassium/argon ages).[117]

At first glance the agreement that was reported by Naeser *et al.* appears to be a powerful confirmation of both fission track dating and the dating method with which it was compared, and a good argument for plateau ages. This is particularly true when it is realized that fission tracks in some minerals can be demonstrated to be reset under geologically reasonable conditions.[118]

However, several considerations appear to have been overlooked. First, one may remember that the use of glasses in potassium/argon dating is discouraged. To use them here because the data obtained fit a particular theory is opportunistic unless such use is further justified. Second, Naeser *et al.* used a value for the ^{238}U spontaneous fission decay constant that was lower than the value found using determinations made on modern standards,[119] thus throwing off that beautiful correlation line by about 17%. And third, the precision of the method is only ± 10%, and even greater if the uranium distribution is not as uniform as expected. Frankly, the data in Geyh and Schleicher (following Naeser *et al.*) look too good for the precision of the method, raising the question of whether the data have been filtered. And it turns out that they have been. Naeser *et al.* in the original paper do not themselves believe that the data are as good as appears in Geyh and Schleicher's treatment.[120]

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[117] Geyh and Schleicher, p. 294, figure 6.96, citing data from Naeser CW Izett GA, Obradovich JD: "Fission-track and K-Ar ages of natural glasses." *US Geol Surv Bull* 1980;1489:31.

[115] For example, see Storzer D, Wagner GA: "Correction of thermally lowered fission-track ages of tektites." *Earth Plan Sci Lett* 1969;5:463-8.

[119] Thiel K, Herr W: "The 238U spontaneous fission decay constant redetermined by fission tracks." *Earth Plan Sci Lett* 1976;30:50-6. The error is about 17%.

[120] See Naeser *et al.*, note 117, p. 13: "It should be noted that this procedure does not always yield concordant results (McDougall [*sic*], 1976, and *this study*)." (citing MacDougall JD: "Fission-track annealing and correction procedures for oceanic basaltic glasses." *Earth Plan Sci Lett* 1976;30:19-26. Italics

Fission-track dating is not an easy way to date fossiliferous formations. Problems in the method are such that "the quality of the data is very dependent on the skillfulness and experience of the laboratory staff."[121] But even with a good laboratory, "The main disadvantage of the FT method is that the results are often difficult to interpret in terms of actual ages."[122]

Why does it take a skillful and experienced laboratory staff? The procedure itself is not hard. One simply irradiates half of a sample with neutrons (expensive but not technically difficult), mounts the samples on epoxy, then puts them in the appropriate reagent for a specified time. There can be up to 50% variation in the time needed in the reagent without significantly altering the results.

The problem is in identifying the tracks. Theoretically, if all the tracks were the same size and shape and there were no confusing structures, the job should be easy. But there are such structures.[123] And the very fact that some minerals have partially

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mine). I can find two glasses which did not give concordant dates that were left out of the graph. In addition, many more were not reported. See p. 3: "These natural glasses were chosen from a large group in our collection . . ." Other papers, such as Naeser CW, Fleischer RL: "Age of the apatite at Cerro Del Mercado, Mexico: A problem for fission track annealing corrections." *Geophys Res Lett* 1975;2:67-70, suggest that annealing does not always provide the answers expected.

Perhaps it would be worth quoting the abstract from Naeser and Fleischer (written 5 years after Naeser *et al.,* note 117):

Fission-track dating and K-Ar dating indicate that the age of apatite from Cerro de Mercado, Mexico, is 30 m.y., in contradiction to previous corrected fission track ages of 40 and 57 my. by other works. Annealing data for the "plateau method" correction of fission-track ages for the Cerro de Mercado apatite lead to corrections by a factor of sixty or more, which give geologically unreasonable ages. In addition, published data concerning the length of fission tracks and the annealing of minerals imply that the basic assumptions used in an alternative procedure, the length-reduction-correction method, are also invalid for many crystal types and must be approached with caution unless individually justified for a particular mineral.

[121] Geyh and Schleicher, p. 287.

[122] Geyh and Schleicher, p. 293.

[123] For example, to finish the quote from Naeser *et al.* in note 120, "These natural glasses were chosen from a large group in our collection because they appear very fresh and because they are essentially free of microlites and crystallines, which can make fission-track dating impossible. Many obsidians are crowded with microlites and crystallines (gobulites and trichites), and these form fission-track-like etch pits following etching with hydrofluoric acid. The etch pits of the microlites and crystallines are difficult to separate from real fission tracks formed from the spontaneous decay of 238U, and accordingly, calculated ages based on counts including the microlite and crystalline etch pits are not reliable."

annealed tracks says that the fission tracks themselves vary in length and width (older tracks should be more annealed than younger tracks).[124] The fission tracks do not come labeled as such. So it takes an experienced eye to pick them out. How do we know that the eye is experienced? Because it gives us the "right" dates. We again have circular reasoning, unless the data can be obtained by individuals who know nothing about the presumed age of the rock.

Even with the plateau correction technique, most fission track dates are too young, even for specimens that have remained (as far as we know) below room temperature over their entire history.[125] Inherited tracks are a concern in some minerals.[126] There is great need for more review, and for more data, particularly blinded data; with all observations fully reported.

Even if fission-track dating presents a major problem to evolutionary theory, a creationist should not feel comfortable about the results at this time. Fission-track dating is theoretically able to disprove a creationist time scale. And there are enough old dates to make a creationist uncomfortable. So we will look at the difficulties for a creationist in more detail.

In order to disprove a short chronology, several conditions must be fulfilled. First, the etching pits must be shown to be due to fission tracks and not to other imperfections (this will be difficult in glasses). Second, the mineral must be shown to have been either formed, or heated to a specified minimum temperature for a specified minimum time (so there are no inherited tracks), at or following the time of the dated event. Third, the deposition should be clearly correlated with the existence of life. Fourth, the dating

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[124] I have not run across any photographs of partially annealed tracks in geological materials in the literature. I am assuming that the annealed fission tracks are not all uniformly decreased in size, like the photograph in Storzer and Wagner (see note 118, p. 465). If they are 99+% the same size, the only model that will fit the data is that of accumulation of fission tracks without annealing followed by a relatively sudden heating episode <1% of the putative age ago. That is not usually a reasonable evolutionary model, and the fission tracks would actually be evidence against the evolutionary time scale in that case. Or perhaps these pits are not fission tracks at all, in which case they are totally irrelevant to our question. Perhaps only the normal-sized tracks should be counted, or perhaps the difficulties of separating fission tracks from other artifacts in glasses are so great that the method cannot give meaningful data.

[125] See MacDougall in note 120.

[126] See Gale in note 84.

must be absolute and not relative. The zeta correction technique is not adequate without a securely dated standard. (In addition, fission tracks from neutron-induced fission of ^{235}U must be negligible, although in the average granite this works out to $\approx 0.01\%$ of the ^{238}U tracks.) I have not had time to review all the literature, but I haven't yet seen the "smoking gun" proving a creationist time scale wrong. The literature should have a thorough review from this standpoint. Incidentally, it would be fascinating to date secondary minerals, perhaps such as aragonite in corals or calcite in brachiopods, or perhaps petrified trees, with the fission-track method.

Pleochroic haloes are fascinating from the standpoint of the age of the earth. They can be found in multiple minerals, but the easiest to use is biotite mica, because it can be easily split into thin flakes. Pleochroic haloes are formed by alpha particle damage, similar to fission fragment track damage. Since alpha particles have higher initial speeds and are less positively charged than fission fragments, they produce minimal track damage until they slow down near the end of their range. At this point they create maximum damage. Thus if one splits a crystal at the point of a uranium inclusion one finds rings around the inclusion which are lighter at the center and darker at the edge. These rings are darkened in proportion to the radiation damage. The diameter of a ring is proportional to the energy of the alpha particles producing the ring. Generally, more stable isotopes emit alpha particles of lower energy and thus make smaller rings, whereas more unstable isotopes emit alpha particles of higher energy and make larger rings. A mineral inclusion of uranium which has all the daughter products present will create a series of concentric rings, with a size characteristic of the mineral.

It would be easy to measure the discoloration of the rings around an inclusion, measure the discoloration of a known alpha dose,[127] measure the uranium and thorium content of the inclusion, and calculate the age. However, this method "is hardly used anymore because of the thermal instability of the haloes and the fact that very old samples often reach a saturation point . . . and

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[127] Or according to Faure (p.355) one can calibrate by "studying halos in other specimens of that mineral of known age." This would immediately involve us in circular reasoning unless the true age of the "known age" mineral was indeed known.

thus yield apparent ages that are too small. The intensity of the coloring may even decrease when saturation is exceeded." ". . . many geologically unacceptable results have been obtained with this method."[128] "This method has been abandoned in favor of the isotopic dating methods."[129]

But is it really that unreliable? Notice that the above results suggest a younger age than the "geologically" acceptable one. One straightforward interpretation would be that at least some pleochroic haloes support nearly contemporaneous formation of some igneous and metamorphic rock formations, much younger than usually assumed. Perhaps the data should be reviewed. It just might be compatible with a creationist time scale.[130]

Amino acid dating is based on the fact that all amino acids except glycine have an asymmetric carbon (threonine and isoleu-

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[128] Geyh and Schleicher, p. 299.

[129] Faure, p. 355.

[130] The literature on the subject is apparently not large, but mostly old and published in obscure journals. In addition, many of the dates are Precambrian and do not bear directly on our question, such as those in Deutsch S, Kipfer P, Picciotto E: "Pleochroic haloes and the artificial coloration of biotites by α particles." *Nuov Cim,* series 10, 1957;6:796-S10. Some of the literature does not give good geologic characterizations of the specimens (for example, Joly J: "Pleiochroic halos of various geological ages." *Proc Roy Soc London A* 1923;102:682-705, where the Devonian halo-containing rocks are identified simply as "Co. Carlow (Ballyellen) mica", without a word as to the geological environment, and similarly "Tertiary mica of the Mourne granite" on p. 695).

To falsify a creationist time scale, one would have to show that pleochroic haloes were found in rocks which had either formed or been heated enough to erase the previous haloes at or after their association with fossils, and that the halos could be reliably dated to well beyond a reasonable creationist time frame. This is indeed theoretically possible. It appears that pleochroic haloes can be erased in mica at 500-705° C (Holmes A: "The age of the earth." *Bull Nat Res Council (U.S.)* 1931;80:159-96, esp. p. 188). In addition, fossils such as petrified trees might produce haloes which would falsify the creationist time scale (the only evidence of this kind that I know of is in favor of the creationist time scale. See Gentry *et al.*, note 93).

Of course, any evolutionist who tries this will also have to deal with the published work on polonium haloes (conveniently collected in Gentry RV: *Creation's Tiny Mystery.* 3rd ed. Knoxville, TN: Earth Science Associates, 1992). There are no good mechanistic evolutionary explanations of polonium haloes. The argument that they must be from uranium decay products ignores the evidence from the "uranium-poor White Mountain (New Hampshire) granites" cited on p. 332-3 (reprinted from Gentry RV: "Response to 'Radioactive halos: Geologic concerns.'" *Creat Res Soc Quart* 1989;25:176-80). I don't imagine that any evolutionist relishes the job of making coherent sense of all the important data within standard evolutionary theory.

cine and the secondary amino acids hydroxyproline and hydroxylysine have two), which can come in either right-handed (D) or left-handed (L) forms (see chapter 2). These amino acids are all found in only one form (the L form) in living organisms (with rare exceptions like D-alanine in some microbial cell walls). These amino acids slowly transform from L to D forms (and back again) randomly. If the transformation constant is known, amino acids may be used like radioactive isotopes for dating.

The obvious disadvantage of this dating method is that several enviornmental influences such as acidity (pH) and temperature influence the transformation "constant". The influence of temperature is particularly striking. A 1° increase in temperature increases the "constant" by 25%.[131] Thus "constants" must be calibrated by other methods. "Ages that are not based on such site-specific calibrations can deviate by several orders of magnitude from the actual ones (Dungworth 1976)."[132] This inaccuracy is enough to blur the difference between the creationist and evolutionary time scales.

One of the apparently repeating phenomena noted in amino acid dating is the decreasing of the racemization "constant" in older specimens.[133] This is particularly interesting in view of the fact that a straightforward interpretation of the creationist time scale largely eliminates the crookedness of this curve. Several very "old" samples still have significant amounts of L-amino acids and are not in equilibrium. In fact, this trend toward smaller "constants" in "older" samples is true for the entire literature.[134]

[131] Geyh and Schleicher, p. 350.

[132] Geyh and Schleicher, p. 350, citing Dungworth G: "Optical configuration and the racemisation of amino acids in sediments and in fossils—a review. *Chem Geol* 1976;17:135-53.

[133] For example, see Geyh and Schleicher, p. 347, fig. 8.2. Also see Dungworth in note 132. On p. 149 he states, "The results for modern bone and that of Aztec origin are in excellent agreement; 700 years age disparity disclose no noticeable difference in the magnitude of the rate constants. . . . In Mammoth bone there is a distinct decrease in the magnitude of the rate constant, while the much older deer and walrus bones, of Pleistocene age, display rate constants which are about one order of magnitude less than those in modern bone. The implication is that the rate of the racemisation reaction is decreasing with time." In fact, on p 140 he reports Jurassic (conventional age 180 million years) material which still has a considerable excess of L-form amino acids. This is quite surprising from an evolutionary perspective.

[134] See Brown RH: "Amino acid dating." *Origins* 1988;12:8-25, which gave an exhaustive survey of the available literature.

The decrease is almost linear. In fact, the decrease approaches asymptotic if the effect of more recent racemization is considered.[135] The chemistry behind this phenomenon is not easily understood when viewed from an evolutionary perspective. Deep (older) sediments would be expected to be hotter, not colder, than surface ones. However, a creationist explanation eliminates this problem. This would seem to indicate that a creationist time scale is more in accord with the amino acid data than an evolutionary one. But the uncertainties inherent in the method undermine its validity as an argument for anything.[136]

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[135] The problem has to do with the way of averaging. We usually average by adding the items and dividing by their number. If there are 2 objects, one being 3 meters high and one 5, their average is (3+5)/2, or 4 meters. But if you go 30 kilometers/hour for 90 kilometers and 90 kilometers/hour for 90 kilometers, your average speed is not 60 kilometers/hour but [(30x3)+90]/4 or 45 kilometers/hour. This is because you spend 3 hours traversing the 30 km/h stretch and only 1 hour on the 90 km/h stretch. In fact, there is a puzzle which says, "If you want to average 60 miles per hour over a 60 mile road and you spend the first 30 miles going 30 miles per hour, how fast do you have to travel the remaining 30 miles?" The answer is not 90 or 120 miles an hour, but at infinite speed. That is, you can't make it. You have already used up the hour during which you should have finished the 60 mile trip.

In the same way, if a racemization "constant" for a 3,000 year old sample is 6.93×10^{-4}/y, so that its "half life" is 1,000 years, and a racemization constant for a 4,000,000 year old sample is 6.93×10^{-7}/y so that its average "half life" is 1,000,000 years, the discrepancy is even greater than it appears. For if the environment of the 6 million year old sample was the same as that of the 3 thousand year old sample for the last 3000 years, then it had at least a two-stage history. In the last stage it lost 7/8 of its leftover unmatched L-amino acids over 3000 years, and in the first stage it lost 1/2 of its unmatched L-amino acids over an approximately 4,000,000 year period (3,997,000 to be exact), for a constant of 1.73×10^{-7}/y. So if one calculates the early "constants" for the older samples, they are even smaller, and in some cases vanish entirely! (a 20,000,000 year old sample and a 20,000 year old sample with the same D/L amino acid ratio in the same environment would imply a racemization constant of zero for all but the last 20,000 years, or else an erroneous time scale.)

[136] One of the problems with using amino acid racemization as a dating technique is that the racemization "constant" not only varies with temperature, acidity, etc., but also with the position of the amino acid residue within the peptide. In general, the residues on the end of peptides are easiest to racemize (have the highest "constants"). However, there are strange cases such as isoleucine which racemizes easiest inside the protein (Kriausakul N, Mitterer RM: "Isoleucine epimerization in peptides and proteins: Kinetic factors and application to fossil proteins." *Science* 1978;201:1011-4). Thus instead of a simple exponential relationship between racemization and time one has a complex curve, depending on how much of the protein has hydrolyzed. There are even cases of the apparent reversal of racemization (Kimber RWL, Griffin CV, Milnes

The obsidian hydration method is based on the idea that freshly broken obsidian hydrates at its surface at a rate that is completely dependent on the type of glass, the temperature, and the time.[137] Because the thickness of the hydration layer varies with the square root of time, older dates are inherently subject to more inaccuracy than younger dates. Also, pressure, water, and solutes must have *something* to do with the rate[138] because the experimental hydration rates are determined in a pressurized reaction vessel with deionized water. In actual application, "dating errors may occur when the obsidian artifact has been subjected to heat because this changes the rate of hydration. Moreover, erosion of the surface, which is difficult to detect, also leads to incorrect ages."[139] Note that erosion would produce too young ages (since it is difficult to detect, one can simply throw out young ages that one does not like simply by claiming that there was erosion). In fact, erosion turns into peeling at 40-50 microns, or less with mechanical or heat stress. So there is an absolute limit to the dating accuracy.

With these problems in the method, I do not know of any data that cannot be explained by either a creationist or an evolution-

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AR: "Amino acid racemization dating: Evidence of apparent reversal in aspartic acid racemization with time in shells of *Ostrea*." *Geochim Cosmochim Acta* 1986;50:1159-61; Kimber RWL, Griffin CV: "Further evidence of the complexity of the racemization process in fossil shells with implications for amino acid racemization dating." *Geochim CosmochimActa* 1987;51:839-46), so that older specimens may look younger than younger specimens subjected to the same conditions. Specimens may also appear to age suddenly. Obviously, this makes the method as presently done incapable of proving anything, and even suggestions must be tentative.

In addition, it is possible that amino acids have a preferred chirality (handedness) at equilibrium when in the middle of a protein. In that case the equilibrium mixture may not be a 1:1 D to L ratio, but something greater or (more likely) less than this. Thus a significant excess of L-amino acids may not necessarily prove that the protein is less than some number of years old. The Jurassic amino acids cited in note 133 may not be younger than the 2 million year limit given by Kimber and Griffin (*ibid.*). This is why I have not given great weight to the above analysis.

[137] The equation used is $d^2 = At e^{-E/RT}$, where d is the thickness of the layer A is a frequency factor, E is the activation energy R is the universal gas constant, and T is the "effective hydration" temperature.

[138] Contrary to the claim that "Moisture content and pH of the surrounding environment seem to have no influence." (Geyh and Schleicher, p. 362).

[139] Geyh and Schleicher, p. 366.

ist time scale. There are too many fudge factors. Obsidian hydration is not much help in determining the most likely time scale.

Now we come to our last group of dating methods, those involving radioactive isotopes produced by cosmic rays. They are ^{53}Mn, ^{36}C1, ^{81}Kr, ^{129}I, ^{26}A1/^{10}Be, and of course, ^{14}C. Of these, all but the last are of limited application. Carbon-14 dating deserves its own section, so we will start with ^{53}Mn.

The ^{53}Mn method is dependent on the constant production of Manganese-53 from iron by cosmic ray bombardment, almost exclusively in meteorites. After the meteorites reach the earth, the production of ^{53}Mn essentially ceases. It then decays with a half life of $3.7 \pm 0.6 \times 10^6$ years. Thus if one knows the initial activity and the activity now, one can calculate the time required. However, the initial activity is difficult to determine. If we knew that all meteorites were saturated with respect to the radioactivity induced by cosmic rays when they entered the atmosphere, we could guess at the terrestrial age of a given meteorite. But "cosmic ray ages" are obtained from meteorites also, which implies that at least some meteorites are not saturated with respect to ^{53}Mn. Thus a meteorite that appears to have an old terrestrial age may simply have a young cosmic ray age instead.

Another complication is the fact that what is measured is not absolute ^{53}Mn concentration, but the ^{53}Mn/^{55}Mn ratio. Suppose a meteorite started out with an inhomogeniety in the distribution of iron and manganese. Since the ^{53}Mn is mostly produced from iron, the ^{53}Mn/^{55}Mn ratio would vary with location. The theoretical uncertainties in the method are such that dating either meteorites or meteorite dust in ice cannot be done with confidence. And for dust dates the possible interference from ^{53}Mn-free manganese from volcanoes would have to be taken into account.

From a creationist point of view it would be interesting to try dating Paleozoic and Mesozoic meteorite fragments. This will never be done in a scientific community dominated by evolutionary theory, but could provide evidence for a young earth. But it would not provide incontrovertible evidence for creationism, because of the uncertainties noted above. I also do not know if the appropriate meteorites have been found.

The ^{36}Cl method is dependent on the production of ^{36}Cl from ^{36}Ar by a neutron-proton reaction, and to a lesser extent from ^{40}Ar by spallation, from ^{40}Ca, and from various potassium species. It is also produced underground by neutrons from ^{35}Cl. The half

life of ^{36}C1 is $3.01 \pm 0.04 \times 10^5$ years. Unlike ^{14}C, which is widely distributed, ^{36}C1 is concentrated at latitude 45° N and S. The ^{36}Cl/Cl ratio can vary by 6 orders of magnitude.[140] The uncertainties in initial levels of ^{36}Cl and the probability that such levels would have been disturbed by a Flood make the method unsuitable as evidence for or against a long chronology.

The ^{81}Kr method is dependent on the production of ^{81}Kr from Rb, Sr, and Zr in meteorites by spallation. Apparently, the supply of ^{81}Kr on earth is largely from meteorites. Its half life is 210,000 years. It is used primarily to date meteorites. Like ^{53}Mn, it is used to measure both cosmic ray ages and terrestrial ages, and the two are mutually exclusive (it is interesting that it is apparently not driven off by the heat produced by entering the earth's atmosphere). The method can be safely ignored in our discussion.

The ^{129}I method is dependent on the production of ^{129}I from ^{129}Xe by cosmic rays, and by uranium fission and muon bombardment of tellurium ores underground. Its half life is 15,700,000 years. It is used to find cosmic ray ages of meteorites and to date tellurium ores. The variables behind this clock and the difficulty being sure the clock is reset make the ^{129}I method of little use deciding our question.

The ^{26}Al/^{10}Be method is dependent on the production of the respective isotopes by cosmic rays, the former apparently from argon and to a lesser extent from silicon and stable aluminum, and the latter from nitrogen, oxygen, and carbon. The production rates of the two isotopes are assumed to be proportional to each other so that the difficulties caused by their uneven production around the world can be ignored (neither the ^{10}Be method nor the ^{26}A1 method were considered more than experimental by Geyh and Schleicher).[141] The method is used for dating ice, sediments, coral, manganese nodules, and "oceanic particulate matter", although the assumptions behind the latter dates seem staggering to me. The assumption of equal deposition of ^{10}Be and ^{26}Al during and immediately after a Flood seems strained, so from a creationist standpoint the method would seem to lack validity. This method again seems not to offer much help in answering our question.

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[140] Geyh and Schleicher p. 197.

[141] The possible accretion of ^{26}Al from cosmic dust, of concern to some earlier investigators (for example, Amin BS, Kharkar DP, Lal D: "Cosmogenic ^{10}Be and ^{26}Al in marine sediments." *Deep-Sea Res* 1966;13:805-24) is apparently ignored.

To summarize, potassium/argon dating of basalts is in favor of a short chronology. Other potassium/argon dates are easily explainable from a creationist perspective, except for evaporites where there are problems for both interpretations. On rubidium/strontium (and potassium/calcium) dating the evidence strongly favors the creationist time frame. The data on uranium/thorium/lead dating is moderately in favor of the creationist position; if one trusts the Gentry data it nearly excludes the evolutionary time scale. On the other hand, the evidence on fission track dating is slightly in favor of the evolutionary time scale, although not coercive. The other methods are simply not helpful enough, although some of them, such as amino acid dating, lean toward the creationist position. All this is true without altering the radioactive time constants.

This will come as a surprise to many. Many have not even considered creationism to be a valid scientific option, let alone the most scientifically defensible one. But there is an even bigger shock in store. The next dating method we will examine, carbon-14 dating, almost mathematically eliminates the evolutionary time scale and almost mandates some kind of creationist time scale. We will examine that evidence now.

Carbon-14 Dating

Carbon- 14 dating is based on the production of ^{14}C in the atmosphere by cosmic rays interacting with ^{14}N (nitrogen).[142] The production rate is nearly constant at the present time. The ^{14}C produced is rapidly turned into $^{14}CO_2$, which mixes in with regular CO_2 to form (before modern industrial society) a $^{14}C/C$ ratio[143] of 1.2×10^{-12}. The mixing is very efficient; within 10 years

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[142] Cosmic rays actually produce little or no ^{14}C directly. Rather they release neutrons which react with ^{14}N (nitrogen) to produce ^{14}C and ^{1}H. To a much lesser extent the neutrons react with ^{17}O (oxygen) to produce ^{14}C and ^{4}He, and with ^{13}C directly to produce ^{14}C. The only other natural process that produces ^{14}C (outside of meteorites) that I have seen considered in the literature is the reaction of high energy ^{4}He nuclei (alpha particles) with ^{11}B (boron) to produce ^{14}C and ^{1}H. This process is unusual even underground, and is practically nonexistent in the atmosphere because of the extremely small amount of boron there.

[143] For decay counting the ratio is usually given in decays per minute per gram of carbon, which relates directly to the $^{14}C/C$ ratio. This is why I have chosen to refer to the $^{14}C/C$ ratio in the text, even though this is not the precise ratio measured in all methods of radiocarbon dating. For decay counting, the $^{13}C/^{12}C$ ratio is also measured

of when atomic bomb tests doubled the amount of ^{14}C in the northern hemispheric atmosphere, it was thoroughly mixed throughout both hemispheric atmospheres.[144] The ^{14}C decays back into ^{14}N by beta decay, with a k of 1.21×10^{-4}/year, corresponding to a half life of 5730 ± 40 years.[145] The ^{14}C/C ratio in the biosphere (excluding the deep ocean regions) has remained nearly constant through the last few thousand years, thus providing the basis for measurement of the age of various carbon-containing substances. Since living things are made largely of carbon compounds and water, this method has the advantage of directly dating plant and animal remains.

Like the other methods we have considered, the ^{14}C method depends on assumptions. For ^{14}C dating, the assumptions are:

1. The decay constant of ^{14}C is invariant.

2. The ^{14}C/C ratio in the biosphere has remained constant.

3. The dated object was in equilibrium with the biosphere at time to.

4. The dated object has not gained any carbon since time to.

5. We can measure the present ^{14}C/C ratio in the object.

If these assumptions are correct, then ^{14}C/C $= (^{14}$C/C$)_0\, e^{-kt}$, and with a little calculus we get $t = \ln\,[(^{14}$C/C$)_0\,/\,(^{14}$C/C$)]\,/\,k$. Graphically the dating method can be represented by the following:

Present ^{14}C/C Ratio

^{14}C/C ($\times 10^{-12}$)

Time (years)
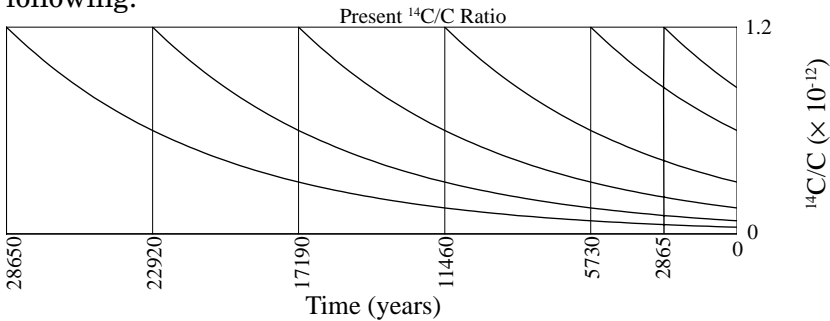
by mass spectrometry to correct for isotopic enrichment effects.

For accelerator dating the amounts of ^{14}C, ^{12}C, and ^{13}C are measured and the ^{14}C/^{12}C and ^{13}C/^{12}C ratios are calculated. These measurements can be used directly to calculate the radiocarbon age. The ^{14}C/C ratio determined by decay counting can be compared with the ratios obtained by accelerator dating straightforwardly: It essentially equals the ^{14}C/(^{12}C $+ \,^{13}$C) ratio, which is only about 1% lower than the ^{14}C/^{12}C ratio and is proportional to it to within the limits of the measurements.

[144] Levin I, Münnich KO, Weiss W: "The effects of anthropogenic CO_2 and ^{14}C sources on the distribution of ^{14}C in the atmosphere." *Radiocarbon* 1980;22:379-91.

To find a radiocarbon age, one measures the ^{14}C/C ratio in a sample, finds it on the right edge of the graph, and follows an exponential curve to the left until it intersects the "present" ^{14}C/C ratio in the biosphere. That point gives the radiocarbon age.

(If assumption 3 is valid, the specimen was in equilibrium with the biosphere, and if assumption 2 is valid, the biosphere had the same ^{14}C/C ratio that we find today when the specimen was last in equilibrium with the biosphere. Combining the two assumptions, the point at which we would expect to equal the present ^{14}C/C ratio is the point at which the specimen was last in equilibrium with the biosphere.)

Again we will assume (in fact, in this case insist on) the invariance of assumption 1. Assumptions 3 and 4 can be violated, but for our purposes we will assume that we have carefully chosen samples which were in equilibrium with the biosphere[146] and

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[145] When reading the literature one has to keep in mind that many references use a half life of 5568 years because of an old inaccurate measurement of the half life. To keep the literature consistent, "radiocarbon years" are usually given in terms of the older (shorter and less accurate) half life. We will follow this procedure here. There is only a 3% difference between the two half lives.

[146] There is a small isotope fractionation effect. One can compensate for this by measuring the ^{13}C/^{12}C ratio. The difference in ^{13}C/^{12}C ratio between ones sample and a standard is almost exactly half the correction needed for the ^{14}C/C ratio. This effect is rarely larger than 3% and is insignificant for our purposes.

Meteorite dating using ^{14}C is not directly comparable to conventional ^{14}C dating. In meteorite dating, the assumption is made that ^{14}C is made by cosmic rays at a constant rate in a given type of meteorite, and that this production essentially ceases when the meteorite lands on the earth. Thereafter the ^{14}C decays exponentially as does the 14C used in conventional radiocarbon dating (see Sears and Hasan in note 113, and Kigoshi K, Matsuda E: "Radiocarbon dating of Yamato Meteorites." In Annexstad *et al.,* see note 113, pp. 58-60).

The ^{14}C found in meteorites is apparently largely produced by the interaction of fast (>10 Mev) neutrons with ^{16}O [^{16}O (n,2pn) ^{14}C], so stony meteorites, which have more oxygen, have higher concentrations of 14C than iron meteorites. The amount of carbon in meteorites is variable, as is its ratio to oxygen, and so the ^{14}C/C ratio is useless in dating meteorites. What is used instead is the amount of 14C per gram of meteorite.

Unfortunately, not all meteorites, even of the same general type, have the same concentration of ^{14}C. Some reports in the literature give the impression that the variation in ^{14}C concentration in recent falls is narrow. For example, Suess and Wänke (Suess HE, Wänke H: "Radiocarbon content and terrestrial age of twelve stony meteorites and one iron meteorite." *Geochim Cosmochim Acta* 1962;26:475-80) give a range of 37 to 56 decays per minute (dpm) per Kg of meteorite for their stony meteorites and 5.5 dpm/Kg for their iron meteorite.

have since not gained (loss does not matter) any carbon from their environment. It is usually fairly easy to satisfy these requirements.

Assumption 5 deserves some discussion. It turns out that initially it was difficult to measure the ^{14}C/C ratio in various samples. If carbon was measured as a solid, the total C was easy to measure; one simply weighed the carbon. But the ^{14}C was hard to measure; the beta decay of ^{14}C in solid carbon could occur in any direction, including into the rest of the sample or into the support, which meant that an uncertain and untestable factor had to be added into the equation. So decay counting is now done by using a carbon-containing gas like carbon dioxide, methane, or acetylene, or sometimes by liquid scintillation counting.

But gas decay counting and liquid scintillation counting have one major drawback; they detect not only ^{14}C decays, but also background radiation. And the background radiation is high, swamping the ^{14}C decays. Some of this background is from radon. The radon can be eliminated by allowing the sample to stand until essentially all the radon has decayed. Some background comes from neutrons, which can largely be absorbed by surrounding the chamber with paraffin and boric acid. But most of the background is produced by cosmic rays. One can shield against these by using steel and/or lead shielding. One can also ignore them by the use of anticoincidence detectors.


However, a different range is given in Goel and Kohman (God PS, Kohman TP: "Cosmogenic carbon-14 in meteorites and terrestrial ages of "finds" and craters." *Science* 1962;136:875-6), namely 47-78 dpmlKg and 1.64-1.80 dpm/Kg respectively Boeckl may describe the situation more accurately (Boeckl R: "Terrestrial age of nineteen stony meteorites derived from their radiocarbon content." *Nature* 1972;236:25-6). His range is 36-108 dpmlKg for stony meteorites. This is quite a wide range and would give an uncertainty of approximately 9000 years in the calculated age of a find (a meteorite whose fall was not witnessed). It appears that meteorites, and even stony meteorites, have a wide range of ^{14}C concentrations when they fall. The range may be even wider than that given by Boeckl.

One is tempted to make the data more precise by measuring the ^{14}C/O ratio. However according to Boeckl (p.25), "Finds usually show substantially higher oxygen values than falls, a fact which can be attributed to weathering." This would tend to decrease the ^{14}C/weight ratio, and to decrease the ^{14}C/O ratio even more. The ^{14}C dating of meteorites needs more study before it is helpful in our discussion. Its precision is not comparable to that of conventional ^{14}C dating.

In an anticoincidence system the sample counter is surrounded by other counters. If a cosmic ray hits the sample counter, chances are very good that it will hit one or more of the other counters at the same time. A computer can be told to ignore discharges that happen simultaneously in the sample counter and one or more of the other counters, and to count only discharges that occur in the sample counter alone.

Using these methods, one can get back to around 30,000 radiocarbon years, or about 1/40 of the present $^{14}C/C$ ratio (2.5 percent modern carbon or pmc). With special shielding deep underground and long counting periods it is possible to extend the range to 50,000 radiocarbon years (0.2 pmc).[147] Decay counting also requires about 5 to 10 grams of carbon, which may call for bone samples of as large as half a kilogram.

Thus there was considerable interest when it was discovered that ^{14}C ions could be separated from all confounding ions by a device called a tandem accelerator mass spectrometer, or AMS for short. The figure illustrates the operation of an AMS.

Tandem Accelerator Mass Spectrometer
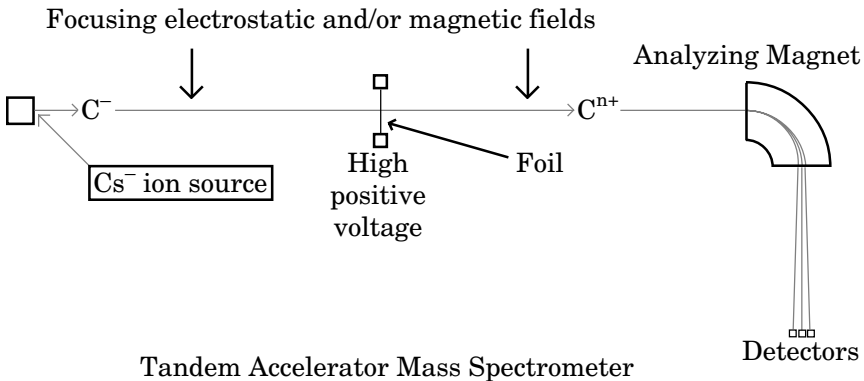
A beam of negative carbon ions is formed by negative cesium ions striking a carbon target. These ions may be partially separated according to mass by use of an analyzing magnet (not shown

[147] Some laboratories (for example, Grootes PM, Mook WG, Vogel JC, de Vries AE, Haring A, Kistemaker J: "Enrichment of radiocarbon for dating samples up to 75,000 years." *Z Naturforsch* 1975;30a:1-14, Grootes PM: "Carbon-14 time scale extended: Comparison of chronologies." *Science* 1978;200:11-5, and Stuiver M, Heusser CJ, Yang IC: "North American glacial history extended to 75,000 years ago." *Science* 1978;200:16-21) are apparently able to obtain dates in the neighborhood of 60,000 radiocarbon years without enrichment, and 75,000 radiocarbon years with isotopic enrichment techniques.

in the figure). They are then attracted to a positive electrode, where they are stripped of part (or all) of their electrons by either a foil or high-pressure gas. As positive ions they are then repelled from the electrode to very high velocities. These high energy ions are formed into a beam and sent through a magnetic field which separates them by their charge-to-mass ratio. A very specialized target is used for ^{14}C, which measures the amount of energy a given particle gives up traveling a definite distance through a semiconductor, and also measures the total energy of the particle. Sometimes the time of flight (and therefore the speed) of the particle is also measured. This gives a unique identification for ^{14}C. Cosmic rays, ^{14}N atoms, or other background factors should not be able to mimic ^{14}C atoms in this detection process. The prediction was repeatedly made that the machine background would be zero.[148] This made it theoretically possible to date very old samples, of the order of 100,000 radiocarbon years (0.0004 pmc). And at the same time it meant that the machine should be able to give dates on milligram-sized samples, as every decay per minute represents some 400 billion carbon atoms. The AMS method is also much faster (minutes versus hours of counting time) than the decay counting method.

The AMS development was particularly interesting from the creationist point of view. It made possible the testing of a creationist prediction that was incompatible with any evolutionist prediction, but which seemed mandatory from any creationist view except that of a gradually decreasing decay constant for radioactivity (which, as we have noted above, is nearly completely parasitic on evolutionary predictions). That prediction is that there should be measurable ^{14}C in all fossil carbon.

To understand the importance of this prediction we should

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[148] To be precise, the prediction was greater than 100,000 radiocarbon years range in Muller RA: "Radioisotope dating with a cyclotron." *Science* 1977;196:489-94; less than 1 count per run (50,000-60,000 radiocarbon years) in Nelson DE, Korteling RG, Scott WR: "Carbon-14: Direct detection at natural concentrations." *Science* 1977;198:507-8; less than 1 count per day in Doucas G, Garman EF, Hyder HRMcK, Sinclair D, Hedges REM, White NR: "Detection of ^{14}C using a small van de Graaff accelerator." *Nature* 1978;276:253-5; and greater than 70,000 years in Bennett CL, Beukens MR, Clover MR, Gove HE, Liebert RB, Litherland AE, Purser KH, Sondheim WE: "Radiocarbon dating using electrostatic accelerators: Negative ions provide the key" *Science* 1977;198:508-10. There were some objections, but these tended to be centered on the difficulty of preventing contamination of the samples.

first note that ^{14}C dating is arguably the most important dating method in establishing the evolutionary time scale. First, using a rather straightforward interpretation of ^{14}C ages, it gives dates that are compatible with the evolutionary time scale in the vast majority of cases. Second, it can be quantitatively tested on recent material and has passed that test repeatedly. So a creationist cannot simply disregard the method entirely (as is sometimes done for the potassium/argon method, for example). He or she has to explain why it works well for recent samples but not for older material.

A good creationist model for radiocarbon dating would seem to have to start by acknowledging that our assumptions 3-5 can be reasonably fulfilled in many kinds of organic material. Altering assumption 1 without a reason would seem to be an *ad hoc* solution and thus should be discouraged, at least at present. So we are left with alterations in assumption 2.

What could disturb the ^{14}C/C ratio in the biosphere? If one interferes with the transport of ^{14}C from where it is produced to the earth's surface, one will only decrease the amount of ^{14}C by the amount that decays on the way down, which in 100 years (a long time by meteorological standards) would be only about 10% with the most favorable assumptions (and probably closer to 1%), not nearly enough to account for the difference between the creationist and evolutionary time scales. One cannot vary the nitrogen content of the atmosphere much. Cosmic ray flux could conceivably be decreased by a stronger magnetic field on the earth, but the maximum reasonable effect would be only to drop the ^{14}C concentration by a factor of four,[149] and its actual effect would probably be less.

But increasing total carbon, the denominator of our ratio, has been demonstrated to give lowered ^{14}C/C ratios and falsely elevated ^{14}C dates. In the late 1800's, with the increasing use of fossil fuels, particularly coal, there was a marked (~5%) decrease in the ^{14}C/C ratio, which is called the Suess effect after its discoverer.[150] So an increase in the total carbon in the biosphere would

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[149] Brown RH: "The interpretation of C-14 dates." *Origins* 1979;6:30-44.

[150] Suess RE: "Radiocarbon concentration in modern wood." *Science* 1955;122:415-7. This is the earliest reference I can find specifically measuring the effect we call the Suess effect (The effect is hinted at in Seuss HE: "Natural radiocarbon measurements by acetyline counting." *Science* 1954:120:5-7 There is a reference in the *Science* articles to a "[H. E. Suess], Proc. Conf. on Nuclear Processes in Geologic Set, Williams Bay, 1953" or "H. E. Suess, paper presented at the NSF Conference, Oct. 1953, Williams Bay, Wis.", which presumably

entail a corresponding decrease in the ^{14}C/C ratio.

And that is precisely what a creationist theory would postulate for the antediluvian (before the Flood) world. All the coal and oil, and some of the limestone, in the fossil record should have been in rough equilibrium with the carbon dioxide in the atmosphere. A standard estimate of this mass would indicate that the ^{14}C/C ratio, from this effect alone, would have been about
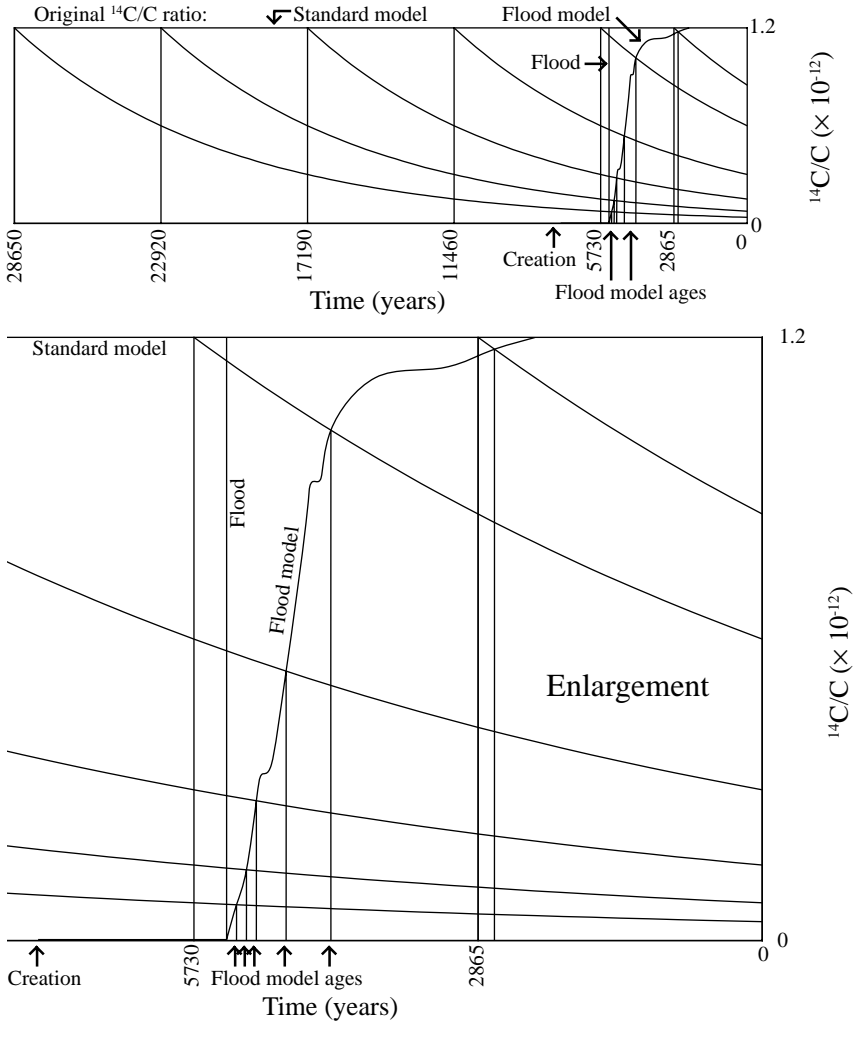
predicts the existence of the effect. I have been unable to locate this paper yet). Because of the Suess effect, wood formed in 1850 was determined to be the reference standard for the ^{14}C/C ratio, rather than wood formed just before the first atomic bomb. This is true even though ^{14}C dates are customarily given in years BP (before present, present being defined as 1950).

1/200th of its present value.[151] So a model has been proposed in which the ^{14}C/C ratio was initially at about 0.1 to 0.5 pmc. According to this model, at the end of the Flood ^{14}C continued to be formed, but was now diluted in a much smaller pool of ordinary carbon, so that the ^{14}C/C ratio of the biosphere rapidly (and perhaps somewhat irregularly) rose, leveling off to near its present concentration within a few hundred years. Thus radiocarbon dates are not discarded, but are reinterpreted as shown in the above figure.

To find the age using this flood model, find the ^{14}C/C ratio at the right of the graph, follow the (exponential) curve to the left until it intersects the flood model ^{14}C/C ratio curve, then read the time from the scale on the bottom.

But this model implied that there should be residual ^{14}C in all antediluvian material. Specifically, if the Flood happened around 1 half life of ^{14}C ago,[152] the antediluvian ^{14}C/C ratio should be approximately 1/400 to 1/1600 the present ratio (0.25-0.0625 pmc).[153]

These measurements are out of range for all but the most careful, time-consuming, and expensive experiments using conventional decay counting. More importantly, with decay counting, it is necessary to measure background counts using a counter identical to the sample except for the absence of ^{14}C. This has usually been done by using fossil carbon, which is "known" to have had all its ^{14}C transformed to nitrogen. But if the question is whether this material still has ^{14}C, no amount of measuring could find ^{14}C by comparing fossil carbon with fossil carbon. Both

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[151] Brown RH, see note 149.

[152] A Septuagint date—the Masoretic Text would be slightly shorter (4,300 to 4,500 years or 0.8 half lives ago) and creationist theories which believe the Genesis 11 record is incomplete might have a Flood date as much as 2 to 3 half lives ago.

[153] The correction factor would be 1/200 for the ratio of antediluvian to postdiluvian biomass, 1 to 1/4 for the effect of the antediluvian magnetic field, and 1/2 for the passage of time. In point of fact, there is some uncertainty in the estimate of fossil carbon, so the factor of 1/200 might be better estimated at 1/100 to 1/400. There is also the theoretical possibility that the earth started out at the time of creation with no ^{14}C whatever, which would give an additional correction factor of down to 1/5 because of non-equilibrium conditions. This is doubtful even on creationist assumptions, since other radioactive minerals which naturally occur in living organisms (for example, ^{40}K) seem to have either been created or have maintained their identity through creation.

measurements would come out the same, almost by definition. But when the AMS method was developed, there were repeated and theoretically persuasive arguments that the background could be essentially eliminated. So if there is ^{14}C in antediluvian material, it should be detectable with the AMS method. Thus we could have a clear-cut method to decide which time scale most accurately reflects the correct time scale for the history of life on the earth.

The earliest reports of measurements on "infinitely old" material were mixed. Several experiments on AMS gave backgrounds of 48,000 to 70,000 radiocarbon years.[154] But as time has continued, it has become general knowledge that there is a wall at about 50,000 radiocarbon years (about 0.2 pmc) that is not breached in practice. This is well within the limits of the creationist prediction, and outside the evolutionary prediction, or even of evolutionary theory.

The first evolutionist reaction to the data was to say that the machines were somehow giving background counts. This was unlikely theoretically, but possible. One should be able to test this possibility by dating carbon that had had practically all its ^{14}C removed, say, by mass spectrometry, and possibly also by

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[154] Some examples follow. Bennett CL, Beukens MR, Clover MR, ElmoreD, Gove HE, Kilius L, Litherland AE: "Radiocarbon dating with electrostatic accelerators: Dating of milligram samples of graphite." *Science* 1978;201:345-7, 48,000 years. Andrews HR, Ball GC, Brown RM, Burn N, Davies WG, Inahori Y, Milton JCD: "Radiocarbon dating experiments with the Chalk River MP tandem accelerator." In Gove HE (ed): *Proc 1st Conf on Radiocarbon Dating with Accelerators.* Rochester, NY: University of Rochester, 1978, pp. 114-26, 58,000 years (on "graphite"., with 2 counts. Dolomite had S counts, which would give it a calculated age of about 50,600 years). Litherland AE: "Radiocarbon dating with accelerators: Results from Rochester-Toronto-General Ionex Corporation." In Gove, *op. cit.,* pp.70-113, 65,000 years (on "graphite"). Bennett CL *et al.,* note 148, 70,000 years (on "petroleum-based graphite").

It is tempting to use the "petroleum-based graphite" of Bennett *et al.* as a measure of carbon from the antediluvian biosphere (from a flood model perspective) or from quite old carbon (from the evolutionary perspective). In this case one could argue that breaking the 50,000 radiocarbon year barrier mentioned below is a function of the form of carbon. However, while I have not been able to find out the geologic history of this particular carbon, I have been told by someone in the field that often graphite that is dated is simply bought from a supplier and the geologic history is not known by the experimenter. It is possible that this graphite was not in equilibrium with the biosphere at any time. Further observations and experiments could clarify this issue.

dating material which had not been in equilibrium with the biosphere near the time of the Flood. Two possible examples that came to mind were carbon from igneous rocks and Precambrian carbon.

I had intended to test this possibility (and in fact had written to one AMS lab asking to arrange for experiments along that line) when I became aware that the most critical experiments had already been done by Schmidt *et al.*[155] They dated "geological graphite" to 69,030 radiocarbon years (0.0185 pmc). Prepared slightly less carefully, it dated at 58,590 to 65,840 radiocarbon years (0.028 to 0.068 pmc). Carbon-12 from the Faraday cup of the accelerator dated at 61,000 radiocarbon years (0.050 pmc).

At the same time, their anthracite coal dated "up to 52,000" radiocarbon years (0.154 pmc), and their marble ran up to 49,690 radiocarbon years (0.206 pmc). Thus, for antediluvian carbon they hit the same wall as other investigators, but they were able to go through this wall with graphite which may have represented carbon not in equilibrium with the antediluvian biosphere. Similar results were obtained with carbon from which ^{14}C had been mostly removed by isotope separation. Thus machine background is not an adequate explanation for more than 0.0185 pmc (radiocarbon age 69,000 years), and probably not for even that much (with the sample holder completely empty, their machine produced "≥ 90,000 years", or no counts in a 30 minute run).

With machine background eliminated as a reasonable explanation, there are only four ways I can think of to explain the background in anthracite coal and marble (and oil). It could be contamination during sample preparation, source contamination with modern carbon, *in situ* formation of ^{14}C, or residual activity.

Contamination during sample preparation seems unlikely to explain all the difference between most fossil carbon and the geologic graphite noted above. It should have affected the geologic graphite and the purified ^{12}C implant as well. And in order to explain the difference the samples would have to be consistently contaminated with a known contaminant (modern post-bomb carbon) at about 1 part in 1000. Anyone who did that would have flunked an analyti-

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[155] Schmidt FR, Balsley DR, Leach DD: "Early expectations of AMS: Greater ages and tiny fractions. One failure? - One success." *Nuci Instr and Meth* 1987;B29:97-9.

cal chemistry class. However, it is still possible that the experiments haven't been done carefully enough,[156] so one could simply take the "geological graphite" and subject it to the same process that the anthracite coal undergoes. If the dates are still different, then sample contamination may be ruled out.

Contamination of the source implies a worldwide exchange of carbon in all the world's known carbon deposits that is relatively even, in spite of the differences in the physical state of coal, oil, and natural gas. It also requires a roughly 50% exchange of the entire biosphere with fossil carbon, within the last 6000 years or so (the longer ago it happened, the greater the required degree of contamination). And again, the exchange rate is 0.2% of ancient carbon, which in a 1,000,000 barrel oil field is approximately 2,000 barrels, again within the past 6000 years. This amount of contamination is hard enough to believe with oil, and frankly incredible with coal.

In situ formation of ^{14}C would involve, in the easiest case, neutrons in massive quantities. There are strong arguments that "Subsurface production of radiocarbon is negligible (Zito *et al.* 1980; Florkowski *et al.* 1988)."[157] And if this were the case, one

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[156] There are two articles I know of that give data that suggest this as a possibility First, in Grootes *et al.,* see note 147, it is noted that oxygen and nitrogen carrier gas apparently have enough carbon dioxide contamination to invalidate very old dates (compare their GrN 6553 with their GrN 6808). Their data are also difficult to interpret if one assumes that anthracite coal has a ratio of approximately 0.2 pmc; the data suggest rather that the ratio is >0.014 pmc. A repeat experiment to confirm these findings would be helpful. For some reason the method is little used nowadays.

Second, Beukins reports (Beukins RP: "Radiocarbon accelerator mass spectrometry: Background, precision and accuracy." In Taylor RE, Long A, Kra RS (eds): *Radiocarbon After Four Decades: An Interdisciplinary Perspective.* New York: Springer-Verlag, 1992) that the contamination in multiple samples from different sources was 0.076 to 0.081 pmc in the IsoTrace AMS. This, if reproducible, would seem to indicate that the major source of background in most AMS apparati is contamination during sample preparation. It would also suggest that the major source of background in the IsoTrace experiments was either residual activity or contamination at the reduction step. This differentiation should be subject to experimental determination.

[157] Geyh and Schleicher, p. 165, citing Zito R, Donahue DJ, Davis SN, Bentley HW, Fritz F: "Possible subsurface production of carbon-14." *Geophys Res Lett* 1980;7(4):235-8, and Florkowski T, Morawska L, Rozanski K: "Natural production of radionuclides in geological formations." *Nucl Geophys* 1988;2:1-14. Zito *et al.* calculated the production of 14C in groundwater from neutrons. Using their best case (granite), the 14C concentration would be 0.00266 pmc for an

might expect the effects to be variable on antediluvian material and to also affect "geological graphite" to a similar extent. *In situ* formation seems highly unlikely.

That leaves us with residual activity. But this mathematically eliminates the evolutionary time scale. For if we started with the entire earth's mass being ^{14}C, within 1 million years all of the ^{14}C would have decayed to ^{14}N except for 1 atom, and that one atom would have a roughly 99% chance of decaying. Each 5,730 years further back doubles the number of earths we would need to have that one atom, and we would need to have filled the universe before we get to 2 million years. The universe is demonstrably not made of ^{14}N. There is no way that 60-600 million-year-old material should have **any** residual ^{14}C, and thus if there is ^{14}C in this material which is not contamination, it is simply not that old. This evidence is in almost complete conflict with the evolutionary time scale. The phanerozoic is almost certainly less than 60,000 years old, and very probably 4 to 8 thousand years old.[158]

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apparent age of 87,100 years (5730 year half life). Florkowski *et al.* seconded their calculations. Redoing the calculations with oil (assuming no nitrogen and a density of 0.9 g/ml which will cancel eventually) and assuming a ^{13}C neutron cross section of 0.0014 barns (using the terminology of Zito *et al.*, $P = 3.89 \times 10^{-7}$ and $N = 14,400$ atoms of ^{14}C per liter of oil), yields 2.7×10^{-8} pmc, which is ridiculously low. It would almost take a neutron bomb to produce enough ^{14}C from neutrons to give the contamination presently found in phanerozoic carbon, and the neutron irradiation would have to be within the last 6000 years or so, or else most of the ^{14}C formed would decay to nitrogen before the measurement took place. Nitrogen is 110,000 times more efficient at producing ^{14}C from neutrons than carbon, so any production of ^{14}C from neutrons would be heavily influenced by the nitrogen content of the fossil material. I know of no such effect reported in ancient carbon. Perhaps it should be sought.

[158] I say "in almost complete conflict with" instead of "incompatible with" because it is still just possible that one of the other explanations for the presence of ^{14}C in Paleozoic and Mesozoic carbon is correct. Further experiments, as suggested above, to rule out or confirm these explanations should be done (and are being planned).

To summarize the experiments, they are: 1. to repeat the experiments of Schmidt et al. (see note 155), 2. to take carbon that dates older than fossil carbon (determined from experiment set 1) and run it through the same preparation procedures that are required for fossil carbon, 3. to determine the dates of fossil carbon from many different sources, and 4. to date fossil carbon of varying nitrogen content. If the fossil carbon from experiment sets 2-4 all has similar ^{14}C contents, which are significantly higher than that of our material found in experiment 1, then the evidence for a short history of life on the earth would be overwhelming. All the strata in the geologic column would be of roughly

This conclusion concerning ^{14}C dating is compatible with the weight of evidence for the other dating methods mentioned above, as well as a straightforward interpretation of the data on ^{10}Be (a "failed" dating method, that is, one which is not easily interpretable using the evolutionary time scale). Ocean floors show no consistent gradients of ^{10}Be concentrations,[159] which is more easily

the same date, and it would be entirely reasonable (since they were almost all, if not all, formed under water) to attribute them to the Flood. If fossil carbon can be prepared with sufficient care (without significant isotope separation) that its ^{14}C content is <0.005 pmc, then this creationist model would be eliminated, leaving only the evolutionary model or a parasitic creationist model which assumes a change in the decay constant at the Flood (which at this point is not convincing). It is also possible that neither of these eventualities will happen, in which case one will simply have to take the best available data and make one's best guess. Given the relative ease with which the experiments should be able to be done, we should not have to settle for this, but it does appear that the evolutionary explanation for the data we have at present is by far the more strained.

The most likely date for the Flood, based on the present ^{14}C data, is one which would account for a present age of fifty thousand radiocarbon years in a biosphere with 200+ times the modern amount of carbon, which would require a Flood roughly 1 radiocarbon half life ago. I have given reasons why I do not trust the standard interpretation of the uranium series disequilibrium dating of corals, the only other consistent physical dating method to match (roughly) ^{14}C dates. Historical dates extend only 5,000 years back at best, and so are not a major problem for a short chronology. The only other major objection to a short chronology is tree ring dating. I have serious reservations about the accuracy of this method as usually applied. I plan to deal with tree ring dating more fully when I take up the subject of the Exodus, and I hope that currently unpublished material regarding the bristlecone pine chronology will be available at that time.

However, even if tree ring dating does turn out to be accurate as usually applied, it still would not solve the ^{14}C problem for an evolutionist. It would simply mean that Genesis 11 did not contain a complete chronology. The earth would still have to be much too young for any kind of evolutionary explanation to be adequate, and Genesis 1-9 would still contain the best available explanation for the fossil record.

[159] See the discussion in Faure, pp. 410-2. See esp. Inoue T, Tanaka 5: "^{10}Be in marine sediments." *Earth Plan Sci Lett* 1976;29:155-60. On p. 155 Inoue and Tanaka stated, "The scarcity of cores having a uniform ^{10}Be concentration at different depths suggests that the sedimentation at the ocean floor has not been uniform but disturbed by some geophysical events in the past." It is of interest that wherever the data roughly matches an exponential curve, it is assumed that production and deposition of ^{10}Be and sedimentation rates have all been constant (Amin BS *et al.,* see note 141, although they also noted on p. 823 a "high frequency of cores with erratic ^{10}Be concentrations at different depths, even within depths of only one meter, suggest[ing] that the ocean floor is physically disturbed in many regions."), whereas later evidence indicates that

explained by a Flood than by very slow deposition of ocean sediments.

In addition, lava apparently formed from subducted ocean floors (which contain ^{10}Be from cosmic ray production) contains up to 7×10^6 atoms/g of ^{10}Be, whereas isolated volcanoes like Kilauea in Hawaii have 0.1×10^6 atoms/g of ^{10}Be. However, a basalt from the Columbia river plateau with an evolutionary age of 14 million years contained 1.0×10^6 atoms/g of ^{10}Be.[160] The half-life of ^{10}Be is 1.5 million years. If we assume that this lava started out with the highest known modern concentration of ^{10}Be, then only 0.01×10^6 atoms/g of ^{10}Be should have been left from the initial lava flow. Where the extra ^{10}Be came from is hard to say assuming the evolutionary time scale, but quite easy if the lava flow in question happened only a few thousand years ago. The existence of this ^{10}Be was predicted by Gentry in 1979 on the basis of a creationist model.[161]

If we are committed to following the weight of evidence we are led to discount theistic evolution and multiple creations as explanations of life on earth. We may also discount the (creationist) theory that decay constants have varied significantly with time, at least back to the Flood. And if it needed any further demonstration, mechanistic evolution is thoroughly discredited. Creationism may not have solved all its problems, but it has solved the major ones, and it is not unreasonable to believe that the rest will be solved with further study, whereas theories requiring millions of years for life (including theistic evolution and multiple creations) appear incapable in principle of solving the ^{14}C problem, and there is solid evidence that they are wrong in their interpretation of other dating methods.

This also means that we should give credence to the early Genesis record, and that we should seriously consider the claims

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given the evolutionary time scale, production rates at least had varied (for example, Somayajulu, see note 109).

[160] Faure, p. 415, citing Brown L, Klein J, Middleton R, Sacks IS, Tera F: "^{10}Be in island-arc volcanoes and implications for subduction." *Nature* 1982;299:718-20. On p. 718 they state that the phenomenon "certainly gives one pause." They try to explain this by the activity of cosmic rays. It would be interesting to test this theory by dating basalts from different depths. About 10 meters should be sufficient for testing purposes.

[161] Gentry RV: "Forum: Time: Measured responses." *EOS; Trans Am Geophys Union* 1979;60(22):474. He also predicted a ^{14}C/C ratio of approximately 0.01 pmc in Paleozoic and Mesozoic fossil material.

of Mosaic authorship, and also the accuracy of the rest of the Pentateuch and Joshua. I will not argue these points at this time. I hope to be able to do so later. For now I will assume that the entire Bible is reliable in the sense noted in chapter 3. I have now outlined, as a scientist might say, my materials and methods. Next, we will deal with some preliminary results.