The Age of the Earth

[Last Update: April 22, 1997]

Overview

Other Links:

Young-Earth Arguments: A Second Look

Former creationist Glenn Morton examines several famous young-earth creationist arguments and provides data to illustrate their flaws.

How Old Is The Earth, And How Do We Know?

The generally accepted age for the Earth and the rest of the solar sytem is about 4.55 billion years (plus or minus about 1%). This value is derived from several different lines of evidence.

Unfortunately, the age cannot be computed directly from material that is solely from the Earth. There is evidence that energy from the Earth's accumulation caused the surface to be molten. Further, the processes of erosion and crustal recycling have apparently destroyed all of the earliest surface.

The oldest rocks which have been found so far (on the Earth) date to about 3.8 to 3.9 billion years ago (by several radiometric dating methods). Some of these rocks are sedimentary, and include minerals which are themselves as old as 4.1 to 4.2 billion years. Rocks of this age are relatively rare, however rocks that are at least 3.5 billion years in age have been found on North America, Greenland, Australia, Africa, and Asia.

While these values do not compute an age for the Earth, they do establish a lower limit (the Earth must be at least as old as any formation on it). This lower limit is at least concordant with the independently derived figure of 4.55 billion years for the Earth's actual age.

The most direct means for calculating the Earth's age is a Pb/Pb isochron age, derived from samples of the Earth and meteorites. This involves measurement of three isotopes of lead (Pb-206, Pb-207, and either Pb-208 or Pb-204). A plot is constructed of Pb-206/Pb-204 versus Pb-207/Pb-204.

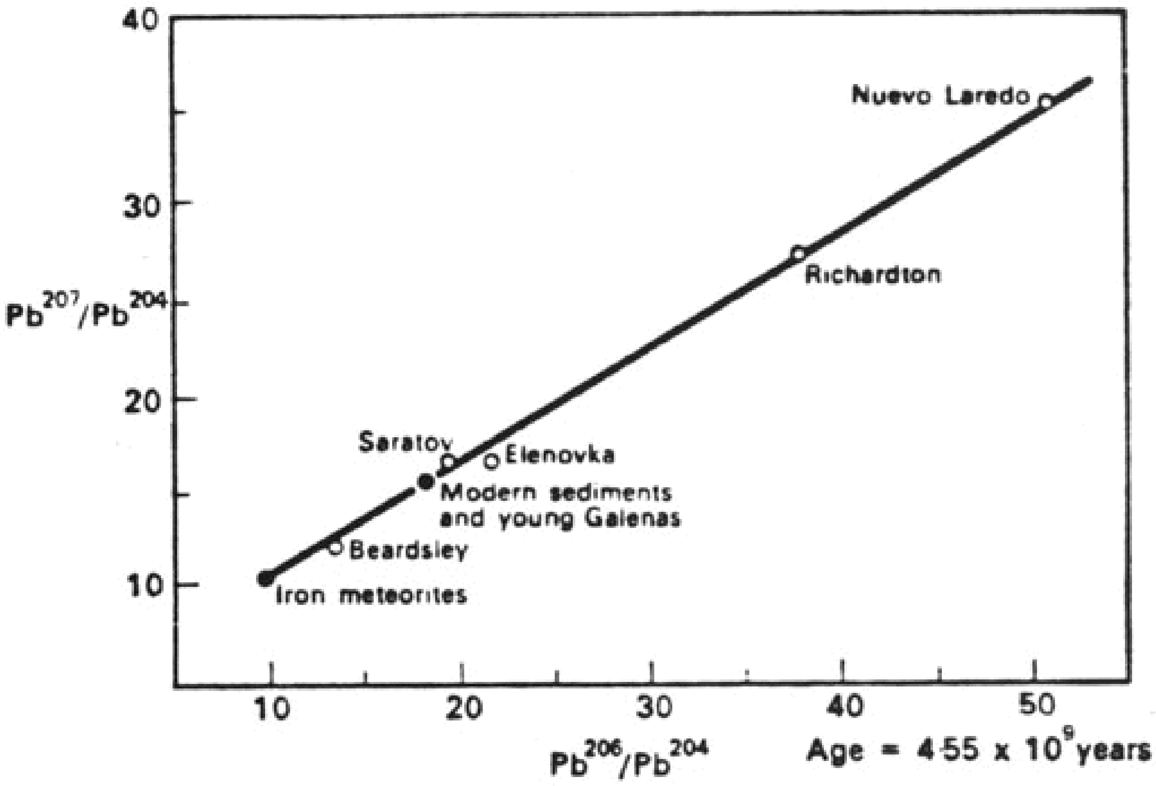
If the solar system formed from a common pool of matter, which was uniformly distributed in terms of Pb isotope ratios, then the initial plots for all objects from that pool of matter would fall on a single point.

Over time, the amounts of Pb-206 and Pb-207 will change in some samples, as these isotopes are decay end-products of uranium decay (U-238 decays to Pb-206, and U-235 decays to Pb-207). This causes the data points to separate from each other. The higher the uranium-to-lead ratio of a rock, the more the Pb-206/Pb-204 and Pb-207/Pb-204 values will change with time.

If the source of the solar system was also uniformly distributed with respect to uranium isotope ratios, then the data points will always fall on a single line. And from the slope of the line we can compute the amount of time which has passed since the pool of matter became separated into individual objects. See the Isochron Dating FAQ or Faure (1986, chapter 18) for technical detail.

A young-Earther would object to all of the "assumptions" listed above. However, the test for these assumptions is the plot of the data itself. The actual underlying assumption is that, if those requirements have not been met, there is no reason for the data points to fall on a line.

The resulting plot has data points for each of five meteorites that contain varying levels of uranium, a single data point for all meteorites that do not, and one (solid circle) data point for modern terrestrial sediments. It looks like this:



Pb-Pb isochron of terrestrial and meteorite samples.
After Murthy and Patterson (1962) and York and Farquhar (1972).
Scanned from Dalrymple (1986) with permission.

Most of the other measurements for the age of the Earth rest upon calculating an age for the solar system by dating objects which are expected to have formed with the planets but are not geologically active (and therefore cannot erase evidence of their formation), such as meteorites. Below is a table of radiometric ages derived from groups of meteorites:

Type	Number Dated	Method	Age (billions of years)
Chondrites (CM, CV, H, L, LL, E)	13	Sm-Nd	4.21 +/- 0.76
Carbonaceous chondrites	4	Rb-Sr	4.37 +/- 0.34
Chondrites (undisturbed H, LL, E)	38	Rb-Sr	4.50 +/- 0.02
Chondrites (H, L, LL, E)	50	Rb-Sr	4.43 +/- 0.04
H Chondrites (undisturbed)	17	Rb-Sr	4.52 +/- 0.04
H Chondrites	15	Rb-Sr	4.59 +/- 0.06
L Chondrites (relatively undisturbed)	6	Rb-Sr	4.44 +/- 0.12
L Chondrites	5	Rb-Sr	4.38 +/- 0.12
LL Chondrites (undisturbed)	13	Rb-Sr	4.49 +/- 0.02
LL Chondrites	10	Rb-Sr	4.46 +/- 0.06
E Chondrites (undisturbed)	8	Rb-Sr	4.51 +/- 0.04
E Chondrites	8	Rb-Sr	4.44 +/- 0.13
Eucrites (polymict)	23	Rb-Sr	4.53 +/- 0.19
Eucrites	11	Rb-Sr	4.44 +/- 0.30
Eucrites	13	Lu-Hf	4.57 +/- 0.19
Diogenites	5	Rb-Sr	4.45 +/- 0.18
Iron (plus iron from St. Severin)	8	Re-Os	4.57 +/- 0.21

After Dalrymple (1991, p. 291); duplicate studies on identical meteorite types omitted.

As shown in the table, there is excellent agreement on about 4.5 billion years, between several meteorites and by several different dating methods. Note that young-Earthers cannot accuse us of selective use of data -- the above table includes a significant fraction of all meteorites on which isotope dating has been attempted. According to Dalrymple (1991, p. 286), less than 100 meteorites have been subjected to isotope dating, and of those about 70 yield ages with low analytical error.

Further, the oldest age determinations of individual meteorites generally give concordant ages by multiple radiometric means, or multiple tests across different samples. For example:

Meteorite	Dated	Method	Age (billions of years)
Allende	whole rock	Ar-Ar	4.52 +/- 0.02
	whole rock	Ar-Ar	4.53 +/- 0.02
	whole rock	Ar-Ar	4.48 +/- 0.02
	whole rock	Ar-Ar	4.55 +/- 0.03
	whole rock	Ar-Ar	4.55 +/- 0.03
	whole rock	Ar-Ar	4.57 +/- 0.03
	whole rock	Ar-Ar	4.50 +/- 0.02
	whole rock	Ar-Ar	4.56 +/- 0.05
Guarena	whole rock	Ar-Ar	4.44 +/- 0.06
	13 samples	Rb-Sr	4.46 +/- 0.08
Shaw	whole rock	Ar-Ar	4.43 +/- 0.06
	whole rock	Ar-Ar	4.40 +/- 0.06
	whole rock	Ar-Ar	4.29 +/- 0.06
Olivenza	18 samples	Rb-Sr	4.53 +/- 0.16
	whole rock	Ar-Ar	4.49 +/- 0.06
Saint Severin	4 samples	Sm-Nd	4.55 +/- 0.33
	10 samples	Rb-Sr	4.51 +/- 0.15
	whole rock	Ar-Ar	4.43 +/- 0.04
	whole rock	Ar-Ar	4.38 +/- 0.04
	whole rock	Ar-Ar	4.42 +/- 0.04
Indarch	9 samples	Rb-Sr	4.46 +/- 0.08
	12 samples	Rb-Sr	4.39 +/- 0.04
Juvinas	5 samples	Sm-Nd	4.56 +/- 0.08
	5 samples	Rb-Sr	4.50 +/- 0.07
Moama	3 samples	Sm-Nd	4.46 +/- 0.03
	4 samples	Sm-Nd	4.52 +/- 0.05
Y-75011	9 samples	Rb-Sr	4.50 +/- 0.05
	7 samples	Sm-Nd	4.52 +/- 0.16
	5 samples	Rb-Sr	4.46 +/- 0.06
	4 samples	Sm-Nd	4.52 +/- 0.33
Angra dos Reis	7 samples	Sm-Nd	4.55 +/- 0.04
	3 samples	Sm-Nd	4.56 +/- 0.04
Mundrabrilla	silicates	Ar-Ar	4.50 +/- 0.06
	silicates	Ar-Ar	4.57 +/- 0.06
	olivine	Ar-Ar	4.54 +/- 0.04

	plagioclase	Ar-Ar	4.50 +/- 0.04
Weekeroo Station	4 samples	Rb-Sr	4.39 +/- 0.07
	silicates	Ar-Ar	4.54 +/- 0.03

After Dalrymple (1991, p. 286); meteorites dated by only a single means omitted.

Also note that the meteorite ages (both when dated mainly by Rb-Sr dating in groups, and by multiple means individually) are in exact agreement with the solar system "model lead age" produced earlier.

Common Young-Earth "Dating Methods"

Young-Earthers have several methods which they claim to give "upper limits" to the age of the Earth, much lower than the age calculated above (usually in the thousands of years). Those which appear the most frequently in talk.origins are reproduced below:

1. Accumulation of helium in the atmosphere
2. Decay of the Earth's magnetic field
3. Accumulation of meteoritic dust on the Moon
4. Accumulation of metals into the oceans

Note that these aren't necessarily the "best" or most difficult to refute of young-Earth arguments. However, they are quite popular in modern creation-"science" literature (even though they should not be!) and they are the ones are posted to talk.origins more than any others.

1. Accumulation of Helium in the atmosphere

The young-Earth argument goes something like this: helium-4 is created by radioactive decay (alpha particles are helium nuclei) and is constantly added to the atmosphere. Helium is not light enough to escape the Earth's gravity (unlike hydrogen), and it will therefore accumulate over time. The current level of helium in the atmosphere would accumulate in less than two hundred thousand years, therefore the Earth is young. (I believe this argument was originally put forth by Mormon young-Earther Melvin Cook, in a letter to the editor which was published in *Nature*.)

But helium can and does escape from the atmosphere, at rates calculated to be nearly identical to rates of production. In order to "get" a young age from their calculations, young-Earthers "handwave away" mechanisms by which helium can escape. For example, Henry Morris says:

> "There is no evidence at all that Helium 4 either does, or can, escape from the exosphere in significant amounts." (Morris 1974, p. 151)

But Morris is wrong. Surely one cannot "invent" a good dating mechanism by simply ignoring processes which work in the opposite direction of the process which the date is based upon. Dalrymple says:

> "Banks and Holzer (12) have shown that the polar wind can account for an escape of (2 to 4) x 10^6 ions/cm^2/sec of ^{4}He, which is nearly identical to the estimated production flux of (2.5 +/- 1.5) x 10^6 atoms/cm^2/sec. Calculations for ^{3}He lead to similar results, i.e., a rate virtually identical to the estimated production flux. Another possible escape mechanism is direct interaction of the solar wind with the upper atmosphere during the short periods of lower magnetic-field intensity while the field is reversing. Sheldon and Kern (112) estimated that 20 geomagnetic-field reversals over the past 3.5 million years would have assured a balance between helium production and loss." (Dalrymple 1984, p. 112)

Dalrymple's references:

- (12) Banks, P. M. & T. E. Holzer. 1969. "High-latitude plasma transport: the polar wind" in *Journal of Geophysical Research* **74**, pp. 6317-6332.
- (112) Sheldon, W. R. & J. W. Kern. 1972. "Atmospheric helium and geomagnetic field reversals" in *Journal of Geophysical Research* **77**, pp. 6194-6201.

This argument also appears in the following creationist literature:

Baker (1976, pp. 25-26)
Brown (1989, pp. 16 and 52)

Jansma (1985, p. 61)
Whitcomb and Morris (1961, pp. 384-385)
Wysong (1976, pp. 161-163)

2. Decay of the Earth's magnetic field

The young-Earth argument: the dipole component of the magnetic field has decreased slightly over the time that it has been measured. Assuming the generally accepted "dynamo theory" for the existence of the Earth's magnetic field is wrong, the mechanism might instead be an initially created field which has been losing strength ever since the creation event. An exponential fit (assuming a half-life of 1400 years on 130 years' worth of measurements) yields an impossibly high magnetic field even 8000 years ago, therefore the Earth must be young. The main proponent of this argument was Thomas Barnes.

There are several things wrong with this "dating" mechanism. It's hard to just *list* them all. The primary four are:

1. While there is no complete model to the geodynamo (certain key properties of the core are unknown), there are reasonable starts and there are no good reasons for rejecting such an entity out of hand. If it is possible for energy to be added to the field, then the extrapolation is useless.
2. There is overwhelming evidence that the magnetic field has reversed itself, rendering any unidirectional extrapolation on field strength useless. Even some young-Earthers admit to that these days -- e.g., Humphreys (1988).
3. Much of the energy in the field is probably locked in toroidal fields that are not even visible external to the core. This means that the extrapolation rests on the assumption that fluctuations in the observable portion of the field accurately represent fluctuations in its total energy.
4. Barnes' extrapolation completely ignores the nondipole component of the field. Even if we grant that it is permissible to ignore portions of the field that are internal to the core, Barnes' extrapolation also ignores portions of the field which are visible and instead rests on extrapolation of a theoretical entity.

That last part is more important than it may sound. The Earth's magnetic field is often split in two components when measured. The "dipole" component is the part which approximates a theoretically perfect field around a single magnet, and the "nondipole" components are the ("messy") remainder. A study in the 1960s showed that the decrease in the dipole component since the turn of the century had been nearly completely compensated by an increase in the strength of the nondipole components of the field. (In other words, the measurements show that the field has been diverging from the shape that would be expected of a theoretical ideal magnet, more than the amount of energy has actually been changing.) Barnes' extrapolation therefore does not really rest on the change in energy of the field.

For information, see Dalrymple (1984, pp. 106-108) or Strahler (1987, pp. 150-155).

This argument also appears in the following creationist literature:

Baker (1976, p. 25)
Brown (1989, pp. 17 and 53)
Jackson (1989, pp. 37-38)
Jansma (1985, pp. 61-62)
Morris (1974, pp. 157-158)
Wysong (1976, pp. 160-161)

3. Accumulation of meteoritic dust on the Moon

The most common form of this young-Earth argument is based on a single measurement of the rate of meteoritic dust influx to the Earth gave a value in the millions of tons per year. While this is negligible compared to the processes of erosion on the Earth (about a shoebox-full of dust per acre per year), there are no such processes on the Moon. Young-Earthers claim that the Moon must receive a similar amount of dust (perhaps 25% as much per unit surface area due to its lesser gravity), and there should be a very large dust layer (about a hundred feet thick) if the Moon is several billion years old.

Morris says, regarding the dust influx rate:

> "The *best measurements* have been made by Hans Pettersson, who obtained the figure of 14 million tons per year[1]."
> Morris (1974, p. 152) [italic emphasis added -CS]

Pettersson stood on a mountain top and collected dust there with a device intended for measuring smog levels. He measured the amount of nickel collected, and published calculations based on the assumption that all nickel that he collected was meteoritic in origin. That assumption was wrong and caused his published figures to be a vast overestimate.

Pettersson's calculation resulted in the a figure of about 15 million tons per year. In the very same paper, he indicated that he believed that value to be a "generous" over-estimate, and said that 5 million tons per year was a more likely figure.

Several measurements of higher precision were available from many sources by the time Morris wrote *Scientific Creationism*. These measurements give the value (for influx rate to the Earth) of about 20,000 to 40,000 tons per year. Multiple measurements (chemical signature of ocean sediments, satellite penetration detectors, microcratering rate of objects left exposed on the lunar surface) all agree on approximately the same value -- nearly three orders of magnitude lower than the value which Morris chose to use.

Morris chose to pick obsolete data with known problems, and call it the "best" measurement available. With the proper values, the expected depth of meteoritic dust on the Moon is less than one foot.

For further information, see Dalrymple (1984, pp. 108-111) or Strahler (1987, pp. 143-144).

Addendum: "loose dust" vs. "meteoritic material"

Some folks in talk.origins occasionally sow further confusion by discussing the thickness of the "lunar soil" as if it represented the entire quantity of meteoritic material on the lunar surface. The lunar soil is a very thin layer (usually an inch or less) of *loose* powder present on the surface of the Moon.

However, the lunar soil is not the only meteoritic material on the lunar surface. The "soil" is merely the portion of powdery material which is kept loose by micrometeorite impacts. Below it is the regolith, which is a mixture of rock fragments and *packed* powdery material. The regolith averages about five meters deep on the lunar maria and ten meters on the lunar highlands.

In addition, lunar rocks are broken down by various processes (such as micrometeorite impacts and radiation). Quite a bit of the powdered material (even the loose portion) is not meteoritic in origin.

Addendum: Creationists disown the "Moon dust" argument

There is a recent creationist technical paper on this topic which admits that the depth of dust on the Moon is concordant with the mainstream age and history of the solar system (Snelling and Rush 1993). Their abstract concludes with:

> "It thus appears that the amount of meteoritic dust and meteorite debris in the lunar regolith and surface dust layer, even taking into account the postulated early intense bombardment, does not contradict the evolutionists' multi-billion year timescale (while not proving it). Unfortunately, attempted counter-responses by creationists have so far failed because of spurious arguments or faulty calculations. Thus, until new evidence is forthcoming, creationists should not continue to use the dust on the moon as evidence against an old age for the moon and the solar system."

Snelling and Rush's paper also refutes the oft-posted creationist "myth" about the expectation of a thick dust layer during to the Apollo mission. The Apollo mission had been preceded by several unmanned landings -- the Soviet Luna (six landers), American Ranger (five landers) and Surveyor (seven landers). The physical properties of the lunar surface were well-known years before man set foot on it. Even prior to the unmanned landings, Snelling and Rush document that there was no clear consensus in the astronomical community on the depth of dust to expect.

Even though the creationists themselves have refuted this argument, (and refutations from the mainstream community have been around for ten to twenty years longer than that), the "Moon dust" argument continues to be propagated in their "popular" literature, and continues to appear in talk.origins on a regular basis:

> Baker (1976, p. 25)
> Brown (1989, pp. 17 and 53)
> Jackson (1989, pp. 40-41)
> Jansma (1985, pp. 62-63)
> Whitcomb and Morris (1961, pp. 379-380)
> Wysong (1976, pp. 166-168)
>
> See the talkorigins.org archived feedback for February and April 1997, for additional examples.

4. Accumulation of metals into the oceans

In 1965, *Chemical Oceanography* published a list of some metals' "residency times" in the ocean. This calculation was performed by dividing the amount of various metals in the oceans by the rate at which rivers bring the metals into the oceans.

Several creationists have reproduced this table of numbers, claiming that these numbers gave "upper limits" for the age of the oceans (therefore the Earth) because the numbers represented the amount of time that it would take for the oceans to "fill up" to their present level of these various metals from zero.

First, let us examine the results of this "dating method." Most creationist works do not produce all of the numbers, only the ones whose values are "convenient." The following list is more complete:

Al - 100 years	Ni - 9,000 years	Sb - 350,000 years
Fe - 140 years	Co - 18,000 years	Mo - 500,000 years
Ti - 160 years	Hg - 42,000 years	Au - 560,000 years
Cr - 350 years	Bi - 45,000 years	Ag - 2,100,000 years
Th - 350 years	Cu - 50,000 years	K - 11,000,000 years
Mn - 1,400 years	Ba - 84,000 years	Sr - 19,000,000 years
W - 1,000 years	Sn - 100,000 years	Li - 20,000,000 years
Pb - 2,000 years	Zn - 180,000 years	Mg - 45,000,000 years
Si - 8,000 years	Rb - 270,000 years	Na - 260,000,000 years

Now, let us critically examine this method as a method of finding an age for the Earth.

- The method ignores known mechanisms which remove metals from the oceans:
    - Many of the listed metals are in fact *known* to be at or near equilibrium; that is, the rates for their entering and leaving the ocean are the same to within uncertainty of measurement. (Some of the chemistry of the ocean floor is not well-understood, which unfortunately leaves a fairly large uncertainty.) One cannot derive a date from a process where equilibrium is within the range of uncertainty -- it could go on forever without changing concentration of the ocean.
    - Even the metals which are not known to be at equilibrium are known to be relatively close to it. I have seen a similar calculation on uranium, failing to note that the uncertainty in the efflux estimate is larger than its distance from equilibrium. To calculate a *true* upper limit, we must calculate the *maximum* upper limit, using all values at the appropriate extreme of their measurement uncertainty. We must perform the calculations on the highest possible efflux rate, and the lowest possible influx rate. If equilibrium is within reach of those values, no upper limit on age can be derived.
    - In addition, *even if* we knew exactly the rates at which metals were removed from the oceans, and *even if* these rates did not match the influx rates, these numbers are still wrong. It would probably require solving a differential equation, and any reasonable approximation *must* "figure in" the efflux rate. Any creationist who presents these values as an "upper limit" has missed this factor entirely. These published values are only "upper limits" when the efflux rate is zero (which is known to be false for all the metals). Any efflux decreases the rate at which the metals build up, invalidating the alleged "limit."
- The method simply does not work. Ignoring the three problems above, the results are scattered randomly (five are under 1,000 years; five are 1,000-9,999 years; five are 10,000-99,999 years; six are 100,000-999,999 years; and six are 1,000,000 years or above). Also, the only two results that agree are 350 years, and Aluminum gives 100 years. If this is a valid method, then the age of the Earth must be less than the lowest "upper limit" in the table. Nobody in the debate would agree on a 100-year-old Earth.
- These "dating methods" do not actually date anything, which prevents independent confirmation. (Is a 19M year "limit" [Sr] a "confirmation" of a 42k year "limit" [Hg]?) Independent confirmation is very important for dating methods -- scientists generally do not place much confidence in a date that is only computed from a single measurement.
- These methods depend on uniformity of a process which is almost certainly not uniform. There is no reason to believe that influx rates have been constant throughout time. There is reason to expect that, due to a relatively large amount of exposed land, today's erosion (and therefore influx) rates are higher than typical past rates.
- There is no "check" built into these methods. There is no way to tell if the calculated result is good or not. The best methods used by geologists to perform dating have a built-in check which identifies undatable samples. The only way a creatonist can "tell" which of these methods produce bad values is to throw out the results that he doesn't like.

One might wonder why creationist authors have found it worthy of publishing. Yet, it is quite common. This argument also appears in the following creationist literature:

Baker (1976, p. 25)
Brown (1989, p. 16)
Morris (1974, pp. 153-156)
Morris & Parker (1987, pp. 284-284 and 290-291)
Wysong (1976, pp. 162, 163)

Conclusion

Obviously, these are a pretty popular set of "dating" mechanisms; they appear frequently in creationist literature from the 1960s through the late 1980s (and can be found on many creationist web sites even today). They appear in talk.origins more often than any other young-Earth arguments. They are all built upon a distortion of the data.

A curious and unbiased observer could quite reasonably refuse to even listen to the creationists until they "clean house" and stop pushing these arguments. If I found "Piltdown Man" in a modern biology text as evidence for human evolution, I'd throw the book away. (If I applied the same standards to the fairly large collection of creationist materials that I own, none would remain.)

Common Creationist Criticisms of Mainstream Dating Methods

Most creationist criticisms of radiometric dating can be categorized into a few groups. These include:

1. Reference to a case where the given method did not work.
2. Claims that the assumptions of a method may be violated:
    1. Constancy of radioactive decay rates.
    2. Contamination is likely to occur.

1. Reference to a case where the given method did not work

This is perhaps the most common objection of all. Creationists point to instances where a given method produced a result that is clearly wrong, and then argue that therefore all such dates may be ignored. Such an argument fails on two counts:

- First, an instance where a method fails to work does not imply that it does not ever work. The question is not whether there are "undatable" objects, but rather whether or not *all* objects cannot be dated by a given method. The fact that one wristwatch has failed to keep time properly cannot be used as a justification for discarding all watches.

  How many creationists would see the same time on five different clocks and then feel free to ignore it? Yet, when five radiometric dating methods agree on the age of one of the Earth's oldest rock formations (Dalrymple 1986, p. 44), it is dismissed without a thought.
- Second, these arguments fail to address the fact that radiometric dating produces results in line with "evolutionary" expectations about 95% of the time (Dalrymple 1992, personal correspondence). The claim that the methods produce bad results essentially at random does not explain why these "bad results" are so consistently in line with mainstream science.

2. Claims that the assumptions of a method may be violated

Certain requirements are involved with all radiometric dating methods. These generally include constancy of decay rate and lack of contamination (gain or loss of parent or daughter isotope). Creationists often attack these requirements as "unjustified assumptions," though they are really neither "unjustified" nor "assumptions" in most cases.

2.1 Constancy of radioactive decay rates.

Rates of radiometric decay (the ones relevant to radiometric dating) are thought to be based on rather fundamental properties of matter, such as the probability per unit time that a certain particle can "tunnel" out of the nucleus of the atom. The nucleus is well-insulated and therefore is relatively immune to larger-scale effects such as pressure or temperature.

Significant changes to rates of radiometric decay of isotopes relevant to geological dating have never been observed under any conditions. Emery (1972) is a comprehensive survey of experimental results and theoretical limits on variation of decay rates. Note that the largest changes reported by Emery are both irrelevant (they do not involve isotopes or modes of decay used for this FAQ), and miniscule (decay rate changed by of order 1%) compared to the change needed to compress the apparent age of the Earth into the young-Earthers' timescale.

A short digression on mechanisms for radioactive decay, taken from <CK47LK.E2J@ucdavis.edu> by Steve Carlip (subsequently edited in response to Steve's request):

> For the case of alpha decay, [...] the simple underlying mechanism is quantum mechanical tunneling through a potential barrier. You will find a simple explanation in any elementary quantum mechanics textbook; for example, Ohanion's *Principles of Quantum Mechanics* has a nice example of alpha decay on page 89. The fact that the process is probabilistic, and the exponential dependence on time, are straightforward consequences of quantum mechanics. (The time dependence is a case of "Fermi's golden rule" --- see, for example, page 292 of Ohanion.)
>
> An exact computation of decay rates is, of course, much more complicated, since it requires a detailed understanding of the shape of the potential barrier. In principle, this is computable from quantum chromodynamics, but in practice the computation is much too complex to be done in the near future. There are, however, reliable approximations available, and in addition the shape of the potential can be measured experimentally.
>
> For beta decay, the underlying fundamental theory is different; one begins with electroweak theory (for which Glashow, Weinberg and Salam won their Nobel prize) rather than quantum chromodynamics.

As described above, the process of radioactive decay is predicated on rather fundamental properties of matter. In order to explain old isotopic ages on a young Earth by means of accelerated decay, an increase of six to ten orders of magnitude in rates of decay would be needed (depending on whether the acceleration was spread out over the entire pre-Flood period, or accomplished entirely during the Flood).

Such a huge change in fundamental properties would have plenty of noticeable effects on processes other than radioactive decay (taken from <16381@ucdavis.ucdavis.edu> by Steve Carlip):

> So there has been a lot of creative work on how to look for evidence of such changes.
>
> A nice (technical) summary is given by Sisterna and Vucetich (1991). Among the phenomena they look at are:
>
> - searches for changes in the radius of Mercury, the Moon, and Mars (these would change because of changes in the strength of interactions within the materials that they are formed from);
> - searches for long term ("secular") changes in the orbits of the Moon and the Earth --- measured by looking at such diverse phenomena as ancient solar eclipses and coral growth patterns;
> - ranging data for the distance from Earth to Mars, using the Viking spacecraft;
> - data on the orbital motion of a binary pulsar PSR 1913+16;
> - observations of long-lived isotopes that decay by beta decay (Re 187, K 40, Rb 87) and comparisons to isotopes that decay by different mechanisms;
> - the Oklo natural nuclear reactor (mentioned in another posting);
> - experimental searches for differences in gravitational attraction between different elements (Eotvos-type experiments);
> - absorption lines of quasars (fine structure and hyperfine splittings);
> - laboratory searches for changes in the mass difference between the K0 meson and its antiparticle.
>
> While it is not obvious, each of these observations is sensitive to changes in the physical constants that control radioactive decay. For example, a change in the strength of weak interactions (which govern beta decay) would have different effects on the binding energy, and therefore the gravitational attraction, of different elements. Similarly, such changes in binding energy would affect orbital motion, while (more directly) changes in interaction strengths would affect the spectra we observe in distant stars.
>
> The observations are a mixture of very sensitive laboratory tests, which do not go very far back in time but are able to detect extremely small changes, and astronomical observations, which are somewhat less precise but which look back in time. (Remember that processes we observe in a star a million light years away are telling us about physics a million years ago.) While any single

> observation is subject to debate about methodology, the combined results of such a large number of independent tests are hard to argue with.
>
> The overall result is that no one has found any evidence of changes in fundamental constants, to an accuracy of about one part in 10^{11} per year.

To summarize: both experimental evidence and theoretical considerations preclude significant changes to rates of radioactive decay. The limits placed are somewhere between ten and twenty *orders of magnitude* below the changes which would be necessary to accomodate the apparent age of the Earth within the young-Earth timescale (by means of accelerated decay).

2.2 Contamination may have occurred.

This is addressed in the most detail in the Isochron Dating FAQ, for all of the methods discussed in the "age of the Earth" part of this FAQ are isochron (or equivalent) methods, which have a check built in that detect most forms of contamination.

It is true that some dating methods (e.g., K-Ar and carbon-14) do not have a built-in check for contamination, and if there has been contamination these methods will produce a meaningless age. For this reason, the results of such dating methods are not treated with as much confidence.

Also, similarly to item (1) above, pleas to contamination do not address the fact that radiometric results are nearly always in agreement with old-Earth expectations. If the methods were producing completely "haywire" results essentially at random, such a pattern of concordant results would not be expected.

Suggested Further Reading

An excellent, detailed exposition of the means by which the Earth's age is known, as well as the history of attempts to estimate that value, is given in Dalrymple (1991). This book is a must-read for anyone who wishes to critique mainstream methods for dating the Earth. A review of this book in the young-Earth creationist journal *Origins* (Brown 1992) includes the following text:

> "Dalrymple makes a good case for an age of about 4.5 billion years for the material of which the Earth, Moon, and meteorites are composed. [...] His treatment in *The Age of the Earth* has made it much more difficult to plausibly explain radiometric data on the basis of a creation of the entire Solar System, or the physical matter in planet Earth, within the last few thousand years. In my opinion, the defense of such a position is a losing battle."
>
> (Note: R.H. Brown believes life on Earth and the geological column to be young, but argues that a proper reading of Genesis allows the Earth itself to be much older.)

For those who wish to develop more than a layman's understanding of radiometric dating, Faure (1986) is the prime textbook/handbook on the topic.

There are several shorter works which describe creationist "dating" methods and/or creationist challenges to mainstream dating methods. The best in my opinion is Dalrymple (1986). Brush (1982) and Dalrymple (1984) are also very good.

Writings by old-Earth creationists demonstrate that argument for an old Earth is quite possible without "assumption of evolution." The best few are Stoner (1992), Wonderly (1987), and Young (1982). In addition, Wonderly (1981), Newman & Eckelmann (1977), and Wonderly (1977) are also good.

And, of course Strahler (1987) covers the entire creation/evolution controversy (including all of the topics discussed here) in a reasonable level of detail and with lots of references.

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