http://www.talkorigins.org/faqs/dating.html

# Radiometric Dating and the Geological Time Scale

Circular Reasoning or Reliable Tools?

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**Other Links:**

A Radiometric Dating Resource List

Tim Thompson has collected a large set of links to web pages that discuss radiometric dating techniques and the age of the earth controversy.

**Overview**

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**Introduction**

This document discusses the way radiometric dating and stratigraphic principles are used to establish the conventional geological time scale. It is not about the theory behind radiometric dating methods, it is about their *application*, and it therefore assumes the reader has some familiarity with the technique already (refer to "Other Sources" for more information). As an example of how they are used, radiometric dates from geologically simple, fossiliferous Cretaceous rocks in western North America are compared to the geological time scale. To get to that point, there is also a historical discussion and description of non-radiometric dating methods.

The example used here contrasts sharply with the way conventional scientific dating methods are characterized by some critics (for example, refer to discussion in "Common Creationist Criticisms of Mainstream Dating Methods" in the Age of the Earth FAQ and Isochron Dating FAQ). A common form of criticism is to cite geologically complicated situations where the application of radiometric dating is very challenging. These are often characterised as the norm, rather than the exception. I thought it would be useful to present an example where the geology is simple, and unsurprisingly, the method does work well, to show the quality of data that would have to be invalidated before a major revision of the geologic time scale could be accepted by conventional scientists. Geochronologists do not claim that radiometric dating is foolproof (no scientific method is), but it does work reliably for most samples. It is these highly consistent and reliable samples, rather than the tricky ones, that have to be falsified for "young Earth" theories to have any scientific plausibility, not to mention the need to falsify huge amounts of evidence from other techniques.

This document is partly based on a prior posting composed in reply to Ted Holden. My thanks to both him and other critics for motivating me.

**Background**

*Stratigraphic Principles and Relative Time*

Much of the Earth's geology consists of successional layers of different rock types, piled one on top of another. The most common rocks observed in this form are sedimentary rocks (derived from what were formerly sediments), and extrusive igneous rocks (e.g., lavas, volcanic ash, and other formerly molten rocks extruded onto the Earth's surface). The layers of rock are known as "strata", and the study of their succession is known as "stratigraphy". Fundamental to stratigraphy are a set of simple principles, based on elementary geometry, empirical observation of the way these rocks are deposited today, and gravity. Most of these principles were formally proposed by Nicolaus Steno (Niels Steensen, Danish), in 1669, although some have an even older heritage that extends as far back as the authors of the Bible. A few principles were recognized and specified later. An early summary of them is found in Charles Lyell's *Principles of Geology*, published in 1830-32, and does not differ greatly from a modern formulation:

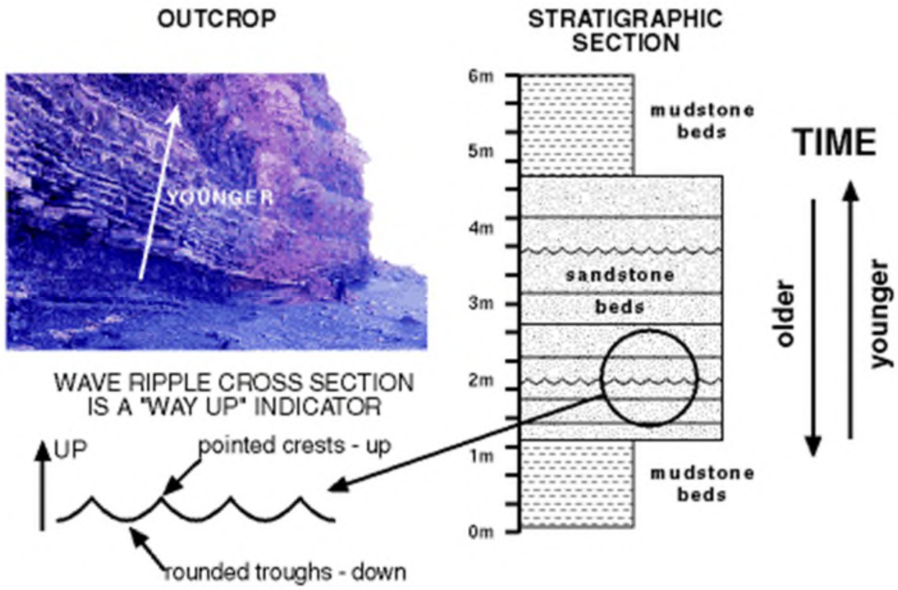
1. The principle of superposition - in a vertical sequence of sedimentary or volcanic rocks, a higher rock unit is younger than a lower one. "Down" is older, "up" is younger.
2. The principle of original horizontality - rock layers were originally deposited close to horizontal.
3. The principle of original lateral extension - A rock unit continues laterally unless there is a structure or change to prevent its extension.
4. The principle of cross-cutting relationships - a structure that cuts another is younger than the structure that is cut.
5. The principle of inclusion - a structure that is included in another is older than the including structure.
6. The principle of "uniformitarianism" - processes operating in the past were constrained by the same "laws of physics" as operate today.

Note that these are *principles*. In no way are they meant to imply there are no exceptions. For example, the principle of superposition is based, fundamentally, on gravity. In order for a layer of material to be deposited, something has to be beneath it to support it. It can't float in mid-air, particularly if the material involved is sand, mud, or molten rock. The principle of superposition therefore has a clear implication for the *relative* age of a vertical succession of strata. There are situations where it potentially fails -- for example, in cave deposits. In this situation, the cave contents are younger than both the bedrock below the cave and the suspended roof above. However, note that because of the "principle of cross-cutting relationships", careful examination of the contact between the cave infill and the surrounding rock will reveal the true relative age relationships, as will the "principle of inclusion" if fragments of the surrounding rock are found within the infill. Cave deposits also often have distinctive structures of their own (e.g., spelothems like stalactites and stalagmites), so it is not likely that someone could mistake them for a successional sequence of rock units.

These geological principles are not *assumptions* either. Each of them is a testable hypothesis about the relationships between rock units and their characteristics. They are applied by geologists in the same sense that a "null hypothesis" is in statistics -- not necessarily correct, just testable. In the last 200 or more years of their application, they are *often* valid, but geologists do not assume they are. They are the "initial working hypotheses" to be tested further by data.

Using these principles, it is possible to construct an interpretation of the sequence of events for any geological situation, even on other planets (e.g., a crater impact can cut into an older, pre-existing surface, or craters may overlap, revealing their relative ages). The simplest situation for a geologist is a "layer cake" succession of sedimentary or extrusive igneous rock units arranged in nearly horizontal layers. In such a situation, the "principle of superposition" is easily applied, and the strata towards the bottom are older, those towards the top are younger.

**Figure 1.** Sedimentary beds in outcrop, a graphical plot of a stratigraphic section, and a "way up" indicator example: wave ripples.




This orientation is not an assumption, because in virtually all situations, it is also possible to determine the original "way up" in the stratigraphic succession from "way up indicators". For example, wave ripples have their pointed crests on the "up" side, and more rounded troughs on the "down" side. Many other indicators are commonly present, including ones that can even tell you the angle of the depositional surface at the time ("geopetal structures"), "assuming" that gravity was "down" at the time, which isn't much of an assumption :-).

In more complicated situations, like in a mountain belt, there are often faults, folds, and other structural complications that have deformed and "chopped up" the original stratigraphy. Despite this, the "principle of cross cutting relationships" can be used to determine the sequence of deposition, folds, and faults based on their intersections -- if folds and faults deform or cut across the sedimentary layers and surfaces, then they obviously came after deposition of the sediments. You can't deform a structure (e.g., bedding) that is not there yet! Even in complex situations of multiple deposition, deformation, erosion, deposition, and repeated events, it is possible to reconstruct the sequence of events. Even if the folding is so intense that some of the strata is now upside down, this fact can be recognized with "way up" indicators.

No matter what the geologic situation, these basic principles reliably yield a reconstructed history of the sequence of events, both depositional, erosional, deformational, and others, for the geology of a region. This reconstruction is tested and refined as new field information is collected, and can be (and often is) done completely independently of anything to do with other methods (e.g., fossils and radiometric dating). The reconstructed history of events forms a "relative time scale", because it is possible to tell that event A occurred prior to event B, which occurred prior to event C, regardless of the actual duration of time between them. Sometimes this study is referred to as "event stratigraphy", a term that applies regardless of the type of event that occurs (biologic, sedimentologic, environmental, volcanic, magnetic, diagenetic, tectonic, etc.).

These simple techniques have widely and successfully applied since at least the early 1700s, and by the early 1800s, geologists had recognized that many obvious similarities existed in terms of the independently-reconstructed sequence of geologic events observed in different parts of the world. One of the earliest (1759) relative time scales based upon this observation was the subdivision of the Earth's stratigraphy (and therefore its history), into the "Primary", "Secondary", "Tertiary", and later (1854) "Quaternary" strata based mainly on characteristic rock types in Europe. The latter two subdivisions, in an emended form, are still used today by geologists. The earliest, "Primary" is somewhat similar to the modern Paleozoic and Precambrian, and the "Secondary" is similar to the modern Mesozoic. Another observation was the similarity of the fossils observed within the succession of strata, which leads to the next topic.

*Biostratigraphy*

As geologists continued to reconstruct the Earth's geologic history in the 1700s and early 1800s, they quickly recognized that the distribution of fossils within this history was not random -- fossils occurred in a consistent order. This was true at a regional, and even a global scale. Furthermore, fossil organisms were more unique than rock types, and much more varied, offering the potential for a much more precise subdivision of the stratigraphy and events within it.

The recognition of the utility of fossils for more precise "relative dating" is often attributed to William Smith, a canal engineer who observed the fossil succession while digging through the rocks of southern England. But scientists like Albert Oppel hit upon the same principles at about about the same time or earlier. In Smith's case, by using empirical observations of the fossil succession, he was able to propose a fine subdivision of the rocks and map out the formations of southern England in one of the earliest geological maps (1815). Other workers in the rest of Europe, and eventually the rest of the world, were able to compare directly to the same fossil succession in their areas, even when the rock types themselves varied at finer scale. For example, everywhere in the world, trilobites were found lower in the stratigraphy than marine reptiles. Dinosaurs were found after the first occurrence of land plants, insects, and amphibians. Spore-bearing land plants like ferns were always found before the occurrence of flowering plants. And so on.

The observation that fossils occur in a consistent succession is known as the "principle of faunal (and floral) succession". The study of the succession of fossils and its application to relative dating is known as "biostratigraphy". Each increment of time in the stratigraphy could be characterized by a particular assemblage of fossil organisms, formally termed a biostratigraphic "zone" by the German paleontologists Friedrich Quenstedt and Albert Oppel. These zones could then be traced over large regions, and eventually globally. Groups of zones were used to establish larger intervals of stratigraphy, known as geologic "stages" and geologic "systems". The time corresponding to most of these intervals of rock became known as geologic "ages" and "periods", respectively. By the end of the 1830s, most of the presently-used geologic periods had been established based on their fossil content and their observed relative position in the stratigraphy (e.g., Cambrian (1835), Ordovician (1879), Silurian (1835), Devonian (1839), Carboniferous (1822), Permian (1841), Triassic (1834), Jurassic (1829), Cretaceous (1823), Tertiary (1759), and Pleistocene (1839)). These terms were preceded by decades by other terms for various geologic subdivisions, and although there was subsequent debate over their exact boundaries (e.g., between the Cambrian and Silurian Periods, which was resolved by proposal of the Ordovician Period between them), the historical descriptions and fossil succession would be easily recognizable today.

By the 1830s, fossil succession had been studied to an increasing degree, such that the broad history of life on Earth was well understood, regardless of the debate over the names applied to portions of it, and where exactly to make the divisions. All paleontologists recognized unmistakable trends in morphology through time in the succession of fossil organisms. This observation led to attempts to explain the fossil succession by various mechanisms. Perhaps the best known example is Darwin's theory of evolution by natural selection. Note that chronologically, fossil succession was well and independently established long before Darwin's evolutionary theory was proposed in 1859. Fossil succession and the geologic time scale are constrained by the observed order of the stratigraphy -- basically geometry -- *not* by evolutionary theory.

### *Radiometric Dating: Calibrating the Relative Time Scale*

For almost the next 100 years, geologists operated using relative dating methods, both using the basic principles of geology and fossil succession (biostratigraphy). Various attempts were made as far back as the 1700s to scientifically estimate the age of the Earth, and, later, to use this to calibrate the relative time scale to numeric values (refer to "Changing views of the history of the Earth" by Richard Harter and Chris Stassen). Most of the early attempts were based on rates of deposition, erosion, and other geological processes, which yielded uncertain time estimates, but which clearly indicated Earth history was at least 100 million or more years old. A challenge to this interpretation came in the form of Lord Kelvin's (William Thomson's) calculations of the heat flow from the Earth, and the implication this had for the age -- rather than hundreds of millions of years, the Earth could be as young as tens of million of years old. This evaluation was subsequently invalidated by the discovery of radioactivity in the last years of the 19th century, which was an unaccounted for source of heat in Kelvin's original calculations. With it factored in, the Earth could be vastly older. Estimates of the age of the Earth again returned to the prior methods.

The discovery of radioactivity also had another side effect, although it was several more decades before its additional significance to geology became apparent and the techniques became refined. Because of the chemistry of rocks, it was possible to calculate how much radioactive decay had occurred since an appropriate mineral had formed, and how much time had therefore expired, by looking at the ratio between the original radioactive isotope and its product, if the decay rate was known. Many geological complications and measurement difficulties existed, but initial attempts at the method clearly demonstrated that the Earth was very old. In fact, the numbers that became available were significantly older than even some geologists were expecting -- rather than hundreds of millions of years, which was the minimum age expected, the Earth's history was clearly at least billions of years long.

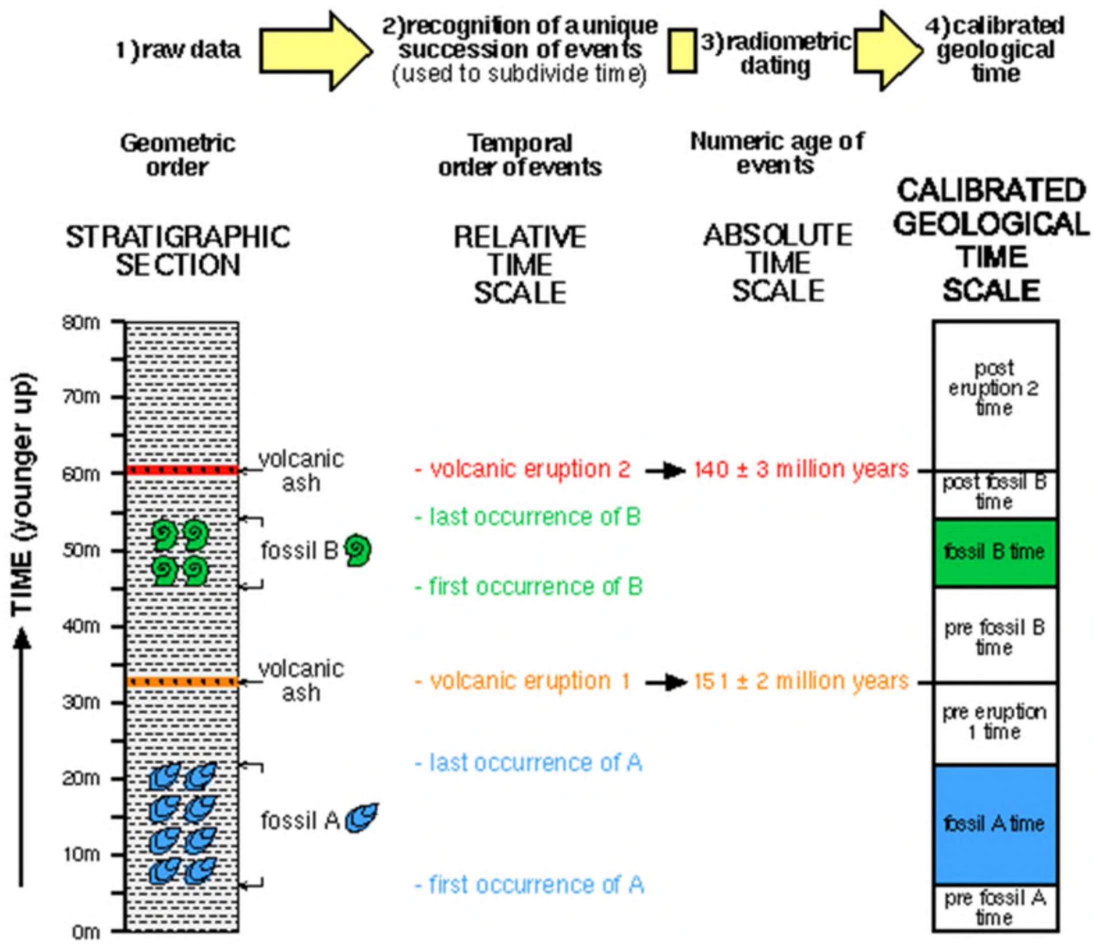
Radiometric dating provides numerical values for the age of an appropriate rock, usually expressed in millions of years. Therefore, by dating a series of rocks in a vertical succession of strata previously recognized with basic geologic principles (see Stratigraphic principles and relative time), it can provide a numerical calibration for what would otherwise be only an ordering of events -- i.e.

relative dating obtained from biostratigraphy (fossils), superpositional relationships, or other techniques. The integration of relative dating and radiometric dating has resulted in a series of increasingly precise "absolute" (i.e. numeric) geologic time scales, starting from about the 1910s to 1930s (simple radioisotope estimates) and becoming more precise as the modern radiometric dating methods were employed (starting in about the 1950s).[1]

**A Theoretical Example**

To show how relative dating and numeric/absolute dating methods are integrated, it is useful to examine a theoretical example first. Given the background above, the information used for a geologic time scale can be related like this:

**Figure 2.** How relative dating of events and radiometric (numeric) dates are combined to produce a calibrated geological time scale. In this example, the data demonstrates that "fossil B time" was somewhere between 151 and 140 million years ago, and that "fossil A time" is older than 151 million years ago. Note that because of the position of the dated beds, there is room for improvement in the time constraints on these fossil-bearing intervals (e.g., you could look for a datable volcanic ash at 40-45m to better constrain the time of first appearance of fossil B).




A continuous vertical stratigraphic section will provide the order of occurrence of events (column 1 of Figure 2). These are summarized in terms of a "relative time scale" (column 2 of Figure 2). Geologists can refer to intervals of time as being "pre-first appearance of species A" or "during the existence of species A", or "after volcanic eruption #1" (at least six subdivisions are possible in the example in Figure 2). For this type of "relative dating" to work it must be known that the succession of events is unique (or at least that duplicate events are recognized -- e.g., the "first ash bed" and "second ash bed") and roughly synchronous over the area of interest. Unique events can be biological (e.g., the first appearance of a particular species of organisms) or non-biological (e.g., the deposition of a volcanic ash with a unique chemistry and mineralogy over a wide area), and they will have varying degrees of lateral extent. Ideally, geologists are looking for events that are unmistakably unique, in a consistent order, and of global extent in order to construct a geological time scale with *global* significance. Some of these events do exist. For example, the boundary between the Cretaceous and Tertiary periods is recognized on the basis of the extinction of a large number of organisms globally (including ammonites, dinosaurs, and others), the first appearance of new types of organisms, the presence of geochemical anomalies (notably iridium), and unusual types of minerals related to meteorite impact processes (impact spherules and shocked quartz). These types of distinctive events provide confirmation that the Earth's stratigraphy is genuinely successional on a global scale. Even without that knowledge, it is still possible to construct local geologic time scales.

Although the idea that unique physical and biotic events are synchronous might sound like an "assumption", it is not. It can, and has been, tested in innumerable ways since the 19th century, in some cases by physically tracing distinct units laterally for hundreds or thousands of kilometres and looking very carefully to see if the order of events changes. Geologists do sometimes find events that are "diachronous" (i.e. not the same age everywhere), but despite this deserved caution, after extensive testing, it is obvious that many events really are synchronous to the limits of resolution offered by the geological record.

Because any newly-studied locality will have independent fossil, superpositional, or radiometric data that have not yet been incorporated into the global geological time scale, all data types serve as both an independent test of each other (on a local scale), and of the global geological time scale itself. The test is more than just a "right" or "wrong" assessment, because there is a certain level of uncertainty in all age determinations. For example, an inconsistency may indicate that a particular geological boundary occurred 76 million years ago, rather than 75 million years ago, which might be cause for revising the age estimate, but does not make the original estimate flagrantly "wrong". It depends upon the exact situation, and how much data are present to test hypotheses (e.g., could the range of a fossil be a bit different from what was thought previously, or could the boundary between two time periods be a slightly different numerical age?). Whatever the situation, the current global geological time scale makes *predictions* about relationships between relative and absolute age-dating at a local scale, and the input of new data means the global geologic time scale is continually refined and is known with increasing precision. This trend can be seen by looking at the history of proposed geologic time scales (described in the first chapter of [Harland et al, 1982, p.4-5], and see below).

**Circularity?**

The unfortunate part of the natural process of refinement of time scales is the *appearance* of circularity if people do not look at the source of the data carefully enough. Most commonly, this is characterised by oversimplified statements like:

> "The fossils date the rock, and the rock dates the fossils."

Even some geologists have stated this misconception (in slightly different words) in seemingly authoritative works (e.g., Rastall, 1956), so it is persistent, even if it is categorically wrong (refer to Harper (1980), p.246-247 for a thorough debunking, although it is a rather technical explanation).

When a geologist collects a rock sample for radiometric age dating, or collects a fossil, there are independent constraints on the relative and numerical age of the resulting data. Stratigraphic position is an obvious one, but there are many others. There is no way for a geologist to choose what numerical value a radiometric date will yield, or what position a fossil will be found at in a stratigraphic section. *Every* piece of data collected like this is an independent check of what has been previously studied. The data are determined by the *rocks*, not by preconceived notions about what will be found. Every time a rock is picked up it is a test of the predictions made by the current understanding of the geological time scale. The time scale *is* refined to reflect the relatively few and progressively smaller inconsistencies that are found. This is *not* circularity, it is the normal scientific process of refining one's understanding with new data. It happens in all sciences.

If an inconsistent data point is found, geologists ask the question: "Is this date wrong, or is it saying the current geological time scale is wrong?" In general, the former is more likely, because there is such a vast amount of data behind the current understanding of the time scale, and because every rock is not expected to preserve an isotopic system for millions of years. However, this statistical likelihood is *not* assumed, it is *tested*, usually by using other methods (e.g., other radiometric dating methods or other types of fossils), by re-examining the inconsistent data in more detail, recollecting better quality samples, or running them in the lab again. Geologists search for an explanation of the inconsistency, and will not arbitrarily decide that, "because it conflicts, the data must be wrong."

If it is a small but significant inconsistency, it could indicate that the geological time scale requires a small revision. This happens regularly. The continued revision of the time scale as a result of new data demonstrates that geologists *are* willing to question it and change it. The geological time scale is far from dogma.

If the new data have a large inconsistency (by "large" I mean orders of magnitude), it is far more likely to be a problem with the new data, but geologists are not satisfied until a specific geological explanation is found and tested. An inconsistency often means something geologically interesting is happening, and there is always a tiny possibility that it could be the tip of a revolution in understanding about geological history. Admittedly, this latter possibility is *VERY* unlikely. There is almost zero chance that the broad understanding of geological history (e.g., that the Earth is billions of years old) will change. The amount of data supporting that interpretation is immense, is derived from many fields and methods (not only radiometric dating), and a discovery would have to be found that invalidated practically all previous data in order for the interpretation to change greatly. So far, I know of no valid theory that explains how this could occur, let alone evidence in support of such a theory, although there have been highly fallacious attempts (e.g., the classic "moon dust", "decay of the Earth's magnetic field" and "salt in the oceans" claims).

## Specific Examples: When Radiometric Dating "Just Works" (or not)

*A poor example*

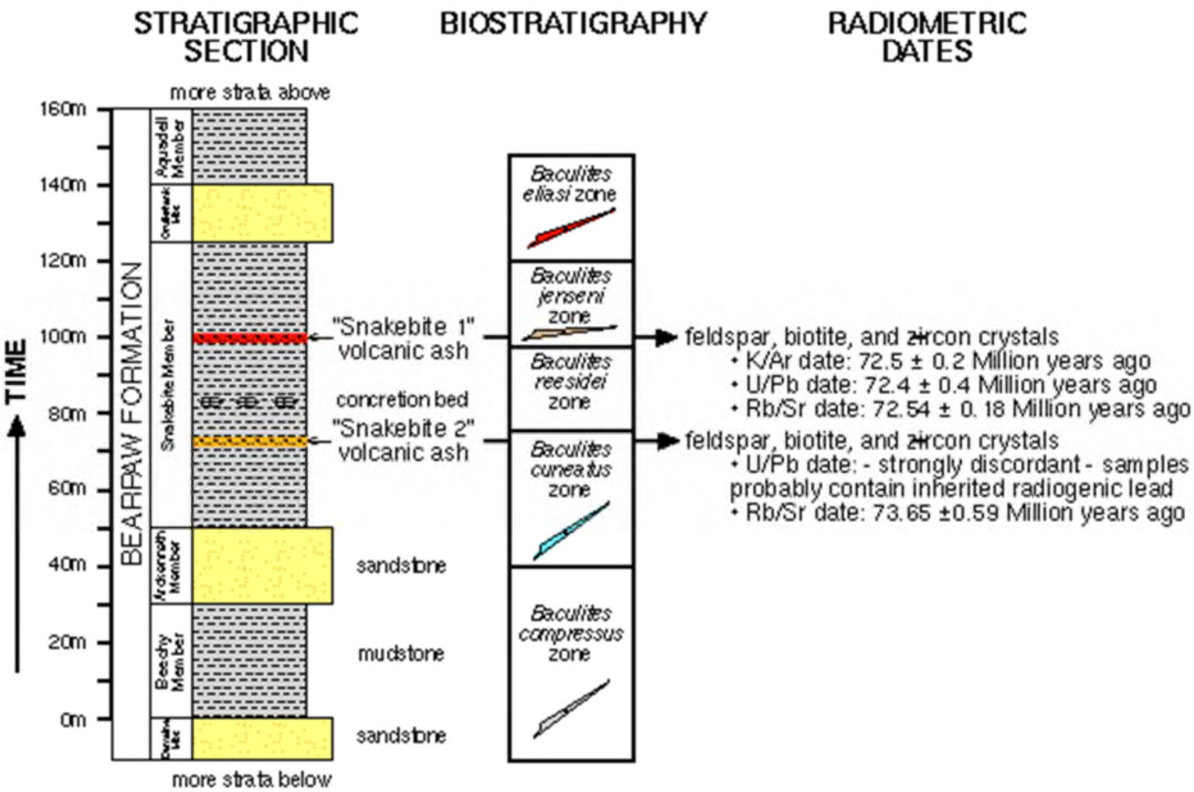
There are many situations where radiometric dating is not possible, or where a dating attempt will be fraught with difficulty. This is the inevitable nature of rocks that have experienced millions of years of history: not all of them will preserve their age of origin intact, not every rock will have appropriate chemistry and mineralogy, no sample is perfect, and there is no dating method that can effectively date rocks of *any* age or rock type. For example, methods with very slow decay rates will be poor for extremely young rocks, and rocks that are low in potassium (K) will be inappropriate for K/Ar dating. The real question is what happens when conditions are ideal, versus when they are marginal, because ideal samples should give the most reliable dates. If there are good reasons to expect problems with a sample, it is hardly surprising if there are!

For example, in the "Dating Game" appendix of his "Bones of Contention" book (1992), Marvin Lubenow provided an example of what happens when a geologically complicated sample is dated -- it can be very difficult to analyze. He discussed the "KBS tuff" near Lake Turkana in Africa, which is a redeposited volcanic ash. It contains a *mixture* of minerals from a volcanic eruption and detrital mineral grains eroded from other, older rocks. It is also a comparatively "young" sample, approaching the practical limit of the radiometric methods employed (conventional K/Ar dating), particularly at the time of the initial dating attempts in 1969. If the age of this unit were not so crucial to important associated hominid fossils, it probably would not have been dated at all because of the potential problems. After some initial and prolonged troubles over many years, the bed was eventually dated successfully by careful sample preparation that eliminated the detrital minerals. Lubenow's work is fairly unique in characterising the normal scientific process of refining a difficult date as an arbitrary and inappropriate "game", and documenting the history of the process in some detail, as if such problems were typical. Another example is "John Woodmorappe's" paper on radiometric dating (1979), which adopts a "compilation" approach, and gives only superficial treatment to the individual dates. Among other problems documented in an FAQ by Steven Schimmrich, many of Woodmorappe's examples neglect the geological complexities that are expected to cause problems for some radiometrically-dated samples.

*A good example*

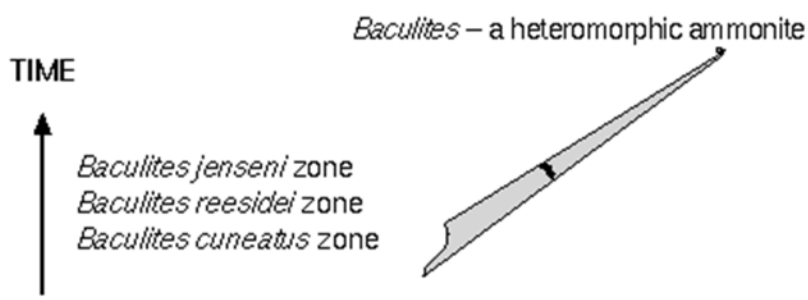
By contrast, the example presented here is a geologically simple situation -- it consists of several primary (i.e. *not* redeposited) volcanic ash deposits with a diverse dateable mineral assemblage (multiple minerals and methods are possible), found in fossil-bearing sedimentary rocks in western North America. It demonstrates how consistent radiometric data can be when the rocks are more suitable for dating. For most geological samples like this, radiometric dating "just works". Consider this stratigraphic section from the Bearpaw Formation of Saskatchewan, Canada (Baadsgaard et al., 1993):

**Figure 3.** Lithostratigraphy (i.e. the sedimentary rocks), biostratigraphy (fossils) and radiometric dates from the Bearpaw Formation, southern Saskatchewan, Canada. Modified from Baadsgaard et al., 1993. The section is measured in metres, starting with 0m at the bottom (oldest).




This section is important because it places a limit on the youngest age for a specific ammonite shell -- *Baculites reesidei* -- which is used as a zonal fossil in western North America. It consistently occurs below the first occurrence of *Bacultes jenseni* and above the occurrence of *Baculites cuneatus* within the upper part of the Campanian, the second to last "stage" of the Cretaceous Period in the global geological time scale. The biostratigraphic situation can be summarized as a vertically-stacked sequence of "zones" defined by the first appearance of each ammonite species:

**Figure 4.** *Baculites* ammonite zones.




About 40 of these ammonite zones are used to subdivide the upper part of the Cretaceous Period in this area. Dinosaurs and many other types of fossils are also found in this interval, and in broad context it occurs shortly before the extinction of the dinosaurs, and the extinction of all ammonites. The Bearpaw Formation is a marine unit that occurs over much of Alberta and Saskatchewan, and it continues into Montana and North Dakota in the United States, although it adopts a different name in the U.S. (the Pierre Shale), mainly for historical and political reasons, rather than any great geological difference.

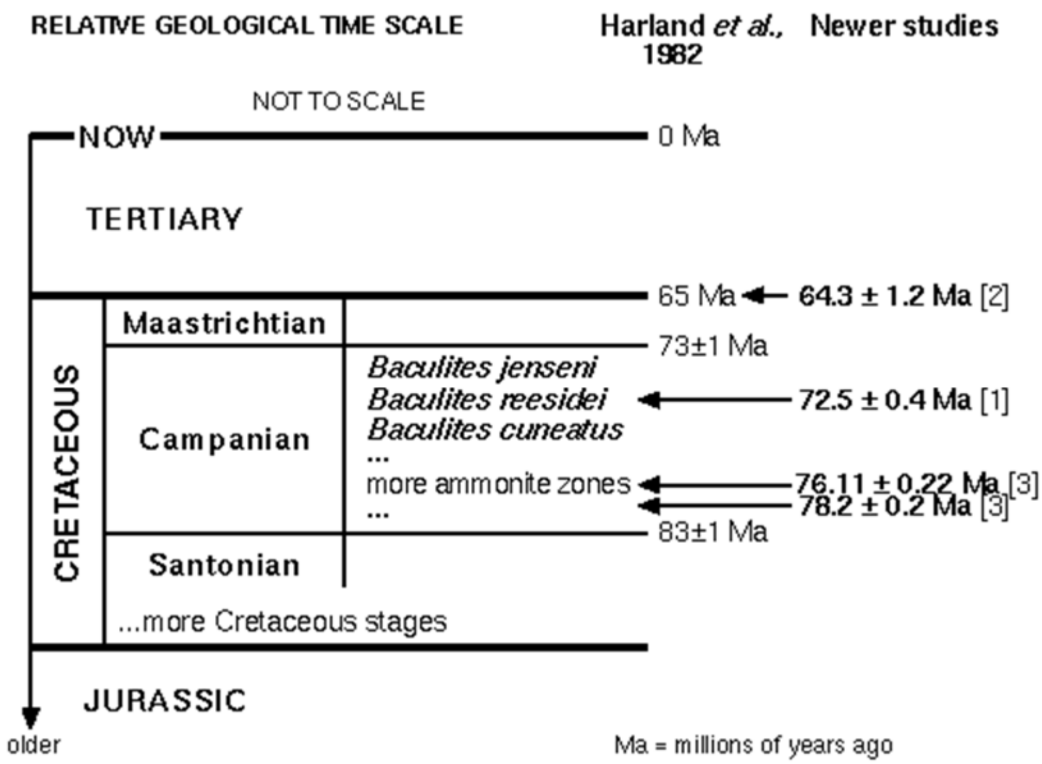
The uppermost ash bed, dated by three independent methods (K/Ar, U/Pb, and Rb/Sr), and from as many as three different minerals (felspar, biotite, and zircon), yields a date of about 72.5 ± 0.4 million years ago (Ma) (weighted mean of several analyses. The numbers above are just summary values). The results for the lower ash bed, although not as complete as for the upper ash bed (only the Rb/Sr isochron method -- the U/Pb isochron was discordant, indicating the minerals did not preserve the date), give the expected result from superpositional relationships -- it is older by about a million years (73.65 ± 0.59 Ma), taking the mean values.

Other examples yield similar results - i.e. compatible with the expectations from the stratigraphy. For example, Baadsgaard and Lerbekmo (1988) dated the age of the Cretaceous-Tertiary (K/T) boundary using three methods (K/Ar, Rb/Sr, and U/Pb, again using multiple minerals) at three localities in the U.S. and Canada. Theoretically, the K/T boundary should be younger than the *Baculites reesidei* zone mentioned above, because the K/T boundary occurs stratigraphically above this level in the same area and globally. The result? 64.3±1.2 million years ago is the weighted average from the three localities, and almost all the results are within 1 million years of each other. The results are therefore highly consistent given the analytical uncertainties in any measurement.

Eberth and Braman (1990) described the vertebrate paleontology and sedimentology of the Judith River Formation, a dinosaur-bearing unit that occurs stratigraphically below the *Baculites reesidei* zone (the Judith River Formation is below the Bearpaw Formation). It should therefore be older than the results from Baadsgaard et al. (1993). An ash bed near the top of the Judith River Fm. yields a date of 76.11±0.22 million years ago, while one almost 100m lower yields a date of 78.2±0.2 million years ago (Eberth and Braman, 1990, figure 5). Again, this is compatible with the age determined for the *Baculites reesidei* zone and its relative stratigraphic position, and even with the relative position of the two samples within the same formation.

How do these dates compare to the (then current) geological time scale? Harland et al. proposed a time scale in 1982 on the basis of data then available, and prior to the specific studies cited above. Here are the numbers they applied to the geological boundaries in this interval, compared to the numbers in the newer studies:

**Figure 5.** Comparison of newer data with the Harland et al., 1982 time scale. [1] is Baadsgaard et al. (1993); [2] is Baadsgaard & Lerbekmo (1988); [3] is Eberth and Braman (1990).




As you can see, the numbers in the rightmost column are basically compatible. Skeptics of radiometric dating procedures sometimes claim these techniques should not work reliably, or only infrequently, but clearly the results are similar: for intervals that should be about 70-80 million years old, radiometric dates do not yield (for example) 100 or 30 million years, let alone 1000 years, 100 000 years or 1 billion. Most of the time, the technique works exceedingly well to a first approximation.

However, there are some smaller differences. The Cretaceous/Tertiary boundary dates differ slightly, but are within the measurement uncertainties of the new date. The date for the *Baculites reesidei* zone is at least 0.1 million years off (taking the outside limit of the data uncertainty), and is below the Campanian/Maastrichtian boundary, so the inconsistency could be even larger. What to do? Well, standard scientific procedure is to collect more data to test the possible explanations -- is it the time scale or the data that are incorrect?

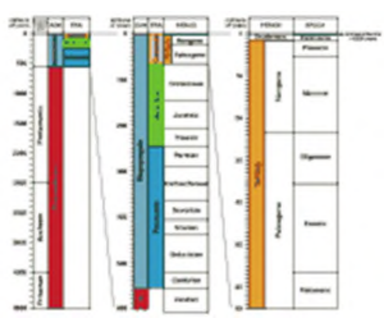
Obradovich (1993) has measured a large number of high-quality radiometric dates from the Cretaceous Period, and has revised the geological time scale for this interval. Specifically, he proposes an age of 71.3 million years for the Campanian/Maastrichtian boundary above the *Baculites jenseni* ammonite zone, based on *independent* dates from other locations. This is completely compatible with the data in Baadsgaard et al. (1993), making it likely the revised, younger date for the Campanian/Maastrichtian boundary is the correct one versus Harland et al. (1982). The other dates are completely consistent with a lower boundary for the Campanian of 83±1 million years ago, as suggested by Harland et al. (1982) (which Obradovich revises to 83.5±0.5 Ma). In summary, it looks like the Campanian/Maastrichtian boundary of Harland et al. (1982) was a little off, but everything else is basically consistent to within the uncertainties of measurement.

**Conclusions**

Skeptics of conventional geology might think scientists would expect, or at least prefer, every date to be perfectly consistent with the current geological time scale, but realistically, this is not how science works. The age of a particular sample, and a particular geological time scale, only represents the *current* understanding, and science is a process of refinement of that understanding. In support of this pattern, there is an unmistakable trend of smaller and smaller revisions of the time scale as the dataset gets larger and more precise (Harland et al. 1982, p.4-5). If something were seriously wrong with the current geologic time scale, one would expect inconsistencies to grow in number and severity, but they do not.

For example, estimates of the age of boundaries in the Tertiary regularly varied by 20-30% in the 1930s to 1970s. Since that time, they have varied by much smaller amounts, rarely approaching 5% (again refer to Harland et al., 1982, p.4-5). The same trend can be observed for other time periods. Palmer (1983) and Harland et al. (1990) present a more recent proposal for the geological time scale, demonstrating that change is still occurring. The latter includes an excellent diagram summarizing comparisons between earlier time scales (Harland et al., 1990, p.8). Since 1990, there have been still more revisions by other authors, such as Obradovich (1993) for the Cretaceous Period, and Gradstein et al. (1995) for the entire Mesozoic.

**Figure 6.** A recent geological time scale, based on Harland et al. (1990)



As another example, Rogers et al. (1993) and Goodwin and Deino (1989) present radiometric dates that bracket the ages of Late Cretaceous fossil occurrences (i.e. dates above and below the fossils) and yield more results that are consistent with predictions from the current time scale.  This is not uncommon.  Besides the papers mentioned here, there are hundreds, if not thousands, of similar papers providing bracketing ranges for fossil occurrences. The synthesis of work like this by thousands of international researchers over many decades is what defines geological time scales in the first place (refer to Harland et al., 1982, 1990 for some of the methods). Although geologists can and do legitimately quibble over the exact age of a particular fossil or formation (e.g., is it 100 million years old or 110 million?), and genuinely problematic samples do exist, claims that radiometric dating is so unreliable that the calibration of the geological time scale could be modified by several orders of magnitude (10000x, 1000x, or even 10x) are ridiculous from a scientific standpoint. The data do not support such an interpretation.  The methods work too well most of the time.

In addition, evidence from other aspects of geology (e.g., estimates of depositional rate and rates of other geological processes) support the great age of the Earth. Prior to the availability of radiometric dating, and even prior to evolutionary theory, the Earth was estimated to be at least hundreds of millions of years old (see above). Radiometric dating has simply made the estimates more precise, and extended it into rocks barren of fossils and other stratigraphic tools.

The geological time scale and the techniques used to define it are not circular. They rely on the same scientific principles as are used to refine any scientific concept: testing hypotheses with data. There are innumerable independent tests that can identify and resolve inconsistencies in the data. This makes the geological time scale no different from other aspects of scientific study.

For potential critics: Refuting the conventional geological time scale is not an exercise in collecting examples of the worst samples possible. A critique of conventional geologic time scale should address the best and most consistent data available, and explain it with an alternative interpretation, because that is the data that actually matters to the current understanding of geologic time.

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**Other Sources**

This document discusses the way radiometric dating is used in geology rather than the details of how radiometric techniques work. It therefore assumes the reader has some familiarity with radiometric dating. For a technical introduction to the methods, I highly recommend these two books:

Dalrymple, G. Brent, 1991. The Age of the Earth. Stanford University Press: Stanford, 474 pp. ISBN 0-8047-1569-6

Faure, G., 1986. Principles of Isotope Geology, 2nd. edition. John Wiley and Sons: New York, p.1-589. ISBN 0-471-86412-9

An excellent introduction to radiometric dating can also be found in the talk.origins FAQ archive:

Age of the Earth FAQ
Isochron dating FAQ

Both are by Chris Stassen.

An excellent source about the integration of radiometric dating, biostratigraphy (the study of fossil succession) and general stratigraphic principles is:

Blatt, H.; Berry, W.B.N.; and Brande, S., 1991. Principles of Stratigraphic Analysis. Blackwell Scientific Publications: Boston, 512p. ISBN 0-86542-069-6.

The history of the geologic time scale is ably described in:

Berry, W.B.N., 1987. Growth of a Prehistoric Time Scale. Blackwell Scientific Publications: Boston, 202p.

And a good summary is in "Changing views of the history of  the Earth" by Richard Harter and Chris Stassen.

**Notes**

[1] Technically, these geologic time scales are known as "geochronologic scales", and there is a conceptually tricky duality to the scale between the rock, the time represented by the rock, and the calibration of the relative time to an absolute scale. A profusion of terms is applied to the different concepts, and, confusingly to the uninitiated, to the names applied to subdivisions of them (e.g., "Cretaceous"). Geologic "Periods" (time) and geologic "Systems" (rock) are different concepts, even though the same label (e.g., "Cretaceous") may be applied to them. The semantic difference exists to distinguish between the different (but relatable) types of observations and interpretation that go into them. For simplicity sake I am sticking to the concepts of "relative" and "absolute" (numerical) time, because these are in common use, and I am glossing over the dual nature of the subdivisions. These issues are explained in much more detail in the citations mentioned in "Other Sources" particularly Blatt (et al., 1991).

**Acknowledgements**

This is my third revision of a FAQ on the application of dating methods. It benefits from the comments of several informal reviewers. Unfortunately, some were so long ago that I no longer have all their names :-( But my thanks goes to all of them anyway, and to four recent ones I do remember: Stanley Friesen, Chris Stassen, Mark Isaak, and Martyne Brotherton.  My thanks also to Brett Vickers for maintaining the talk.origins archive.