“Polonium Halos” Refuted

A Critique of “Radioactive Halos in a Radiochronological and Cosmological Perspective” by Robert V Gentry

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[This article is an extract of a longer treatment of these issues posted on-line at <http://earthfriendarts.tripod.com/evolve/gentry.html>. Readers are encouraged to consult the extended version.]

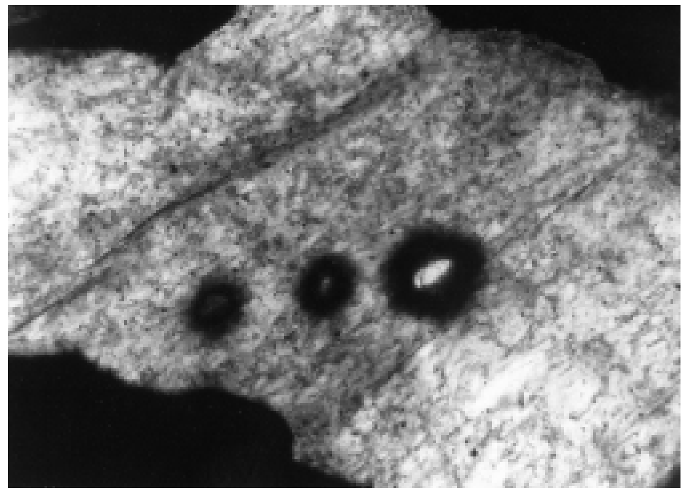

FIGURE 1: *Radiation damage haloes around zircon inclusions in pyroxene (160X magnification). Author's collection.*

INTRODUCTION

As the creationism/evolution debate continues, there has been an increasing sophistication of certain creationist arguments and publications. In the early days of “scientific creationism”, its proponents sought to challenge the scientific view of the natural world by simply adopting scientific-sounding terminology. However, these poorly cloaked Bible-based assertions about the history of the earth (and the universe) were continually rejected by the courts as being inappropriate for public school classrooms. Continuing to evolve, modern creationists produce highly technical and sophisticated reports that have all the trappings of scientific research. Refuting these pseudoscientific reports can be an especially difficult challenge when creationist authors have professional credentials and have published in mainstream scientific journals. One such individual is Robert Gentry, who holds a master's degree in physics (and an honorary doctorate from the fundamentalist Columbia Union College). For nearly two decades he held a research associate's position at the Oak Ridge National Laboratory, where he was part of a team that investigated ways to neutralize nuclear waste. Gentry has spent most of his professional life studying the nature of very small discoloration features in mica and other minerals, and has concluded that they are proof of a young earth. To understand Gentry's hypothesis, a basic background in geology, mineralogy, and radiation physics is helpful. (Readers may refer to sidebars on p 18 and 19.)

Gentry's thesis has several components. First is his contention that the granitic rocks from which his samples reportedly came constitute the “primordial” crust of the earth. Within these rocks are biotite (an iron-bearing form of mica) and fluorite crystals which bear a relatively uncommon class of tiny, concentric discoloration “halos” (Figure 1). These halos were considered to be the result of damage to the crystal structure of the host minerals caused by high energy alpha particles (*see the article by Collins and Collins beginning on p 11*). In numerous papers published in scientific journals in the 1970s and 1980s, Gentry built the case that the different alpha decay energies of various naturally occurring radioactive isotopes resulted in distinctly different halo diameters. Thus, Gentry concluded that he could distinguish halos resulting uniquely from the radioactive decay of various isotopes of the element polonium, which is part of the decay chains of natural uranium and thorium. Because polonium has a very short half-life (from a few microseconds to days, depending on the specific isotope), Gentry argues that concentric halos associated with polonium decay — but without any rings corresponding to any other uranium decay series isotopes — were evidence that the host rock had formed almost instantly, rather than by the slow cooling of an original magma over millions of years. Gentry extrapolates that all Precambrian granites — his primordial crustal rock — must have formed in less than three minutes, and that polonium halos are therefore proof of the young-earth creation model according to Genesis.

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About the Rocks

Geologists classify rocks into three main categories — sedimentary, igneous, and metamorphic — based on the way in which they form.

Igneous rocks form from molten material, and are further subdivided into two main categories: the volcanic rocks, which form from lava extruded at or near the surface; and plutonic rocks, which form from magma, deep within the crust. Both types of igneous rocks comprise a mixture of different minerals. As igneous rocks cool, mineral crystals form following a specific sequence. The crystals develop an interlocking texture with some of the trace minerals, becoming completely surrounded by later forming crystals. Volcanic rocks, because they are able to cool and crystalize rapidly, have a very fine-grained texture; the individual mineral grains are too small to see easily with the naked eye. Plutonic rocks, on the other hand, cool very slowly, on the order of a million years or more for some deeply buried and insulated magmas. The mineral grains in these rocks can grow very large and are readily distinguished in hand samples.

Granite is a well-known type of plutonic igneous rock, but there are many others as well. Geologists distinguish these types of rock based on their chemical and mineralogical composition. Granites, for example, have more than 10% quartz and abundant potassium feldspar. Other plutonic rocks have less quartz and potassium, and different ratios of calcium and sodium feldspar minerals. True granites are relative latecomers on the geologic scene, as they require recycling of crustal materials several times to differentiate and concentrate potassium. In an earlier issue of *RNCSE*, Lorence Collins (1999 Mar/Apr; 19 [2]: 20–2, 27–9) provided a thorough overview of the origin and nature of granitic rocks.

Metamorphic rocks represent alterations of precursor sedimentary, igneous, or other metamorphic rocks. Through the cycles of burial, folding, faulting, and subduction of crustal plates, rocks get pushed and dragged down to depths where — under heat and pressure — changes take place. In metamorphic rocks, new minerals form that are more stable at higher temperatures and pressures. Sometimes the minerals segregate into distinct bands. When burial pressures and temperatures get too great, the rocks melt completely, becoming new igneous rocks.

Sedimentary rocks are secondary in formation, being the product of precursor rocks (of any type).

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Fortunately, several components of Gentry's thesis allow us to pose questions that can be answered by looking at the evidence from the natural world:

1. Do the rocks from which Gentry drew his samples represent the "primordial" basement rocks of the originally created earth?
2. Are the concentric halos observed by Gentry actually caused by alpha particle damage to the host crystal structure?
3. If the concentric halos are indeed caused by alpha radiation damage, is polonium decay the only possible cause?
4. Is Gentry's hypothesis consistent with, or does it explain, all other evidence pointing to a *great* age for the earth?

A "yes" answer to each question would significantly strengthen Gentry's arguments. Of course, a "no" answer would invalidate any inference or proposition based on that component.

Answers in Nature

Do the rocks from which Gentry drew his samples represent the "primordial" basement rocks of the originally created earth?

Gentry is a physicist, not a geologist. Contrary to accepted geologic reporting practice, he consistently fails to provide the information that a third party would need to collect comparable samples for testing. For his research, Gentry utilized microscope thin sections of rocks from samples sent to him by others from various places around the world. Thus, he is unable to say — and others are unable to confirm — how his samples fit in with the local or regional geological setting(s). He also does not provide descriptive information about the individual rock samples that make up his studies — that is, the abundance and distribution of major, accessory, or trace minerals; the texture, crystal size and alteration features of the rocks; and the presence or absence of fractures and discontinuities.

Because Gentry does not acknowledge that the Precambrian time period represents fully 7/8 of the history of the earth, he does not recognize the wide diversity of geologic terranes that came and went over that enormous time span. In Gentry's model, any rock looking vaguely like a granite and carrying the label Precambrian is considered to be a "primordial" rock — a claim that is patently incorrect. True granites are themselves evidence of significant crustal recycling and elemental differentiation (see for example, Taylor and McLennan 1996) and cannot be considered primordial. A little detective work by Wakefield (1988) showed that at least one set of rock samples studied by Gentry are not from granites at all, but were taken from a variety of younger Precambrian metamorphic rocks and pegmatite veins in the region around Bancroft, Ontario. Some of these rock units cut or overlie older, sedimentary, and even fossil-bearing rocks.

Furthermore, polonium halos are found only in rocks that contain myrmekite — a replacement mineral intergrowth — which is a clear indication that the rock is not "primordial" but one that has undergone significant change over an extended period of time. Collins (1997) has noted these and several other contradictory situations between the polonium halo hypothesis and observed geological relationships in the field.

Are the concentric halos observed by Gentry actually caused by alpha particle damage to the host crystal structure?

Reviewing Gentry's early research (Gentry 1968, 1971; Gentry and others 1973), it is apparent that the association of concentric colored halos with polonium is actually speculative. Gentry adopts and expands on the work of Joly (1917) that polonium isotopes were the most likely cause of the circular patterns observed in certain rocks. Joly did most of his work with discoloration halos in the first decade of the 20th century — a time when the structure of the atom was just being discovered and before the crystal structure of minerals had been unraveled. This was also the period when the nature of radioactivity was just being uncovered. Joly made the very speculative assumption that if alpha particles could travel 3–7 centimeters in air, then they would only travel 1/2000 of that distance in biotite mica.

From this generalization, and without considering variability in the density and the crystal structure of the host mica (or even the variable density of air), Joly attempted to correlate the size of the radius of concentric ring halos with the alpha particles of specific isotopes (he was first to suggest polonium). He also tried to develop an age dating technique based on the diameter of the halo features — the larger the halo, the longer the radiation had been affecting the host mineral grain. Henderson (1939) carried Joly's work further, developing a classification scheme for the different patterns of discoloration halos he observed, and deriving hypotheses for how short-lived polonium could find its way into the host crystal structure. Gentry followed Joly's approach of defining an idealized model based on the average distance traveled in air by alpha particles of different energy. He then measured concentric ring halos in mica (or fluorite, or cordierite) to see which ones matched his model.

How can alpha particle emissions result in discrete colored rings? Gentry's (1992) explanation is that "alpha particles do the most damage at the end of their paths." This would appear to be a reference to the "Bragg Effect" — the phenomenon whereby charged particles lose energy during penetration of different media. When charged particles (a proton or an alpha particle) pass through matter, they lose energy primarily by ionizing the atoms of material they pass through and different atoms require different amount of energy to ionize. In general, the lower the energy of the impacting charged particle, the faster it loses energy. As the particle loses energy, it slows down, and as it slows down, it interacts more strongly with surrounding atoms, causing it to decelerate even more rapidly. Finally, the particle loses all of its kinetic energy and comes to rest, at which time it can capture electrons and become a neutral atom (Knoll 1979). In a uniform medium, the amount of energy loss — and thus the degree of disruption — is greatest at the end of the particle's path of travel (although energy will have been given up and ionization of surrounding atoms will have occurred along the entire path).

The effects of alpha particles in crystalline materials, the physical properties of which vary depending on orientation, are complex. Gentry's own attempts to duplicate alpha particle damage in minerals using a helium ion beam illustrates this problem.

The pattern produced by Gentry through ion beam bombardment was a zone of discoloration, faintest near the source, and increasing in intensity up to a relatively sharp termination. Gentry's ion-beam work, however, was not able to produce multiple bands or the sharply defined concentric ring structure of certain halos. It is likely that intense alpha particle bombardment disrupts the crystallinity of the target mineral (a well-known natural radiation effect), changing its physical properties along the particle path. This would tend to broaden the Bragg Effect rather than creating a narrow zone of disruption that produced a simple ring.

Gentry himself (1970, 1974) notes a number of aspects about concentric halos that cannot be explained by the alpha decay hypothesis. Dwarf and giant halos cannot be reconciled with any known alpha decay energies. Gentry postulates that these

Radioactivity

Radioactivity is a phenomenon of the nuclei of atoms. You may recall from high school chemistry class that atoms are composed of protons, which carry a positive charge; neutrons, with no charge; and negatively charged electrons. The protons and neutrons together form the nucleus of the atom, surrounded by a swarm of electrons in distinct orbits. In neutral atoms, the numbers of protons and electrons always match, their charges balancing. It is the number of protons (and hence the number of electrons) that give an element its unique chemical characteristics.

Atoms, however, can have different numbers of neutrons without changing their chemical behavior. For example, the simplest atom, hydrogen, has one proton and one electron. Two additional varieties of hydrogen exist: one which has one neutron in addition to the proton (called deuterium); and one with two neutrons (known as tritium). Different varieties of the same element are known as isotopes. Uranium has 92 protons, but has different isotopes with 141, 142, 143, 144, 145, and 146 neutrons.

Radioactivity is a complex phenomenon, but it can be thought of simply as the consequence of the imbalance caused in an atomic nucleus by an overabundance of neutrons. Isotopes that have too many neutrons try to become more stable by getting rid of neutrons through a number of means, the most common being the emission of high-energy alpha and beta particles. An alpha particle comprises two protons and two neutrons and is chemically indistinguishable from a helium nucleus (as a matter of fact, all the helium gas sold commercially comes from the radioactive decay of uranium, the gas occasionally being trapped in oil deposits that overlie uranium ore bodies). Emission of an alpha particle creates a new chemical element with two fewer protons than its parent atom. The radioactive isotope ^{238}uranium (92 protons) decays by giving off an alpha particle to become an atom of ^{234}thorium (90 protons).

Beta particles are created when a neutron breaks down into a proton and an electron — the beta particle thus is an electron, only in this case it comes from the nucleus. In beta decay, the proton remains in the nucleus, also causing the atom to adopt a new chemical identity. ^{87}Rubidium (37 protons) decays to become ^{87}strontium (38 protons). Other types of radioactive decay schemes are known to exist, but are much less common than alpha and beta particle emission — and are not really relevant to the subject at hand.

One last point — radioactivity is a statistical phenomenon. Not all the radioactive atoms within a mass decay at the same time. For example, an amount of ^{238}uranium decays at a rate such that after 4.5 billion years half of the original mass has been converted to other atoms. Several of the "daughter" atoms in the decay series of ^{238}uranium are themselves radioactive and decay at their own statistical rates until eventually the stable, non-radioactive isotope of ^{206}lead is reached.

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anomalous size halos represent new elements or new forms of alpha decay. Neither explanation seems likely given the current state of knowledge of radioactive elements (ICRP 1983; Parrington and others, 1996). Other halos show "ghost" rings that do not correspond to any measured alpha decay energy and remain unexplained. Finally, there are "reversed coloration" halos, supposed uranium halos in which the gradation of color intensity in the circular band is opposite to, and the ring diameters offset from, those in a "normal" uranium pattern. Other exceptions to Gentry's energy-versus-ring diameter model have been noted by Odom and Rink (1989) and Moazed and others (1973). Gentry speculates on the cause(s) of some of these anomalous features, but provides no empirical data to support any explanation. Indeed, Gentry appears to be more willing to question the evidence provided by the physical samples than to question the validity of his model.

Perhaps the most damaging challenge to Gentry's hypothesis comes not from what has been observed, but from what is missing. Of the three major naturally occurring radioactive elements, uranium, thorium, and potassium, two — uranium and thorium — demonstrate decay series involving alpha particle emissions. Thorium is between three and four times more abundant than uranium in the earth's crust. Gentry attributes polonium halos to alpha particle decay of the polonium isotopes ^{210}Po, ^{214}Po, and ^{218}Po, all part of the ^{238}uranium decay chain. However, the decay series of ^{232}thorium to stable ^{208}lead also includes two polonium isotopes: ^{212}Po and ^{216}Po. These polonium isotopes from thorium decay series have alpha decay energies well within the range documented for uranium-series polonium decay. Thus, polonium isotopes which result from the decay of naturally occurring ^{232}thorium should also produce characteristic halos. However, as Collins (1997) points out, Gentry has identified only halos for those isotopes of polonium associated with the decay of ^{238}uranium; halos attributable to ^{212}polonium and ^{216}polonium are not found. Additionally, halos attributable to the two polonium isotopes in the decay series of ^{235}uranium (^{211}Po and ^{215}Po) are also missing. ^{235}Uranium currently comprises 0.71% of naturally occurring uranium (^{238}uranium makes up 99.3%); 3 billion years ago, ^{235}uranium accounted for greater than 3% of natural uranium isotopes. If Gentry's model is valid, halos associated with all of these other polonium isotopes should be observed, some in even greater abundance than the ones he reports. The failure to understand and confirm the full range of a model's predictions suggests that the model is flawed, and conclusions based on that model are unreliable. Clearly, more work is required to resolve all of these questions. The association of ring-type halos with any specific energy of alpha decay must be considered speculative.

If the concentric halos are indeed caused by alpha radiation damage, is polonium decay the only possible cause?

Even if we accept that concentric ring halos actually are due to alpha radiation damage, an immediate problem arises from the short half-life of the polonium isotopes themselves. Under Gentry's model, in order to leave a visible radiation damage halo, the affected mica or fluorite grains would have to crystallize before the polonium decayed away to background levels — about 10 half-lives. For polonium isotopes, this correlates to between a fraction of a second (^{212}Po, ^{214}Po, ^{215}Po) and 138.4 days (^{210}Po). Gentry's hypothesis calls for literally millions of atoms of isotopically pure, polonium to be concentrated at the center of each ring. His model makes no distinction between which polonium isotopes should be present — thus there should be equal likelihood for all. He points out that there is no known geochemical process by which such concentrations can occur during crystallization of a magma, concluding therefore that polonium halos are indicative of some non-natural or supernatural occurrence.

Polonium isotopes are produced in the radioactive decay chain of naturally occurring ^{238}uranium, ^{232}thorium, and ^{235}uranium.

Table 1: Decay Series of Uranium and Thorium Isotopes

Decay Series	Polonium Isotopes	Particle Energy (MeV)
^{238}Uranium	^{218}Polonium	6.00
	^{214}Polonium	7.69
	^{210}Polonium	5.3
^{235}Uranium	^{215}Polonium	7.38
	^{211}Polonium	7.45
^{232}Thorium	^{216}Polonium	6.78
	^{212}Polonium	8.78

Gentry's studies identify concentric ring structures correlated with each of the three polonium isotopes in the ^{238}uranium decay series. Ring halos correlated with polonium isotopes from the ^{235}uranium or the ^{232}thorium decay series are not reported, although they would have to be present under Gentry's primordial origin hypothesis.

Gentry does not provide a conclusive argument for demonstrating the relationship between concentric halos and polonium decay. Brawley (1992) and Collins (1997) note, however, that many concentric ring halos line up along visible fractures within the host mica. Such fractures are very common in mica crystals. Microfractures and cleavage planes could provide conduits for the rapid movement and concentration of ^{222}radon, a gaseous daughter product of ^{238}uranium which forms part way along the decay chain leading to polonium. ^{222}Radon, itself an alpha emitter, has a half-life of 3.82 days and is produced continuously in the decay of the parent uranium. Radon, one of the noble gases, is chemically inert and is known to migrate rapidly through large thicknesses of rock. Indeed, radon emanometry (measurement at the surface of radon being released from buried rock formations) is a well-developed technique in the exploration for uranium ore bodies.

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TABLE 2: HALF-LIFE OF RADON ISOTOPES

Decay Series	Radon Isotope	Radon half-life
^{238}Uranium	^{222}Radon	3.823 days
^{235}Uranium	^{219}Radon	3.92 seconds
^{232}Thorium	^{220}Radon	51.5 seconds

Migration of radon along fractures with hold-up points at tiny structural traps would result in exactly the same concentric ring pattern assigned by Gentry to polonium alone (because polonium is an immediate daughter isotope of radon decay). Assigning a halo diameter to radon is difficult since the radon alpha decay energy is very close to that of ^{210}polonium; where measured accurately, the two ring structures commonly cannot be distinguished (Moazed and others 1973).

The development of fractures in the grains of mica after crystallization has occurred, and the migration of radon along these fractures over the course of millennia, are much more in keeping with current geologic models of rock formation. Thus, the radon hypothesis is more attractive than Gentry's model since it fits the observed evidence and does not require supernatural occurrences.

WHAT CAUSES "HALOS"?

Certain minerals, such as zircon and monazite, which form as common trace constituents in igneous rocks, have crystal structures that can accommodate varying amounts of the naturally occurring radioactive elements uranium and thorium. When these minerals occur as inclusions in certain other minerals, most notably the mica family, they are often seen to develop discoloration, or "pleochroic" halos. The halos are caused by radiation damage to the host mineral's crystalline structure. The zone of damage is roughly spherical around a central mineral inclusion or radioactive source. Note that the halo has the highest intensity of discoloration near the source, gradually fading with distance in the host mineral to a "fuzzy" edge.

Radiation damage halos around mineral inclusions are well known from the geological literature. Discoloration halos in younger rocks tend to be smaller and less intense than in older rocks, indicating that the zone of crystal damage increases with time. From these observations, early attempts were made to use the dimensions of halos as an age dating technique. This was never fully successful since the size/intensity of an observed damage halo is also a function of the abundance of radionuclides present.

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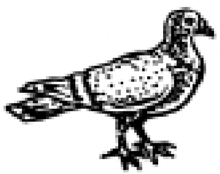
IS GENTRY'S HYPOTHESIS CONSISTENT WITH OTHER AGE DETERMINATIONS FOR THE EARTH?

Over the past six decades, geologists and physicists have developed numerous techniques for dating various types of rock and other natural materials. To reconcile his presumed young age for the earth with reported isotopic age dates for rocks around the world, Gentry (1992) argues that radioactive decay rates have varied over time. However, he is forced by his model to conclude that decay rates for his chosen polonium isotopes have *remained constant* in contrast to those of dozens of other radioactive isotopes that were greater by many orders of magnitude at the origin of the planet (6000 to 10 000 years ago). This of course gives rise to several major inconsistencies.

- Many rocks have been dated by a variety of techniques using different isotope pairs having very different decay mechanisms, and yet the results show remarkable consistency in measured ages. Gentry's hypothesis would require that in the course of these changes in rate, all of the different decay schemes for the different radioactive isotopes must have been accelerated by just the right, but very different amounts to give the consistent age dates we find for rocks today. For example, the decay rate for ^{238}uranium (half-life = 4.5 billion years) would have to be accelerated by nearly four times the rate for ^{40}potassium (half-life = 1.25 billion years.). Given the large number of different radioactive isotopes and decay schemes that have been used in dating rocks, the chance of this coincidence's taking place is essentially zero.
- A general principle of radioactive decay is that the more rapid the decay rate, the more energy that is released. The slow radioactive decay of uranium, thorium, and ^{40}potassium has been identified as a primary source of the earth's internal heat. Speeding up the radioactive decay rates of these isotopes by many orders of magnitude to be consistent with a 6000–10 000-year age for the earth requires that the energies of decay 10 000 years ago would have been extreme, keeping the earth in a molten state to the present day. Obviously this has not occurred.
- Perhaps most critical: if one is going to propose that radioactive decay rates of all the other isotopes varied, and varied differently for each one over time, there is no reason why the decay rates of numerous polonium isotopes should not also have varied. Under a variable decay rate model, it can even be proposed that polonium decay rates might have been much longer than observed today. In fact, once the idea of variable decay rates is introduced, it becomes impossible to assign discoloration halos to any specific isotope or isotopic series, and Gentry's hypothesis falls completely apart.
- The decay rate and the energy of emitted alpha particles are both related to the imbalance of neutrons and protons in an atomic nucleus and are controlled by the strong nuclear force and the binding energy for the particular nuclide. Anything more than a fractional change in the decay rate over time would require variation in the fundamental forces of nature and the relationship of matter and energy. There is no evidence that anything of the sort has ever occurred.

There are many independent lines of reasoning beside radiometric age dating for concluding that the earth is far older than 6000 years. Other geologic processes, with completely independent mechanisms, that demonstrate a long period for earth history include:

- the slow crystallization and deposition of great thicknesses of limestones occurring over and over in the geologic record;
- the growth of salt domes in the Gulf Coast region of the US and beneath the deserts of Iran by slow, plastic deformation over millions of years of a deeply buried salt bed in response to the slow accumulation of overlying sediments;
- the spreading of the world's ocean basins, recorded in the symmetrical patterns of magnetization of the basalts on each side of the mid-ocean ridges. The current measured rate of spreading results in an age estimate for the western margin of the Pacific Basin of approximately 170 million years — an age which has been confirmed by radiometric dating.



Literally hundreds of other examples could also be presented. All of them lead to the same conclusion: Gentry's model requires assumptions that are not supported by observations of naturally occurring geophysical processes and when the model components are replaced by scientifically accepted values, there is no support for a young earth.

Summary/Conclusions

Gentry's polonium halo hypothesis for a young earth fails, or is inconclusive for, all tests. His samples are not from "primordial" pieces of the earth's original crust, but from rocks which have been extensively reworked. He is unable to demonstrate that concentric halos in mica are caused uniquely by alpha particles resulting from the decay of polonium isotopes. Finally, his hypothesis cannot contend with the many alternative lines of evidence that demonstrate a great age for the earth. In the end, Gentry's young-earth proposal, based on years of measuring discoloration halos, fails to generate a scientific model that is either internally consistent or consistent with generally accepted scientific understanding of geophysical processes and earth history.

Gentry rationalizes any evidence which contradicts his hypothesis by proposing three "singularities" — one-time divine interventions — over the past 6000 years. As with the idea of variable radioactive decay rates, once Gentry moves beyond the realm of physical laws, his arguments fail to have any scientific usefulness. If divine action is necessary to fit the halo hypothesis into some consistent model of earth history, why waste all that time trying to argue about the origins of the halos based on current scientific theory? Indeed, this is where most creationist arguments break down: when they try to adopt the language and trappings of science.

Creationists frequently point out that Gentry's research was published in mainstream, peer-reviewed scientific journals. Like many creationist statements, this is partly true. Gentry published his research findings related to his hypothesis that circular halo features were caused by alpha particles from the decay of naturally occurring radioactive isotopes. However, Gentry never presented his hypothesis or conclusions regarding a young earth in these research articles. The closest he ever came to this type of statement is found in a cryptic question posed at the end of a 1974 article in *Science* (Gentry 1974): "... can they [polonium halos] be explained by presently accepted cosmological and geological concepts relating to the origin and development of the earth?" Based on the above analysis, the answer is a resounding *yes*!

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