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$^{40}Ar/^{39}Ar$ Calibration against Novarupta: No Good Reason to Believe in Millions of Years

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Abstract

June 6–8, 2012, marked the one hundredth anniversary of the Novarupta-Katmai eruption in southwest Alaska. It was one of the biggest eruptions in recorded history, and the largest since Krakatoa in 1883. A bulk sample from the top of the Novarupta lava dome, collected in July 2009, was age-dated in 2012 using the 40Ar/39Ar method. A key assumption in the method is that an igneous sample has no argon when it solidifies. Environmental conditions were ideal for setting this sample's "argon clock" to zero, and atmospheric contamination was accounted for. Yet the 100-year-old rhyolite from Novarupta still gave apparent ages as high as 5.50±0.11 million years old. Bias is introduced to the Ar/Ar method because, prior to analysis, technicians request an age estimate for the sample. Because Scripture, not experimental evidence, is the ultimate authority for Creation researchers, the burden of proof lies with "deep time" historians to explain why anyone should believe radiometric methods determine actual sample ages. Radiometric methods are better suited for interpreting a rock's environmental history. In addition to discussing known environmental effects on argon solubility, the effect of event energy on accelerated nuclear decay is explored as a possible cause of the excess argon.

Introduction

Natural History Research vs. Scientific Research

Geology was built in the late eighteenth and early nineteenth centuries using a framework that included a vast prehuman prehistory accessible only through scientific study of rocks and fossils (Reed and Williams, 2012). Geologic actualism, the interpretive framework for secular geologists, is the idea that present processes are the only options for explaining past events. For actualists, physical continuity through history is a required part of explaining past events.

But things are different today. Many geologists acknowledge that past major catastrophic events have shaped the landscape we see today. Neocatastrophism gained footing with the work of G. Harlan Bretz. Although it took 40 years, geologists finally acknowledged that postglacial, catastrophic floods provided the best explanation for the Channeled Scablands of eastern Washington.

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There was no way to continue invoking a "muddled view of uniformitarianism against Bretz's hypothesis" (Burr et al., 2009). Up to that point, secular geologists had been dogmatic about interpreting the past through the lens of Lyell's "gradualism," where present-day features were shaped by millions of years of low-energy, continuous processes. Though still powerful, uniformitarianism is a doctrine facing many problems, to the extent that Reed (2010) suggested that even the term be retired in favor of the prior "actualism."

Whitcomb and Morris (1960) sparked renewed interest in the Genesis Flood. Clearly, the rock record shows widespread evidence of discontinuity, which is a problem for secular uniformitarians, though not for Christians who acknowledge God's work in Creation and the Flood (Reed and Williams, 2012). High-energy, short-term events played a primary role in shaping Earth's crust (Reed et. al., 1996; Reed, 2005).

Today, secular interpretations of earth history have more in common with the biblical view than many geologists know. Both adhere to a linear view of time, a Christian innovation (Greeks believed in cyclical time, and Hindus and other Eastern religions still do). Both acknowledge catastrophism. Where they differ is that a biblical view allows for continuity in the will of God alone. God's chief and ultimate end in creating the world was the manifestation of His own glory in the happiness of mankind (Edwards, 2006). And Scripture is clear that God reveals His glory in both natural and supernatural ways. Therefore, the biblical view of nature acknowledges discontinuity of "natural laws" and the reality of miracles, while secular neocatastrophist and "actualistic creationism" views do not (Reed and Williams, 2012).

Most who study Earth's past also fail to realize the vast differences between natural history research and scientific research. Simply put, natural history research is about interpretation, while scientific research is about verification. Natural history research is a mixed question (Adler, 1965; Reed and Williams, 2012), one that requires the use of multiple tools, including scientific tools and historical documents like Scripture. The goal of natural history research is to come up with the best interpretation of past events, while humbly acknowledging that other interpretations are possible.

Scientific research is about repeatability, while natural history research is about interpreting an unrepeatable event. It also follows that "futurology" is not the same as scientific research either. Futurology is about using scientific methods to make futuristic claims that are almost impossible to verify. For example, daily weather predictions are easily verified, while long-term climate models are not.

No Room for "Millions of Years" Interpretations

Scripture does not provide a place for "millions of years." What it does provide are genealogical records that result in thousands of years of history, not millions. Letting Scripture interpret Scripture, we look at the Creation days in Genesis 1, with their self-evident reference to normal, 24-hour days, and see confirmation of this in Exodus 20:11 and 31:17. When we read in Romans 1:20 that "since the creation of the world, His invisible attributes are clearly *seen*" (NKJV), it is again self-evident that those doing the "seeing" must be humans. Some Christians find places to add massive amounts of time to the biblical narrative, while at the same time forgetting that we are not supposed to add or take away from His Word (Proverbs 30:6; Revelation 22:18–19).

Novarupta-Katmai

While reasons exist to believe the earth and universe are billions of years old, the purpose here is to provide further evidence that there are no *good* reasons. Geologists like to say, "Every rock has a story," and this is true. Unfortunately, most of those stories we can only speculate about, because no human was there to record the events.

However, such is not the case for Novarupta volcano, one of the largest eruptions in recorded history (Figure 1), and 30 times larger than Mt. St. Helen's 1980 blast (Shormann, 2010). Also referred to as "Novarupta-Katmai," its one hundredth anniversary was in 2012. It erupted violently June 6–8, 1912, depositing up to 700 feet of ash and tephra in places (Shormann, 2010). It was so massive that if it occurred at New York City, it would have engulfed all of Manhattan Island and an equal area besides (Griggs, 1922). We also know that after June 8, 1912, there was one more dome-forming event at Novarupta; a dacite dome was blasted out and replaced by the current rhyolitic dome (Hildreth and Fierstein, 2012). The exact date of this dome-forming event is unknown, but seismic recordings suggest it happened in the months following the June 6–8 blast (Hildreth and Fierstein, 2012). The first photograph of the dome was taken by Robert Griggs in 1917, and while releasing far less steam and other gases, the shape of the dome is basically the same today (Figure 2).

Whether you believe in thousands of years or something vastly greater, one thing all natural history researchers are trying to do is match an idea with reality. For Creation researchers, the "idea" is that Scripture reveals a pattern of Creation/Flood/Ice Age/Present. We look for evidence in nature where this idea matches what we see. And we find it everywhere, including at Novarupta (Figure 3). Readers who favor secular models start with the notion that long-term, low-energy events are the dominant shapers of earth's crustal features. But is this pattern really that evident in nature? Also, since high-energy events are now so infrequent, we know very

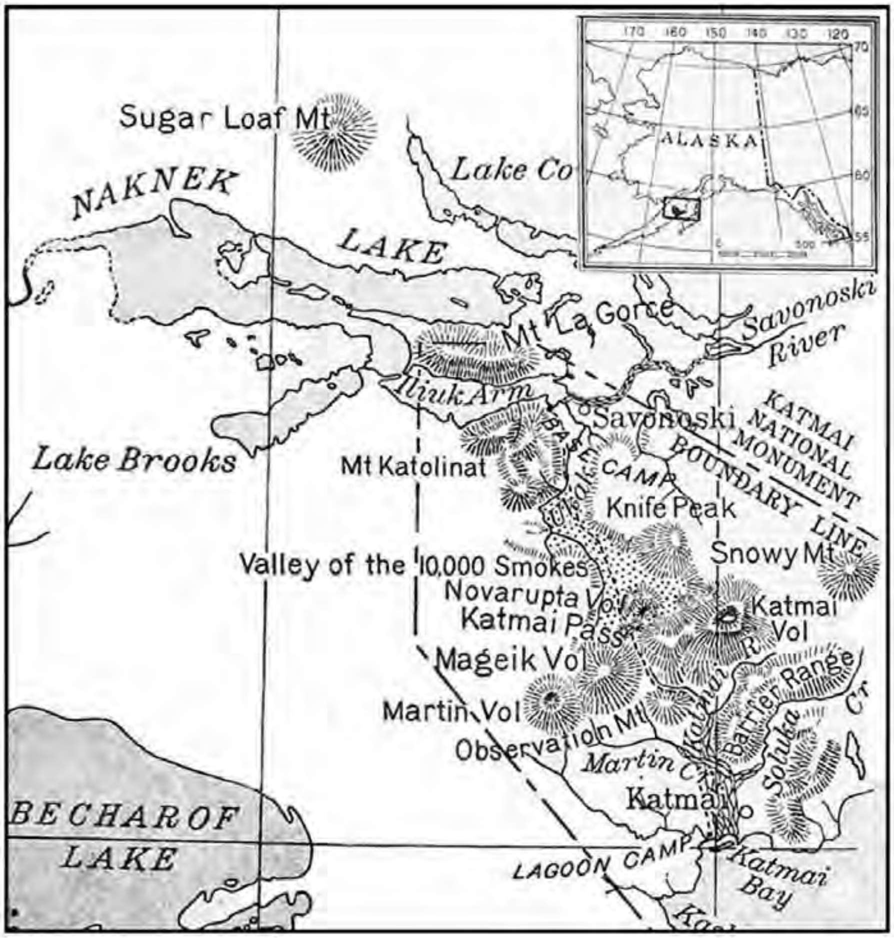

Figure 1. Map of The Valley of 10,000 Smokes, modified from Griggs (1922).

little about physical processes that might be associated with high-energy events, such as accelerated nuclear decay (DeYoung, 2005; Vardiman et. al., 2005).

Radiometric Dating and "Excess Argon"

Currently, radiometric dating is the dominant method used as evidence supporting secular models of earth history. In a nutshell, radiometric dating involves measuring the ratio of a radioactive isotope to its decay product. The older a rock, the more decay product it should contain. A more thorough understanding of radiometric dating fundamentals is found in DeYoung (2005).

This paper focuses on the $^{40}Ar/^{39}Ar$ method, and its predecessor, K/Ar. McDougal and Harrison (1999) give a thorough review of the method and its assumptions from a "deep time" perspective. The Ar/Ar method is believed to be more accurate, though when researchers dated samples less than 2,000 years old, the result were in error by over 70% (Overman, 2010). ^{40}Ar is the decay product of radioactive ^{40}K (^{40}K also decays into ^{40}Ca). ^{39}Ar is produced by placing

Figure 2. Novarupta then (left, from Griggs, 1922, p. 280) and July 2009 (right).

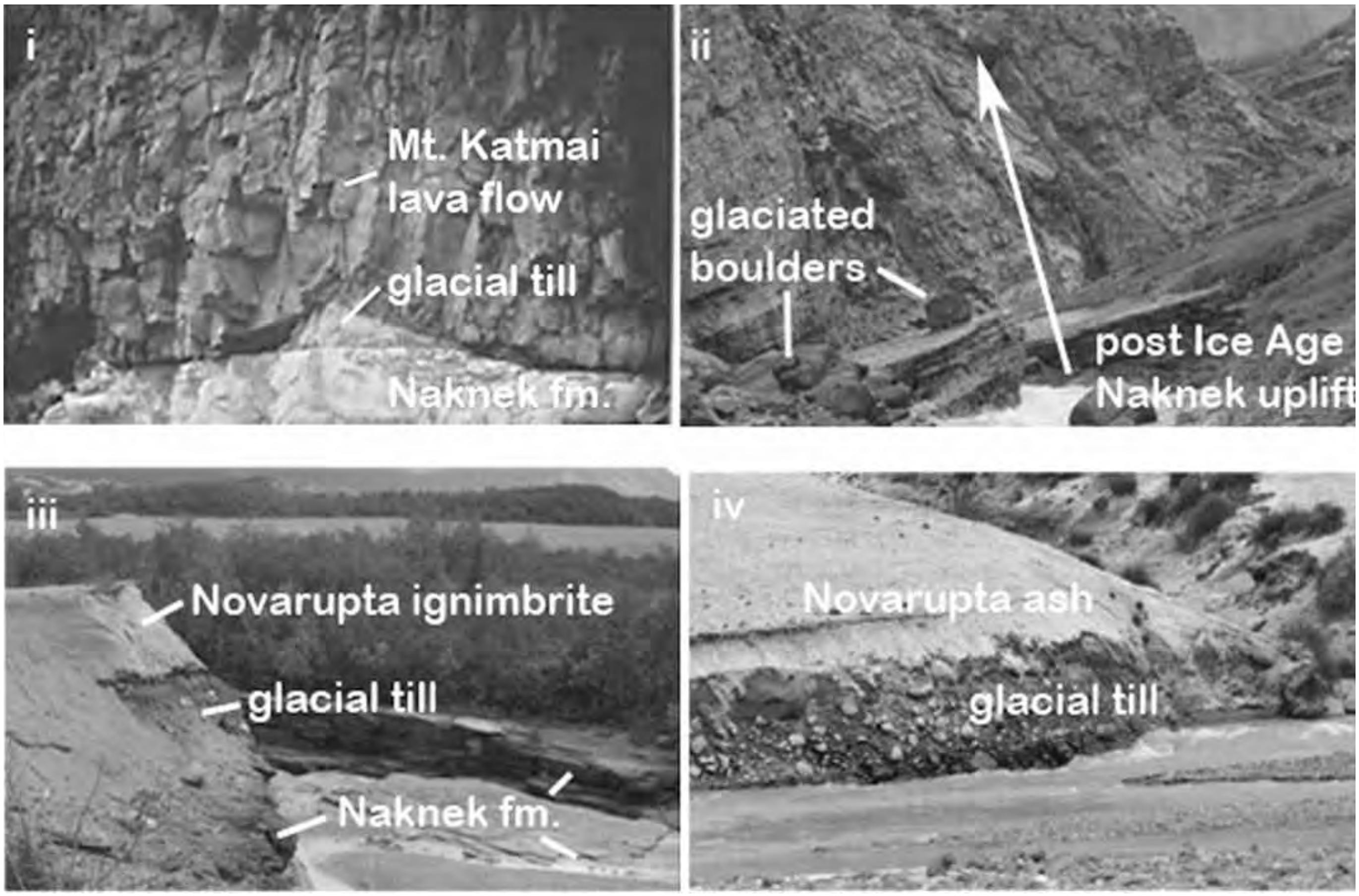

Figure 3. Evidence of the Creation/Flood/Ice Age/Stasis pattern is everywhere in the Novarupta-Katmai region. The water-deposited and sedimentary Naknek formation was probably a Flood deposit, followed by Ice Age glacial action, with volcanic mountain forming during and after glacial retreat. Photo i from Katmai Canyon by Griggs (p. 125). Photo ii (2011) shows post-Ice Age uplift of Naknek formation between Mount Katmai and Noisy Mountain, with glacially smoothed boulders still resting on uplifted blocks. Photo iii shows Flood/Ice Age/Stasis pattern along upper Ukak River. Photo iv (2011) shows Ice Age/Stasis pattern in extreme upper Katmai Valley.

the sample in a nuclear reactor and bombarding it with fast neutrons, converting ^{39}K to ^{39}Ar. This allows for two gases to be measured in a mass spectrometer, reducing the chances of measurement errors (Snelling, 2009). Assuming the ratio of $^{40}K/^{39}K$ is a constant, the ^{39}Ar is therefore an estimate of the original parent amount of ^{40}K. Or:

$$^{40}Ar/^{39}Ar = {}^{40}Ar/^{40}K \quad (1)$$

Radiometric dates from samples of unknown age cannot be verified. Problems with the Potassium-Argon (K/Ar) method were noted early in its application, particularly the problem of "excess" argon contained in samples (Aldrich and Nier, 1948). Some samples had so much excess argon that they gave apparent ages of 9 Ga (billion years ago); almost twice Earth's secularly assumed age (Harrison and McDougal, 1981). Woodmorappe (1999) showed how the "excess argon" label is invoked as a way to discount once-accepted Ar-Ar dates. Since the secular Earth age is actually not verifiable, is it also possible that most, if not all K/Ar and Ar/Ar samples contain excess argon? Results from a study of over 500 articles suggest there is excess (Overman, 2013).

Dates obtained from rocks of known age provide the best samples for demonstrating the method's unreliability. Overman (2010) showed that Ar/Ar measurements made by Renne et al (1997) on Mt. Vesuvius were 72% older than the known eruption date. Austin (1996) sampled the recently cooled dacite lava dome formed atop Mt. St. Helens on October 26, 1980 and found it contained up to 2.8 million years' worth of excess argon. Similarly, Snelling (1998) sampled the June 30, 1954 andesite lava flows from Mt. Nguaruhoe, New Zealand, which measured up to 3.5 million years' worth of excess argon. Other examples are cited in Snelling (2009, pp. 804–806), who also summarizes many Ar/Ar method pitfalls. In addition, John Woodmorappe tabulated hundreds of examples where K/Ar and other radiometric ages differed from expected ages (Woodmorappe, 1979).

Researchers offer many possibilities for this extra argon, the most common being that it was "inherited" from surrounding rocks. One of the supposed benefits of the K/Ar and Ar/Ar methods is that the hotter a rock is heated, the greater the amount of gas that will diffuse out of it. Molten rock, therefore, should release all of its argon, so that when the rock crystallizes, it will be set to "zero" (Dalrymple and Lanphere, 1969). However, several years before Dalrymple and Lanphere made their claims (which Dalrymple repeated in 1991), researchers had discovered that under high temperatures and high argon pressure tests, common crustal rocks absorbed up to 5 billion years of excess argon (Karpinskaya et al., 1961)!

For magmas and lavas, the effect of pressure on gas solubility is understood with Henry's law, which describes the solubility of a gas as directly proportional to the partial pressure of that gas in surrounding fluids. Applying Henry's law, K/Ar dating method pioneer Garnis Curtis (Dalrymple was one of his graduate students) stated, "Magmas formed at depths of 50 to 100 km are under sufficient confining pressure to keep significant quantities of old radiogenic argon in solution, argon that has been formed from ^{40}K decay deep within the earth" (Curtis, 1966). Also, Funkhouser et al. (1966) suggested that phenocrysts formed at depth would have higher Ar values than those formed at shallower depths.

It is clear that a rock can gain or lose argon, depending on its environmental conditions. Therefore, samples from volcanic eruptions of known age that give extremely old dates are assumed either to have inherited argon from surrounding rocks or to be remnants of older rocks, broken off and blasted out without the chance to completely degas.

Unfortunately, follow-up questions are usually left unanswered. What is the source of argon in the surrounding rocks? And if they lost some of their radiogenic argon, would they not yield an anomalously young age? If argon is so mobile, would it not be better to use K/Ar and Ar/Ar ratios as tools to study a rock's environmental history, as Kirsten suggested back in 1966 (see p. 7)?

Methods of K/Ar Measurements

Previous Measurements

Novarupta is no stranger to radiometric age-calibration experiments. Dalrymple and Lanphere (1969) mention that a boulder-sized granitic xenolith collected by Curtis (1966) from the welded tuff of Novarupta gave an age of 4 million years, when Curtis said it is supposed to be 150 million years old. They concluded that it did not get hot enough to lose all of its argon. But they also said, "Apparently, volcanic rocks cool much too quickly, leaving insufficient time for complete degassing to occur" (Dalrymple and Lanphere, 1969, p. 143). But if volcanic rocks cool quickly, that also means magma along the edges of a conduit could cool and form granite, and be just a few years (or days?) old at the time of an eruption. After all, rapid granite formation is possible (Snelling, 2008).

Dalrymple and Lanphere (1969) also noted that a Sierra Nevada basalt flow, which being hotter should have experienced more degassing, contained a granitic xenolith from a 90 Ma pluton with a K/Ar age of 2 Ma. They concluded this meant it retained 2.2% of its argon. Then, at Katmai, the welded tuff xenolith (cooler, so less degassing) retained 4/150 (2.7%) of its argon. Dalrymple and Lanphere (1969, p. 143) stated, "Xenoliths in welded tuffs can be expected to retain even more of their radiogenic argon, because welded tuffs are erupted at temperatures several hundred degrees lower than basalt." But 0.5% more is hardly "more" and avoids the question of why there was so much excess argon.

Adding further confusion, expert Wes Hildreth (personal communication, Nov. 9, 2011) claimed the granite underlying Novarupta was not 150 Ma but "Miocene," meaning a secular age around 5–20 Ma. If correct, the Novarupta xenoliths therefore retained 4/15 (27%) of their original argon, and a Miocene age for the granite makes Dalrymple and Lanphere's conclusion more reasonable. But another alternative is that the measurements are more relevant to the environmental history of the granite, which includes temperature, pressure, chemistry, and rate of cooling. It is also curious how the granite beneath Novarupta-Katmai "lost" up to 145 million years in age between 1966 and 2011.

The big assumption here is that the granitic xenoliths formed millions of years ago but retained some radiogenic argon despite heating and degassing. But there is no way to know for sure if this is what happened. Only the K/Ar method has been used to date the Novarupta granite. Multiple methods should be used and should match. The most reliable method for age-dating the xenoliths is an eyewitness account, and this seems to be ignored. And, finally, if this granite boulder really did lose argon from heating, there is no reason to believe it should have lost it uniformly. Could not some of the argon, especially in the core of the boulder, remain trapped? Why would the entire boulder be homogeneous? The fact that it is homogeneous (Curtis, 1966) suggests to me that the granite cooled rapidly at a fairly constant T and high pressure, trapping argon from the environment, or possibly from within.

Beside the granitic xenoliths, Curtis (1966) also tested the K/Ar method on Novarupta-Katmai rhyolite pumice, which gave an age less than 10,000 years. Curtis (1966, p. 154) said, "We found the contents of ^{40}Ar to be less than would give an age of 10,000 years, or within the experimental limits of detection." So it sounds as though they found radiogenic argon, just not that much.

It is interesting to note that pumice forms so rapidly that it solidifies at normal atmospheric pressures while flying through the air. Therefore, it is an ideal candidate for having its "argon clock" set to zero. One alternative hypothesis to that of Curtis (1966) and Dalrymple and Lanphere (1969) is that the Novarupta granite, an intrusive rock (formed underneath earth's crust), solidified at a high pressure, which meant more Argon was dissolved in the magma it solidified from, giving it an old radiometric age of 4 million years. The Novarupta pumice, though, which is an extrusive rock (formed above earth's crust), formed at normal atmospheric pressures, which is why it had so little radiogenic argon.

New K/Ar Measurements

So what would a Novarupta sample that was neither pumice nor granite reveal if age-dated? A rock from its rhyolite dome would not degas as much as pumice but more than rapidly formed granite from depth. Rhyolite is the extrusive form of granite and forms at or near earth's surface.

A fist-sized sample was collected from the top of the Novarupta lava dome on July 28, 2009 (Figure 4). Hildreth and Fierstein (2012) describe the current Novarupta dome as 95% rhyolite (76–77% SiO_2) streaked with 5% andesite and dacite. A major assumption of both the K/Ar and Ar/Ar methods is that the ^{40}Ar generated from the decay of ^{40}K escapes continually until the rock solidifies and cools (Dalrymple and Lanphere, 1969). Therefore, the rhyolite at the top of the dome (841 m above sea level) should have lost its excess argon before cooling, unless it cooled too quickly to release it. Also, since it was not surrounded by rocks with higher argon concentrations, it would not be possible to inherit argon from anything else. The sample also showed evidence of hydrothermal alteration, at least on the outside surface, providing more evidence that it was heated to high temperatures after solidifying, giving it further opportunity to reset its radiogenic argon to zero. Hildreth and Fierstein (2012) noted that the magma temperatures for the rhyolite dome probably exceeded 830° C, much higher than typical melting temperatures for rhyolite (650–800°C). Several decades ago, Bowen (1956) showed that high silica rocks have lower melting points than more mafic rocks.

Figure 4. Left: July 28, 2009, author photo from top of Novarupta lava dome, looking west. Dark-colored mountains in background are the Buttress Range. Ash-covered Baked Mountain is on the right. Part of Falling Mountain is visible in the left foreground, with Mount Cerebrus directly behind it. Right: Novarupta rhyolite sample prior to sending off for analysis (Photo by Larry Bledsoe).

Thus, during a massive eruption, like Novarupta, rhyolites would be in the liquid phase the longest and therefore have the greatest chance to release any excess argon.

The photograph Griggs took in 1917 of the Novarupta dome (Figure 2) also provides evidence of high temperatures at the surface several years after the eruption. Everything about the Novarupta sample (Figure 4) is favorable for having its "argon clock" set to zero upon solidifying.

Following collection, the sample remained at room temperature in a sealed plastic bag until shipped for analysis in May 2012 to the New Mexico Geochronology Research Laboratory (NMGRL). Interaction with NMGRL was conducted by Larry Bledsoe, owner of Chemical Sampling Services.

Prior to sample analysis, NMGRL asked us to estimate the sample's age. Although concerned this might introduce bias, we agreed and gave an estimate of 30–50 Ma, which is the secular age for the Naknek formation underlying the Novarupta-Katmai region. One way an age estimate leads to bias is in the Ar/Ar step-heating procedure. The NMGRL website specifically states "the heating schedule varies depending on what type of material is being analyzed and *how much information we are trying to obtain*" (NMGRL, 2013a, emphasis added). Since an older age, i.e. "more information," was estimated for this sample, it was heated longer and hotter than if we had estimated a younger age (see Discussion). The choice of fluence monitor is based on the age estimate given. For the Novarupta sample, NMGRL used the Fish Canyon Sanidine (assigned "age" = 28.02 Ma; Renne et al., 1998) as the standard.

The bulk sample (SAES 51012) was initially prepared by crushing, sieving, and then washing away clay-sized material. The mineral separate and fluence monitors were loaded into aluminum discs and irradiated for 40 hours at the USGS TRIGA reactor in Denver, Colorado. Nuclear irradiation with fast neutrons converts non-radiogenic K-39 to Ar-39. The groundmass concentrate was analyzed as a bulk sample with the incremental heating age spectrum method using a defocused CO_2 laser. Although temperatures were not specified, the 10 heating steps ranged from a power setting of 19 W to 50 W. More detailed methods are available on the New Mexico Geochronology Research Laboratory website (NMGRL, 2013b) and in NMGRL (2013c).

Results

Although below detection limit levels of radiogenic Argon (labeled as Ar*) were expected based on normal Ar* assumptions (Dalrymple and Lanphere, 1969, pp. 50–51), sample SAES51012 contained 3.6% radiogenic argon (Figure 5). Individual heating steps gave apparent ages as high as 5.5 Ma.

Two of the steps (C and D) gave negative ages, which NMGRL attributed to analytical problems. Steps C and D contained gas (possibly hydrocarbons) that was difficult for their extraction line to clean up (NMGRL, 2013c). This is a reasonable assumption regarding the analytical error, especially since Griggs (1922) confirmed the presence of hydrocarbons at the Novarupta dome.

By summing the product of each step's apparent age and the $\%^{39}Ar$ released, an "integrated age" can be estimated. Excluding steps C and D gives an integrated age estimate of about 2.36 ± 0.05 Ma.

Discussion

The integrated "age" estimate of 2.36 Ma falls between Curtis's (1966) pumice sample (<10,000 years) and granitic xenolith (4 Ma). Excess argon is what one would expect if the argon concentration in a sample were really more a function of environmental conditions when the rock solidified. It is not what one would expect if the Ar/Ar method were a reliable age-dating tool. If the Ar/Ar method were reliable, then sample SAES51012 would have below-detection-limit levels of Ar*.

An important part of the Ar/Ar method is the "step-heating" process, where temperature is increased in a stepwise manner in a vacuum, and all the argon released in each step is pumped off before the temperature is raised for the next step. The step heating can reveal important information for a sample's environmental history, such as whether or not it appears that subsequent reheating events added or removed argon from the rock. Lower temperature steps often have less radiogenic argon, and higher temperature steps have more. The Novarupta rhyolite sample followed this trend (Figure 5, top). The trend is attributed to low-temperature anomalies causing argon to diffuse away from the outer edges of crystals.

As Dalrymple (1991) stated, high temperatures encourage argon release. What this also means is that during step heating, the amount of heat, and the duration a rock is heated, can greatly influence the amount of argon released. As previously mentioned, NMGRL admits "the heating schedule varies depending on what type of material is being analyzed and *how much information we are trying to obtain*" (NMGRL, 2013a, emphasis added). But that also means sample "ages" can be adjusted to match predicted "ages," simply by heating the samples for certain durations using certain temperatures, while excluding data that do not fit the estimate.

Apparently, this happened when Renne et al. (1997) attempted to use the Ar/Ar method to date a sample from the AD 79 eruption of Mt. Vesuvius. They presented their Ar/Ar isochron age of 1,925 ±94 years as an example of the method's accuracy. But to get the isochron age of 1,925 years ago, they ignored the first two steps in the step-

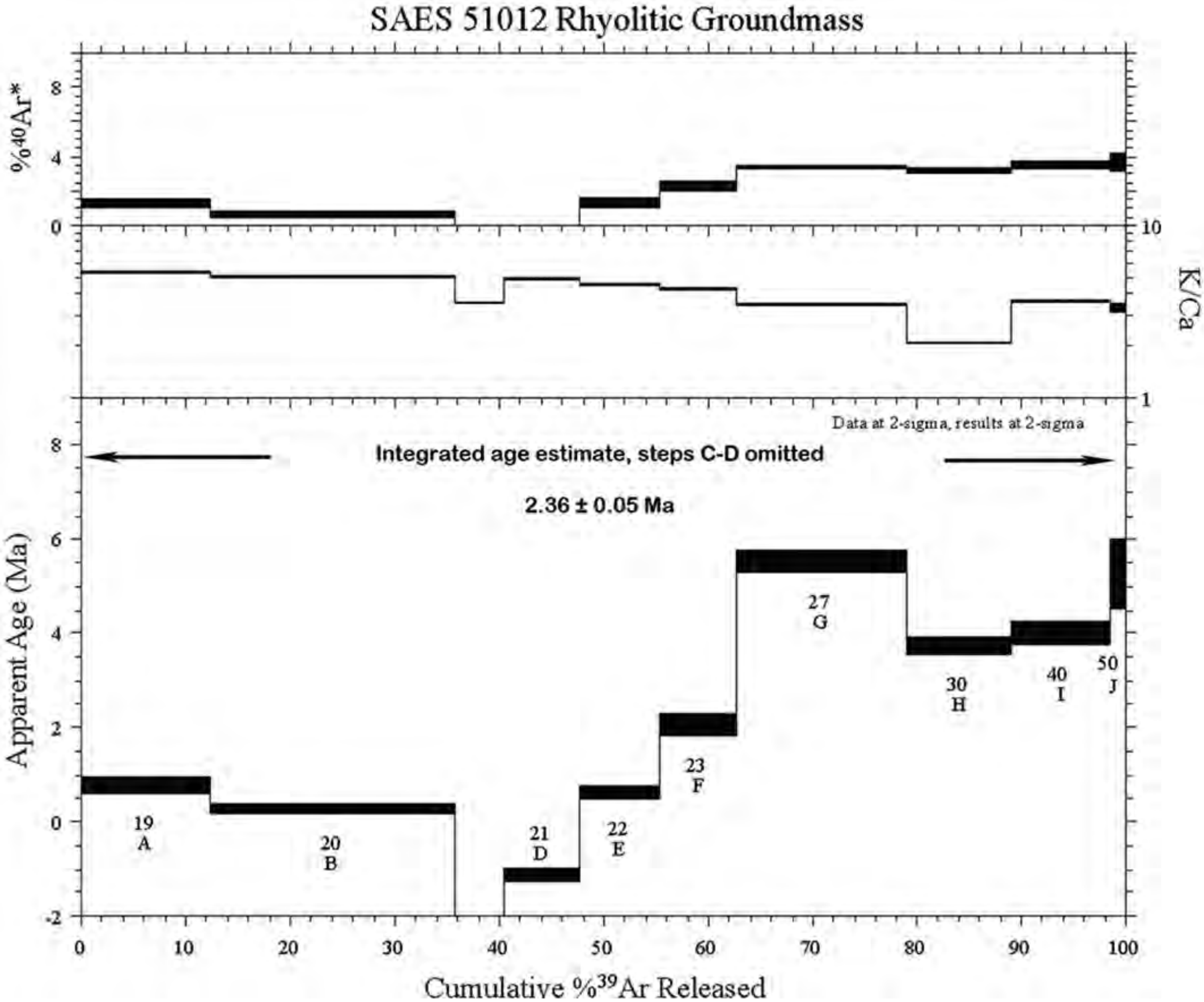

Figure 5. Step heating results for % radiogenic argon (Ar*) released (top), K/Ca ratio (middle) and apparent ages in millions of years (Ma) (bottom). Black bars at top of each step represent 2-sigma errors.

heating process, one of which gave an apparent age of 521 Ka. But this step contained less than 1% of the total ^{39}Ar released. More important, the heating steps were from 1–20 W, which is cooler than the 19–50 W settings used to heat the Novarupta sample. Both studies used a CO_2 laser to heat the samples. For Novarupta, over 50% of the ^{39}Ar released was from temperatures greater than 20 W (Steps E-J were between 21 and 50 W). These steps also gave the highest apparent ages (Figure 5).

In addition, Overman (2010) showed that the Renne et al. (1997) total gas date of 3,300 years was actually a better fit to the mathematical model used to calculate the date, which meant their results gave an Ar/Ar age 72% older than expected. The question remains: What would the Mt. Vesuvius data reveal if heated over 20 W? Or what if the heating range stayed the same but the duration of each step was increased? Either way, it is likely that more argon would be released, giving an even older date.

If there ever was a rock sample to so closely approach the Ar/Ar assumption of zero initial argon, the sample from the top of the current Novarupta dome should be it. So why did it have up to 5.5 Ma worth of excess Ar?

Possible Explanations for the Excess Argon

1. The sample absorbed excess argon from surrounding rocks. The current Novarupta lava dome was the third (second at Novarupta's vent) and last dome to form in the Novarupta-Katmai eruption (Hildreth and Fierstein, 2012, Fig. 60). Evidence exists that the rhyolite lava for the dome was formed in a shallow reservoir (Shormann, 2013). As discussed previously, solubility, as well as diffusion of argon into a rock, is known to increase with increasing temperature and pressure (the deeper it is, the higher the Ar concentration); but if the rhyolite was formed in a shallow chamber, then it had a better opportunity to release any excess argon. Furthermore, since the rhyolite dome was the last dome to form, it pushed up through newly solidified and deposited material from the June 6–8, 1912 eruption. Deposits are 700 feet thick surrounding Novarupta's vent (Shormann, 2010). If Dalrymple and Lanphere's (1969) assumption of zero initial argon is true, it does not seem that the newly formed surrounding rocks would have much argon to transfer to the rhyolite magma before it solidified.

2. The rhyolite magma solidified at depth, where argon concentrations might be higher. Recall that Curtis (1966) attributed the 4-million-year-old "age" of a granitic boulder blasted out of Novarupta to the possibility that the granite was attached to the sidewall of Novarupta's vent and became dislodged and ejected outwards. Curtis assumed the granite was not heated sufficiently during the eruption to release all of its argon. But granite can form rapidly (Snelling, 2008). And if granite can form rapidly, this also leads to the possibility that the extrusive rhyolite dome solidified rapidly at a shallower depth than Curtis's intrusive granite, which is why the rhyolite appears to have less excess argon. However, it is unknown how deep the current Novarupta dome was when it formed. Evidence surrounding the dome suggests that it rose in the months after the eruption. Above it was a rapidly cooled dacite dome, which was blasted out from the gas pressure that built up underneath (Hildreth and Fierstein, 2012). The gas pressure was provided by open-system degassing of the rhyolite, as well as steam buildup from groundwater (Hildreth and Fierstein, 2012). The large amount of open-system degassing that occurred most likely included argon gas from the rhyolite, making the shallow rhyolite a superb candidate for having its "argon clock" set to zero. Also, sample SAES51012 was collected from the top of Novarupta's dome (Figure 4), where any effect from Henry's law would be the least.

3. Magma chemistry affects argon retention. Austin's work on Mt. St. Helen's dacite dome suggests different magma types vary in their ability to release excess argon before solidifying (Austin, 1996). He found that more mafic minerals like orthopyroxene retain the most argon, followed by hornblende, and finally, plagioclase. Minerals more common in basalts like orthopyroxene also have the highest melting temperatures, so they would be expected to crystallize deeper in the magma chamber, where argon concentrations are expected to be higher (Curtis, 1966; Austin, 1996). The NMGRL report for the Novarupta sample supports this idea, mentioning that basalts giving similar secular ages to the Novarupta rhyolite normally have almost 3 times more Ar* than the Novarupta rhyolite (NMGRL, 2013c). The correlation between magma chemistry and argon retention supports the idea that K/Ar and Ar/Ar values are better suited as tools to study environmental histories of magmas (Snelling, 2005; Snelling, 1998; Austin and Snelling, 1998).

4. Atmospheric contamination. The model used to estimate % radiogenic argon accounts for atmospheric argon, assuming the ratio of ^{40}Ar to ^{36}Ar in the atmosphere is a constant value of 295.5 (NMGRL, 2013b). Since the sample was collected from the surface, any heating events after the dome formed should have helped equilibrate the rock with atmospheric levels of ^{40}Ar. Also, the dome rests approximately 831 m above sea level, where atmospheric pressures are lower, allowing even more gas to escape than at sea level.

5. Accelerated decay caused the excess argon. A primary assumption of radiometric methods is that the isotope's decay rate remains constant (Dalrymple and Lanphere, 1969; McDougal and Harrison, 1999). Everything about the Novarupta sample suggests it should have had near-zero radiogenic argon in 1912 or even later. So where did its extra 3.6% radiogenic argon come from? The RATE project provided multiple lines of evidence for accelerated nuclear decay during the Creation, the Fall, and the Flood (Vardiman et al., 2005; DeYoung, 2005). However, Froede and Akridge (2012) note that the RATE evidence alone is insufficient and suggest accelerated decay should be considered only as an "interesting hypothesis." Indeed, having multiple working hypotheses (eliminative induction) is the best approach for conducting natural history research (Reed and Klevberg, 2011).

In working toward making accelerated nuclear decay a viable hypothesis, Froede and Akridge (2012) suggest directing efforts toward a radiometric-age date "conversion factor." A functional conversion factor might lend support to the accelerated decay hypothesis, providing a simple tool to convert secular timescales to biblical ones. However, this idea assumes that radiometric methods are actually capable of estimating the timing of past events.

What if radiometric decay rates are not constant and radioisotopes are really more of a "signature" describing conditions at the time of rock formation? In

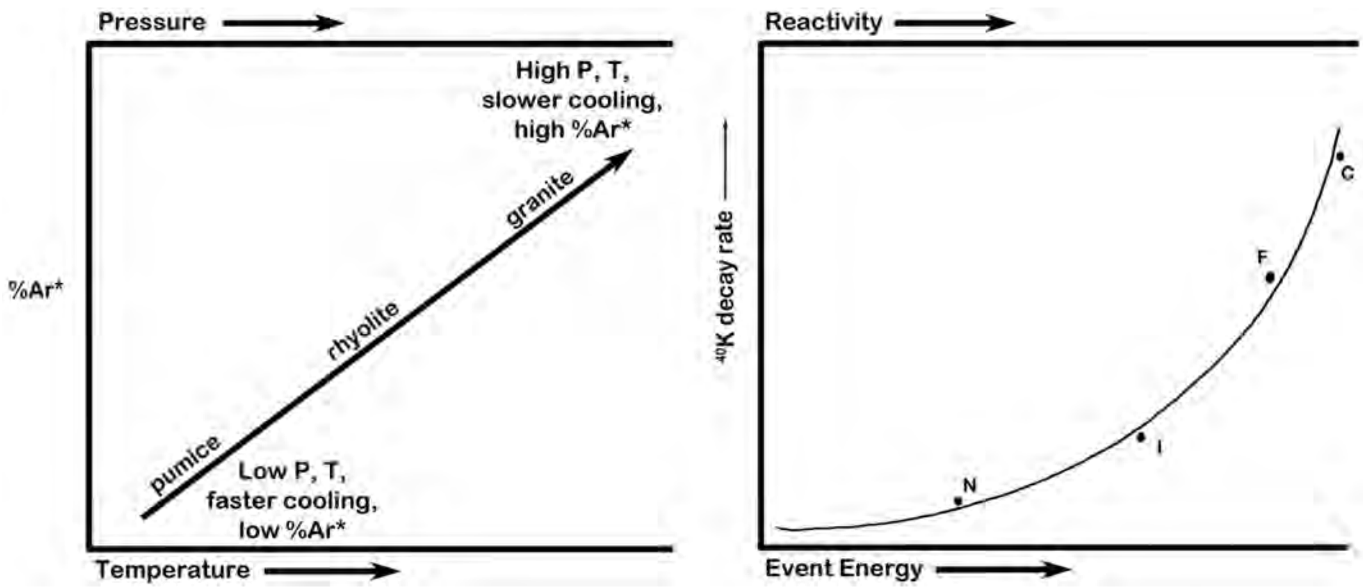

Figure 6. Left: Possible scenario for the excess argon found in igneous rocks. Faster-cooling extrusive rocks like pumice will have little time to generate excess argon by accelerated decay, while slower-cooling intrusive rocks like granite have more time spent in environmental conditions favorable for both accelerated nuclear decay and inheritance of extraneous argon. Right: Hypothetical continuum for ^{40}K decay rate as a function of event energy. Data points show possible locations of Novarupta (N), Ice Age supervolcanoes (I), Flood (F), and Creation (C).

mathematical terms, what if $dN/dt \neq -kN$? What if this relationship is too simplistic and rates are actually a function of multiple environmental conditions like event energy, temperature, pressure, and magma chemistry, as hypothesized in Figure 6? Evidence supporting the assumption of constant decay rates exists (Dalrymple and Lanphere, 1969), but research also shows rates are not always constant. For example, studies show that environmental conditions affect electron capture, the same process by which ^{40}K converts to ^{40}Ar (McDougal and Harrison, 1999; Walker, 2000). Is it possible that radioisotopes are more helpful as "envirometers" than as "chronometers?"

The Novarupta rhyolite seemed like an excellent sample for having its "argon clock" set to zero, but this zero setting was not detected. If the excess argon did not come from extraneous sources, then what if it came from within by accelerated ^{40}K decay (Figure 6)? Pumice expands greatly and cools rapidly, so fast that the expanding gas bubbles "freeze" in midair, giving pumice its high porosity. Rapid cooling and expansion would leave less time for accelerated decay to have an effect, resulting in Curtis's 1966 pumice samples having the lowest Ar* levels recorded at Novarupta. Surface- and near-surface-cooled materials like rhyolite follow, and finally intrusive rocks like granite (Curtis, 1966) that cool the slowest. If accelerated decay is not just an anomaly of events like Creation, the Flood, and Ice Age supervolcanoes (Austin, 1998) and environmental conditions do affect it, then slow-cooling samples would have higher Ar*, and fast-cooling samples would have less.

Summary

In the twenty-first century, high-energy, short-term events like Creation and the Flood are nonexistent. We do not have a way to replicate these events. We can only speculate about physical processes that occurred during these events that do not seem to occur today. However, catastrophic events like Novarupta provide a glimpse into this mysterious world, revealing clues of physical processes that may be associated only with high-energy events.

Results presented here provide no good reasons to believe the 2012 Novarupta rhyolite dome sample shows anything but a problem with excess argon in samples. This is not a new problem, as Curtis (1966) found the same problem with Novarupta pumice and granite samples, and his samples were almost 50 years younger than the sample used here. In addition, bias is introduced to the method because technicians request an age estimate prior to analysis. Technicians use the estimate to adjust the duration and temperature settings for the step-heating process, to choose a fluence monitor, etc.

It does seem, though, that Ar/Ar ratios and the step-heating method are useful aids for interpreting the environmental history of igneous rocks, while revealing evidence for accelerated nuclear decay and/or argon solubility being affected by temperature, pressure, and magma chemistry. In any case, all age-calibration studies from Novarupta reveal a major flaw in the assumption of zero initial argon. Because this assumption is flawed, the method is flawed and therefore should be rejected as a tool for estimating sample age.

All natural historians, regardless of their interpretive framework for natural history, should be highly skeptical of radiometric dating techniques. Because Scripture, not experimental evidence, is the ultimate authority for Creation researchers, the burden of proof lies with adherents of "deep time" to explain why reasonable people should accept the results of radiometric dating as fact (Woodmorappe, 1999). The author hopes this study will encourage all readers to put less faith in the idea of "deep time" and more faith in Scripture as a true and reasonable historical account.

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