

# Argon diffusion data support RATE's 6,000-year helium age of the earth

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Here I present a new analysis of old (1986) argon retention data from the same borehole that provided helium retention data for the Radioisotopes and the Age of the Earth (RATE) research initiative.<sup>1</sup> The deepest part (4.56 km) of the borehole was hot enough to cause more than a 20% loss of radioactivity-generated argon-40 from feldspar in the granitic basement rock, conventionally dated to be 1.5 Ga old. Data and equations from the 1986 article show that at the present temperature (313°C) at that depth, it would take only 5,100 (+3,800/-2,100) years for the feldspar to lose that much argon. This supports the 6,000 ( $\pm 2,000$ ) year helium diffusion age that RATE found for zircons in the same borehole.

## Old article interprets argon data oddly

In a recent letter to this journal,<sup>2</sup> Gary Loechelt, a critic of the RATE helium project, focused my attention on a paper about past temperatures in the borehole (figure 1) that provided the helium data we used. In 1986 the *Journal of Geophysical Research* published the article,<sup>3</sup> by T. Mark Harrison, Paul Morgan, and David D. Blackwell, three geoscientists at three U.S. universities. It was one of three articles I had cited about the temperature issue. Readers can see my detailed review of all three articles in my recent letter replying to Loechelt.<sup>4</sup> As I focused on the 1986 article, I saw that it appeared to ignore the heat that a nearby volcano would have provided to the borehole during the alleged one million years (1.04 Ma) since its last ash eruption. Instead, its authors thought (along with Loechelt) that the temperatures in the borehole were relatively low, e.g. at 2.9 km depth falling below 130°C 870 Ma ago and reaching 87°C more than a million years ago. Then only twenty thousand years ago, they claimed, the temperatures rose dramatically, by more than 100°C, up to the high values observed today.

This seemed quite odd to me, especially since a 1978 study<sup>5</sup> by the authors' Los Alamos colleagues showed that the nearby volcano would heat the borehole up to within 50°C of today's temperatures, maintaining that high temperature for (allegedly) the last 0.8 Ma. The temperature would have been a lot more if the magma body causing the volcano had been somewhat closer to the borehole than they assumed in that model. Confirming the latter, a 1989 study<sup>6</sup> of fluid inclusions in the rock gave data (not theory) that past temperatures in the borehole had peaked at levels about 50°C *higher* than today's levels. By conventional uniformitarian dating, the peak would have been about 0.9 Ma ago. I would have thought that Harrison *et al.* would be quite aware of the possibility of such heating from the volcano. So why did they want the borehole to be relatively cool (e.g. 87°C at a depth of 2.9 km) until very recently? Why did they ignore the volcano?

I will show below that it was probably because they knew borehole minerals could not have retained the observed large percentages of argon for hundreds of millennia at

anywhere near today's high borehole temperatures. Much more argon would have diffused out of the minerals. Here I will show that their argon diffusion data favor an age of only 5,100 (+3,800/-2,100) years. That strongly supports the helium diffusion age RATE found for zircons in the same borehole, 6,000 ( $\pm 2,000$ ) years.<sup>7</sup>

## Experimenters measured leak rates of argon in feldspar from GT-2

The deep Precambrian granitic 'basement' rock from borehole GT-2 contains not only zircons, but also a potassium-bearing feldspar called microcline ( $KAlSi_3O_8$ , figure 2). The potassium is mostly the stable isotope <sup>39</sup>K, but as with all natural potassium, about 0.01% of it is the

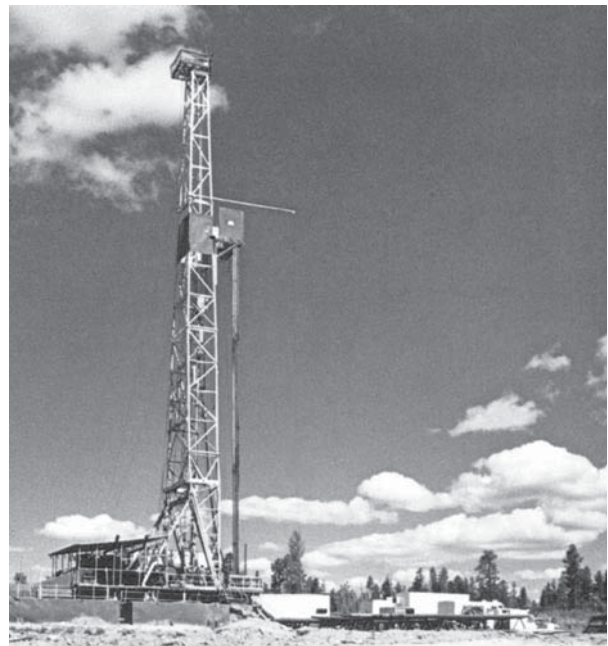


Photo by Los Alamos National Laboratory

**Figure 1.** Drilling rig for borehole GT-2 at Fenton Hill, New Mexico, USA, which provided the zircons used in the RATE helium project and the feldspar whose argon is the basis for this study.



Photo courtesy of www.wikipedia.org

**Figure 2.** Microcline feldspar from Colorado. Impurities in this variety (amazonite) color the normally-white crystals blue-green (colors in website version). Black crystals are smoky quartz.

radioactive isotope  $^{40}\text{K}$ . The latter decays (with a present half-life of 1.25 Ga) into two daughter atoms, one of which is the stable argon isotope  $^{40}\text{Ar}$ . So if a researcher finds out how much potassium is in the feldspar, he can use the  $^{40}\text{Ar}$  in it to try to estimate the age of the mineral.

Harrison *et al.* took samples of feldspar from five depths (table 1) in the borehole. Then they put them into a nuclear reactor for a calibrated length of time. The neutrons in the reactor convert some of the stable  $^{39}\text{K}$  into  $^{39}\text{Ar}$ . The latter is not stable, but its 269-year half-life is long enough to allow researchers to use it to estimate the amount of  $^{39}\text{K}$  in the sample. Comparing that with the  $^{40}\text{Ar}$  in the sample is the basis of the ‘argon-argon’ variety of potassium-argon dating.<sup>8,9</sup>

Then, in a vacuum chamber, they heated each sample in 50°C steps and measured how much of each argon isotope was released during each step. That gives the diffusivity  $D$  (‘leakiness’) of argon moving through and out of the feldspar at that temperature. More specifically, the rate of outgassing (fraction of the eventual total lost per unit time) gives values of  $D/a^2$  directly as a ratio, where  $a$  is the average radius of the crystals (or ‘diffusion half width’, which the authors symbolized with an  $l$ ). Harrison and his co-workers fit the values of  $D/a^2$  to the following equation:

$$\frac{D}{a^2} = \frac{D_0}{a^2} \exp\left(-\frac{E}{RT}\right), \quad (1)$$

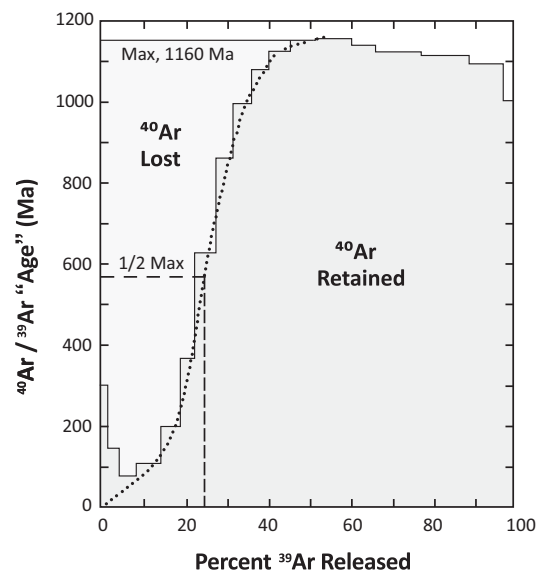
where  $R$  is the gas constant (1.986 calories per mole-Kelvin),  $T$  is the absolute temperature in Kelvin,  $D_0$  is the ‘frequency factor’, and  $E$  is the ‘activation energy’. The last two parameters are constant with temperature for any given sample, but are often different for samples from different locations. Here the authors got one set of values of  $D_0/a^2$  and  $E$  for depths 1, 2, and 3, and a different set of values for depths 4 and 5. I’ve shown both sets of values in table 1.

The authors’ report of the argon diffusivities leaves something to be desired for my purpose of determining age.

They show (in their figure 3) only the diffusivity data for depths 1, 2, and 3, not for depths 4 and 5. They report error bars for the former set but not for the latter, saying only that the parameters of eq. (1) for the two deeper samples are “~ 8,000 s<sup>-1</sup>” and “~ 44 kcal mol<sup>-1</sup>”. That suggests the fit, normally to a straight line on a plot of  $\ln(D/a^2)$  versus  $1/T$ , was not too good for samples 4 and 5. Perhaps that is because the slope of the fit starts to decrease at lower temperatures. Such a decrease is very common in naturally-occurring minerals.<sup>10</sup> In support of that idea, their figure 3 does not show any diffusion data at lower temperatures, showing only a straight-line fit from 700°C down to 400°C. Therefore the values of  $D/a^2$  in table 1 for the three shallowest depths, being extrapolated beyond the data down to rather low temperatures, are probably lower than the real numbers. However, it turns out that I only need data for the fifth sample, at 313°C. That is not far below the low end of the temperature range of the fitted data, so the extrapolated value in the table should be good enough.

### Feldspar from hottest parts of borehole lost some argon

In the laboratory, the first argon emerging from a sample comes from the outermost parts of the crystals. Argon emerging later comes from deeper within the crystals. The  $^{39}\text{Ar}$ , having been produced in the reactor from  $^{39}\text{K}$ , is uniformly distributed throughout the crystals. But the  $^{40}\text{Ar}$  comes from  $^{40}\text{K}$  decaying *in situ* over a long time. If any  $^{40}\text{Ar}$  has leaked out of the crystals *in situ*, it will have come from the outer parts first. So any diffusion taking



**Figure 3.** ‘Age spectrum’ for sample 5 (4.56 km), giving  $^{40}\text{Ar}/^{39}\text{Ar}$  ratio released from the sample during heating steps. Lightly-shaded area represents  $^{40}\text{Ar}$  lost from the feldspar due to heating *in situ*. The dark-shaded area represents  $^{40}\text{Ar}$  that remained in the sample until it was heated to higher temperatures in the laboratory.

place down in the hot rock will leave the outer parts of the feldspar crystals depleted in <sup>40</sup>Ar.

Harrison *et al.* examined this issue by plotting ‘age spectra’ in their figure 2. Their graph showed, for each of the five samples, the <sup>40</sup>Ar-based ‘age’ on the vertical axis and the percent (of the eventual total) <sup>39</sup>Ar released on the horizontal axis. My figure 3 reproduces the curve for the deepest sample, number 5, adding the shading and annotation. The ‘age’ values of course depend on the assumption that nuclear decay rates have always been at their present slow rates. The peak of 1,160 Ma shows that over ‘one billion years’ worth of <sup>40</sup>K to <sup>40</sup>Ar decay occurred in situ. RATE hypothesized that occurred during several episodes of accelerated nuclear decay in the past, the more recent one being during the year of the Genesis flood. We also hypothesized an accelerated cooling mechanism that would get rid of much of the resulting radiogenic heat.<sup>11</sup>

Figure 2 by Harrison *et al.* shows that the curves for samples 1, 2, and 3 rose almost immediately to their maximum value. They estimated that sample 3 had lost less than 2% of its <sup>40</sup>Ar, and that samples 1 and 2 lost even less than that. Sample 4 showed a somewhat slower rise, representing a nominal 5% loss. But the authors thought that value was small enough to have been greatly perturbed by other factors:

“The combination of the small amount of <sup>40</sup>Ar\* [asterisk indicates radiogenic] together with some absorbed excess <sup>40</sup>Ar ... results in poor resolution of the outgassing event.”

However, the authors have more confidence in their estimate of the losses from the fifth sample (the one I show in my figure 3 above):

“This sample has apparently lost about 20% <sup>40</sup>Ar\* in response to the recently elevated temperatures.”

My figure 3 shows why I think ‘20%’ is a slight underestimate of the argon loss. The ratio of the areas in the lightly-shaded and dark-shaded regions should give the ratio of <sup>40</sup>Ar lost to <sup>40</sup>Ar retained. The intersection of the dashed ‘1/2 Max’ line with the dotted curve should specify the area ratio fairly well. The intersection occurs at 25%, not 20%. The 0.2 Max and 0.8 Max horizontal lines (not shown here) intersect the dotted curve at 19% and 33%. I will use

these values below to estimate an error range for the age. I’ve included my estimated 25% loss as a fraction in the bottom of the right-hand column of table 1. I put the losses Harrison *et al.* estimated in the other rows of the column. I’ve put parentheses around the less accurate values.

### Reckoning the argon diffusion age

Harrison *et al.* give an approximation,<sup>12</sup> their eq. (1) relates the heating time *t* and the fractional loss *f* to the value of *D/a*<sup>2</sup> at a particular temperature:

$$\frac{D}{a^2} \cong \frac{\pi f^2}{4 t} \quad (2)$$

Turning this around gives the time *t* it would take at constant temperature to get a loss *f*:

$$t \cong \frac{\pi f^2}{4 D/a^2} \quad (3)$$

Harrison *et al.* give an expanded form of this equation, their eq. (2), but it contains a typographical error (right-hand bracket in wrong place). I’ve included the resulting ages in the last column of table 1.

The only age that is relatively accurate is that of sample 5. Assuming that the 0.2 Max and 0.8 Max points (not shown) on the dotted curve of my figure 3 cover a range of error larger than all the other errors, we can assign the borehole an argon diffusion age of

$$5,100^{+3,800}_{-2,100} \text{ years}$$

After their eq. (2), Harrison *et al.* list similar results:

“Results of these calculations yield maximum estimates of peak heating duration of between 3 and 60 ka. This dispersion is in part due to the near negligible, and therefore difficult to estimate, <sup>40</sup>Ar\* loss from the four shallowest samples and the exponential dependence of temperature on heating duration.”

Since their assumed ‘transient’ heating episode lasts until the present, the ‘heating durations’ above are really age estimates. Their 3 ka age (the result one gets for *f*= 0.2 on the fifth sample) is the same as the lower limit of my

**Table 1.** Argon data from borehole GT-2. Values in parentheses have large errors.

No.	Depth(km)	T(°C)	D <sub>0</sub> /a <sup>2</sup> (sec <sup>-1</sup> )	E(kcal/mol)	D/a <sup>2</sup> (sec <sup>-1</sup> )	Argon Loss	Age(years)
1	1.13	110	330 <sup>+380</sup> <sub>-180</sub>	34.5 ± 1.1	(6.6 × 10 <sup>-18</sup> )		
2	2.62	177	330 <sup>+380</sup> <sub>-180</sub>	34.5 ± 1.1	(5.6 × 10 <sup>-15</sup> )		
3	2.90	197	330 <sup>+380</sup> <sub>-180</sub>	34.5 ± 1.1	(2.9 × 10 <sup>-14</sup> )	(>0.02)	
4	3.58	240	~ 8,000	~ 44	~ 1.4 × 10 <sup>-15</sup>	(0.05)	(44,000)
5	4.56	313	~ 8,000	~ 44	~ 3.1 × 10 <sup>-13</sup>	~ 0.25	~ 5,100

estimate. Their highest age, 60 ka, differs somewhat from my 44 ka calculation for the fourth sample, perhaps because they were able to use non-curve-fit values and error bars for  $D/a^2$ . But it is noteworthy that they did not include the fifth sample, the deepest one, in their caveat about the argon loss estimates. So we can take the loss for that sample, and consequently its age, as better-founded.

### Discussion

Taking the temperature as constant at about 313°C during most of the diffusion history of the sample is a good approximation, from either the uniformitarian or creation viewpoint. That is because the rock is dry, preventing water or other fluids from carrying heat by convection. That leaves only heat conduction to change the temperature. Since heat conduction is very slow in rock,<sup>13</sup> the temperature should remain roughly constant for thousands of years. According to the two RATE hypotheses, accelerated nuclear decay and accelerated cooling during and a little after the year of the Genesis flood, the rock temperature should have changed very little in the more than 4,300 years (Hebrew Bible chronology) that have elapsed since the Flood ended. So there is every reason to believe that the argon age is roughly correct—that the deep Precambrian ‘basement’ rock is thousands, not billions, of years old.

It is clear that the shortness of the argon age (relative to a million years, and certainly to a billion years) is the reason why Harrison *et al.* could not tolerate the idea that the volcano heated the borehole at any time earlier than about 20,000 years ago. (Even 20 millennia seems large in light of my diffusion age of only 5100 years.) With their low temperatures during the (alleged) 1.5 Ga before that, the argon losses would have been large even for the shallower samples.<sup>14</sup> Yet if one grants the uniformitarian age of the nearby volcano, about 1 Ma, it would have heated the site more than enough<sup>15</sup> to cause much greater losses just during that (alleged) megayear.<sup>16</sup> In other words, the observed high argon retentions conflict severely with the uniformitarian-assumed long ages. These data say that the feldspar generated over a billion years’ worth of  $^{40}\text{Ar}$ , and then retained it, during a period of time that began only thousands of years ago. The argon data thus support accelerated nuclear decay, RATE’s young helium age, and the biblical youth of the world.

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10. Humphreys, ref. 7, pp. 34–36. Note ‘defect line’ in fig. 5, p. 35, Erratum: on p. 34 of this reference, in my eq. (3), the second exponential should have a minus sign in its argument, as does the first exponential.
11. Humphreys, ref. 7, pp. 67–74.
12. Carslaw, H.S. and Jaeger, J.C., *Conduction of Heat in Solids*, 2<sup>nd</sup> ed., Clarendon Press, Oxford, England, section 3.3, p. 97, eq. 11, 1959. To get the Harrison *et al.* equation, replace  $1-(v_w/V_0)$  by  $f$ ,  $\kappa$  by  $D$ ,  $l$  by  $a$ , and take the approximation for  $t$  small compared to  $a^2/D$ .
13. Harrison *et al.*, ref. 3, p. 1906, fig. 9, have the temperature at the bottom of the borehole, close to their conjectured heat source (therefore moving heat fast), rising by conduction less than an average of 0.01°C per year.
14. Humphreys, ref. 7, p. 50, eqs. 10–14. Use  $a=b$ ,  $t = 1.5 \text{ Ga} = 4.7 \cdot 10^{16} \text{ s}$  and  $D/a^2 = 3.645 \times 10^{-19} \text{ s}^{-1}$ . The latter value is an extrapolation of the diffusion parameters of sample 3 in table 1 down to the 87°C desired by Harrison *et al.* for that depth. This value of  $D/a^2$  is probably a severe underestimate in light of the usual crystal defects, which can raise diffusivities by several orders of magnitude at low temperatures (ref. 7, pp. 34–36). Even with the low temperature and the underestimated diffusivity, the loss during 1.5 Ga would be about 39%, an order of magnitude greater than the (less than) 2% observed at that depth.
15. Humphreys, ref. 4, p. 37, section titled “The best uniformitarian picture of temperature history”.
16. Humphreys, ref. 7, p. 50, eqs. 10–14. Use  $a=b$ , assume the deepest sample got no hotter than its present temperature of 313°C, and use the table 1 value of  $D/a^2 = 3.1 \times 10^{-13} \text{ s}^{-1}$  with a time  $t = 1 \text{ Ma} = 3.1 \times 10^{13} \text{ s}$ . Then the argon loss would be very close to 100%, leaving essentially no argon at all, a loss much greater than the observed loss of 25%.

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