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THE TEMPORAL, GEOGRAPHICAL, AND GEOLOGICAL UBIQUITY OF EXCESS ARGON WITH A YOUNG-EARTH ANALYSIS

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KEYWORDS: Argon-Argon Dating, Excess Argon, Geochronology, Geologic Column, Potassium-Argon Dating, Radiometric Dating

ABSTRACT

Over 500 articles, published in 30 different secular journals that deal with the subject of K-Ar and Ar-Ar dating on terrestrial samples were reviewed to determine the prevalence of excess Argon documented in the secular literature. The findings are that the problem of excess Argon is ubiquitous throughout the world and in all layers of the standard geologic column. Secular geochronolgists' attempts to deal with the problem have been unsuccessful. An analysis of 7,404 apparent ages extracted from 347 of the articles is performed to evaluate the relationship between the dependant variable of apparent age and 4 independent variables: 1) analysis type (K-Ar or Ar-Ar); 2) whether the researcher identified the geologic strata before or after obtaining the apparent ages; 3) whether the rock dated is volcanic or metamorphic; 4) the geologic strata of the sample as identified in the original article. The conclusions are that secular and creationist Geochronologists make similar statements regarding argon based dating, so any claim that creationist Geochronologists are using anomalous results is unfounded. Argon based dating methods are ineffective at identifying the absolute date of the rock being tested. The ^{40}Ar/^{39}Ar ratio is not related to the age of the rock. Argon based dating methods do not replicate the standard geologic column. The problem of "excess" argon is not anomalous or isolated but ubiquitous. The data from this study indicate that there are differences between Precambrian and Phanerozoic rocks. A potential mechanism of argon retention in some basaltic rock to account for the excess argon is proposed.

INTRODUCTION

My original research evaluated the argon-argon (Ar-Ar) dating method (Overman, 2010, 2012). This research takes a closer look at the phenomenon of excess argon found through potassium-argon (K-Ar) and Ar-Ar dating and begins to evaluate argon dating from a young-earth perspective along with a possible young earth explanation for excess argon.

The existence of excess argon is documented in creationist literature (e.g. Austin, 1996; Snelling, 1998). On the basis of their analyses, Austin and Snelling questioned the validity of the K-Ar dating method with respect to obtaining an absolute age for the sample rocks. Dr. Kevin Henke challenged that assertion by stating that "Austin's application of the K-Ar method is flawed and that he has failed to prove that the K-Ar method is universally invalid" (Henke, no date). In his spirited defense of the K-Ar dating method, Henke states, “Certainly, there are times when scientists obtain anomalous results and they can only say ‘we don’t know why we got these results’.” (Henke, no date) Henke seems to be trying to leave the impression that Austin’s and Snelling’s results are anomalous and are not representative of the results found by other geochronologists.

Austin (1996) found that the Mt. St. Helen’s “lava dome in 1986 gives a whole rock K-Ar ‘age’ of 0.35 ± 0.05 millions of years (Ma)” (p. 335). This is similar to results found by Esser *et al*. (1997). They found that “Historically erupted (1984) anorthoclase phenocrysts from Mt. Erebus yield K/Ar and $^{40}Ar/^{39}Ar$ apparent ages as old as 700 [thousand years] ka indicating the presence of excess argon” (p. 3789). Here, Esser *et al*. found that lava that solidified two years before Austin’s sample gave K-Ar and Ar-Ar dates two times older than Austin’s sample. Snelling (1998) performed K-Ar dating on Mt. Ngauruhoe lava that solidified in 1949, 1954, and 1975. Snelling (1998) states that “the excess $^{40}Ar^*$ [* indicates radiogenic argon] was still present in the lavas upon eruption and cooling. The evidence indicates that the parent basaltic magma was generated in the upper mantle where the excess $^{40}Ar^*$ in the geochemical reservoir is now known to be upwards of 150 times more than the atmospheric content, relative to ^{36}Ar” (p. 520). A mantle component of excess Ar was also found by Arevalo, *et al*. (2009). The possibility of a mantle component to the excess Ar problem was suggested by Dalrymple (1969). A mantle component implies that there is a reservoir of argon in the mantle magma that does not all percolate out while the lava is in a liquid state. Rugg and Austin (1998) found that “Most interesting is the olivine in QU-16, which of all the analyses has the lowest ^{40}K (0.302 ppm), but has the highest $^{40}Ar^*$ (3.65 × 10-4 ppm)” (p. 478). They concluded that “There must be ‘excess argon’ in the olivine of QU-16” (p. 478). This is significant because olivine has very little potassium, so the abundance of argon could only come from the mantle.

THE PROBLEM OF EXCESS ARGON

Excess argon is identified when there is more apparent radioactive decay than expected based on other dating methods as indicated by the amount of ^{40}Ar. Extra ^{40}Ar is also called inherited or extraneous Ar. The distinction is provided by Lanphere and Dalrymple (1976):

> "excess argon" is incorporated into rocks and minerals by processes other than in-situ decay of ^{40}K, whereas "inherited argon" originates within mineral grains by decay of ^{40}K prior to the rock forming event. "Extraneous argon" includes both excess and inherited argon (p. 141).

Conversely, Geochronologists must also deal with the problem of argon loss where there is less apparent radioactive decay than expected (this would be the subject of a different paper). The existence of excess, inherited, extraneous, or lost argon highlights a very important point regarding radiometric dating techniques. When performing radiometric analysis, the Geochronologist is measuring the apparent amount of radioactivity that has occurred. This quantity of radioactivity is expressed as a date, but the date is an inference based on other factors (i.e. the decay rate, closed system, initially known quantity). While he is specifically addressing the Rb/Sr dating method, Moorbath (1967) comments below equally apply to argon dating methods and support this point.

> Strictly speaking, radiometric dates on minerals and rocks relate to a time and temperature, during cooling, when diffusion of radiogenic nuclide out of the system ceased, and not to the time of crystallization. … It is evident from the ever increasing number of published radiometric age determinations that most geologists and geochronologists are still paying insufficient attention to the exact significance of geochronometric data. In the great majority of cases it is simply assumed that the frequently very precise analytical dates relate to major geological events such as intrusion, metamorphism, orogeny, etc. … If one is to claim with any confidence that the analytical date from a mineral or rock indicates the time of crystallization, the following conditions are necessary: (1) that the decay constant of the radioactive nuclide is accurately known; [and has stayed the same over time] (2) that proper correction has been made for the amount of radiogenic nuclide (if any) incorporated into the mineral or rock at the time of crystallization; (3) that there have been no gains or losses of parent or daughter nuclide in the mineral or rock since the time of crystallization by processes other than radioactive decay. … Conditions 1 and 2 have figured prominently in the geochronological literature of recent years and it may be stated that, for all intents and purposes, they can be satisfactorily met despite an annoying little uncertainty of 6% in the decay constant of ^{87}Rb. However, condition 3 is usually taken for granted without further discussion (p. 111-112).

Hence, the “date” given is not an absolute date but is representative of the amount of radioactivity that may have occurred. Therefore, radiometric dates, that are given in millions of years (Ma), only mean that millions of years worth of radioactive decay have apparently occurred (under specific assumed conditions) not that the radioactive decay occurred over millions of years.

Ubiquity of Excess Argon

I reviewed earth and planetary science publications on the ScienceDirect.com website. Table A-1 is a list of the 30 publications from which articles used in this analysis were drawn. The website was searched for the words ”excess” and ”argon”, with the number of papers containing those words documented by decade from the 1960’s through the 2000’s (see Figure 1). A total of 4,999 articles were found. All of the papers were reviewed to select those that dealt with the subject of excess argon with respect to the K-Ar or Ar-Ar dating of terrestrial samples (see Figure 2). Over 500 papers were selected from the first group and are referred to later as “group 2”.

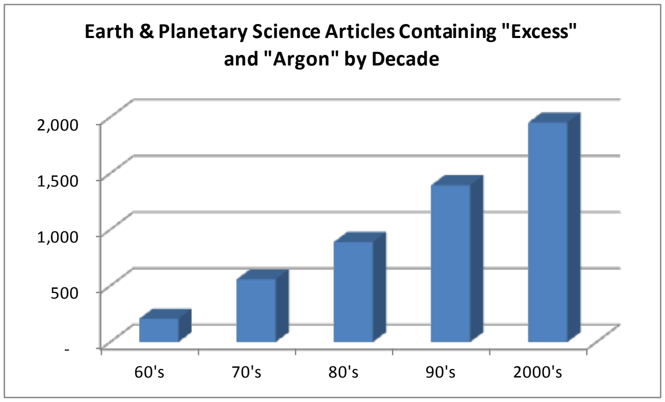


Figure 1

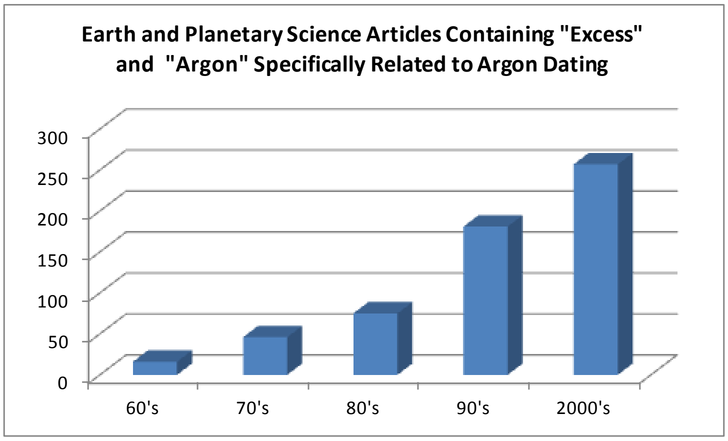


Figure 2

Additional review of the selected articles that made up the second group found that excess argon has been found all over the world and throughout the "geologic column". Tables 1 and 2 provide the continents/countries and geologic layers respectively in which researchers specifically identified that they had found excess argon.

Africa			Antarctica			Europe			North America	
	Algeria		Asia				Austria			Canada
	Angola			China			Bulgaria			Costa Rica
	Botswana			Czech Republic			Finland			Cuba
	Burundi			India			France			Dominica
	Cameroon			Indonesia			Germany			Dominican Republic
	Canary Island			Iran			Greece			Honduras
	Cape Verde Islands			Israel			Greenland			Martinique
	Congo			Japan			Hungary			Mexico
	Etheopia			Kazakstan			Iceland			St Lucia
	Ghana			Napal			Italy			United States of America
	Guinea			Oman			Morocco		Ocenia	
	Ivory Coast			Pakistan			Norway			Australia
	Kenya			Republic of Djibuti			Portugal			Fiji
	Liberia			Russia			Russia			New Zealand
	Madagascar			Saudi Arabia			Slovia			Papau New Guinea
	Mali			South Korea			Spain			Tasmania
	Nambia			Syria			Sweden		South America	
	Nigeria			Taiwan			Switzerland			Argentina
	Reunion Island			Turkey			United Kingdom			Bolivia
	Rodina			Vietnam						Brazil
	Rowanda			Yemen						Chile
	South Africa									Columbia
	Swaziland									French Guyana
	Tanzania									Paraguay
	Togo									Peru
	Uganda									Surinam
	Zambia									Venezuela
	Zaire									

Table 1

Precambrian				Cenozoic		
	Archaen				Paleogene	
	Proterozoic					Eocene
Phanerozoic						Oligocene
	Paleozoic				Neogene	
		Cambrian				Miocene
		Ordovician				Pliocene
		Silurian			Quarternary	
		Devonian				Pleistocene
		Carboniferous				Holocene
		Permian				
	Mesozoic					
		Triassic				
		Jurassic				
		Cretaceous				

Table 2

Dealing with Excess Argon

As with other geochronological techniques, argon dating (both K-Ar and Ar-Ar) relies on basic assumptions. One is the assumption of a closed system as described by Mussett and McCormack (1978).

> At the present time some of the basic assumptions of the K-Ar dating method are being questioned. As first developed the method assumed a system closed since

> the event to be dated and with no argon present at the time of closure. Although examples of argon loss or excess argon were known the only violation normally allowed for was the addition of argon assumed to derive from air which could be corrected for by measuring the amount of ^{36}Ar present.
>
> More recently however two additional violations have been claimed to be present. These are ‘initial argon’, containing both ^{40}Ar and ^{36}Ar in fixed but unknown ratio … and ‘inherited ^{40}Ar’ in fixed concentration (p. 1877).

The atmospheric correction has been an important issue when dealing with the problem of excess argon. Renne *et al*. (2009) describe the role of atmospheric correction and the problems associated with it.

> The isotopic composition of atmospheric argon is fundamentally important for K–Ar and ^{40}Ar/^{39}Ar geochronology. Resolving atmospheric ^{40}Ar from radiogenic ^{40}Ar (^{40}Ar*) can be the most critical limitation of accuracy … but a value of 295.5 for this ratio was adopted among various other values of physical constants by convention of the International Union of Geological Sciences (IUGS) in 1976 … A redetermination of the isotopic composition of atmospheric argon has been published recently by Lee *et al*. (2006). The atmospheric ^{40}Ar/^{36}Ar (298.56 ± 0.31) determined by Lee *et al*. (2006) is significantly distinct from, and more precise than, Nier’s (1950) results (p. 289).

As indicated, the correction value of 295.5 has been in use since before 1976, but it may not be valid. “Evidence for a detectable increase in atmospheric ^{40}Ar/^{36}Ar over the past 800 ka … leads to the possibility that large age errors can result from an erroneous assumption that paleoatmospheric ^{40}Ar/^{36}Ar is identical to modern values” (Renne *et al*., 2009, p. 298). The problems with atmospheric correction are not new. “This leads to a critical appraisal of conventionally calculated K-Ar ages with the conclusion that *a priori* assumptions regarding the isotopic composition of non-radiogenic argon and, hence, the standard atmospheric correction, are no longer tenable” (Italics theirs) (Siedner and Mitchell, 1976, p. 292). The issue here is that when performing K-Ar analysis, the researchers must try to account for the atmospheric contaminant, but they cannot always be sure if the correction is correct.

Another attempt to deal with excess argon was the use of the Ar-Ar dating process, specifically step heating. Samples in a study by Johnson, *et al*. (1998) “were dated using the stepwise laser incremental heating technique on approximately 30-mg groundmass separates…, [this is] an appropriate technique because these samples contain significant amounts of olivine and pyroxene phenocrysts, minerals known to have very low K concentrations and possibly excess argon” (p. 643). The Ar-Ar step heating process has not been successful in eliminating the excess Ar problem as indicated by Harrison, *et al*. (1994). “However, the general conclusion of these studies … was that, apart from providing conservative criteria for the upper age limit of a sample, ^{40}Ar/^{39}Ar step-heating studies did not provide a complete solution to the problem of excess argon in minerals” (p. 95). Also see Li *et al*. (1994) and Arnaud and Kelly (1997) for more examples that step heating techniques have not solved the problem.

While many other attempts to deal with excess argon have been made, a recent method and the final one to be addressed here, is to hand select minerals to avoid ones that may contain excess argon. Udagawa *et al*. (1999) tried this when "Phenocrysts and magnetic minerals were removed by hand picking and then by magnetic separation to increase the K and Ar contents as well as to avoid contamination due to excess Ar" (p. 159). However, they still found that the "Existence of excess Ar may be a possibility in some of the samples" (p. 164). Also see Guillou *et al*. (1998), Guillou *et al*. (2000), and Evins *et al*. (2009).

Retention of Excess Argon

Having established the ubiquity of excess argon, the obvious question is how the argon is retained in the liquid magma. Argon, a noble gas, does not bind to other atoms in the magma. Therefore, it is assumed to escape the magma while it is in the liquid state. Yet, a substantial amount of argon is retained. Especially in the Olivine structural lattice (Rugg and Austin, 1998). Given this plethora of excess argon, it is necessary to identify a physical mechanism for argon retention in the liquid magma.

Olivine is the first mineral to crystallize when basalt cools. As it crystallizes, it forms a lattice as shown in Figure 3 (Klein and Dutrow, 2008 Figure 18.4). Austin (2013) states that the "oxygen in the -2 valance has an ionic radius of 1.40 angstroms. The length of a side of the silica tetrahedron is 1.40 + 1.40 = 2.80 angstroms. In the olivine model, there is a five-sided hole about 3.8 angstroms diameter, big enough to hold a fat 3.8 angstrom diameter argon atom (1.88 angstroms is van der Waals radius of argon)" (see Linde, 2008). Figures 4 and 5 illustrate the argon atom and the argon atom imbedded in the olivine lattice. The hypothesis is that the argon gets "stuck" in the lattice and becomes a part of the structure via a van der Waal bond. When heated for K-Ar or Ar-Ar dating, the thermal energy vibration breaks the van der Waal bond and the released argon mixes with any radiogenic argon in the sample. All basaltic rocks do not contain olivine so this mechanism will not account for all of the trapped argon. However, argon may be trapped by other minerals, so more research is required. This should be considered a feasible working hypothesis.

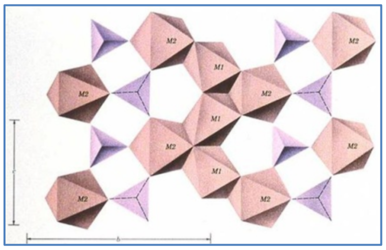


Figure 3

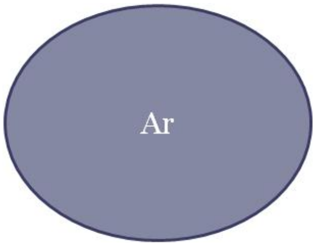


Figure 4

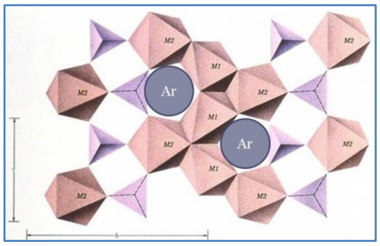


Figure 5

Conclusions from Literature Review

The problems with excess argon in geochronology are extensive and persistent. "In our opinion… the excess argon problem in phengite from eclogites may be more common than previously thought" (Li *et al*., 1994, p. 348). Researchers have suggested limiting the use of K-Ar dating as early as 1963. Hurley *et al*. (1963) say that in some cases it should be avoided. Li *et al*. (1994) state, "We would suggest that ^{40}Ar/^{39}Ar or K-Ar method in many occasions may not be suitable for dating of phengite from orogenic eclogite because of its potential excess argon problem" (p. 348).

The literature review shows that the problem of excess argon has not been resolved for calculating ages of rocks. If it was resolved, the number of articles relating to this excess argon problem, as shown in Figure 2, would have increased to some point, and then decreased once the solution was implemented. Since they are still increasing, the solution has not been found. The challenge is described by Harrison (1990).

> In a discipline which well understands precision as a product of repetition, appreciation of the "spectral" nature of ^{40}Ar/^{39}Ar results may not be intuitive. In contrast to virtually all other modern geochronological methods, the daughter product is obtained from the sample in an indirect manner during which time experimental artifacts can complicate or obscure the primary chronological information (Harrison, 1983). Although the challenge to ensure ideal behavior, or at least understand misbehavior, should guarantee full employment for some time, mastery comes so slowly that at times our response has been more expedient than patient (p. 219).

The challenge of understanding the "misbehavior" may begin with the olivine lattice model. In general, the argon dating techniques, by themselves, do not provide geochronologically meaningful information. Every argon date must be compared to another dating method to determine whether it is concordant or discordant. If it is concordant, it is considered to be a meaningful date. If it is discordant, it is discarded with some excuse. Kennan *et al*. (1995) had to add a caveat to their results. They state, "**In the absence of other data we assume** that the crystal does not contain excess ^{40}Ar and that this date represents the age of intrusion" (p. 182) (emphasis mine).

YOUNG EARTH ANALYSIS

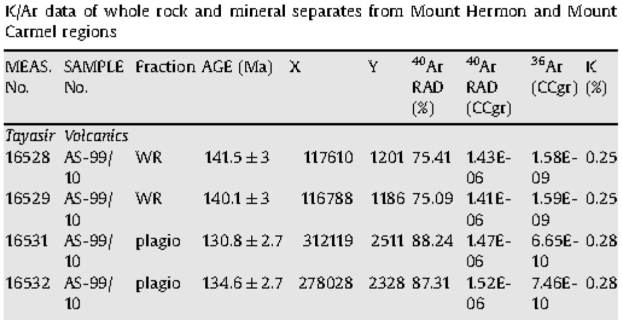
Because argon dating techniques are not useful in establishing absolute dates, the remainder of this paper explores the potential of evaluating argon dating from a young earth perspective. This is possible by making relative comparisons of the published apparent ages. Since the same techniques and constants are used, the apparent ages can be used as a proxy for the amount of argon released from the sample so the apparent ages can be compared one to another.

The Radioisotopes and the Age of the Earth (RATE) team "has convincingly shown that the first and most fundamental of these assumptions [the rate of radioisotope decay has always been constant] is invalid… [and] nuclear decay has been accelerated during brief episodes of earth's history. Furthermore, this increase in decay rate was not a small amount, but on the order of a billion times greater than the rates observed today" Vardiman *et al*. (2005) p. 13. As previously discussed, the geochronologist is measuring millions of years worth of apparent decay, not that the decay was over millions of years. An accelerated decay rate would account for millions of years worth of apparent decay over a short period of time. This analysis evaluates the dates reported in the papers selected from ScienceDirect.com that performed argon analyses on terrestrial rocks.

It is important to note that this is a preliminary analysis to see what, if any, tentative conclusions can be drawn that are consistent with a young earth view. Apparent ages from the articles are treated equally regardless of the minerals or rocks that were analyzed. More detailed analyses of minerals, whole rock, or other aspects of the studies could be the subject of future papers.

Data Gathering

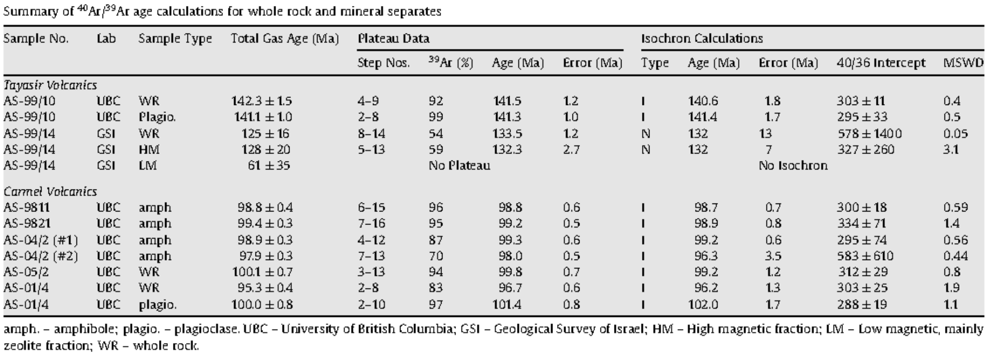
All of the selected articles from group 2 were reviewed to extract the K-Ar or Ar-Ar dates reported in the articles. The dates are generally reported in the format shown in Tables 3-5. Table 3 shows the typical format for reporting K-Ar dates and is from Segev (2009 p. 817). The "age (Ma)" is the column that is used as the dates for this paper. Table 4 is also from Segev (2009 p. 816). Multiple ages are generally calculated from Ar-Ar data. The age that is most directly related to the entire amount of Ar released is the "total gas age" or the "Integrated age". The other ages reported (e.g. the plateau age or the isochron age) are calculated based on portions of the Ar released. Since the total gas age or the integrated age are based on the total amount of Ar released, these are considered to represent the most "pure" age and are used in this study. Table 5, from Hofmann, *et al*. (2000) shows the other general format for reporting Ar-Ar data. In this format, the age from the release of Ar gas in each heating step is calculated. When the heating is completed, the individual step ages are combined to calculate the total gas age or the integrated age. Each step may have widely varying ages, but the final age is based on the total amount of Ar gas released in all of the steps.



K/Ar data of whole rock and mineral separates from Mount Hermon and Mount Carmel regions

MEAS. No.	SAMPLE No.	Fraction	AGE (Ma)	X	Y	^{40}Ar RAD (%)	^{40}Ar RAD (CCgr)	^{36}Ar (CCgr)	K (%)
Tayasir	*Volcanics*								
16528	AS-99/10	WR	141.5 ± 3	117610	1201	75.41	1.43E-06	1.58E-09	0.25
16529	AS-99/10	WR	140.1 ± 3	116788	1186	75.09	1.41E-06	1.59E-09	0.25
16531	AS-99/10	plagio	130.8 ± 2.7	312119	2511	88.24	1.47E-06	6.65E-10	0.28
16532	AS-99/10	plagio	134.6 ± 2.7	278028	2328	87.31	1.52E-06	7.46E-10	0.28

Table 3

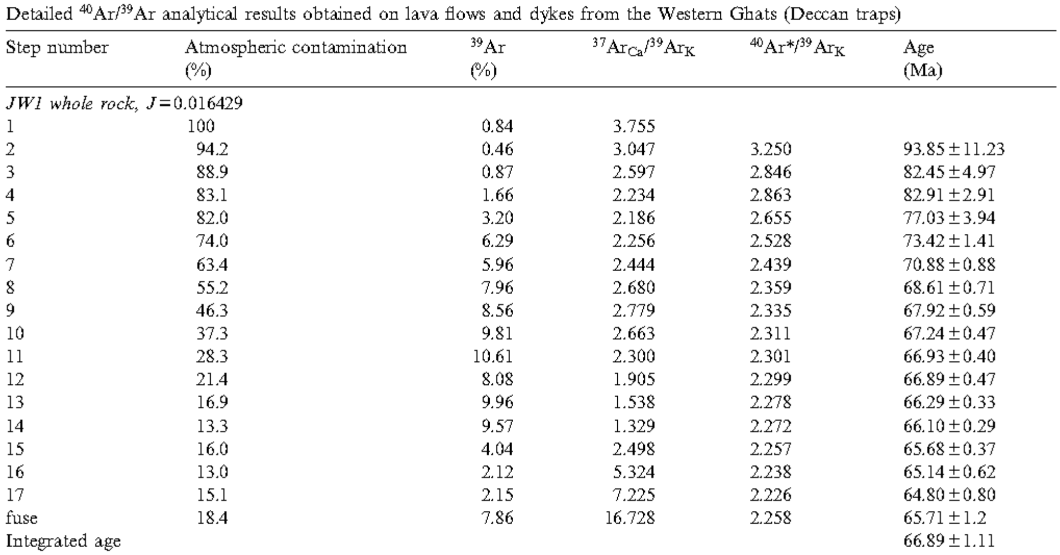


Summary of ^{40}Ar/^{39}Ar age calculations for whole rock and mineral separates

Sample No.	Lab	Sample Type	Total Gas Age (Ma)	Plateau Data				Isochron Calculations				
				Step Nos.	^{39}Ar (%)	Age (Ma)	Error (Ma)	Type	Age (Ma)	Error (Ma)	40/36 Intercept	MSWD
Tayasir Volcanics												
AS-99/10	UBC	WR	142.3 ± 1.5	4–9	92	141.5	1.2	I	140.6	1.8	303 ± 11	0.4
AS-99/10	UBC	Plagio.	141.1 ± 1.0	2–8	99	141.3	1.0	I	141.4	1.7	295 ± 33	0.5
AS-99/14	GSI	WR	125 ± 16	8–14	54	133.5	1.2	N	132	13	578 ± 1400	0.05
AS-99/14	GSI	HM	128 ± 20	5–13	59	132.3	2.7	N	132	7	327 ± 260	3.1
AS-99/14	GSI	LM	61 ± 35		No Plateau					No Isochron		
Carmel Volcanics												
AS-9811	UBC	amph	98.8 ± 0.4	6–15	96	98.8	0.6	I	98.7	0.7	300 ± 18	0.59
AS-9821	UBC	amph	99.4 ± 0.3	7–16	95	99.2	0.5	I	98.9	0.8	334 ± 71	1.4
AS-04/2 (#1)	UBC	amph	98.9 ± 0.3	4–12	87	99.3	0.6	I	99.2	0.6	295 ± 74	0.56
AS-04/2 (#2)	UBC	amph	97.9 ± 0.3	7–13	70	98.0	0.5	I	96.3	3.5	583 ± 610	0.44
AS-05/2	UBC	WR	100.1 ± 0.7	3–13	94	99.8	0.7	I	99.2	1.2	312 ± 29	0.8
AS-01/4	UBC	WR	95.3 ± 0.4	2–8	83	96.7	0.6	I	96.2	1.3	303 ± 25	1.9
AS-01/4	UBC	plagio.	100.0 ± 0.8	2–10	97	101.4	0.8	I	102.0	1.7	288 ± 19	1.1

amph. – amphibole; plagio. – plagioclase. UBC – University of British Columbia; GSI – Geological Survey of Israel; HM – High magnetic fraction; LM – Low magnetic, mainly zeolite fraction; WR – whole rock.

Table 4



Detailed $^{40}Ar/^{39}Ar$ analytical results obtained on lava flows and dykes from the Western Ghats (Deccan traps)

Step number	Atmospheric contamination (%)	^{39}Ar (%)	$^{37}Ar_{Ca}/^{39}Ar_K$	$^{40}Ar^*/^{39}Ar_K$	Age (Ma)
JW1 whole rock, J = 0.016429					
1	100	0.84	3.755		
2	94.2	0.46	3.047	3.250	93.85 ± 11.23
3	88.9	0.87	2.597	2.846	82.45 ± 4.97
4	83.1	1.66	2.234	2.863	82.91 ± 2.91
5	82.0	3.20	2.186	2.655	77.03 ± 3.94
6	74.0	6.29	2.256	2.528	73.42 ± 1.41
7	63.4	5.96	2.444	2.439	70.88 ± 0.88
8	55.2	7.96	2.680	2.359	68.61 ± 0.71
9	46.3	8.56	2.779	2.335	67.92 ± 0.59
10	37.3	9.81	2.663	2.311	67.24 ± 0.47
11	28.3	10.61	2.300	2.301	66.93 ± 0.40
12	21.4	8.08	1.905	2.299	66.89 ± 0.47
13	16.9	9.96	1.538	2.278	66.29 ± 0.33
14	13.3	9.57	1.329	2.272	66.10 ± 0.29
15	16.0	4.04	2.498	2.257	65.68 ± 0.37
16	13.0	2.12	5.324	2.238	65.14 ± 0.62
17	15.1	2.15	7.225	2.226	64.80 ± 0.80
fuse	18.4	7.86	16.728	2.258	65.71 ± 1.2
Integrated age					66.89 ± 1.11

Table 5

Table 6 shows how the age data in each of the articles that reported dates was tabulated. The Index # is a number that relates to the reference. In Table 6, index number 1 represents Folinsbee, *et al*. (1956) and index #2 represents Evernden, *et al*. (1961). The date type is whether the data is from a K-Ar analysis or an Ar-Ar analysis. The sample is the sample number provided by the original author. The mineral is the mineral dated from the collected rocks. The apparent age is the age provided in the original paper and the error is the error reported in the original paper. It is noted that some authors reported a 1 standard deviation (1σ) error and some authors reported a two standard deviation (2σ) error. For the purposes of this analysis, only the apparent age is used, so it was not necessary to distinguish between the numbers of standard deviations in the error. The B/A column identifies whether the standard geologic column strata was identified by the author before or after the ages were obtained. M/V indicates whether the sample is volcanic or metamorphic. Finally, the strata are the portion of the standard geologic time scale from which the author reported the sample came. In some cases, the author reported multiple strata that included more than one eon. In those cases, the data was associated with the oldest eon. For example, Hofmann *et al*. (2000) identified their rock as being Cretaceous-Tertiary. For the purpose of this analysis, they are considered to be Cretaceous. Also, authors often identified their rock samples with geological periods, epochs, or ages. This analysis is performed at the supereon and eon level so each of the ages were categorized to the appropriate eon based on the 2009 Geologic Time Scale (Walker and Geissman, 2009). Using this method of gathering the data, 7,404 individual dates were extracted from 347 articles.

Index #	Date type	Sample	Mineral	Apparent Age (Ma)	Error (±)	B/A	M/V	Strata
1	K-AR	K.A. 9	Microperthite phenocrst	83	Not Provided	A	V	Cretaceous
1	K-AR	K.A. 8	Porphyry	88	Not Provided	A	V	Cretaceous
1	K-AR	K.A. 10	Biotite	108	Not Provided	A	V	Cretaceous
1	K-AR	K.A. 32	Sylvite	347	Not Provided	A	V	Devonian
1	K-AR	K.A. 23	Plagioclsse from diorite	1250	Not Provided	A	V	Precambrian
1	K-AR	K.A. 21	Plagioclase	1440	Not Provided	A	V	Precambrian
1	K-AR	K.A. 24	Feldspar and muscovite	1630	Not Provided	A	V	Precambrian
1	K-Ar	GA1983	Plagioclase	1934	30	A	V	Proterozoic
1	K-Ar	GA1980	Plagioclase	1981	20	A	V	Proterozoic
1	K-Ar	GA2051	Plagioclase	1983	25	A	V	Proterozoic
1	K-AR	K.A. 33	Rhyolite Porphyry	2000	Not Provided	A	V	Precambrian
1	K-AR	K.A. 12	Muscovite-Biotite Granite	2230	Not Provided	A	V	Precambrian
1	K-Ar	GA1980	Pyroxene	2635	100	A	V	Proterozoic
1	K-AR	K.A. 30	Biotite and hornblende from diorite	2640	Not Provided	A	V	Precambrian
1	K-AR	K.A. 31	Biotite from Muscovite-Biotite Granite	2650	Not Provided	A	V	Precambrian
1	K-Ar	GA1980	Pyroxene	2670	100	A	V	Proterozoic
1	K-Ar	GA1983	Pyroxene	2670	100	A	V	Proterozoic
1	K-Ar	GA1983	Pyroxene	2713	100	A	V	Proterozoic
1	K-Ar	GA2051	Pyroxene	2912	100	A	V	Proterozoic
1	K-Ar	GA2051	Pyroxene	3130	100	A	V	Proterozoic
2	K-AR	KA 192	Glauconite	5.2	Not Provided	B	M	Pliocene
2	K-AR	KA 322	Glauconite	10	Not Provided	B	M	Miocene
2	K-AR	KA 132	Biotite	11	Not Provided	B	M	Pliocene

Table 6

Data Analysis

There is much more data that was collected than can be analyzed and reported in one conference size paper. An evaluation of four independent variables (analysis type, B/A, V/M, and strata) and one dependent variable (apparent age) is provided in the Appendix A. Table A-2 provides the number of apparent ages (count), average, minimum, and maximum apparent age and the standard deviation of the apparent ages for all combinations of the independent variables. All of the combinations will not be analyzed, but they are all provided to facilitate future analyses by this author or other authors. It is noted that the 2009 Geologic Time Scale (Walker and Geissman, 2009) does not identify the supereon Phanerozoic. Some authors identified their samples as phanerozoic so that supereon is included. The Phanerozoic supereon included all eons above Precambrian (Reed and Oard, 2006 p. 5). It is also noted that the numbers in Table A-2 for the supereons, Phanerozoic and Precambrian, represent the cases where the authors of the original papers only identified their samples at the supereon level.

Geologic Column Analysis

Combinations 1-7 in Table A-2 include only the strata independent variable. This can be directly compared to the standard geologic column. Figure 6 shows the date ranges of the standard geologic time scale from Walker and Geissman (2009) on the left and the range of dates for each eon from Table A-2 on the right.

It is obvious from Figure 6 that if the ages of the geologic time scale were determined solely on K-Ar and Ar-Ar dates, it would look very different from the standard geologic time scale. It is also interesting that the Precambrian rocks (Archean and Proterozoic) have much less variability in their apparent ages than the Phanerozoic (Paleozoic, Mesozoic, and Cenozoic) rocks.

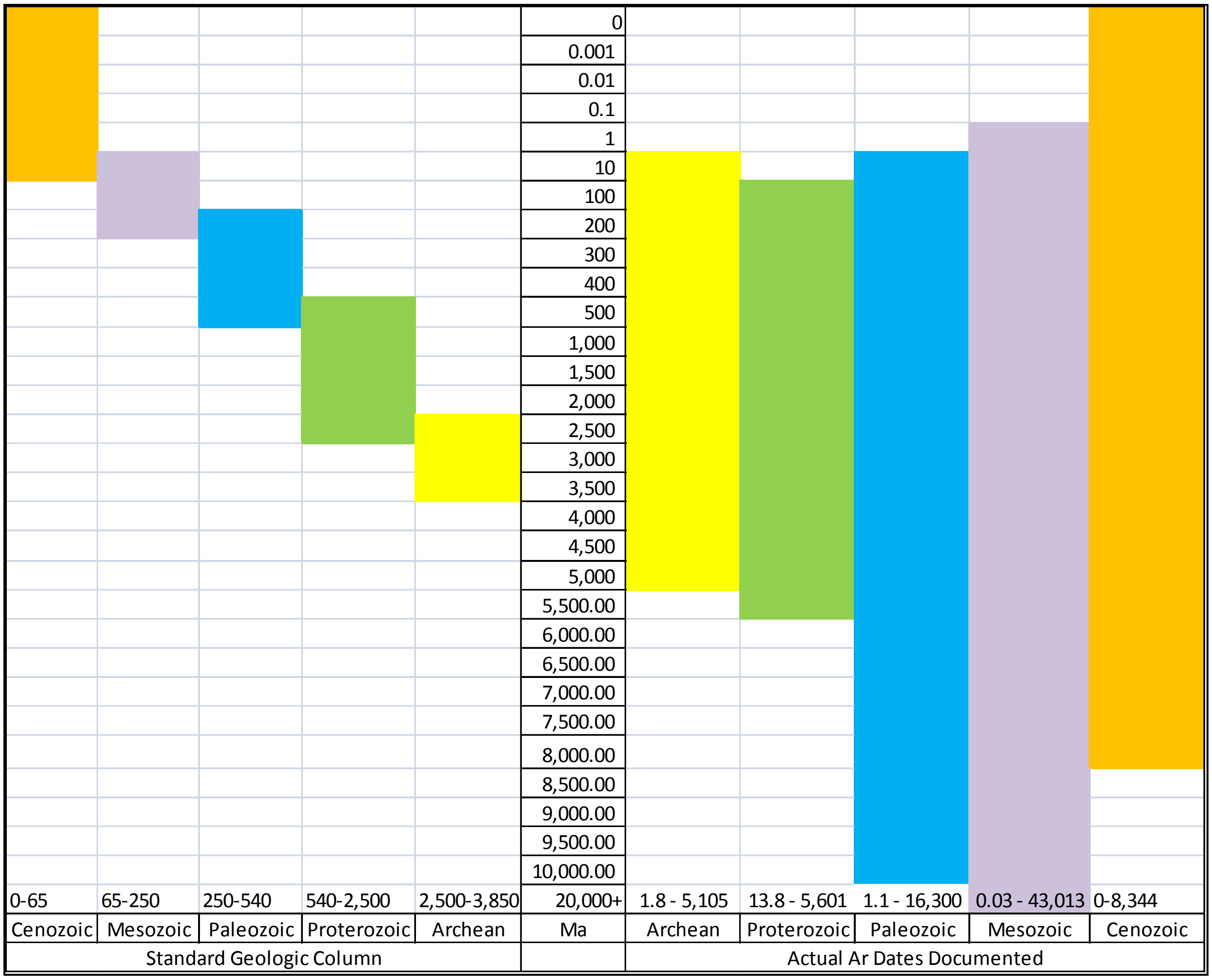


Figure 6

Before and After Analysis

The next area of interest is the claim that radiometric dates are accepted or rejected based on the expected geologic strata age. Froede (2010) provides an example of this claim, "…many terrestrial dates have been shown to have been driven by investigator bias. … Clearly, naturalistic radiometric age dating is inconsistent because it yields a variety of dates that can be selected based on expectations of age" (p. 3).

Anecdotally, while reviewing the many papers published in secular journals for this study, I noted that Froede's claim often occurred. Ages that matched the expected age were accepted and ages that did not were rejected. Index #1 in Table 6 is an example of the declared strata being based on the apparent age. The question of interest is to what extent the identified stratum is based on the age obtained and how does this relate to the standard geologic column? Table 7 shows the number of articles in which the author identified the strata before or after the apparent age was obtained. From Table 7 it is clear that it is not common practice in secular literature to wait until the samples are dated to identify the geologic strata. While the obtained dates are declared concordant or discordant based on the assumed strata age, the assumed strata age is generally not based on the obtained date.

After	85	26%
Before	242	74%
	327	100%

Table 7

Table 8 shows the number and percentage of individual apparent ages that are less than, within, or greater than the standard geological age for each eon when the eon was identified before or after the apparent ages were obtained. It appears from Table 8 that apparent ages outside the standard age tend to be younger than expected. This pattern holds regardless of whether the stratum was identified before or after the apparent ages is obtained. The obvious exception is the Cenozoic which starts at age zero, so no apparent ages can be younger than expected. It is also interesting that the Precambrian strata (Archean and Proterozoic) were the only eons with a higher percentage of apparent ages outside the standard age range than within the standard range. This was true for the Archean when the stratum was declared before the apparent ages were obtained and for the Proterozoic when the stratum was identified after the apparent ages were obtained. When the Proterozoic stratum was declared before the apparent ages were obtained, the Phanerozoic pattern is observed.

K-Ar Method, Compared to the Ar-Ar Method Analysis

This analysis evaluates the differences, if any, between K-Ar and Ar-Ar analyses in general and as related to the standard geologic column. If these dating methods are valid for obtaining absolute ages, there should be no statistically significant difference in the average apparent ages between the two methods. Table 9 provides the results of the analysis. Table 9 gives the average apparent age for each dating method by geologic strata, the % difference between the methods from equation 1, and whether the difference is statistically significant with 90% confidence using the comparison of means method (see Table A-3). In general, the Ar-Ar method seems to give older dates than the K-Ar method. This is true for all of the Phanerozoic eons. Interestingly, for the dates identified as Precambrian or for the Precambrian eons, the K-Ar method gave older dates or there were no significant difference (Archean). To further investigate this observation, the papers were searched for instances where K-Ar and Ar-Ar dates were performed on the same sample. The search found 42 Cenozoic samples that had both methods performed within seven papers. No other eons had samples upon which both methods were used. Table 10 provides the percent difference, number of times where one method was larger than the other, average ages and standard deviations. While the average Ar-Ar age was higher than the average K-Ar age, the difference is not significant. Therefore, it cannot be conclusively said that the Ar-Ar method gives older dates than the K-Ar method without analysis of more data from all eons.

$$\%\text{Diff} = ((\text{Ar-Ar Avg. Age}) - (\text{K-Ar Avg. Age}))/(\text{K-Ar Avg. Age}) * 100 \qquad (1)$$

	Before		After	
Cenozoic				
0-65.5	1825	95%	788	83%
>65.5	94	5%	163	17%
Total	1919		951	
Mesozoic				
<65.5	272	30%	206	32%
65.5-251	585	64%	396	61%
>251	50	6%	44	7%
Total	907		646	
Paleozoic				
<251	329	34%	119	32%
251-542	498	51%	244	66%
>542	151	15%	9	2%
Total	978		372	
Proterozoic				
<542	109	28%	103	41%
542-2500	270	69%	96	38%
>2500	10	3%	52	21%
Total	389		251	
Archean				
<2500	115	54%	None	
2500-3850	74	35%	None	
>3850	23	11%	None	
Total	212			

Table 8

	K-Ar Avg. (Ma)	Ar-Ar Avg. (Ma)	% Diff	Significant
Overall	275.9	512.6	86%	Yes
Cenozoic	23.7	129.5	446%	Yes
Mesozoic	132.8	211.9	60%	Yes
Paleozoic	316.4	466.7	48%	Yes
Precambrian	1374.8	1173.4	-15%	Yes
Proterozoic	1287.1	1124.5	-13%	Yes
Archean	2272.9	2437.4	7%	No

Table 9

Average		6%
# K-Ar > Ar-Ar		14
# Ar-Ar > K-Ar		23
No Difference		5
Average K-Ar Age		15.6
Average Ar-Ar Age		16.2
Std Dev K-Ar Age		13.6
Std Dev Ar-Ar Age		14.0

Table 10

Volcanic vs. Metamorphic Analysis

The final analysis compares dates obtained for volcanic and metamorphic rocks. Table 11 provides the relevant information similar to table 9. There does not seem to be a discernible pattern with respect to the standard geologic strata. Table A-4 provides the comparison of means analysis.

	Volcanic Avg. (Ma)	Metamorphic Avg. (Ma)	% Diff	Significant
Overall	290.9	570.8	96%	Yes
Cenozoic	75.8	54.7	-28%	Yes
Mesozoic	150.1	192.9	29%	No
Paleozoic	408.1	392.0	-4%	Yes
Precambrian	517.4	1380.1	167%	Yes
Proterozoic	1444.1	1022.7	-29%	Yes
Archean	2772.9	2024.0	-27%	Yes

Table 11

DISCUSSION

While analyzing the data, it became apparent that there are differences between Precambrian rocks and Phanerozoic rocks. In 3 of the 4 analyses, Precambrian rocks showed a different pattern. With respect to the range of ages, Precambrian rocks showed a tighter range of ages that was within the range of ages of all of the Phanerozoic eons (Figure 6). Precambrian rocks had a higher percentage of dates outside (usually younger) than the standard age while Phanerozoic rocks had a higher percentage within the standard age. Finally, the Ar-Ar method tended to give older ages for Phanerozoic rocks while the K-Ar method tended to give older ages for Precambrian rocks. Each of these observations individually may have different meanings or have no special meaning. However, taken together, the pattern shows that there appears to be something different about Precambrian rocks than Phanerozoic rocks.

It has been suggested by Snelling (1981) when analyzing U-Pb data that “A logical extension of these data & conclusions is to suggest as others already have the U/Pb ratios may have nothing to do with the age of the mineral” (p. 56) Based on the analysis above with the highly variable ages, discordance between the two dating methods, and the plethora of excess argon found all over the world and in every stratum, a similar statement could be made with respect to Ar based dating methods. Specifically that the ^{40}Ar/^{39}Ar ratio has nothing to do with the age of the mineral.

CONCLUSIONS

1. Secular and Creationist Geochronologists make similar statements regarding argon based dating, so any claim that Creationist Geochronologists are using anomalous results is unfounded.
2. Ar based dating methods are ineffective at identifying the absolute date of the rock being tested.
3. The ^{40}Ar/^{39}Ar ratio is not related to the age of the rock.
4. Argon based dating methods do not replicate the standard geologic column.

5. The problem of "excess" argon is not anomalous or isolated but ubiquitous.
6. The data from this study indicate that there are differences between Precambrian and Phanerozoic rocks.
7. Argon trapped in olivine crystals while the magma cools may be one explanation for excess argon.

ADDITIONAL RESEARCH

As previously stated, this research is a preliminary analysis. While some interesting patterns have been identified, these patterns will need to be confirmed by analyses of other dating methods. The expectation is that the observations seen in this paper should also be seen with other dating techniques. Therefore, future research may include performing a similar comprehensive analysis of U/Pb, Rb/Sr and other dating methods. Another potentially fruitful line of research is in determining to what extent olivine can trap argon and what other minerals have the same capacity to trap argon. Being able to explain the physical mechanism of how argon gets trapped in molten lava will help understand and explain the argon dating method patterns from a young earth perspective.

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APPENDIX A: Supporting Tables

C. R. Geoscience	Journal of Geochemical Exploration
Chemical Geology	Journal of South American Earth Sciences
Chemical Geology (Isotope Geoscience Section)	Journal of Southeast Asian Earth Sciences
Chemie der Erde	Journal of Structural Geology
Cretaceous Research	Journal of Volcanology and Geothermal Research
Earth and Planetary Science Letters	Lithos
Earth-Science Reviews	Palaeogeography, Palaeoclimatology, Palaeoecology
Geochimica Acta	Physics of the Earth and Planetary Interiors
Geochimica et Cosmochimica Acta	Precambrian Research
Global and Planetary Change	Quaternary Geochronology
Gondwana Research (Gondwana Newsletter Section)	Quaternary International
Gondwana Research	Quaternary Research
Isotope Geoscience	Russian Geology and Geophysics
Journal of African Earth Sciences	Sedimentary Geology
Journal of Asian Earth Sciences	Tectonophysics

Table A-1

#	Combination	Count	Avg. (Ma)	Max. (Ma)	Min. (Ma)	St. Dev. (Ma)
1	Cenozoic	2870	73.1	8344	0	329.2
2	Mesozoic	1554	170.2	43013	0.029	1114.7
3	Paleozoic	1350	398.7	16300	1.105	888.6
4	Phanerozoic	25	553.2	1044.4	491	116.1
5	Precambrian	374	1234.8	8228	15.32	1124.6
6	Proterozoic	640	1171.5	5601	13.82	900.4
7	Archean	212	2405.5	5105	1.794	1266.7
8	K-Ar dates	3413	275.9	8344	0	627.5
9	K-Ar Cenozoic	1530	23.7	8344	0	220.4
10	K-Ar Mesozoic	820	132.8	6100	0.029	283.6
11	K-Ar Paleozoic	611	316.4	2724	11.4	247.5
12	K-Ar Phanerozoic	None	None	None	None	None
13	K-Ar Precambrian	114	1374.8	4535	26	961.9
14	K-Ar Proterozoic	185	1287.1	4755	23	1171.9
15	K-Ar Archean	41	2272.9	4970	574	995.5
16	Ar-Ar dates	3991	512.6	43013	0.001	1161.2
17	Ar-Ar Cenozoic	1340	129.5	3343.65	0.001	413.3
18	Ar-Ar Mesozoic	734	211.9	43013	0.233	1593.5
19	Ar-Ar Paleozoic	739	466.7	16300	1.105	1175.8
20	Ar-Ar Phanerozoic	25	553.2	1044.4	491	116.1
21	Ar-Ar Precambrian	260	1173.4	8228	15.32	1185.5

22	Ar-Ar Proterozoic	455	1124.5	5601	13.82	759.5
23	Ar-Ar Archean	171	2437.4	5105	1.794	1324.0
24	Volcanic dates	4425	290.9	8344	0	703.2
25	Volcanic Cenozoic	2502	75.8	8344	0	350.8
26	Volcanic Mesozoic	826	150.1	2030	0.029	210.0
27	Volcanic Paleozoic	560	408.1	8069	4.19	549.0
28	Volcanic Phanerozoic	None	None	None	None	None
29	Volcanic Precambrian	63	517.4	2650	15.32	692.1
30	Volcanic Proterozoic	226	1444.1	4755	50.6	755.6
31	Volcanic Archean	108	2772.9	5000	1.794	1359.1
32	Volcanic K-Ar dates	2121	166.5	8344	0	487.9
33	Volcanic K-Ar Cenozoic	1360	21.3	8344	0	232.5
34	Volcanic K-Ar Mesozoic	386	129.7	2030	0.029	190.6
35	Volcanic K-Ar Paleozoic	228	344.2	2724	19	343.9
36	Volcanic K-Ar Phanerozoic	None	None	None	None	None
37	Volcanic K-Ar Precambrian	21	1087.9	2650	26	770.5
38	Volcanic K-Ar Proterozoic	60	1721.4	4755	80.3	978.1
39	Volcanic K-Ar Archean	11	2180.1	3420	574	955.1
40	Volcanic Ar-Ar dates	2304	405.4	8069	0.001	838.7
41	Volcanic Ar-Ar Cenozoic	1142	140.6	3343.65	0.001	444.6
42	Volcanic Ar-Ar Mesozoic	440	167.9	1972	0.233	224.3
43	Volcanic Ar-Ar Paleozoic	332	451.9	8069	4.19	650.6
44	Volcanic Ar-Ar Phanerozoic	None	None	None	None	None
45	Volcanic Ar-Ar Precambrian	42	232.1	1709	15.32	429.6
46	Volcanic Ar-Ar Proterozoic	166	1343.9	3557	50.6	631.2
47	Volcanic Ar-Ar Archean	97	2840.1	5000	1.794	1385.3
48	Metamorphic dates	2979	570.8	43013	0.1	1229.1
49	Metamorphic Cenozoic	368	54.7	782.8	0.1	90.3
50	Metamorphic Mesozoic	728	192.9	43013	3.1	1613.4
51	Metamorphic Paleozoic	790	392.0	16300	1.105	1066.0
52	Metamorphic Phanerozoic	25	553.2	1044.4	491	116.1
53	Metamorphic Precambrian	311	1380.1	8228	44.7	1140.3
54	Metamorphic Proterozoic	414	1022.7	5601	13.82	938.3
55	Metamorphic Archean	104	2024.0	5105	486.3	1039.0
56	Metamorphic K-Ar dates	1292	455.6	6100	3.1	773.1
57	Metamorphic K-Ar Cenozoic	170	42.2	639	4	68.3
58	Metamorphic K-Ar Mesozoic	434	135.5	6100	3.1	346.2
59	Metamorphic K-Ar Paleozoic	383	299.8	1451	11.4	163.7
60	Metamorphic K-Ar Phanerozoic	None	None	None	None	None
61	Metamorphic K-Ar Precambrian	93	1439.6	4535	44.7	992.2
62	Metamorphic K-Ar Proterozoic	125	1078.6	3179	23	1203.2

63	Metamorphic K-Ar Archean	30	2306.9	4970	614	1023.7
64	Metamorphic Ar-Ar dates	1687	659.0	43013	0.1	1480.9
65	Metamorphic Ar-Ar Cenozoic	198	65.3	782.8	0.1	104.6
66	Metamorphic Ar-Ar Mesozoic	294	277.8	43013	7.7	2504.0
67	Metamorphic Ar-Ar Paleozoic	407	478.7	16300	1.105	1472.3
68	Metamorphic Ar-Ar Phanerozoic	25	553.2	1044.4	491	116.1
69	Metamorphic Ar-Ar Precambrian	218	1354.7	8228	63.3	1199.2
70	Metamorphic Ar-Ar Proterozoic	289	998.5	5601	13.82	798.3
71	Metamorphic Ar-Ar Archean	74	1909.4	5105	486.3	1029.8
72	Before analysis	4803	420.3	43013	0	1064.6
73	Before analysis Cenozoic	1919	24.4	844	0	64.1
74	Before analysis Mesozoic	908	189.6	43013	0.233	1448.3
75	Before analysis Paleozoic	978	439.1	16300	1.73	1036.3
76	Before analysis Phanerozoic	22	518.3	561	491	19.8
77	Before analysis Precambrian	354	1178.1	8228	15.32	1104.1
78	Before analysis Proterozoic	389	1097.3	3557	13.82	613.4
79	Before analysis Archean	212	2405.5	5105	1.794	1266.7
80	Before analysis K-Ar dates	2052	222.6	6100	0	532.0
81	Before analysis K-Ar Cenozoic	1097	20.7	844	0	65.4
82	Before analysis K-Ar Mesozoic	434	154.1	6100	3.1	360.9
83	Before analysis K-Ar Paleozoic	340	335.3	2724	11.4	317.5
84	Before analysis K-Ar Phanerozoic	None	None	None	None	None
85	Before analysis K-Ar Precambrian	99	1255.7	3270	44.7	873.5
86	Before analysis K-Ar Proterozoic	23	1395.0	2047	429	679.1
87	Before analysis K-Ar Archean	41	2272.9	4970	574	995.5
88	Before analysis Ar-Ar dates	2751	567.7	43013	0.001	1310.4
89	Before analysis Ar-Ar Cenozoic	822	29.4	373	0.001	62.1
90	Before analysis Ar-Ar Mesozoic	474	222.2	43013	0.233	1975.1
91	Before analysis Ar-Ar Paleozoic	638	494.5	16300	1.73	1258.9
92	Before analysis Ar-Ar Phanerozoic	22	518.3	561	491	19.8
93	Before analysis Ar-Ar Precambrian	255	1148.0	8228	15.32	1181.7
94	Before analysis Ar-Ar Proterozoic	366	1078.6	3557	13.82	605.2
95	Before analysis Ar-Ar Archean	171	2437.4	5105	1.794	1324.0
96	Before analysis volcanic dates	2932	282.2	8069	0	695.0
97	Before analysis volcanic Cenozoic	1681	21.0	844	0	62.8
98	Before analysis volcanic Mesozoic	505	149.9	2030	0.233	169.3
99	Before analysis volcanic Paleozoic	440	471.0	8069	4.19	600.0
100	Before analysis volcanic Phanerozoic	None	None	None	None	None
101	Before analysis volcanic Precambrian	54	346.2	1709	15.32	451.9
102	Before analysis volcanic Proterozoic	128	1468.1	3557	552	550.9
103	Before analysis volcanic Archean	108	2772.9	5000	1.794	1359.1

104	Before analysis volcanic K-Ar dates	1421	111.7	3420	0	291.8
105	Before analysis volcanic K-Ar Cenozoic	998	18.4	844	0	63.7
106	Before analysis volcanic K-Ar Mesozoic	211	150.4	2030	6.3	183.1
107	Before analysis volcanic K-Ar Paleozoic	174	418.5	2724	101.6	361.0
108	Before analysis volcanic K-Ar Phanerozoic	None	None	None	None	None
109	Before analysis volcanic K-Ar Precambrian	12	745.6	1152	377	269.1
110	Before analysis volcanic K-Ar Proterozoic	None	None	None	None	None
111	Before analysis volcanic K-Ar Archean	11	2180.1	3420	574	955.1
112	Before analysis volcanic Ar-Ar dates	1511	442.5	8069	0.001	896.9
113	Before analysis volcanic Ar-Ar Cenozoic	683	24.8	349.2	0.001	61.3
114	Before analysis volcanic Ar-Ar Mesozoic	294	149.5	1240	0.233	159.0
115	Before analysis volcanic Ar-Ar Paleozoic	266	505.3	8069	4.19	712.9
116	Before analysis volcanic Ar-Ar Phanerozoic	None	None	None	None	None
117	Before analysis volcanic Ar-Ar Precambrian	42	232.1	1709	15.32	429.6
118	Before analysis volcanic Ar-Ar Proterozoic	128	1468.1	3557	552	550.9
119	Before analysis volcanic Ar-Ar Archean	97	2840.1	5000	1.794	1385.3
120	Before analysis metamorphic dates	1871	636.7	43013	0.1	1441.0
121	Before analysis metamorphic Cenozoic	238	48.6	639	0.1	68.4
122	Before analysis metamorphic Mesozoic	403	239.5	43013	3.1	2166.2
123	Before analysis metamorphic Paleozoic	538	413.1	16300	1.73	1287.7
124	Before analysis metamorphic Phanerozoic	22	518.3	561	491	19.8
125	Before analysis metamorphic Precambrian	300	1327.9	8228	44.7	1120.5
126	Before analysis metamorphic Proterozoic	261	915.4	2188.7	13.82	558.9
127	Before analysis metamorphic Archean	104	2024.0	5105	486.3	1039.0
128	Before analysis metamorphic K-Ar dates	631	472.2	6100	3.1	799.7
129	Before analysis metamorphic K-Ar Cenozoic	99	43.9	639	4.95	77.7
130	Before analysis metamorphic K-Ar Mesozoic	223	157.7	6100	3.1	471.5
131	Before analysis metamorphic K-Ar Paleozoic	166	248.0	1451	11.4	235.6
132	Before analysis metamorphic K-Ar Phanerozoic	None	None	None	None	None
133	Before analysis metamorphic K-Ar Precambrian	87	1326.1	3270	44.7	904.9
134	Before analysis metamorphic K-Ar Proterozoic	23	1395.0	2047	429	679.1
135	Before analysis metamorphic K-Ar Archean	30	2306.9	4970	614	1023.7
136	Before analysis metamorphic Ar-Ar dates	1240	720.3	43013	0.1	1669.8
137	Before analysis metamorphic Ar-Ar Cenozoic	139	51.9	373	0.1	61.0
138	Before analysis metamorphic Ar-Ar Mesozoic	180	340.9	43013	7.7	3200.6
139	Before analysis metamorphic Ar-Ar Paleozoic	372	486.7	16300	1.73	1535.5
140	Before analysis metamorphic Ar-Ar Phanerozoic	22	518.3	561	491	19.8
141	Before analysis metamorphic Ar-Ar Precambrian	213	1328.6	8228	63.3	1199.4
142	Before analysis metamorphic Ar-Ar Proterozoic	238	869.1	2188.7	13.82	524.7
143	Before analysis metamorphic Ar-Ar Archean	74	1909.4	5105	486.3	1029.8
144	After analysis	2248	326.5	8344	0.00643	687.9

145	After analysis Cenozoic	951	171.3	8344	0.00643	551.9
146	After analysis Mesozoic	646	142.8	1972	0.029	201.3
147	After analysis Paleozoic	372	292.3	1699	1.105	165.2
148	After analysis Phanerozoic	3	808.9	1044.4	624.1	214.7
149	After analysis Precambrian	20	2237.7	4535	26	1031.8
150	After analysis Proterozoic	251	1286.5	5601	23	1210.9
151	After analysis Archean	None	None	None	None	None
152	After analysis K-Ar dates	1272	293.5	8344	0.011	683.4
153	After analysis K-Ar Cenozoic	433	31.2	8344	0.011	401.3
154	After analysis K-Ar Mesozoic	386	108.8	1178	0.029	153.4
155	After analysis K-Ar Paleozoic	271	292.8	424	19	104.1
156	After analysis K-Ar Phanerozoic	None	None	None	None	None
157	After analysis K-Ar Precambrian	15	2160.6	4535	26	1168.9
158	After analysis K-Ar Proterozoic	162	1271.7	4755	23	1226.6
159	After analysis K-Ar Archean	None	None	None	None	None
160	After analysis Ar-Ar dates	976	369.5	5601	0.00643	691.7
161	After analysis Ar-Ar Cenozoic	518	288.4	3343.65	0.00643	628.5
162	After analysis Ar-Ar Mesozoic	260	193.2	1972	6.7	248.3
163	After analysis Ar-Ar Paleozoic	101	291.2	1699	1.105	268.3
164	After analysis Ar-Ar Phanerozoic	3	808.9	1044.4	624.1	214.7
165	After analysis Ar-Ar Precambrian	5	2469.0	2942	1860	430.5
166	After analysis Ar-Ar Proterozoic	89	1313.3	5601	31.2	1188.2
167	After analysis Ar-Ar Archean	None	None	None	None	None
168	After analysis volcanic dates	1374	273.9	8344	0.00643	639.6
169	After analysis volcanic Cenozoic	821	188.0	8344	0.00643	590.4
170	After analysis volcanic Mesozoic	321	150.4	1972	0.029	261.7
171	After analysis volcanic Paleozoic	120	177.4	699	19	140.9
172	After analysis volcanic Phanerozoic	None	None	None	None	None
173	After analysis volcanic Precambrian	9	1544.3	2650	26	987.1
174	After analysis volcanic Proterozoic	98	1412.8	4755	50.6	961.9
175	After analysis volcanic Archean	None	None	None	None	None
176	After analysis volcanic K-Ar dates	665	228.6	8344	0.011	681.0
177	After analysis volcanic K-Ar Cenozoic	362	29.5	8344	0.011	438.3
178	After analysis volcanic K-Ar Mesozoic	175	104.9	1178	0.029	196.9
179	After analysis volcanic K-Ar Paleozoic	54	105.0	347	19	69.2
180	After analysis volcanic K-Ar Phanerozoic	None	None	None	None	None
181	After analysis volcanic K-Ar Precambrian	9	1544.3	2650	26	987.1
182	After analysis volcanic K-Ar Proterozoic	60	1721.4	4755	80.3	978.1
183	After analysis volcanic K-Ar Archean	None	None	None	None	None
184	After analysis volcanic Ar-Ar dates	709	316.5	3343.65	0.00643	595.5
185	After analysis volcanic Ar-Ar Cenozoic	459	313.0	3343.65	0.00643	661.2

186	After analysis volcanic Ar-Ar Mesozoic	146	205.0	1972	6.7	314.9
187	After analysis volcanic Ar-Ar Paleozoic	66	236.6	699	24.3	156.7
188	After analysis volcanic Ar-Ar Phanerozoic	None	None	None	None	None
189	After analysis volcanic Ar-Ar Precambrian	None	None	None	None	None
190	After analysis volcanic Ar-Ar Proterozoic	38	925.5	1869	50.6	708.5
191	After analysis volcanic Ar-Ar Archean	None	None	None	None	None
192	After analysis metamorphic dates	874	409.3	5601	1.105	750.5
193	After analysis metamorphic Cenozoic	130	65.8	782.8	4	120.0
194	After analysis metamorphic Mesozoic	325	135.2	881	12	113.5
195	After analysis metamorphic Paleozoic	252	347.1	1699	1.105	146.9
196	After analysis metamorphic Phanerozoic	3	808.9	1044.4	624.1	214.7
197	After analysis metamorphic Precambrian	11	2805.0	4535	1860	675.6
198	After analysis metamorphic Proterozoic	153	1205.6	5601	23	1343.3
199	After analysis metamorphic Archean	None	None	None	None	None
200	After analysis metamorphic K-Ar dates	607	364.7	4535	4	679.4
201	After analysis metamorphic K-Ar Cenozoic	71	39.8	286	4	52.8
202	After analysis metamorphic K-Ar Mesozoic	211	112.0	881	12	104.9
203	After analysis metamorphic K-Ar Paleozoic	217	339.5	424	211	36.9
204	After analysis metamorphic K-Ar Phanerozoic	None	None	None	None	None
205	After analysis metamorphic K-Ar Precambrian	6	3085.0	4535	2490	746.8
206	After analysis metamorphic K-Ar Proterozoic	102	1007.3	3179	23	1284.1
207	After analysis metamorphic K-Ar Archean	None	None	None	None	None
208	After analysis metamorphic Ar-Ar dates	267	510.5	5601	1.105	884.4
209	After analysis metamorphic Ar-Ar Cenozoic	59	97.0	782.8	5.36	163.8
210	After analysis metamorphic Ar-Ar Mesozoic	114	178.1	507.9	23	116.9
211	After analysis metamorphic Ar-Ar Paleozoic	35	393.9	1699	1.105	384.9
212	After analysis metamorphic Ar-Ar Phanerozoic	3	808.9	1044.4	624.1	214.7
213	After analysis metamorphic Ar-Ar Precambrian	5	2469.0	2942	1860	430.5
214	After analysis metamorphic Ar-Ar Proterozoic	51	1602.2	5601	31.2	1383.5
215	After analysis metamorphic Ar-Ar Archean	None	None	None	None	None

Table A-2

	Ar-Ar	K-Ar	Comparison of Means calculation	
Avg	512.6	275.9	Pooled Estimate of Variance (sp2)	908342.9
Std	1161.2	627.5	SQRT(sp2(1/n1+1/n2))	22.2
N	3991	3413	y1-y2	236.7
s^2	1348385	393756.3	df (n1+n2-2)	7402.0
	Overall		Fα @ 90% confidence	1.0
			F stat (Do=0)	10.7

	Ar-Ar	K-Ar	Comparison of Means calculation	
Avg	129.5	23.7	Pooled Estimate of Variance (sp2)	105647.4
Std	413.3	220.4	SQRT(sp2(1/n1+1/n2))	12.2
N	1340	1530	y1-y2	105.8
s2	170816.9	48576.16	df (n1+n2-2)	2868.0
	Cenezoic		Fα @ 90% confidence	1.0
			F stat (Do=0)	8.7

	Ar-Ar	K-Ar	Comparison of Means calculation	
Avg	211.9	132.8	Pooled Estimate of Variance (sp2)	1241711.3
Std	1593.5	283.6	SQRT(sp2(1/n1+1/n2))	56.6
N	734	820	y1-y2	79.1
s2	2539242	80428.96	df (n1+n2-2)	1552.0
	Mesozoic		Fα @ 90% confidence	1.0
			F stat (Do=0)	1.4

	Ar-Ar	K-Ar	Comparison of Means calculation	
Avg	466.7	316.4	Pooled Estimate of Variance (sp2)	784353.4
Std	1175.6	247.5	SQRT(sp2(1/n1+1/n2))	48.4
N	739	611	y1-y2	150.3
s2	1382035	61256.25	df (n1+n2-2)	1348.0
	Paleozoic		Fα @ 90% confidence	1.0
			F stat (Do=0)	3.1

	Ar-Ar	K-Ar	Comparison of Means calculation	
Avg	1173.4	1374.8	Pooled Estimate of Variance (sp2)	1259555.6
Std	1185.5	961.9	SQRT(sp2(1/n1+1/n2))	126.1
N	260	114	y1-y2	-201.4
s2	1405410	925251.6	df (n1+n2-2)	372.0
	Precambrian		Fα @ 90% confidence	1.0
			F stat (Do=0)	-1.6

	Ar-Ar	K-Ar	Comparison of Means calculation	
Avg	1124.5	1287.1	Pooled Estimate of Variance (sp2)	806554.5
Std	759.5	1171.9	SQRT(sp2(1/n1+1/n2))	78.3
N	455	185	y1-y2	-162.6
s2	576840.3	1373350	df (n1+n2-2)	638.0
	Proterozoic		Fα @ 90% confidence	1.0
			F stat (Do=0)	-2.1

	Ar-Ar	K-Ar	Comparison of Means calculation	
Avg	2437.4	2272.9	Pooled Estimate of Variance (sp2)	1607922.4
Std	1324.02	995.6	SQRT(sp2(1/n1+1/n2))	220.5
N	171	41	y1-y2	164.5
s2	1753029	991219.4	df (n1+n2-2)	210.0
	Archean		Fα @ 90% confidence	1.2
			F stat (Do=0)	0.7

Table A-3

	Volcanic	Metamorphic
Avg	290.90	570.80
Std	703.20	487.90
N	4425.00	2979.00
s2	494490.24	238046.41
Overall		

Comparison of Means calculation	
Pooled Estimate of Variance (sp2)	391316.81
SQRT(sp2(1/n1+1/n2))	14.83
y1-y2	-279.90
df (n1+n2-2)	7402.00
Fα @ 90% confidence	1.00
F stat (Do=0)	-18.88

	Volcanic	Metamorphic
Avg	75.80	54.70
Std	350.80	90.30
N	2502.00	368.00
s^2	123060.64	8154.09
Cenozoic		

Comparison of Means calculation	
Pooled Estimate of Variance (sp2)	108356.77
SQRT(sp2(1/n1+1/n2))	18.38
y1-y2	21.10
df (n1+n2-2)	2868.00
Fα @ 90% confidence	1.00
F stat (Do=0)	1.15

	Volcanic	Metamorphic
Avg	150.10	192.90
Std	210.00	1613.40
N	826.00	728.00
s^2	44100.00	2603059.56
Mesozoic		

Comparison of Means calculation	
Pooled Estimate of Variance (sp2)	1242787.89
SQRT(sp2(1/n1+1/n2))	56.67
y1-y2	-42.80
df (n1+n2-2)	1552.00
Fα @ 90% confidence	1.00
F stat (Do=0)	-0.76

	Volcanic	Metamorphic
Avg	451.90	392.00
Std	549.00	1066.00
N	560.00	790.00
s^2	301401.00	1136356.00
Paleozoic		

Comparison of Means calculation	
Pooled Estimate of Variance (sp2)	790109.82
SQRT(sp2(1/n1+1/n2))	49.10
y1-y2	59.90
df (n1+n2-2)	1348.00
Fα @ 90% confidence	1.00
F stat (Do=0)	1.22

	Volcanic	Metamorphic
Avg	517.00	1380.10
Std	692.10	1140.30
N	63.00	311.00
s2	479002.41	1300284.09
Precambrian		

Comparison of Means calculation	
Pooled Estimate of Variance (sp2)	1163403.81
SQRT(sp2(1/n1+1/n2))	149.02
y1-y2	-863.10
df (n1+n2-2)	372.00
Fα @ 90% confidence	1.00
F stat (Do=0)	-5.79

Avg	Volcanic	Metamorphic
Std	1444.10	1022.70
N	755.60	938.30
s^2	226.00	414.00
	570931.36	880406.89
Proterozoic		

Comparison of Means calculation	
Pooled Estimate of Variance (sp2)	771265.83
SQRT(sp2(1/n1+1/n2))	72.63
y1-y2	421.40
df (n1+n2-2)	638.00
Fα @ 90% confidence	1.00
F stat (Do=0)	5.80

	Volcanic	Metamorphic
Avg	2772.90	2024.00
Std	1359.10	1039.00
N	108.00	2979.00
s2	1847152.81	1079521.00
Archean		

Comparison of Means calculation	
Pooled Estimate of Variance (sp2)	1106145.51
SQRT(sp2(1/n1+1/n2))	103.02
y1-y2	748.90
df (n1+n2-2)	3085.00
Fα @ 90% confidence	1.00
F stat (Do=0)	7.27

Table A-4