EDUCATIONAL COLUMN

A DEMONSTRATION OF THE MIXING MODEL TO ACCOUNT FOR Rb-Sr ISOCHRONS

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Received 23 November 1988; Revised 21 February 1989

Abstract

The rubidium-strontium isotopic dating method has been used extensively for approximate age determination of igneous rocks. Yet, this method suffers from unproven assumptions concerning the original concentrations of isotopes in the rocks. The isochron method appears to overcome this weakness. Nevertheless, the isochron method is not the only possible explanation of the isotopic data, and it is clearly invalid in many cases. Another concept, the mixing model, has been introduced which appears to be a valid explanation for a large portion of the isotopic data. It might be considered, therefore, to be a superior scientific model. This report describes a method to demonstrate the apparent superiority of the mixing model over the isochron method to students interested in geochronology.

Introduction

Isotopic dating methods are relied upon heavily by scientists interested in determining approximate age dates for artifacts. Consequently, the validity of the theoretical assumptions and accuracy of experimental methods involved in them need to continually be reappraised and revised when necessary. The rubidium-strontium dating method is no exception. This report describes a method to demonstrate the apparent superiority of the mixing model over the isochron method to explain rubidium-strontium isotopic data.

The rubidium-strontium method has been used for dating igneous rocks that happen to contain both potassium rich minerals (e.g., orthoclase, biotite, and muscovite) and calcium containing minerals (e.g., plagioclase and apatite). Because of similarities in ionic radius and charge, rubidium (Rb^+) often replaces potassium (K^+) in the crystal lattice sites of potassium rich minerals. Similarly, strontium (Sr^{++}) often replaces calcium (Ca^{++}) in the crystal lattice of calcium rich minerals. Consequently, rocks containing minerals rich in both potassium and calcium will also contain traces of rubidium and strontium (Faure, p. 75).

Rubidium-87 ($^{87}_{37}Rb^+$) is a naturally occurring radioactive isotope of rubidium and spontaneously decays (Reaction 1) to strontium-87 ($^{87}_{38}Sr^{++}$), a stable isotope of strontium, with elimination of β - radiation (electrons eliminated from the nucleus when a neutron is converted to a proton). Thus, the atomic mass (superscript) is essentially constant, but the atomic number (subscript) is increased by one unit due to the formation of another proton in the nucleus. Consequently, radiogenic $^{87}Sr^{++}$ will be found along with nonradiogenic $^{87}Sr^{++}$ and $^{86}Sr^{++}$ in rocks rich in potassium and calcium. The ratio of $^{87}Sr^{++}$ to $^{86}Sr^{++}$ is thought to depend upon the $^{87}Rb^+/^{86}Sr^{++}$ concentration ratio, and the time elapsed since crystallization of the rock (Faure, p. 76).

$$\text{Reaction 1:} \quad ^{87}_{37}Rb^+ \rightarrow ^{87}_{38}Sr^{++} + ^{0}_{-1}\beta-$$

The rubidium-strontium isochron dating method involves three basic steps: (1) determining the ratio of $^{87}Sr^{++}$ to $^{86}Sr^{++}$ in several fragments of the same rock, (2) plotting the values against the ratio of $^{87}Rb^+$ to $^{86}Sr^{++}$ found in the same fragments, and (3) interpretation of the results (Faure, pp. 79-81; Jager, pp. 15-16). If a line with a positive slope (an isochron) is obtained from such a graph, it is generally thought by geochronologists that the data is valid and that a reliable date for crystallization of the rock can be calculated from its slope (using Equation 1, where t is the apparent age of the rock in years, and λ is the decay constant for $^{87}Rb^+$, 1.42×10^{-11} yr^{-1}; Jager, p. 4). If the data is scattered so that a reliable line with a positive slope cannot be obtained, it is generally assumed that the data is not valid due to metamorphism (e.g., minerals having been leached into or out of the rock). Therefore, no meaningful age can be calculated, and the data is sometimes ignored (Faure, pp. 77, 90). Finally, the y intercept of the isochron (Figure 1) represents a sample with no rubidium ($^{87}Rb/^{86}Sr = 0$). The value of $^{87}Sr/^{86}Sr$ at this point is assumed to represent the original primordial ratio of strontium isotopes in the rock (approximately 0.699, Faure, p. 111). Thus, the isochron method appears to overcome the common radiometric dating difficulty of not knowing the original concentration of daughter isotope in the rock (Faure, p. 81; Young, pp. 185-93).

$$\text{Equation 1:} \quad t = \frac{\ln(1 + \text{slope})}{\lambda}$$

The isochron dating method is not the only possible explanation of the isotopic data, however. A second interpretation, called the mixing model, has been presented which suggests that there may not actually be any valid relationship between the isotope ratios and the age of the rock at all. The mixing model suggests that the isotope ratios may be explained by assuming that two or more igneous rocks originally containing different concentrations of isotopes were heterogeneously mixed (Akridge, 1982; Arndts and Overn, 1981, p. 1; Kramer, Arndts, and Overn, 1981, p. 1; Austin, 1988; Faure, pp. 97-106; Mandock, pp. 65-91).

Formation of a straight line when $^{87}Sr/^{86}Sr$ is plotted vs. 1/Sr (where Sr is the total concentration of strontium isotopes) is an indication that mixing has indeed occurred (Faure, pp. 97-106; Kramer, Arndts, and Overn, 1981, p. 1). Formation of a straight line with a

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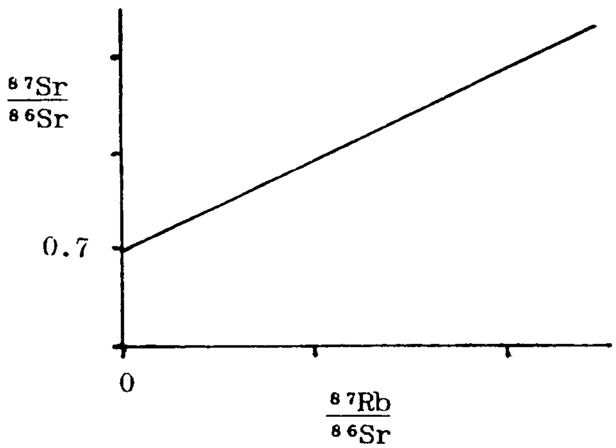

Figure 1. Rubidium-strontium isochron.

correlation coefficient larger than 0.9 has actually been found in 8 (44%) of the 18 published isochrons examined, with an additional 5 (28%) having a correlation coefficient greater than 0.8! Only 5 (28%) had a correlation coefficient less than 0.8. However, failure to obtain a straight line does not rule out the possibility of mixing. Isotopic data which do not produce a straight line with this test could still be the result of mixing if random dilution by material not containing strontium has occurred (Kramer, Arndts, and Overn, 1981, p. 1). Therefore, it is clear that in many published reports, erroneous ages have been calculated from lines which are actually the result of mixing, not aging. The following procedure is a simple way of illustrating to students interested in geochronology the apparent superiority of the mixing model to explain rubidium-strontium isotope ratios in rocks.

Procedure

1. Use different colored beads to represent individual atoms of the isotopes of Rb and Sr. For example, use:

   GREEN beads to represent ^{87}Sr atoms
   ORANGE beads to represent ^{86}Sr atoms
   WHITE beads to represent ^{87}Rb atoms

2. Prepare three sets of beads (A, B, C) containing different numbers of each color of bead to represent three different rocks containing different concentrations and different ratios of each isotope, as shown in Table I. Place each set in a separate container and label accordingly.

Table I: Isotope Composition of Three Individual Rocks

Set (Rock)	Number of Beads: Green (^{87}Sr)	Orange (^{86}Sr)	White (^{87}Rb)	$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$
A	7	10	0	0.70	0.00
B	8	10	20	0.80	2.00
C	12	12	30	1.00	2.50

Notice that Rock A contains no radioactive ^{87}Rb. Consequently, it contains no radiogenic ^{87}Sr. Therefore, its ratio of ^{87}Sr to ^{86}Sr is arbitrarily set at 0.70, which is thought to be a relatively common ratio for nonradiogenic strontium in igneous rocks (Faure, p. 111). Rocks B and C contain radioactive ^{87}Rb, and consequently might have higher $^{87}Sr/^{86}Sr$ ratios due to the presence of radiogenic ^{87}Sr.

Prepare eight additional sets of beads (D - K), as shown in Table II, to represent fragments of a rock formed by heterogenous mixing of the three original rocks while they were in a molten state. Notice that each set, D - K, is simply a combination of sets A, B, and C in various proportions as shown in Table II. Place each set in a separate container and label accordingly.

Finally, sets A, B, D, E, and F form Group I, which is analyzed by one student. Sets A, C, G, H, and I form Group II, which is analyzed by a second student. Similarly, sets B, D, G, and H form Group III, which is analyzed by a third student, and sets B, G, J, and K form Group IV, which is analyzed by a fourth student. Each group represents a different combination of fragments of the *same rock* which had originally been formed by the heterogeneous mixing of three different rocks: A, B, and C.

Results

The first student will analyze the rock by counting and recording the number of atoms of each isotope found in each set (fragment) in Group I. Then he will calculate and record the ratios of ^{87}Sr to ^{86}Sr and ^{87}Rb to ^{86}Sr for each set (as shown in Tables I and II). The ratios are then plotted on linear graph paper with $^{87}Sr/^{86}Sr$ on the vertical axis and $^{87}Rb/^{86}Sr$ on the horizontal axis, as shown in Figure 2. The best straight line is drawn through the points, and its slope determined. Finally, the apparent age (t) of the rock is calculated from the slope and the decay constant (A) for ^{87}Rb using Equation 1. For this group of data, the slope is calculated to be 0.050 and the apparent age is, therefore, 3.44 x 10^9 years. The $^{87}Rb/^{86}Sr$ ratio of zero on this line corresponds to an original primordial $^{87}Sr/^{86}Sr$ ratio of 0.700.

The second student analyzes the *same rock* similarly using the sets (fragments) in Group II and plots the data (Figure 2). For this group, the slope is found to be 0.120 and the apparent age is 7.98 x 10^9 years. A $^{87}Rb/^{86}Sr$ ratio of zero also gives a $^{87}Sr/^{86}Sr$ ratio of 0.700.

The third student analyzes the *same rock* using Group III and plots the data (Figure 2). However, the points are so scattered that it is not possible to draw a straight line through the data with any degree of reliability. Therefore, no age for the rock may be calculated from this data, and no y-intercept can be obtained.

The fourth student analyzes the *same rock* and plots the data (Figure 2) obtained from Group IV and discovers a negative slope, -0.100, and therefore, a negative age! Consequently, no meaningful age can be calculated for the rock from this data either. Extrapolation gives a y-intercept of 1.001.

Conclusions

The isochron dating method has produced four different results for the same rock! Obviously, all cannot be correct. Furthermore, if this method does produce the correct age, how can it be recognized

Table II. Isotope Composition of Eight Fragments of a Heterogeneous Rock Formed by Mixing Rocks A, B, and C in Various Ratios.

Set (Fragment)	Formed by Mixing	Number of Beads			$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$
		Green (^{87}Sr)	Orange (^{86}Sr)	White (^{87}Rb)		
D	1A + 1B + 0C	7 + 8 = 15	10 + 10 = 20	0 + 20 =20	0.75	1.00
E	2A + 1B + 0C	2(7) + 8 = 22	2(10) + 10 = 30	2(0) + 20 = 20	0.73	0.67
F	4A + 1B + 0C	4(7) + 8 = 36	4(10) + 10 = 50	4(0) + 20 = 20	0.72	0.40
G	1A + 0B + 1C	7 + 12 = 19	10 + 12 = 22	0 + 30 = 30	0.86	1.36
H	2A + 0B + 1C	2(7) + 12 = 26	2(10) + 12 = 32	2(0) + 30 = 30	0.81	0.94
I	6A + 0B + 1C	6(7) + 12 = 54	6(10) + 12 = 72	6(0) + 30 = 30	0.75	0.42
J	1A + 1B + 1C	7 + 8 + 12 = 27	10 + 10 + 12 = 32	0 + 20 + 30 = 50	0.84	1.56
K	1A + 4B + 1C	7 + 4(8) + 12 = 51	10 + 4(10) + 12 = 62	0 + 4(20) + 30 = 110	0.82	1.77

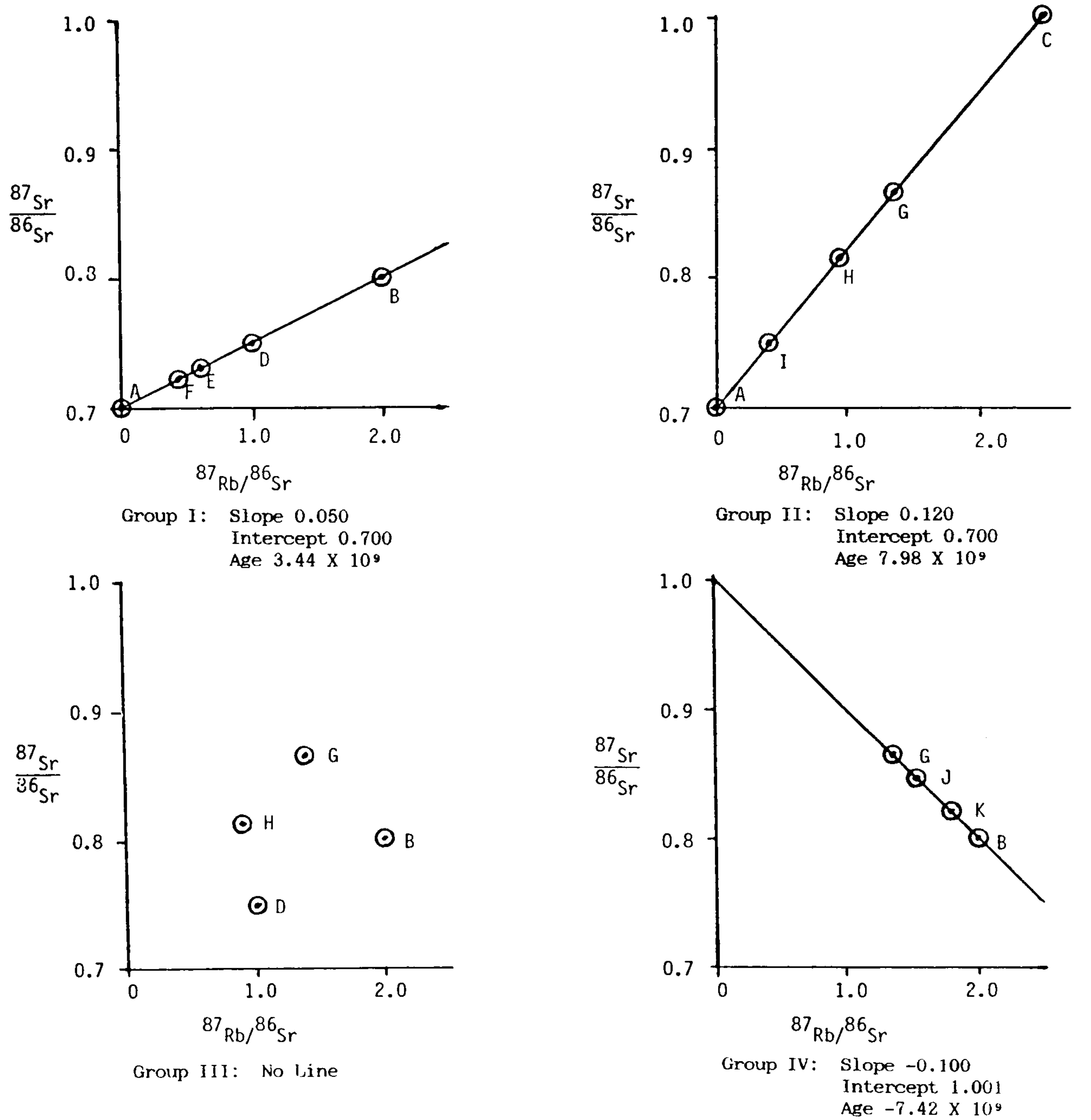

Figure 2. Graphs of various combinations of isotopic data from the same heterogeneous rock.

since two different ages were obtained? Finally, how can one be sure that the age is correct, since it was produced using the same method which obviously gives incorrect ages? From this demonstration, it is clear that the age determined for a rock using the isochron dating method cannot be recognized as accurate simply because a line is obtained with minimal scatter of data. If this were true, all lines should have had the same slope, resulting in the same age for the rock. But they do not. Furthermore, a valid isochron cannot be recognized simply because the y-intercept provides an acceptable $^{87}Sr/^{86}Sr$ ratio of 0.70. Lines obtained by the first two students both meet this requirement, but both cannot be correct.

Conversely, poor data, often ascribed to a partial loss of one or more isotopes (leaching) since crystallization of the rock, cannot be recognized simply because of scatter or a negative slope for the line. Notice that students analyzing Groups III and IV used some of the same data as students analyzing Groups I and II. If the data was recognized as valid by students analyzing Groups I and II because they obtained isochrons, how could it be declared invalid by students analyzing Groups III and IV when scatter or a negative slope is obtained? What, then, does allow one to recognize valid or invalid data and results?

The results seem to depend solely upon the individual sets of data chosen for the analyses. Since there is no apparent reason to select some data as accurate and reject other data as inaccurate before doing the analyses, it appears that the validity of the analyses can only be determined by whether the results are consistent with some predetermined factors or presuppositions. Therefore, whether the results are accepted or rejected is not determined by the accuracy and validity of the data itself or the inherent validity of the method, as is commonly thought, but by the validity of the researcher's presuppositions. If the results happen to agree with these presuppositions, they are arbitrarily accepted as valid. If they disagree, they are arbitrarily rejected as invalid. Consequently, the isochron dating method appears to add nothing of value to our understanding of the age of rocks. Furthermore, if the linear data is due to mixing, any age calculated from the slope would be erroneous.

Student Instructions

Introduction

Each student will be given the "Introduction" to the demonstration and four or five sets of beads. Each set represents a different sample of the *same* large rock. The beads represent atoms in the rock sample:

Green = ^{87}Sr
Orange = ^{86}Sr
White = ^{87}Rb

Procedure

1. Count the number of each type of atom in each sample and record the data in a table.
2. Calculate and record in the table the values of $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ for each sample.
3. Plot the data on graph paper with $^{87}Sr/^{86}Sr$ on the vertical axis and $^{87}Rb/^{86}Sr$ on the horizontal axis. Draw the best straight line through the points.
4. According to evolutionists, what information can be obtained from the graph about the original rock?
5. Determine the "original" ratio of $^{87}Sr/^{86}Sr$.
6. Calculate and record the slope of the line.
7. Calculate and record the "age" (t) of the rock in years using the following equation:

$$t = \frac{\ln(1 + \text{slope})}{1.42 \times 10^{-11}}$$

8. Repeat steps 2 - 7 for the data obtained by the other three students.

Conclusions

1. Does the "original" ratio of $^{87}Sr/^{86}Sr$ determined from your data agree with the ratio determined from the other students' data?
2. Does the age calculated with your data agree with the age calculated with the other students' data?
3. Is it legitimate to ignore part of the data?
4. What do your answers to Questions 1, 2, and 3 tell you about the validity of this dating method?
5. Referring to information in Tables I and II, is it possible to account for all of the data?
6. Can you test this explanation graphically?
7. Which explanation of the isotope ratios appears to be superior?

References

Akridge, R. 1982. Radiometric dating using isochrons. Impact No. 113. Institute for Creation Research. El Cajon, CA.

Arndts, R. and W. Overn. 1981. Isochrons. *Bible-Science Newsletter* 19(4).

Austin, Steven A. 1988. Grand Canyon lava flows: a survey of isotope dating methods. Impact No. 178. Institute for Creation Research. El Cajon, CA.

Faure, Gunter. 1977. Principles of isotope geology. John Wiley. New York.

Jager, E. and J. C. Hunziker. 1979. Lectures in isotope geology. Springer-Verlag. New York.

Kramer, M., R. Arndts and W. Overn. 1981. Proof of the validity of the mixing model. *Bible-Science Newsletter* 19(8).

Mandock, R. L. N. 1982. Scale time versus geologic time in radioisotope age determination. Institute for Creation Research. El Cajon, CA.

Young, D. A. 1977. Creation and the Flood. Baker Book House. Grand Rapids.

QUOTE

In the Bible God is Himself the Good and He declares His original creation to be essentially good. God's commandments articulate and summarize His will for His creatures, and by this His own righteous standard He judges all people and nations. He suspends our destiny in eternity on our response to His law and to Jesus Christ "the just and holy one."

For Plato, the Good was independent of God and was normative for the Demiurge who according to Plato gave form to the universe. But for the Bible nothing is absolutely independent of God; everything is dependent on Him. Augustine, Duns Scotus and the Protestant Reformers insisted that God Himself decrees the good.

Henry, Carl F. H. 1986. The God of the Bible and moral foundations in Burke, Thomas J., editor, *The Christian vision: man and morality*. The Hillsdale College Press. Hillsdale, MI p. 5.