Age Dating of Rocks

By Richard J. Bottomley

Few things on earth are so underrated as rocks. They seem so dull. Yet from rocks we create the metals and materials used for home and industry. Rock is the source of petroleum, which makes modern transportation and plastics possible, and the dominant factor in the shape of the natural world around us. But more fascinating than any of these insights is the fact that rocks can speak to us—not in the English language, of course, but they speak nonetheless. Every rock is like a miniature "black-box" flight recorder that can be examined in a lab. There it can reveal such things as what temperatures and pressures it has seen, the direction of the north pole when it was formed, often the climate in which it was created and, most surprisingly, how old it is.

Let's consider why rocks have different ages. Why don't they all have one age that reflects the time of their creation? The answer to this is that natural processes like wind and water eat away at rock and reduce it to sand and mud, which eventually drain to the sea. There they become deposited and glued together again into "new" rocks called sandstone and shale. "New" carbonate rock such as limestone can also be created by reef-building organisms in the sea. Other processes such as metamorphism and volcanism also create "new" rock. This "new" rock often remembers only the age of its latest reincarnation.

I would like to explain how simple it is to date a rock. This technique is not cloaked in mystery. The fact that we can do this is a result of God's natural laws, the master plan by which he structured the universe. Everything we can see in the earth or universe can be described by four basic forces. You are already quite familiar with the gravitational force, which holds you down, and the electromagnetic force shown in phenomena such as light and chemistry. The other two forces, the strong and weak nuclear forces, are not as easily observed in everyday life. The sun is an example of an environment where strong and weak forces predominate. It is an astounding and yet humbling thought that with these four forces, the whole universe as we know it can be described—clearly a tribute to the creative genius of God.

One of the results of the interactions of these forces is the periodic table (Fig. 1) we all remember from high school chemistry that describes how the different elements relate to each other. You will remember that an

Editor's Note

Creation Reconsidered
Scientific, Biblical and Theological Perspectives
James L. Hayward, Editor
Association of Adventist Forums

In August 1985, under the aegis of the Association of Adventist Forums, a group of 104 registrants and their families examined firsthand evidence of the earth's past recorded in the rocks and fossils of the Rocky Mountains. They also spent four days evaluating the implications of this evidence for faith and belief at a conference on Geology and the Biblical Record held in West Yellowstone, Montana. Papers presented at this conference form most of the twenty-seven chapters of this provocative volume.
—from the book jacket

Understanding the time element of Creation occupied much of the scientific discussion at this conference. Other presentations in addition to the following presentation by Richard Bottomley, included addresses by Ervin Taylor on radiocarbon dating's problems for young earth creationists and P.E. Hare on pleochroic halos and time as well as amino acid racemization dating of fossils.

We are pleased to bring this book to the attention of our readers by including this chapter.

Key: element name / atomic number / element symbol / 1997 atomic weight (mean relative mass)

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
hydrogen 1 H 1.00794(7)																		helium 2 He 4.002602(2)
lithium 3 Li 6.941(2)	beryllium 4 Be 9.012182(3)												boron 5 B 10.811(7)	carbon 6 C 12.0107(8)	nitrogen 7 N 14.00674(7)	oxygen 8 O 15.9994(3)	fluorine 9 F 18.9984032(5)	neon 10 Ne 20.1797(6)
sodium 11 Na 22.989770(2)	magnesium 12 Mg 24.3050(6)												aluminium 13 Al 26.981538(2)	silicon 14 Si 28.0855(3)	phosphorus 15 P 30.973761(2)	sulfur 16 S 32.066(6)	chlorine 17 Cl 35.4527(9)	argon 18 Ar 39.948(1)
potassium 19 K 39.0983(1)	calcium 20 Ca 40.078(4)		scandium 21 Sc 44.955910(8)	titanium 22 Ti 47.867(1)	vanadium 23 V 50.9415(1)	chromium 24 Cr 51.9961(6)	manganese 25 Mn 54.938049(9)	iron 26 Fe 55.845(2)	cobalt 27 Co 58.933200(9)	nickel 28 Ni 58.6934(2)	copper 29 Cu 63.546(3)	zinc 30 Zn 65.39(2)	gallium 31 Ga 69.723(1)	germanium 32 Ge 72.61(2)	arsenic 33 As 74.92160(2)	selenium 34 Se 78.96(3)	bromine 35 Br 79.904(1)	krypton 36 Kr 83.80(1)
rubidium 37 Rb 85.4678(3)	strontium 38 Sr 87.62(1)		yttrium 39 Y 88.90585(2)	zirconium 40 Zr 91.224(2)	niobium 41 Nb 92.90638(2)	molybdenum 42 Mo 95.94(1)	technetium 43 Tc [98.9063]	ruthenium 44 Ru 101.07(2)	rhodium 45 Rh 102.90550(2)	palladium 46 Pd 106.42(1)	silver 47 Ag 107.8682(2)	cadmium 48 Cd 112.411(8)	indium 49 In 114.818(3)	tin 50 Sn 118.710(7)	antimony 51 Sb 121.760(1)	tellurium 52 Te 127.60(3)	iodine 53 I 126.90447(3)	xenon 54 Xe 131.29(2)
caesium 55 Cs 132.90545(2)	barium 56 Ba 137.327(7)	57-70 *	lutetium 71 Lu 174.967(1)	hafnium 72 Hf 178.49(2)	tantalum 73 Ta 180.9479(1)	tungsten 74 W 183.84(1)	rhenium 75 Re 186.207(1)	osmium 76 Os 190.23(3)	iridium 77 Ir 192.217(3)	platinum 78 Pt 195.078(2)	gold 79 Au 196.96655(2)	mercury 80 Hg 200.59(2)	thallium 81 Tl 204.3833(2)	lead 82 Pb 207.2(1)	bismuth 83 Bi 208.98038(2)	polonium 84 Po [208.9824]	astatine 85 At [209.9871]	radon 86 Rn [222.0176]
francium 87 Fr [223.0197]	radium 88 Ra [226.0254]	89-102 **	lawrencium 103 Lr [262.110]	rutherfordium 104 Rf [261.1089]	dubnium 105 Db [262.1144]	seaborgium 106 Sg [263.1186]	bohrium 107 Bh [264.12]	hassium 108 Hs [265.1306]	meitnerium 109 Mt [268]	ununnilium 110 Uun [269]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]		ununhexium 116 Uuh [289]		ununoctium 118 Uuo [293]

*lanthanides	lanthanum 57 La 138.9055(2)	cerium 58 Ce 140.116(1)	praseodymium 59 Pr 140.90765(2)	neodymium 60 Nd 144.24(3)	promethium 61 Pm [144.9127]	samarium 62 Sm 150.36(3)	europium 63 Eu 151.964(1)	gadolinium 64 Gd 157.25(3)	terbium 65 Tb 158.92534(2)	dysprosium 66 Dy 162.50(3)	holmium 67 Ho 164.93032(2)	erbium 68 Er 167.26(3)	thulium 69 Tm 168.93421(2)	ytterbium 70 Yb 173.04(3)
**actinides	actinium 89 Ac [227.0277]	thorium 90 Th 232.0381(1)	protactinium 91 Pa 231.03588(2)	uranium 92 U 238.0289(1)	neptunium 93 Np [237.0482]	plutonium 94 Pu [244.0642]	americium 95 Am [243.0614]	curium 96 Cm [247.0703]	berkelium 97 Bk [247.0703]	californium 98 Cf [251.0796]	einsteinium 99 Es [252.0830]	fermium 100 Fm [257.0951]	mendelevium 101 Md [258.0984]	nobelium 102 No [259.1011]

Fig. 1. The Periodic Table of Elements

atom is a dense central core made up of particles called neutrons and protons, and that a cloud of electrons circles the nucleus. The number of electrons equals the number of protons for any one species of atom. The periodic table is a manifestation of the basic structure of matter. Start with hydrogen, the lightest element, then keep adding protons and neutrons to make up successively heavier atoms. For the moment let's ignore neutrons. If you add one proton to hydrogen you get helium. You can keep adding protons until you have a nucleus with eighty-three protons. This is the element bismuth. If you add one more proton, something rather surprising happens. The element you form with atomic number eighty-four (polonium) is radioactive! It doesn't want to stick together. If you leave it long enough it will decay into other nonradioactive elements. It is unstable—the nuclear glue is no longer strong enough to hold the nucleus together and thus it decays. This explains why there isn't an infinite number of chemical elements. All nine natural elements heavier than bismuth are also radioactive and decay. Humans have tried for over forty years to glue heavier elements together, but each one is radioactive and eventually decays to lighter elements. Thus we see that radioactivity is a natural phenomenon tied to the fundamental structure of matter. It is related to the strong and weak nuclear forces and is not an independent physical quantity that can be varied at will; it comes about when the nuclear glue is no longer strong enough to hold a particular nucleus together. Because it is a nuclear process, virtually nothing we can do externally can affect the process. Heat, pressure, electricity, and explosions all involve the electrons of an atom, not the nucleus.

In a simple radioactive decay, we call the radioactive atom the "parent atom" and the stable atom that results the "daughter atom." The rate of transformation from parent to daughter is constant for any particular radioactive nucleus. Every radioactive atom has a characteristic half-life. The half-life is simply how long it takes for one-half the radioactive atoms to decay. Some radioactive atoms have half-lives of billionths of a second while others have half-lives of billions of years. The term "decay constant" is related to half-life and is simply a measure of the probability that an atom will disintegrate in a unit of time.

Because the decay rate of radioactive atoms is constant, we can use it to tell time in the same way that the constant movement of hands of a clock enables us to tell time. Even a small piece of rock contains trillions of atoms, some of which are naturally radioactive. Throughout the life of this rock these radioactive parent atoms decay into daughter isotopes at a steady, predictable rate. If we count the parent and daughter atoms, we can tell how old the rock is.

Let's demonstrate how this can be done. Think of a rock as a box made up of golf balls of different colors, each color representing a different type of atom such as iron or silicon. Assume that the box contains one hundred radioactive white golf balls and that they decay at a rate of one ball per year. Every time one decays it turns green. I can come back anytime during the next hundred years and tell how much time has passed simply by noting how many golf balls have turned green. If there are seventy-five white balls and twenty-five green balls, we know that twenty-five years have passed. In this simple situation we could tell the amount of time that passed by looking solely at the white balls (100 - 75 = 25 years) or just at the green balls (25 years). This is because we knew how many balls there were at zero time. In a real rock we don't know how many radioactive atoms there are to begin, so we must count both the parent and the daughter atoms because the total number of white balls plus the total number of green balls add up to the original number of white balls before the decay process started. Rock dating is basically that simple. The machine used to measure the atoms is called a mass spectrometer, and it allows one to count the relative number of each type of atom in a rock. The people who make these measurements are called geochronologists.

Now we can think of three problems that may interfere with the accuracy of this process:

1. Radioactive decay constants change with time.
2. Someone steals balls from the box or puts extra balls into the box while we're away.
3. There are extra green balls in the box before we start.

Radioactive Decay Constants Change

As we have seen, decay constants are a natural function of the nuclear glue that holds the universe together. You can't change them at random without destroying everything around us. What would be the result of weakening the nuclear force enough to compress the radiometric ages into a short time scale? First, many atoms that are stable now would decay into different atoms. All life, which is dependent on complex molecules such as DNA, enzymes, and proteins, would cease as the delicate binding and shape of these molecules became totally disrupted by atoms turning into different atoms.

Second, increased radiation from decay would be lethal to life. Third, the amount of energy given off during decay would probably be enough to totally melt the surface of the earth. Radioactive decay even at its present slow rate is a major reason that the core of the earth is presently molten. Lastly, if this had happened in the recent past, we would still find naturally occurring simple radioactive elements with short half-lives (less than ten thousand years) not related to the decay of the longer-lived isotopes, but this is not observed in nature. Changing the nuclear force by enough to make the dates fit a six- thousand-year chronology would be equivalent to making gravity a million times weaker in the past. In short, any change of this magnitude in nuclear forces is bound to leave behind evidence that we could see today.

Extra Balls Added to the Box

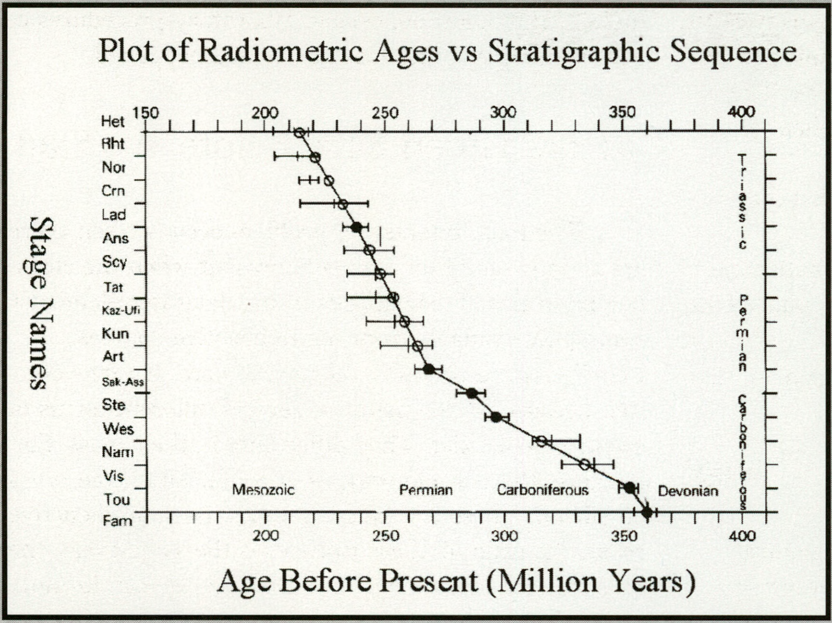
In some rocks, atoms can be added or subtracted by natural processes such as water percolating through pore spaces. Geochronologists avoid this problem by choosing minerals that are known to resist these processes and keep the parent and daughter population locked in. In addition, certain laboratory procedures can help identify whether loss has indeed happened.

Extra Green Balls Before We Start

The most interesting problem occurs when there are already daughter elements present when the clock begins to tick. This happens if the daughter element is commonly available from nonradioactive sources. Luckily nature comes to our rescue here. It turns out that because of the neutron, several different forms of each element exist. They differ only in their mass. For instance, there are four types of sulfur and three types of silicon. These are called isotopes. In nonradioactive rocks, the ratio of these isotopes is the same everywhere on earth. By measuring these isotopes, we can formulate ratios that represent the amount of contaminating isotope at zero time. The calculated amount of contaminating isotope can now be subtracted from the total in the rock we are attempting to age.

The idea is much easier to understand in terms of golf balls. Let's consider a box of one hundred white balls, with six green balls and two red balls already present. If we didn't account for the green balls, we would estimate that the box was already six years old before the clock even started. But if we know that in nonradioactive rocks there are three green balls for every red ball, we know that when we find the two red balls we have to subtract the six green balls before we calculate any age. For instance, suppose we came back some years later and found thirty-one green balls and two red balls. We subtract three green balls for each red ball we find. Thus we have $31 - 6 = 25$ green balls due to radioactive decay, and we know the box is twenty-five years old.

But what about the scientists who do the dating? Aren't they atheists who will hide any six-thousand-year dates and only publish the ones that are hundreds of millions of years old? Surprisingly, most scientists whom I have met over the years have a belief in God and are not out to prove that he doesn't exist. Physical scientists are quite honest and forthright in their publications for two very good reasons. First, the purpose of publishing is to let everyone know what you've discovered by your research. These results are almost always checked by someone else sooner or later. If you lie or cheat, you will be caught and your career ruined. Second, as one geochronologist (who is an avowed atheist) once told me, "I would love to prove the earth is six thousand



A plot of the radiometrically determined age (with error bars) plotted against the stratigraphic sequence of fossil life. The width of each vertical stage is based on the assumption that they represent equal units of time. If this assumption was nonsense, then we would expect a broad scatter of points across the diagram indicating there is no relationship between the order of fossil development and their radiometrically determined age.

Diagram is modified after *Harland, Cox, Llewellyn, Pickton, Smith and Walters, A Geologic Time Scale,* Cambridge, 1982.

years old if I could." What he meant was this: He would be world famous and be remembered as the man who made a really significant discovery in earth science—the equivalent to finding a cure for all heart attacks in medicine.

So it is basically simple to get a rock to tell you how old it is. Even potential problems that might interfere with this radioactive clock can be solved, and the method is constantly being improved and refined. Many rocks can also be dated by two or more separate and independent methods. This gives us confidence that the ages we get from rocks are reliable, and, as you already know, many of them are extremely ancient. They must be saying something important about the age of the earth.

Significance of Radiometric Dates to the History of Life

From a Christian point of view, the most startling aspect of radiometric dating is the relationship between ages and fossils in rocks. The different layers in rocks imply a sequence—the bottom rock being laid down before the younger rock, which is on top of it. But we also observe a sequence of "critters" in these rocks. Certain critters are only found in young rocks and others only in old rocks.

When the rocks on earth are classified into groups on the basis of distinctive critters they contain, we call each of these units a "stage." Stages are defined strictly by fossils and relative stratigraphy, and stage boundaries are usually marked by a distinctive change in critter morphology or population. They represent a sequence of younger to older rocks, but without further information we don't know whether this sequence represents one year or a billion. It is possible, however, to radiometrically date rocks that are associated with each stage. As expected, we find that stages at the top of a series are younger than stages at the bottom. But what is really surprising is that the dates spread over hundreds of millions of years! Even more amazing is the consistency of the dates. Rocks containing a certain type of critter only give a small range of ages for that critter.

Each stage, then, appears to be associated with rocks of a certain age range. This is really astounding because stages are defined by fossils in rocks and stratigraphic relationships while ages are totally independent. Radiometric ages, as we have seen, are dependent on nuclear processes, not geology or critters. Yet, clearly, certain critters and certain ages are always correlated. The simplest explanation of this link is that the stages really do represent long intervals of time and that the rocks involved could not have been deposited over a short period of time. Any model we propose to describe early earth history will have to satisfactorily explain results such as these.

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