EDITORIAL

THE PROBLEM OF MORALS

A recent book, *Abusing Science*, by Philip Kitcher (1982. Cambridge, MA: MIT Press) presents a detailed analysis of "scientific creationism." Kitcher discusses, chapter by chapter, the creationists' strong points, along with their criticisms of evolutionary theory. In conclusion, he states to his satisfaction that there is no substance to the creationists' claims to superiority of theory.

In the final chapter, "The Bully Pulpit," Kitcher believes himself to have at last discovered the fundamental reason for the debate between creationists and evolutionists: the issue of human morality. He provides numerous quotations from creationist authors which blame the theory of evolution for all of society's evils. The lengthy list of problems include aggressive wars, racism, promiscuity, homosexuality, and communism. Kitcher claims (perhaps rightly so) that evolutionary theory is not the source of all these evils.

He then proceeds to make a case for the recently developed concept that the morals of a society can be the natural result of evolutionary processes. In other words, man's mind has evolved so that introspection is possible, and with his ability to reason from cause to effect, certain societal behaviors may be advantageous for survival. (Kitcher's position forces him to swim upstream against a spate of semipopular and popular literature written by *pro-evolutionary* authors. These claim that many abhorrent social traits are rooted in an evolutionary past and that our present war-like, sexual, etc., behaviors are merely remnants of a more primitive stage).

While Kitcher may claim that belief in evolutionary theory is not the basis of society's ills, he fails to recognize an even more fundamental issue. This is the question of *who* determines the basic morals of a society and what is the end result of this particular choice. Practically speaking, for most of the people on this planet, social morals are determined by their society. Divergent moral codes found throughout the cultures and regions of the earth thereby take on a relativistic position. Thus man himself becomes the final arbiter and determiner of his moral system. It is this relativism that the creationist cannot abide.

Creationists claim that man cannot determine morals, because these must come from an all-wise and loving God if society is to function optimally. The creation of man, his fall from grace, and the Divine rescue mission all shout loudly of man's inability to determine his moral values. So, while evolutionary theory does not contain the elements of society's ills, it does provide a philosophical basis for moral relativism which surely is the basis of these ills. It is this contrast between relativistic morals and divinely given morals that will forever be the basis for conflict between these two powerful ideas.

Richard D. Tkachuck

REACTIONS

Readers are invited to submit their reactions to the articles in our journal. Please address contributions to: ORIGINS, Geoscience Research Institute, 11060 Campus St., Loma Linda, California 92350 USA.

RE: HAYWARD & CASEBOLT: GENESIS 5 AND 11 STATISTICAL STUDY (ORIGINS 9:75-81)

This interesting study has hardly said the last word. In fact, probably the best explanation for last digit nonrandomness has been overlooked (or, at least, thoroughly obscured under the heading of “digit preferences”).

That explanation is rounding, to a nearby multiple either of 10 or of 5. What could be more likely, when nearly half the last digits are 0 (19 of 40, per Tables 5 & 6) and another 20% are 5 (8 of 40)? Furthermore, the total absence of 1 and 6 as last digits hints at a rounding down to 0 and 5, respectively.

If the numbers in Table 4 had occurred in a modern document (as, for example, figures on an income tax return), rounding would doubtless have been the first explanation to come to mind for last digit nonrandomness. But critical scholarship is ever pushing us to view the early chapters of Genesis as irrational and arbitrary and to prefer explanations which match that presupposition.

In reality, rounding was even more likely in Bible times than now. “The people of Bible times, as in many parts of the East today, thought more in terms of round numbers than we do, and did not demand mathematical exactitude.”[1] It is extremely unlikely that Moses would even attempt, like the modern demographer, “to handle fractions of years consistently” by using “the age of the individual at his most recent birthday” (p 77).

If rounding alone is sufficient to account for the nonrandom distribution of last digits, then nonrandomness *of last digits* would not imply nonrandomness of the absolute values *of the ages* themselves. In that case, Hayward and Casebolt have *not* actually demonstrated that the “*age data* form a significantly nonrandom distribution” (p 75).

In more precise terms, the study of Andrews University age data showed that “If age data is *non-rounded and* random, then last digits are random” ($[p \wedge q] \Rightarrow r$). This is logically equivalent to its contrapositive, “Ifvst digits are nonrandom, then age data is *either* rounded *or* non-random” ($\sim r = [\sim p \vee \sim q]$). Thus, if rounding has occurred, nonrandomness of age data is not necessarily implied.

Rounding to a multiple of 10 or of 5 is obviously tied to the base 10 number system. Thus one way of testing whether last digit nonrandomness could be due solely to (base 10) rounding is to change all data to base 11 and see whether last digits then become random. They do — See Tables A and B. (To simplify matters, only pregenerative years are discussed here, since only they are really pertinent to chronology. Results are even more favorable — from my point of view — for postgenerative years.)

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[1] Seventh-day Adventist Bible Dictionary, revised edition (1979), p 208.

TABLE A: Pregenerative years of 20 patriarchs in Gen. 5 & 11 (MT)

Base 10	Base 11	Base 10	Base 11	Base 10	Base 11
130	109[2]	187	160	30	28
105	96	182	156	32	2T
90	82	500	415	30	28
70	64	100	91	29	27
65	5T[3]	35	32	70	64
162	138	30	28	100	91
65	5T	34	31		

TABLE B: Frequency distribution of base 11 last digits from Table A

Last digit	Observed frequency
0	1
1	3
2	2
3	0
4	2
5	1
6	2
7	1
8	4
9	1
T	3

Expected frequency =20/11.

$x^2 = 7.5$, d.f. = 10, P » 0.05: Observed and expected frequencies are *not* significantly different. More exactly, P =0.67±, that is, by chance alone, distributions in which observed values even differ more widely from the expected will occur in 2 cases out of 3.

A more direct, but theoretically more suspect, way of testing whether the non-randomness of last digits can be explained solely by rounding is simply to "unround" the numbers by likely guessing. Two possible pre-rounding distributions are found in columns (a) and (b) of Table C.

TABLE C. Frequency distribution of (base 10) last digits from Table A after unrounding by conjecture.

Last digit	Observed frequency after rounding	a) Likely "observed" frequency before rounding	(b) Minimally unrounded "observed" frequency before rounding	
0	10	4	5	
1	0	3	3	
2	3	3	3	
3	0	0	0	
4	1	2	1	(unchanged)
5	4	2	4	
6	0	1	0	
7	1	1	1	
8	0	1	0	
9	1	3	3	

(Expected frequency = 2; d.f. 9.)

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[2] ($= 1\times11^2 + 0\times11 + 9\times1$)

[3] ($= 5\times11 + 10\times1$)

Column (a) assumes that one 6 and one 4 had been rounded to the nearest 5, and that three 1's, two 9's, and one 8 had been rounded to the nearest multiple of 10. X^2 = 7.0, P » 0.05: Observed and expected frequencies are *not* significantly different. More exactly, P = 0.64±, that is, by chance alone about 2 distributions out of 3 will have observed values that differ even more widely from the expected.

Column (b) represents minimal unrounding to avoid a significant difference. It assumes only that three 1's and two 9's had been rounded to the nearest multiple of 10. X^2 = 15.0, P > 0.05: Observed and expected frequencies are *not* significantly different.

What implications would rounding have for the traditional practice of adding the pregenerative age data to calculate the time since creation? If rounding up (e.g., 9 to 10) and rounding down (e.g., 1 to 0) occurred on a roughly equal scale, it makes practically no difference. The rounding per columns (a) or (b) of Table C makes no more than a year's difference in the time from creation to the birth of Isaac. In the light of the much larger differences in the time periods given by the various ancient texts (LXX, MT, etc.), even a few years difference caused by rounding would be hardly worth mentioning.

I conclude that:

1. Rounding is a totally sufficient explanation and the most likely explanation for the observed nonrandomness in the base 10 last digits of the age data of Genesis 5 and 11.
2. Such rounding has *virtually no effect* on the precision of a pre-Abrahamic chronology constructed from such age data (— unless one desires an unusual degree of precision!).
3. Such last digit nonrandomness is virtually irrelevant to the defensibility (whatever that is) of the Genesis chronology.

Mitchell P. Nicholaides
Camden, South Carolina

P.S. Since Seth was not Adam's "first-born son," the second sentence of Hayward and Casebolt's article contains its own sort of "rounding."

J. L. HAYWARD AND D. E. CASEBOLT REPLY:

We commend Mitchell Nicholaides for his careful statistical analyses and lucidly stated opinions. We heartily agree that our paper "has hardly said the last word" on the topic. As stated in our introduction, "We do not attempt to completely resolve the genealogy/chronology problem." However, for several reasons we disagree with Nicholaides' a priori assertion that "Rounding is a totally sufficient explanation and the most likely explanation for the observed nonrandomness" in the age values, and his implicit conclusion that a meaningful chronology can be constructed from the genealogical data.

First, if rounding of real age values occurred as Nicholaides posits, it did not occur consistently. While 27 of the 40 independent age values are multiples of 5 or 10, 13 are not. Nicholaides' analysis implies that many digits one number removed from 5 and 10 are rounded. For example, in constructing his Column (a) of Table C he assumes that one 6, one 4, two 9s and even one 8 have been rounded to either 5 or 10. Yet, to choose only two examples (without considering the numbers ending in 2s or 7s) we find that Eber's and Nahor's pregenerative ages of 34 and 29, respectively, were not rounded.

Second, deviation from an expected distribution of values in the age data is particularly apparent when multiples of 100 are considered. Again, assuming a random distribution of frequencies, the expected frequency of multiples of 100 in a series of 40 numbers is less than 1 (40/100 = 0.4). However, examination of our Table 3 reveals that eight (20%) of the 40 independent age values are multiples of 100. (A X^2 comparison between the observed and expected values is not too meaningful due to an expected value of less than 1. However, the difference between observed and expected values is so large that statistical testing is unnecessary to evaluate these data.) Those who defend the rounding hypothesis must consider the possibility that not only is a large percentage of the numbers rounded to the nearest 10, but an unnaturally high proportion seem rounded to the nearest 100 as well.

Third, several factors suggest that the writer of the Genesis genealogies was more concerned with style than with chronology. For example, Enoch, the *seventh* from Adam "walked with God" and was therefore "taken" by God (Genesis 5:22-24). (Also, when he was "taken" he was 365 years old, corresponding to the 365 days of a complete year.) Noah, the *tenth* from Adam "walked with God" (Genesis 6:9), "won the Lord's favour" (Genesis 6:8), and during the Flood "only Noah and his company survived" (Genesis 7:23). Abraham, the *tenth* post-Flood patriarch, was made the father of "a great nation" (Genesis 12:2) with the prediction that "All the families on earth will pray to be blessed as you are blessed" (Genesis 12:3). (All the above quotes are from the NEB.) One searches in vain for mention of comparable benefits accruing to patriarchs of numerically nonsignificant generations. (Of course, other numbers like 3 and 12 held special significance to Hebrew writers, though the patriarchs of corresponding generations did not receive extraordinary blessings. But we think it more than coincidental that each of the patriarchs receiving exceptional recognition by God were members of numerically significant generations.)

Also, the genealogies are neatly organized into two groups of ten patriarchs each, the first group containing antediluvians and the second group containing postdiluvians to the time of Abraham, the father of the Hebrew people. Interestingly, the last patriarch to bear children in each group of ten bore three children, presumably as triplets: Noah fathered Shem, Ham, and Japheth during his 500th year (Genesis 5:32), and Terah begat Abraham, Nahor, and Haran during his 70th year (Genesis 11:26).

Finally, the average pregenerative age of the first nine patriarchs was 116 years, while Noah's pregenerative age was 500 years, over four times the average. If Noah had had sons at the average pre-Flood age, and if these sons had fathered children at the same average age, and if these children produced descendants of their own at the same average age, and these descendants the same, there would have been an additional three generations of patriarchs alive during the Flood besides Noah and his sons. But, of course, this would have altered the balance the writer achieved by placing ten patriarchs before and ten after the Flood.

The Genesis genealogies would suit well a Hebrew writer's intent to show ancestral continuity between the Creator God and the Hebrew people, albeit in a somewhat stylistic fashion. But to force Genesis 5 and 11 to assume the role of "chronogenealogies" demands more of scripture than we believe was intended by the inspired writers or is warranted by the evidence.

ARTICLES

MOUNT ST HELENS AND SPIRIT LAKE

Harold G. Coffin
Geoscience Research Institute

WHAT THIS ARTICLE IS ABOUT

The eruption of Mount St. Helens has become a unique opportunity to study rapid geologic activity. Miles of forests were blasted down, giant slides and debris flows changed the topography of the Toutle River Valley, and new lakes were formed. At the base of the mountain, a larger Spirit Lake now supports a huge log raft. Some of the logs are floating erect or are sitting upright on the bottom. Some past geologic phenomena such as the series of petrified forests of Yellowstone may be explained in part by the study of this eruption and its associated activities.

On May 18, 1980, Mount St. Helens erupted with a roar heard 200 miles away and a force equal to 500 Hiroshima atomic bombs (Findley 1981, p 17). Enough ash and rock were moved to provide a ton for every person on earth. A blast of ash-charged superheated gas was flung northward killing 61 humans and thousands of animals.* Millions of trees in 240 mi^2 of prime forest were blown down or killed (Christiansen & Peterson 1981, p 17).

The eruption that removed over 1300 feet from the top of the beautiful mountain was triggered or preceded by a 4.9 magnitude earthquake (Rosenfeld 1980, p 498). The immediate result of the jolt was a massive avalanche down the north face which had been bulging at a rate of 5 feet per day for several weeks (U. S. Dept. Agriculture 1980). The eruption following the slide eviscerated the mountain, leaving a crater 2000 feet deep. A resort lodge and thirty cabins were pulverized and buried under 300 feet of sediments.

The rapid melting of snow fields and glacial ice and the heavy rainfall that accompanied the eruption soon filled both forks of the Toutle River with flooding crests of mud that picked up huge piles of logs awaiting transport to sawmills. This chaos of logs and mud demolished lumber

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* Federal authorities estimate that the eruption of Mount St. Helens killed 1.5 million small mammals and birds, 100 mountain goats, 5,250 Roosevelt elk, 15 mountain lions, 6,000 blacktailed deer, 200 black bears and 441,177 salmon, steelhead and trout.

camps and bridges. Three hundred homes in the valley were buried or swept away (Findley 1981, p 13).

DETAILS OF THE MAY 18 ERUPTION

The eruption of Mount St. Helens at 8:32 Sunday morning, May 18, was observed by several people both from the air and from adjacent campsites or logging areas (Foxworthy & Hill 1982, p 44-59). The northward bulge of the north face of the mountain had been expanding rapidly since at least April 25. By May 18 great fractures had developed all over this vast flank. The 4.9 magnitude earthquake appeared to have been the trigger that brought about the collapse of this unstable face. Photographs fortuitously taken at the moment of collapse show the north face of the mountain sliding down into the North Toutle River Valley in three or four stages (Stoffel 1980; Rosenbaum & Waitt 1981, p 53-67; Voight et al. 1981, p 347-377; Foxworthy & Hill 1982, p 46-47).[8] The slippage of this vast section of the mountain, the greatest rock slide ever observed, produced an almost vertical face. Out of this face came a high velocity blast of steam and ash. The result of this directed blast (lateral — rather unusual in volcanic eruptions) was the devastation of many square miles of terrain in a 160° arc to the north. The high velocity wind (initially close to 200 miles per hour) (Findley 1981, p 17) produced by the collapse of the mountain was immediately followed by the lateral volcanic eruption. Temperatures in the area adjacent to the summit of the mountain reached as high as 500°C (Rosenfeld 1980, p 501). After the initial northward blast the eruption changed into a vertical phase, and continued so for several hours. The vertical eruption lowered the south wall of the mountain and, along with the collapse of the north flank, produced a huge crater with the rim approximately a mile in diameter and at least 2 miles long.

THE DEBRIS FLOW AND STUMP TRANSPORTATION

The debris flow, a curious geologic phenomenon, that began to move down the north fork of the Toutle River appeared to have been lubricated or buoyed up by a steam layer so that the sediments were little disturbed or mixed. It funneled 15 miles down the north fork at a speed averaging close to 90 miles per hour (Christiansen & Peterson 1981, p 23; Voight et al. 1981, p 347). The result is a long tongue of sediment with a most unusual hummocky topography.

The very hot rocks (although not molten) that erupted from the mountain caused steam blast craters where they encountered water or wet sediments. Mount St. Helens was clothed with several glaciers. The ice from these glaciers either was thrown out with the rocks or formed great rumbling slides. Where ice was buried by sediments, collapse pits were formed by its subsequent melting. Thus the surface of the North Toutle River Valley is now a terrain of hummocky mounds up to 200 feet high and explosion and collapse pits some 100 feet deep (Foxworthy & Hill 1982, p 60, 70). This is truly a unique terrain that gives occasion for visitors such as former President Jimmy Carter to liken it to a lunar landscape after flying over it. Without doubt it will be an area of great geological interest and research for many years to come.

In the area north of St. Helens the forests were devastated. Huge trees, some of them 7 feet or more in diameter, were felled like matchsticks. The areas closer to the mountain showed blast destruction without much regard for the topography although trees on the south-facing slopes were more completely destroyed or removed than those on the north-facing slopes. Areas farther from the mountain showed effects of the topography where the blast was channeled down valleys. In some basins there actually appeared to be occasional backward turbulent curling of the blast to topple trees *toward* Mount St. Helens.

Between the blowdown area and the green intact forest was a relatively narrow zone of scorched standing trees. The demarcation between the blowdown area and the undisturbed forests was extremely sharp in most cases. Experiments done by exposing fir needles to heat and noting under the microscope the effects produced demonstrated that trees in the scorched zone had been burned by temperatures ranging from 50-250ºC (Winner & Casadevall 1981, p 315).

FIGURE 1. One hundred and fifty-seven square miles of forests were blown down and destroyed. Large trees (7 feet in diameter in this example) were toppled over. Others were snapped off above the roots.

FIGURE 2. Aerial view of Spirit Lake. Most of the visible surface of the lake is covered with logs. The central point of land is largely denuded of trees and soil.

Those who have clambered over the piles of huge trees in the blow-down area and have wandered among the hillocks of the fantastic debris flow in the North Toutle River Valley have been impressed by the power involved in a volcanic eruption. The rapidity of erosion and sedimentation is also most impressive.

A unique phenomenon associated with the St. Helens eruptions that has helped understand past geologic processes has been the transport of trees and stumps and their deposition in upright position in new locations. The geologic record has numerous examples of vertical petrified trees and stumps. These traditionally have been interpreted as trees in position of growth. Mud slides and turbid floods down the North Fork of the Toutle River have shown a method for upright transport and burial of stumps.

Numerous erect stumps in various stages of burial have been scattered on some of the mud flats and gravel bars (Fritz 1980b). One huge stump 7 feet in diameter and 45 feet tall sits on top of newly deposited mud near the end of the 15 mile debris flow.

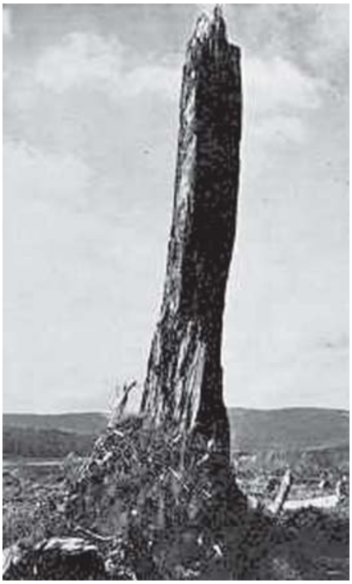

FIGURE 3. This large stump (7 feet in diameter and 45 feet tall) was transported by the debris flow and left standing on the surface near the toe.

THE TREES IN SPIRIT LAKE

Those who believe in a major world catastrophe in the past history of the earth are unable to make good comparative studies because no modern analog exists. Would a global flood remove by erosion large quantities of trees with their root systems and transport and deposit them upright?

Most trees seen in rivers and lakes are logs without roots floating horizontally. Opportunities for observations on significant numbers of floating stumps with roots have been few. In casting about for a modern (if local) example, I thought of Spirit Lake at the base of Mount St. Helens. Here is a large body of water supporting thousands of trees, many of which still retain their root systems. Perhaps research at Spirit Lake could throw light on the flotation characteristics of trees.

Spirit Lake was a beautiful gem among virgin forests with the majestic mountain as a backdrop. It probably originated during past eruptions of the mountain similar to the current ones. The floor of the north fork of the Toutle River Valley (the outlet for Spirit Lake) was raised by volcanic debris. This natural dam impounded the water that became Spirit Lake. The current eruptions are raising the valley floor still higher and enlarging the area of the lake.

The water from Spirit Lake was displaced 850 feet up the south side of Mt. Margaret by the rock fall and eruption. The backwash of the water carried trees and soil back into the lake. The same backwash ran up the opposite shore of the lake. As a result, oscillations continued for a time and produced unusual erosional features around the lake shoreline and lifted log debris onto hills and elevations now well above water level. The lake now is shallower, higher in elevation and broader in area than it was before the eruption (Voight et al. 1981, p 365). A huge raft or floating mat of logs and debris covers much of the lake surface. It consists of plant material from chips of bark to trees with trunks 8 feet in diameter.

Access to Spirit Lake since the major eruption of May 18, 1980 had been only by helicopter. In September, 1982, a road was built to the lake from the east. Armed with the necessary permits and safety equipment, I made use of this road the first day it was opened. As soon as we reached the top of the east ridge of hills surrounding the lake and could see its surface, erect floating trees were noticed.

The lower slopes of the surrounding hills were totally denuded of trees, stumps and soil. The erect stumps seen in the water probably were not likely anchored in their growth positions. To be certain that they truly were floating or had drifted into shallow water where they were now grounded, SCUBA divers examined the lower ends of many of the stumps.

FIGURE 4. A SCUBA diver threads his way through the maze of logs and stumps in Spirit Lake.

They found that the root systems were either well above the lake bottom (truly floating) or that they were lightly grounded on the bottom (Coffin 1983). The latter could be pushed around or even pulled over, whereupon they bounced back into vertical position.

Some stumps that had been floating erect were now standing upright on the bottom, their tops well below the surface of the water. Since the water was the color of weak coffee, black when viewed from above, visibility was limited and underwater flash photography was not satisfactory.

Some stumps projected only two or three inches above the water surface whereas others protruded several feet. Two and one half years had passed since the major eruption. How many floating stumps and logs had already sunk to the bottom? The log raft is smaller now than shortly after May 18, 1980 as determined by comparing aerial photographs of the lake. This decrease in size is due to the sinking of some stumps to the bottom. Others, originally floating along the edge of the raft, have been pushed onto the rocks and sand flats along the

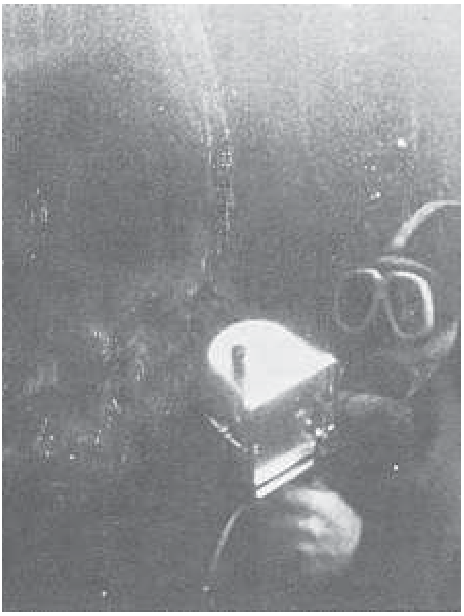

FIGURE 5. Underwater photo in murky Spirit Lake of SCUBA diver beside the base of erect floating stump.

shore, even as piles of ice are pushed onto shore when wind provides tremendous force against large drifting ice flows in polar regions. Many erect stumps pushed near shore now protrude diagonally from the water surface because the depth is insufficient for them to float upright. When dragged to deeper water, they reassumed their erect stance.

Except for one example, all of the examined erect floating stumps had root balls. In contrast, most of the horizontally floating logs were without roots. This feature may partially explain why some stumps assumed erect positions whereas others remained prone.

Changing wind directions caused the log raft to drift from one end of the lake to another. The horizontal logs provided greater wind resistance and drifted faster, the erect stumps followed more slowly behind. There was a tendency for concentrations of the upright stumps to develop in shallow areas and parallel to the banks. Others were scattered loosely among the log raft or in the open water. At this point in time it does appear that the eruption of Mount St. Helens, with its effects on surrounding forests, is proving to be a helpful model of what could happen to trees in a worldwide flood.

The erect flotation of trees has been observed many times (Challenger 1885; Francis 1961, p 28; Ager 1963, p 85). Experiments on the floating characteristics of plants and trees indicate that if the trees are in the water long enough for saturation and if the water is deep enough, stumps (and even cut logs without roots) will often become vertically suspended in the water or will settle onto the bottom in an upright position (Fayol 1886, Coffin 1971).

The petrified forests of Yellowstone National Park are buried in volcanic sediments. These sediments were probably derived from lahars (volcanic mud slides), braided streams and turbidites (underwater mud flows) (Dorf 1960, p 2530260; Fritz 1980a). Erect petrified stumps are found on many levels between the flows. Possible mechanisms for their implacement may be seen in the

FIGURE 6. South of Spirit Lake Mount St. Helens' steaming dome warns the observer of possible future eruptions.

upright stumps laid down by the Toutle River floods and by the vertical floating of stumps in Spirit Lake. Both mechanisms are not limited to volcanic phenomena. They would apply equally well to any catastrophe involving sufficient water for erosion, transportation and drift of trees. A worldwide deluge would produce optimum conditions. The petrified trees and forests often found in the geologic record may or may not represent trees *in situ*. Only careful examination of each situation will allow final conclusions to be safely drawn.

Mount St. Helens, the once beautiful mountain with a blue forest-ringed lake at its feet, is now a shattered remnant of its former self and the lake is stark and foreboding. But this loss is partially compensated by the information this volcano is giving us, not least of which is a glimpse of what could have happened to many trees during the Genesis flood. Continuing research will undoubtedly enlarge and refine this picture.

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ARTICLES

PALEOMAGNETISM I

Ivan E. Rouse
Associate Professor of Physics
Loma Linda University

WHAT THIS ARTICLE IS ABOUT

When molten rock from a volcano cools or when sedimentary rocks are formed, the magnetic particles in each align themselves according to the prevailing magnetic field of the earth. Igneous rocks are the most magnetic and sedimentary the least, but both have sufficient magnetic minerals to be useful in studying the past history of the earth's magnetic field. The correct determination of the direction and intensity of the ancient magnetic field is affected by the various ways a rock can become magnetized as well as by alteration of the original rock magnetism with time.

If the shape and orientation of the earth's magnetic field in the past can be assumed to be similar to the present, then it is possible to predict the original magnetic latitude and orientation of a magnetized rock. This type of information has been used extensively in the development of the theory of plate tectonics. Paleomagnetism also gives strong evidence of "reversals" of the earth's magnetic field. Did these reversals of the earth's magnetic field, in fact, occur? Have the plates really moved about on the surface of the earth? If so, then what are the implications for the tectonic history and age of the earth?

In the first of two articles the author hopes to provide the reader with sufficient background information that he can, with some understanding, appreciate the applications and implications of this fascinating area of geophysics for the study of earth history.

General Comments on the Earth as Magnet

Most individuals are aware that the earth has magnetic properties. All have seen a compass needle move and know that the direction it points gives one some confidence of where north is. However, questions concerning the cause of earth's magnetic characteristics are not easy to answer.

To the creationist, the magnetism of the earth would be a peripheral topic were it not for the following observations. When molten rock from volcanic activity cools, the magnetic particles in this lava align themselves according to the prevailing magnetic field, much like iron filings surrounding a small magnet. When the rock solidifies this alignment is "frozen" into place, leaving a record of the direction of the earth's magnetic field. This "frozen in" magnetism is referred to as *paleomagnetism*.

When one examines the paleomagnetism of various rock layers it can be seen that the earth's magnetic field appears to have reversed its polarity numerous times. This means that if a compass were available when the magnetic field is reversed, it would point south rather than north. The importance of paleomagnetic studies in contemporary geology and geophysics cannot be minimized. Paleomagnetism provided the principal evidence for the major shift in geologic interpretation from the concept of stationary continents to that of plate tectonics.

It is the purpose of this article and Part II (which will appear in the next issue of *Origins* to 1) acquaint the reader with the basic concepts of magnetism, 2) assist him in understanding the magnetic field of the earth, and 3) give an overview of paleomagnetism and its implications for a creationist point of view.

I. ELECTROMAGNETISM AND MAGNETIC MATERIAL

Electromagnetism is concerned with interactions between charged objects. These electric and magnetic interactions can be described in terms of forces between objects or in terms of *electric* and *magnetic fields*. Electrical interactions will be discussed first as a preparation for the discussion of magnetic interactions. These topics are presented to assist the general reader in understanding the basic concepts used in this discussion of paleomagnetism and in evaluating the significance of paleomagnetic data concerning the history of the earth.

A. Electrical Interactions

In addition to having such properties as mass and volume many objects also have a positive or negative charge value which may be measured in coulombs. One coulomb is equivalent to 6×10^{18} electrons. Atoms are composed of three major particles, the protons which have a positive charge, electrons which have a negative charge and neutrons which have zero charge. The number of particles usually is such that the resulting atom has no net charge, i.e., the positive and negative charges exactly cancel out in a neutral atom. If an atom is deficient in electrons, then its net charge will be positive.

Any electrically charged object exerts an electrical force, F_E, of attraction or repulsion on another electrically charged object. Objects of similar or opposite charge repel or attract respectively. This electrical force is described by Coulomb's Law

$$F_E = \frac{kq_1q_2}{r^2} \qquad (1)$$

where k is a physical constant (9×10^9 Newton-meter^2/coulomb^2), q_1 and q_2 are the respective charges in coulombs, and r is the separation between the charges in meters. This equation means that, as r gets larger, F_E gets smaller (one fourth as much if r doubles, e.g.).

Another helpful way of describing the effects of one charge on another is to realize that when an electric charge is placed in some region of space, the space is somehow altered. The space now contains energy due to the presence of the first charge, and the term *electric field* is used to describe the effect the charge has on the space surrounding it. In fact, the field can be used to calculate the energy contained in the space surrounding the source of the field. The electric field has a magnitude (value) and points in a particular direction at every point in space. Figure 1 shows an example of an electric field due to two opposite charges. By referring to Figure 1, we see that the force on the positive test charge, q_t, placed at a point in the electric field is in the same direction as the electric field. The following equation shows the relationship between the electric field, E, the test charge, q_t, and the electric force, F_E, on the test charge by the field (actually by the charge producing the field).

$$F_E = E \times q_t \qquad (2)$$

The electric field is a useful concept that helps one to visualize the force that may be experienced by a stationary charge.

B. Magnetic Interactions

Magnetic forces are quite a bit more complicated than electric forces because they only occur between charges that are moving relative to each other. Magnetic force depends in a complicated way on the charges, their separation, and their relative motion. As in the electrical case, we say that the motion of a charge somehow alters the space surrounding it. The term *magnetic field* is used to describe the motion-related properties of the space surrounding a moving charge. In general, if the charge is moving faster it produces a greater magnetic field, which means that the energy

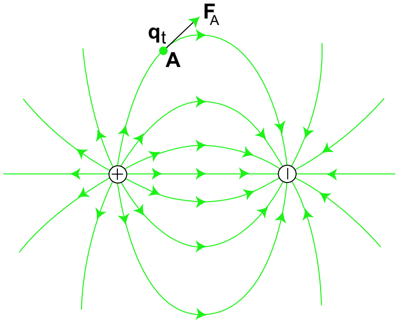


FIGURE 1. The lines with arrows on them represent the electric field for the positive end negative charge. This type of field is called a dipolar field. Electric field is a useful concept because it can graphically represent the electric force exerted on some charge q_t by the charges producing the field. In general, the field and hence the force is the strongest where the field lines are the closest together. The field line at any particular point is in the direction of the force on a positive charge at that point. For example, in the figure, the force on the positive test charge q_t at point A is represented by the arrow marked F_A. Note that it is in the same direction as the electric field at point A.

stored in the field is greater and the forces exerted on other moving charges and magnets are greater. Note that the moving charges could be in a wire, in an atom, or simply moving through space. The magnetic field created by charges moving in a "circle" whose plane is perpendicular to the paper is shown in Figure 2a by drawing lines that have direction. The direction of the line indicates the direction of the field and the closeness of the adjacent lines indicates the strength of the field. If the lines are close together the magnetic field is strong.

The magnetic field does not directly tell us the direction of the magnetic force on a moving charge at some point, as the electric field does. However, the magnetic field at a particular point in space does tell us the direction that a compass (which is really a small magnet) would point if placed at that location in space. One can then easily "map" the magnetic field of a bar magnet as shown in Figure 2b. Notice that the field lines go from the north pole, or end, of the bar magnet to the south pole.

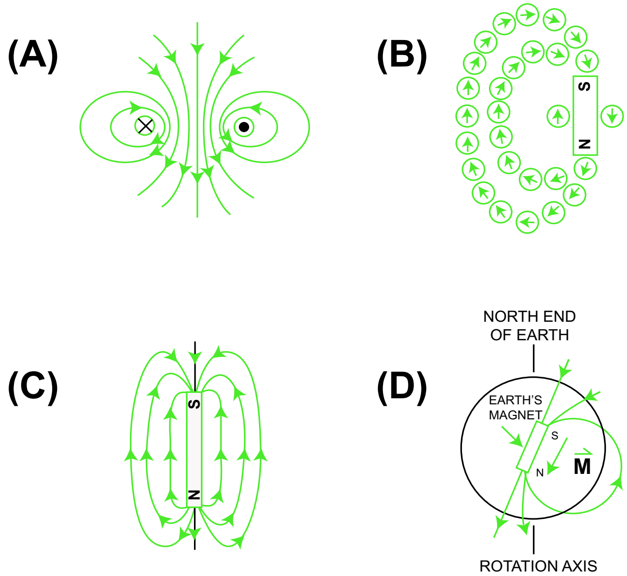


FIGURE 2. (a) Magnetic field lines for charges flowing in a circular wire loop perpendicular to the page with the positive charges going into the page on the left and coming out on the right. (b) Small compasses may be used to plot the magnetic field lines for any magnetic field such as that of a bar magnet. A compass always points in the direction of the magnetic field. (c) The magnetic field obtained by this method would look like this with the field the strongest near the ends of the magnet where the field lines are the closest. (d) The magnetic field of the earth is essentially that of a bar magnet placed at the center of the earth with the south end pointing northward. Note that the magnet is tipped 11.5° from the geographic north pole.

The field of the earth is very similar to what one would observe if there were a bar magnet at the center of the earth, oriented as shown in Figure 2c. The type of field shown in Figure 2 is referred to as a magnetic dipole field where the di-prefix refers to the fact that there are two ends or poles on the bar magnet.

There are two ways to describe the strength of a magnetic dipole field. One is to indicate the strength of the magnet producing the field. This is called the *magnetic dipole moment*, or just magnetic moment and has units of gauss-cm^3. The other approach is to state the value of the field itself at some point in space. The strength of the magnetic field produced between the ends of a typical child's horseshoe magnet may be a few tens or hundreds of gauss while the magnetic field produced in a research electromagnet may be as high as 100,000 gauss or 100 kilogauss. In comparison to these values, the earth's magnetic field is very small, about 0.5 gauss. For convenience, another type of unit is used when describing small fields such as the earth's. This unit is a gamma and is defined such that 1 gauss = 10^5 gamma. This means that the earth's magnetic field is about 50,000 gamma. The earth's field will be described carefully in a later section of this paper.

C. Magnetic Properties of Materials

All magnetic fields are produced by moving charges, but what are the moving charges in a permanent magnet such as a bar magnet or horseshoe magnet? The atomic electrons in their motion about the nuclei of the individual atoms produce the magnetism. Why then aren't all materials magnetic since all matter is composed of atoms? There are two fundamental reasons why all matter is not magnetic: 1) The electrons must be aligned in a certain way in the atom for it to be magnetic, and 2) even if the atoms of a solid are magnetic the magnetic fields of all the atoms must be oriented so that more are aligned in one direction than in any other direction if the solid is to behave as a magnet.

Electrons move in orbits about the nucleus as well as spin about their axes like a top (very much like the earth spins on its axis as it goes around the sun). Both types of electron motions give rise to magnetic fields. The magnetic field due to the electron spin is generally larger than the field that results from the orbital motion of the electron. In most atoms the fields due to the spins of the constituent electrons cancel each other, giving no net field for the atom as a whole because there are equal numbers spinning in opposite directions. In other atoms with an odd number of electrons, the electron's spin magnetic fields are not cancelled out and as a result the atom has a net magnetic field or a permanent magnetic moment. These atoms are said to be *paramagnetic*.

When placed in an external field, B_0, the magnetic moments of all the atoms in the material tend to line up in a uniform way that is either in the same or opposite direction with respect to the external field. Generally, when the external field is removed the moments rapidly become randomly oriented due to thermal agitation if the temperature is sufficiently high.

Some elements such as iron, nickel, cobalt, and their alloys have particularly large atomic magnetic fields or moments. These strongly paramagnetic elements are referred to as *ferromagnetic*. This means that when placed in an external field, the atomic magnetic moments tend to all line up in the same direction, significantly increasing the total field, perhaps by a factor of several hundred. Even when an external field is not present, the atoms in a small volume or *domain* will be aligned parallel to each other.

One important reason why these materials may not appear to be magnetic is that the permanent magnetic moments of the domains may be randomly oriented so that there is no net magnetic field produced by the solid as a whole as depicted in Figure 3a. When a piece of ferromagnetic material is placed in an external field, the atomic magnetic moments tend to line up with the field, as shown in Figure 3b. This means that the domains with a magnetic moment in the same direction as the external applied field actually grow larger as the others grow smaller. When iron or any ferromagnetic material is placed in a very strong external field all the domains will be lined up in the direction of the external field, thus creating a magnet.

Whether the material's domains will stay aligned (the material will stay magnetized) depends on the temperature. At high temperatures, when the atoms "vibrate" vigorously, the thermal energy will be large enough to cause the alignment of the domains to be lost. Then the material behaves paramagnetically instead of ferromagnetically. The temperature at which a sample changes from ferromagnetic to paramagnetic is called the *Curie Temperature* and is usually between 400 and 600ºC. For pure iron, the Curie Temperature is 770ºC, while for pure nickel it is 358ºC. It should be

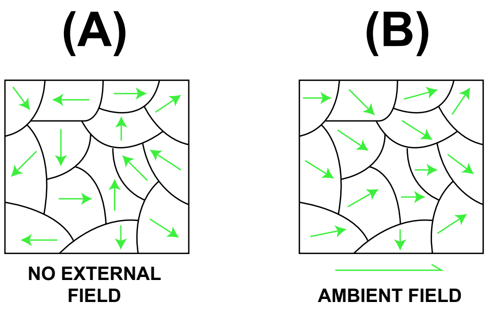


FIGURE 3. (a) Randomly oriented magnetic domains in ferromagnetic material give zero net field for the sample. (b) Domains in an external field show a tendency to orient their directions in the external magnetic field direction giving a net magnetic field for the sample.

noted that these temperatures are significantly below the melting points which are 1535ºC and 2732ºC, respectively.

It is convenient to define a magnetic property of materials called the *magnetic susceptibility*. The induced magnetic moment in the sample is related to the magnetic susceptibility in the following way:

$$\left(\begin{array}{c}\text{magnetization induced}\\ \text{in the sample}\end{array}\right) = \left(\begin{array}{c}\text{magnetic susceptibility}\\ \text{of the material}\end{array}\right) \times \left(\begin{array}{c}\text{strength of}\\ \text{external field}\end{array}\right) \qquad (3)$$

For the situations we will discuss in this paper, the external field will be the magnetic field of the earth. This means that the larger the susceptibility, the larger the magnetic moment that will be induced in the sample. It is this *induced magnetic moment* due to the earth's field that is preserved in igneous and sedimentary rocks making them weak magnets. Figure 4 shows a graph of the relative magnetic susceptibility per cubic centimeter for several common types of rocks. It is apparent from Figure 4 that sedimentary rocks are much less magnetic than igneous effusives or plutonics. This occurs because igneous rocks, in general, contain a much higher percentage of ferromagnetic elements such as iron than do sedimentary rocks.

We will now proceed to describe the magnetic field of the earth and hint at how it may be produced. The discussion in Part II will finally put us in a position to understand how the earth's magnetic field may be produced and what the ancient or *paleomagnetism* "frozen" in the rocks of the earth can possibly tell us about the history of the earth.

II. THE GEOMAGNETIC FIELD

Familiarity with the overall features of the *geomagnetic field* (GMF) and the terms used to describe it is crucial to the understanding of paleomagnetism. Smith (1967) has made extensive review and analysis of the available data on the intensity of the ancient GMF. He points out that the present

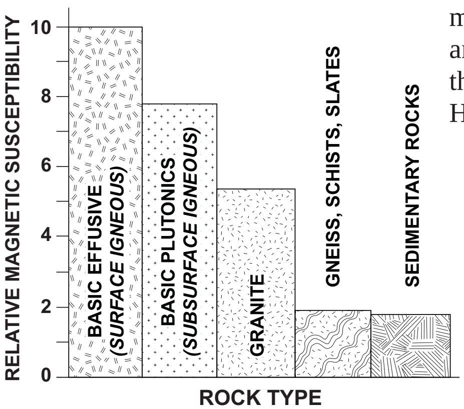


FIGURE 4. The relative magnetic susceptibility (vertical axis) of various types of rocks (horizontal axis) is shown. Note that basic effusives, or surface lava is clearly the most magnetic and that sedimentary rocks are in general much less magnetic (Griffiths 1965).

GMF may be described completely in terms of three components:

1. A dipole component (like that of a bar magnet) which is the most important part of the field and which originates inside the earth.
2. A smaller non-dipole component that is also of internal origin.
3. A much smaller component that originates externally to the solid earth and is due to electric currents in the ionosphere.

Only the first two components are significant from a paleomagnetic point of view and consequently only brief mention will be made of the third. The two principal components will be described in terms of their spatial and temporal variations.

A. Spatial Description of GMF

In order to discuss the spatial features of the GMF it is convenient to use what is called the *main geomagnetic field*. The *main* GMF is an average field that is determined by repeatedly making measurements of the intensity and direction of the GMF at stations all over the earth's surface so that temporal variations with periods of a few years are averaged out. The main field changes slowly with time and is due to sources within the earth (Garland 1979). The general features of the main GMF of the earth can be closely approximated by the field of a magnetic dipole such as a bar magnet or current loop with its center approximately at the center of the earth. In fact, spherical harmonic analysis of the GMF has shown that about 80% of the earth's field can be attributed to a single geocentric dipole inclined at 11.5º to the earth's axis of rotation with a magnetic moment of 8×10^{25} gauss-cm^3 (Stacey 1969). The earth's magnetic field strength varies from about 30,000 gamma (0.3 gauss) at the equator to 70,000 gamma (0.7 gauss) at the poles.

The rest of the field, commonly called the non-dipole field, exhibits roughly eight regions, extending over several thousand kilometers on the surface of the earth, where the field is either greater or less than the dipole field by about 15,000 gamma (0.15 gauss) (Tarling 1971). Careful observation of the non-dipolar part of the GMF has shown that it drifts westward by about 0.18º annually indicating that its primary source is most likely to be within the earth and below the crust (Takeuchi & Uyeda 1967). It also seems reasonable that such rapid changes would occur in a liquid core rather than a solid core. In fact, all available geophysical evidence suggests the model of a liquid outer core and a solid inner core.

In addition to these rather slow variations, or anomalies, from a dipolar field, one sees other smaller amplitude variations that occur over distances of tens or hundreds of kilometers. These are attributable to the remanent magnetization of the rocks of the crust, such as that observed above the ocean floor.

At first it might appear that the earth's magnetic field lines would be parallel to the surface of the earth since we usually use compasses that are mounted horizontally. However, this is not the case as can be seen by referring to Figure 2d or Figure 5. Figure 5 shows that, near the polar regions, the field lines point very nearly straight down into the ground or straight up out of the ground. Only near the equator does the magnetic field lie approximately parallel. This accounts for the fact that simple children's compasses will often appear to be heavier on one end than the other and thus tip down toward that end. What is actually happening is that the compass is just trying to point in the direction of the magnetic field which is at an angle to the surface of the earth.

We can see that in order to describe completely the spatial variation of the GMF, one must be able to specify the direction and intensity of the field at each point on the surface. Since the GMF is approximately axially symmetric (dipolar), two numbers are needed to specify the direction and one to specify the intensity. Figure 5 shows the (dipolar) magnetic field lines for the GMF. Note that the magnetic axis through the earth is at an angle of 11.5º to the geographic or rotation axis as shown in Figure 5. For the study of paleomagnetism it is important to have a consistent system for describing the magnetic field at a specific point on the earth's surface. Consider a point at magnetic latitude, Φ, on the surface of earth as shown in Figure 5. The GMF at this point will have an inclination angle, I, which is measured *down* from the horizontal to the magnetic field line direction as shown in Figures 5 and 6. For a dipolar magnetic field, there is a

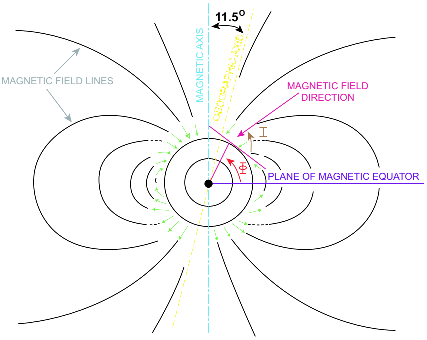
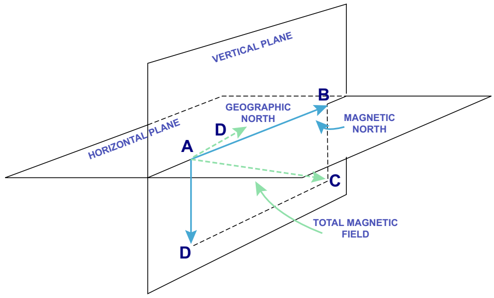


FIGURE 5. The magnetic field is represented by magnetic field lines. The field lines show the direction a compass would point if placed at that location in space. The magnetic forces are the strongest where the lines are the closest together, i.e., at the north and south poles. Note that the magnetic field is inclined at an angle of 11.5º from the geographic or rotational north pole. This type of field is called a dipolar field. The direction of the magnetic field at any latitude, F, is described in terms of its inclination and declination directions. On this figure is shown the inclination angle I for the magnetic field at a point in the northern hemisphere (Redrawn from Hamblin 1975). See Figure 6 for further clarification of inclination and declination.

FIGURE 6. The diagram illustrates the notation commonly used to describe magnetic field direction at a point on the surface of the earth. D refers to the declination angle and I to the inclination angle (Redrawn from Takeuchi & Uyeda 1967).



straightforward mathematical relationship between the inclination angle, I and the latitude angle, Φ. The latitude and inclination are related by

$$\tan I = 2 \tan \Phi \qquad (4)$$

If we imagine ourselves to be standing on the surface and making measurements, it is convenient to think in terms of the situation diagrammed in Figure 6. At any point on the earth the declination, D, is the angle between the direction to the geographic north pole or axis and the direction of magnetic north. The direction of the GMF at a latitude, Φ, is completely described by specifying the inclination and declination. To describe the intensity or strength of the GMF at a point, one must either give the value in gammas (length of the arrow) of the total field or the horizontal and vertical components of the field as indicated in Figure 6.

B. Temporal Variations in GMF

We commented earlier that the earth's field was not constant in time. In fact, the GMF has a wide spectrum of time variations as shown in Figure 7 from Garland (1979). The horizontal scale represents the period of the temporal change. The heights of the vertical lines give the relative magnitudes of the contribution from each of the types of magnetic field that exists. These temporal changes are due to internal and external sources of field and may be intensity and/or directional changes. The most important external sources are those labeled storms (sporadic) and diurnal (daily). Magnetic storms can cause fluctuations as high as 500 gammas or 1% of the 50,000 gamma GMF (Tarling 1971). Typical diurnal changes are 50 gammas or 0.1% of the GMF (Garland 1979, Jacobs 1963) and are caused by the effects of fast charged particles from the sun on the earth's ionosphere and thus the earth's GMF.

Internally caused changes in the GMF are of two types: 1) those with periods on the order of 10^2 to 10^3 years, called secular changes, and 2) reversals, which are generally, in geological terms, presumed to have periods on the order of 10^6 years. Both types are generally assumed to be

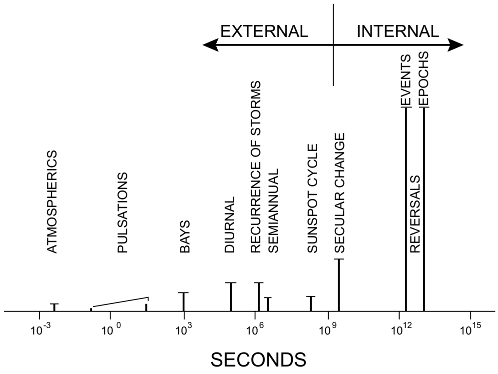


FIGURE 7. Internal and external temporal changes in the magnetic field observed on the surface of the earth are represented in this figure. The horizontal axis describes the time period for each of the various contributions to the total magnetic field. The vertical axis represents the approximate relative size of the contribution of each of these sources to the total geomagnetic field. The amplitudes of the shorter-period changes are exaggerated relative to the secular change and reversals. The semi-annual variation occurs because of the greater ability of the earth's field to trap particles when one pole is tipped toward the sun. Pulsations are believed to be the magnetic affects of hydrodynamic waves trapped in the magnetosphere. (Redrawn from Garland 1979).

caused by the motion of fluid in the core. Looking first at the intensity data, Figure 8, which has been extensively discussed by Smith (1967), we see that the secular variation of the intensity of the earth's magnetic field has been directly measured since about 1830 and measured paleomagnetically for samples with radiometric ages of at least 8500 years. Other references (Barnes 1971, Cox 1973, Smith 1967, Takeuchi & Uyeda 1967) also discuss the data in Figure 8.

During the historical observation period of 130 years the magnetic moment decreased at a rate of about 5% per hundred years, and at this rate would disappear entirely in about 2000 years (Rees 1961). Considerable discussion centers on whether the decrease is linear (as assumed in making the 2000 year disappearance estimate) or exponential since this has implications concerning the nature of the source of field (Barnes 1971). Smith (1967), however, has shown (see Figure 8), using paleomagnetic data, that the field was probably actually increasing earlier than 2000 years ago. Part II will discuss this topic further as it describes how the geomagnetic field is produced. Special attention will be given to the Barnes model (Barnes 1971) for the source of earth's magnetic field and his conclusions concerning the age of the earth based on this model.

The direction of the GMF is easier to measure and has been regularly observed in specific locations since about 1830 A.D. For example, the direction of the GMF was monitored in Paris and London for a period of about 300 years. This data along with other historic data is shown in Figure 9. Secular variations in direction and magnitude have also been observed by studying paleomagnetism in lava, pottery, bricks, and kilns (Aitken & Weaver 1965, Tarling 1971).

With some background in the properties of the geomagnetic field of the earth, we are now in a position to study the effects that this field can have on the magnetic materials that exist on the earth. Can these materials record a magnetic history of the earth? If so, this information may be very valuable for the creationist who tries to model a short history for the world since creation. Does the magnetic history of the earth as "frozen" in the rocks provide new information not available from radiometric dating? We will find that this is indeed the case.

III. INTRODUCTION TO PALEOMAGNETISM

The earth contains numerous elements that are generally classified as ferromagnetic. These elements can form minerals and thus rocks with strong magnetic properties. These rocks are actually rather complicated materials that can contain several types of minerals. A small proportion, 5% or less, of a typical crustal rock will be made up of iron-bearing magnetic minerals such as magnetite and hematite (Rees 1961). Below the crust/mantle boundary, or Moho, the temperature is greater than the Curie Temperature for most materials. This means that the Moho is the lower magnetic boundary for permanently magnetized materials since the magnetic directions of the magnetic domains are randomly oriented thus giving no net field if the temperature is any higher than the Curie temperature (Wasilewski, Thomas & Mahew 1979)!

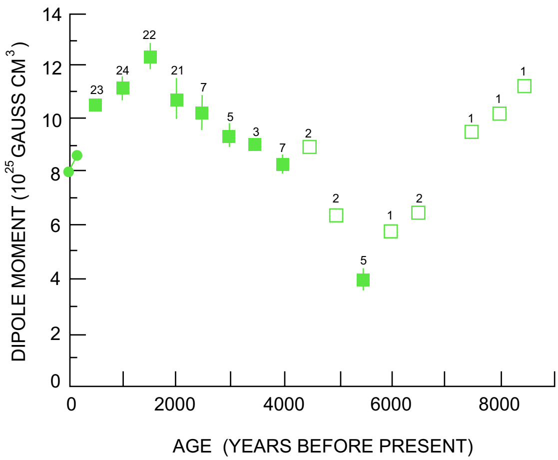


FIGURE 8. Variations in the strength of the geomagnetic field are here expressed in terms of the geomagnetic dipole moment. Changes during the post 130 years, as determined from observatory measurements, are shown by the short slanting bar at the left. This is the only data that is used by Barnes (1971) in his discussion of the history of the earth's magnetic field. The other values on the graph were determined paleomagnetically. The number of data points that were averaged for each point plotted is shown above the point and the standard error of the mean is indicated by the vertical lines except for the points (open squares) with too few points to provide meaningful statistics (Cox 1973).

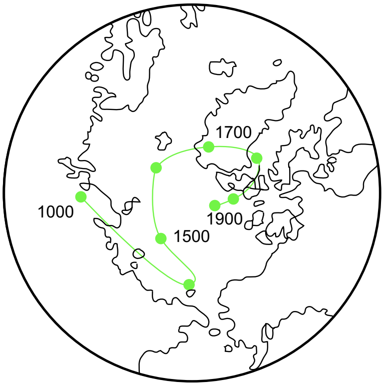


FIGURE 9. The apparent motion of the magnetic north pole as determined from paleomagnetism of historic specimens and direct measurements. The direct measurements were made in London (Jacobs 1963, Young 1982). Note that from these historic determinations we can conclude that the magnetic north pole does seem to wander about on the surface of the earth as a function of time. Data points cover the range AD 1000 to AD 1900.

This section will consider the various processes that can cause a crustal rock to be magnetized, that is, have a *magnetic moment*, or *remanent magnetization*. Processes of magnetization that occur during the initial formation of the rock, or primary magnetizations will be considered first. Most of this *primary remanent magnetization* takes place over a few years for igneous rocks, and over perhaps as much as several hundred years for sediments. The magnetization or magnetism that we observe in a particular rock sample, the *natural remanent magnetization* (NRM), is composed of whatever primary magnetization remains, as well as more recent, *secondary magnetizations*. These secondary magnetizations can contribute components to the natural remanent magnetization (NRM) that can give us a distorted picture of the ancient geomagnetic field. Consequently, it is particularly important to understand them as we study the magnetic history of the earth.

Rocks with natural remanent magnetism (NRM), i.e., those with ferromagnetic minerals that have "frozen in" magnetic fields, are studied for two reasons (Garland 1979). 1) The magnetic materials that produce local distortions of the earth's magnetic field are used to study structures in the crust such as ore deposits; 2) The rocks also provide information about the past history of the earth's magnetic field.

Rocks are composed of minerals, which in turn are composed of a variety of sizes of crystalline grains. Grains can have many physical shapes and may contain from one to several magnetic domains. Neel (1955), Stacey (1962, 1963), and Dunlop (1968) discuss in detail the effects of these parameters on remanent magnetism. The physics of rocks containing ferromagnetic crystalline minerals is quite complicated and much has been written on this topic. For our purposes only a brief summary will suffice, but more complete discussions are available (Garland 1979, Tarling 1971). Of these references, Tarling (1971) has the clearest description of the basic physics involved. This discussion is summarized below.

A. Primary Remanent Magnetization

When an igneous rock is formed, the hot (1000ºC) molten rock slowly cools, solidifying at around 800ºC, and then cools down to normal surrounding temperatures. Submarine lavas cool quite rapidly, but subaerial or surface deposited lavas may remain hot for several years. Intrusive, or underground, igneous rocks may take many hundreds of years to cool down. As the igneous rock, composed of a group of grains is cooled down past the Curie Temperature the group acquires a permanent magnetization in the direction of the GMF. This phenomenon is known as *thermoremanent magnetization* (TRM).

It should be kept in mind that the primary magnetization of any rock does not really remain constant in time but decays exponentially (*viscous demagnetization*). The rate at which it decays decreases as grain volume increases and increases with increasing temperature. For accurate paleomagnetic studies, then, one would ideally like large grains that have been stored at low temperatures so that the relaxation time of the primary magnetization will be long.

Sedimentary rocks can also preserve a record of the earth's past magnetic field, but since they have not been cooled from a high temperature they contain no thermoremanent magnetization (TRM). They do, however, contain grains of magnetite and hematite that have been eroded from igneous rocks possessing TRM. These fine magnetized grains behave like small magnets or compasses. As these particles of varying shapes and sizes settle out of the air or water to form a sediment, they tend to become aligned with the ambient GMF. The primary remanent magnetization that is thus acquired is called *depositional* or *detrital remanent magnetization* (DRM). As was discussed earlier, sediments are generally much less magnetic than igneous rocks, making the DRM generally about a hundred times weaker than the TRM of igneous rocks. Because of this fact, studying the remanent magnetism of sediments requires much more sensitive instruments.

There are several factors that can affect the magnetization of sediments: depositional environment, chemical reduction, disintegration, cementing processes, and compaction. The first will be discussed here since it occurs at the time of rock formation, some of the others, which occur later, will be discussed in the next section.

The depositional environment has been studied recently with respect to ash from Mount St. Helens (Steele 1981), and it was determined that the DRM of the ash which was deposited from the air accurately recorded the local geomagnetic field (GMF) in eastern Washington. However, the DRM measured for ash deposited in water in streams exhibited significant inclination and declination errors, similar to those reported in other studies

(King 1955, Steele 1981, Tarling 1971). At locations where the stream's current direction was evident, the direction of the DRM was rotated toward the current direction. This makes sense, since it is generally assumed that magnetic grains are magnetized along their long axis (Tarling 1971) and it has been shown that sand grains deposited in a current have their long axes aligned in the stream direction (Rusnak 1957). It should be noted that most studies of NRM of sediments are not done on sediments deposited in streams where currents are important, but on sediments deposited in lakes and oceans where the depositional environment is quite calm. Consequently, sediments from lakes and oceans are more likely to reliably record the ancient GMF.

B. Secondary Remanent Magnetization

Secondary magnetizations are, by definition, those magnetizations that have occurred more recently than the original formation of the rock. They include *viscous remanent magnetization* (VRM), *chemical remanent magnetization* (CRM), lightning magnetization, and weathering magnetization. These can cause numerous complications in determining the primary magnetization of a rock. In addition, some materials are *magnetically anisotropic*, which means that they have a preferred direction of magnetization and thus may not accurately record the magnetic field direction that existed at the time of rock formation.

In the previous section, viscous demagnetization was mentioned. This means that the ferromagnetic domains in a grain are aligned by an external magnetic field but are also continually having their directions randomized by the thermal agitation. Temperature is a measure of this agitation, which means that at constant temperature in an external field, the magnetization direction gradually moves away from the original direction toward an equilibrium value along the axis of lowest energy, the easy axis, giving the sample a viscous demagnetization which is generally in the direction of the ambient geomagnetic field. To have slow relaxation rates and thus avoid significant VRM effects, one would ideally like to use samples with large grains that have been stored at temperatures below the Curie Temperature.

If the source of agitation, i.e., the temperature, of a sample is kept constant, and the particle size allowed to increase by chemical growth, a secondary magnetization can develop as the particle volume increases. This occurs because the new material will be magnetized in the current geomagnetic field direction rather than the original field direction at the time of rock formation. This effect is referred to as *chemical remanent magnetization* (CRM) and will be in the direction of the ambient GMF at the time the volume became larger. It may, in fact, be in a very different direction than the thermal remanent magnetization (TRM) or the detrital remanent magnetization (DRM) and can thus be a significant source of error in careful studies trying to determine the geomagnetic field direction at the time of rock formation.

Application of mechanical stress or hydrostatic pressure to ferromagnetic materials can result in *pressure remanent magnetization* (Tarling 1971), but the effects of pressure haven't been studied enough for firm conclusions to be drawn. However, in most rocks the effects of pressure seem to be less important than those caused by thermal effects, chemical effects and anisotropic magnetic rock properties.

Anisotropic materials are crystalline materials that have a preferred or easy direction of magnetization. The least magnetizing energy is required for a sample to be magnetized along the easy direction. If the materials responsible for the primary magnetization have anisotropic properties, then the direction of magnetization acquired by the sample may be other than parallel to the ambient geomagnetic field (GMF). When determining the direction of the ancient GMF by studying natural remanent magnetization (NRM), it is crucial, then, to establish how much anisotropy is present. There are four important types of anisotropy: crystalline, magnetostrictive, shape, and induced. For further study of these effects see Tarling (1971).

Much of the previous discussion applies to igneous rocks. It seems appropriate to also make some comments about sedimentary and metamorphic rocks. As a sediment dries out, oxidation, and reduction occur. Both of these generally lead to the formation of hematite. In addition, the sediments are continually being cemented by carbonate or silicate cements, which also contain fine hematite grains (Tarling 1971). This means that many sediments, possibly most, will acquire a chemical remanence (CRM) as these new minerals grow.

This raises an important question. Which sediments are the most reliable for paleomagnetic studies of ancient field directions? Since the processes of converting wet sediments into sedimentary rock may take considerable time, few types of sediments carry a stable remanence closely related to the actual time of deposition (Tarling 1971). For rocks that geologists classify as being greater than 100 million years old, the most reliable sediments for paleomagnetic studies are red siltstones, since they probably underwent most of their oxidation and dehydration during the first few thousand years after deposition. Varves, deep sea sediments, and any other sediments that have remained chemically stable since soon after deposition may potentially have stable primary remanent magnetization.

Metamorphic rocks have normally been subjected to pressures and temperatures that are large enough to destroy any primary remanence that may have existed. Consequently, the magnetization of metamorphic rocks is usually secondary and may be of little use except to possibly date a specific metamorphic event. Because of these problems, few paleomagnetic studies have been done on metamorphic rocks, compared to igneous and sedimentary types.

At this point it should be clear that the principal difficulties in trying to obtain and interpret paleomagnetic field direction data are knowing what the storage temperature has been, and how much the rocks have changed physically and chemically since their formation (Jacobs 1963). However, it should also be pointed out that in many situations, one can actually sort out which part of the natural remanent magnetization (NRM) is primary and which part is due to other complicating factors.

SUMMARY AND CONCLUSIONS

This paper has introduced the reader to the area of geophysics commonly referred to as geomagnetism. First we looked at fundamental ideas about electric and magnetic interactions. The concept of a "field" was introduced, a useful concept for describing any entity that has a value and a direction at every point in space.

The earth's magnetic field is primarily dipolar, which is similar to the field that would be produced by a bar magnet situated at the center of the earth. In the next paper, this information will allow us to determine the magnetic latitude and orientation of a magnetic rock at the time that it acquired a natural remanent magnetization. This type of information has been used extensively in the development of the theory of plate tectonics. The earth's field is certainly not static in time and the temporal variation of the field that is of particular interest to this discussion is that commonly referred to as "magnetic reversals."

Various types of magnetic matter have different properties when placed in an external field. Ferromagnetic materials are of most interest in studies of paleomagnetism. The term "magnetic susceptibility" was introduced to describe just how "magnetic" a particular mineral or substance is. Igneous rocks are the most magnetic and sedimentary rocks the least. However, both have sufficient magnetic minerals to be useful in studying the past history of the earth's magnetic field including both intensity variations and reversals.

This "reversal" phenomena is of fundamental importance to the study of the magnetic history of the earth and hence of interest to the creationist. Did these reversals of the earth's magnetic field, in fact, occur? If so, then what are the implications for the tectonic history and the age of the earth?

Correct determination of the direction and intensity of the ancient magnetic field is affected by the various ways a rock can become magnetized as well as the alteration of original magnetism with time. Igneous rocks are originally magnetized as they cool in the presence of the earth's magnetic field thus "freezing" in a natural remanent magnetization. Sedimentary rocks contain a few very small pieces of magnetic material. As these tiny magnets settle out of the air or water, they behave as compasses and orient themselves in the direction of the ambient earth's field, giving the rock a detrital remanent magnetization. Several processes can alter these original magnetic directions as time passes.

The goal of this paper has been to provide the reader with sufficient background information that he can, with some understanding, appreciate the applications of this fascinating area of geophysics to the study of earth history as will be presented in PALEOMAGNETISM II.

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LITERATURE REVIEWS

Readers are invited to submit reviews of current literature relating to origins. Mailing address: ORIGINS, Geoscience Research Institute, 11060 Campus St., Loma Linda, California 92350 USA. The Institute does not distribute the publications reviewed; please contact the publisher directly.

YOUNG'S OLD EARTH

CHRISTIANITY AND THE AGE OF THE EARTH. Davis A. Young. 1982. Grand Rapids, MI: Zondervan Publishing House. 188 p.

Reviewed by Stephen F. Barnett, Division of Natural Sciences, Bryan College, Dayton, Tennessee

Davis A. Young is both a practicing geologist and a theologically conservative, evangelical Christian. He is acutely distressed at the credence given to "recent creationism" by so many within the evangelical community. *Christianity and the Age of the Earth* appeals to those Christians to reject recent creationism as a view neither mandated by Scripture nor supported by science.

In the first of the book's three major "considerations" bearing on the age of the earth, Young traces the development of an ancient earth concept in the theological and geological communities. The predominant view from the time of the early Church until about the 18th century, says Young, was a literal acceptance of creation in 24-hour days within the past few thousand years. Early geologists thus tended to interpret evidences from stratigraphy and paleontology in light of the Genesis flood account. However, many observations in those and other areas, such as geomorphology and geochemistry, seemed to indicate processes requiring longer than the few thousand years allowed by a traditional view of Genesis. By the latter half of the 19th century most geologists, many of whom were Christians affirming the validity of the Genesis narrative, adopted a much longer chronology for earth history and viewed the flood as a minor element in earth history.

The changing consensus among geologists prompted theologians to examine Genesis anew. They began to develop exegeses that were believed to be consistent with both the internal evidence of the Scriptures and with the accumulating evidence from geology. This "age of harmonization" (p 55), as Young terms it, lasted well into the 20th century until "reactionary developments" (p 65) led to a resurgence in flood geology. Price, Nelson, Clark, and Rehwinkel were the early proponents (1920-1950s), but the strength of the movement is attributed primarily to Whitcomb and Morris' *The Genesis Flood* and to the Institute for Creation Research, the Creation Research Society, and like organizations.

The resurgence in flood geology is a mistake, says Young, predicated by the faulty reasoning that an ancient earth is part and parcel with evolutionary humanism; the issues are separate and "while evolution falls if the antiquity of the Earth falls it does not necessarily stand if the antiquity of the Earth stands" (p 66). In fact, Young continues, the ancient Earth view was developed by Christians who affirmed both creation and the flood but who were forced by the facts to recognize the antiquity of our planet.

In his second consideration, the scientific evidences against creationism and favoring long ages are presented. In support of his contention that the flood geology of recent creationists is ill-founded, Young cites examples from many aspects of earth science such as stratigraphy, geochemistry and sedimentology. He asserts that the problems confronting flood geologists, when recognized, have been inadequately addressed. They either have attempted to answer the problem but failed, as in the case of radiometric dating, or they have merely given the illusion of solving problems through spurious proofs. He further asserts that many of the best evidences cited by creationists for catastrophic deposition of the geologic column (e.g., polystrate trees and fossil graveyards) can be explained as well, if not better, by long-age models.

According to Young, creationists have not solved the problems confronting their model and they have been similarly unsuccessful in attacking uniformitarian models. Their arguments are weak due to a basic lack of geological knowledge and improper reasoning.

His third area of consideration is philosophy and apologetics. Young challenges the creationists' claim that catastrophism alone can explain the geologic column. He insists that despite their insistence that uniformitarian thinking is ungodly and inadequate as a basis for historical geology, "creationists are really uniformitarians who have falsely interpreted the evidence of geology" (p 136).

The final chapter analyzes the relationship between science and faith and between truth as revealed in nature and in Scripture. Young affirms that both natural and written revelation emanate from one God of Truth; as such there can be no conflict except in our interpretations. There will be tensions in matters of faith because we do not know all the facts nor do we interpret them aright; but tension in the matter of the antiquity of the earth is inexcusable because we have clear natural revelation that conflicts only with certain faulty exegeses of Genesis. Creationists would do well to examine both their science and their understanding of Genesis and see that this is so.

It is difficult to review *Christianity and the Age of the Earth* with objectivity for, whatever the merits of the book, it is itself decidedly weighted in its presentation. In the preface Young states his worthwhile objective: “to examine some of the evidence of nature that relates to the age of the earth’’ (p 10); yet, the reader is not given the opportunity to evaluate that evidence for himself.

Discussion of the scientific data is mostly confined to the middle third of the book, the rest being historical observation and philosophical conjectures. The data are generally accurate and referenced (with the exception of all text-figures), but the presentation is not impartial. To begin with, the tenor of the text clearly disparages both the belief of recent creationists and their persons as well. For instance, creationists are labeled as “the equivalent of Miller’s ‘anti-geologists’’’ (p 14), and those who hold to flood geology are generally “Christians who are not engaged in scientific endeavors” (p. 64) or who “have looked only at those rocks” favoring their *a priori* beliefs whereas “geologists have looked at all the rocks’’ (p 148).

The presentation of the creationist’s case seems slanted also. Time after time Young cites Whitcomb & Morris’ *The Genesis Flood*, a book 22 years old, to show the weaknesses of flood geology. For example, in the case of fossil reefs, he reproves Whitcomb & Morris for not explaining how reef-like blocks of limestone could be deposited over fine-grained sediments. Their view is “totally unsupportable’’ and the “only realistic interpretation of the evidence is to say that the reef structures grew in place on an ancient sea floor” (p 85). But, although Young refers to a 1975 article by Nevins claiming that some so-called reefs were not true reefs at all, Young does not address Nevins’ data; he just shows that Whitcomb & Morris’ model for reef emplacement is ill-supported.

Again, his chapter on radiometric dating records only weak creationist arguments for a short chronology, but in another chapter he notes in passing that Gentry has done work with serious implications for radiometric dating (p 151). The nature of that data or why it “is indeed problematic” for standard dating methods is neglected. If only the facts provided by Young are considered his conclusions seem well supported, yet one feels that there is probably more to be said for the flood model than Young has presented.

Another difficulty is Young's occasional use of interpretation in the place of data. For instance, he refers to "varves" rather than laminated couplets (p 90), to the "obvious terrestrial derivation" of some rocks (p 79), and to claims that certain cross-bedded sandstones from the Colorado Plateau could not be flood deposits because these "ancient desert sandstone[s]" (p 91) required a very long and dry period for their deposition. There may be sound reason for these interpretations, but they are not facts. Regarding, for instance, the so-called ancient desert sandstones, there is strong disagreement among uniformitarian geologists (e.g., Marzolf 1969, Freeman 1976) as to their depositional environment, and Young should so inform his readers. Picard (1977), for example, disagrees with some of the alternate depositional environments proposed for the Navajo Sandstone, but, unlike Young, he makes clear that his preference for eolian deposition is an interpretation, not a fact.

If Young may be faulted for providing a polemic rather than the even-handed evaluation anticipated, his book may not, on that account, be lightly dismissed. To begin with, Young is somewhat unique among geologists holding an ancient-Earth view in that he also holds a very high view of Scripture. "The Bible is true, it is infallible, it is without error no matter what our theories of geology may be" (p 151). Furthermore, he is a practicing geologist who has published in his discipline and has also addressed, in print, the difficult issue of the relation between geology and the Genesis narrative (Young 1977). Young therefore represents an informed, Christian viewpoint that merits consideration.

The problems presented in *Christianity and the Age of the Earth* are real problems that have yet to be resolved with great satisfaction. Some are less serious than Young believes, others are indeed problematic, but none may be ignored. His perceptions merit attention and response.

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GENERAL SCIENCE NOTES

THE EL NIÑO EVENT

Richard D. Tkachuck
Geoscience Research Institute

Unusual weather patterns were the rule from Adelaide to Quito. Australia experienced killing droughts and subsequent fires devastated large sections of land. In Equador, areas that normally receive 13 mm of rain during a dry-season month were inundated with 583 mm. Ocean temperatures along major portions of the west coasts of the Americas were in some areas 10º warmer than usual. These warm waters caused a marked drop in primary production of microorganisms, and as a result the usually enormous anchovy population disappeared. Animals which depended on the fish either starved or hunted elsewhere for food. On Christmas Island, for example, an estimated 17 million eggs and unfledged young of sea birds were abandoned because the food in surrounding waters literally disappeared.

The cause of these seemingly unrelated phenomena is blamed on El Niño (The Christ Child). El Niño historically has been a periodic warm-water current that starts moving along the coast of Peru near Christmastime. As coastal water is driven west by trade winds, a current of warm water from the north moves southward usually around February or March and covers the colder water along the coast. With the nutrient-rich water now very deep, fish which depend on the plankton and other organisms for survival move to other locations. In times past this yearly warming marked the end of the fishing season around February.

Currently, the term El Niño is much more limited in its use and presently describes the interannual catastrophic events which destroy much life caused by massive amounts of warm water flowing in from the mid-Pacific instead of the more normal northerly warm current. These events have a 6-8 year cycle, in contrast to the more mild yearly warming events described above.

Just what causes the El Niño event is somewhat like the chicken-or-the-egg question. Under normal conditions nearly constant westerly trade winds in combination with the Coriolis effect (phenomena related to the rotation of the earth) push the coastal surface water in the equatorial latitudes towards Asia. The water warms significantly as it moves across the Pacific.

Only recently have scientists begun to unravel why some seasonal changes are more devastating than others. It is now realized that the El

Niño is coupled to another atmospheric event in the eastern Pacific known as the Southern Oscillation.

In the Southern Oscillation major shifts in barometric pressure take place between two areas in the Pacific. One centers in Malaysia with a measuring station situated in Darwin, Australia. The other is in Tahiti. If the pressure is high in Darwin, it will be low in Tahiti. The converse is similarly true. Over a period of several years the pressure difference seesaws back and forth with periods varying from 2-8 years.

In the low-pressure area, a circular air current, known as the Walker Circulation, also develops. Water-laden air dumps its moisture as it rises into the upper atmosphere. After moving across large distances in the upper atmosphere, it then returns to sea level at the other end of the pressure cell. The location of the rising column of air controls where the heaviest rain fall will take place. The low-pressure area is additionally important because it attracts the westerly trades and determines their general direction of movement.

In the El Niño event of 1982-83, the low-pressure area, which should have been located at Tahiti, moved farther east. Record pressure differences were recorded between Darwin and Tahiti. This low-pressure area then drew the westerlys. To the west of this atmospheric basin, the normally westerly winds reversed themselves and blew in the opposite direction, probably attracted by the low-pressure area.

The current El Niño event was anomalous in that a second cell of warm water developed in the western Pacific in addition to the warm water which the wind pushed in from the coast of South America. As the water along the equator heated, the intensity of the trades decreased and ultimately stopped. This, combined with a greater-than-average heating, produced water temperatures at the equator much above normal. Conditions were now set for what has been called a once-in-a-century event.

The warm water, which was originally derived from South America, combined with the anomalous warm cell and started to return eastward to the South American coast because it was no longer held back by the westerly winds. Several months were required for the water to reach the South American coast. In some oceanic islands the sea level changed a foot or more as the warm water sloshed eastward.

Upon reaching the continental coast, the current divided into branches moving north and south along the coast and did its destructive work. Record high ocean temperatures were recorded as far north as Washington. Eventually, with the mixing of colder waters and the resumption of the trade winds now blowing toward Darwin again, the El Niño faded.

The anomalous weather patterns in the central Pacific affect significantly weather patterns in far distant portions of the globe. Known as teleconnections, these are statistically consistent changes that occur in El Niño years, causing large weather shifts in the northern latitudes and perhaps being partly responsible for the strange weather experienced on several continents.

When the next El Niño event will arrive is not known, of course, but one can be certain that the mammoth interannual weather shifts will be here sooner than some would wish. The El Niño event should also give one pause to consider that world-wide disturbances can be caused by seemingly small events such as the shifting of a low-pressure area or the elevation of water temperature by a few degrees. The earth is perhaps more fragile than most would suspect.

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EDITORIAL

WHERE HAS THE SCIENCE GONE?

"Creationism is scientific prostitution," the newspaper headline read. Although it was only one of many similar statements that I had heard on the previous day at a national meeting of the Geological Society of America in New Orleans, I was surprised that such acrimony received prominent publicity.

The statement quoted above came from a professor of geology at Oregon State University who chaired one of two symposium sessions on creation and geology. He also declared that creationists are "as crooked as a three-dollar bill" and "intentionally and cynically mislead well-intentioned citizens." A biologist from Boston University stated that "Biblical catastrophism" is "dishonest, nasty"; the same speaker also asserted that creationism as a science "represents political and religious mischief." A prominent scientist from the American Museum of Natural History referred to creationism as the "tyranny of a well-organized and strongly motivated minority." Another scientist from the same institution labeled both creation science and ecological zonation (the idea that ecology is responsible for the fossil sequence) as "a ruse." A scholar from Georgia State University pronounced creationism to be "erroneous pseudoscience they pass off as scholarship," and a geologist from the United States Geological Survey warned that one "should not let science fall to the fraud of creationists" and that "if you are a creationist, you are in the wrong place."

This last statement seemed even more obvious when at the end of one session an individual supporting creation was denied the privilege of speaking, because his viewpoint was considered inappropriate. While creation was at issue in each symposium, no creationist was represented among the 15 speakers scheduled. This was hardly a balanced approach.

The emotionalism demonstrated at these sessions far exceeded what I had observed at any other scholarly meetings. Too many of the scientists had moved from objectivity to name-calling. I wondered what had happened to the scientist who is supposed to represent the cool unbiased appraiser of data. Evolutionists have been foremost in purporting that creation, in contrast to evolution, is not scientific; however, the behavior of several evolutionists at these meetings failed to convince me that evolution was a purely scientific concern.

Realistically, if creation is "nonsense," is it worthy of especial concern? Why expend such emotional energy on something so obviously erroneous? The overabundance of ridicule, condescension and depreciation of character made one wonder if creation was not a more equal foe than the speakers were willing to acknowledge. One is reminded of the statement by Michel de Montaigne: “He who establishes his argument by noise and command shows that his reason is weak.”

Lest creationists settle smugly into the comfort of self-righteousness, let me state that several speakers at these symposia presented well-documented examples of errors made by creationists. These errors were far too numerous to be dismissed as totally unrepresentative. On the basis of personal acquaintance as well as performance at these symposia, I can vouch for the gentlemanliness, decorum, and scholarship of some of the speakers. Their decorum is usually above reproach.

Unwarranted criticism and even depreciation of character are not limited to evolutionists. Some creationists have been equally at fault. Evolutionists are offended when creationists publish statements purporting that evolution “has served effectively as the pseudoscientific basis of atheism, agnosticism, socialism, fascism, and numerous other false and dangerous philosophies over the past century.

This melee is bewildering. Is the game now one of name-calling, and if it is, what purpose does it serve? Will the new approach of verbal abuse bring us closer to an understanding of the great questions of origins? Has the issue between creation and evolution become so polarized that science, reason, and understanding can no longer function? Given the accusations reported above, one must conclude that emotional reaction is interfering with scholarship and that confidence in the scientific process is depreciated by such behavior.

I am a firm believer in creation; nevertheless, I believe that evolutionists and creationists can learn from each other. Creationists must realize that some of their present scientific conclusions are not based on rigorous modes of scientific evaluation. Evolutionists must learn that their naturalistic explanations fail in trying to answer adequately the important questions of reason for existence, evidence of intelligent design, primal origins, aesthetics, values, etc.

It is regrettable that the inquiry into the fundamental question of origins has degenerated to such an emotional level. Goethe’s warning that “nothing is more terrible than ignorance in action” is appropriate to evolutionists and creationists alike. Objectivity is suffering seriously, time and energy are being wasted on both sides. Attitudes must be improved, and efforts now devoted to name-calling should be redirected towards good scholarship.

Ariel A. Roth

REACTIONS

Readers are invited to submit their reactions to the articles in our journal. Please address contributions to: ORIGINS, Geoscience Research Institute, 11060 Campus St., Loma Linda, California 92350 USA.

Re: Hayward & Casebolt: Genesis 5 and 11 Statistical Study (ORIGINS 9:75-81); and subsequent discussion by Nicholaides, Hayward, and Casebolt (ORIGINS 10:5-8).

From the analyses presented by Nicholaides and by Hayward & Casebolt, it is most reasonable to conclude that Moses did not have precise chronological data for about half the individuals listed in chapters 5 and 11 of Genesis, and that where the data available to him was uncertain, he gave rounded estimates to the nearest five or ten years. Readers who are not familiar with chi-squared statistical treatment may find it helpful to note that the probabilities for six and seven out of ten randomly selected numbers being divisible by 5 is one chance in 182 and one chance in 1272, respectively. The probability of six out of ten randomly selected numbers being divisible by 10 is only one chance in 7258.

Since other genealogical lists in the Bible may be demonstrated to be abbreviated, there is good reason to presume that those in Genesis 5, Genesis 11, and 1 Chronicles 1 are also abbreviated. But the omission of lesser important individuals to obtain stylized lists of the ten most notable patriarchs between Adam and the Flood and between the Flood and Abraham does not nullify Moses' apparent effort to establish a chronologic framework by specifying as closely as he could the age of each listed patriarch at the time the next-named was born.

Regarding Hayward & Casebolt's comments concerning triplet births, it should be pointed out that according to Genesis 12:4 and 11:32, Abraham was born when Terah was 130 years old and was most likely the youngest of the three named sons who were born to Terah after he was 70 years old (Genesis 11:26). Others not named may have been born during this 60-year period. Likewise from Genesis 8:13 and 11:10 it is evident that Shem was born when Noah was 503 years old, and was at the most the second oldest of the three named sons who were born to Noah after he was 500 years old (Genesis 5:32).

R. H. Brown
Geoscience Research Institute

A R T I C L E S

THE LITTLE ICE AGE

Richard D. Tkachuck
Geoscience Research Institute

WHAT THIS ARTICLE IS ABOUT

All are aware that climatic changes occur in cycles measured in days, seasons, and years. A question more difficult to determine is whether climatic changes can occur over centuries. Evidence is reviewed which demonstrates that around 1450 AD, the northern hemisphere experienced a significant cooling which lasted approximately 400 years. Increase in the severity of winters, famine and disease, the advance of glaciers, the shortening of growing seasons, plus a host of other factors attest that this time period was cooler than our present time. In the mid-1800s this trend was reversed and the average mean temperature of the earth began to increase. The causes of this cooling are obscure and unknown. The most likely candidates are a decrease in sunspot activity or an increase in the amount of atmospheric pollutants, perhaps caused by volcanic activity.

INTRODUCTION

The changeability of weather is a phenomenon known to all who live on Earth. Daily fluctuations in temperature, moisture and wind represent the most rapid weather changes that we experience. Changes in weather patterns through the seasons, the annual cycles, as well as multi-annual cycles are generally predictable. Spring does, in fact, follow winter year after year. Climate is defined as the composite of all the components that determine weather in a particular area averaged over time (i.e., a number of years). A particular region can be defined by the dominant weather feature(s) which affect the environment to the greatest extent: polar, mon-

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soon, desert, tropical, etc. While a climate is described in terms of certain weather features, the presence of anomalies such as an unusual rainstorm or high-velocity wind need not change one's opinion about the overall climate for a specific region. In other words, extremes in a particular weather factor can be included just as long as the measurable weather characteristics approximate some average value over long periods of time.

Long-term climate changes measured in decades or centuries are difficult to quantify. Reminiscences of old-timers who recount the rigors of winters in the olden days are often taken with the proverbial grain of salt. Yet such comments do indeed raise the question: Has the climate in different parts of the earth changed over the centuries? The answer appears to be yes, but the basis for this answer is complex and, of necessity, relies on inferential data. It is the purpose of this article to examine a postulated climatic change in recent history. More specifically we shall analyze a time spanned by the dates 1450 AD to about 1850 AD when, at least in the Northern Hemisphere, there appeared to be temperatures much cooler than at present, a time which some have named the "Little Ice Age."

As we examine this topic, it will be seen that evidence for a significant fundamental climatic change is substantial, but — and perhaps more interestingly — the specific reasons for this change are not understood. It is hoped that the reader will gain an appreciation for the very delicate balance that allows life on Earth to continue, and for the serious changes in this balance that could result from catastrophic events.

There are certain difficulties in attempting a historical study of climate because the most common instruments of today such as the thermometer, wind gauge, barometer and rain gauge are all of quite recent development or only relatively recently came into continuous and extensive use for climatic measurements. Therefore, in order to deduce the climate in past centuries, inferential data must be taken from records intended for other purposes. These include shipping logs, taxation schedules, settlement or community histories, crop production records and, interestingly, information from literature and art.

The name "Little Ice Age" implies that there was also a significantly larger ice age. Several large-scale ice movements are postulated to have occurred in the Pleistocene epoch. Evidence suggests that the polar ice caps extended significantly further from the poles than they do now. In the Western Hemisphere, much of Canada and a portion of the northern United States show evidence of glaciation: glacial soils, scouring marks and striations on rocks, moraines, and erratic boulders moved far from their site of origin. All these testify to the presence of a significant amount of ice and its large-scale movement.

The Little Ice Age is not characterized by similar amounts of polar ice so far south but rather by a period of several hundred years in which the winters were particularly severe in the Northern Hemisphere. In addition, other climatic features such as cooler summer temperatures, changes in the amount of rainfall and major shifts in wind patterns were observed. There were significant changes in the size of glaciers in the mountains. The period just before the Little Ice Age — 1100-1300 — also presents a weather anomaly. It was characteristically different from the present day in that average temperatures were higher. Thus a more marked shift to a colder time is more visible in the historical record.

HISTORICAL INDICATORS OF CLIMATIC CHANGE

Let us first examine the effect of climatic changes as indicated by plants and animals. The cultivation of grapes for wine making was extensive throughout the southern portion of England from about 1100 to around 1300 (Lamb 1965). This represents a northward latitude extension of about 500 km from where grapes are presently grown in France and Germany. Grapes were also grown in the north of France and Germany at this time, areas which even today do not sustain commercial vineyards. The grape production in England was more than that of local farmers for their own use. The amount of wine produced in England during this period was substantial enough to provide significant economic competition with the producers in France. With the coming of the 1400s, temperatures became too cold for sustained grape production, and the vineyards in these northern latitudes ceased to exist. It is interesting to note that at the present time the climate is still unfavorable for wine production in these areas.

Estimates can be made as to the average temperature differences between the warm period and the centuries which followed. In this warm time, vineyards were found at 780 meters above sea level in Germany. Today they are found up to 560 meters. If one assumes a 0.6-0.7ºC change/100 meter vertical excursion, these data imply that the average mean temperature was 1.0-1.4ºC higher than the present. For the successful production of grapes a frost-free spring is required after the blossoms are finished. Additionally a warm summer and autumn are required to increase the sugar content. Harvesting should be accomplished before the first fall frost.

A further botanical evidence which suggests a climatic shift to a colder time is the lowering of the tree line by 70 to 300 meters in the Alps (Lamb 1977, p 436). This observation is supported by the remains of peat deposits and forests at higher elevations than they presently occur. A similar 100-200 meter lowing of the tree line also occurred in Northern Germany. Iceland experienced a 300 meter lowering of the tree line to the present day levels (Lamb 1977, p 228). Birch tree trunks are still being expelled at the termini of Icelandic glaciers. In addition, the decrease in temperature resulted in lower-altitude requirements for fruit-and-grain crop production areas and an extension of 20 days for the average grape ripening time.

Human remains in Norse burial grounds located in Greenland have been found which are now in permanently frozen soil. This suggests an average local temperature at the time of Norse occupation 2-4ºC higher than at present. Additionally, the finding of plant roots at this same level supports this supposition, since the permafrost layer provides a barrier to growth. There is evidence that American Eskimos occupied areas in the north of Greenland, on Ellesmere Island and the New Siberia Islands. At these locations, large dwellings made from driftwood have been found. There is also archeological evidence of large villages that were developed for whaling and fishing. These settlements eventually were forced south by climatic change until they came in contact with Viking colonies in southern Greenland. Conflict occurred, and the Viking colonies eventually died out in the 1400s (Lamb 1977, p 248). Communication with Europe was abandoned in 1410 and not re-established until the 1720s. Europeans did not recolonize there until the 1800s. The excavation of Viking colony sites on Greenland has shown the presence of corn pollen, which implies cultivation of this crop. Historical records predating the Little Ice Age also suggest that grain was grown in the Viking colonies, an occupation not attempted again in this region until the present century (Lamb 1977, p 257).

Grain growing in Iceland was given up in the 14th century. In 1695 sea ice completely surrounded Iceland except for one port. Even from the highest mountains, open water could not be seen in all directions (Figure 1h) (Lamb 1977, p 453). This and later sea ice flows resulted in the island getting its present name.

Glaciers can provide a record of long-range weather conditions. Glaciers begin their life in snowfields at high elevations. The compacted snow flows by gravity to form a river of ice. At the lower elevations the ice at the terminal end of the glacier breaks off (calves) and melts away. If the average temperatures become warmer, there will be a transition in which the rate of melt is greater than the rate of formation, and the glacier will diminish in size and recede to higher elevations. The opposite transition will occur if average temperatures become cooler, provided the moisture supply is maintained.

While it is not possible to look back into history and say that the cooling trend began in a particular year or even decade, certain phenomena can act as harbingers of these trends. Glacial advances in Europe began about the mid-13th century. Habitable structures which were once at high altitudes in the Alps were destroyed by glacial activities. Extension of glaciers continued into the 16th century. For example, a glacier blocked the Saas valley, including its river, in 1589 and eventually formed a lake (Lamb 1977, p 9). Ponded water from the river soon broke through the ice and caused flooding. Similar events were repeated in this area numerous times in the next two centuries. In the late 1500s, land and property were destroyed in Chamonix (France) by glacial action.

Glacial advances in North America occurred from 1711-1724 and 1835-1849 (Lamb 1977, p 453). Increase in the amount of Arctic sea ice resulting from calving of more northern glaciers also was observed. Once-productive Icelandic farms were covered by advancing glaciers. So serious was the climatic change experienced by Icelanders that Denmark, the parent country, considered evacuating all the islanders and re-settling them in Europe.

The change in climate during these years can also be deduced by the economic conditions in the affected lands. Such perturbations can greatly affect crop production and animal husbandry. The availability of varieties of seed with tolerances for extremes of cold or heat, wetness or drought as are found in the present day was, of course, unknown centuries ago. Thus it is possible to detect climatic changes by measuring productivity or its absence — famine.

Warm climatic conditions are generally accompanied by a tendency towards dryness resulting from reduced rainfall and increased evaporation. If seasons are cooler than usual, rainfall increases (cooling favors increased condensation of moisture-laden air), and there is also a reduced level of evaporation after the rain has fallen.

In the middle of the Little Ice Age (ca. 1700), there was famine in the higher elevations of Scotland (Lamb 1977, p 11). Each grain crop requires several conditions before a successful growing season and harvest is possible. Minimum temperatures are necessary for seed germination. Higher altitudes are more susceptible to adverse climatic cooling. Frost will occur later in the spring and earlier in the fall causing a shortened growing season. Increased cloud cover and cool weather retard the growing process and prolong the ripening of the grain. In addition, if the summer remains wetter than usual, grain crops may not be able to mature by drying out. If an early frost comes, the still-moist grain will suffer damage. Thus, a cooling trend can affect the growing plant in several ways, compounding the possibility of crop failure.

Using a variety of indicators, Lamb (1965) has synthesized a temperature profile of the average mean temperatures in England from about 1100 AD to the present (Figure 1a). This estimate was based on a wide variety of data such as economic values of produce and severity of winters recorded in historical records, to list a few (Figure 1b,c). For example, in the years of the Little Ice Age the price of grain increased over five times, imposing an obvious hardship on the poor (Figure 1d).

It is estimated that in the coldest decades of the Little Ice Age the growing season was shortened by 3-4 weeks (Manley 1957). This may represent an approximate reduction of 20% of the total growing season which would range from May to September in the northern latitudes.

Significant crop production differences result from small temperature changes. In Iceland in the late 1950s the mean April-October temperature was 7.6ºC, resulting in a 4.33 metric ton/acre hay yield. In 1966 for the same time period, the mean temperature was 6.8ºC and the hay yield was 3.22 tons/acre.

Exceptionally grim reports of mass deaths are frequent in the literature of this time. There were population decreases in large portions of Europe. While diseases such as bubonic plague (Black Death) definitely had their

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FIGURE 1a. Estimated mean yearly temperatures based on a variety of climatic, political and social indicators. Redrawn from Lamb 1977.

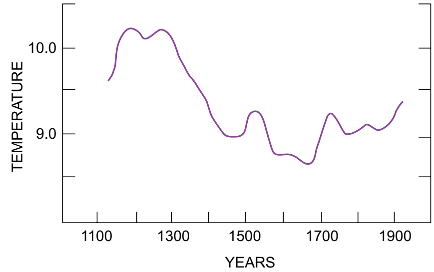
FIGURE 1b. Winter severity and summer dryness for northern Europe. Redrawn from Lamb 1977, p 440.

FIGURE 1c. Weather patterns as a function of winter severity as measured in Paris and London. Redrawn from Schneider &nd Mass 1975.

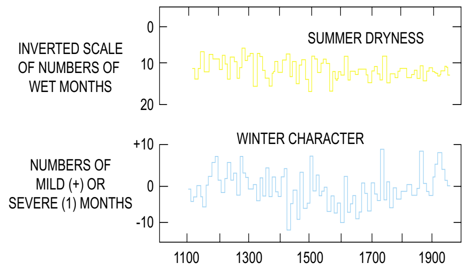
FIGURE 1d. Average price of wheat expressed in gilders. Redrawn from Lamb 1977, p 440.

FIGURE 1e. Record of changes in $^{18}0$ values preserved in ice core from Camp Century, Greenland. Redrawn from Schneider & Mass 1975.

A


TEMPERATURE
10.0
9.0
1100
1300
1500
1700
1900
YEARS

B


INVERTED SCALE
OF NUMBERS OF
WET MONTHS
0
10
20
SUMMER DRYNESS
NUMBERS OF
MILD (+) OR
SEVERE (1) MONTHS
+10
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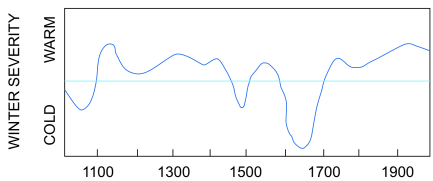
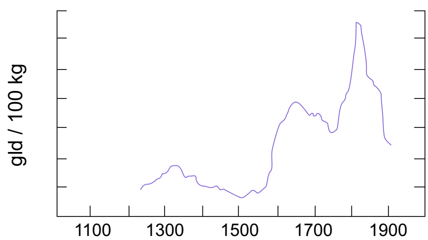
-10
WINTER CHARACTER
1100
1300
1500
1700
1900

C


WINTER SEVERITY
WARM
COLD
1100
1300
1500
1700
1900

D


gld / 100 kg
1100
1300
1500
1700
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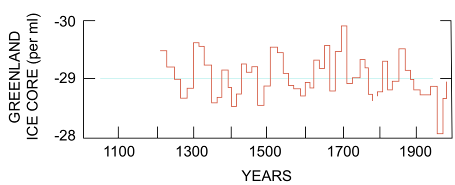
E


GREENLAND
ICE CORE (per ml)
-30
-29
-28
1100
1300
1500
1700
1900
YEARS

effect, the generally weakened health of the people in years of poor harvest must certainly be considered. In fact, population declines attributed to low food levels began 40 years before the plague arrived (Lamb 1977, p 455).

Support for climatic difficulties affecting the lives of people can also come from a variety of other sources. For example, the number of days that prayers for rain were offered increased during this time in a certain city in Spain. Crop production values and census data for domestic animals likewise imply harsh conditions. Tax receipts indicate an increase in the number of abandoned lands and villages further suggesting an unusual occurrence (Lamb 1977, p 459-473).

During this time of exceptionally severe winters, the Baltic Sea and major rivers such as the Thames froze over (Lamb 1977, p 570). It is also interesting to note that in the paintings produced during this time, the percentage of open sky decreases and the cloud cover increases, suggesting that the contemporary artists were inadvertently recording the effects of the Little Ice Age (Lamb 1967).

PHYSICAL INDICATORS OF THE LITTLE ICE AGE

We have now looked at the economic and social records that imply the presence of the Little Ice Age. I shall next examine a variety of physical evidences that also seem to promote this idea.

Plants incorporate various atoms (carbon, hydrogen and oxygen) from their surroundings into their structure. Once incorporated, these atoms no longer exchange with those in the environment unless decay sets in. Thus the chemical composition of a plant can give a fingerprint of the climatic conditions under which it grows. In the natural world there are different isotopes of carbon, hydrogen, and oxygen. These isotopes vary in their weight as well in their relative abundance. The ratio of incorporation of these various isotopes into the plant is a function of temperature (Libby

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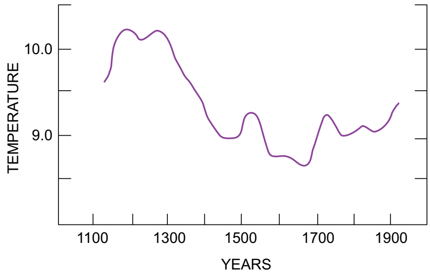
FIGURE 1f. Average tree-ring widths of bristle cone pines from the White Mountains, California. Redrawn from LaMarche 1974.

FIGURE 1g. Changes in carbon-14 abundance in wood samples as a function of sunspot number. Redrawn from Eddy 1977.

FIGURE 1h. Variation in amount of polar ice seen from Iceland. Redrawn from Lamb 1977, p 452.

A


TEMPERATURE
10.0
9.0
1100
1300
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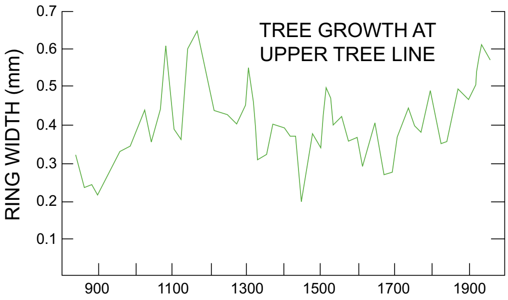
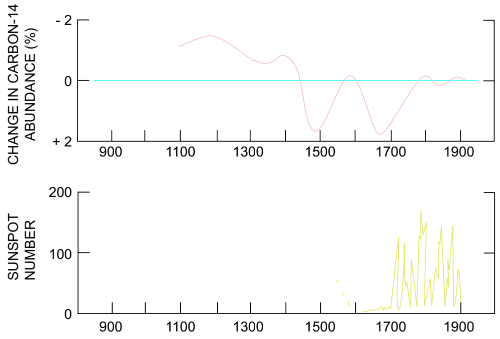
1700
1900
YEARS

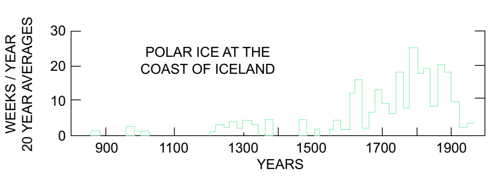
F


RING WIDTH (mm)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
TREE GROWTH AT
UPPER TREE LINE
900
1100
1300
1500
1700
1900

G


CHANGE IN CARBON-14
ABUNDANCE (%)
- 2
0
+ 2
900
1100
1300
1500
1700
1900
SUNSPOT
NUMBER
200
100
0
900
1100
1300
1500
1700
1900

H


WEEKS / YEAR
20 YEAR AVERAGES
30
20
10
0
POLAR ICE AT THE
COAST OF ICELAND
900
1100
1300
1500
1700
1900
YEARS

& Pandolf 1974). As can be seen in Figure 1e changes occur in the years of the Little Ice Age. It is also interesting to note the increase in concentration of ^{14}C during this time. This later observation may provide a clue as to the cause for the Little Ice Age.

Additional isotopic evidence in ice cores from Greenland also suggest a cooling during this time (Figure 1e). In water the most abundant form of oxygen has a weight of 16. The rarer form — oxygen 18 — is present in only small amounts. If one measures the change in the $^{18}O/^{16}O$ ratio in the water of the ice, changes occur that correspond with theoretical predictions about rates of incorporation with respect to temperature (Libby 1972).

Tree rings also provide supportive evidence for the Little Ice Age. The width of a ring measures how favorable the climate is for growth, i.e., the wider the ring, the more favorable the conditions; the narrower, the less favorable for growth (LaMarche 1974). Figure 1f shows that in the warmer and more favorable years the width increased, while in the years postulated for the Little Ice Age the width was reduced. A subsequent recovery is shown in the last century.

Similar studies of a coral which exhibits yearly growth bands again yielded isotope data suggesting that average mean water temperatures during the Little Ice Age did indeed decrease by about 1ºC (Druffel 1982).

POSSIBLE CAUSES OF THE LITTLE ICE AGE

While it is relatively easy to find evidence for a general cooling trend, it is more difficult to define the cause(s) for this phenomena. More likely, it is the result of several factors. Before we examine these, a brief discussion of the energy structure of Earth is necessary.

The sun, obviously, is the source of energy for this planet. Fluctuations in the amount of energy absorbed by the Earth will cause variations in the total amount of heat retained or lost. Particulate matter in the atmosphere which blocks some of the incoming energy has been observed to promote a cooling trend for short periods of time. This particulate matter until the present century was largely a result of volcanic activity. Recent industrial pollution is proposed as a cause of the recent cooling trend that began in the 1950s. The explosions of volcanoes in the 19th century have been correlated with a subsequent coolness in the weather in the following years. The explosion of Tambora in 1815 which catapulted 150 cubic kilometers of rock dust is given credit for “the year without summer” in 1816. The explosion of Krakatoa in 1883 presumably lowered the mean earth temperature about 1ºC for several years (Rampino & Self 1982). The presence of this particulate matter may increase the amount of precipitation, because the ejected material acts as condensation nuclei around which water droplets can form. Without these nuclei the air becomes supersaturated.

In addition to particulate matter being ejected, perhaps even greater absorption of the sun's rays is due to absorption by ejected sulfur compounds (Pollack et al. 1976). These sulfur compounds eventually form fine droplets of sulfuric acid which may remain suspended for years in the upper atmosphere, forming large clouds which reduce the penetration of the sun's energy. Because of the ejection of an aerosol into the upper atmosphere by the volcano El Chichon which exploded in Mexico in 1982, several meteorologists predicted a winter colder than usual for 1982 (Kerr 1982). Whether the action of volcanoes is responsible for a cooling that lasted several hundred years is debatable. It seems unlikely that a single volcanic event would be great enough to cause such a cooling effect. History does not record such a single large event but does record many smaller events which occurred in various parts of the world at frequent intervals.

After the cooling event has begun, it can, to some extent, become self-perpetuating. With increased snow cover the amount of energy absorbed by the earth is reduced. Up to 80% of the incoming radiant energy normally captured can be lost due to the reflectivity of the snow and ice (Lamb 1977, p 285). This is a significant loss of potential heat, further exacerbating the cooling effect. The polar latitudes are a constant area of heat loss for the global system. In summer the amount of heat absorbed is not equal to the amount lost during the winter. Were it not for an equal overbalance in the equatorial regions where heat gain is 2.5 times greater than heat loss, the Earth would become increasingly colder. The mixing of the excess equatorial heat with the overall heat deficit in the northern latitudes promotes a stable environment that can be maintained even in latitudes where there is net heat loss, e.g., the temperate zones.

The presence of large bodies of water such as oceans tends to balance the cooling trend on the land masses. As the air and water temperatures cool, less moisture is evaporated into the atmosphere resulting in less rain or snow. If precipitation is less, a relative increased melting of previously fallen snow can take place.

Warming of the atmosphere can result from an increase in the CO_2 levels. The effect of CO_2 on climate is a topic of considerable interest at the present time (see Revelle 1982 as an example of support; Madden & Ramanthan 1980 for negative evidence). Briefly, as the sun shines on Earth, unabsorbed light waves are reflected back into the atmosphere in the form of longer wavelength energy. The CO_2 in the atmosphere absorbs some of this infrared radiation, resulting in increased molecular motion or heat which in turn causes a warming of the atmosphere and ultimately the earth itself. This "greenhouse effect" has provoked some to become alarmists fearing that warming due to increased CO_2 in the atmosphere as a result of burning fossil fuels will cause the polar caps to melt, thereby raising the average level of the oceans and also increase the area of deserts. It might be suggested that the Industrial Revolution's intensified burning of coal and wood increased the atmospheric CO_2 sufficiently to hasten the end of the Little Ice Age.

Another theory for the cause of the Little Ice Age centers not on the atmospheric restriction of the amount of energy flowing into the earth, but on the concept that the sun itself is variable in its energy production. It is estimated that a fluctuation of only a few tenths of 1% in energy output would be sufficient to produce significant changes in climate (Budyko 1969). An interesting coincidence held meaningful by many is the absence of sunspot activity through most of the latter and most severe period of the Little Ice Age (Eddy 1976). While accurate astronomical records are increasingly difficult to obtain as one moves back in history, there is yet a convincing amount of data which allows one to have confidence in the historical sunspot record.

At present sunspots — large areas of reduced surface temperature and increased magnetic field strength — increase and decrease numerically through an approximately 11-year cycle. These changes in solar magnetic field also affect the rate at which ^{14}C is produced on earth and may provide a retrospective record of variations in sunspot activity (Figure 1g). Observations from the 1700s to the present have established a remarkable regularity in sunspot activity. Over the years there have been numerous attempts to correlate these cycles with weather cycles. While sunspot/weather analysis has not produced a consistent correlation, it is widely accepted that sunspot activity does indeed influence the weather. However, an interesting near absence of sunspot activity is found in the early decades of the 1600s extending into the first decade of the 1700s. This time corresponds remarkably with the coldest period of the Little Ice Age.

CONCLUSIONS

In conclusion there is ample evidence that a significant cooling occurred for several centuries starting around 1450 AD. This cooling caused significant changes in the distribution of plant and animal life and in the way man responded to the environment. The causes for this cooling may have derived from a combination of changes in the energy output of the sun and changes in the atmosphere of the earth which resulted from volcanic activity that reduced the amount of energy absorbed.

This uncertainty as to the cause for this cooling which so markedly affected life should warn those who demand that the Earth responds only to massive (forceful) events. Very subtle changes in the factors determining climate during the Little Ice Age occurred. One wonders how much greater they need be to cause a true ice age.

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ARTICLES

PALEOMAGNETISM II

Ivan E. Rouse
Professor of Physics
Loma Linda University

WHAT THIS ARTICLE IS ABOUT

The magnetic information that is stored in the various types of rocks is providing geoscientists with a wealth of information about the earth and its history. However, for this information to be of greatest use, an understanding of the source of the field as well as its overall properties such as "shape" and strength is necessary. The Barnes Free Decay model for the source of the geomagnetic field is compared to the available data and to the conventional dynamo model as possible models for the source of the geomagnetic field. Which model fits the data best and what implications does it have for creationists?

Paleomagnetic data is proving to be useful in numerous applications, but the data really has little meaning unless certain assumptions are made. What are these assumptions, and do they appear to be valid from a creationist perspective?

Paleomagnetism is responsible for the widely held idea that the geomagnetic field of the earth has reversed itself many times in the course of the history of the earth. This reversal information has been used to establish a "magnetic reversal time scale" that is being widely used to study "magnetic stratigraphy." Another application of paleomagnetic data has been in the study of the dynamics of the earth's crust and the subsequent development of the theory of plate tectonics. This theory has had a tremendous impact on the geosciences. What problems do these models of earth history present for creationists, and have creationists seriously addressed them? Are there other valid explanations for these phenomena that fit well with a short earth history?

Paleomagnetism I *reviewed the basic principles of geomagnetism. In* Paleomagnetism II *we discuss the various models for the source of the earth's magnetic field and the implications these models have for a creationist viewpoint. We must also give some attention to the highly complicated science of paleomagnetic sample collection and analysis.*

I. INTRODUCTION

The magnetic information that is stored in the various types of rocks can tell us a great deal about the earth and its history. However, in order to appreciate and understand this information, an understanding of some properties of the geomagnetic field as well as the ways in which magnetic information is actually obtained from the rocks is needed. As is often the case in science, this process of getting the information about the paleomagnetic field is not always as direct as one would wish and involves certain assumptions.

II. SOURCE OF GEOMAGNETIC FIELD

The general shape of the geomagnetic field has been known since the time of Gilbert, some 400 years ago. Since then, there has been a great deal of speculation about the source of this field (Jacobs 1963). In the last 20 years our understanding of possible generating mechanisms has made significant progress, but the source of the earth's field is not yet completely understood.

A. Possible Source Models

Geomagnetism, as it is known today, owes much to the early analysis made by Gauss in 1839 (Garland 1979, Jacobs 1963). It was readily apparent to Gauss that the field was primarily due to an internal dipole. More precise data and calculations in recent years have substantiated Gauss' conclusion that the "main" geomagnetic field is internal in origin and not from outside the earth.

Could the source of geomagnetic field be charges on the surface of the rotating earth? The electric field of about 100 V/m at the surface of the earth can be used to calculate a surface charge (Feynman 1964). It can then be easily shown that the rotation of this surface charge is much too small to account for the geomagnetic field (Garland 1979).

Could the earth's field be due to ferromagnetism frozen into the rocks of the earth? The temperature gradient observed in the crust is about 30ºC/km. This means that at a depth of about 25 km, the temperature would be approximately at the Curie point for iron, or about 750ºC (Jacobs 1963). Since there is no evidence that the Curie point increases with increasing pressure, it is reasonable to conclude that the only part of the earth that could have ferromagnetic properties is the outer shell in which rocks would be cool enough to exhibit ferromagnetism (Wasilewski et al. 1979, Jacobs 1963).

To further narrow down the source of the earth's field it would be helpful to measure the strength of the field as a function of depth below the surface. Runcorn et al. (1951) made just such a study and their results suggest that the source is deep inside the earth, thus ruling out ferromagnetism of the surface rocks as the source. This leads us to seriously consider the role of the earth's core in the production of the geomagnetic field. Geochemical, geophysical, and density considerations are consistent with a liquid outer core that is composed of iron and possibly nickel. Could the geomagnetic field be due to large electric currents (circa 10^9 amps) within the conducting core of the earth?

There are two fundamentally different ways that the currents in the core might produce the geomagnetic field. These theories might best be referred to as the "free decay" model and the "regenerative dynamo" or "dynamo" model.

B. Barnes Free Decay Model

The free decay theory assumes that the motion of the charges in the core is simple circular motion around the magnetic polar axis of the earth. In addition it is generally assumed that the energy of the "original" electric currents is being continually dissipated away as heat in the conductor and that none is being supplied to take its place. Stacey (1969) and Jacobs (1963) both make estimates of the necessary time for the earth's magnetic field to decay exponentially to 1/e (37%) of its original value and arrive at times of 10^4 years and 10^5 years respectively.

The free decay theory has been favored by several creationist groups since it seems to imply a short age for the earth. Perhaps the leading spokesman for this view is Thomas G. Barnes, of the University of El Paso, Texas, who in 1971 wrote an article under the title "Decay of the Earth's Magnetic Moment and the Geochronological Implications," thus launching a new creationist method of dating the age of the earth based on the decay of its magnetic field. His free decay theory is based exclusively on the available direct measurements of the intensity of the earth's field as a function of time (see Figure 8 in PALEOMAGNETISM I).

McDonald (1967), Akridge (1980), and Barnes (1971, 1972, 1973a, 1973b, 1975, 1981) have made statistical analyses of the laboratory intensity data which was collected between 1835 and 1965. In addition, recent Magsat satellite data obtained in 1979 and 1980 has been analyzed (Wilford 1980). All of these studies conclude that the intensity of the earth's magnetic field has been decreasing during this period of time.

Barnes & Akridge (1980) calculate from mathematical fits to the data that the geomagnetic field must be decaying exponentially with a half life of 1400 years. Barnes then extrapolates this 130 years worth of data back (154-fold) to 20,000 BC and finds that the strength of the geomagnetic field would have been 18,000 gauss! He then argues that organic life would have been impossible in such a strong magnetic field and that an 18,000 gauss field would require unfeasibly large currents in Earth's core on the order of 50,000 times larger than the presumed present value (10^9 amps, Chapman 1940). Based on these arguments Barnes concludes that the earth must be less than 10,000 years old and more likely 6 to 7,000 years old, in agreement with the traditional interpretation of the Biblical record.

The magnetic decay method of dating, as it is called, has been proclaimed to be the most reliable evidence for a young earth age and thus the strongest evidence against the long ages of radiometric dating. Henry Morris (1983) states "If any process should be a *reliable* indicator of the earth's age, *this* should be — and it indicates an upper limit for the age of about 10,000 years!" In another discussion (Morris & Parker 1982) the Barnes method of dating is listed as the first in a list of 68 scientific evidences for a young earth.

On the other hand, Barnes hasn't been without his critics both from the ranks of creationism and from the geologic community in general. A comprehensive rebuttal of the magnetism decay method of dating was recently published in the *Journal of Geological Education* by G. Brent Dalrymple (1983), who is employed by the U. S. Geological Survey as an expert in radioactive dating, especially the potassium-argon method. In reaction to Dalrymple's criticisms, Barnes has written a response (Barnes 1983) entitled "Earth's Magnetic Age: The Achilles Heel of Evolution." Others have also entered the controversy on both sides of the issue (Young 1982, Morris 1983).

Warren Johns (1984) has put together a well-written layman's discussion of this controversy from the point of view of a creationist interested in evaluating the theory's scientific support.

He (1984) concludes that "In spite of its seemingly impressive scientific credentials, it falls short of being a valid scientific method of dating because of at least four major problem areas." Three of the four points are pertinent to this discussion.

1) *Magnetic age dating is more rigidly uniformitarian than the uniformitarianism of conventional geologists.* Uniformitarianism means that the present is assumed to be an adequate key to the past. A good example of uniformitarianism is radioactive dating. Although radioactive dating extrapolates backwards in time, it does not do so without some independent cross checks. There are many radioactive isotopes that can be checked against each other to provide some "quality control." However "the magnetic decay dating method looks for virtually no checkpoints prior to 1835; it ignores any possible evidence from archeomagnetism, paleomagnetism, geology, or historical records to test the validity of its extrapolation.... It is ... more rigorously uniformitarian than the age-dating methods used by geologists" (Johns 1984).
2) *Paleomagnetic intensity measurements indicate that the earth's magnetic field has been decreasing in intensity only in the last 2800 years and more rapidly only in the last 800 years*. The advocates of the magnetic dating method claim that there is no validity to paleomagnetic intensity measurements. Burlatskaya et al. (1969) show that paleomagnetic data for the last 750 or 800 years is consistent with the direct laboratory measurements. It seems that if the paleointensity data parallels the observatory measurements this well we must accept the paleointensity data as accurate for at least the last several thousand years. When one looks at the paleomagnetic intensity data (see Figure 8 in PALEOMAGNETISM I) one sees that the Barnes approach totally ignores the fact that at times in the past the paleointensity has clearly been less than it is at present, and may in fact have reversed many times.

3) *The equation developed for predicting past intensities of the earth's magnetic field is entirely arbitrary*. Akridge's studies showed very little difference (2%) between the goodness of fit for the linear and exponential decay models for the intensity of the magnetic field. The exponential decay fit is chosen because it is the type of magnetic moment decay that is produced by real currents which dissipate energy through Joule heating (Barnes 1975). However, since very little is really known about what is happening in the core, without some type of corroborating data, major reliance should not be placed on the exponential decay assumption.

Although heralded by many creationists as the "answer" to their long age problems, this free decay model of Barnes does not seem to be well supported by the data if one carefully considers *all* the available data.

C. Dynamo Model

In the dynamo model the charge motions are envisioned to be complicated motions resulting from the interactions between a moving conducting fluid and a magnetic field. In brief, the dynamo theory states that a conducting liquid core moving in a pre-existing magnetic field produces an electric current. These moving charges are assumed to sustain and intensify the initiating magnetic field. In this way, especially with an external energy source, the earth's magnetic field could be produced and sustained over an extended period of time.

The dynamo theory of generation of the earth's magnetic field was first proposed in detail by Elsasser (1946a, 1946b, 1950) and by Bullard (1949). Since Elsasser's time, the discussion and investigation of whether this dynamo process can indeed occur centers on 1) the existence of suitable motions of the liquid, 2) low resistance electrical flow in the fluid, 3) a suitable energy source to maintain the motion, and 4) a small original field (Garland 1979). There has never been much question about 2) or 4), but 1) and 3) have generated a great deal of discussion.

The physics involved in solving this problem is very difficult. Fuller (1983) puts it well when he states "The origin of the geomagnetic field remains a mystery. There is no argument that some sort of dynamo in the outer core is responsible for it, but there is little agreement as to which sort it is." For example, the forces and energies necessary to produce the fluid motions in the dynamo are not known. The promising possibilities are (Levy 1979, Stacey 1969): 1) thermal buoyancy or convection as a result of heat produced by radioactive decay, 2) chemical separation and latent heat at the boundary between earth's solid inner and liquid outer core, 3) different precession rates of the core and mantle, 4) gravitational energy release by shrinking of the earth as the denser solid core grows. The actual amount of energy necessary to maintain the geomagnetic field is dependent on the model as well as the conditions in the core, which are not well known.

It is readily apparent that much work needs to be done in this important and fascinating area of geophysics. Much more complete discussions of this topic and many more references may be found in several review articles (Busse 1978, Carrigan 1979, Hoffman 1983, Levy 1976, Rees 1961) and books (Cox 1973, Gubbins 1979, Jacobs 1975, Merrill & McElhinny 1983, Moffatt 1978).

The dynamo model seems to be the only viable model for the source of the earth's field and as such is accepted by virtually all geophysicists. This doesn't make it the right model but it does seem to be the best model available at the present time.

What are the implications of the various dynamo models for creationists? It is difficult to answer this question without a better understanding of the type of dynamo responsible for the geomagnetic field. This would then seem to be an area of study that has significant potential for helping the creationists better understand the complexities of the world that God has made.

III. METHODOLOGY

Geomagnetic data may be obtained in a number of ways. The magnetic field above the surface of the earth is usually measured using magnetic field sensing instruments called magnetometers. These instruments are carried by ships, aircraft or spacecraft, or are housed in stationary observatories. Aside from the data on the magnetism of the ocean floor collected by ships and aircraft, most paleomagnetic data is obtained by laboratory study of the magnetic field frozen into small oriented rock samples.

A. Sample Collection

Because of the sophisticated nature of the analysis that is done on paleomagnetic samples, it is usually not possible to accurately determine either the direction or intensity of a rock sample in the field. This means that many carefully oriented samples must be collected by drilling a cylindrical plug out of the formation under study. Needless to say, the original orientation of the sample must be measured as accurately as possible. If the bedding or deposition plane has been tilted since deposition, the original orientation before tilting must be determined. Irving (1964) and Tarling (1971) have more complete discussions of sample collection.

B. Determination of Sample Properties

The determination of the direction and intensity of the paleomagnetic field of the earth necessitates the careful measurement, using a magnetometer, of the direction and magnitude of the magnetic moment or field of a cylindrical sample of material having a volume of a few cubic centimeters.

These magnetometer measurements are sufficient to determine the direction and magnitude of the magnetization of the sample, assuming that the sample contains no complicating secondary effects. If there are secondary effects, a process called demagnetization must be carried out to remove the unwanted "soft" components of the field. This is done in one of two ways. Both methods involve processes that randomize these easily changed secondary components of the magnetic field so that their net contribution to the total magnetic field of the sample will then be zero. This randomizing can be done either by careful heating of the sample or by exposing the sample to a weak alternating external magnetic field. When the direction and strength of the field of the sample seems to be stabilized as this demagnetization process is carried out, it is generally assumed that all the secondary magnetic effects have been randomized and that the direction of the magnetic field remaining in the sample is the same as when magnetism was originally "frozen" into the sample. This residual magnetic direction is then used to establish the directional properties of the ancient magnetic field of the earth.

The magnetic direction of any particular sample or set of samples must be referred to some common datum. This is usually done by calculating a predicted or virtual magnetic north and south pole based on the magnetic field direction data from a particular sample.

Determination of the intensity of the ancient field is inherently a much more difficult task than determining the direction of the ancient field. The magnetometer measurements determine the strength of the field frozen into the sample but it is a difficult step to get from the strength of the sample's field to the strength of the earth's field that caused the sample field in the first place. Due to these experimental difficulties, and the fact that paleointensity is of lesser importance in geological studies, there has been relatively little study of paleointensity. Smith (1967) has made an extensive study of the methods and data related to the intensity of the ancient field.

To determine the paleointensity (Tarling 1971) one must make a comparison of the intensity of the natural remanent magnetization of the sample with the intensity or strength of the thermal remanence acquired by the rock during heating and subsequent cooling in a known magnetic field.

Since the intensity varies systematically from a minimum at the equator to a maximum at the poles it must be corrected to some common point on the surface of the earth for comparison. Another means of comparison of intensity data is to calculate a corresponding magnetic moment or strength for the overall earth field assuming a dipolar field.

C. Paleomagnetic Data Quality

An ideal paleomagnetic sample would be isotropic, homogeneous, and have no secondary magnetizations. If all samples were ideal, then paleomagnetic studies would be quite straightforward. In reality, very few samples are ideal and secondary effects slightly change the direction of magnetization from its original value. There are usually ways to identify the problems mentioned above, and in many cases reliable data can be obtained after proper corrections are made.

Many rocks acquire a secondary or “soft” component of magnetization at some time after the original formation of the rock. It is therefore normal for the initial results of a paleomagnetic study to show a considerable degree of scatter in direction of magnetizaton as shown in Figure 1. As mentioned in PALEOMAGNETISM I, these “soft” components may be due to a number of causes such as exposure to an external field other than the original field, or lightning induced fields. Examples of effects due to lightning have been found (Cox 1961, Rees 1961), but are probably not common. Furthermore, the current caused by the lightning usually travels horizontally through the rocks, soil, and water and decays exponentially with depth. This means that the magnetization induced by lightning will have a characteristic pattern that is identifiable and that will not penetrate beyond a depth of about 20 meters.

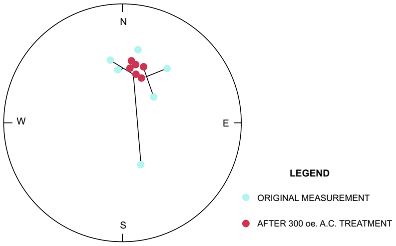

FIGURE 1. Effects of partial demagnetization on directions of natural remanence in six specimens from a single lava flow. The data are plotted on the lower hemisphere of an equal area projection. Open circles represent directions before treatment and solid circles after partial demagnetization. (Redrawn from Cox & Doell 1960).

When all the possible factors that can affect the paleomagnetic measurements are considered, it is usually possible to define the natural remanence direction to within ±3° and the intensity to within ±20%. How stable is the remanence observed in the sample? One test for stability has to do with the clustering of the magnetization directions determined from a group of samples from the same site. If the directions from a particular site are well clustered or consistent, a stable remanence is indicated. Tests for consistency, and thus stability, are the most meaningful if several different types of rock from the same location are compared.

D. Age of Remanence

At this point it is appropriate to ask how old the observed remanence is. There are two types of answers that can be given — the absolute age and the relative age. Both of these types of answers can, of course, often be checked for consistency with other paleomagnetic measurements as well as other paleoclimatic or geologic data that is pertinent. There are also objective tests to determine if the stable remanence is primary, i.e., of the same age as the rock.

The most important of these is referred to as the fold or tilt test (Tarling 1971) and can give a relative age for the remanence. Primary remanence that is acquired in the usual fashion from the earth's field at the time of rock formation will have the same direction throughout a particular formation. If this formation is then later tilted or folded, the primary magnetization directions will also be tilted or folded. Careful study of the tilting and folding will allow the experimenter to correct the magnetization directions for individual samples within the formation into a tight cluster. If the remanence is not tilted or folded but all the same direction in spite of the tilting and folding of the formation, the remanence obviously was acquired after the tectonic activity. Tarling (1971) also mentions several other tests for relative age of remanence.

To obtain an "absolute" age for the rocks and thus for their primary remanence, either standard stratigraphic correlation techniques or radiometric methods, typically potassium-argon dating, are used. It should be cautioned that there are numerous difficulties that can be encountered with both the relative and absolute dating methods, and the experimenter must proceed with great care.

IV. PALEOMAGNETIC ASSUMPTIONS

As we shall see in the next section, there are numerous potential areas of application for paleomagnetic data. However, we should ask the following question. What does the paleomagnetic data tell us directly without any assumptions other than those discussed in the METHODOLOGY section above? It tells us the direction and intensity of an ancient geomagnetic field that *could have* produced the measured remanent magnetism at the location of the rock sample. This information is not very useful in itself. What we would like to know are the predicted positions of the ancient geomagnetic poles and some measure of the overall strength of the ancient geomagnetic field. Consequently, in order for the paleomagnetic data to have the most utility, three basic assumptions are generally made.

A. Primary Magnetization Parallel to the Ancient Field

The direction of the primary magnetization of samples obtained from historic sites has been determined and compared to the historically known direction of the field at the time the rock was formed. Mount Etna, which deposited ash and lava over a wide area in an A.D. 1669 eruption, provides just such an opportunity. The direction of the primary magnetization of the samples was determined after demagnetization to remove secondary fields. The geomagnetic pole calculated from this direction agreed to within one degree with the known location of the geomagnetic pole at the time of the eruptions (Seyfert & Sirkin 1979). More recently, a similar study was made of the volcanic ash deposited by the eruption of Mount St. Helens in 1980. Steele (1981) has shown that "ash from the May 18, 1980 eruption of Mount St. Helens, deposited from the air, faithfully records the direction of the local geomagnetic field in eastern Washington."

It would appear then that the primary magnetization of carefully chosen rocks can accurately record the direction of the ancient geomagnetic field at the time of formation. The consistency of the data from all over the world seems to support this conclusion.

B. Dipolar Nature of Ancient Field

Since the early 1950s, studies of rocks from relatively recent geologic periods (60 to 70 million years of assumed geologic time) have found that the main geomagnetic field for the corresponding time periods has been stable and dipolar (Cox 1973, Opdyke & Henry 1969, Tarling 1971, Takeuchi & Uyeda 1970, Torreson et al. 1949). Figure 2 shows inclination data from deep sea cores which support the dipolar assumption. Based on this and other evidence, the earth's magnetic field is generally assumed to have always been primarily dipolar, with one north and one south geomagnetic pole.

The dipolar assumption, although generally accepted, certainly needs further study. As more data is amassed from all over the world, it should eventually be possible to evaluate the possibility of a non-dipolar ancient field. If the dipolar assumption is not valid, the generally accepted plate tectonic model of the history of the surface of the earth would have to be dramatically revised.

C. Coincidence of Average Geomagnetic and Geographic Poles

The average direction of primary magnetization from a consistent group of samples can be used, assuming a dipolar field in the past, to infer an apparent or virtual ancient magnetic pole position on the surface of the earth. This virtual pole position is merely another mathematical method of expressing the magneti-

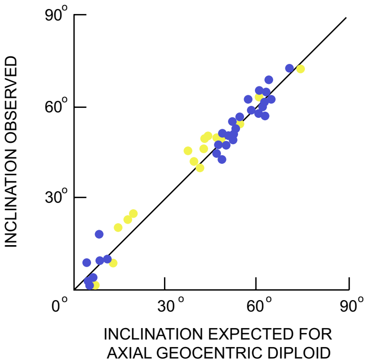

FIGURE 2. The inclination in deep-sea sedimentary cores, less than 2×10^6 conventional years old, showing inclinations which are statistically identical to those expected for an axial geocentric dipole during this period. (After Opdyke & Henry 1969).

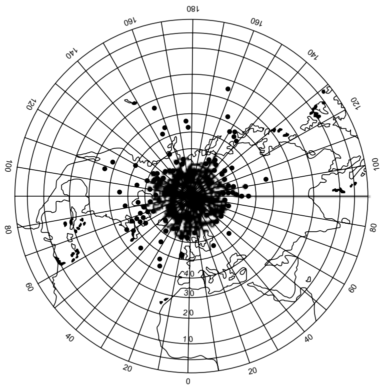

FIGURE 3. Virtual geomagnetic pole positions for over 2000 igneous rocks up to 20 million conventional geologic years old. (Tarling 1971).

zation direction and is not necessarily the same as the actual location of the ancient geomagnetic pole. When the virtual geomagnetic pole, VGP, positions corresponding to sample magnetization directions for igneous rocks (Cox 1973, McElhinny 1973) and for sediments (Opdyke 1969, Tarling 1971, Torreson et al. 1949) are plotted for samples from all parts of the world, their distribution is clearly centered on the earth's rotation axis as shown in Figure 3. The conclusion of these studies is that paleomagnetic data can best be interpreted in terms of an axial geocentric dipole.

V. PALEOMAGNETIC APPLICATIONS

Finally we are in a position to briefly discuss some of the promising applications of paleomagnetism. Most of the ideas to be discussed in this section are so well accepted by the scientific community that few individuals still question whether the current theories might have serious flaws. What weaknesses are there in the accepted theories? What are possible alternative explanations for creationists?

A. Reversals of the Earth's Field

The rather unexpected idea that the earth's main geomagnetic field periodically reverses polarity was first suggested, early in this century, by geophysicists who were studying the remanent magnetization of volcanic rocks and baked earth (Brunhes 1906, Chevallier 1925, Matayama 1929, see also Cox 1973 for reprints of old classic papers). In studying rocks of early Pleistocene age, or older, these scientists discovered that a large proportion of the samples were magnetized in a direction nearly 180º from the present field direction. Even baked earth in contact with the reversely magnetized rocks was reversely magnetized. Based on these results, they proposed that the geomagnetic field had, in the past, actually been in the reverse or opposite direction.

Since these early studies, tens of thousands of paleomagnetic samples of many types of rocks from all over the world have been studied. Surprisingly it is found that there are on the average about as many samples that are reversely magnetized as are normally magnetized (Cox, Doell, Dalrymple 1967; Cox 1973). Any theory that is proposed to account for the reversely magnetized rock must account for this bimodal distribution of polarities.

One of the commonly mentioned explanations by creationists involves lightning strikes. These can certainly magnetize rock, but it is very unlikely that they can account for 50% of the rocks studied worldwide. Furthermore, lightning effects are generally easily detected and removed (Cox 1961, 1973; Graham 1961).

There are two other possible explanations for this data. Either the geomagnetic field actually did reverse, or self-reversal on a global scale took place. Self-reversal is a phenomena in which rocks can be spontaneously magnetized at 180º to the ambient field at the time of cooling.

The significant question here is whether all reversely magnetized rocks have undergone self-reversal. Cox (1967, 1973) heated and cooled hundreds of reversely magnetized samples in a known field and then measured their acquired magnetization to check for self-reversal and found fewer than 1% were self-reversing. Other studies (Wilson 1962; Cox 1963, 1973) have reached the same conclusion and consequently it is generally believed that self-reversal is a very unlikely explanation for reversely magnetized samples.

In addition to the evidence supporting reversals there is one apparently significant piece of contrary evidence involving the differences in chemistry or oxidation state between reversed lavas and adjacent normal lavas that have been reported by several authors (Ade-Hall & Wilson 1963, Ade-Hall 1964, Wilson 1967, Balsley 1954) but not by others (Larson & Strangeway 1966, Ade-Hall & Watkins 1970). This data is generally considered to be paradoxical but not crippling to the field reversal hypothesis (Cox 1973). This area would seem a fertile one for creationists to investigate. For example, what are the implications for the marine basaltic reversals (to be discussed later)?

The second, and perhaps the most convincing, approach for testing for self-reversal, is a worldwide test of the correlation of reversals with mineralogy and rock age. To carry out this type of test it is important to be able to accurately correlate rocks over large global distances. At least for igneous rocks with age assignments of less than 4 or 5 m.y., the dating method of choice is potassium-argon dating. The early studies done between 1963 and 1969 by at least three separate groups of investigators were able, using K-Ar dating, to extend the time scale of reversals back to 4.5 m.y. of presumed geologic time (Cox 1973, McDougall 1964, 1966; Doell 1966, Dalrymple 1967). Their results rapidly converged to what is known today as the geomagnetic-reversal time scale which is shown in Figure 4. Note that this figure includes worldwide data from many investigators and many types of rocks.

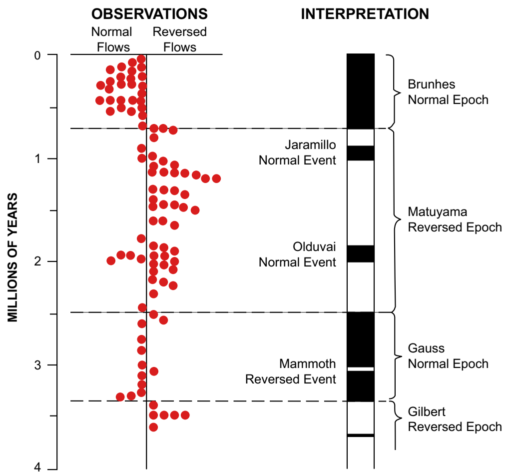

FIGURE 4. Time scale for reversals of the earth's magnetic field that was established on the basis of nearly 100 volcanic formations in both hemispheres. It is clear that the flows fall into four principal groupings, or geomagnetic polarity "epochs," during which the field was predominantly of one polarity. Superimposed on the epochs are shorter polarity "events" (After Cox 1973).

Examination of this data leads one to conclude that there appear to have been four major worldwide *epochs* of one polarity lasting approximately 10^6 K-Ar years, with brief *events* within these epochs during which the polarity reversed for 10^4 to 10^5 K-Ar years. For an exhaustive review of land-based polarity stratigraphy, see the work by Irving et al. (1976).

Further confirmation of the early evidence for reversals, which was primarily from igneous rocks on land, came from cores of deep-sea sediments that formed over the last 2 to 3 m.y. of presumed geologic time. Since the oceanic deposition processes appear to be quite continuous, they have the potential of supplying a detailed record of the earth's magnetic field over the time that the present oceans have been in existence. Figure 5 shows the magnetic reversal time scale as determined from land-based rocks as it compares to the magnetic reversal

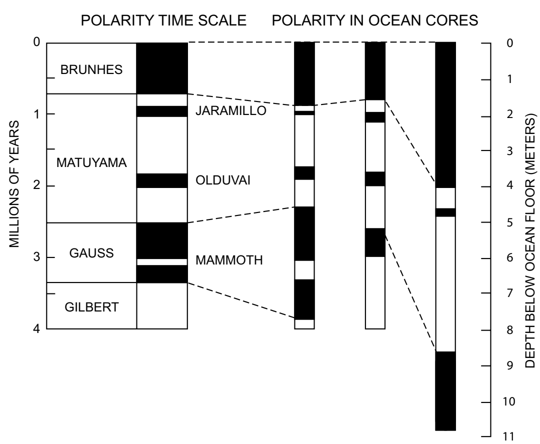

FIGURE 5. Magnetic reversal patterns for deep-sea sediments compared to the reversal time scale compiled from land based date. Magnetic particles become oriented in the direction of the earth's field as they settle through the water. (Cox 1973).

patterns from deep-sea sedimentary cores. These comparisons confirm a worldwide pattern of polarity changes (Tarling 1971, Opdyke et al. 1974, Harrison 1974) and give strong support to the idea that the earth's geomagnetic field has reversed in the past. A comprehensive review of the magnetic reversal time scale is given in *Magnetic Stratigraphy of the Sediments* edited by Kennett (1980).

One last and powerful argument in favor of reversals of the earth's magnetic field comes from measurements of the total intensity of the earth's magnetic field above the ocean floor. These studies have revealed a series of dramatic north-south trending magnetic anomalies that are found over almost all the ocean floor. Comparing these anomalies, which have magnitudes of several hundred gammas, to the geomagnetic reversal time scale from land based rocks and sediments, one sees a striking resemblance as shown in Figure 6. The reader is referred to Blakely (1979) and Cox (1973) who give extensive lists of references on this topic.

Using standard stratigraphic dating techniques combined with polarity determinations of continental rocks, the reversal time scale can be extended back (Ness et al. 1980) into the Mesozoic or to about 140 million years of conventional geologic time, as shown in Figure 7. In summary, magnetic reversals have been observed in igneous rocks on land, oceanic sedimentary rocks, deep-sea sediment cores, anomaly patterns above the ocean floor, basaltic cores from the ocean floor (Johnson et al. 1978), and even some slowly cooled, large intrusive igneous masses. The generally accepted conclusion based on this data is expressed well by Cox (1963), one of the foremost geophysicists in the study of reversals:

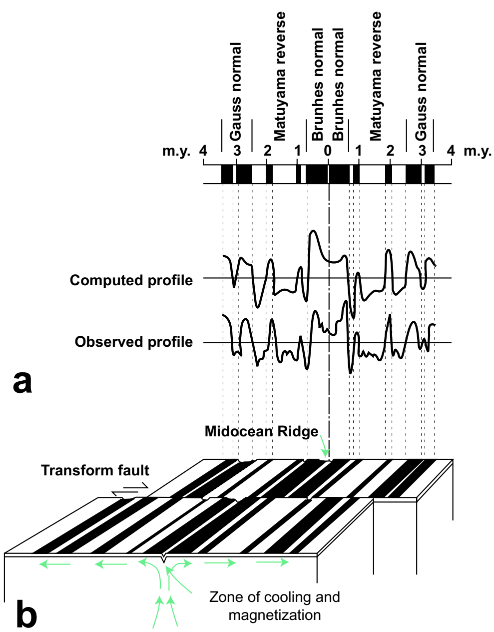

FIGURE 6. Comparison of the observed geomagnetic anomaly profile with the computed profile for the east pacific rise and with the reversal time scale derived from continental rocks (Takeuchi & Uyeda 1967).

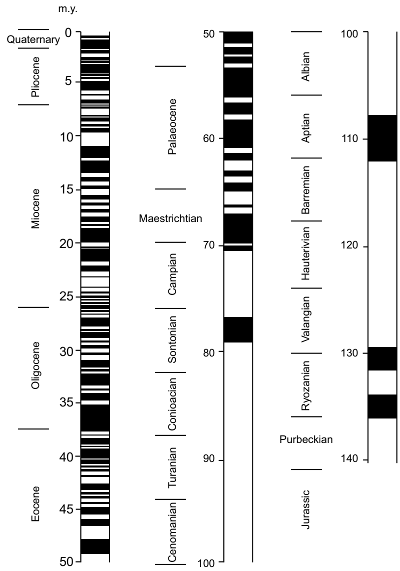

FIGURE 7. The polarity time scale for the last 140 million years of presumed geologic time as determined from thousands of paleomagnetic samples and ocean floor anomaly data. The younger rocks are typically dated by potassium-argon dating, but the older samples from the ocean floor can only be dated assuming constant spreading rates for the ocean floors. (After Tarling 1971).

The abundance and distribution of reversely magnetized rocks preclude their being dismissed as rare, unexplained accidents: these rocks exist on all continents; they occur among many petrological rock types, and they constitute about half of all Tertiary and Pleistocene rocks. Moreover, their stratigraphic distribution is not random. Normal and reversed rocks usually occur in stratigraphic groups of like polarity, and in areas of late Pleistocene volcanism, the youngest group is invariably normal.

What counter arguments are there to this rather impressive array of data? It is difficult to find careful, thorough discussions of alternative viewpoints in the recent literature. Perhaps the most comprehensive collection of papers presenting criticism of plate tectonics (see the next section) and hence also of paleomagnetism is the volume titled *Plate Tectonics — Assessments and Reassessments* edited by Kahle in 1974. Barnes (1971, 1972, 1973a, 1973b, 1975), Akridge (1980), and Overn (1980) have also made arguments against reversals. These authors typically cite many possible exceptions, i.e., various means of self-reversal, but are either unaware of or refuse to carefully consider the bulk of the magnetic reversal data that has been discussed above. Creationists need to take a more thorough and careful approach to the study of this very complex problem.

C. Plate Tectonics

Paleomagnetism has made important contributions to the theory of plate tectonics. The magnetic reversal time scale, magnetic reversal stratigraphy, as well as magnetic direction information have been used extensively to refine the theory of plate tectonics. Although it is not the purpose of this discussion to give a comprehensive review of the theory of plate tectonics, a brief summary is desirable in order to make the following discussion more meaningful.

Concisely stated, plate tectonics is based on the following ideas. Studies of seismic wave velocity within the earth have established that the top 100 km of the earth's crust are relatively rigid, and lie on top of a layer with low seismic velocity which implies that it has a low viscosity and is relatively soft. The outer rigid layer is envisioned to be floating on top of and carried along by convection currents occurring in the soft layer. The convection currents rise up at the mid-ocean ridges creating new ocean floor as indicated by the sea floor magnetic anomalies. This means that new ocean floor is continually being created and that the continents, as part of large crustal plates, are mobile and have moved considerable distances over the surface of the earth. The movements of the plates and hence of the continents are indicated by the magnetic anomaly patterns on the ocean floor and by what are known as geomagnetic polar wander paths. For further reading on plate tectonics and continental drift see Runcorn (1962), Marvin (1975), Hallam (1972), Hurley (1968), and McElhinny (1973).

Specifically what kind of tectonic information can be obtained from the paleomagnetic data? If paleomagnetic studies are done at several locations on a continent using rocks of the same age, an accurate location for the apparent ancient or paleomagnetic pole can be determined. This pole position may indeed not coincide with the present geographic pole of the earth. However recall that one of the basic assumptions normally made is that the geomagnetic poles have, on the average, coincided with the geographic pole of the earth. If this assumption is true, and if the apparent geomagnetic pole, as determined from the paleomagnetic study of the rocks, is at a different location, the continent must have moved about on the surface of the earth.

Where was the continent earlier? Nothing can be said about the longitude since the magnetic field of a dipole is symmetric with respect to the longitude. However the magnetic field direction for different latitudes is different as shown in Figure 8a. This means that from the direction of the "frozen in" magnetism in the rock one can get a good idea of the latitude of the rock at the time of the rock's formation. A very nice example of this involves India. The Jurassic rocks there have an inclination direction as shown in Figure 8b. This means that, if the geomagnetic field has always been dipolar, the Jurassic rocks of India must have been at a much more southerly latitude when formed. Figure 8c shows how India must have moved with time if the assumptions of paleomagnetism are true. If the geographic and geomagnetic poles are assumed to have always coincided, at least approximately as at present, the ancient magnetic poles for all continents should have been at the same location for all continents. One way to use this information is to calculate the paleomagnetic poles for similar aged rocks from all the continents. Then we could try to move

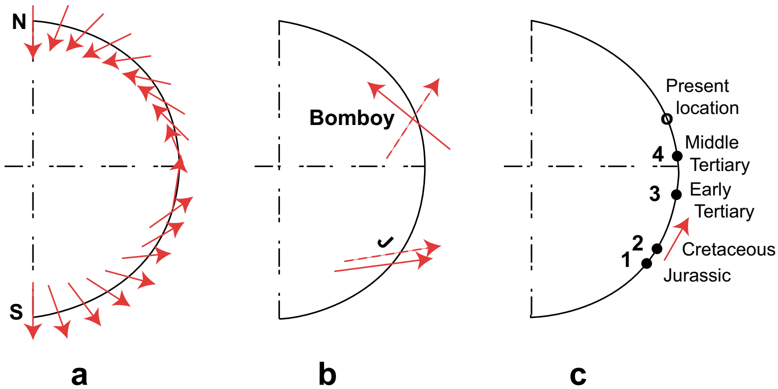

FIGURE 8. a) Magnetic inclination as a function of latitude. b) Jurassic position and paleomagnetic direction of India compared to present values. c) Positions of India as a function of time as inferred from paleomagnetic data. (Redrawn from Takeuchi & Uyeda 1967).

FIGURE 9. Carboniferous paleomagnetic pole positions for a Pangea reconstruction of the continents. NA = North America, EA = Eurasia, Af = Africa, SA = South America, Au = Australia, In = India. (After Seyfert & Sirkin 1979).

all the continents about such that the poles from all the continents are in the same small region on the surface. An example of this is shown in Figure 9. When this is done for Carboniferous, Permian, and Triassic age rocks we find that we can, within the constraints of the paleomagnetic data, fit all the continents into a single super continent usually called Pangea. The general thrust of plate tectonics is that this super continent gradually split up into the continents that we have today.

Many other kinds of paleontological, mineralogical, and paleoclimatic data seem to support these ideas concerning plate tectonics. The theory of plate tectonics has risen rapidly to the position of almost universal acceptance by geologists and geophysicists. To put this in perspective for the discussion of this paper, we should say that paleomagnetic data had a key part in this rapid revolution in geologic thinking and consequently must be taken seriously by creationists as they try to understand the history of the earth.

Where do creationists find themselves with reference to the theory of plate tectonics? Perhaps the embarrassing question is: Have creationists seriously studied these theories and seriously tried to pick the best points with which to build a coherent history of the earth? The answer, unfortunately, would seem to be negative.

IV. IMPLICATIONS, QUESTIONS AND CONCLUSIONS

This paper was written with several goals in mind. The first goal was to provide the reader with a fairly complete introduction to this fascinating and yet challenging area of geophysics. For those readers with professional interests that could make use of paleomagnetic data, it is hoped that these two articles can provide enough background to enable them to intelligently read and utilize the paleomagnetic literature related to their discipline. In addition to just providing information, it is hoped that these articles will challenge some readers to seriously study paleomagnetism and then try to find meaningful ways to interpret the data so as to enhance their understanding of God's revelations concerning the wonderful world he has made.

Paleomagnetism, as we have seen, can provide a wealth of information about the history of the earth. How does one interpret this data? What are the implications? The answers to these questions depend on one's philosophical perspective. Indeed, no scientist comes to the study of nature without some philosophical framework within which to work.

The "standard" evolutionary geological and geophysical interpretation of paleomagnetic data is that reversals of the earth's field occurred many times during the last several hundred million years. This data has, in fact, been compiled and refined into what is referred to as the magnetic reversal time scale. Furthermore it is generally accepted that the remanent magnetization directions in rocks can be used to support the theory of plate tectonics over the past several hundred million years of presumed geologic time.

On the other hand, Biblical creationists study nature using models that generally call for a much shorter age for life on earth, and in many cases for the earth itself. This apparent age discrepancy means that the Biblical creationist must ask several important questions concerning paleomagnetism. It seems that paleomagnetism, plate tectonics and other geophysical areas of study pose significant problems to the Biblical creationist above and beyond the usual concerns about radiometric dating. It would seem that the following areas of concern need to be given intense study by properly qualified creationists.

1. Are the various lines of evidence for global scale reversals of the earth's magnetic reversals as strong as claimed by most scientists? Are there other possible and feasible mechanisms that might reasonably account for this apparently global phenomena?
2. If the reversals did indeed take place, what fundamental physical constraints are there on how fast the reversals can take place?
3. How reliably do the extensively used potassium-argon radiometric dates, that are used to calibrate the reversal time scale, indicate real time? How close and necessary are the ties between the standard geologic column and the reversal time scale? Is it reasonable to significantly compress the reversal time scale on a worldwide basis?
4. Are there sound approaches for revising the plate tectonic theory so that it would be more acceptable for creationists who try to support a short chronology?
5. What fundamental physical constraints can be put on how fast the plates can separate?
6. Is there a correlation between core processes, such as the geomagnetic dynamo, and mantle processes such as plate tectonics?

These questions point out a definite need for creationists to look deeper inside the earth. Besides just looking at the crust, they need to be concerned with the processes going on in the mantle and core if they are going to attempt to answer the questions above. Only by doing this will creationists be able to ascertain the fundamental physical constraints that these processes place on their speculations concerning the history of the earth. Geophysicists, in particular, have significant contributions to make in the study of the available data and in the development of creationist theories concerning the history of the earth and the interior of the earth.

Scientists, theologians, and others tend to concentrate so much on their particular area of interest that they neglect to *synthesize* information from their disciplines with data from other areas. *Synthesis* is never easy because it necessitates both good communication between disciplines and a knowledge of subject areas outside narrow areas of specialty. Creationists, however, must utilize the input from a broad range of disciplines if they are to carefully and intelligently construct a viable model for the history of the earth and life on earth.

Hopefully, greater utilization of a broad data base will help creationists avoid the tendency to concentrate on various “exceptions to the rule,” even though these exceptions may be supportive of the creationist point of view. Indeed, exceptions are useful pieces of data that need to be studied, but all too often it seems that creationists completely ignore or easily dismiss the great bulk of data available for study. For this reason their attempts to explain the physical world are often seriously hampered. In addition, this frequent neglect of the great body of available data puts any theory proposed by creationists under immediate suspicion by the scientific community. *In short, creationists need to do a better job of doing their homework*. Balance, thoroughness, and completeness are essential to any endeavor and certainly the study of earth history is no exception.

Can creationists come up with a serious global tectonic model for earth history that fits *all* the evidence from nature *and* from revelation? Since nature and revelation have the same author, shouldn’t there ultimately be some way of harmonizing the frequent apparent conflicts between them? Ultimately, the answer must be yes. Certainly progress can be made, but it will require a great deal of creativity and careful study to come up with new approaches to the significant problems that exist. It is somehow particularly uncomfortable for creationists to cope with unanswered questions and with data that doesn’t fit into their present models of the history of the earth. Creationists need to learn to live with disagreements between what nature and revelation seem to be telling them. They also need to realize that these experiences are crucial to the ongoing process of studying the world in order to obtain deeper insights and bring harmony between their understandings of revelation and nature.

It seems fitting to close with the following quote from Van der Voo (1979):

> *... throughout this review, uncertainties and unresolved problems have been identified. It is impossible to speculate which of these problems will be solved in the near future or which will have to wait another decade. One thing is certain: there is plenty of work that remains to be done.*

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LITERATURE REVIEWS

Readers are invited to submit reviews of current literature relating to origins. Mailing address: ORIGINS, Geoscience Research Institute, 11060 Campus St., Loma Linda, California 92350 USA. The Institute does not distribute the publications reviewed; please contact the publisher directly.

LIFE FROM SPACE

LIFE ITSELF. Francis Crick. 1981. NY: Simon & Schuster. 192 p.
EVOLUTION FROM SPACE. Fred Hoyle. 1982. Wales: University College Cardiff Press. 30 p.

Reviewed by Richard D. Tkachuck, Geoscience Research Institute

The formation of living systems on this planet has been discussed at length from both creationist and evolutionary perspectives. To the creationist, God is plainly and simply the source of life. To the evolutionist who excludes the supernatural from his world view, the explanation of the origin of life in all its complexity must be described in terms of natural forces at work today. Early in this century A. I. Oparin performed experiments in which two or more polymers (proteins, lipids or carbohydrates) were shaken in water. When the resulting solution was examined under the microscope, small spherical droplets called coacervates were seen. When viewed more closely, these droplets seemed to have a membrane structure similar to that found in living cells. Oparin proposed that coacervates could have been the beginning structures of early life forms.

Since Oparin started with proteins in his experiments, it was important to determine how proteins could have formed. In the 1960s Fox simulated supposed prebiotic conditions by heating amino acids on hot rocks. Protein-like compounds were made, and when these were added to water, microspheres sometimes formed. When this information was coupled with the experiments of Miller and Urey in which amino acids, nucleic acids and sugars were formed from simple compounds such as ammonia, water, methane, hydrogen, etc., in the presence of electrical discharge, it seemed that the mechanics describing the formation of life would soon be known. The literature of the 60s and 70s dripped with this optimism.

Recently, new voices have been heard in the evolutionary scenario which strangely echo the creationist call that life is just too complex to have been formed by random interactions of chemicals in some primordial organic swamp. Interestingly, these new voices do not come from the lunatic fringe within the scientific community, but rather from authorities of the stature of Nobel Laureate Francis Crick and Sir Fred Hoyle. Hoyle has used the metaphor of an explosion in a junk yard producing a Boeing 747 to show how improbable is the spontaneous generation of living from non-living material. These men are suggesting that life is just too complicated to have formed within the limited portion (2-3 billion years) of earth history in which temperatures and conditions would permit life to exist.

In his recent book, *Life Itself*, Crick devotes the first half convincing his audience that the probability of life forming spontaneously on this earth is vanishingly small. He notes, for instance, that the probability of a protein randomly forming in the proper sequence is about 1 chance in 10^{260}. When one considers that the total number of elementary particles in the *universe* is about 10^{80}, one can see that such probabilities are impossibly small. Using metaphors seemingly directly out of the creationist literature, Crick says, “There is, in fact, a vanishingly small hope of even a billion monkeys, on a billion typewriters, ever typing correctly even one sonnet of Shakespeare’s during the present lifetime of the universe.” He then attempts to inject hope into the situation by saying that some of the paragraphs typed would contain meaningful statements and that these are the stuff for the initial stages of the formation of life. He then proceeds to define the requirements of a living system: replication, energy, information transfer from one generation to another, etc., and discusses the difficulties these requirements present in the formation of life.

Other problems also surface. Did the primitive atmosphere of the earth contain oxygen? In order for the Miller/Urey experiment to work, none must be present. Yet much data suggest that oxygen was present. Crick discusses the difficulty of identifying the first replicating molecule and chooses RNA as his favorite. He then builds a living system upon its foundation. Still, the chances of life starting spontaneously on earth are considered to be vanishingly small. So small, in fact, that he is convinced it did not happen here. But if not on earth, then where? On some other planet?! Yes, life evolved on some faraway planet. He argues that since the earth has too short a history for life to develop, it must have developed on some planet in a solar system which was formed several billion years earlier than ours. If, he reasons, numerous planets in the universe have conditions favorable to the formation of life, then, given enough time — somewhere out there — the formation of a living system almost becomes inevitable.

But if life started on some other planet, how did it arrive here? With this question Crick rises to his speculative best. He proposed that life began somewhere else in the universe and evolved to a much higher technical level than is now present on earth. He next suggests these life forms are now sending rockets containing primitive life forms (perhaps bacteria or blue-green algae) throughout the universe, spreading the seeds of life hither and yon. Crick even describes the rocket's design and postulates the conditions necessary for successful re-entry into our atmosphere.

In a lecture given at the Royal Institution, Fred Hoyle also postulates that life came from elsewhere. In fact, he thinks that life-forms are still raining down upon earth and contaminating it. He proposes that certain structures in meteorites might be the fossils of bacteria, and perhaps the sudden spread of virus diseases may be the result of a massive contagion influx from space.

Other authors have looked at stromatolites, life-like structures in Precambrian rocks, and have concluded that their date of origin postulated by radiometric dating to be one and a half billion to two billion years ago precludes the possibility of their development on this earth.

Have the suggestions of Crick and Hoyle helped creationists win the war over the origin of life? Although there are allusions to metaphysical ideas in the professional literature that deal with the origin of life, the concept of a Creator-God as described in Genesis is not included among the possibilities. But it is interesting to note that the song sung by creationists about the complexity of life on earth is being chorused by others, admitted in *piano* tones. Although the rhythm, harmony and melody certainly are different, the careful listener will recognize that the words are remarkably similar.

GENERAL SCIENCE NOTES

HOW SOLID IS A RADIOISOTOPE AGE OF A ROCK?

By R. H. Brown, Geoscience Research Institute

The steady spontaneous transmutation of a radioactive isotope into a stable daughter isotope provides a means for determining the length of time the accumulation of daughter atoms has been maintained in association with its parent source — the radioisotope age of the mineral that contains the parent and daughter atoms. It is reasonable to expect that a radioisotope age for a mineral formation should specify the length of time that formation has been in existence, and also the minimum age of any fossils that may be associated with it. On this basis a quantitative geologic time scale has been developed (Harlan et al. 1964, 1971).

To be suitable for geologic time scale calibration a radioisotope age must meet three requirements: chemical isolation, stratigraphic control, and biological control. To meet the requirement of chemical isolation there must be no indication that either radioactive parent atoms or daughter type atoms have been transferred into or out of the mineral during the indicated time period. Diffusion due to heat, and solution or deposition due to contact with water can violate the chemical isolation requirement. Stratigraphic control requires that the mineral sample come from a clearly defined geologic formation which has an expected age range that is consistent with the radioisotope age of the sample. For example, a radioisotope age of either 100 million years (m.y.) or 3000 m.y. would not be accepted as the "true" real time age of a rock obtained from a geologic formation that is unquestioningly of Cambrian classification, regardless of how precise and accurate the isotope determinations may be. To be desirable as a calibration of the phanerozoic time scale, a radioisotope age should also meet standards of biological control, i.e., it should relate to a mineral sample that is associated with the proper index fossils for the age in question. While biological control and stratigraphic control are interrelated, applying each explicitly makes a more stringent requirement. The reader who is interested in the stance of the professional literature on these criteria should consult W. B. Harland et al. (1964), George V. Cohee et al. (1978), and Giles S. Odin (1982).

Lack of chemical isolation generally (but not always) has been expected to produce radioisotope ages that are most likely to be younger than the correct real time age, particularly when the daughter isotope is highly mobile, as is the case for the inert gas (argon) produced by the radioactive decay of potassium. Radioisotope ages that are younger than what would be expected on the basis of stratigraphic control and biological control are usually accounted for as evidence that chemical isolation has not been maintained.

Radioisotope ages that are older than allowable on the basis of stratigraphic or biological control are explained as due to retention of daughter isotopes from a state in which the mineral components existed previous to the association in which they are now found. Brooks et al. (1976) list 22 examples of rubidium-strontium (Rb-Sr) ages ranging from 70 million to 3300 m.y. which are stratigraphically constrained to represent volcanic activity within the last 65 m.y. (late Flood and/or post-Flood volcanic activity, according to conservative Biblical creationist interpretations of geology). Five continents are represented in this set of examples. Othman et al. (1984) have recently reported an extensive study of 32 typical worldwide granulite samples that have geologic age assignments ranging from 20 to 3100 m.y., yet have samarium-neodymium (Sm-Nd) radioisotope ages that in most cases are greater than the geologic ages and range from 851 to 3744 m.y. Rb-Sr ages for this sample set range from 596 to 3650 m.y. Allègre & Rousseau (1984) report Sm-Nd ages ranging from 1870 to 3780 m.y. for a set of seven Australian shale samples that have geologic age assignments ranging from 200 to greater than 3300 m.y.

In contrast with the earlier perception that potassium-argon (K-Ar) ages for glauconites are probably less than the formation age, it has now been established that K-Ar ages for a glauconite should be considered suspect as too old, due to possible incorporation of radiogenic argon along with potassium at the time of glauconite formation (Odin & Dodson 1982). Volcanics associated with organic material that can be dated by radioactive carbon generally have a K-Ar age much greater than that given by radiocarbon for the eruption (Stapor & Tanner 1973). A prime example is the 485,000 K-Ar age for volcanics from a Mt. Rangitoto eruption which destroyed trees less than 300 C-14 years old (McDougall et al. 1969).

The brief review reported in this article should make it apparent that while techniques for the determination of radioisotope age are precise and accurate, the interpretation of a radioisotope age in terms of real time is subjective and will reflect the biases of the interpreter. For illustration, consider the 12.3 to 519 m.y. K-Ar ages obtained for glauconitized coprolites from the Gulf of Guinea (see Odin & Dodson 1982, p 286). A 12.3 million year age for a mineral presumed to have formed 500 m.y. ago could be explained as the consequence of argon loss caused by heating in a recent portion of the presumed 500 m.y. existence of the specimen. The 12.3 m.y. age also could be explained on the basis of radiogenic argon incorporation together with potassium in a crystallization that occurred only 4000 years ago. And the 12.3 m.y. could be considered to be a "correct" indication of the time this glauconite has been in existence (Odin & Dodson only presume that these coprolites formed "less than 100,000 years ago"). Each of these interpretations is equally valid scientifically until measured against definitive evidence to the contrary. One's theoretical biases will determine what he allows as definitive evidence, and how he treats this evidence. Returning to the title for this review, it can be said that the real time interpretation of a radioisotope age for a rock is no more solid than the theoretical perspective of the interpreter.

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