

Origins

Volume 24 Number 1 1997

Special Edition: The Yellowstone Petrified “Forests”

by Harold G. Coffin

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Cover Pictures

Front Cover: Specimen Creek Ridge, where over twenty levels of fossil trees can be readily seen. **Back Cover:** Small fossil tree (28 cm diameter) extending through two volcanic ash levels. Photographs by Clyde L. Webster.

FOREWORD

Very few things capture one's imagination quicker than finding a fossil while on a nature walk or even a walk through a museum. There is an almost mystical drawing power associated with fossils. Questions of What? Where? When? Why? and How? immediately flood one's mind, and in some cases may remain there forever, as the relic from the past is contemplated.

This booklet — *The Yellowstone Fossil “Forests”* — is the outcome from Dr. Harold Coffin's lifelong quest for answers concerning not just one fossil but literally a whole “forest” of fossils, the fossil forests of Yellowstone National Park (YNP). Through the years Dr. Coffin has pioneered research into the various fossil areas of YNP looking for clues that would help him unravel the questions of origins for these magnificent fossil trees. He has been responsible for introducing numerous other investigators to the “intrigue” of the forest, always seeking, always asking, never leaving one stone left unturned, if that stone might help answer the questions of the “Fossil Forest.” Dr. Coffin's quest for answers has taken him from the tops of high mountains, to encounters with grizzly bears, to walks into the destruction zone of Mount Saint Helens. His drive for answers is equaled only by the prospector bitten by the gold bug or the diver searching for the lost Spanish galleon.

As you read through Dr. Coffin's narrative on the Yellowstone Fossil Forest it is my wish that you will not only become enthralled with the *Fossil Forest* but that you will also recognize and appreciate the careful scientific work that has brought Dr. Coffin to his conclusions.

There is still a list of unanswered questions that continue to beckon researchers for answers. If you feel a desire for adventure, why not consider the intrigue of a fossil forest?

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THE YELLOWSTONE PETRIFIED “FORESTS”

Harold G. Coffin

I. INTRODUCTION

The Petrified Forests of Yellowstone National Park in Wyoming and Montana are perhaps the most spectacular and extensive petrified forests in the world and have stimulated scientific investigations for over 100 years.

The first historical records of the petrified trees of Yellowstone National Park came from trappers in the first half of the 19th century, some of whom developed exaggerated stories about the Yellowstone country and about the petrified trees.¹ In 1878 and 1879, W. H. Holmes gave us the first scientific accounts of these unique forests.²

II. GENERAL DESCRIPTION

The classic petrified forests are found on Specimen Ridge and Mt. Amethyst, both located in the northeast sector of Yellowstone National Park (Figure 1).³ Other fossil forests in the northeastern part of the park are found in the Cache Creek Area, and on both sides of Soda Butte Creek and



Figure 1. Specimen Ridge from the Lamar Valley. Note petrified trees left of center on the sloping ridge below the cliffs.

the Lamar Valley. The most spectacular of the fossil forests can be found along the drainage of Specimen Creek in the northwest corner of the park (Figure 2). In addition, significant petrified forests are located north of the



Figure 2. One of the spectacular exposures of petrified trees in the Specimen Creek area in the northwest corner of Yellowstone National Park.

park in the Tom Minor Basin and surrounding mountains, as well as south of the park in the Stratified Primitive Area north of Dubois, Wyoming (Figure 3).⁴

A. STRATIGRAPHY

The Eocene to Oligocene deposits containing the fossil forests consist mainly of multiple layers of volcanic conglomerates and breccias (angular pebbles and boulders) interspersed with volcanic ash and occasional flows of basalt. This series of volcanic tree-containing deposits rests on various surfaces, although most often they overlie Cambrian or Mississippian beds. In some areas younger welded tuffs (volcanic ash fused into hard rock by heat) cover the breccias and conglomerates. Extensive erosion has exposed more than 1000 vertical meters of these volcanics and has created a rugged topography. Near the northeast boundary of the Park and eastward, a sequence of beds down to the Lower Cambrian have been disrupted by a major horizontal movement of strata called the Heart Mountain Thrustfault.⁵ Mountain glaciers, now absent, scoured the entire Yellowstone area and rounded some of the valley floors.⁶ The large Yellowstone caldera, now largely filled with

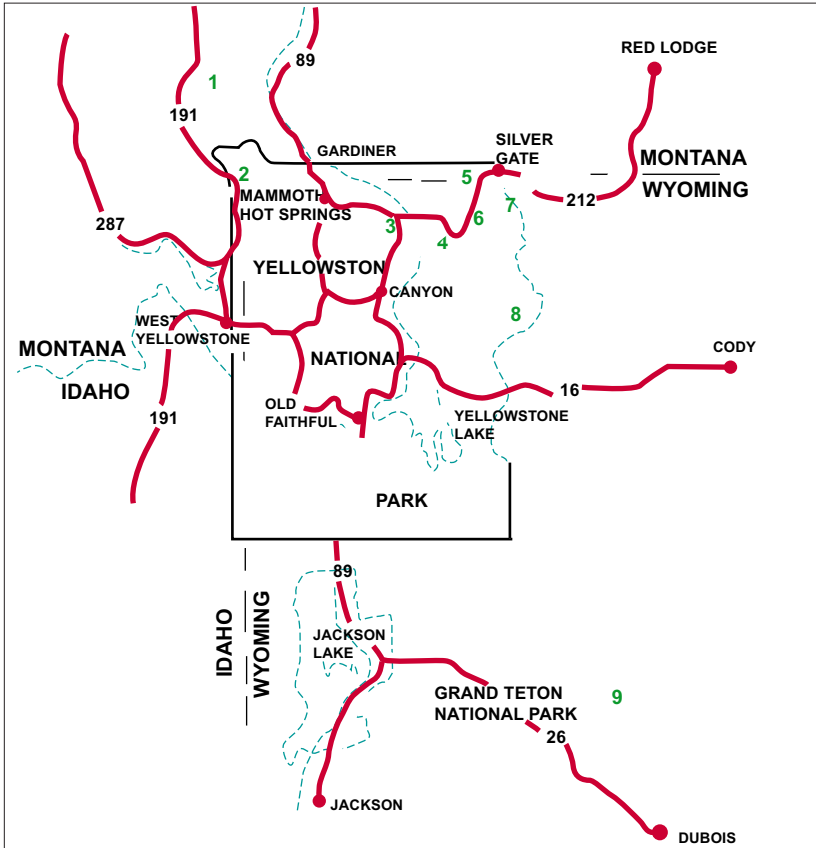


Figure 3. Map of Yellowstone National Park, Teton National Park, and surrounding areas showing the locations (numbers 1 to 9) of several petrified forests.

welded tuffs, lies south of the petrified forests of the Lamar and Soda Butte Creek valleys.⁷ To the west the Yellowstone volcanics lie adjacent to the uplifted Precambrian and Paleozoic formations of the Madison Range.

B. SUCCESSIVE LAYERS

Petrified wood and trees are found in numerous locations around the world, but the Yellowstone Petrified Forests are unusual because of the many levels stacked one upon another. In 1960 Erling Dorf of Princeton University studied the Amethyst Mountain Fossil Forest and counted 27 levels.⁸ I have plotted 31 levels on Mount Hornaday on the west side of the Soda Butt Creek Valley (Figure 4). The greatest sequence of superimposed fossil forest levels

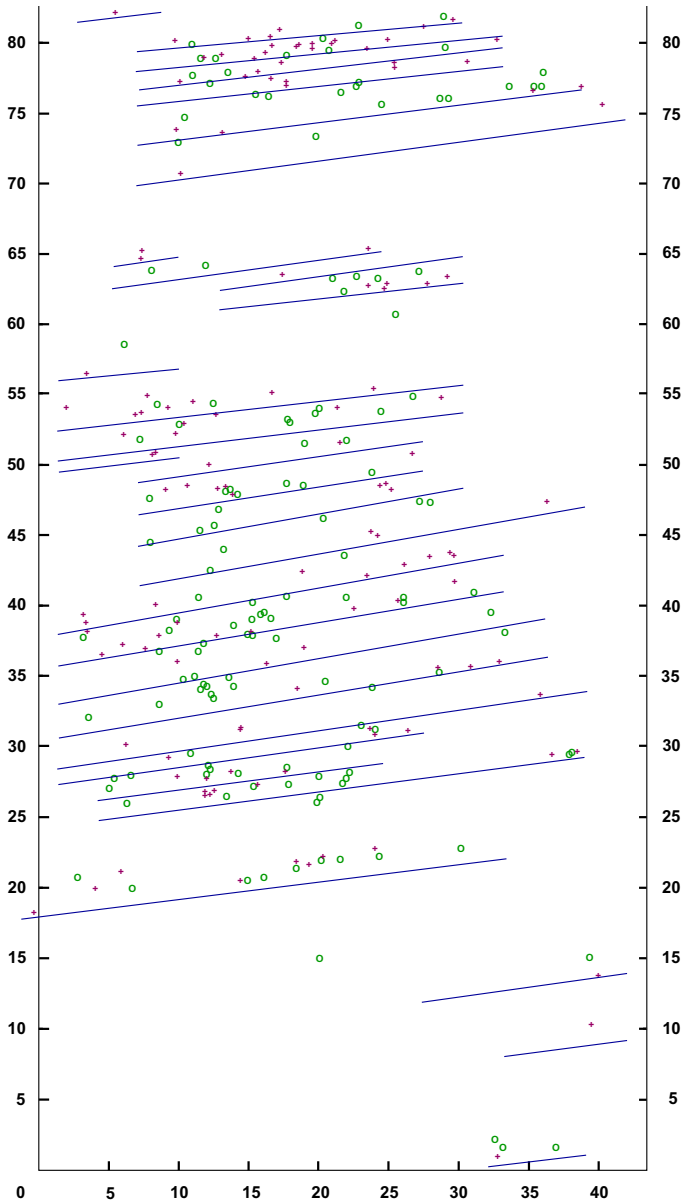


Figure 4. Plot of Mt. Hornaday Petrified Forest with 31 levels. Several more levels seen in the cliffs below were inaccessible. The solid lines are organic levels or levels upon which upright trees stand. Symbols: \circ = horizontal trees; $+$ = upright trees.

TABLE 1. NUMBER OF LEVELS FROM SIX MAJOR SITES

SITE	UPRIGHT TREE LEVELS	ORGANIC LEVELS	TOTAL
		(No upright trees visible)	
Cache Creek	13	12	25
Fossil Forest	32	9	41
Mt. Hornaday	37	5	42
Specimen Creek	48	17	65
Mt. Norris	5	0	5
Specimen Ridge (East shoulder)	11	3	14

is located in the Specimen Creek area where 65 or more levels can be counted (Table 1). Other areas with fewer levels are Mt. Norris on the east side of Soda Butte Creek Valley (5 levels), Specimen Ridge flanking the Lamar Valley (15 levels), and Cache Creek (26 levels).⁹ Multiple levels are also seen at Miller Creek northeast of the Lamar Valley, in Tom Minor Basin (including Ramshorn Peak), and in the Stratified Primitive Area. Scattered trees and petrified wood can be found throughout the northern region of Yellowstone Park and other surrounding areas.

III. DESCRIPTION OF THE PETRIFIED TREES

Both upright and horizontal trees are found in the deposits, but the percentage of upright trees varies from locality to locality (Table 2). For three levels of the Fossil Forest (Amethyst Mountain) with 208 petrified trees, only 28% are upright. On the other hand, the Petrified Tree area near Roosevelt Lodge exhibits 30 upright out of a total of 40 visible petrified trees (75%). Individual levels may be even more variable — some with all trees horizontal or all upright. These figures are based upon trees revealed in the irregular cross-section exposed by the eroded cliff faces. If a surface view of the total fossil forest for any particular level were possible, the percentages for standing and fallen trees could be different.

A puzzling feature of all the petrified forests in and around Yellowstone Park is the absence of diagonal or leaning trees. I know of only three locations (two with one large tree each, and the other with three or four small trees) where leaning trees can be seen (Figure 5).

The upright trees may range in height from just above ground level to over 6 m. Sometimes they look like old dead snags, and close examination is needed to determine that they are petrified.

Most of the wood tissue of the Yellowstone forests is well preserved, even though limbs and bark are usually absent. Roots are present and often

TABLE 2. NUMBER OF TREES FOR SITES ACTUALLY PLOTTED

SITE	NUMBER ERECT	NUMBER PRONE	PERCENTAGES
Specimen Creek (Levels 33-37)	50	20	71/29
Mt. Hornaday	157	173	58/52
Fossil Forest (3 levels only)	58	150	28/72
Specimen Ridge (East shoulder)	57	26	69/31
Petrified Tree ¹	30	10	75/25
Mt. Norris	29	31	48/52

¹ Petrified forest on the ridge above the fenced petrified tree
(accessible by automobile) east of Tower Junction.



Figure 5. A green stick fracture or leaning tree seen in the Tom Minor Basin north-west of Yellowstone Park. Note the absence of roots on the stump.

can be seen extending a short distance from the bases of the petrified stumps. Occasionally stumps and logs show driftwood-like abrasion or broken and reduced root systems.

The tops of many stumps terminate at or just below the next higher organic level. A few penetrate into the next overlying level and may overlap any trees that might arise from that level (Figure 6). When visible, the original broken top of the stump usually is abrupt and jagged. Despite this evidence of violent breakage, green stick fractures are almost unknown (note Figure 5 for a rare exception). Horizontal logs found near the broken tops of erect stumps never appear to belong to the stump as determined by size, rings, or species. Careful examination of the top few centimeters of the broken tops of erect stumps sometimes shows the wood tissue to be twisted and smashed, not from the breakage of the tree trunk, but from subsequent abrasion, perhaps by rocks and colliding trees.

Some observers have suggested that the petrified trees originally grew on the hillside and thus give the impression of multiple layers of trees one above another. This opinion cannot be substantiated. Trees growing on a



Figure 6. Overlapping trees in the Specimen Creek Petrified Forest. The larger tree arises from a lower level and overlaps the base of the smaller tree. Some time after this picture was taken, the smaller tree fell from its perch into the canyon below. This photograph first appeared in: Coffin HG 1983. Origin by Design. Washington DC: Review and Herald Publishing Assn., p 136.

hillside have roots extending up and down slope. Such root arrangement was not observed for any of the petrified stumps. The flat spread of the roots of the petrified stumps indicates that they grew on a relatively flat surface. Furthermore, the surfaces on which the trees stand, which can be traced in gullies back into the mountain, deviate from horizontal only by 7° or less.

A. TAXONOMY

The original identification of fossil trees and plants was based largely on leaves and needles.¹¹ Identifications of fossil wood and pollen have increased the number of plant species to over 200.¹²

Table 3 lists identified woods from the Specimen Creek Petrified Forest. The most abundant trees are sequoia. Pines are second in abundance. Deciduous trees are well represented in some areas by sycamore leaves. Wood of angiosperms (most deciduous trees) appears to be less common but is not rare.¹³

TABLE 3. FOSSIL PLANTS OF YELLOWSTONE: A PARTIAL LIST *

Abies	fir	Juglans	walnut
Acacia	acacia	Larix	larch
Acer	maple	Laurus	laurel
Aralia	spikenard	Magnolia	magnolia
Arctostaphylos	bearberry	Myrica	bayberry
Artocarpus	breadfruit	Pandanus	screw pine
Betula	birch	Persea	bay
Carya	hickory	Pinus	pine
Castanea	chestnut	Platanus	sycamore
Castanopsis	chinquapin	Quercus	oak
Cercidiphyllum	katsura	Rhamnus	buckthorn
Cinnamomum	cinnamon	Salix	willow
Comus	dogwood	Sapindus	soap berry
Corylus	birch	Sequoia	redwood
Cycad	sago palm	Sparganium	bur-reed
Euonymus	staff tree	Thuja	cedar
Ferns (several species)		Tilia	linden
Ficus	fig	Ulmus	elm
Fraxinus	olive family	Viburnum	arrowwood
Horsetails (several species)		Vitis	grape
Hydrangea	syringa		

*From Dorf 1960, and Fisk 1976

Note the wide range of habitats and ecological requirements. The fossil wood and leaves have been identified to modern genera that live in widely differing habitats and environments.

Upright stumps range from broom handle size to over 4 m in diameter (Figures 7 and 8). Some stumps consist of little more than a mat of roots, whereas others include lengthy portions of the trunk. What may well be the tallest erect petrified tree in the world (estimated at approximately 15 m) is located at the base of Ramshorn Peak in the Tom Minor Basin (Figure 9).

B. ORIENTATION OF LOGS AND STUMPS

The alignment of the fallen petrified trees on any particular level is parallel (Figure 10).¹⁴ The compass direction of these aligned trees is not the same for all levels. Wind and gravity could cause such alignments, but these forces may not be the factors involved. The compass directions of the long axes of the cross sections of the upright stumps that are not a perfect circle are often also parallel to the lay of the fallen trees.



Figure 7. A beautiful petrified tree (4.5 m high) on the slopes of Specimen Creek Petrified Forest.

C. DENDROCHRONOLOGY

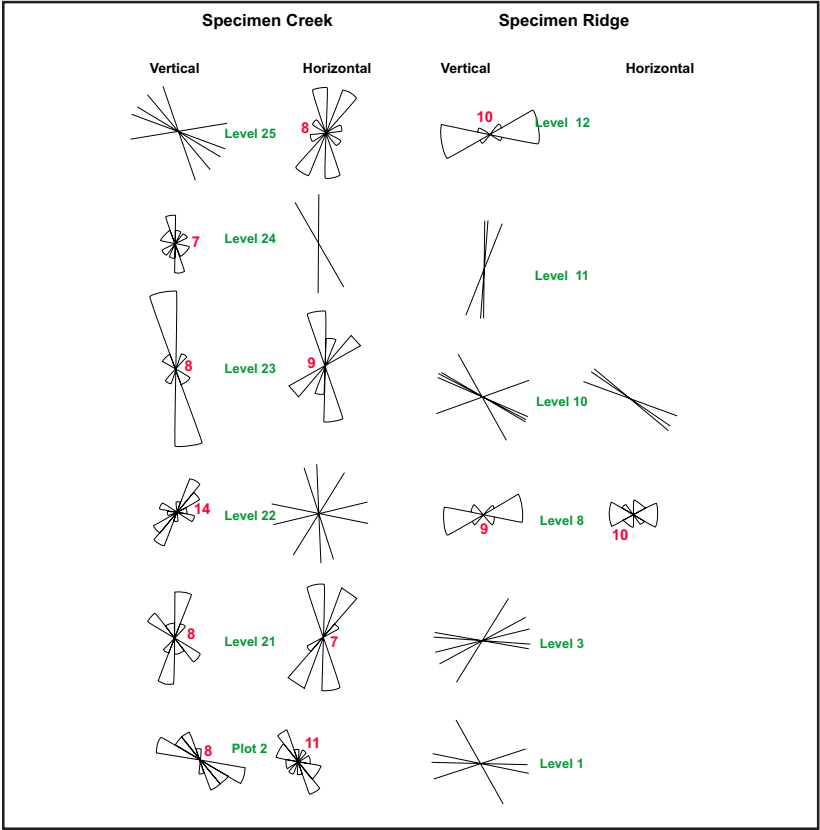
In 1929-1930 A.E. Douglas, a pioneer in dendrochronology, was unable to cross-match the rings of the Yellowstone petrified trees on Specimen Ridge.¹⁵ Little additional dendrochronological work has been done on petrified trees until recently. In 1979 and 1991 Michael Arct located several small trees in the Specimen Creek forest that had similar bands of distinctive anomalous growth-ring patterns.¹⁶ Another report claims to cross-match two trees on the same level on Specimen Ridge.¹⁷ Because of the good preservation of the wood tissue, rings are clearly visible and often reveal



Figure 8. A small petrified tree that arises from a thin organic level. Note the coarseness of the sediments surrounding it. This is typical Yellowstone volcanic breccia.



Figure 9. A magnificent petrified tree (nearly 15 m tall) located on the lower slopes of Ramshorn Peak in the Tom Miner Basin. This may be the tallest standing petrified tree in the world.



*Figure 10. Orientation of upright and horizontal petrified trees on several levels in the Specimen Creek and Specimen Ridge Fossil Forests. Note that the orientations of the cross-sections of the long axes of the standing stumps are usually similar to that of the horizontal logs. Each tree from levels with five or less specimens is represented by a line. Those levels with more than five trees are represented by a rose graph with the number of specimens indicated. Colorized edition of the illustration first appeared in: Coffin HG 1976. Orientation of trees in the Yellowstone Petrified Forests. *Journal of Paleontology* 50(3):539-543. Reprinted with permission of the Society of Economic Paleontologists and Mineralogists.*

variable widths suitable for tree-ring studies (Figure 11). However, sequoia is not the best tree for such studies because of tendencies for rings to split or merge from one side of the stump to the other. In Yellowstone the ring studies are not for the purpose of dating the trees but for comparison of trees from the same or different levels. Thus it may be possible to ascertain if they are in situ or transported from elsewhere.

IV. DESCRIPTION OF THE “SOIL” LEVELS

The petrified trees usually are seen to arise from layers or zones of ash containing needles, leaves and organic debris. These organic levels that look like the surfaces in which the petrified trees originally took root have been called soil levels or growing surfaces (Figure 12). Much of the discussion of these forests relates to the nature of these fine sediment layers (hereafter referred to as organic levels).¹⁰ Are these true soils that show mature time-dependent characteristics, or are they merely sediments containing organic matter that was transported and deposited rapidly?



Figure 11. An illustration of the good preservation of most of the Yellowstone petrified trees. This stump with variable ring widths is suitable for dendrochronological studies.

A. THICKNESS OF ORGANIC LEVELS

Sixty-five levels of organic matter on the slopes above Specimen Creek range from a trace to as much as 20 cm thick. The average thickness is close to 3 cm. These dimensions are for the total depth of the organic matter or “soil.” Of 130 different levels with upright trees representing several petrified forests, 24% contain no discernible organic matter. However, different sites vary widely. The number of levels without forest debris is 16 out of 37 (43%) for Mt. Hornaday, and 2 out of 48 (4%) for the lower 48 levels of Specimen Creek.



Figure 12. Most of the petrified trees arise from organic levels best seen on the right in this photo.

B. SOIL PROFILES

Cross-sections of true soils usually have an organic profile detectable as a downward color gradient from dark to light. There is a decrease in organic matter from the top downward. The top of the profile may consist of needles, leaves, etc., recently fallen and little changed; whereas the forest litter at the bottom of the profile has been changed by decay and chemical alteration until no longer recognizable. Such typical soil profiles are difficult to find for the Yellowstone Petrified Forests — one or two percent at the most.

Some of the organic levels have multiple bands of forest litter only a few centimeters apart. They may not contain visible petrified trees. Could the upper organic bands of these levels represent the leaf-fall zones associated with air-drop ash in volcanic eruptions? In such cases the lowest band would represent the true soil level, whereas the upper one(s) would result from physical and chemical stripping of leaves and needles from the trees by volcanic activity. These upper bands should not be growth surfaces unless no further ash accumulation occurred for many years and a new forest established itself on these levels. Study accompanying the survey of the complex Specimen Creek Petrified Forests failed to distinguish any significant differences between levels from which visible fossil trees arise and adjacent levels containing no visible upright trees. Levels both with and

without upright trees, and also organic bands within levels, were sampled and examined in thin-section studies. If leaf-drop zones are present, they are not readily apparent and cannot be distinguished from the other levels.

V. EVIDENCE FOR TRANSPORT OF THE “SOILS”

Since the time of Holmes (1879) these petrified forests have been interpreted as living forests that were buried by successive volcanic mud slides over many thousands of years. However, research within the past 30 years has unearthed facts that seem to indicate that the trees were somehow transported to their present locations. If the in situ model (trees in position of growth) is incorrect, what is the correct picture? What model better fits the available evidence?

Support for the transport model coming from a study of the organic levels deals mainly with their physical structure, organic contents and lack of weathering. Eight of the more important considerations are discussed below.

A. INSUFFICIENT ORGANIC MATTER

Many of the organic levels of the Yellowstone petrified forests are thin and contain insufficient organic matter to qualify as “soils.” Modern forests, with growing trees several meters in diameter, have deep humus floors unless they are growing on significant slopes. Often large petrified trees in Yellowstone sit on only a trace of organic matter. Other trees may arise from 2-3 cm of “soil” — far short of the amount expected from the age of the trees, based on study of modern trees of comparable species and size growing on a level forest floor.

B. ORGANIC AND INORGANIC SORTING

In this research, gross identification of the wood specimens in the organic levels was undertaken. Trees were classified as pine-type (resin ducts present), sequoia-type (no resin ducts), and deciduous (vessels present). Leaves and needles in the organic levels were identified using the same categories.

Taxonomic sorting of the constituents in the organic bands (needles and leaves not mixed together) was noticed early in the research. Under normal conditions leaves, needles, cones, limbs, bark, etc., fall as a well-mixed litter onto the forest floor year by year as the seasons pass and the trees grow. A flotation experiment involving aspen and poplar leaves and fir needles in a tank of water showed that the needles became saturated and sank to the bottom first. Thus flotation in water is a possible explanation for the observed taxonomic sorting in the “soil” levels.

Occasional organic levels from Specimen Creek Fossil Forest, and Mt. Norris and Miller Creek petrified forests show a relationship between the size of the ash sediment and the size of the organic material — fine sediments, fine organic matter, coarse sediments, coarse organic matter. The Eagle Creek Formation of the Oregon Cascades is a coarse volcanic sediment that contains many petrified trees similar to the breccias of Yellowstone. That these trees in Oregon have a similar origin and history to those of Yellowstone is a reasonable assumption. An example from an organic level from this Oregon formation shows similar size sorting of the inorganic particles among or between leaves (Figure 13).¹⁸ The leaves are seen in cross-section as long, somewhat undulating lines. The sediments show normal grading between the lines (grading from coarse to fine upward).



*Figure 13. Cross-section of an organic zone from the Eagle Creek Formation in Oregon. See text for discussion of similarities of this Oregon site with Yellowstone. Note that sediments are sorted between the deciduous leaves (dark wavy horizontal lines). This illustration first appeared in: Coffin HG. 1983. *Origin by Design*. Washington DC. Review and Herald Publishing Assn., p 143.*

C. ATYPICAL SOIL PROFILES

The organic levels associated with the Yellowstone petrified forests range from soil profiles typical of a true growing surface to reverse profiles; however, the majority 86 (71.6%) of 120 microscopic cross-sections through organic levels give evidence of water sorting. The rest, although not typical soil profiles, do not give clear evidence for either in situ or transported origins. The organic matter is usually randomly oriented (Figure 14). Ten percent of the organic cross-sections showed a reverse profile — more dense at the bottom and less dense toward the top.¹⁹ Sufficient water to rework the soil would also wash out growing trees, especially smaller ones. The water transport of both the "soil" and the trees is a more reasonable explanation.



Figure 14. A microslide of a thin section from an organic level in the Cache Creek area. The wavy dark horizontal lines are cross-sections of deciduous leaves. Note the following features: a) clean ash or sand between the leaves; b) sudden change in grain size between the upper and lower halves of the organic level; and c) different types of organic debris in the fine and coarse sediments.

Differential decay of the organic matter characteristic of a forest floor — better preserved leaves and needles on top and more decayed downward — is not seen.²⁰

The movements of volcanic lahars over the ground could produce atypical soil profiles, but, most likely, any soil profile would be eliminated. These anomalous profiles might be produced by small streams sorting and redepositing humus and forest litter. However, these organic levels are often widespread and uniform in thickness. This feature and the lack of evidence of widespread erosion would appear to eliminate small streams as agents for sorting and redepositing the organic matter.

Three transects (50 m long and 1 m wide) that I did in a Central California mature redwood forest revealed 135 sequoia cones and 79 other cones on the surface of the forest floor. Although sequoia cones are small and fragile, they do remain intact and visible for several months after falling. Sequoia cones are absent

or rare in the Yellowstone fossil forests despite the dominance of sequoia trees. Cones of any type are uncommon in the petrified forests (Figure 15).

In a mixed forest of redwood and deciduous trees such as exists in California, the redwood needles greatly predominate in the forest floor litter. For the area overshadowed by a tree, conifers appear to drop proportionately many more needles than do deciduous trees their broad leaves. In 1899, Knowlton remarked about the absence of needles in the organic levels associated with the large fenced petrified tree near Roosevelt Lodge in Yellowstone National Park.²¹ Our studies there are summarized in Table 4. There is a lack of taxonomic agreement between the dominant petrified trees in the area and the leaves and needles. One would expect to find great numbers of sequoia needles and some cones, since most of the upright trees are sequoia. However, large numbers of broad leaves and only a few pine needles



Figure 15. A rare but beautiful petrified cone (not Sequoia) found on Mt. Hornaday. This photograph first appeared in: Coffin HG 1983. Origin by Design. Washington DC. Review and Herald Publishing Assn., p 145.

are seen in the organic levels. Sequoia needles were rare or absent. Although petrified sycamore stumps are not common, leaves of sycamore are the most abundant broad-leaf fossils. Transport by water could bring about sorting and separation of plant parts.

TABLE 4. TAXONOMIC BREAKDOWN OF THE PETRIFIED FOREST 2 KM WEST OF ROOSEVELT LODGE, YELLOWSTONE NATIONAL PARK					
	SEQUOIA- TYPE	DECIDUOUS	PINE- TYPE	UNKNOWN	TOTAL
Petrified Trees	28	5	4	3	40
Organic Samples	0	75	27	0	102

If a volcanic mud slide buried only the lower parts of the trunks of the trees of a growing forest, the taxonomic composition of the new forest that grew on this new surface would be similar to the composition of the forest

that was buried. The cones, seeds, nuts, and fruits would fall from the unburied branches and foliage and repopulate the new surface with a similar forest. Such correlation between adjacent levels of the Specimen Creek Petrified Forest has not been found.²²

D. COMPLEX ORGANIC LEVELS

Most modern growing surfaces are a single layer of humus. I have seen multiple growing surfaces that were caused by shifting sand dunes. The organic levels of the Yellowstone Fossil Forests are more complex than would be expected to result from these modern processes. Flooding could cause humus to be redeposited, perhaps creating multiple levels. This is apparent especially in the Cache Creek and Specimen Creek petrified forests (Figures 16 and 17). Note the penetration of trees b and e through overlying organic zones as seen on a section of cliff face from the Cache Creek Petrified Forest. The Specimen Creek organic levels are even more complex.²³ Some of the organic levels associated with this forest split and recombine. Levels one and two are less than a meter apart. Such multiplicity and complexity of organic levels is beyond that reasonably expected for growing surfaces and are better understood as organic matter brought in and deposited by water.

E. PALYNOLOGY

Many genera are represented only by pollen, but this might be expected, since the wood samples have not received thorough study. On several levels in the fossil forests, wood and pollen have been identified. There is not a good match between the types of wood and pollen, as would be expected in an in situ forest. More difficult to explain, if the trees are in position of growth, are the cases represented only by wood or leaves. Trees with wind-transported pollen, such as walnut and sycamore, should have left a pollen record in the forest floor, but little or no pollen of these two has been found.

Modern forest floors contain pollen in abundance inversely proportional to the distance from the source trees — especially trees for which wind is the pollen-transporting agent. Research done on four levels of Specimen Creek Petrified Forest showed no positive correlation between fossil pollen abundance and the proximity of possible source trees.²⁴ No positive correlation was found to exist between the taxonomic composition of pollen of one organic level with that of levels directly above or below. Pine is a prolific pollen producer, but pine pollen was severely under-represented in three of the four forest levels analyzed. One of these three levels showed a severe under-representation of pine pollen and a severe over-representation of deciduous pollen compared to the number of petrified trees in these categories.

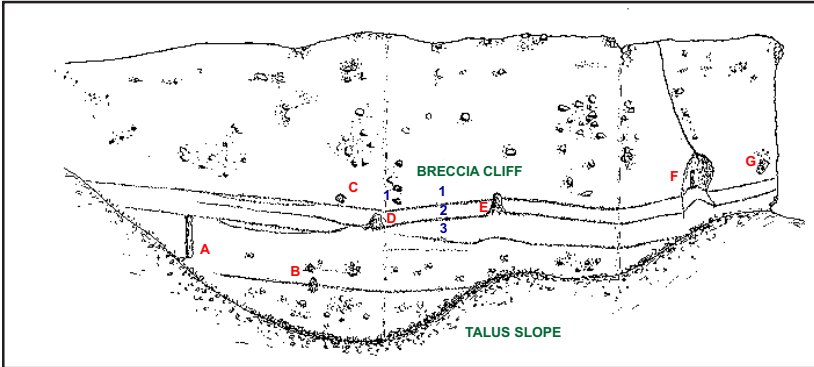


Figure 16. A section of a cliff from the Cache Creek Petrified Forest showing complex organic levels and associated trees. Modified from the illustration in: Coffin HG 1979. The organic levels of the Yellowstone Petrified Forests. Origins 6(2):71-82.

F. LACK OF EVIDENCE FOR WEATHERING

The formation of clay by the slow breakdown of feldspar and other minerals occurs during the normal maturation of soils. Analyses by x-ray diffraction and infrared scans were done on over 350 samples from 65 levels in the Specimen Creek area.²⁵ Nine bands of clay that included 7 organic levels were found distributed through this sequence of 65 levels. Clay content was up to 60%, but no typical soil profile was detected in any of the 7 organic zones. Horizontal sampling of two of the clay bands at 2.5-3 m intervals for 30 m showed a constant mineral distribution. Abundant unweathered feldspar is scattered throughout the Yellowstone organic levels, suggesting rapid burial and limited diagenesis or alteration of the feldspar to clay.

None of the 58 organic levels outside the 9 bands of clay contained detectable amounts of clay. The apparent absence of clay in the majority of levels (implying that normal weathering of soil did not occur) raises questions about the passage of long time intervals between levels. This datum also questions the validity of the assumption that the organic levels, upon which trees with hundreds of rings sit, represent true soils. Furthermore, the sudden abundant appearance of clay in a few horizontal bands that included both organic levels and layers of clay in the associated breccia beds between levels suggests transport rather than in situ formation of the clay minerals.

The rate of clay formation is variable, depending on climate and the parent rock. A sequence of mud slides on Mt. Shasta that occurred from 27 to 1200+ years ago does not show much increase in clay content with age.²⁶ In contrast, clay formed on the volcanic ash soils of the West Indian

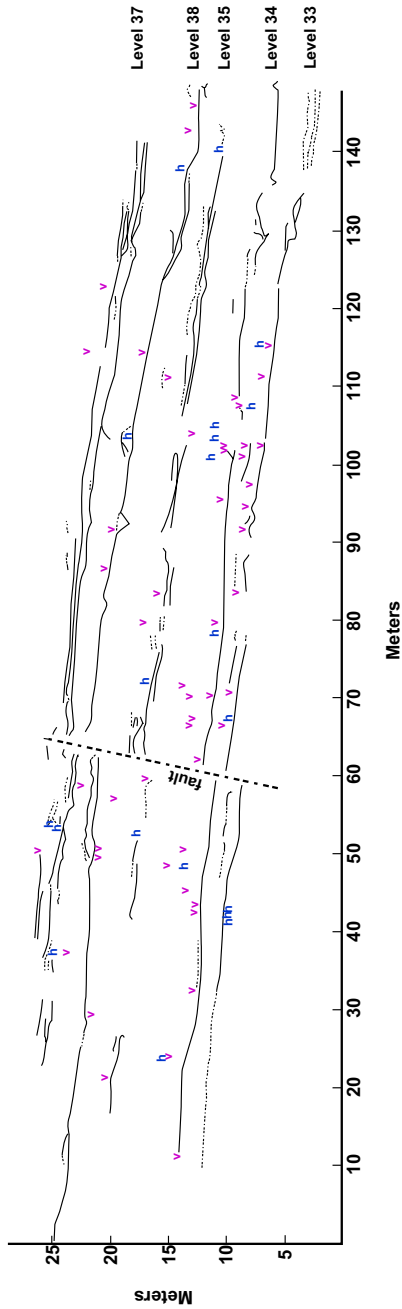


Figure 17. A plot of organic levels 33 to 37 in the Specimen Creek Petrified Forest. Note the irregularity and complexity of these levels. Symbols: v = vertical trees; h = horizontal trees. Modified from the diagram in: Coffin HG. 1983. *Origin by Design*. Washington DC: Review and Herald Publishing Assn., p 142.

island of St. Vincent at the rate of 0.5 m per 1000 years.²⁷ Some levels in Yellowstone with large trees (up to 5 m in diameter) would represent soil development well over 1000 years duration if the trees are in growth position. The mixed flora of the Yellowstone fossil forests suggests a climate closer to the tropics than to that of Mt. Shasta.

The tentative results from the study of clay suggest that no significant passage of time was involved in the formation of the organic levels of Yellowstone.

G ABSENCE OF ANIMAL FOSSILS

Despite much study of the Yellowstone Petrified Forests, no animal fossils have been found. Why are animal remains absent from the plant fossil-bearing levels of Yellowstone? Because forests would be expected to harbor a wide variety of animals, some of which would be buried by the successive mud slides, the absence of animal fossils has been a mystery. Volcanic activity could have caused larger forest animals to flee elsewhere, but flight cannot be used as an explanation for the absence of all animal remains because many animals could not or would not leave their forest habitats. Land snails, some amphibians and reptiles, many insects, arachnids, and worms would not escape burial. Immature members of many types would be unable to flee. In addition, bones, eggs, teeth, scales, molted skins, castings, droppings, burrows, etc., would qualify as evidence of animal life. None of these have been found in the fossil forest organic levels during a century of research. Considering that delicate plant parts are excellently preserved, animal remains should also have been preserved if they were present. Only one exception is known. Remains of termites have been found in chambers within the petrified wood.²⁸

If the petrified trees are standing where they originally grew and if the organic levels are the growing surfaces still intact and undisturbed, the absence of animal fossils is difficult to explain. If, however, the trees and the organic debris making up the soil levels were transported by water, the separation of animals from the plants before burial is much easier to explain.

H. TRACE ELEMENT PROFILES

The organic levels from which the petrified trees arise usually have a high volcanic ash content. Where did the ash come from? Spark source mass spectrometry analysis of trace elements in the bands of ash revealed pulses of ash from four source areas for the Specimen Creek Petrified Forest.²⁹ The four trace element profiles interfinger in an irregular manner up the sequence of 65 organic levels of Specimen Creek Petrified Forest. If these

65 ash layers (organic levels) were laid down over a long time span, the ash that was laid down thousands of years later near the end of the series of ash eruptions would have changed sufficiently to produce a new and different trace element profile. This has not been the case. Quick burial of the whole sequence seems to be required. Two of the sources for the ash appear to be Electric Peak in the northwest corner of Yellowstone Park and Lone Mountain 48 km farther northwest.³⁰

I. EXAMPLES OF ORGANIC LEVELS FROM ELSEWHERE

Two examples of organic levels from Washington and Oregon add support to the proposition that organic levels like those in Yellowstone can be laid down underwater.

A road cut for Interstate 84 in the Miocene Eagle Creek formation near Cascade Locks, Oregon, exposed several levels of petrified trees, both vertical and horizontal, and bands of organic debris in volcanic breccia — a situation closely similar to that of Yellowstone. Whatever interpretation is achieved for the Yellowstone breccias will probably apply also to the breccias of this Oregon location, and vice versa (refer to Figure 13). A pronounced gradation of sediments between the deciduous leaves (seen in cross-section) is striking. Such grading is unexpected in normal undisturbed soil and suggests transport.

The extensive Ohanapecosh formation in Mount Rainier National Park, Washington, contains some organic levels, although they are less strongly developed than those of Yellowstone. Horizontal petrified trees also were noted. These breccias have been interpreted as subaqueous deposits.³¹ Obviously these organic levels cannot be growth surfaces if the deposits slid into position underwater.

VI. EVIDENCE FOR TRANSPORT OF THE PETRIFIED TREES

The factors relating to the petrified trees that are of most significance for a transport model deal mainly with their position and condition, internal structure, and taxonomy.

A. THE ROOTS

Some of the petrified trees have broken roots; but when were they broken? Even if a permit to collect petrified wood within the park is obtained, excavation of stumps is not permitted; furthermore, digging is difficult in the hard rock. Consequently, to determine if the root breakage seen is pre- or post-petrification is difficult. Several examples of abrupt root terminations from Mt. Hornaday, Mt. Norris, Tom Minor Basin, and Specimen Creek strongly indicate that, at least in some cases, the tree roots were broken

before the trees were buried by volcanic gravels and muds. This evidence supports the view that the trees were transported.

Small rootlets can be located at the bases of upright stumps, and this feature has been used to argue against transport.³² Observations in Spirit Lake near Mount St. Helens and of trees uprooted by bulldozing operations show that the small roots and rootlets are usually still intact, but the larger roots often may be broken (Figure 18). The presence of small roots extending from the base of a petrified tree therefore is not evidence for an in situ interpretation unless large roots also extend unbroken. Broken and frayed large roots could be the result of changing stream currents eroding the bases of growing trees, but such activity should leave evidences in the sediments. Furthermore, erosion must be limited; otherwise, trees would be removed or toppled.

B. LACK OF DECAY

If a forest were killed by a mud flow that buried the bases of the trees, the tops of the trees would extend above the new ground surface. They would overlap a new second forest that would commence growing on the new surface. During the time of the growth of the new second forest (before it in turn was buried by another volcanic mud slide) the old first forest snags would have time to rot, to be infested with insects, and to break down. Even the tops of stumps that reached only to the root area of the second forest level (no actual overlap) would also be expected to experience decay. The soil in which the roots of the second forest grew would not be a good preserving medium for the tops of the stumps extending up from below. One of the striking features of the Yellowstone petrified trees is their good preservation (refer to Figure 11). If pieces of the petrified wood are prepared as microslides, the wood tissue may look nearly as fresh as tissue from a living tree. Seldom do they exhibit any evidence of decay and weathering. This suggests that the trees have not been subjected to these processes during the passage of time.

C. ORIENTATION OF STUMPS AND LOGS

The parallel orientation of the horizontal logs, mentioned earlier, is better explained by water or mud transport. The dip of the beds from which the trees arise seldom exceeds 7°, which is not enough to cause all the trees to fall downhill. The dip may be due to post-deposition uplift. Prevailing winds or volcanic blasts could align fallen trees, but they would not cause the long axes of the cross-section of the upright stumps to have a similar compass alignment.



Figure 18. A tree torn out of the ground by the eruption of Mount St. Helens. Note that the large roots are broken while the small rootlets are largely intact.

The asymmetry of the cross-section of a stump, especially at its base, is usually a result of the influence of major roots that cause flare to extend for some distance up the stump. Volcanic lahars (fast-moving volcanic mud slides) or currents of water or mud could be the forces that acted on roots and trunks to produce similar alignment for both stumps and logs.

D. ABNORMAL ECOLOGY

The many petrified trees and plants in the Yellowstone area represent a diverse grouping of species. Exotic genera such as cinnamon, breadfruit, katsura and chinquapin are presently restricted to southeastern Asia. Erling Dorf accounted for this unusual assemblage by postulating a basin at low elevation (to accommodate the tropical and semitropical species) into which leaves and wood from surrounding higher elevations were transported.³³ On the other hand, William Pierce suggests that gravity sliding of the Heart Mountain Thrust Fault from west to east could occur only if the area supporting the ancient Yellowstone forests was at high elevation.³⁴

The mixed flora is most easily explained by the transport of trees and plant parts from different habitats and geographical locations into a flooded basin where lahars, mud flows, or turbidity currents left accumulations of sediments (Figure 19).

E. DENDROCHRONOLOGY

The results of dendrochronological research might appear at first to support an in situ interpretation. However, matching of rings from trees on different levels would be most unlikely if they are in position of growth. Arct³⁵ has found matching growth ring patterns for upright trees separated by one or more levels. Living forests on successive levels that are sequentially buried by volcanic mud slides could not have grown at the same time and under the same weather conditions. Sequences of wide rings (abundant rain) and narrow rings (drought) would be different. These results are a strong argument for their being allochthonous (transported from elsewhere).

F. ABSENCE OF BARK AND LIMBS

One of the first observations made when research commenced on the petrified forests was the barkless condition of both the horizontal and upright trees. Subsequent examination has revealed some thin layers of bark remaining on a few of the trees. In addition to the trees being mostly barkless, all the branches have been broken off. Even large branches, 25 cm or more in diameter, have been removed. Only scoured stubs remain on the tree trunks. Trees buried and later excavated by water erosion during the eruption of Mount St. Helens did not have all the bark or limbs removed. Trees floating for a period of time in turbulent water would more likely lose bark and branches due to softening of the bark and abrasion.

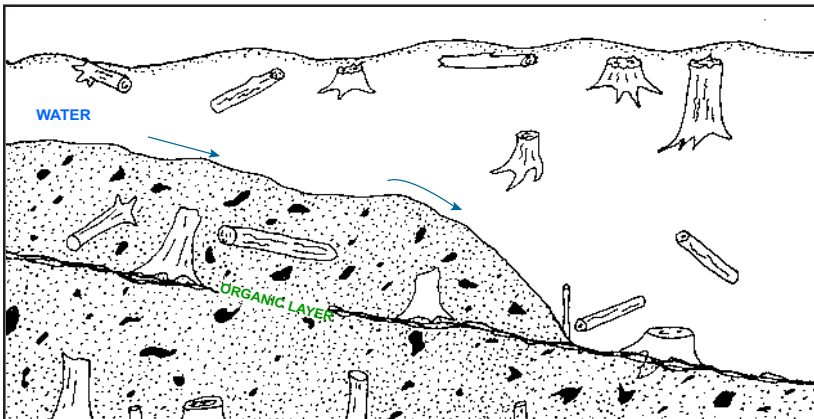


Figure 19. A sketch of a model for the rapid burial of trees (both upright and horizontal), and organic debris, by underwater volcanic mud slides (coarse-grained turbidites). Modified from the illustration in: Coffin HG 1983. Origin by Design. Washington DC: Review and Herald Publishing Assn., p 151.

VII. A MODERN CASE HISTORY

A. THE ERUPTION OF MOUNT ST. HELENS

On May 18, 1980, Mount St. Helens in the state of Washington erupted with a roar heard 300 km away and a force equal to 500 Hiroshima atomic bombs.³⁶ 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.³⁷ Millions of trees in 600 km² of prime forest were blown down or killed.³⁸

The eruption that removed nearly 400 m from the top of the beautiful mountain was triggered or preceded by a 4.9 magnitude earthquake.³⁹ The immediate result of the jolt was a massive avalanche down the north face which had been bulging at a rate of 1.5 m per day for several weeks.⁴⁰ The eruption following the slide eviscerated the mountain, leaving a crater 600 m deep. A resort lodge and thirty cabins were pulverized and buried under 90 m of sediments.

The forests in the area north of the mountain were devastated. Huge trees, some of them 2 m or more in diameter, were felled like matchsticks (Figure 20). 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-



Figure 20. The eruption of Mount St. Helens snapped and uprooted thousands of trees, some of great size.

facing slopes. When the incandescent blast began to lose speed farther from the mountain, it funneled down the valleys, leaving the trees on the tops of the surrounding hills untouched.

B. RIVER TRANSPORT OF UPRIGHT STUMPS

Associated with the St. Helens eruptions, trees and stumps have been transported upright to new locations. Mud slides and turbid floods down the North Fork of the Toutle River have deposited and buried trees in an upright position. Many erect stumps in various stages of burial have been scattered on some of the mud flats and gravel bars (Figure 21).⁴¹ One huge stump over 2 m in diameter and 13 m tall sits on the toe of the 24-km-long debris flow.



Figure 21. Stumps of trees previously logged were torn out of the ground by volcanic activity associated with the eruption of Mount St. Helens, transported down the Toutle River, and dropped upright onto the scoured floor of the river. Note that some of the upright stumps are partially buried. This photograph first appeared in: Coffin HG 1983. Origin by Design. Review and Herald Publishing Assn., p 149.

C. SPIRIT LAKE

Before the eruption of Mount St. Helens, Spirit Lake, located at the base of the mountain on the north side, was a beautiful gem among virgin forests with the majestic mountain as a backdrop. The lake probably originated during similar past eruptions of the mountain when the floor of the north



*Figure 22. A portion of the log raft on the surface of Spirit Lake near the base of Mount St. Helens. Note the trees floating upright off Eagle Point. Upright trees are in the log mat also, but not as obvious as those in the open water. This photograph first appeared in: Coffin HG 1983. Erect floating stumps in Spirit Lake, Washington. *Geology* 11:298-299. Reprinted with permission of the Geological Society of America.*

fork of the Toutle River Valley was raised by volcanic debris. This natural dam impounded the water that became Spirit Lake.

Most trees seen in rivers are rootless logs floating horizontally. Opportunities for observations on significant numbers of floating logs with roots have been few. In casting about for a modern (if local) example, I thought of Spirit Lake. The eruption of Mount St. Helens tore thousands of trees out of the ground and threw many of them into Spirit Lake. When the north face of the mountain collapsed into Spirit Lake, water surged scores of meters up surrounding hills and washed many trees into the lake. A huge floating mat of logs and debris now covers nearly half of the lake surface (Figure 22). It consists of plant material ranging from chips of bark to trees with trunks nearly 2.5 m in diameter. Many of the trees still retain their root systems. Research on this log raft has thrown light on the flotation characteristics of trees.

D. RESEARCH IN SPIRIT LAKE

Our research began at the lake in September 1982, two and a half years after the eruption. We noticed many stumps upright in the water (Figure 23).



Figure 23. A small sample of the log raft on Spirit Lake. The upright trees in the foreground are lightly grounded in shallow water, whereas those in the background are floating free.

Some of them could be seen drifting with the wind. To be certain that they were not anchored to the bottom in their original positions of growth but 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. They found that the root systems were either well above the lake bottom (truly floating) or that they were lightly grounded on the bottom.⁴² The latter could be pushed around and when tilted would swing back into vertical position. Some stumps that had sunk were standing upright on the bottom, their tops well below the surface of the water. Others floated or sat on the bottom mud with tops protruding above the water surface (Figures 24 and 25).

We wondered how many floating stumps and logs had already sunk to the bottom. To answer that question, we chose to utilize side-scan sonar. Although scuba divers had verified that stumps were sitting erect on the bottom, quantitative measurements were not possible by this method because of the size of the lake, the depth of the water, the darkness below certain depths because of water turbidity, and other factors.

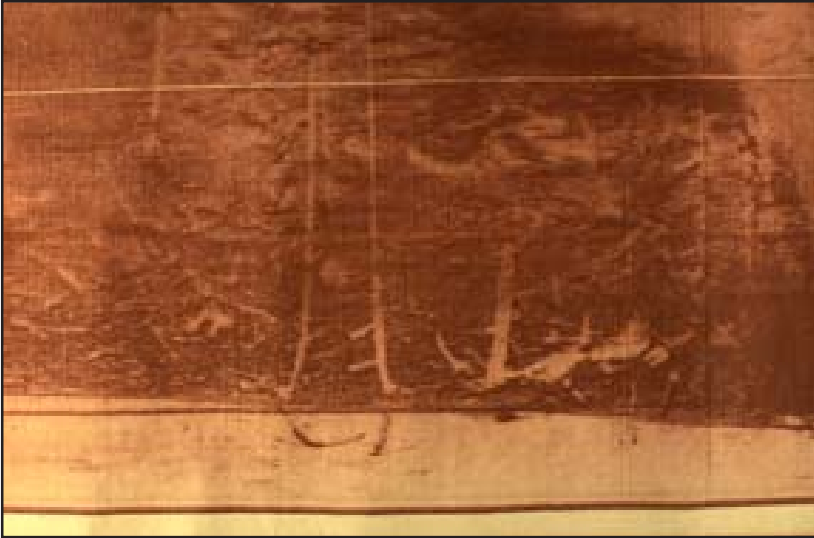
Using side-scan sonar, transects covering slightly under 1% of the lake bottom yielded 154 vertical stumps and 95 prostrate logs.⁴³ A sonograph reveals light areas or reverse shadows when objects block sound transmission (Figure 26). The vertical light streaks are sonar shadows cast by erect trees. Confirmation of these sonar results was obtained by divers at specific sites and by observing the sonograph recordings of vertical stumps whose protruding tops revealed their locations. Extrapolation to the entire lake bottom gave approximately 19,500 erect stumps and about 12,000 horizontal logs. The submerged stumps and logs range in height from less than 1 m to more than 20 m.



*Figure 24. A large erect stump sitting on the bottom of Spirit Lake that extends within a meter of the surface of the water. This stump is representative of thousands that are sitting upright on the bottom of Spirit Lake. This photograph first appeared in: Coffin HG. 1987. Sonar and scuba survey of a submerged allochthonous “forest” in Spirit Lake, Washington. *Palaios* 2:179-180. Reprinted with permission of the Society of Economic Paleontologists and Mineralogists.*

Figure 25. Floating tree trunks with tops protruding above the surface of Spirit Lake. In time they likely will sink upright and disappear into the depths if the water is sufficiently deep.





*Figure 26. Side-scan sonograph showing several erect trees in a 75 m length on the bottom of Spirit Lake. The vertical streaks are sonar shadows cast upon the bottom of the lake by upright stumps. Scattered wood debris is also visible. This illustration first appeared in: Coffin HG 1987. Sonar and scuba survey of a submerged allochthonous “forest” in Spirit Lake, Washington. *Palaios* 2:178-180. Reprinted with permission of the Society of Economic Paleontologists and Mineralogists.*

After the completion of a safety tunnel that lowered the lake surface approximately 7 m, submerged upright stumps in the process of being buried became visible. Underwater examination via scuba divers also verified this observation.

E. FLOTATION CHARACTERISTICS

The floating log raft in Spirit Lake also provided some insights on taxonomic sorting. Most of the stumps sitting erect on the bottom of Spirit Lake are Silver Fir, Noble Fir, and Hemlock. Douglas Fir, abundant in the surrounding forests, has only 2.2% representation. Sampling of the trees in the floating raft solved this discrepancy; 48% are Douglas Fir. Apparently this species is more buoyant and resistant to water saturation. Cedar was represented by 2.2% of logs floating in the lake; yet the surrounding forests contained a higher percentage of cedars. Sampling of the broken wood pieces along a transect on the shore gave 11% for cedar. Cedar is brittle wood, and evidently most cedar trees were shattered by the volcanic blast and associated violence.

Some of the erect trees floating in the lake or standing on the lake bottom are over 20 m tall. The argument that tall petrified stumps must be in position of growth does not apply to a flotation scenario.

The flotation of organic matter (including trees in an upright position) as illustrated in Spirit Lake at the base of Mount St. Helens provides a model for interpreting the upright petrified trees of Yellowstone. Trees and plants will float vertically when there is sufficient water and time. The research at Spirit Lake helps explain the presence of the organic layer at the level of the roots. Saturated organic debris sinks to the lake bottom to produce a layer of organic matter. Upright floating trees also have dropped out of suspension onto the bottom of Spirit Lake in a spacing pattern similar to that of growing forests (Figure 27). They are not jumbled together in log jams as might be expected.⁴⁴

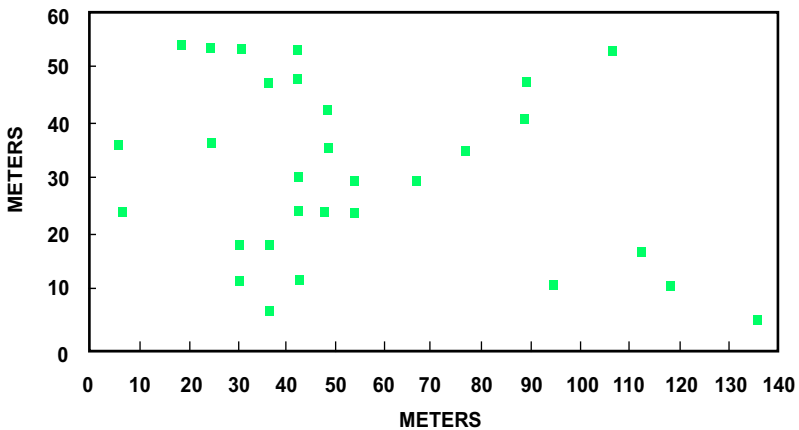


Figure 27. Spacing of erect stumps on the bottom of Spirit Lake. The plot represents a continuous 140 by 60 m area of lake bottom. (Note that the right half is a continuation from the top of the left half.)

Some have argued that Spirit Lake is not a good analog for the Yellowstone Fossil Forests, because the large number of logs accumulating on the bottom of Spirit Lake is very different from the more scattered fossil logs and stumps in Yellowstone. However, one important difference between the two deposits is that Spirit Lake has not had adequate sediment input to bury the sinking logs and stumps. If the 1980 Mount St. Helens eruption had been followed by a series of volcanic breccia flows into Spirit Lake, spaced long enough apart to bury successive sets of logs and stumps as they sank, it would likely have produced a deposit very similar to the Yellowstone Fossil Forests.

VIII. ALLOCHTHONOUS MODEL

A. ALLOCHTHONOUS ORGANIC LEVELS

The normal accumulation of organic debris and the subsequent formation of humus and true soil that proceeds relentlessly on modern growth surfaces do not readily account for several of the phenomena seen in the organic levels of Yellowstone. These are specified below.

1. The absence or thinness of organic matter on levels with abundant and large trees.
2. The sorting of organic and inorganic matter.
3. The lack of a typical soil profile.
4. The multiplicity and complexity of the organic levels.
5. Lack of agreement between leaves and pollen and the dominant wood types.
6. The absence of clay, or, when present, uncorrelated to the organic levels.
7. The absence of evidence of animals expected in typical forest plant-animal associations.
8. The evidence from the study of the trace elements of the volcanic ash, associated with the organic levels, for repeated eruptions during a short span of time of insufficient duration to support the growth of a superimposed series of forests.

B. ALLOCHTHONOUS TREES

The main factors that support the transport of the trees seen in the Yellowstone Petrified Forests are summarized below.

1. Large roots that can be traced to upright trees are broken or terminate abruptly.
2. The good preservation of tree wood. Decay is seldom seen.
3. The parallel alignment of logs and stumps appears to require their transportation by a moving force such as water or mud.
4. The variety of habitats and climatic preferences seen by the great taxonomic diversity of trees and plants suggests transport.

5. Matching growth rings for trees on different levels requires contemporaneous growth elsewhere and subsequent transport to a new location.
6. Battered and barkless trees are better explained by transport in violent water than by growth in situ.

IX. CONCLUSION

The evidence presented here provides a basis for additional detailed research that could be done. Such research would be beneficial for our understanding of these unique fossil deposits. Offhand, the in situ model would appear to be the simplest and most natural explanation, but closer examination uncovers features that are difficult to explain for trees in growth position. A transport model involving the flotation of trees and organic debris in a body of water, as illustrated in Spirit Lake, gives a better fit to the data as observed in the Yellowstone Petrified Forests. We propose that the Yellowstone Petrified Forests provide an example of catastrophic deposition.

ACKNOWLEDGMENTS

I wish to thank Donald Jones and John Boyd who assisted greatly in plotting some of the Yellowstone sites. I am thankful to Lanny Fisk who gave many helpful suggestions and assisted with field studies and subsequently went on to make significant contributions to the Yellowstone research. I am indebted to Ivan Holmes and Clyde L. Webster, Jr., for important contributions in geochemistry; the former for the x-ray diffraction studies of Specimen Creek Fossil Forest organic levels and the latter for trace element research. Steve Austin gave assistance at Spirit Lake with the side-scan sonar research and underwater photography for which I am grateful.

GLOSSARY

- Basalt** — an extrusive molten rock, dark in color and often exhibiting columnar jointing.
- Breccia** — rock consisting of angular broken fragments cemented together.
- Caldera** — a large crater produced by explosion or collapse at the summit of a volcano.
- Cambrian** — a period (the earliest) in the Paleozoic Era.
- Conglomerate** — rock composed of rounded fragments of heterogeneous size and composition cemented together.
- Cretaceous** — a period in the Mesozoic Era.
- Ecology** — the study of the relationships of organisms to one another and to their environment.
- Eocene** — an epoch in the Cenozoic Era.
- Formation** — a clear-cut unit of rock usually with uniform texture and composition.
- Genera** (singular, genus) — a unit of classification above the species but below the family.
- Geologic column** — the total vertical sequence of strata considered to have been laid down during geologic time. Creationists consider the geologic column largely to be the result of a worldwide flood.
- In situ** — in natural position; not transported or moved.
- Lahars** — mud slides full of volcanic debris.
- Miocene** — an epoch in the Cenozoic Era.
- Mississippian** — a period in the Paleozoic Era.
- Oligocene** — an epoch in the Cenozoic Era.
- Organic** — any matter consisting of, or produced by, living organisms.
- Palynology** — the study of fossil pollen.
- Petrification** — the process of becoming hard like rock.
- Precambrian** — all time or deposits before the Cambrian.
- Sedimentary** — composed of particles; consisting of sediments.
- Species** — a unit of classification below the genus. Animals and plants able to interbreed are usually considered in the same species.
- Stratigraphy** — the study of stratified rocks as they relate to Earth's crust.
- Taxonomy** — the study of the relationships and the classification of organisms.
- Thrustfault** — a fault that has resulted from one mass of rock being thrust onto another.

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EDITORIAL

GENESIS AND GENOMICS

In a book published in 1994,¹ molecular biologist Periannan Senepathy proposed that life was polyphyletic — having many separate lineages with independent origins. Unfortunately, the book contained many errors and strange ideas, and was soundly rejected by the scientific community. However, the issue raised by Senepathy is of considerable interest to creationists: how many independent lineages are there, and how can we distinguish them? Recent advances in molecular genetics may help provide an answer by adding a new potential criterion for identifying independent lineages.

Several creationists have published attempts to develop criteria for identifying lineages with separate origins. For example, Marsh² proposed two principal criteria for identifying “Genesis kinds” or “baramins”: physiological compatibility (ability to hybridize) and morphological similarity. Two organisms must belong to the same “Genesis kind” if they are able to produce a fertilized egg, or if they can each interbreed with a third species.³ If fertilization is not possible, the two organisms may still belong to the same “Genesis kind” if they are sufficiently similar morphologically.

Lester and Bohlin⁴ discussed this issue further, taking into account the enormous increase in understanding of genetic systems that had taken place since Marsh’s book was written. They proposed several criteria for identifying independent lineages, which they termed “prototypes.” Their criteria for identifying a “prototype” include: morphology, embryology, chromosome morphology, structural genes, and regulatory mechanisms. They especially emphasized regulatory genetic mechanisms, including developmental processes, as important in distinguishing “prototypes.”

This issue of Origins includes a brief review of a book by Walter ReMine.⁵ The book contains a chapter entitled “Discontinuity Systematics”, in which the problem of identifying separate lineages is discussed. ReMine describes three criteria for identifying separate “baramins”: ability to interbreed, experimental demonstrations of morphological overlap, and clear-cut phylogeny. By “clear-cut”

phylogeny, ReMine apparently means demonstrable morphological overlap of living and fossil forms. These criteria are similar to Marsh's criteria, but developed in greater detail.

Other creationists have studied this problem, but this sample probably includes the major criteria so far proposed for identification of lineages having independent origins.

I now return to Senepathy's book, in which he proposed two criteria for identifying lineages with independent origins: the presence of unique genes, and unique developmental programs. Although Senepathy is not a creationist, his idea seems worth pursuing.

Until recently, scientists have lacked the techniques to test for unique genes or developmental programs, but this situation is changing. Scientists now have the ability to sequence entire genomes, and have successfully sequenced genomes of several unicellular species, including representatives from each of the three identified major groupings of organisms: the Eubacteria, Archaea, and Eucarya.⁶ Results indicate that there is considerable difference in these genomes, despite the potential for cross-species gene exchange.⁷

A new field is being born — comparative genomics. We can expect to see rapid advances in comparative genomics as new genomes are sequenced, especially among unicellular organisms. Progress among multicellular organisms will be slower, due to their much-larger genomes. Analysis will also be increasingly complex, due to putative gene duplications, effects of movable elements, and possible horizontal transfers. But it appears that the current procedure for estimating phylogenies by comparing gene sequences may be replaced eventually by a new procedure that compares suites of genes.⁸

It may be decades before we can evaluate the usefulness of comparative genomics for identifying independent lineages. But at least the idea can be tested. A means for confidently identifying separate "baramins" may yet be developed.

L. James Gibson

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ARTICLES

CARBON-14 DATING MODELS AND EXPERIMENTAL IMPLICATIONS

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WHAT THIS ARTICLE IS ABOUT

Eight categories of models for converting carbon-14 dates into real time are discussed. Six of these models are based on a creation as described in Genesis and a short age of life on earth. Differences between the models are specified, especially those that are subject to experimental testing. Such features include (1) differences between ring years and radiocarbon years in trees that should be immediately postdiluvian by creationist theories, (2) the accuracy, or lack thereof, of the dendrochronological radiocarbon calibration curve in the historical era, and (3) the possible existence of carbon-14 in antediluvian fossil material. Suggestions are offered for experimental projects that would resolve these uncertainties.

In this paper I will discuss eight categories of carbon-14 models and their experimental implications. Six, or three-quarters of these, are creationist models. The purpose of this paper is to stimulate thinking and to argue for an experimental perspective.

CONSTRAINTS

Any model of carbon-14 dating must satisfy certain constraints. First, since carbon-14 dating is objective and reproducible, it cannot be ignored. One cannot simply dismiss it out of hand; there should be an explanatory model for the data. Second, it has been validated at least back to 300 B.C. by comparison with many other reliable dating methods.¹ Therefore, any model must account for this data, and it is not reasonable to consider carbon-14 dating completely unreliable before that point, particularly when used as a relative dating method.

Another universally recognized constraint is the level of carbon-14 in geologically old material. Although the existence of a very low level of carbon-14 in ancient or antediluvian fossil material, for example Pennsylvanian coal (conventional age ~350,000,000 years) is controversial

(see discussion below), it is universally agreed that the level of carbon-14 in such materials is at least very low, if not non-existent.

There are five other less universally accepted constraints that determine which of the eight categories of models will be chosen:

1. Strict uniformitarianism
2. The evolutionary time scale
3. An invariant decay constant for carbon-14
4. The dendrochronological carbon-14 calibration curve prior to around 300 B.C.
5. The date of the Flood, and its presumed consequences

How important one considers each of these constraints determines which category of model will be most appealing.

THE UNIFORMITARIAN MODEL

The first category we will consider is models that assume strict uniformitarianism. The model initially proposed was strictly uniformitarian (Libby 1955). This simple model is no longer supported by any worker in the field. It is of interest as an object lesson in the fallibility of strict uniformitarianism.

However, because of its mathematical simplicity, it is still used, even though it is known to represent only general trends. A simple translation can be made between model age and percentage of carbon-14. Citations of uncalibrated carbon-14 dates in the professional literature use this model by convention. It roughly approximates the evolutionary model.

The uniformitarianism model assumes that the ratio of carbon-14 to ordinary carbon (the $^{14}\text{C}/\text{C}$ ratio) in the atmosphere has always been constant at its present value (100 percent modern carbon, sometimes written as 100 pmc). According to this model, plants that get their carbon from the atmosphere would incorporate carbon with a constant $^{14}\text{C}/\text{C}$ ratio. The carbon in animals that eat these plants might be around 2 years “old”, which is negligible in terms of radiocarbon dating. The carbon in carnivores would be slightly “older” but still of negligible “age”. A dead plant or animal, or wood produced by a plant, does not exchange carbon with the environment (if the sample is chosen with sufficient care), and the $^{14}\text{C}/\text{C}$ ratio gradually decreases exponentially, with a half-life of 5568 years. One simply measures the $^{14}\text{C}/\text{C}$ ratio and compares that to the present ratio, using the formulas in Table 1. For those who find graphics more understandable, the graph in Figure 1 may be used. The

TABLE 1
Formulas for Carbon-14 Dating

$$({}^{14}\text{C}/\text{C}) = ({}^{14}\text{C}/\text{C})_0 e^{-kt}$$

$$t = \ln [({}^{14}\text{C}/\text{C})_0 / ({}^{14}\text{C}/\text{C})] / k$$

where $k = \ln(2) / t_{1/2}$

$$t_{1/2} = 5568 \text{ years}$$

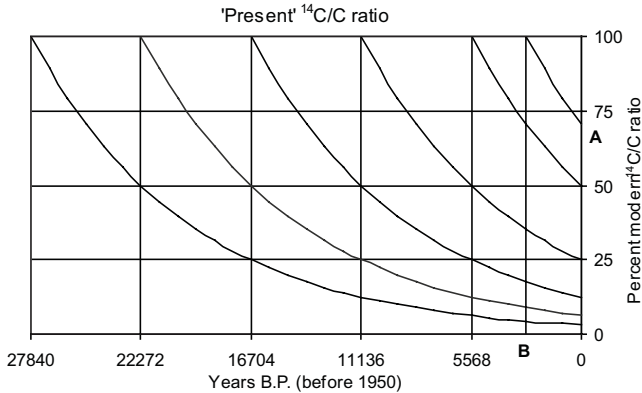
$$T / t_{1/2} = -\log_2(\text{pmc}/100)$$

pmc = percent modern carbon [= ${}^{14}\text{C}/\text{C}$ ratio expressed as a percentage of that found in the "modern" (1850) biosphere]

formulas themselves are non-controversial. The graph associates every measured ${}^{14}\text{C}/\text{C}$ ratio with an age (for example, Age B, or Ratio A).

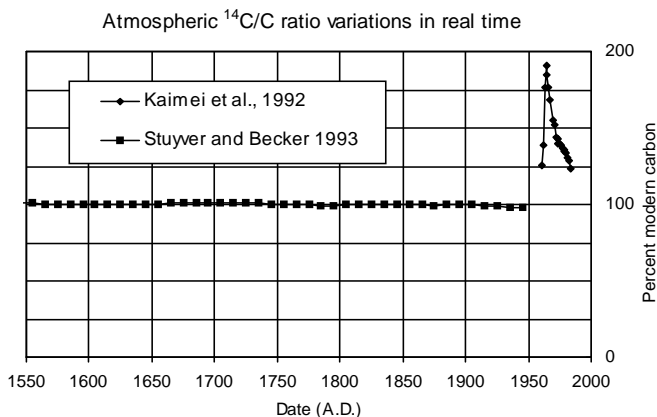
This model has been supplanted because it has been demonstrated that the ${}^{14}\text{C}/\text{C}$ ratio in the biosphere has varied during the recent past, and there is evidence that it has also varied in the more remote past. When massive amounts of carbon-14 were produced in the Northern

FIGURE 1



Hemisphere by nuclear explosions in the 1950s and 1960s the ${}^{14}\text{C}/\text{C}$ ratio in the atmosphere nearly doubled (see, for example, the data from Kaimei et al. 1992, shown in Figure 2). Since nuclear explosions in the atmosphere have been discontinued, this ratio has gradually decreased toward the ratio found before the nuclear age. The ${}^{14}\text{C}/\text{C}$ ratio in the biosphere had been slowly dropping over the 100-200 years prior to the nuclear age, apparently due to the introduction of essentially "dead"

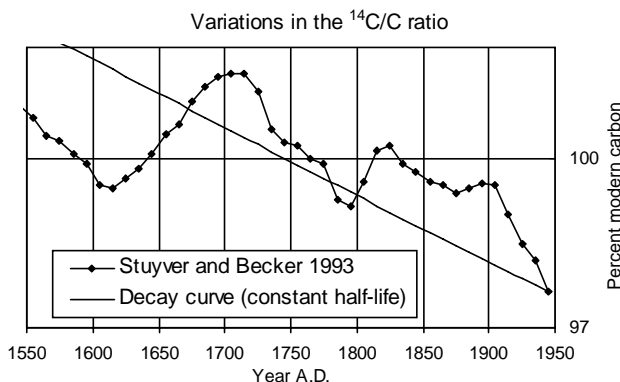
FIGURE 2



carbon from the use of fossil fuels (coal, oil, natural gas, etc. See Figures 2 and 3, especially Figure 3). The $^{14}\text{C}/\text{C}$ ratio of a 1945 sample from the biosphere actually is lower (and the specimen therefore “older”) than that of a sample from 1850, or even 1700 (see Figure 3).

One may be tempted to say that the above variations were manmade, and that nature, if left alone, would be uniformitarian. But these are not the only documented variations in the $^{14}\text{C}/\text{C}$ ratio. For example, the decrease of the $^{14}\text{C}/\text{C}$ ratio between 1535 and 1615, or the increase between 1615 and 1705, has not been correlated with any causative human activity.

FIGURE 3



Recent, more precise measurements of the half-life of carbon-14 are closer to 5730 years than to the 5568-year half-life used in earlier calculations. So the conventional uniformitarian model would need minor modification, even if the assumption of a constant $^{14}\text{C}/\text{C}$ ratio in the biosphere were correct.

Since the $^{14}\text{C}/\text{C}$ ratio has varied in the recent past, one cannot relate measurements to the “modern” level without specifying which modern level. By convention, “modern” carbon is the $^{14}\text{C}/\text{C}$ ratio that existed in 1850, before most of the industrial revolution and well before the nuclear age. Thus the carbon in our bodies has a $^{14}\text{C}/\text{C}$ ratio of roughly 110-120 “percent modern carbon”, which sounds a bit strange but makes sense once one understands the convention.

Since carbon-14 dating is an inaccurate measure of real time without some sort of calibration, uncalibrated carbon-14 dates are usually reported on the basis of the old (less accurate) 5568-year estimate of the half-life. As calibration is necessary, the correction for the wrong half-life can be included in the calibration. This makes it unnecessary to recalculate all the old published dates, or worry about which half-life has been used. By convention all uncalibrated carbon-14 dates are reported using the 5568-year value for the half-life. Those who use the 5730-year value are supposed to explicitly state that they are doing so.

THE EVOLUTIONARY MODEL

The next model we will consider, the evolutionary model, in common with all the other models except the uniformitarian model, uses a calibration curve to convert radiocarbon years to real-time years. In order to construct a calibration curve one must either have a model of how radiocarbon dates should correlate with real time, or one must have some specimens which can be securely dated by some other method and for which radiocarbon dates may be obtained. In the case of the evolutionary model, the latter is attempted.

The fundamental data on which the evolutionary model is built is the dendrochronological radiocarbon calibration curve. This calibration curve is based on work in which tree rings from Irish oak specimens were matched to each other to create a master sequence (Stuiver & Pearson 1993; Pearson & Stuiver 1993; Stuiver & Becker 1993; and Pearson et al., 1993; see also Kromer & Becker 1993). There may be circular reasoning in this process, as the specimens were apparently

first radiocarbon dated to give an approximate time-range estimate before detailed ring matching was attempted.² Specimens from defined 10-year or 20-year intervals were radiocarbon dated. A given radiocarbon date from a specimen with unknown calendar age is then matched with the radiocarbon date from one or more of these 10-year or 20-year specimens, and the real-time date for the unknown specimen is assumed to be the same as that of the specimen or specimens which it matches. The shape of the calibration curve, and uncertainties in the measurement of the unknown radiocarbon date may lead to a range of possible dates.

There is a belief that multiple lines of evidence support the master Irish Oak calibration curve. However, the curve derived from German oaks (Becker 1993) is incomplete, especially at 500 B.C. (Kromer et al., 1996). Bristlecone pine calibration disagrees with the Irish oak calibration from 600-300 B.C.³ A calibration based on varves (sedimentary layers laid down in lakes and assumed to be deposited yearly) disagreed with the Irish Oak calibration in the range of 1,000-10,000 B.C. (Tauber 1970). Radiocarbon dates on archaeologically dated material (which will be the subject of another paper) disagree with the dendrochronological calibration curve at 614-612 B.C. The present standard of the conventional scientific and historical community for the period from the present to 6,000 B.C. is the Irish oak dendrochronological calibration curve.

For ages greater than the maximum age of the dendrochronological calibration curve, there is rough agreement between various investigators that the ¹⁴C/C ratio has ranged from the present value to twice the present value. While there is disagreement among various estimates, the data of Bard et al. (1990) appear to have had a stabilizing influence on the interpretation of the data.

CREATIONIST MODELS

There are at least 6 different major groups of models from which creationists may choose. They may be grouped as follows:

- | | |
|-------------------------------------|-------------------------------------|
| 1. Masoretic Flood, constant decay | 2. Masoretic Flood, variable decay |
| 3. Septuagint Flood, constant decay | 4. Septuagint Flood, variable decay |
| 5. Ancient Flood, constant decay | 6. Ancient Flood, variable decay |

The choice among these models hinges on the date postulated for the Flood, and the assumption of constancy, or variability, of the carbon-14

decay constant. The first row of models is based on a placement of the Flood 4,300 to 4,500 years ago, depending on the length of the sojourn of the descendants of Israel in Egypt (an interesting and potentially important point for other purposes, but one which is of minor significance here). This placement of the Flood is derived from the numbers in Genesis 11 as given in the Masoretic Text. The next row of models assumes a Flood roughly 5,500 years ago, in accordance with the numbers in Genesis 11 as given by the Septuagint. The final row places the Flood at a point usually between 10,000 to 30,000 years ago, and require major gaps in the genealogy of Genesis 11. The precise point is usually not specified by any biblical, archaeological, or geological data. The most defensible suggestion for a date for the Flood from this perspective is given by Aardsma at 12,00 B.C. (1991).

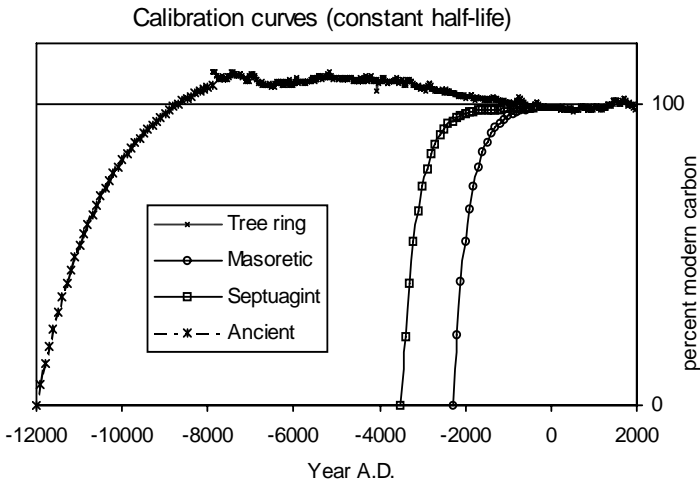
All six categories of creationist models require a rapid rise of the apparent $^{14}\text{C}/\text{C}$ ratio during the period immediately following the Flood, the left three explaining this by ordinary geophysical processes, and the right three by invoking a change in the radioactive decay constant of carbon-14. Both the constant decay and variable decay models make, in most cases, precisely the same predictions in terms of present-day measurements of the $^{14}\text{C}/\text{C}$ ratio and their correlation with real time. If we could have measured the $^{14}\text{C}/\text{C}$ ratio at a given time in the past, for example 4,000 B.P. for the Masoretic Flood models or 13,000 B.P. for some Ancient Flood models, the constant decay models predict a $^{14}\text{C}/\text{C}$ ratio much lower than the evolutionary model would predict. In contrast, the variable decay models can account for an initial $^{14}\text{C}/\text{C}$ ratio near, at, or even greater than that predicted by the evolutionary model. However, both models predict the same carbon-14 date for a given historical date, and so the variable decay models cannot be distinguished from the constant decay models by their predictions for carbon-14 dates for a given historical date. Where the predictions of the constant decay models and the variable decay models converge, I will use the term “apparent $^{14}\text{C}/\text{C}$ ratio” to describe this convergence.

Testable Prediction #1: Discrepancy Between Tree-Ring and Radiocarbon Years

It is obvious that the models based on the Masoretic Text and those based on the Septuagint require a rapid rise in the apparent $^{14}\text{C}/\text{C}$ ratio immediately after the Flood.⁴ Measurements of carbon-14 in presumably

antediluvian fossil material consistently are less than 1% of the modern $^{14}\text{C}/\text{C}$ ratio. Even if one disregards the data from the dendrochronological calibration curve before 450 B.C., it is still necessary to go from a very low or zero apparent $^{14}\text{C}/\text{C}$ ratio at the time of the Flood to near the present ratio in less than 3000 years (see Figure 4). But what is not always appreciated is that the same is true for the ancient flood models. They have been designed specifically to agree with the dendrochronological calibration curve until its maximum age. In the model proposed by Aardsma, if the dendrochronological calibration curve at 11,000 years B.P. requires a $^{14}\text{C}/\text{C}$ ratio approximately 110% of that at present, and if the Flood occurred at 14,000 years B.P. (12,000 B.C.), then we still have only 3,000 years to reach that level (see Figure 4). No matter how it is constructed, any reasonable creationist model must have rapidly rising apparent $^{14}\text{C}/\text{C}$ ratios after the Flood.

FIGURE 4



Herein lies the first experimentally testable difference between some creationist models and the evolutionary model for carbon-14 dating. Consider a tree that is perhaps 35,000 radiocarbon years old. It is not unreasonable to assume that, since according to Genesis 8:22, “seedtime and harvest, . . . summer and winter” were not to “cease”; “while the earth remains,” the rings on such a tree must represent a close approximation of the number of years it grew. Since by hypothesis there is a

rapidly rising apparent $^{14}\text{C}/\text{C}$ ratio during this period, there would be a difference in the carbon-14 dates between the inside and the outside of this tree much greater than the number of real-time years. Therefore, according to any creationist scenario, a sufficiently old tree should have a significant difference between the carbon-14 dates for the inner and outer wood — much more than the difference predicted by standard evolutionary theory. For Septuagint models, the constraints are tighter than for Ancient Flood models; and for Masoretic Flood models, the constraints are even more severe. Wood that is 6,000 radiocarbon years old should have this feature for either Septuagint or Masoretic Flood models. In contrast, the predictions of most Ancient Flood models match those of the evolutionary model for specimens less than perhaps 11,000 radiocarbon years.

The simpler Masoretic and Septuagint models are more easily tested than one might think. Take for example a 250-ring specimen from Mt. Mazama (the Crater Lake region in Oregon), which blew up approximately 5,700 radiocarbon years ago. If one assumes a roughly exponential rise in the apparent $^{14}\text{C}/\text{C}$ ratio after the Flood, this specimen should have approximately 1,200 to 2,700 radiocarbon years' difference between the inside and the outside according to the Septuagint models. The exact difference depends on the rate of rise of the $^{14}\text{C}/\text{C}$ ratio in the post-Flood biosphere. According to the Masoretic models, there should be approximately 2,400 to 8,400 radiocarbon years' difference between the inside and the outside. An evolutionary or Ancient Flood model would predict roughly 150-250 radiocarbon years' difference between the inside and the outside (calculations available from the author; see Table 2).

It is important to note that the argument is not affected whether one accounts for the rapid rise of carbon-14 dates by dilutional effects, by changing production rates, by changing decay constants, or by any combination of these and/or any other factors. The simple fact is that if you wish to get from <1 percent modern carbon (pmc) to >97 pmc, the curve must slope upwards.

Some may wish to claim that this may not be true for all specimens. The plot of the atmospheric $^{14}\text{C}/\text{C}$ ratio versus time most likely is not completely smooth, and may even have occasional reversals. But for every part of the plot with no rise or with a reversal, the plot must have an even steeper section elsewhere. For a sufficiently long time period,

TABLE 2

Difference in Radiocarbon Years Between Inside and Outside of 250-Year-Old Tree with Bark Date of 5,700 ¹⁴C Years

(Expected difference by evolutionary or ancient Flood models 180-230 radiocarbon years)

Mean life of ¹⁴ C in the upper biosphere	Expected age difference Septuagint Flood model	Expected age difference Masoretic Flood model
500 years	1,200 ¹⁴ C years	2,100 ¹⁴ C years
375 years	1,500 ¹⁴ C years	2,900 ¹⁴ C years
250 years	2,700 ¹⁴ C years	8,400 ¹⁴ C years

Mean life of ¹⁴C in the biosphere at present = 375 years (Hesshalmer et al., 1994)

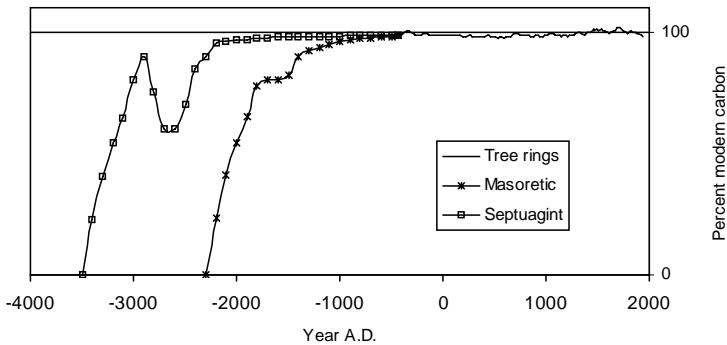
say 3,000 years, the trend mathematically must be observable (see Figure 5). Each of these creationist models is falsifiable.

Some creationist readers may resist the notion of testing our ideas. What if we are proved wrong? I would point out three significant benefits of falsifiability. First, testability places one indisputably in the field of science. Creationism can no longer be honestly disparaged as making no testable predictions. It is, or at least can be partly, scientific.

Second, to what is our ultimate allegiance due? Is it not to truth? If our beliefs are not true, then why hold them? One cannot ultimately evade the thrust of this question by saying that even if all the evidence

FIGURE 5

Effect of arbitrary irregularities in curves



is against our beliefs, they are still true. The claim of the Judeo-Christian (and Muslim) religious tradition is that our God is the God of the Universe. If the observable universe is truly understood, and does not match some part of our religious tradition, then that part needs modification or revision.

Third, and most importantly, if creationists are right, and the results of the experiments corroborate our theories while falsifying those of others, we provide an opportunity for anyone who is honest in heart to see that our theories are more correct than theirs. Let me state this in the negative. If we are right, but refuse to allow our beliefs to be tested, do we not give the message to our opponents, perhaps accurately, that we really do not believe — that we actually doubt? And do we not prevent them from ever finding out that we are right? I see the present situation, not as dangerous, but as a win-win situation. If we are wrong, we will find out. And if we are right, we will provide an opportunity to anyone who is honest in heart to see it. We should do the experiments.

One point to remember is that the Bible is not determinative for all knowledge. The Bible is not a good manual for automobile repair. The Bible does not even give a clear indication whether the sun moves around Earth, or vice versa. Such indication as was given seemed to the readers to be in favor of the former at the time when a major scientific dispute took place. The best Galileo could do was to argue that the Bible did not intend to address the question. It is certainly possible to read the genealogies of Genesis 11 as incomplete and not specifying the precise date of the Flood. Perhaps scientific data, including radio-carbon data, may help us determine this question.

Another point that deserves emphasis is that it is simply not true that whenever the mechanistic view of nature (usually mislabeled “science”) conflicts with religion, science always wins and religion always loses. Specific cases in point that are now generally conceded are whether the universe has a beginning; whether the geologic record gives evidence of catastrophes; and, in the field of history, whether the numbers of First and Second Kings and First and Second Chronicles are accurate. Were it not for the fact that the question strikes at the heart of the mechanistic view, the same would be the case for the origin of life. In the case of Seventh-day Adventists, the same is true for the toxicity of tobacco. Thus religion is not destined to lose every time it stands up to the current majority scientific view. This means that religion should not surrender too quickly when challenged by what appears to be science.

Testable Prediction #2: Errors in the Calibration Curve in the Historical Era

A second difference in the predictions of our models deserves mention. The Masoretic and Septuagint models require a rising $^{14}\text{C}/\text{C}$ ratio during the historical era. This contrasts with the Ancient Flood and evolutionary models, and is testable in principle. The Masoretic and Septuagint models thus require the dendrochronological calibration curve to be grossly inaccurate in some portion of the historical era.

The most likely location at which to find the inaccuracy in the dendrochronological calibration curve, if there is such, is in the era between 450 B.C. and 765 B.C. Variations in the dendrochronological calibration curve in this region are unexplained geophysically. The Irish Oak data are irregular, and in two places the 10-year and 20-year curves disagree.⁵ The bristlecone pine data disagree with both Irish oak curves in this area, as noted above, and the German oak data have a gap here. The dendrochronological calibration curve is not supported by the extant archaeological dates.

There is now direct experimental evidence that the dendrochronological calibration curve is incorrect in this region. Human bone archaeologically dated to 612 B.C. has a preliminary uncalibrated carbon-14 date of 720 ± 30 B.C. (± 1 S.D.). The probability of the date being this different by chance is $p < 0.001$. At a later date I plan to discuss this carbon-14 date in detail.⁶

It may be argued that this would be only one area where the dendrochronological calibration curve is apparently in error, and is irrelevant to the larger question of whether the curve is fundamentally in favor of a short-age creationist or an evolutionary time scale. In one sense this is true. It would only subtract around 300 years from conventionally calibrated dates, and the rest of the curve is not necessarily affected. However, once the conclusion is reached that the calibration curve is in error here, the question of further errors cannot be ignored, and it is entirely possible that the shape of a revised curve would be highly favorable to a short time scale.

The dendrochronological calibration curve appears to be an example of a data set that looked good at first but had significant problems on closer inspection. I think it is one of the duties of creationists to test this calibration curve, and to expose it as erroneous if it does not pass the test. This is especially true of those who subscribe to either the Septuagint or the Masoretic Flood models.

Testable Prediction #3: The Existence of Carbon-14 in Very Old Fossil Material

Finally, there is the question of whether very old fossil material contains carbon-14. Views that allow alterations of the radiometric decay constants can account for the complete absence of carbon-14 in antediluvian or very ancient fossil material, matching evolutionary requirements. On the other hand, models that explain carbon-14 dates by ordinary geophysical processes without changing the decay constants are virtually required to predict that there is a small but now measurable amount of carbon-14 in antediluvian fossil material. This constitutes the third experimental difference in predictions between models.

Evidence for the existence of this small amount of carbon-14 in very old/antediluvian material will be discussed in another paper. This carbon-14 has five possible explanations. It could be machine error, contamination *in situ*, contamination during processing and/or measurement, nuclear synthesis *in situ*, or residual activity. Machine error can be largely eliminated experimentally. Nuclear synthesis can be essentially eliminated on theoretical grounds. So the carbon that is measured is apparently either contamination or true residual activity.

If this carbon-14 can be firmly proven to be residual, the entire evolutionary time scale would be invalidated. To have a residual activity of 1 atom after 1 million years requires starting with a mass of pure carbon-14 over 100 times larger than the earth.⁷ Thus if there is residual carbon-14 in material that is supposedly 350 million years old, it is simply not that old. Further experiments in this area should be a high priority for creationists.

SUMMARY

To summarize, there are several testable creationist models for carbon-14 dating, which have implications for biblical interpretation and historical reconstruction. Testable areas include: 1) differences between ring years and radiocarbon years in trees that should be immediately postdiluvian by creationist theories, 2) the accuracy, or lack thereof, of the dendrochronological radiocarbon calibration curve in the historical era, and 3) the possible existence of carbon-14 in antediluvian fossil material. These models should be tested, so we may know which, if any, of them deserves our confidence.

ENDNOTES

1. The most specific examples are Dead Sea Scrolls which have reliable historical dates on them, which were dated twice (Bonani et al., 1992; Jull et al., 1995; see also Rodley 1993) with results that agree with the carbon-14 dates derived from dendrochronological calibration. Although there may be controversy over the accuracy of historical dates, and their matching with the dendrochronological calibration curve, in the era preceding 330 B.C. (see Testable Prediction #2), the accuracy of calibrated dates in the era from 330 B.C. to the present is secure.
2. This is known to have happened for Bristlecone pine. See Michael and Ralph (1981).
3. The difference averages over 100 years. The probability of this happening by chance is $p < 10^{-24}$. Even if one allows for uncertainties in the data by expanding the standard deviations of the measurements on bristlecone pine by multiplying by 1.3 and adding 20 years to the measurements, the probability is still $p < 10^{-14}$. See Suess (1978) for the data on bristlecone pine.
4. This has been noted by, among others, Brown (1979).
5. The 20-year calibration curve gives an uncalibrated radiocarbon date for 450 B.C. (± 10 years) of 481 ± 13 B.C., whereas the comparable dates from the 10-year curve, at $445 (\pm 5)$ and $455 (\pm 5)$ B.C., are 522 ± 44 B.C. and 558 ± 30 B.C. respectively. The 20-year curve gives an uncalibrated radiocarbon date for 670 (± 10) B.C. of 554 ± 13 B.C. whereas the 10-year curve gives a date for 661 B.C. of 495 ± 25 B.C. The probability of either of these two happening is $p < 0.05$.
6. The date itself has been reported, although in much abbreviated form, in Burky et al., 1998.
7. For details of the argument, see Giem (1997, p 175-188).

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EDITORIAL COMMENT

The editors feel this paper makes a valuable contribution to creationist writing, and we are pleased to publish it. However, we feel that a word of caution is in order. Historical theories are inherent difficult to test decisively, because one is attempting to reconstruct initial conditions, and the number of possibilities is, for practical purposes, infinite. Even if we can test a few possibilities, there may be too many variables to be able to disprove an idea completely. Furthermore, we have reservations about the power of science to test conclusively historical scenarios in which supernatural intervention is proposed. In historical science, tentativeness of conclusions is always appropriate, and more so when dealing with issues at the interface of science and Scripture. With this caveat in mind, we hope this article will indeed stimulate creationists to test their ideas wherever possible.

ARTICLES

THE NATURE OF EVIDENCE FOR THE ACTIVITY OF SUPERNATURAL INTELLIGENCE, AS ILLUSTRATED BY POLONIUM RADIOHALOS

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ABSTRACT

The polonium isotopes that produce radiohalos do not have a pattern of isotope abundance ratios similar to that of the other naturally occurring 91 chemical elements. Instead, polonium radiohalos are limited to the isotopes produced by daughters of long-lived uranium and thorium parents. Moreover, polonium radiohalo abundances are not in the 1:1 ratio of radioactive daughter-product production. Their abundance ratios are more similar to the associated half-life ratios. This feature could indicate relative time of survival in transport from the point of origin, simultaneous deposition from a solution carrying isotopes in equilibrium, or a combination of these processes.

For many individuals, the rare occurrence of 164 microsecond Po-214 radiohalos and of radiohalos in diamonds are readily accounted for by presuming de novo, in situ fiat creation. Another model based on infusion of daughter-product solutions accounts for the incongruities in the direct creation model. The present limited knowledge of hydrothermal diffusion through crystal lattice planes, and of geochemistry at lattice imperfection and impurity sites does not provide an unquestionable selection between the two models for explaining polonium radiohalos. Either model is within the creation classification, the difference being the level at which basic activity of the Creator is presumed to have been manifest.

INTRODUCTION

How can a particular phenomenon be evidence for the activity of a supernatural intelligence? From the baffling intricate characteristics of atoms, to the amazing yet barely perceived dynamics of stellar galaxies;

from the complex operation of a living cell, to the unexplained capabilities of the human mind; where can we find specific evidence for the activity of an all-encompassing intelligence, objective evidence for God?

Confronted with the reality of the material universe, with all its intricate complexity and delicately balanced interaction, it is logical to presume the existence of an all-encompassing intelligence as the Designer, Initiator, and Maintainer of the vast range of phenomena that we observe. In his epistle to the Romans, the Apostle Paul affirms that individuals who do not reach such a conclusion are “without excuse” (Rom. 1:19,20).

Ancient man tended to consider all physical phenomena as a direct manifestation of deity. For example: God in the sun; God, or perhaps another god, in the moon; god in the mountain; god in the sea; god in the tree; god in the lion. As knowledge increased, that which was considered to be a direct expression of deity has been pushed back to the level where understanding ceased. We now base our understanding of stars, geological formations, plants, and animals on the characteristics of the 92 different elements (kinds of atoms) and their compounds. However, the properties of these 92 basic elements and their compounds, and anything that cannot be explained on the basis of underlying phenomena, is considered by some individuals to be evidence of immediate and direct activity by the Intelligence who created and sustains the physical universe. Subsequent increased understanding may transfer the “evidence” to a simpler, more basic level, and foster an enlarged perception of the fundamental laws that were established by the Creator to maintain the universe.

An example of this progression to a more basic level is provided by the element lead. It is no longer necessary to postulate that God created lead in a mystifying wide variety of isotope ratios in various minerals. The range of lead isotope variation may be accounted for readily by mixing of primordial (from an initial creation event, whether a supernova explosion or a simple “God spoke” event) lead with lead produced by radioactive decay of uranium and thorium. This advanced understanding in no way diminishes the significance of atomic structure as evidence for design, creation, and maintenance by the Creator.

EXPECTATIONS CONCERNING PRIMORDIAL POLONIUM

The primary object of this paper is consideration of the evidence for the source of the element polonium. Each polonium atom contains

84 protons that determine its chemical characteristics. Eighty-four protons will not stay together in a nucleus unless they are accompanied by at least 106 neutrons. The number of accompanying neutrons may be as great as 134. The range of allowed neutrons gives polonium 29 isotopes (different forms which have the same chemical characteristics, but slightly different physical properties).

None of the 29 proton-neutron combinations in which polonium may be produced is stable. There is a spontaneous trend toward combinations that are stable. This trend is called radioactivity, because it was first observed in investigation of the element radium, which also is unstable. There is no known way to predict when an individual radioactive atom will convert to the next stage in the trend toward a stable proton-neutron combination; but it is possible to measure for a large number of atoms the statistical average of the time required for transition. The most convenient way to represent this average is known as half-life.¹ The most stable isotope of polonium — Po-209, which has 125 neutrons — has a half-life of 102 years. The least stable polonium isotope — Po-212, which has 84 protons and 128 neutrons — has a half-life of only 0.299 microseconds. Any Po-209 that was brought into existence in primordial creation (an initial creation event) would have diminished to about $1/1000$ of its initial amount by 1000 years later.²

To anticipate what might be expected in the primordial composition of polonium, we can compare polonium with two other elements that, like polonium, may exist in a wide range of isotopes. Tin, with 38 isotopes, and tellurium, with 14 isotopes, are the best elements for indicating the primordial abundance ratios and half-life features that we might expect for polonium. Tellurium and polonium have similar chemical characteristics, and are classified as Periodic Table Column VIA (Chemical Abstracts Service notation) elements.

Figure 1 shows the relative nuclear binding energies of the isotopes of tin compared with isotope 118 arbitrarily set as 1.000. There is no binding energy data currently available for isotopes 135, 136, and 137. Ten of the 38 isotopes of tin are stable. The percentage relative abundance of these ten stable isotopes is given at the top of their respective bars in Figure 1. Logarithms (base 10) of the half-lives of the unstable tin isotopes are represented in Figure 2. The available data only permit determination of a minimum (150 nanoseconds) for the half-lives of tin 102, 135, 136, and 137.³

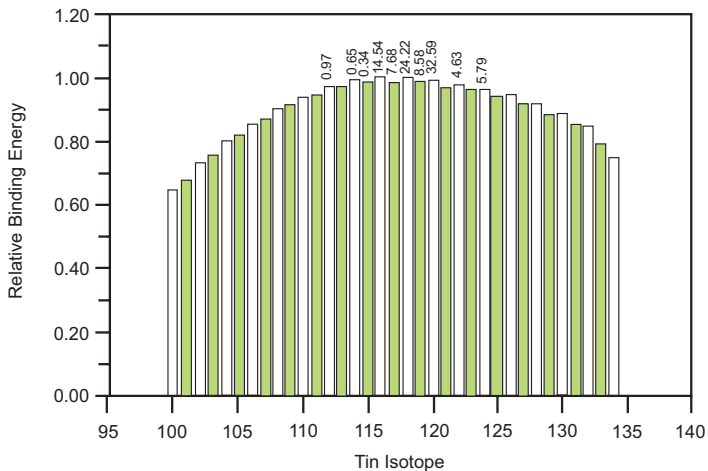
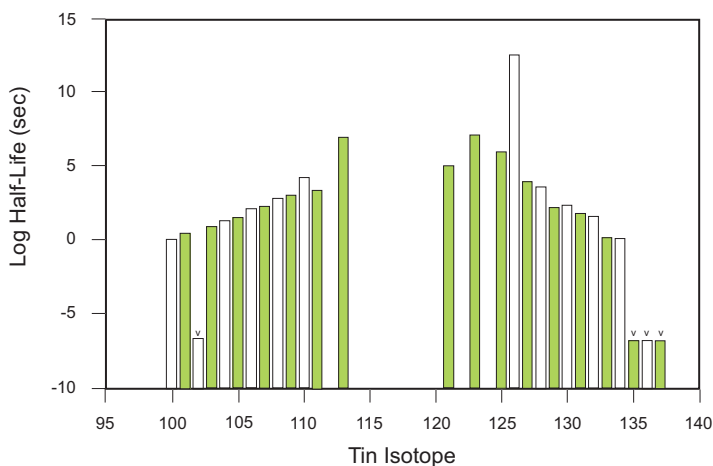


FIGURE 1. Relative Binding Energies of Tin Isotopes. Binding energy for Figures 1, 3 and 5 is taken with respect to the minimum of a smoothed line for a plot of nuclear binding energy vs isotope number. For convenient comparison, the binding energy is normalized to 1.00 for the isotope which has the highest binding energy of the group. Natural abundance percentage designated at the tops of the bars representing stable isotopes. No binding energy data available for tin isotopes 135, 136 and 137.

FIGURE 2. Tin Isotope Half-Life. Minimum value of uncertain half-life determination for isotopes 102, 135, 136 and 137 indicated by V.



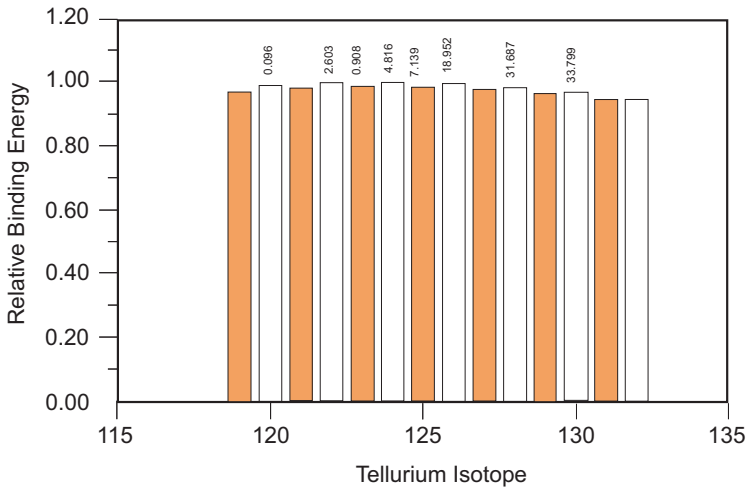
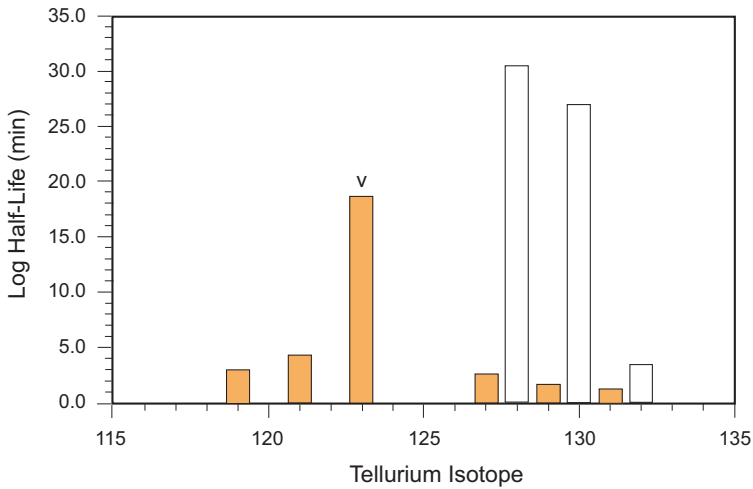


FIGURE 3. Relative Binding Energies of Tellurium Isotopes. Natural abundance percentage designated at the tops of the bars representing stable isotopes.

FIGURE 4. Tellurium Isotope Half-Life. Minimum value of uncertain half-life determination for isotope 123.



Similar corresponding data for tellurium are presented in Figures 3 and 4. The half-life of Te-123 is only known to be greater than 1×10^{13} years (5×10^{18} min). Although Te-128 and Te-130 are considered to be stable isotopes (abundance 31.687% and 33.799%, respectively), they are weakly radioactive (double-beta decay to xenon 128 and 130), with half-lives 7.7×10^{24} years and 2.7×10^{21} years, respectively.

POLONIUM RADIOHALOS

Since polonium has no stable isotopes, the question arises as to what evidence might be expected for the existence of primordial polonium. Polonium isotopes 199 to 207 decay principally by electron capture in which a proton is changed into a neutron, producing an isotope of bismuth. These bismuth nuclei also capture an electron and convert to an isotope of lead. All the other 20 polonium isotopes decay principally, or entirely, by emission of an alpha-particle (He-4 atom nucleus) to eventually become an isotope of lead. These alpha-particles may damage crystal structure in the surrounding region and produce what are known as radiohalos. Since the damage done by the alpha-particle is greatest at the end-portion of its track, a cross-section through the damaged crystal will show a circle (halo).

The distance an alpha-particle will travel before losing all its kinetic energy will depend on the electron density of the medium in which it is released. Table 1 lists the alpha-track length in standard air for the polonium isotopes 208 through 218. The data in Table 1 were obtained from laboratory measurements on alpha-particles of the same energy as those released by polonium.⁴ Conversion of the ranges listed in Table 1 to the corresponding range in a crystal such as mica or fluorite may be estimated to a close approximation by multiplication with the ratio of electron density in standard air to that in the crystal. The average distances traveled in mica for the Po-218, Po-214, and Po-210 alpha-particles are 23.1, 34.4, and 19.5 microns, respectively.⁵ *Creation's Tiny Mystery*⁶ contains an excellent collection of radiohalo photographs.

PRIMORDIAL POLONIUM IDENTIFICATION

As indicated in Figures 5 and 6, polonium isotopes 210, 211, 212, 214, 215, 216, and 218 are continually produced by the radioactive decay of thorium and uranium. Only isotopes 208, 209, 213, and 217 in the upper range could be considered uniquely primordial, since there is no

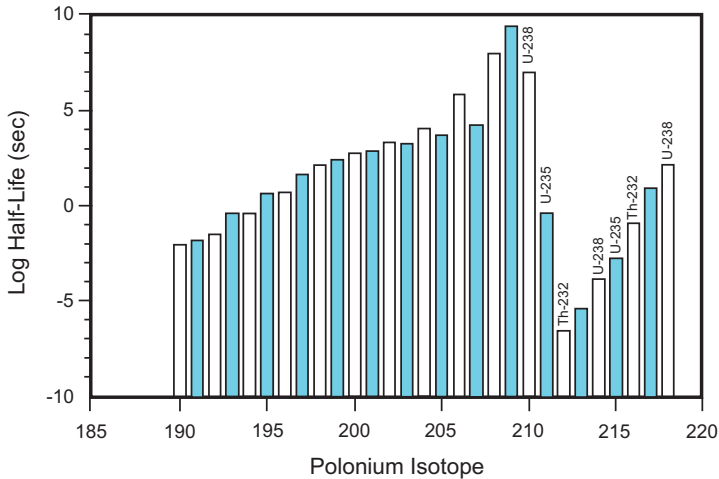


FIGURE 6. Polonium Isotope Half-Life. Long-lived radioactive parent of isotopes associated with radiohalos designated at the tops of the bars for these isotopes.

other known source for their existence. Any of the polonium isotopes below 199, all of which are alpha emitters, also could provide radiohalo evidence of primordial polonium. The maximum abundance areas in the stable isotope abundance data for tin and tellurium, Figures 1 and 3, suggest that the most likely alpha-emitting primordial polonium isotopes are in the range 208 to 213.

The data in Table 1 indicate that radiohalos from isotopes 208, 209, and 213 would be readily distinguishable from halos produced by uranium and thorium daughter products. Within the limits of my knowledge, all radiohalos in the 4-9 MeV range reported in the literature are satisfactorily accounted for by uranium and thorium daughters. But consideration must be given to the possibility that some polonium radiohalos that exist today were formed by primordial polonium, rather than by daughters of thorium and uranium.

The longest half-life of the polonium daughters of uranium and thorium is 138.376 days (Po-210, daughter of U-238). Five years after a creation event all primordial polonium of the sort that can be produced also by radioactive decay of a parent would have disappeared.⁷ Halos from polonium isotopes in this category may be interpreted either as having been formed within five years of a primary creation event, or as a consequence of subsequent radioactivity.

A prominent feature of isotope abundance is the predominance of isotopes that have even numbers of both protons and neutrons. This feature is illustrated by the abundance data in Figures 1 and 3. Accordingly, the most abundant isotope of primordial polonium would most likely be the even-even (84 protons, 124 neutrons) isotope Po-208 with a 2.898 year half-life. The stable daughter of Po-208 is Pb-204 (half-life $>1.4 \times 10^{17}$ yr), which is 1.4% of common lead. The complete absence of this lead isotope from the central inclusions of some polonium radiohalos⁸ clearly indicates that the polonium which formed them was the product of radioactivity rather than primordial creation.

A significant amount of even-odd 102-year isotope 209 would also be expected as a component of primordial polonium. I do not know of any investigation that has reported detection of either Thallium-205, the stable daughter, or Lead-205, the 15.3 million-year radioactive daughter, of Po-209 in the center of polonium radiohalos.

The conspicuous absence of halos associated with polonium isotopes 208 and 209 strongly indicates that the polonium radiohalos which have been observed are a consequence of uranium and thorium radioactivity, and do not provide conclusive evidence of primordial polonium.

THE POLONIUM RADIOHALO ENIGMA

The existence of radiohalos in minerals such as mica has been known since the first decade of the nineteenth century. Efforts to provide an explanation for polonium halos that do not have evidence of a supporting long-lived radionuclide at the halo center (isolated halos) extend as far back as the late 1930s.⁵ A halo set produced by 164 microsecond half-life Po-214 (two rings), or by 3.1 minute half-life Po-218 (three rings), without any evidence of a radioactive parent at the site, has been an enigma. The favored explanation has been penetration of a hydrothermal radioactive solution along crystal lattice planes. This explanation readily accounts for the extreme rarity of halos from the six alpha-particles emitted in the decay of thorium to Pb-208, although thorium is over three times more abundant in Earth's crust than is uranium. Thorium and its compounds are relatively insoluble in water, and would not be as easily transported as uranium.

Another enigma is the relative frequencies with which the various types of polonium radiohalos (three rings, two rings, or one ring for the U-238 sequence) are observed.

A clue for finding satisfactory insight into these considerations may be provided by the existence of Po-210 radiohalos in coalified wood from uraniferous sands in the Colorado Plateau.⁹ This subfossil wood was evidently buried in the late stages of the Flood, or possibly during a period of intense geological activity in early post-Flood time. Subsurface water carrying highly soluble uranyl ions, together with uranium-series daughter products, evidently infused buried logs. Sites that favored chemical deposition of polonium or polonium precursors accumulated sufficient polonium atoms to produce a detectable polonium halo — in the order of 10^8 atoms, or more.⁵

In a solution containing uranium and equilibrium concentrations of its daughter-products, polonium isotopes 210, 218, and 214 would be present in concentration ratios

$$[\text{Po-210}]/[\text{Po-218}]/[\text{Po-214}] = 1.000/(1.5 \times 10^{-5})/(1.3 \times 10^{-11}),$$

since equilibrium concentrations are proportional to half-life. Infusion into the wood over sufficient time to accumulate enough Po-210 atoms to make only a discernible Po-210 halo site, as in the Colorado specimens, would not deposit enough atoms to produce visible Po-218 or Po-214 halo sites.

To the extent that the intensity of a halo ring is proportional to the number of alpha particles passing through a unit of area, rings from Po-210 daughters of Po-214 may be expected to be 3.3 (range ratio squared) times as intense as rings from Po-214. For polonium deposited from a solution with equilibrium ratios of concentration the corresponding intensity ratio is 73 billion! On this basis complete saturation of crystal damage for the Po-210 ring would occur long before a Po-214 ring became discernible. These considerations raise a question as to why any polonium ring sets occur that have a Po-214 ring without an associated Po-218 ring (Po-214 halos). In an equilibrium state Po-218 is 1.2 million times more abundant than Po-214.

Given a constant supply of Po-218, as is possible from radium, equilibrium ratios among the polonium isotopes would not be reached until about 100 years after a zero-level starting point, because 22.3 year half-life Pb-210 is between Po-214 and Po-210 in the decay sequence (see Figure 7). If the Po-218 input rate is constant, Po-218 and Po-214 will reach equilibrium ratio of 1.1×10^6 (ratio of half-lives) about 3 hours after a zero-level startup, since 26.8 minute half-life Pb-214 and 19.9 minute half-life Bi-214 are between Po-218 and Po-214 in the

decay sequence. During the first few hours of the 100 years required for Po-210 to go from zero-level to equilibrium ratio with Po-218, Po-218 would be more abundant than Po-210 (see Appendix).

In the natural circumstances in which polonium halos were formed, there probably were large temporal variations in solution flow rates and also isotope concentrations. And there may have been complex geochemical reactions involving polonium, lead, and bismuth. The preceding idealized treatment was provided to indicate parameters within which a logical explanation may be developed for the predominance of Po-210 halos, and for the extreme rarity of Po-214 halos. The chance for a polonium atom finding a binding site in the Colorado fossil wood may have been so low that only Po-210 atoms existed long enough to bind in sufficient numbers to produce a visible radiohalo.

If the infusing solution did not contain a significant amount of radium, any Po-214 and Po-218 that it may have contained would have essentially disappeared within five hours of migration. Polonium-210 that might remain, and Po-210 produced by 22.3 year half-life Pb-210, could be deposited and form Po-210 halos in the wood.

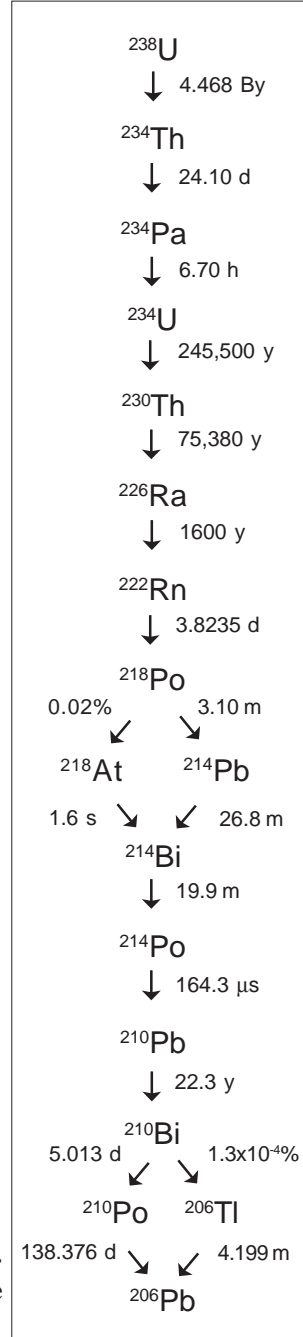


FIGURE 7. Uranium-238 Decay Sequence. Half-life is designated for each stage. Percentage designated for alternate decay routes.

In the development of a model for radiohalos produced by solution infusion, it is important to maintain a distinction between halo density and halo intensity. Density is the number per unit volume of host rock, or number per unit area of field in a viewing microscope. Intensity designates the degree of host crystal deformation in the halo ring, which is related to the number of polonium atoms that produced the halo. Density may relate only to the concentration of sites in the host that are favorable to the deposition of polonium. Intensity is determined by polonium concentration in the infusing solution, infusion rate, and infusion time.

The presence of complete ring sets from Po-218, Po-214, and Po-210 (“Po-218 halos”), and rare double ring sets from Po-214 and Po-210 (“Po-214 halos”), together with predominant single Po-210 rings (“Po-210 halos”) in minerals, suggests a fluid-infusion-based separation process similar to that which accounts for the occurrence of only Po-210 halos in coalified wood. A broad study of the relative frequency of Po-210, Po-218, and Po-214 halos in the various minerals in which they may be found, and of the relative intensities of the rings within these halo sets, would be of great value toward resolution of the radiohalo enigma.

The hydrothermal infusion explanation requires that the host mineral lattice contains impurity sites that favor the chemical deposition of polonium or a precursor. Wherever Po-218 is deposited, successive stages in the decay series will produce Po-214 and Po-210, but either of these lighter isotopes could be deposited simultaneously with, or subsequent to, Po-218. Determination of the portion of simultaneous or subsequent deposition could be made by comparison of the intensities of the three rings in the set.¹⁰

That the postulated hydrothermal infusion process may occur in mica has been fully established. Copper inclusions 0.002 to 0.1 microns thick, and up to 1.0 micron in diameter, are found in favored lattice planes of some biotites.¹¹ The normal lattice plane separation in biotite is 0.001 micron. Ilton and Veblen have obtained impressive transmission electron microscope images of biotite cross-sections that contain Cu inclusions. The Cu in these inclusions was evidently deposited from a hydrothermal solution. We can expect that similar images for mica containing uranium and polonium radiohalos would show the lead (stable daughter of uranium and polonium) inclusions that x-ray analysis has demonstrated exist at radiohalo centers.¹² The unique Spectacle Halo

impressively indicates diffusion of a uraniferous solution across a biotite lattice plane.¹³

The limited knowledge with which we can attempt to model a fluid infusion process, together with selective deposition of polonium isotopes at different sites on the infusion plane — particularly the 164 microsecond half-life Po-214 — leave “explanations” for radiohalos in an unsatisfactory state. There is a difference of opinion as to whether these halos, particularly those from Po-214 and Po-218, are the direct consequence of a unique creation event, or are the consequence of physical and chemical processes that were established at creation.

When faced with a phenomenon their understanding is unable to comprehend, some individuals who believe in deity as First Cause may form a conclusion as to “how God did (does) it” that way. If a position on the subject is then taken publicly, it is difficult to modify this position when additional evidence indicates that God did it in a different way than they initially thought. It is desirable for all individuals who have taken a position regarding the origin of 164 microsecond polonium halos to hold that position lightly, and in humility, since definitive experimental evidence is limited. The direct creation *in situ* model readily accounts for some features that have not yet been explained to complete satisfaction by migration of radioactive daughter-products.¹⁴ A model based on infusion of daughter-product solutions accounts for incongruities in the direct creation model.¹⁵

SUMMARY

As a summary of the observational/experimental evidence, it can be noted that the following considerations favor diffusion of a radioactive solution through crystal lattice planes as an explanation for radiohalos.

1. Association of mineral specimens in which radiohalos are found with a region that has a relatively high level of radioactivity.
2. The positive relationship between the frequency of radiohalo appearance and the solubility of the radioactive parent(s) associated with the isotope that produced the halo type.
3. The positive relationship between the frequency of radiohalo appearance and the half-life of the isotope that produced the halo.
4. The restriction of observed halo-producing isotopes to the radioactive daughters of uranium and thorium.

5. Complete absence of halos from the most probable primordial isotopes that are not also daughters of uranium and thorium.
6. The radiohalo features of uraniferous wood.
7. Copper and polonium deposition site patterns on mica lattice planes.

ACKNOWLEDGMENTS

Readers of this treatment are greatly benefited by suggestions from unnamed reviewers whose contributions I am pleased to acknowledge.

ENDNOTES AND REFERENCES

1. While the nuclear half-life is a quantitative designation only for a statistically large number of atoms, it nevertheless is a precise characteristic of the isotope. See: Brown RH. 1990. Radiohalo evidence regarding change in natural process rates. *Creation Research Society Quarterly* 27(3, December):100-102. Additional comments in *CRSQ* 28 (4, June 1991):40-41.
2. 1000 years is equal to 9.80 half-lives of 102 years each. $(\frac{1}{2})^{9.80} = 0.00112$.
3. Nuclear data in this paper are taken from Nuclear Wallet Cards (5th edition, July 1995). Jagdish K. Tuli, National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973.
4. Bethe HA. 1950. The range-energy relation for slow alpha-particles and protons in air. *Reviews of Modern Physics* 22(2):213-219.
5. Meier H, Hecker W. 1976. Radioactive halos as possible indicators for geochemical processes in magmatites. *Geochemical Journal* 10:185-195.
6. Gentry RV. 1988. *Creation's tiny mystery*. Second ed. Knoxville, TN: Earth Science Associates.
7. Five years is 13.2 periods of 138.4 day half-life. $(\frac{1}{2})^{13.2} = 0.000,107$. Po-210 will not reach an insignificant level until its parent 22.3 year half-life Pb-210 does. 13.2 periods of 22.3 years is 294 years.
8. (a) Gentry RV. 1971. Radiohalos: some unique lead isotope ratios and unknown alpha activity. *Science* 173:727-731; (b) Gentry RV. 1973. Radioactive halos. *Annual Review of Nuclear Science* 23:347-362; (c) Gentry RV, Cristy SS, McLaughlin JF, McHugh JA. 1973. Ion microprobe confirmation of Pb isotope ratios and search for isomer precursors in polonium radiohalos. *Nature* 244:282-283.
9. (a) Gentry RV, Christie WH, Smith DH, Emery JF, Reynolds SA, Walker R, Cristy SS, Gentry PA. 1976. Radiohalos in coalified wood: new evidence relating to the time of uranium introduction and coalification. *Science* 194:315-318; (b) York D. 1979. Polonium halos and geochronology. *EOS, Transactions of the American Geophysical Union* 60(33):617-618.
10. If there is no simultaneous or subsequent deposition of the daughter isotopes, the halo density ratios should be approximately inverse to the squares of the halo radii. Simultaneous or subsequent addition of one of the daughter isotopes would make its halo more dense than expected in comparison with the Po-218 ring.
11. Ilton ES, Veblen DR. 1988. Copper inclusions in sheet silicates from porphyry Cu deposits. *Nature* 344:516-518.
12. See Endnote 8c.

13. The Spectacle Halo is a unique formation of overlapping Po-210 halos. The individual halo centers form a pattern of two circles, one slightly smaller than the other, connected by a tangential straight line. See Endnote 6, Fig. 12 on p 279.
14. An example is radiohalos in diamond. Armitage M. 1995. Internal radiohalos in diamond. *Creation Ex Nihilo Technical Journal* 9(1):93-101.
15. An individual who wishes to pursue this topic further may find the following additional references helpful: (a) Wise KP. 1989. Radioactive halos: geological concerns. *Creation Research Society Quarterly* 25(4):171-176; (b) Brown RH, Coffin HG, Gibson LJ, Roth AA, Webster CL. 1988. Examining radiohalos. *Origins* 15(1):32-38.

APPENDIX: POLONIUM ISOTOPE RATIOS

The radioactive solution infusion model requires consideration of isotope ratios during the early stages of solution development. An investigation of the possible values for these ratios can begin with postulation of a solution in which all isotopes below Po-218 in the sequence of Figure 7 are initially at zero concentration, and Po-218 is introduced at rate R to maintain a concentration [Po-218]. When equilibrium is attained each radioactive isotope in the series will decay at rate R. With T representing half-life, $R = [\text{Po-218}] (\ln 2) / T_{\text{Po-218}}$.

At a constant formation rate, a radioactive isotope will be brought from zero-level to 95% of equilibrium level in 4.322 half-lives. During this time the number of isotope atoms produced will be 4.322T times R. The difference between production and 95% of equilibrium will be conveyed to succeeding isotopes in the sequence. In this example the equilibrium level for Pb-214, the daughter of Po-218, is given by $T_{\text{Pb-214}}/T_{\text{Po-218}}$ times [Po-218]. Calculation of the difference between production and 95% of equilibrium yields 17.7 [Po-218].

For Pb-214, 95% of equilibrium will be reached in 116 minutes. If we assume that after 116 minutes Pb-214 is an essentially constant source of Bi-214, Bi-214 will reach 95% of equilibrium 86 minutes later, 202 minutes following start from zero level. In 202 minutes Pb-214 will be at the 99.5% of equilibrium level. This consideration, plus the 17.7 [Po-218] carryover from the first 116 minutes, indicates that Bi-214 will be near 100% of equilibrium by 202 minutes after start from zero level.

Since the equilibration time for Po-214 is negligible in comparison with the half-life of parent Bi-214, the concentration of Po-214 will closely follow that of Bi-214, and all isotopes from Po-218 to Po-214 will be in essential equilibrium at rate R by 200 minutes after beginning of the formation process.

Since the equilibration times for Bi-210 and Po-210 (21 days and 600 days, respectively) are small compared with the half-life of parent Pb-210 (22.3 years), the concentrations of these isotopes will follow the Pb-210 concentration rather closely. At 200 minutes after startup from zero level, Pb-210 will be at only 0.0012% of its equilibrium level for input rate R, and Po-210 will be at the same proportionate level. Since the [Po-210]/[Po-218] equilibrium ratio is 0.667×10^5 , its ratio at 200 minutes is about 0.8.

On the basis of these considerations we can expect a fresh radium solution to have a Po-210/Po-218 ratio less than one for the initial several hours of the time for development of the 6.67×10^4 ratio that is attained after 100 years.

It is readily apparent from Figure 7 that a site at which there is a deposit of bismuth and/or lead without polonium will not have a Po-218 ring. The only polonium halos in the U-238 sequence that can be produced from deposition at such sites are the Po-214 (two rings) and Po-210 (one ring) varieties. The relative frequency with which Po-214 halos and Po-218 halos are observed may be considered as an indication of the probability for bismuth and lead deposition without polonium.

ANNOTATIONS FROM THE LITERATURE

COMPARATIVE GENOMICS

Blattner FR, Plunkett G, Bloch CA, + 14 others. 1997. The complete genome sequence of *Escherichia coli*. *Science* 277:1453-1462.

Summary: *Escherichia coli*, common in animal digestive tracts, has what is probably the most intensively studied genetic system of any species. Complete sequencing of its genome not only contributes to a greater understanding of how *E. coli* operates, but will also provide an excellent check on conclusions drawn from many years of research. The genome contains 4288 protein-coding genes, of which 1632 (38%) were previously unknown. This number may be reduced, since 383 known *E. coli* proteins have not yet been matched with any gene sequence, but this would still leave 29% of the genes classified as previously unknown. As expected, *E. coli* is similar to *Haemophilus influenzae* — the two species share 1130 genes, nearly two-thirds of the entire genic complement of *H. influenzae*. The archaeon *Methanococcus jannaschii* shares only about 231 (13%) of its genes with *E. coli*, and the eukaryote *Saccharomyces cerevisiae* shares about 254 (less than 5%) of its genes with *E. coli*.

Comment: From the limited sample available, it appears that species considered to be closely related on other grounds also have similar sets of genes, while species considered to be only distantly related share a relatively small number of genes. This is not surprising, but it does confirm that bacteria are an extremely heterogeneous group.

Bult CJ, White O, Olsen GJ, + 36 others + Venter JC. 1996. Complete genome sequence of the methanogenic archaeon, *Methanococcus jannaschii*. *Science* 273:1058-1073.

Summary: The genome sequencing era continues with the first member of the group of bacteria known as Archaea. Archaea include a variety of autotrophic bacteria that live in such inhospitable places as hydrothermal vents, hot springs and deep underground. Their relationships, if any, to other organisms are controversial, and distant

at best. This is the first report of the genome sequence of an archaean species. The genome consists of three circular elements, containing 1682, 44 and 12 apparent genes. Most of the genes were new to science. The function of only 38% of the genes could be identified with confidence, while another 6% matched apparent genes in other organisms for which the protein function is unknown. Comparisons with two other species of bacteria showed an overlap of only 11% (*Haemophilus influenzae*) and 17% (*Mycoplasma genitalium*) of their genes. Genes involved in cell division, energy production, and metabolism were more similar to those of Eubacteria, while genes involved in gene processing (transcription, translation, replication) were more similar to those of eukaryotes. In general, *Methanococcus* has greater similarities to eukaryotes than to ordinary bacteria.

Comment: The differences between this archaean bacteria and the known ordinary bacteria are startling, although suggested by previous studies. We are reminded again of the great complexity and diversity of living organisms, and the great amount of study that must be done if we are to understand how life operates at even the simplest level.

Fraser CM, Casjens S, Huang WM, + 35 others. 1997. Genomic sequence of a Lyme disease spirochaete, *Borrelia burgdorferi*. Nature 390:580-586.

Summary: Bacteria include a group of spiral-shaped forms known as spirochaetes. Many spirochaetes are pathogenic, including *Borrelia burgdorferi*. Lyme disease was apparently present in Europe since the beginning of the 1900s, but was first identified in the United States in the mid 1970s. It is now known to occur widely in the Northern Hemisphere. The causative agent, *B. burgdorferi*, was finally isolated in the early 1980s. The genome consists of a linear chromosome with 853 coding sequences, of which 249 (29%) have not been identified in any other organism. Another 430 coding sequences are present in a total of 11 plasmids. More than half (250, 58%) of these have not previously been seen.

Comment: Nearly every newly sequenced bacterial species seems to have a large complement of genes never observed previously. The great diversity of gene complements in different

types of bacteria complicates the search for a possible suite of genes that represents the minimal genetic requirements for a living cell. *Mycoplasma genitalium* has the smallest genome of any cell capable of independent living (even *M. genitalium* is a parasite). The genome of *M. genitalium* is believed to approximate the minimal genetic requirements for a living cell, yet it contains 310 genes not identified in *Escherichia coli*. The remaining 158 of its 468 proteins are probably not enough for survival, so the minimal genetic complement must be greater than 158, but less than 468.

Klenk H-P, Clayton RA, Tomb J-F, + 48 others. 1997. The complete genome sequence of the hyperthermophilic, sulphate-reducing archaeon *Archaeoglobus fulgidus*. *Nature* 390:364-370.

Summary: This sulphur-metabolizing organism has a genome of 2436 coding regions, of which 639 (26%) have no match with previously known genes. The only other archaeon to be sequenced so far is *Methanococcus jannaschii*. Comparison of the two genomes shows a match of 916 genes, about 53% of the *M. jannaschii* genome. Genes for processing information are similar in the two archaeon species, while genes for intermediary metabolism show notable differences.

Comment: This result shows that even among bacteria in the same group, Archaea, there is great diversity in the gene complement.

Kunst F, Ogasawara N, Moszer I, +148 others. 1997. The complete genome sequence of the Gram-positive bacterium *Bacillus subtilis*. *Nature* 390:249-256.

Summary: *Bacillus subtilis* is probably the best-known Gram-positive bacterium. It is common in soil, water and plants, and is non-pathogenic. The genome contains about 4100 protein-coding genes, of which 58% have known functions and 30% do not match any genes previously discovered. The remaining 12% match sequences previously discovered, but for which the function remains unknown. Sequences were identified indicating infection with at least ten different prophages (viruses), which could have transmitted genes to *B. subtilis* from other species. *Mycoplasma genitalium* is thought to be derived from bacteria similar to *B. subtilis*. Comparison of their two genomes identified 300 genes in common,

and reduced the number of unique genes in *M. genitalium* from 96 genes to 90 genes. The intestinal bacterium, *Escherichia coli*, is a Gram-negative bacterium, believed to be only distantly related to *B. subtilis*. The two species share about 1000 clearly identifiable genes.

Comment: About 20% of the genes of *M. genitalium* are not identifiable in its putative relative, *B. subtilis*. Perhaps further study will reveal whether these genes have been lost in *B. subtilis* or gained in *M. genitalium*. If they have been gained in *M. genitalium*, it will be of interest to determine whether the best explanation is cross-species gene transfer, or within-species mutations.

Mewes HW, Albermann K, Bahr M, + 9 others. 1997. Overview of the yeast genome. *Nature* 387:7-65. Reaction: Clayton RA, White O, Ketchum KA, Venter JC. 1997. The first genome from the third domain of life. *Nature* 387:459-462.

Summary: The common baker's yeast, *Saccharomyces cerevisiae*, is a single-celled eukaryote. It is the first species with an organized nucleus to have its genome completely sequenced. The genome contains perhaps 5800 genes, which is almost half again as many as either *Escherichia coli* or *Bacillus subtilis*. Functions could be identified for 3167 genes. Some 2000 "orphan" genes remain without known function or matches in other organisms.

Comment: With fewer than 20 species sequenced so far, the number of genes shared by all species is surprisingly low, and each species appears unique. The uniqueness of each bacterial species makes it dubious to use any one of them as representative of a large group of species. It seems likely that uniqueness is pervasive among eukaryotes, and that yeast should not be taken as representative of eukaryotes.

Tomb J-F, White O, Kerlavage AR, + 39 others. 1997. The complete genome sequence of the gastric pathogen *Helicobacter pylori*. *Nature* 388:539-547.

Summary: Nearly half the population of the world is believed infected with *Helicobacter pylori*, which causes peptic ulcers and is associated with some kinds of cancer. Of the 1590 recognizable coding sequences in *H. pylori*, a member of the Gram-negative Eubacteria, nearly one-third (499) do not match previously known

sequences. Many proteins of *H. pylori* are similar to those of *Escherichia coli* and *Haemophilus influenzae*, which are thought to be closely related. However, many other proteins involving production of amino acids, production of proteins, and other cellular processes are more similar to bacteria thought to be only distantly related. This could be due to horizontal gene transfer, or to retention of original forms of proteins.

Comment: The situation where some genes suggest one set of relationships while other genes suggest different relationships provides an interesting problem for understanding the origins of biodiversity.

DESIGN

Dembski WA. 1997. Intelligent design as a theory of information. *Perspectives on Science and Christian Faith* 49:180-190.

Summary Intelligent design can be regarded as a theory dealing with the origin and flow of information. Information itself is difficult to define, but is related to probability. The lower the probability of an event, the greater the information that can be derived from the event. For example, the probability of being dealt a royal flush in a hand of playing cards is about 2×10^{-6} . Knowledge that such a hand was dealt carries more information than knowledge that a person was not dealt a royal flush (which carries a probability of about 0.999998). Information can be defined as the negative base 2 logarithm of the probability of an event.

Information can be “specified” or “unspecified.” It is specified if the event can be independently identified by a pattern; otherwise it is unspecified. For example, suppose an archer shoots an arrow at the wall. The probability is very low that any specific spot will be struck. However, this low probability is not enough to infer intelligent design, because the event is unspecified. If a target is first painted on the wall, and the arrow strikes the “bull’s-eye”, one can readily identify a specification of the event. Specification of information is easily understood when the pattern is identified before the event occurs, but it may also occur in some cases when the pattern is identified after the event. In the latter case, the key is that the pattern produced by the event is sufficient to identify the occurrence of the event, independently of knowledge of the occurrence of the event. Information that is both specified and complex is indicative of

intelligent design. Another way of expressing this is to say that intelligent design is characterized by choice, and choice is identified by the actualization of a specified event, to the exclusion of other possibilities.

According to Dembski, information cannot originate from natural causes. This is because natural causes are based on chance and necessity. Information is based on contingency, which means that it cannot be derived from necessity. Chance may produce information that is complex, or that is specified, but it is inadequate to produce information that is both complex and specified. Combining chance and necessity merely means arranging their effects in some sequence, which does not solve the problem. Because complex specified information (CSI) cannot be generated by natural causes, certain conclusions can be drawn relative to intelligent design: the CSI in a closed system of natural causes remains constant or decreases, and the CSI in any closed system of natural causes must have been put there before the system became closed. Since life requires CSI, it must be the product of intelligent design.

Comment: The necessity for “intelligent design” is being promoted by a number of scholars, including William Dembski. Critics of intelligent design have pointed to the lack of a suitable definition of design. This paper is a useful and thoughtful response to these criticisms.

GENETIC ENGINEERING

Wilmut I, Schnieke AE, McWhir J, Kind AJ, Campbell KHS. 1997. Viable offspring derived from fetal and adult mammalian cells. *Nature* 385:810-813.

Summary: Cloning of animals generally requires material from very early in development, as it appears that cells become committed to a specific function (differentiated) early in development. Thus they lose their ability to produce an entire individual, because many genes have been permanently turned on or off, in accordance with the specific function of the cell. This paper is the first report of production of an individual from a body cell of an adult mammal. The procedure involved transfer of a cell nucleus into an unfertilized sheep egg from which the nucleus had been removed. Three types of donor cells were used, including adult mammary gland cells.

All three cell types successfully produced viable young, although the fetal mortality rate was high. In each case, the characteristics exhibited by the lamb were those of the donor of the nucleus, rather than of the egg.

Comment: This result opens up many new possibilities in biological research, and many new questions in bioethics. It also serves as a lesson that many of the things we know may be wrong.

GEOLOGY

Evans DA, Beukes NJ, Kirschvink JL. 1997. Low-latitude glaciation in the Palaeoproterozoic era. *Nature* 386:262-266.

Summary: Ancient glaciations have been inferred on the basis of deposits of unsorted clasts of mixed sizes, striated rocks, and polished rocks. Yet such deposits are sometimes found closely associated with evidence of tropical conditions, such as carbonate rocks and evaporites. In such cases, estimates of paleolatitude might indicate whether the area of the supposed glaciation was located near the poles. The Precambrian Makganyene diamictite of South Africa is one such deposit. It is overlain by volcanic rocks, the Ongeluk Lava, for which it is possible to take paleomagnetic measurements. Results are interpreted to indicate a paleolatitude of about 11 degrees. This result merely deepens the enigma of the supposed tropical ice ages.

Comment: Although the authors do not propose it, an alternative explanation for the geological evidence that does not include glaciation seems in order.

Renne PR, Sharp WD, Deino AL, Orsi G, Civetta L. 1997. $^{40}\text{Ar}/^{39}\text{Ar}$ dating into the historical realm: calibration against Pliny the Younger. *Science* 277:1279-1280.

Summary: Volcanic material from the 79 A.D. eruption of Mt. Vesuvius in Italy was dated by the argon/argon method at 1925 +/- 94 years ago. This is in good agreement with the historical date of 1918 years ago for the eruption. This result shows that argon/argon dating can be used for events within historical times. During the procedure, significant amounts of "excess argon" were noted, yielding ages up to 521,000 years. By gradual, stepwise heating of

the sample, it was possible to obtain ages that agreed with the known historical age of the sample.

Comment: It is remarkable that such precision was achieved. However, without knowledge of the true age of the sample, it might be difficult to know whether to accept the 521,000-year age instead.

HUMAN FOSSILS

Krings M, Stone A, Schmitz RW, + 3 others. 1997. Neandertal DNA sequences and the origin of modern humans. *Cell* 90:19-30.

Summary: The original specimen of “Neandertal Man” was used as a source of DNA, which was sequenced and compared with DNA from living humans. Results indicate that the Neandertal specimen differed from the reference sequence, taken from a living human, at 27 positions out of 360. Living humans differ from each other at an average of 8 positions. This is interpreted to mean that Neandertals were a separate species, and were not directly ancestral to living humans. Modern humans differ from chimps at an average of 55 positions. Unfortunately, no comparable figure was reported for a Neandertal/chimp comparison. Although numerous problems are involved in sequencing DNA from fossils, the results of this study were obtained in two independent trials, supporting its reliability.

Comment: It seems premature to conclude that Neandertals were a separate species from modern humans on the basis of this study. Although replication of the results lends credibility to the report, it should not be overlooked that scientists have failed in attempts to extract DNA from fossils associated with Neandertal skeletons. It would be helpful if DNA could be recovered from another Neandertal skeleton and compared with the results reported here. Another point of interest is that modern humans vary at 225 positions in the sequence, although the full range of variation is not seen in any single comparison. Of the 27 differences reported here in the Neandertal sequence, 25 have been previously reported in modern humans. Thus only two positions in the Neandertal sequence are not known to be shared with some humans. Another point to consider is that mitochondrial DNA may be much more changeable than has been generally thought, as illustrated by recent studies.

LIFE ON MARS?

McKay DS, Gibson EK, Thomas-Keprta KL, + 6 others. 1996. Search for past life on Mars: possible relic biogenic activity in Martian meteorite ALH84001. *Science* 273:924-930.

Summary: A meteorite discovered in the Antarctic in 1984 contains carbonate globules and polycyclic aromatic hydrocarbons, which could have been produced by bacteria. The mineralogy of the meteorite suggests an origin on Mars, and it is thought that it was blasted to Earth by an asteroidal or cometary impact. If the carbonate globules and hydrocarbons are due to biological activity, it could indicate that life is present on Mars. Magnetite and iron sulfides are also present. Each of these features could be produced by either biological or inorganic processes, but when considered collectively, they point to a biogenic origin for the carbonates in the meteorite.

Comment: This sensational proposal has stimulated a great deal of discussion, both in the scientific literature and in the public press. The announcement was made at a NASA press conference, the timing of which seemed remarkably close to Congressional consideration of funding for NASA's budget. Some of the scientific responses are described below.

Shearer CK, Papike JJ. 1996. Evaluating the evidence for past life on Mars. *Science* 274:2121.

Summary: Living organisms produce fractionation of sulfur isotopes, but study of sulfur isotope ratios in pyrite grains of the "Martian meteorite" do not support the inference of bacterial activity. Sulfur isotope ratios in the "Martian meteorite" are consistent with impact processes or low temperature weathering processes.

Bradley JP, Harvey RP, McSween HY. 1997. No 'nanofossils' in Martian meteorite. *Nature* 390:454.

Summary: Many of the elongated forms found on surfaces within the Martian meteorite are actually the emergent edges of microstructural elements of minerals in the meteorite. Others appear to be "magnetite whiskers." The majority of these structures appear to be inorganic, although a biogenic origin cannot be ruled out in every case.

McSween HY. 1997. Evidence of life in a Martian meteorite? Geological Society of America Today 7(7):1-7.

Summary: Terrestrial contamination by Antarctic meltwater may explain the presence of organic matter in cracks in the Martian meteorite. The polycyclic aromatic hydrocarbons found in the meteorite resemble those found in Antarctic ice. Some reports of carbon isotopic fractionation may be due to laboratory contamination. The supposed microorganisms match in size and shape the magnetite whiskers reported by Bradley et al., and it is unlikely they represent fossilized bacteria. A critical but unresolved issue is the temperature at which the carbonate globules formed. Kirschvink et al. (1997: Science 274:1629-1633) claim a low temperature origin, while Scott et al. (1997: Nature 387:377-379) argued for a high-temperature history of the meteorite.

Scott ERD, Yamaguchi A, Krot AN. 1997. Petrological evidence for shock melting of carbonates in the Martian meteorite ALH84001. Nature 387:377-379.

Summary: Petrological studies of the Martian meteorite show that carbonate, plagioclase and silica in the meteorite were melted by a shock event which also locally crushed the pyroxene. This shock event would have raised the temperature of the carbonate sufficiently to melt it, destroying any evidence of life if it were present. Therefore, the carbonate globules cannot represent the effects of bacterial action, but are inorganic in origin.

Yockey HP. 1997. Life on Mars? Did it come from Earth? Origins and Design 18:10-15.

Summary: Arguing against the notion that an Antarctic meteorite has evidence of life on Mars, Yockey points out that Mars is an unlikely place to find life. The Martian atmosphere is only 0.6% as dense as that on Earth, and is 95.3% carbon dioxide, with tiny amounts of water vapor, oxygen, and other gases. There is no ozone shield to protect organisms from ultraviolet light. There is no appreciable magnetic field to protect life against ionizing radiation from solar flares. With respect to the meteorite, it is igneous rather than sedimentary. No amino acids have been found in the meteorite, and the organic compounds detected do not appear to be biogenic.

Comment: Eventually, scientists concluded that the meteorite ALH84001 does not provide evidence for life on Mars. However, this conclusion did not receive the extensive publicity given to the original claim.

MOLECULAR EVOLUTION

Cunningham CW, Jeng K, Husti J, + 4 others. 1997. Parallel molecular evolution of deletions and nonsense mutations in bacteriophage T7. *Molecular Biology and Evolution* 14:113-116.

Summary: Six lines of Bacteriophage T7 were grown in a medium containing a mutagen, with periodic sampling to determine changes in DNA within a sequence of five genes. Each line was divided into two, so that a total of six pairs of lineages were studied. Each pair of lineages began as a single individual, and each lineage was bottlenecked to a single individual three additional times. Mutants were compared with each other and with previously identified mutants. Every lineage experienced a similar deletion, involving the loss of genes 2,3, and 4, and the loss of function of gene 5. The deletion had no observable effect on the bacteriophages. Nine independent breakpoints were identified; seven of these were identical to a previously described “H1” deletion. All lineages also developed nonsense (“stop”) mutations in the remaining portion of the last gene of the sequence. A total of 14 independent nonsense mutations were detected; these were confined to only 7 nucleotide positions, although 14 mutational sites were available for single-step nonsense mutations. Nonsense mutations occurred more frequently than expected by chance in lineages without a previous nonsense mutation, but not in lineages already possessing one. In each case, the H1 deletion occurred before the nonsense mutation.

Comment: The independent occurrence of the same change in DNA sequence is known as parallel evolution, a widely recognized difficulty in studies of phylogeny. The results of this experiment indicate that specific deletions and nonsense mutations may arise independently, and may not always be reliable indicators of common ancestry.

Kidwell MG, Lisch D. 1997. Transposable elements as sources of variation in animals and plants. *Proceedings of the National Academy of Sciences (USA)* 94:7704-7711.

Summary: Transposable elements (TEs) are discrete DNA sequences that can move and replicate within the genome. They have been found in all living species that have been examined. They may comprise a major fraction of the genome — more than 50% in maize, 10-15% in *Drosophila*. Two major classes exist. Class I TEs transpose by reverse transcription of an RNA intermediate. Class II TEs transpose directly from DNA to DNA. Some recently discovered TEs (MITEs) have an unknown transposition mechanism. Some TEs (autonomous) code for their own transposition, while others (nonautonomous) lack this ability.

TEs are an important cause of mutations, from changing a single nucleotide to inserting or deleting long stretches of DNA, or even causing massive chromosome breakage. Their effects vary from none to lethal. They may insert in an exon, an intron, a regulatory region, or heterochromatin. They may also affect the rate of recombination, perhaps by providing additional recombinational sites. Movement of TEs, and accompanying increases in mutation rates, seems to be stimulated by stress.

Insertion of TEs may be nonrandom. *P* elements in *Drosophila* show a preference for insertion into regulatory regions of genes, rather than exons. The yeast *Tyl* TE seems to insert preferentially into or near tRNA genes, or in preexisting long terminal repeats, rather than within ordinary genes. Some TEs are tissue specific; for example, the *Drosophila P* element infects only the germ line. Several TEs have been implicated in affecting gene regulation, for example, certain *Alu*-containing sequences in humans. A beneficial function of TEs is the repair of chromosomal ends (telomeres) by certain retroelements in *Drosophila*.

Comment: It appears that TEs have the potential for causing significant changes in species physiology and metabolism. It may be conjectured that they also have the potential for causing significant morphological change, but the extent to which this may have occurred is not known.

MOLECULAR PALEONTOLOGY

Austin JJ, Ross AJ, Smith AB, Fortey RA, Thomas RH. 1997. Problems of reproducibility — does geologically ancient DNA survive in amber-preserved insects? *Proceedings of the Royal Society of London B* 264:467-474.

Summary: Several reports have been made of recovery of DNA from insects preserved in amber thought to be Oligocene. But amber is permeable to some liquids, and has had long exposure to seawater. Attempts to recover DNA from stingless bees and scuttle flies in Dominican amber proved unsuccessful. This raises doubts about previous reports of DNA preserved in ancient amber.

Comment: Previous reports of DNA from ancient amber were greeted positively by creationists, including herein (*Origins* 19:77, 1992; *Origins* 22:77, 1995). It now appears that these reports may have been based on contamination or misinterpretation.

Schweitzer MH, Marshall M, Carron K, + 6 others. 1997. Heme compounds in dinosaur trabecular bone. *Proceedings of the National Academy of Sciences (USA)* 94:6291-6296.

Summary: Chemical breakdown products of hemoglobin have been identified within bony tissue of the hind leg of a fossil *Tyrannosaurus rex* from Montana. The result was confirmed by six different techniques. Further analysis of this and possibly other biomolecules from fossils might permit sequence comparisons with various groups.

Comment: Recovery and comparison of biomolecules and their decomposition products could provide data bearing on the history of the fossil, as well as possible relationships among species.

ORIGIN OF LIFE

Bradley D. 1994. A new twist in the tale of nature's asymmetry. *Science* 264:908.

Summary: In a magnetic field, virtually pure chiral enantiomers (composed of only one of two "mirror image" forms of a biomolecule)

may be produced. (This was reported by E. Breitmaier et al. in *Angewandte Chemie*.) A field of 1.2 to 2.1 teslas applied to the reaction solution produced 98% of a single enantiomer. By adding a “seed” of the preferred chiral form, they could select which enantiomer was produced. The team was working with aldehyde alkylations and ketone reductions. This discovery has been hailed by Tony Barrett of London “as the single most important finding since chemists discovered the chiral carbon atom itself.”

Comment: This discovery opens up new possibilities for the experimental purification of chiral molecules. However, it does not appear to be a satisfactory method for producing the chiral molecules needed in origin-of-life scenarios. The strength of Earth’s magnetic field is about 0.00005 teslas. This is about five orders of magnitude weaker than the experimental conditions, leaving the problem of chirality still unexplained.

Lee DH, Granja JR, Martinez JA, Severin K, Ghadiri MR. 1996. A self-replicating peptide. *Nature* 382:525-528.

Summary: A 32-unit alpha-helical peptide can accelerate the condensation of 15-unit and 17-unit fragments to produce more copies of itself. The 32-unit peptide is based on the leucine zipper domain of the yeast transcription factor GCN4. Templates with a conservative substitution, alanine for leucine at position 26, lose the self-replication ability. The possibility should be considered that self-replicating proteins were important in the origin of life.

Comment: This result does not help explain the origin of life. No prebiotic source for the peptides was identified, and no cell or cell component was formed. The sensitivity of the protein to amino-acid substitution illustrates the improbability of producing a functional protein molecule by random processes.

Melendez-Hevia E, Waddell TG, Cascante M. 1996. The puzzle of the Krebs Citric Acid Cycle: assembling the pieces of chemically feasible reactions, and opportunism in the design of metabolic pathways during evolution. *Journal of Molecular Evolution* 43:293-303.

Summary: Life depends on biochemical pathways in which specific enzymes control the flow of energy and materials so that the products of one reaction are the reactants of the next

reaction in the pathway. The resulting chemical activity must be useful to the cell, interacting with other biochemical processes to form the cellular metabolism. But how could such a system originate in small evolutionary steps? And are current metabolic pathways optimal, or could they be improved through evolution? Mathematical principles have previously been applied theoretically to evaluate the degree of optimization of the pentose phosphate and Calvin cycles. Here they are applied to a hypothetical scenario for the evolution of the citric acid cycle (CAC).

The authors propose three stages in the evolution of the CAC. The proposed first stage in the evolution of the CAC involved the minimal metabolism of glucose, the pentose cycle, and the pathways for synthesis of amino acids, nitrogen bases, some coenzymes, and fatty acids. In the second proposed stage, the respiratory chain was organized, while the proposed third stage involved organization of the CAC. Addition of the CAC would require only one additional enzyme (succinyl-CoA synthetase) beyond those already present but used for very different purposes. The result was the best chemically possible design for the CAC.

The authors conclude that the CAC is organized around the best possible chemical design. It has the least possible number of steps and the greatest possible yield of ATP. A chemical engineer could not have done better.

Comment: Creationists cannot assume *a priori* that all cellular processes are optimal, since these processes may have degenerated since their origin. However, it is interesting to find that the citric acid cycle does appear to be optimally designed. The haphazard nature of evolutionary processes and the existence of other potential biochemical pathways makes such optimality seem highly improbable. Such systems can readily be considered evidence of an intelligent Creator.

PALEONTOLOGY

Agosti D, Grimaldi D, Carpenter JM. 1997. Oldest known ant fossils discovered. *Nature* 391:447.

Summary: Seven fossil ants were discovered in amber from New Jersey. The amber is from the Turonian portion of the Upper

Cretaceous, and contains the stratigraphically lowest known fossil ants. Four different genera are represented. One of these is *Sphecomyrma*, a previously known genus interpreted as primitive. Another specimen, as yet unnamed, has traits linking it with the Ponerinae, a living subfamily. The Ponerinae were previously unknown from deposits lower than the Eocene.

Comment: The presence of diversity at first fossil appearance, and the mixture of taxa interpreted as primitive and derived, provide interesting subjects for further study.

Bengston S, Zhao Y. 1997. Fossilized metazoan embryos from the earliest Cambrian. *Science* 277:1645-1648.

Summary: A reexamination of tiny spherical fossils in Lower Cambrian deposits has resulted in interpretation of them as fossilized developing eggs, containing embryos of marine animals. Two distinct types of eggs have been discovered. Identification of the specific kinds of animals is uncertain, but one type may be a jellyfish-like animal, while the other may resemble an annelid or arthropod. The fossils are phosphatized, which permits detailed preservation. Precambrian and other sediments should be more carefully examined to see whether similar tiny fossil invertebrate eggs may be present.

Comment: This exciting discovery, if verified, raises the possibility that the fossil record may contain much more information than hitherto suspected.

Burke AC, Feduccia A. 1997. Developmental patterns and the identification of homologies in the avian hand. *Science* 278:666-668.

Summary: Many evolutionary paleontologists believe that birds evolved from dinosaurs. Another group of paleontologists dissents from that view, claiming the required physiological and anatomical changes are biologically implausible. A strong case is made here for rejecting the dinosaurian ancestry of birds. The argument is based on identification of the digits in the “hand” of birds and dinosaurs. The basic vertebral “hand” has five digits. *Herrerasaurus*, one of the first dinosaurs in the fossil record, shows dramatic reduction in digits 4 and 5, with digits 1, 2 and 3 fully developed. Similar digital arrangements have been found in some other dinosaurs.

The inference is that three-toed descendants of these dinosaurs should have digits 1, 2 and 3. Developmental evidence reported here shows instead that the three digits in the hands of birds are actually 2, 3 and 4.

Comment: Dinosaurs and birds share some character traits, and we cannot *a priori* determine which traits were or were not shared. However, reports such as this show that there is good scientific reason to doubt the proposed dinosaurian ancestry of birds, despite its present popularity.

Ruben JA, Jones TD, Geist NR, Hillenius WJ. 1997. Lung structure and ventilation in theropod dinosaurs and early birds. *Science* 278:1267-1270.

Summary: Dinosaurs are widely promoted as the ancestors of birds, but this hypothesis is difficult to reconcile with differences in lung structure. Birds and reptiles both have lungs with a structure like an open sac with partitions (septa). The reptilian lung functions like a bellows, with air flowing in and out through the same pathway, powered by muscles attached to the diaphragm. Crocodiles have such a system.

Bird lungs, on the other hand, have a more complex structure. Portions of the lung are expanded into air sacs, returning the air through a pathway different from the incurrent pathway. This permits unidirectional air flow and a higher rate of metabolic activity. Avian lung air flow is powered by movements of the ribs, tail and pelvic girdle, and there is no diaphragm. Differences in respiratory movements are reflected in differences in pelvic structure between crocodiles and theropods on one hand, and ordinary birds on the other. Enantiornithine birds, including *Archaeopteryx*, apparently lacked typical avian flow-through lungs, and were probably ectothermic (“cold-blooded”). The authors conclude that theropods were probably ectothermic, that *Archaeopteryx* and the enantiornithine birds were tree-dwellers, that flight originated in trees rather than on the ground, and that theropods do not make suitable ancestors for birds.

Comment: Differences between avian and reptilian lungs seem more readily explained by design and separate origins, than by a genealogical link between theropods and birds.

RELIGIOUS SCIENTISTS?

Larson EJ, Witham L. 1997. Scientists are still keeping the faith. *Nature* 386:435-436.

Summary: James Leuba conducted a survey of 1,000 scientists in 1916, and found that only 40% believed in a God. Leuba predicted that such belief would decline as the population became increasingly educated. This prediction was tested in a 1996 survey. Surprisingly, the percentage of believers in God has changed very little, remaining at almost 40%. Nearly as many believe in human immortality, although this does reflect a decline since 1916, when an additional 10% reported belief in God but not in immortality.

Comment: Although few scientists accept the Bible as a reliable history of origins, a strong number still believe in a God who has interacted in nature in some way. We can hope that it will become more acceptable for a scientist to acknowledge that nature cannot be understood completely without reference to the supernatural.

A later study (*Nature* 394:313) noted that members of the prestigious National Academy of Sciences were much less likely to believe in a personal God.

SPECIATION

Reznick DN, Shaw RH, Rodd FH, Shaw RG. 1997. Evaluation of the rate of evolution in natural populations of guppies (*Poecilia reticulata*). *Science* 275:1934-1937.

Summary: Guppies on Trinidad may live in communities where waterfalls divide the streams into regions where predators are common (below the falls) or rare (above the falls). Guppies from below the falls were transplanted to regions above the falls to determine what changes might occur when predators were few. Populations from the two types of habitats were compared after eleven years. Results showed that the guppies from low-predator habitats matured at a later age, were larger in size, and produced fewer offspring. Phenotypic changes occurred at a rate from 10,000 to 10,000,000 times faster than those inferred from the geological time scale.

Comment: The authors ask, “If evolution can be so fast, why does it appear to be so slow in the fossil record?” A variety of answers has been proposed to this question, but one answer worthy of consideration is that the fossil record is not a record of long ages of history, but of a short, catastrophic interval.

LITERATURE REVIEWS

Readers are invited to submit reviews of current books or journal articles relating to origins. Please submit contributions to: ORIGINS, Geoscience Research Institute, Loma Linda University, Loma Linda, California 92350. The Institute does not distribute the publications reviewed; please contact the publisher directly.

CAN WE FIND A MESSAGE IN THE PATTERN OF LIFE?

*Reviewed by L. James Gibson,
Geoscience Research Institute*

THE BIOTIC MESSAGE: EVOLUTION VERSUS MESSAGE THEORY. Walter James ReMine. 1993. St. Paul, MN: Saint Paul Science. 538 p. Cloth, \$44.95.

The major thesis of this book is that biodiversity was created in a pattern that was designed to resist naturalistic explanations. This pattern reveals the existence of a supernatural designer; thus it is called the “biotic message.” The biotic message has a two-part structure: a unifying component and a non-naturalistic component. The unifying component is seen in the similarities among organisms, which are intended to show that all life comes from a single designer. The non-naturalistic component is seen in such features as morphological convergence and the lack of identifiable ancestors. This component is intended to show that diversity must be the result of a supernatural process.

The idea of a “biotic message” is an original and intriguing concept. It seems entirely reasonable that a supernatural designer might create biodiversity in a pattern that contained a message. The question then is, does biodiversity convey the biotic message as ReMine claims?

The book consists of 26 chapters and 4 appendices. The principal focus of the book is evolutionary biology. Among the issues addressed are the nature of science, the origin of life, Darwinian selection, systematics, the problems of the fossil record, and molecular evolution. Lesser-known topics include Haldane’s Dilemma, error catastrophe, and horizontal gene transfer.

ReMine attempts to cover a wide range of topics, with mixed success. I felt that he spent an inordinate amount of time trying to show that evolution (naturalism) was not scientific, when most of his criticisms were actually against naturalistic philosophy. This theme is repeated throughout the book, adding unnecessarily to its length and apparently stimulating numerous side-excursions. It seemed to me that he also spent too much time speculating on the motives of others, including both the evolutionists and the designer. Many of his arguments were based on processes not understood, such as frequencies of non-neutral mutations, rather than on known processes. He often criticized evolution for only explaining, but not predicting, certain phenomena. I regard this as a problem inherent in the nature of historical science.

On the other hand, there are several points worthy of commendation. ReMine has taken the trouble to become acquainted with a wide body of evolutionary literature. The bibliography runs to nearly 500 references, virtually all by evolutionists. This has permitted ReMine to demonstrate the diversity — and frequent contradiction — of viewpoints represented by the term “evolution.” He repeatedly holds up statements for close scrutiny and points out the presuppositions upon which they are based, the lack of convincing evidence to indicate that they are true, and their contradictions with other evolutionary statements. He points out numerous weaknesses in the evolutionary view, such as its failure to explain satisfactorily: the lack of identifiable ancestors; the origins of morphological novelties; the problem of error catastrophe in the origin of life and its diversification; the problem of Haldane’s dilemma; and the enigma of developmental patterns.

ReMine not only points out some of the problems with evolutionary theory; he contributes toward development of creationist theory. His thesis of the biotic message may or may not be correct, but he has produced an interesting idea that should stimulate further thought and analysis by other creationists. His suggestions for research using discontinuity systematics are worth developing further.

The overly handsome, clothbound book runs some 538 pages. I did not notice a single diagram or photograph. I was rather distracted by the large blank areas on many of the pages. If these were all removed, the book might be shortened several pages. Some topics were treated in multiple chapters, sometimes separated by chapters on other topics. It should be possible to streamline the presentation by uniting the material on a particular topic. Developing this kind of focus might also help identify

places where the author became diverted by side issues. Removing side issues, streamlining the presentation, and removing unnecessary blank areas would reduce the length of the book noticeably. Reducing the size of the book and substituting a paper cover might bring the price of the book more into line with what people would expect a book of this type to cost. In its present form, I think the book would be of interest primarily to creationists with at least an undergraduate degree in biology and an interest in speciation and natural selection.

LITERATURE REVIEWS

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A NATURAL UNION

SCIENTIFIC THEOLOGY. Paul A. L. Giem. 1997. Riverside, CA: La Sierra University Press. 291 p. Paper, \$17.99.

Reviewed by R.H. Brown, Yucaipa, California

Individuals who are seeking a rational harmony between science and religion based on the Bible may expect fresh insight, stimulation, and assurance from this book. Dr. Giem gives a broad-based and candid appraisal of some areas of misinterpretation that has contributed to disharmony between science and religion. In the Introduction he states that:

...theology has something worthwhile to say to science,...[and] science,...in particular scientific methodology, can make a real contribution to theology (p viii, ix).

The character of the book is portrayed by the following quotations from Chapter 1:

The thesis of this book is that science and theology have profound interactions with each other (p 12).

Science and theology both approximate truth, and therefore must fit together harmoniously where they overlap. We do not have one truth for science and another for theology (p 12).

...good theology must incorporate science, and other systems of fact such as history, into its structure (p 15).

...a good theory (or doctrine) should make unambiguous, falsifiable, and yet accurate predictions (p 28).

The author sets the tone of the following chapters by his statements that

...the majority of scientists have been mistaken in the past, and there is no guarantee that the conclusions of today are free from error” (p 14),

and that

...most theologians do not have the grasp of science necessary to treat the relationship between science and theology as carefully as I believe will be done here. They either tend to be overwhelmed by science, or to ignore it (p 31).

The treatment of the nature of physical reality in Chapter 2 draws heavily on modern quantum physics theory and experiment. Readers who become overwhelmed by the technical discussion should be prepared to proceed resolutely to the conclusion that scientific evidence indicates physical reality is the ongoing expression of intelligence, rather than the consequences of innate properties of independently existing matter. This is a crucial consideration for the evolution/creation controversy.

A stimulating discussion of criteria for establishing the credibility and authority role of manuscripts (the Bible and the Koran, e.g., as well as scientific treatises) and individuals (Moses and Mohammed, e.g., as well as prominent scientists) runs through Chapters 3 and 4. In his discussion regarding the book of Daniel, Giem notes that disbelief is generally the parent, not the offspring of higher criticism that challenges the validity of historical data in the Bible (see p 99).

Chapter 5, “The Pentateuch and Joshua,” is a book within a book (80 pages of a 270-page total). It contains scientific data on radioisotope dating that to my knowledge has never been published before in creationist literature. Without hesitation I recommend it as essential resource material for everyone who is concerned with radioisotope age interpretations that conflict with the young-earth testimony of Moses. Giem’s suggestions concerning the increase of radioisotope age with depth in the geologic column will be appreciated by a wide range of readers. After reviewing all aspects of the scientific evidence, he concludes that “the difficulties of interpretation within an evolutionary time scale are far worse than those within a creationist time scale” (p. 148).

In anticipation that it will encourage reading of the entire book, I will quote a concluding paragraph from Chapter 5:

If we are committed to following the weight of evidence we are led to discount theistic evolution and multiple creations as explanations of life on earth. We may also discount the (creationist) theory that decay constants have varied significantly with time, at least back to the Flood. And if it needed any further demonstration, mechanistic evolution is thoroughly discredited. Creationism may not have solved all its problems, but it has solved the major ones, and it is not unreasonable to believe that the rest will be solved with further study, whereas theories requiring millions of years for life (including theistic evolution and multiple creations) appear incapable in principle of solving the ¹⁴C problem, and there is solid evidence that they are wrong in their interpretation of other dating methods (p 189).

In Chapters 6-10 the development of scientific theology is extended to the usual range of theological concerns — the nature of God, sin, the Ten Commandments, salvation, human responsibility, and life after death. The author's approach to these topics is intellectually stimulating, and will enhance the quality of religious experience for many readers.

The book concludes with a four-page summary (Chapter 11) in which the author says:

Throughout the book I have endeavored not only to argue for positions which I thought were sound, but to avoid overstating my arguments and to instead give alternative positions and their rationales (p 269).

[There are a number of unfortunate, minor errors in the first printing of this book. Some line drawings are difficult to understand without correction. Readers who have a copy of the first printing should obtain a list of corrections, from either the publisher, or via e-mail from the author: <PGiem@ahs.llumc.edu>.]