Article

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Testing and Verifying Old Age Evidence: Lake Suigetsu Varves, Tree Rings, and Carbon-14

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Carbon-14 measurements from layered sediments collected in 2006 from Lake Suigetsu, Japan, together with tree-ring data, offer an unprecedented opportunity to demonstrate how competing old- and young-earth hypotheses can be quantifiably tested. Conventional observation of radioactive decay rates, atmospheric carbon-14 production, tree-ring growth, cross-dating, and varve formation yields a narrow range of expected values for the carbon-14 content of samples over the last 50,000 years. Young-earth challenges to each observation should result in specific and predictable departures from conventional expectations. This article documents a sequence of tests to demonstrate beyond reasonable doubt that carbon-14 decay rates have remained unchanged, estimates of past atmospheric production rates are accurate, cross-dating of tree rings is reliable, the sampled trees have grown one ring per year going back more than 14,000 years, and finely layered sediments from Lake Suigetsu were deposited annually going back more than 50,000 years.

In 2010, we wrote a paper that combined published carbon-14 measurements from tree rings and annually laminated sediments from Lake Suigetsu, Japan, to show how we can test and validate assumptions about Earth's past.[1] That paper made use of carbon-14 from sediment cores collected up through 1993. In 2006, the Suigetsu team collected a new set of cores with greater controls on sediment recovery between extractions. Detailed analyses of the new cores, with publications leading up to 2013, included more sophisticated counting methods, Ar-Ar dating of an ancient ash layer, and a greatly increased sampling density for carbon-14. The new data, plus published reactions to our 2010 paper by young-earth writers, has provided material for a more rigorous comparison to test competing conventional and young-earth models.

The objectives of this article are two-fold. The first is to illustrate how calculations about past geologic processes can be rigorously tested and verified. By combining independent measurements such as counts of tree rings, counts of lake-sediment couplets that appear to be annual deposits, and carbon-14 content, we can demonstrate beyond reasonable doubt that the trees put on one ring per year, the sediments in question formed annual layers, radioactive decay rates have not changed over time, estimates of past atmospheric production of carbon-14 are accurate, and the history of

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Earth goes back far beyond a few thousand years. At the same time, speculative arguments made by young-earth advocates can likewise be objectively tested and shown to be untenable. This will be done in a stepwise fashion, beginning with tree rings, then incorporating carbon-14, and finally adding the annual sediment couplets (varves) from Lake Suigetsu.

Our second objective is to shed light on the typical methods employed by young-earth writers to turn confidence into doubt. This is an important part of the story, for the best scientific explanations go unheeded by many in the church if the alternative explanations provided by young-earth advocates sound equally convincing. After each of our steps that describe how we can test and verify specific hypotheses, we follow with example arguments that young-earth advocates employ to create doubt in the validity of those tests. These sections each start with the heading *Casting Doubt*. The coverage of young-earth tactics is not exhaustive, but the examples are broadly representative of the methods employed to distract readers from the obvious implications of the scientific evidence.

To set up the sequential tests, we first need some background information.

Tree rings

In many trees (conifers and dicot angiosperms), a pattern of light and dark bands forms annually as a result of different growth rates. In the spring or wet season, rapid growth produces larger, lighter-colored cells. In the autumn or dry season, smaller, darker-colored cells form. The two together form one growth ring. Environmental conditions or tree health can occasionally result in more than one ring in a year or no ring at all, though for an individual tree, these are readily identified by comparing with tree-ring cores from other trees in the same area.

The oldest known living trees are bristlecone pines in the White Mountains of California, with one possessing more than 5,000 rings.[2] Counting beyond the age of living trees is accomplished by cross-dating. Variable environmental or climatic conditions from one year to the next result in trees putting on thicker or thinner growth rings, producing a pattern of rings comparable to a commercial bar code. Trees that grew in the same region (experiencing the same environmental conditions) that died sometime after our living trees began to grow, will have some growth rings that overlap our living tree record. Aligning the ring patterns allows us to extend the counting back in time (fig. 1). Finding even older wood that overlapped in time with the dead trees extends the count back farther still.

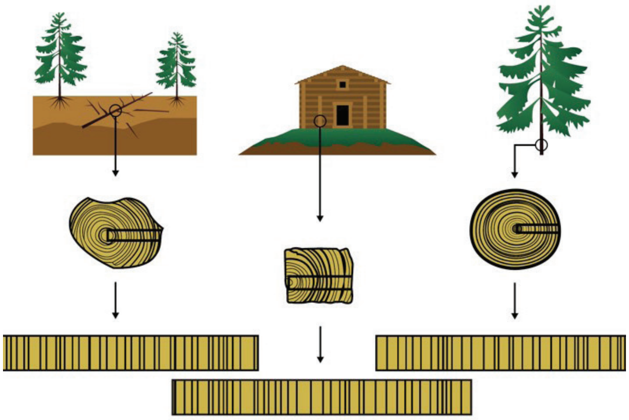

Figure 1. Cross-dating of tree rings. Patterns in ring growth from trees growing in the same region are aligned to extend the count back in time.

In principle, this record could be extended as far back in time as there were trees on Earth. However, there is a practical limitation, as it becomes increasingly difficult at a given location to find very old wood that reliably overlaps to yield an *unbroken* sequence far back in time. A gap in the record may be due, for example, to climatic changes in the past when trees did not readily grow in that area, or a time interval when most of the fallen trees fully decomposed. At present, the oldest reliable cross-dated count goes back about 14,000 years, based on living and fossil trees from Central Europe.[3]

Carbon-14

Most radioactive atoms, especially of the heavier elements, are not produced on Earth. The concentrations of these radionuclides have been diminishing since Earth was formed. Some, however, like carbon-14, are produced in the upper atmosphere. Carbon-14 is formed by collisions of cosmic rays with nitrogen atoms that result in the loss of a proton and gain of a neutron. The new configuration is unstable and eventually decays back to nitrogen. Freshly formed carbon-14 in the atmosphere readily joins with oxygen to form $^{14}CO_2$. Growing plants absorb the $^{14}CO_2$, turning it into complex organic molecules as part of their tissue. Carbon-14 continually decays and is replenished as long as the plant lives, maintaining a concentration essentially equal to what is in the atmosphere. When the plant dies, the resupply of carbon-14 is cut off and the concentration begins to diminish. Animals that eat plants are similar, ingesting carbon-14 from the plants and incorporating it into their organic tissues until the time that they die. The carbon-14 content then begins to diminish at a predictable rate, raising the possibility of estimating the age based on the amount of carbon-14 left.

The primary requirements for determining age are (1) a constant radioactive decay rate, (2) knowledge of the original carbon-14 content, and (3) quantification of any old carbon that may have been incorporated into the specimen. The last requirement applies mostly to marine samples, in which ocean-dwelling organisms, even today, extract carbon from seawater that has been "pre-aged" by long isolation from the atmosphere.[4] Terrestrial samples, such as tree rings and lake sediments, are less susceptible to this complicating factor, limiting the primary requirements to the first two.

If the concentration of carbon-14 in the atmosphere were constant over time, and if carbon-14 decay rates have remained constant, it would be a relatively simple matter of measuring the amount still present in an old sample and calculating the age by applying the radioactive decay equation:

$$t = -\ln (A/A_o)/\lambda \qquad [1]$$

where t equals the time since cell death, A_o is the initial atmospheric carbon-14 concentration, A is the concentration of carbon-14 remaining today, and λ is the decay constant for carbon-14 (0.000121 for a half-life of 5730 years).[5]

But recall how carbon-14 is formed. Variations in cosmic-ray flux, caused by a variety of factors such as solar flares and changes in Earth's magnetic field, result in variable carbon-14 production. To turn a measured carbon-14 value into an age, independent methods are employed to first provide realistic assessments of past atmospheric production rates. This is an important note, for young-earth writers routinely make the false assertion that conventional geologists naively assume a constant historical production rate.[6]

Varves

In some lakes, environmental or climatic conditions result in seasonal changes in the character of sediment deposition, producing alternating laminations. Where lakes freeze over in winter, laminations may alternate between fine-grained silt and clay in winter, and coarser-grained sands in spring. In other places, such as Lake Suigetsu, Japan, seasonal blooms of algae litter the lake floor with microscopic shells. If biological activity of bottom-dwelling organisms is low, such as when bottom waters are anoxic, the layers may be preserved. Pairs or sets of alternating layers that represent annual deposits are called *varves*. In the Green River Formation in southwest Wyoming, ancient lithified lake deposits contain hundreds of thousands of laminated layers that are believed to be varves—each varve couplet representing the passage of one year. In Lake Suigetsu, cores contain sections with tens of thousands of varves, with a total record estimated to represent more than 150,000 years.

Casting Doubt: An Alternative Flood Model

Young-earth writers cast doubt on virtually every aspect of dating using tree rings, carbon-14, or varves. To explain observed data, leading young-earth models call upon a violent global flood with flow dynamics that produced thick monolithic deposits in some places, and innumerable fine-scaled laminations in other places (misinterpreted by conventional geologists as varves).[7] Carbon-14 in the biosphere is said to have been very low at the start of the flood, resulting in massive fossil-bearing deposits containing low, but measurable, levels of carbon-14.[8] After the flood, wild climatic swings with cycles of months, days, or even a few hours resulted in continued deposition of multiple sediment layers per year. New trees sprouted, producing multiple rings per year for centuries.[9] Carbon-14 produced in the sub-surface by the neutron flux from accelerated decay of uranium-series isotopes began to escape to the atmosphere, raising the carbon-14 content over several hundred years until reaching near-modern levels by the time of Israel's first king (allowing semi-accurate radiocarbon dating of biblical artifacts).[10]

There are many issues of illogic and misrepresentation made in the young-earth model and objections to conventional dating, enough to require a book-length manuscript to adequately describe.[11] Rather than listing and debunking individual arguments, we will take a completely different approach here that sets aside possible fallacies: an approach that tests competing claims and expectations directly against what we actually find when combining tree rings, carbon-14, and sediment laminae. We will conduct the tests in a step-wise fashion, following each step with the relevant young-earth responses.

Step 1. Quantify Conventional Expectations: Carbon-14

The conventional geologic model gives us specific expected outcomes for how much carbon-14 should be present in tree rings or varves of particular ages. This is a natural outgrowth of assuming constant radioactive decay rates, and annual production of tree rings and varves. The young-earth model (also known as *flood geology*), in contrast, does not have any *inherent* expectations, for purported fluctuations in natural processes during and after the flood could produce virtually any outcome. To explain observed data, however, there are specific claims that young-earth advocates make that, in turn, should produce predictable departures from the expectations of the conventional model.

In this first step, we will build a plot of expected carbon-14 content today versus age (equivalent to tree-ring or varve count). Note that we are not plotting calibrated radiocarbon ages here, just the raw carbon-14 concentrations we expect to find when real measurements are made. This will greatly simplify the discussion, because it will bypass debates over the nuances or validity of radiocarbon dating and the use of calibration curves. For the conventional model, the plot will assume (1) carbon-14 decay rates have been constant, (2) sampled trees grew one ring per year, (3) cross-dating of tree rings was done correctly, (4) sampled sediment layers are varves (one per year), (5) terrestrial tree rings and varves are free of "pre-aged" carbon, and (6) variation in atmospheric production of carbon-14 over the period of interest was limited within a discernable range.

The expected concentration of carbon-14 remaining today in a sample of a particular age can be found by rearranging equation 1 to solve for A (see eq. 1 above for definition of terms):

$$A = A_o e^{(-\lambda t)} \quad [2]$$

If the atmospheric concentration of carbon-14 (A_o) were constant in the past, the equation would yield a single line of expected carbon-14 concentrations versus tree-ring or varve count. We already noted, however, that atmospheric production rates were *not* constant. We will thus need to establish upper and lower boundaries for our expected carbon-14 values today based on estimates of maximum and minimum production rates over the years of interest.

One way to establish these limits is using beryllium-10 concentrations in sediments that contain carbon-14 above background levels. Beryllium-10 is also produced in the atmosphere by cosmic rays, but unlike carbon, it readily falls to the ground, potentially preserving a record of variations in cosmic flux. From this record of flux, we can calculate proportional carbon-14 production.[12] Based on this and other methods, atmospheric carbon-14 was modestly lower at some times in the past, falling to roughly 95 percent Modern Carbon (pMC),[13] and significantly higher at other times, reaching levels of 185 pMC or higher. The beryllium-10 concentrations exhibit a high degree of variation, suggesting significant variability in cosmic flux. In general, however, the lower concentrations (lower flux) tend to be found in layers containing higher *current* carbon-14 (deposited in the recent past), and the highest concentrations (higher flux) tend to be in layers containing lower *current* carbon-14 (deposited in the more distant past). Given conventional expectations, even if atmospheric carbon-14 was double today's level, the low carbon-14 samples should be on the order of 50,000 years.[14]

Based on these observations, we can set ballpark boundaries on expected production rates in the past (fig. 2B). For the upper boundary, we will set the modern value at 100 pMC and allow it to rise linearly to 200 pMC at 50,000 years. For the lower boundary, we will start at 95 pMC to accommodate lower rates in the recent past, and allow it to increase linearly to 120 pMC.[15] Actual year-to-year fluctuations in the past should fall mostly between these two boundaries.

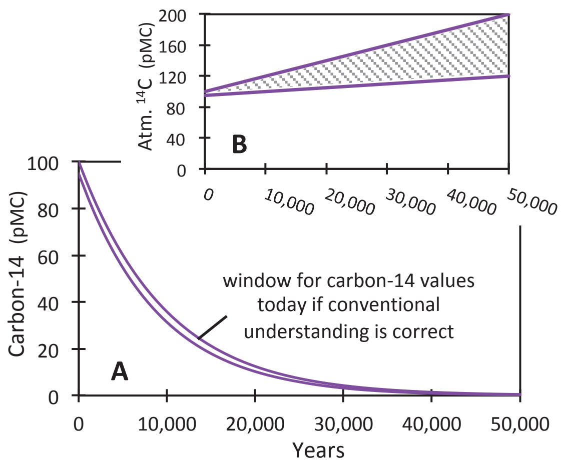

Figure 2. (A) Expected range of carbon-14 values for samples currently of the age on the X-axis if conventional geologic understanding is correct, and using the range of initial atmospheric carbon-14 concentrations shown in (B).

We are then ready to apply the radioactive decay equation (2) to each point along the upper and lower boundary to determine how much carbon-14 should still be present today for a sample of a particular age, up to 50,000 years. The result is shown in figure 2A, where we can see that conventional expectations form a surprisingly narrow band of carbon-14 versus tree ring or varve count (equivalent to age). If *any* of the conventional assumptions is not correct, it should become readily apparent as measured values trend outside this window. Moreover, specific young-earth claims should result in predictable departures from conventional expectations that would lend support to their model.

Step 2. Combine Tree Rings and Carbon-14: Testing Rings per Year and Cross-Dating

This step is designed to test the competing claims about tree rings. The conventional model assumes one tree ring per year and accurate cross-dating to obtain a continuous record of 14,000 rings, equal to 14,000 years. For this test, we need only the left portion of figure 2A, the 14,000 years covering the time range applicable to the sample tree-ring count (fig. 3). If all the conventional assumptions are valid, then carbon-14 measured in our sampled tree rings should fall within the window. Multiple tree rings per year, postulated by Flood geologists, should yield values that fall above the window (rings are younger and higher in carbon-14 than conventionally expected). On the other hand, if atmospheric carbon-14 was much lower in the past, the data should plot well below the window. And any errors in cross-dating the tree rings, due to false-positive matches in ring patterns, should be readily apparent by data that abruptly shifts upward (wood younger than the match suggested) or downward (wood older than the match suggested).

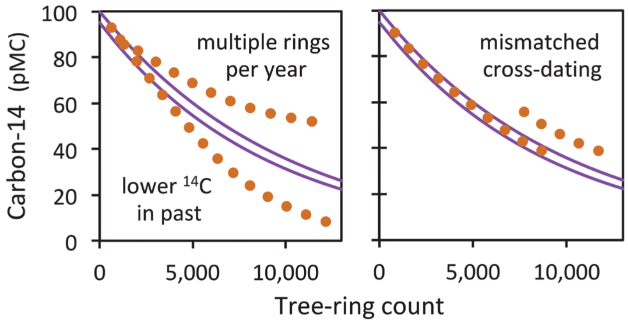

Figure 3. Expected tree-ring count vs. carbon-14 content for different young-earth scenarios (circles), relative to conventional expectations (lines). Only the tree-ring time range of 14,000 years of figure 2A is plotted.

What we actually see are data that fit conventional expectations beautifully (fig. 4). No contrived explanations are necessary to account for this fit. No calibration or manipulation of data. No initial assumption of ages. Just the raw tree-ring count and the measured carbon-14 content. Small-scale perturbations in the data are consistent with our understanding of fluctuations in the atmospheric production rate (within the expected range).

The result means one of two things. Either God saw fit that 14,000 tree rings equals 14,000 years, or God manipulated unrelated and independent processes (tree rings per year, atmospheric carbon-14 production, and radioactive decay rates) in a *precise* manner over a much more abbreviated time frame such that they are indistinguishable from the expectations of conventional geology. By any rational measure, Test 1 confirms conventional understanding of tree rings, cross-dating, and carbon-14 back to at least 14,000 years.

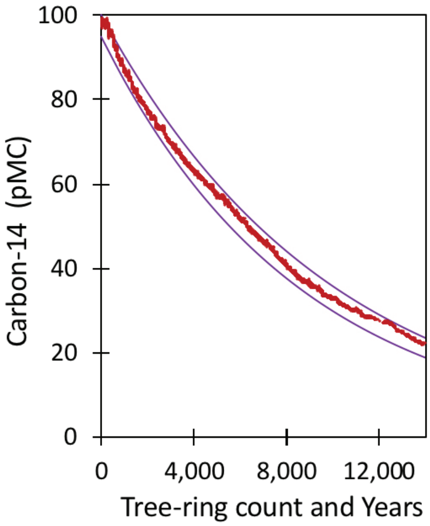

Figure 4. Tree-ring count vs. measured carbon-14 content in tree rings (line represents 4,310 samples). Solid boundary lines represent the window for conventional expectations.[16]

Casting Doubt: Circular Reasoning

For our first test, young-earth advocates charge that our measured carbon-14 values are misrepresented, arguing that they are *calculated* values derived from calibrated radiocarbon ages that are in turn based on a host of untestable assumptions. If values were manipulated to fit expectations of age, then of course a plot of the values versus age will meet expectations—circular reasoning![17]

Some of the measured carbon-14 data used in this and the 2010 paper were indeed calculated from published work, though the charges of circular reasoning are unfounded. At issue is the meaning of "radiocarbon age." It can be a little confusing for those who are unfamiliar with carbon-14 research, but a radiocarbon age is not an age at all, nor is it massaged to fit any uniformitarian expectations. It is a *reporting convention* that dates back to the early days of carbon-14 research when an old half-life of 5,568 years was being used (now known as the "Libby half-life," after Willard Libby), and not much was yet known about variability of carbon-14 production in the atmosphere.[18] In those days, measured carbon-14 was converted to an estimated age in "years before 1950" (prior to atmospheric perturbations from nuclear weapons testing), assuming constant atmospheric production, and using the Libby half-life. Years later, more accurate measurements of the carbon-14 half-life yielded a value of 5,730 years, and knowledge of atmospheric variability greatly increased.

This led to a dilemma of how to report new measured values in a way that was directly comparable to older data sets. A collective decision was made to continue the convention of reporting using the Libby half-life and a fixed 100 pMC initial atmospheric content, adjusted relative to 1950.[19] Not all are happy with this decision, but everyone working in the field understands what it is. A reported "radiocarbon age" is not a date or an actual age; it is a reporting convention easily and simply converted back to the measured value using equation 2 with Ao equal to 100, and a decay constant (λ) of 0.000124. Some researchers report both the "radiocarbon age" and the measured carbon-14 content. At least one of our sources did this, so anyone can check our numbers.[20]

A closely related charge is that the tree-ring and varve studies were performed for the purpose of improving a radiocarbon calibration curve; therefore, our claim of not making use of calibration curves is somehow employing circular reasoning and our conclusions invalidated.[21] This charge boils down to the nonsensical assertion that one cannot use data for more than one purpose. The cited researchers used their measured carbon-14 to refine a calibration curve. We made use of their measured data for a completely different purpose. Circular reasoning was left in the unemployment line.

Other young-earth claims of circular reasoning have similar explanations.

Step 3. Combine Varves and Carbon-14: Lake Suigetsu, Japan

Lake Suigetsu is a part of a multi-lake system on the western coast of Japan, sitting nearly at sea-level (fig. 5). Several factors make this site of particular interest for those studying lake sediments for evidence of Earth's recent history. River inflow enters adjacent Lake Mikata where most of the coarse-grained material settles out before water and fine-grained sediments pass into Lake Suigetsu. Each spring, algal blooms grow in the lakes, producing tiny shells that rain out on the lake floor. The bottom waters of Suigetsu are anoxic (no oxygen), preventing burrowing organisms from disrupting the sediments, allowing preservation of annual couplets (varves) of alternating darker sediments and lighter shells.[22]

The region is also seismically and volcanically active. Earthquakes shake loose sediments along the flanks that then flow across the lake floor (forming deposits called *turbidites*), and volcanic eruptions from both Japan and South Korea have periodically blanketed the lake with ash. The chemical compositions of ash from the different volcanoes are distinct, permitting an investigator to trace the origin of a layer of deposited ash to its source. Intermittent flood deposits are likewise recognizable in the sequence of layers. All these together make for a potentially ideal site to

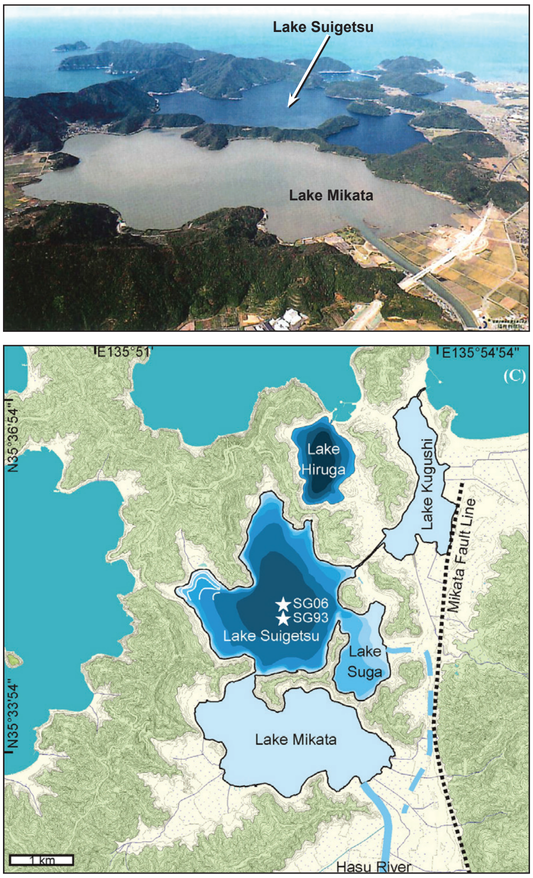

Figure 5. Lake Suigetsu, ~50 km north of Kyoto, Japan. Locations of SG93 and SG06 core sampling sites shown on map. Larger grains washed into Mikata tend to settle out before flowing into Suigetsu, as illustrated by the photo after a heavy rain. (Photo provided by Fukui Shimbun.)

preserve a long-term, datable record of past climate, volcanism, seismicity, and ecology.[23]

With this interest, several small cores and a longer 75 m core were collected from the lake by 1993. Below the first meter, a roughly 12 m interval was not varved, suggesting a span of time when bottom waters were oxygenated and organisms mixed the seasonal deposition of diatoms. Current anoxic conditions were likely caused by the introduction of brackish water when a channel was cut in 1664 from Suigetsu to Lake Kugushi which connects to the Sea of Japan.[24] Below 12 m in the core, tens of thousands of preserved varves were observed. In a series of reports leading up to the year 2000, more than 21,000 varves had been logged, with thousands more waiting to be counted. Though core recovery was nearly complete, it was recognized that small losses between each recovered core segment meant the varve count underestimated the total. Carbon-14 measurements were made from over 275 samples, which were the primary subject of our 2010 paper.[25]

The Suigetsu team returned in 2006 to collect four new cores, within 40 m horizontal distance from each other. Recovery intervals were offset this time such that a break between any two recovered segments in one core was represented by an uninterrupted length from an adjacent core.[26] Multiple flood, turbidite, and ash "event layers" distributed through the profile allowed confident correlation between the four cores to ensure time-equivalency with depth, with no significant correlation errors within the top 46 m.[27] The composite record from the four cores is referred to by the Suigetsu research team as *SG06*, reaching a depth of 73 m. The event layers also allowed correlation with the original *SG93* cores to account for missing sediments between the earlier core segments.

Varve counting was carried out using two different methods, (1) high-resolution photography under a high-powered optical microscope, and (2) X-ray fluorescence and X-radiography for geochemical variation. In places where it was difficult to confidently differentiate layers, counts were estimated based on average layer thicknesses above and below the uncertain sections.[28] By 2013 reports, approximately 31,000 varves had been logged between 12 and 32 m, with a continuous sequence of uncounted varves continuing to 41 m.[29] Still more varves were found continuing to 46 m, though interrupted by unvarved sections.[30]

Carbon-14 analyses in the Suigetsu cores were done on macrofossil samples that were handpicked from individual varves (fig. 6). The majority of samples were tree leaves, although small twigs and a few segments of insects provided carbon for some analyses. Combining the new analyses with those from the SG93 cores resulted in over 800 carbon-14 measurements from near the surface to a depth of approximately 41 m at an estimated age in excess of 50,000 years.[32] Figure 7 shows the results as a function of "event free depth" (thickness of ash, flood, and turbidite deposits subtracted), with different data markers for the varved and unvarved sections.

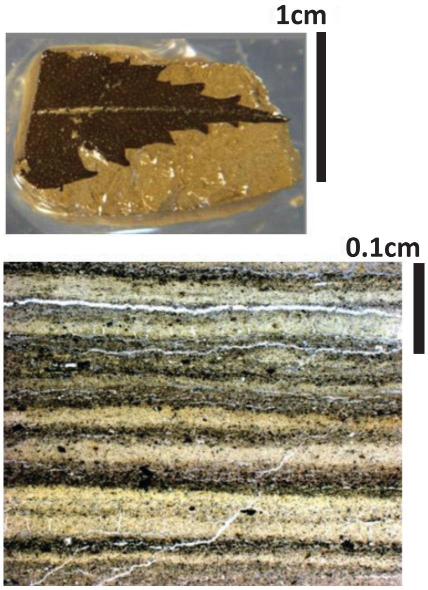

Figure 6. Photos of Suigetsu varves and samples used for carbon-14 analyses.[31]

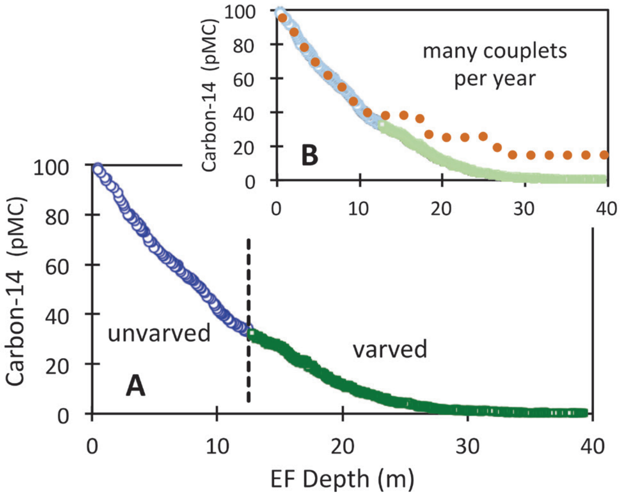

Figure 7. "Event free" (EF) depth vs. carbon-14 content for Lake Suigetsu core. The inset shows, qualitatively, what should be expected for the young-earth model, with myriad couplets deposited per year in stair-step fashion during and after the flood.

The first thing that should be obvious from this data is the relatively smooth decline in carbon-14 content with depth, all the way to background levels near zero. Based on conventional geologic understanding, the shape of the curve is consistent with a fairly uniform annual sediment deposition rate between episodic volcanic, earthquake, or flood inputs. Conventional understanding allows for periods of Earth history with higher or lower frequencies of things like earthquakes or eruptions, but for this area, the flood, turbidite, and ash layers are distributed relatively equally throughout the core. The 31,000 varves and estimates of tens of thousands more are consistent with carbon-14 content declining over a time span of roughly 50,000 years. At depths greater than 40 meters, the carbon-14 content falls below the level of resolution.

In contrast, the young-earth model expects (1) massive sediment deposits during the flood year, and (2) a prolonged period of environmental and geologic instability resulting in many sediment couplets deposited in any given year, *and* a higher frequency of earthquakes and eruptions. Near-zero carbon-14 content in older samples is accommodated by the hypothesis that atmospheric carbon-14 content at the time of the flood was only about 0.5 pMC and rose rapidly in the years following the flood. Given these criteria, the end of the flood must be represented by sediments near 40 m, where the carbon-14 content first begins to climb in the overlying layers.

Conditions during a global catastrophic flood should be quite different from the conditions that follow, so at the very least, we should see a marked transition in the nature of the deposits above and below 40 m. We find no such change. Not only do the varves appear the same above and below, but the frequency and thickness of interspersed ash, flood, and earthquake-induced turbidite deposits also vary little above and below.[33] One Suigetsu study even noted that turbidite deposits (caused by shaking loose sediments on the perimeter slopes) document a regular pattern of earthquakes throughout the core, varying by 1,200 to 5,300 varves (years) between events.[34]

If multiple sediment couplets formed in pulses in the early post-flood years, deposits that formed in rapid succession should have nearly the same carbon-14 content. This should produce a stair-step appearance to a plot of carbon-14 versus depth or varve number, with flat stretches indicative of couplet-layers deposited at nearly the same time (fig. 7 inset). There is no evidence of such stair-steps in the observed data.

It gets still worse. To account for the observed data in a few thousand years, we do not just need "multiple" sediment couplets per year. In the early years after the flood, it would require over 1,000 couplets per year—on the order of 3 per day—to match the observed data. Aside from the impossibility of cyclical diatom blooms happening over periods of hours, the flood model also needs these successive blooms to stay separated as they settle down to the lake bottom to form distinct, unmixed couplets formed hours apart. In other words, miraculous intervention is required to exactly mimic conventional expectations.

Casting Doubt: Questioning the Varve Count

Collecting more than one core allowed Suigetsu researchers to compare the number of varves counted between event markers in cores collected from different locations. For example, an obvious ash layer and an underlying flood layer found in one core could be easily identified at approximately the same depths in another core, and the number of varves counted between the event markers. If they come out the same, confidence is greater that the varve layers represent annual deposition over the whole lake. Young-earth writers latch on to any differences as evidence that the layering is discontinuous and untrustworthy for estimating age, without informing readers of the evidence provided that either explains differences, or that demonstrates that differences are exceedingly small. Outdated studies may also be cited in which discrepancies between cores were reported, without letting readers know that more recent studies with better sampling controls and analytical methods show minimal discrepancies. For example, Hebert et al. (2016) discussed mismatches on varve counts from the SG93 cores from Lake Suigetsu published in 1995, but not the work from the new cores and analyses with much better controls and results published in 2012 and 2013.[35] But even if there is some error in the count, or if some of the couplets do not cover the entire lake bottom, the fact remains that there are tens of thousands of these layers, with carbon-14 contents that decline *as expected* if those tens of thousands of layers represent tens of thousands of years.

Step 4. Combine Tree Rings, Varves, and Carbon-14: Testing Annual Deposition Claim

The Suigetsu core has a limitation that also provides a unique *opportunity* to demonstrate the power of forensic science (the science of determining what happened in the unobserved past). The varves do not continue all the way to the surface, so the starting age of the first varve below 12 m is not obtainable by simple counting. However, the carbon-14 content of our counted tree rings overlaps with the carbon-14 content of these varves (fig. 8). Tree rings and leaves/twigs from the Suigetsu cores all get their carbon-14 from the atmosphere, so if they were growing at the same time, they should have close to the same carbon-14 content. We

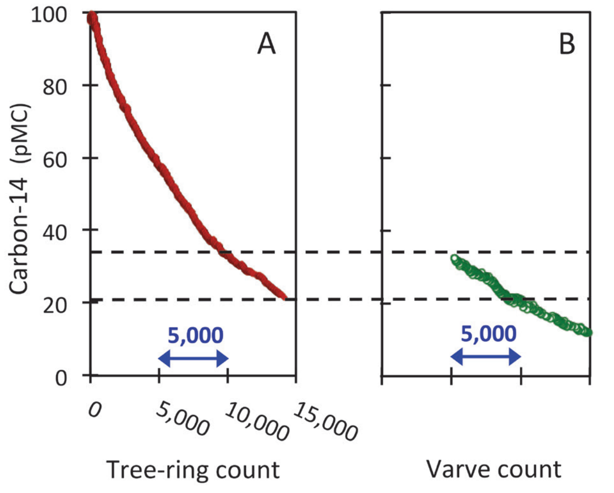

Figure 8. (A) Tree-ring count vs. carbon-14 content, and (B) varve count vs. carbon-14 content (for upper varve data). No numbers are placed on the varve count, but are plotted with the *same spacing* as the tree rings (5,000 tree rings with same spacing as 5,000 varves). Dashed lines show overlap in carbon-14 content.

can use this information in two ways. First, we can use the carbon-14 overlap to match contemporaneous tree-ring growth with sediment deposition (same carbon-14 content equals same time of formation). Second, we can test the hypothesis that the sediment layers in this range are truly varves—meaning they are genuinely annual deposits and not myriad couplets deposited within the same year.

The test for annual deposition of sediment couplets is simple in principle. We start with a plot of tree-ring count versus carbon-14 content. On the same graph, we will add the varve count with the initial assumption of one varve equaling the same time as one tree ring. This is equivalent to taking the two graphs in figure 8 and sliding the varve data over the tree-ring data to see how well the points do or do not align. For our example, we will initially assign the uppermost varve the same number as the tree ring number with an equal carbon-14 content. This will serve as a hinge point from which we can see how the remaining varves line up. If, in fact, more than one sediment couplet formed each year, it should be obvious, for the sediment data will diverge from the tree-ring data beyond the first matched point. Specifically, if more sediment layers deposited in a year than the number of rings grown in the trees, the sediment data should plot increasingly above the tree-ring data. If each sediment couplet is annual, the varves and tree rings should follow the same curve.

Suigetsu researchers employed this conceptual approach, though using a more robust method that effectively nudges the sediment data left and right to find the best match of all the overlapping data rather than just the first point. With the more robust method, multiple sediment couplets per year would still plot with an *obviously* different slope than the tree-ring data. What we find in the actual data is an unequivocal alignment between the tree rings and varves (fig. 9). The tree-ring data pass right down the middle of the varve data. Not only do they match in general, there is a particularly strong alignment in a downward jog in the data around tree-ring number 11,240. Though the entire overlapping sequence effectively anchors the age of the varves, those conducting this research identified the steep portion of the data as the principle anchor linking the varve ages to the tree-ring ages.[36] No unverified starting assumptions of age were required. No calibrated carbon-14 curves. Just measured carbon-14, and counts of tree rings and varves.

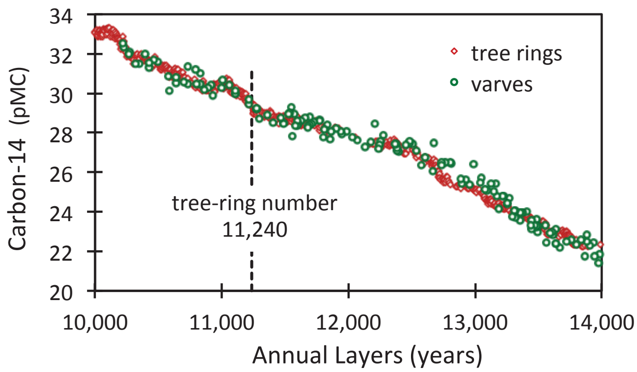

Figure 9. Tree-ring and varve count plotted against carbon-14 content for the range of overlap. Uncertainty (1σ) in varves data is approximately ±1 pMC. Most varve values represent 1 varve. Tree-ring samples average 10 annual increments (number of tree-ring samples in this range = 656).[37]

These results mean one of two things. Either God was superintending one sediment couplet per year at the same time that trees were adding one growth ring per year 11,000 years ago, *or* God manipulated unrelated and independent processes (tree rings per year, atmospheric carbon-14, decay rates, and sediment couplets per year) in a precise manner over a much more abbreviated time frame such that they are indistinguishable from the expectations of conventional geology.

Casting Doubt: Not a "One to One" Match

Young-earth advocates try to cast doubt on the match between tree rings and varves with claims that many sediment points do not exactly match with the tree ring data.[38] While this is technically a truthful statement, the implication that this means the varve and tree-ring data do not align is utterly false. The greater scatter in the sediment data *is expected* for two simple reasons. (1) The tree-ring data represents the carbon-14 content of multiple annual increments (one data point represents the average carbon-14 content of four or more annual rings).[39] The majority of the leaf/twig samples were from a *single* varve.[40] Multi-year composite samples will always have less scatter than year-by-year measurements. (2) The leaf/twig samples from these varves were small, resulting in greater uncertainties (plus or minus a little over 1 pMC). The tree-ring data lies easily within the analytical uncertainty.

What is also left out of young-earth claims is that none of this even matters. If multiple sediment couplets were deposited in various years, the sediment data would not just fall a bit above and below the tree ring data, they would not align *at all.* An incorrect assumption of one varve per year would result in sediment data sitting well above the tree ring data in figure 9. The alignment of the two data sets—one tree ring and one varve per year—is unequivocal.

Step 5. Combine Varves and Carbon-14: Testing Continued Annual Deposition to 50,000 Years

When addressing tree rings and carbon-14, we established a narrow range of expected carbon-14 with age that should be observed only if our conventional understanding is correct (one tree ring per year, constant decay rate, and atmospheric production ranging up to twice current levels). The actual data falls nicely within that narrow range. We can apply the same principle to the Lake Suigetsu varve data.

If we have anchored the dates of the Suigetsu varves correctly to the tree rings, and *if* the couplets continue to be annual deposits moving back in time, the sediment data should continue to fall within that very narrow expected range. Conversely, if numerous sediment couplets formed each year, the data should plot above the conventional expectation. More specifically, as we move back in time closer to the flood, we should see a stair-step pattern emerge, with long flat sections where myriad sediment couplets were deposited in rapid succession with nearly the same carbon-14 content (fig. 7).

What we find, again, is that the data plot within the narrow range of conventionally expected values down to the point where there is too little carbon-14 left to reliably measure (figs. 2 and 10). Tens of thousands of additional varves lie below these layers, strongly

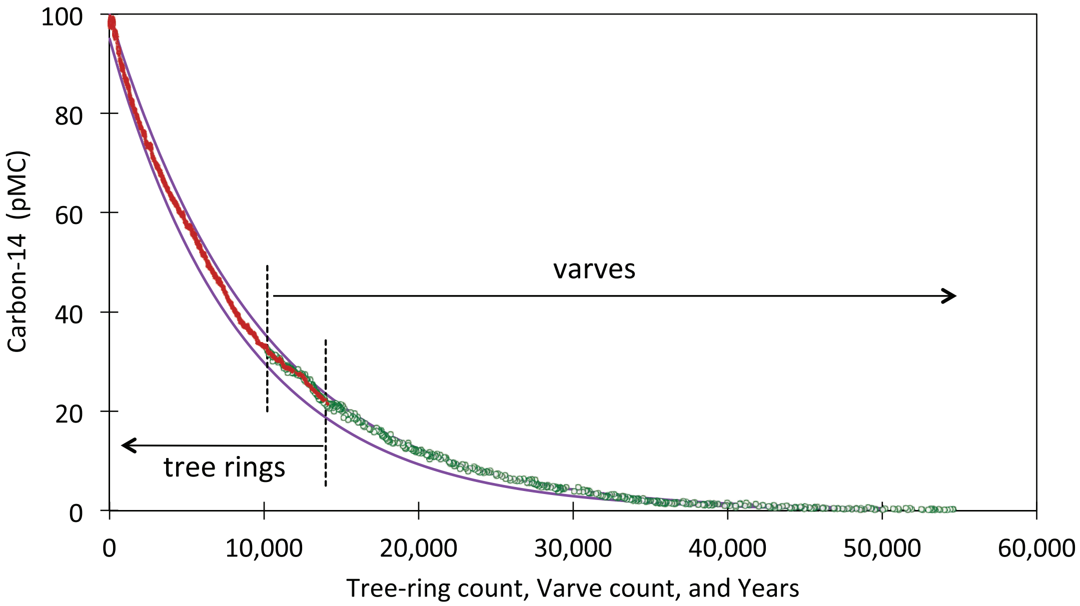

Figure 10. Tree ring and varve count vs. carbon-14 content. Solid lines represent window for conventional expectations (from fig. 2).[41]

suggesting a history of this lake that goes back more than 100,000 years. Higher in the core, the transition between varved and unvarved sediments fits with the timing of the end of the last ice age roughly 11,000 years ago. Large climatic shifts could be responsible for the change in this particular lake from anoxic conditions to oxygenated bottom-water, where organisms began to disturb and mix the annual couplets.

Once again, we have two options. Option 1 is that God gave us amazing tools to test and verify that carbon-14 decay rates have not changed and sediments in Lake Suigetsu have been accumulating for more than 50,000 years. Option 2 is that God precisely manipulated multiple independent phenomena—tree ring growth, atmospheric carbon-14 production, and sediment couplet formation—to *mimic* conventional expectations.

Understanding the significance of this warrants a little more detail. The conventional model is based on simple natural processes of annual weather patterns producing one tree ring and one sediment couplet each year, with atmospheric carbon-14 production varying within a fairly generous range due to well-understood fluctuations in cosmic ray influx. All straight-forward phenomena. For the flood model to mimic these results, atmospheric carbon-14 after the flood must have begun to rise at a pace precisely matched to myriad sediment couplets such that it would appear today *as if neither actually happened*, followed by a period of accelerated tree-ring production that would also be precisely paced to match the number of sediment couplets forming in a lake half way around the world from forests in Europe, and controlled by completely unrelated processes. Rising atmospheric carbon-14 production continued to precisely match multiple tree rings per year to coincidentally make the results indistinguishable from conventional expectations.

The God whose character we are told is manifest in his natural creation (Rom. 1:20) is not the God of option 2. His glory is evident in the beauty and simplicity of option 1.

Casting Doubt: "Non-independence" of Variables

Young-earth writers call attention to the fact that the tree-ring data is used to determine the starting varve count for the sediment data, and therefore claim that the varves are *not* an independent data set. The implication, of course, is that the whole argument is thus nullified and void. This is yet another example of a truthful factoid being used to promote a false conclusion. The hinge point of the varve count at tree ring 11,240 (fig. 9) is indeed dependent on the tree-ring count, so the age of the uppermost varves is not determined independently. What is left out is that the hinge point is not the only use of the varve data. First, when assessing the general question of whether the Suigetsu couplets are *annual* deposits, we did not need to assume any ages for either tree rings or varves. The alignment of the overlapping tree-ring and sediment data provided *independent* evidence that the tree rings and varves are, in fact, annual formations. The young-earth explanation (simultaneous nonannual tree rings and nonannual sediment couplets with a coincidental alignment if assuming one year for each) requires either divine meddling with intent to confuse, or fantastically improbable changes in unrelated natural processes to yield false confidence in conventional understanding.

Second, once the hinge point for the varves was established, we employed an *independent* method of testing the hypothesis of one varve per year back as far as carbon-14 can be employed. If our hinge point is incorrect, or if multiple varves formed each year, or if the varve count is wrong, or if carbon-14 was much lower, or if decay rates were faster, the data should plot outside the narrow window expected by conventional geology. It does not. God gave us awesome tools to test and verify the unobserved past!

Step 6. Varves, Tree Rings, and Ar-Ar Dating: Testing with Another Method

The presence of volcanic ash deposits in the Lake Suigetsu sediments presents an opportunity to compare our results from tree rings, varves, and carbon-14 with other radiometric dating methods. A radiometric dating technique called argon-argon (Ar-Ar) dating is commonly used on igneous rocks (crystalized from melted rock). The method works best with well-formed crystals, and not as well with the fine-grained, crystal-poor ash found far from the point of eruption. Different volcanoes often have unique chemical compositions that allow distant ash deposits to be matched to the volcano of origin. Eruptions from the same volcano separated in time also frequently have their own geochemical fingerprint, allowing a distant ash bed to be traced back to a specific eruption from a volcano.

The Suigetsu team picked an ash layer near the top of the varved sequence in a range where the carbon-14 content overlaps tree rings. The carbon-14 content directly above and below the ash layer aligns with tree rings in the range of 10,200 to 10,230 (fig. 11). The chemical composition of this ash layer is indistinguishable from the composition of the "U4" deposit from an eruption of the Ulleungdo volcano in South Korea. That eruption has been Ar-Ar dated at 10,000 years, with an uncertainty of plus or minus 300 years. In other words, the Ar-Ar dates are consistent with the varve ages based on carbon-14 and tree rings.[42]

Step 7. Tree Rings, Carbon-14, and Biblical Artifacts: Testing against Archaeology

We established above that the carbon-14 content of tree rings behaves as expected if 14,000 rings equals 14,000 years, which extends back well before Abraham and the inception of the nation of Israel. So what happens if we compare the carbon-14 content of biblical artifacts to the content found in tree rings? We could pick a number of examples, but one of our favorites is the Dead Sea Scrolls, particularly as it relates to the book of Isaiah. Isaiah 53 describes the "suffering servant," a depiction that seems to describe the life and death of Jesus so directly, critics long argued it was written after the time of Christ. For most of church history, no pre-Christian era copies of Isaiah were known. The discovery of the Dead Sea Scrolls in the late 1940s, however, raised the possibility of putting the competing claims to the test with carbon-14 dating.

The result? The carbon-14 content in the Isaiah scroll is approximately the same as found in tree rings ranging from about number 2,120 to 2,350 (if counting from today) (fig. 11). If one tree ring equals one year, the calendar date for the Isaiah scroll is somewhere between 107 and 335 BC.[43] In other words, carbon-14 confirms that Isaiah 53 pre-dates the sufferings of Christ.

The young-earth response is that atmospheric carbon-14 rose rapidly after the flood, reaching nearly modern levels just in time for carbon-14 dating of biblical artifacts to yield accurate results based on, once again, conventional geologic expectations.[44] Apparently, carbon-14 works when young-earth advocates *want* it to work.

Casting Doubt: Measurable Carbon-14 in Samples Supposedly Millions of Years Old

The discussion of carbon-14 would be incomplete without addressing the observation that samples deeper in the Suigetsu core, and even samples geologists say are millions of years old, yield carbon-14 measurements as much as one hundred times higher than the instrumental detection limit. In the Suigetsu core, approximately 50 samples were taken from depths estimated to be 90,000 to 100,000 years old. These were measured as "dead carbon" samples, meaning that enough time has passed to drop the original carbon-14 content below the detection limit of the instrument. The amount measured in the dead-carbon samples is considered to be "background" and is subtracted from all the other measurements. For the deep Suigetsu samples, the background value averaged about 0.3 pMC.[45]

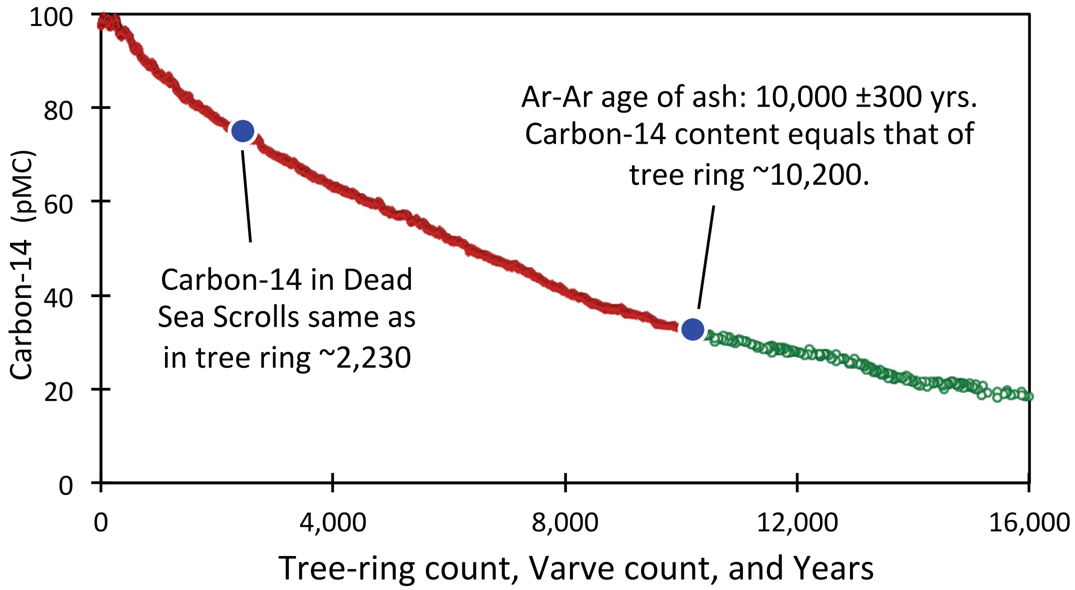

Figure 11. Carbon-14 dating of the Dead Sea Scrolls and Ar-Ar dating of an ash bed from the Suigetsu core are consistent with ages determined by tree-ring counts.

Young-earth advocates have objected to the subtraction, arguing that these carbon-14 levels are well above the instrument detection limit (~0.003 pMC) and represent residual carbon-14 from the time of deposition. Ages of hundreds of thousands or millions of years are thus declared to be impossible. Instead, it is argued that the carbon-14 content of the atmosphere and organisms at the time of the flood was only about 0.5 pMC. In the roughly 4000 years since the flood, this has decayed to ~0.3 pMC. Miles of fossil-bearing deposits laid down during the flood all now have roughly the same amount of this residual carbon-14.[46]

To understand why this raises no concern among carbon-14 researchers, we need to know a little about how samples are processed. Biological samples are never just brushed off and analyzed. There are many potential sources of contamination that must be eliminated first, such as bacterial growths that may be much younger than the sample. Cleaning is done using an aggressive sequence of caustic chemicals. Though great care is taken to isolate samples and chemicals from the atmosphere or other sources of carbon-14, it is inevitable that tiny amounts of contamination end up in the sample. By way of analogy, consider cleaning a dirty window. With each pass of a cloth, a few fibers *from the cloth* are left behind on the glass. With a sequence of fresh cloths, we will clean off far more contamination than we will add, but eventually, every wipe will add as much contamination as it removes.

We know this is happening with our sample processing for a simple reason. There are some materials that can be run with and without treatment. Ancient graphite samples analyzed directly on a modern accelerator mass spectrometer yield values around 0.003 pMC—the detection limit below which random detector noise cannot be differentiated from real carbon-14 atoms. The same graphite samples run after taking them through the whole chemical treatment processes yield values around 0.3 pMC.[47] This is called the "laboratory background," which gets subtracted from subsequent measurements. This accounts for the vast majority of "measurable carbon-14" levels in ancient samples.

Young-earth advocates will still insist that there are some ancient samples that seem to contain more carbon-14 than they should, even after accounting for additions during processing.[48] There are indeed occasions where results are obtained that are not readily explainable without additional investigation. That is the nature of real science. Typically, answers are found with further study, but there is a more important question. Why would God choose an atmospheric level of carbon-14 *and date* of the flood, such that samples today would fall in the range that is indistinguishable from laboratory background noise? The flood-era carbon-14 level could have been *any* value. Why didn't God set it at 2 pMC or higher, where all those ancient samples measured today would level out well above the laboratory background? Why would God make all the evidence of a global catastrophe fit exactly within the expectations of conventional geology? It makes far more sense, and fits the nature of God as described in scripture far better, if the data fits expectations for an ancient Earth because it *is* ancient.

Conclusions

Contrary to young-earth claims that historical science is not real science because it cannot be tested, God has given us amazing tools for testing hypotheses and assumptions about the unobserved past. Tree-ring growth, atmospheric carbon-14 production, radiometric decay rates, sediment couplets, and ash chemistry are all independent phenomena. Combining these independent measurements allows a rigorous comparison of conventional and young-earth models. The data, in total, fit amazingly well with conventional geologic understanding, requiring no disruptions of natural laws or unfathomably improbable alignment of unrelated processes. Even accurate biblical dates of artifacts are possible with conventional understanding. In contrast, the young-earth model can explain the data only by calling upon a host of unrelated processes aligning in perfect synchronization to coincidentally match conventional expectations. It requires supernatural manipulation of nature with no apparent purpose other than to mislead.

Many in the world marvel at the handiwork of God while denying the Creator. In response, young-earth advocates demand that to acknowledge the Creator, we must deny his workmanship. Can there be a more ineffective witness? Why not rejoice in the fact that God gave us the ability to explore not only the present world in which we live, but also the wonders of creation that predate our presence on this Earth? Romans 1:20 tells us that God's character is manifest in his creation. Why should we work to undermine scripture with arguments that ultimately require nature to be deceptive? If, after seeing the evidence in God's creation in figures 10 and 11, the church insists that the obvious meaning is not true, we create a completely unnecessary stumbling block to faith. Christ himself is a sufficient stumbling block—we need not create any other! ✻

Notes

[1]Gregg Davidson and Ken Wolgemuth, "Christian Geologists on Noah's Flood: Biblical and Scientific Shortcomings of Flood Geology," *BioLogos Scholarly Essay* (2010), https://biologos.org/uploads/projects/davidson_wolgemuth_scholarly_essay.pdf.

[2]Rocky Mountain Tree-Ring Research, www.rmtrr.org/oldlist.htm.

[3]M. Friedrich et al., "The 12,460-year Hohenheim Oak and Pine Tree-Ring Chronology from Central Europe—A Unique Annual Record for Radiocarbon Calibration and Paleoenvironment Reconstructions," *Radiocarbon* 46, no. 3 (2004): 1111–22; P. J. Reimer et al., "IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years Cal BP," *Radiocarbon* 55, no. 4 (2013): 1869–87.

[4]Deep circulating ocean waters contain dissolved carbon that has been isolated from the atmosphere for hundreds of years. Organisms drawing on this carbon reservoir start with "pre-aged" carbon, requiring a correction for estimating actual age. The well-studied phenomenon is called the "reservoir effect."

[5]The concentration is technically referred to as the *activity,* referring to the number of decays per second. Higher concentrations of carbon-14 will have a proportionally higher level of radioactivity.

[6]Jake Hebert, Andrew Snelling, and Timothy Clarey, "Do Varves, Tree-Rings, and Radiocarbon Measurements Prove an Old Earth? Refuting a Popular Argument by Old-Earth Geologists Gregg Davidson and Ken Wolgemuth," *Answers Research Journal* 9 (2016): 339–61; Walt Brown, *In the Beginning: Compelling Evidence for Creation and the Flood,* 8th ed. (Phoenix, AZ: Center for Scientific Creation, 2008), 342–43; and Mike Riddle, "Doesn't Carbon-14 Dating Disprove the Bible?," in *The New Answers Book 1,* ed. Ken Ham (Green Forest, AR: Master Books, 2006), 77–87.

[7]Michael J. Oard, "Do Varves Contradict Biblical History?," in *Rock Solid Answers: The Biblical Truth Behind 14 Geological Questions*, ed. M. J. Oard and J. K. Reed (Green Forest, AR: Master Books, 2009), 125–48.

[8]John R. Baumgardner, "Carbon-14 Evidence for a Recent Global Flood and a Young Earth," in *Radioisotopes and the Age of the Earth: Results of a Young-Earth Creationist Research Initiative,* ed. Larry Vardiman, Andrew A. Snelling, and Eugene F. Chaffin (El Cajon, CA: Institute for Creation Research, 2005), 587–630.

[9]Oard, "Do Varves Contradict Biblical History?," 131; John Morris, "Tree Ring Dating," *Acts & Facts* 41, no. 10 (2012): 15; and John Woodmorappe, "Biblical Chronology and the 8,000-Year-Long Bristlecone Pine Tree-Ring Chronology," *Answers in Depth* 4 (2009): 4–5.

[10]Hebert, Snelling, and Clarey, "Do Varves, Tree-Rings, and Radiocarbon Measurements Prove an Old Earth?," 353.

[11]One of our favorite young-earth objections to our own work is the routine complaint that "uniformitarian" geologists do not keep up with young-earth literature; otherwise, we would know that the Suigetsu varves had already been debunked. Upon looking up the primary citation for one such claim, we found this statement about Lake Suigetsu: "Unfortunately, there is very little literature on these varves in English, and so it is difficult to analyze them" (Hebert, Snelling, and Clarey, "Do Varves, Tree-Rings, and Radiocarbon Measurements Prove an Old Earth?," 341, citing Oard, "Do Varves Contradict Biblical History?," 131).

[12]Beryllium-10 is also radioactive, though with a very long half-life (~1.4 million years), resulting in very little change over 50,000 years.

[13]Modern Carbon refers to the concentration, or activity, of carbon-14 in the atmosphere in 1950, prior to atmospheric testing of nuclear weapons.

[14]R. Muscheler et al., "Geomagnetic Field Intensity during the Last 60,000 Years Based on ^{10}Be and ^{36}Cl from the Summit Ice Cores and Carbon-14," *Quaternary Science Reviews* 24 (2005): 1849–60; and C. B. Ramsey et al., "A Complete Terrestrial Radiocarbon Record for 11.2 to 52.8 kyr B.P.," *Science* 338, no. 6105 (2012): 370–74.

[15]Raising the lower boundary to 120 pMC makes the expected window for conventional expectations smaller (i.e., *easier* for young-earth arguments to be found valid if true).

[16]IntCal13 database, http://intcal.qub.ac.uk/intcal13/query/. Under advanced query, the first 8 datasets (*setno*) are tree rings, *calage* is the dendrochronological age before 1950, *calspan* is the number of tree rings in each sample, *c14age* represents the measured carbon-14 content reported as a "radiocarbon age" using Equation 2. (Laboratory and isotopic fractionation corrections applied to the raw data do not visibly change any plots shown in this paper.)

[17]Hebert, Snelling, and Clarey, "Do Varves, Tree-Rings, and Radiocarbon Measurements Prove an Old Earth?," 346; Young-earth writers throw in additional distractions for good measure, like the "isotopic fractionation correction" as supposed evidence of manipulating results to meet expectations. In this case, if the very small and very non-controversial correction factor were left out, you would not visibly see a change in figure 4.

[18]W. F. Libby, E. C. Anderson, and J. R. Arnold, "Age Determination by Radiocarbon Content: World-Wide Assay of Natural Radiocarbon," *Science* 109, no. 2827 (1949): 227–28.

[19]E. C. Anderson and W. F. Libby, "World-Wide Distribution of Natural Radiocarbon," *Physical Review* 81 (1951): 64–69; M. Stuiver and H. A. Polach, "Discussion: Reporting of Carbon-14 Data," *Radiocarbon* 19, no. 3 (1977): 355–63; and A. R. Millard, "Conventions for Reporting Radiocarbon Determinations," *Radiocarbon* 56, no. 2 (2014): 555–59.

[20]R. A. Staff et al., "New Carbon-14 Determinations from Lake Suigetsu, Japan: 12,000 to 0 CAL BP," *Radiocarbon* 53, no. 3 (2011): 511–28. The measured carbon-14 content is tabulated under the $F^{14}C$ heading (represents *fraction* Modern Carbon rather than *percent* Modern Carbon).

[21]Hebert, Snelling, and Clarey, "Do Varves, Tree-Rings, and Radiocarbon Measurements Prove an Old Earth?," 351.

[22]Y. Suzuki et al., "Mass Accumulation Rate of Detrital Materials in Lake Suigetsu as a Potential Proxy for Heavy Precipitation: A Comparison of the Observational Precipitation and Sedimentary Record," *Progress in Earth and Planetary Science* 3 (2016): 1–14.

[23]G. Schlolaut et al., "Event Layers in the Japanese Lake Suigetsu 'SG06' Sediment Core: Description, Interpretation and Climatic Implications," *Quaternary Science Reviews* 83 (2014): 157–70.

[24]Suzuki et al., "Mass Accumulation Rate of Detrital Materials in Lake Suigetsu as a Potential Proxy for Heavy Precipitation," 2.

[25]H. Kitagawa et al., "AMS Carbon-14 Dating of Varved Sediments from Lake Suigetsu, Central Japan and Atmospheric Carbon-14 Change during the Late Pleistocene," *Radiocarbon* 37, no. 2 (1995): 371–78; H. Kitagawa and J. van der Plicht, "Atmospheric Radiocarbon Calibration

to 45,000 yr B.P.: Late Glacial Fluctuations and Cosmogenic Isotope Production," *Science* 279, no. 5354 (1998): 1187–90; H. Kitagawa and J. van der Plicht, "A 40,000-Year Varve Chronology from Lake Suigetsu, Japan: Extension of the Carbon-14 Calibration Curve," *Radiocarbon* 40, no. 1 (1998): 505–15; and H. Kitagawa and J. van der Plicht, "Atmospheric Radiocarbon Calibration Beyond 11,900 CAL BP from Lake Suigetsu Laminated Sediments," *Radiocarbon* 42, no. 3 (2000): 370–81.

[26]Staff et al., "New Carbon-14 Determinations from Lake Suigetsu, Japan," 513.

[27]T. Nakagawa et al., "SG06, A Fully Continuous and Varved Sediment Core from Lake Suigetsu, Japan: Stratigraphy and Potential for Improving the Radiocarbon Calibration Model and Understanding of Late Quaternary Climate Changes," *Quaternary Science Reviews* 36 (2012): 168.

[28]M. Marshall et al., "A Novel Approach to Varve Counting Using μXRF and X-radiography in Combination with Thin-Section Microscopy, Applied to the Late Glacial Chronology from Lake Suigetsu, Japan," *Quaternary Geochronology* 13 (2012): 70–80; and G. Schlolaut et al., "An Automated Method for Varve Interpolation and its Application to the Late Glacial Chronology from Lake Suigetsu, Japan," *Quaternary Geochronology* 13 (2012): 52–69.

[29]R. A. Staff et al., "The Multiple Chronological Techniques Applied to the Lake Suigetsu SG06 Sediment Core, Central Japan," *Boreas* 42, no. 2 (2013): 259–66.

[30]Richard Staff, personal communication, 2017.

[31]Photos from the Suigetsu Varves 2006 website, http://www.suigetsu.org.

[32]R. A. Staff et al., "Integration of the Old and New Lake Suigetsu (Japan) Terrestrial Radiocarbon Calibration Data Sets," *Radiocarbon* 55, no. 4 (2013): 2049–58; Ramsey et al., "A Complete Terrestrial Radiocarbon Record for 11.2 to 52.8 kyr B.P.," supplemental data.

[33]Staff et al., "The Multiple Chronological Techniques Applied to the Lake Suigetsu SG06 Sediment Core, Central Japan," 263.

[34]Nakagawa et al., "SG06, A Fully Continuous and Varved Sediment Core from Lake Suigetsu, Japan," 171.

[35]Hebert, Snelling, and Clarey, "Do Varves, Tree-Rings, and Radiocarbon Measurements Prove an Old Earth?,"citing the varve correlation of Kitagawa et al., "AMS Carbon-14 Dating of Varved Sediments from Lake Suigetsu, Central Japan and Atmospheric Carbon-14 Change during the Late Pleistocene," but not the improved correlation reported in Nakagawa et al., "SG06, A Fully Continuous and Varved Sediment Core from Lake Suigetsu, Japan," or in Staff et al., "New Carbon-14 Determinations from Lake Suigetsu, Japan," and in Staff et al., "The Multiple Chronological Techniques Applied to the Lake Suigetsu SG06 Sediment Core, Central Japan."

[36]Staff et al., "The Multiple Chronological Techniques Applied to the Lake Suigetsu SG06 Sediment Core, Central Japan," 262. An alignment method that matches unique patterns of increases and decreases in the carbon-14 content of two separate sample sets is known as *wiggle matching*.

[37]IntCal13 database, http://intcal.qub.ac.uk/intcal13/query/.

[38]Hebert, Snelling, and Clarey, "Do Varves, Tree-Rings, and Radiocarbon Measurements Prove an Old Earth?," 350.

[39]IntCal13 database, http://intcal.qub.ac.uk/intcal13/query/.

[40]Staff et al., "New Carbon-14 Determinations from Lake Suigetsu, Japan," 513.

[41]The Lake Suigetsu data is also available in the IntCal13 database, http://intcal.qub.ac.uk/intcal13/query/, under advanced query, *setno* = 9.

[42]V. C. Smith et al. (plus Suigetsu 2006 Project Members), "Toward Establishing Precise ^{40}Ar/^{39}Ar Chronologies for Late Pleistocene Palaeoclimate Archives: An Example from the Lake Suigetsu (Japan) Sedimentary Record," *Quaternary Science Reviews* 30 (2011): 2845–50.

[43]G. Bonani et al., "Radiocarbon Dating of the Dead Sea Scrolls," *Atiqot* 20 (1991): 27–32; A. J. T. Jull et al., "Radiocarbon Dating of Scrolls and Linen Fragments from the Judean Desert," *Radiocarbon* 37 (1995): 11–19.

[44]Baumgardner, "Carbon-14 Evidence for a Recent Global Flood and a Young Earth," 618; Hebert, Snelling, and Clarey, "Do Varves, Tree-Rings, and Radiocarbon Measurements Prove an Old Earth?," 353; Brown, *In the Beginning: Compelling Evidence for Creation and the Flood*, 8th ed., 343.

[45]Kitagawa and van der Plicht, "A 40,000-Year Varve Chronology from Lake Suigetsu, Japan," 506.

[46]Baumgardner, "Carbon-14 Evidence for a Recent Global Flood and a Young Earth," 624.

[47]Warren Beck, University of Arizona AMS radiocarbon laboratory, personal communication.

[48]Marcus R. Ross, "Fossil Record (Young-Earth Creation View)," in *Dictionary of Christianity and Science*, ed. P. C. Copan, T. Longman III, C. L. Reese, and M. G. Strauss (Grand Rapids, MI: Zondervan, 2017), 290–94; Baumgardner, "Carbon-14 Evidence for a Recent Global Flood and a Young Earth," 622.

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