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The Dating "Pedigree" of Seafloor Sediment Core MD97-2120: A Case Study

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Abstract

The fact that different, seemingly independent dating methods appear to "tell" a consistent "story" about Earth history over millions of years is a seemingly formidable argument for an old earth. Hence, in the minds of many, this apparent agreement is a major obstacle to serious consideration of the biblical creation position. Hence, it is important for creation scientists to understand and be able to clearly explain why the different dating methods are not really independent of one another. The interconnectedness of the different dating methods can be illustrated by tracing the dating "pedigree" of a particular deep-sea sediment core, the MD97-2120 sediment core from the Chatham Rise east of New Zealand. Dating of the deep sediment cores, including this one, is tied to the astronomical (or Milankovitch) hypothesis of Pleistocene ice ages via a process known as "orbital tuning." Moreover, dating of a deep-sea sediment core frequently involves "tying" that core's timescale to that of other sediment cores, as well as to those of the deep ice cores of Antarctica and Greenland. This critique includes suggestions for future creation research in this area.

Introduction

Critics of biblical creation argue that the apparent agreement between multiple dating methods presents an unchallengeable argument for an old earth. How, they ask, can the earth really be only ~6,000 years old, when so many different, and apparently *independent*, dating methods yield age assignments of millions of years, age assignments that appear to "tell" a consistent "story" of Earth history? Hence, in order to demonstrate to a skeptical world the reasonableness of the young-earth position, it is important that creation scientists have a clear understanding of how such generally "consistent" dating results are obtained. Once we are clear in our own understanding of how the different dating methods are interconnected, then we can communicate to others why the apparent agreement between different dating methods is not the formidable argument that it initially appears.

With a few exceptions (Oard, 1984, 1985; Vardiman, 1996; Hebert, 2014), uniformitarian dating of the seafloor

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sediments has received little attention in the creation technical literature, although the subject has been touched upon in works dealing with the dating of the ice cores (Oard 2004, 2005, 2007). This paper discusses one particular sediment core in an effort to shed some light on the interconnectedness of the different dating methods.

Scientists have drilled and extracted cores from the deep-seafloor sediments and assigned them, via uniformitarian assumptions, ages of many millions of years. However, these dates are often obtained by assuming the validity of the astronomical (or Milankovitch) hypothesis of Pleistocene ice ages and then using that theory to date the sediments via a technique called *orbital tuning*. Moreover, dating of the seafloor sediments often involves the "tying" of different sediment and ice cores to one another, showing that the dates assigned to the different cores are not truly independent. This is illustrated by examining, as a case study, the methods used to date the MD97–2120 core from the Chatham Rise off the eastern coast of New Zealand. The methods used to date this core are described by Pahnke et al. (2003). A very brief overview of the dating of this core was provided by Hebert (2014), but this paper examines the dating of the core in much greater detail.

Background: The Oxygen Isotope Ratio

In order to understand the interconnectedness between the age assignments for different sediment and ice cores, it is necessary to first cover some background material. Foraminifera (or forams) are ocean-dwelling marine protists. Generally speaking, *planktonic* foraminifera are free-floating organisms that can dwell at various depths (Mortyn and Charles, 2003), while *benthic* forams dwell on and within the seafloor sediments (Kingston, 2010). These forams construct shells (or tests) composed of calcium carbonate ($CaCO_3$). Some of the oxygen within the calcium carbonate is the "heavier" but less abundant oxygen-18 isotope, while some is the "lighter" and more abundant oxygen-16 isotope (oxygen-17 is very rare and will not be considered here). The ratio of "heavy" oxygen-18 to the "lighter" oxygen-16 isotope (compared to a "standard" $^{18}O/^{16}O$ value) is called the *oxygen isotope ratio*, denoted by the symbol $\delta^{18}O$. This "standard" $^{18}O/^{16}O$ value was originally taken to be the $^{18}O/^{16}O$ ratio from the crushed shell of a Cretaceous squidlike creature called a *belemnite*, taken from the South Carolina Peedee formation. Other standards have since been calibrated to this original standard (Wright, 2010). It should be noted that $\delta^{18}O$ values also can be calculated for seawater and ice, due to the presence of oxygen in the H_2O molecule. Also, a similar "deuterium/hydrogen," or D/H, ratio (sometimes denoted by the symbol δD) may be calculated for water or ice using isotopes of the hydrogen atom (deuterium is a "heavy" isotope of hydrogen). When the forams die, their shells become part of the thick ocean sediments accumulating on the ocean floors.

Scientists have drilled and extracted cores from the sediments on the ocean floor, and oxygen isotope ratios may be calculated from foram tests at different depths within these cores. If one plots these $\delta^{18}O$ values on a graph, multiple "wiggles" become apparent (Figure 1). Secular scientists believe that the oxygen isotope ratio is a climate indicator: larger foram $\delta^{18}O$ values from within the sediments are generally thought to indicate times of greater global ice volume, while smaller values are thought to indicate times of decreased amounts of global ice. However, there are a number of complications that make inferring information about past climates from foraminiferal $\delta^{18}O$ values quite problematic.

The most obvious difficulty in attaching climatic significance to these foram $\delta^{18}O$ values is that an empirically determined formula for these $\delta^{18}O$ values has *two* unknowns, the temperature and $\delta^{18}O$ value for the surrounding ocean water at the time the foram test was formed (Oard, 1984; Wright, 2010). The foram $\delta^{18}O$ value can be determined

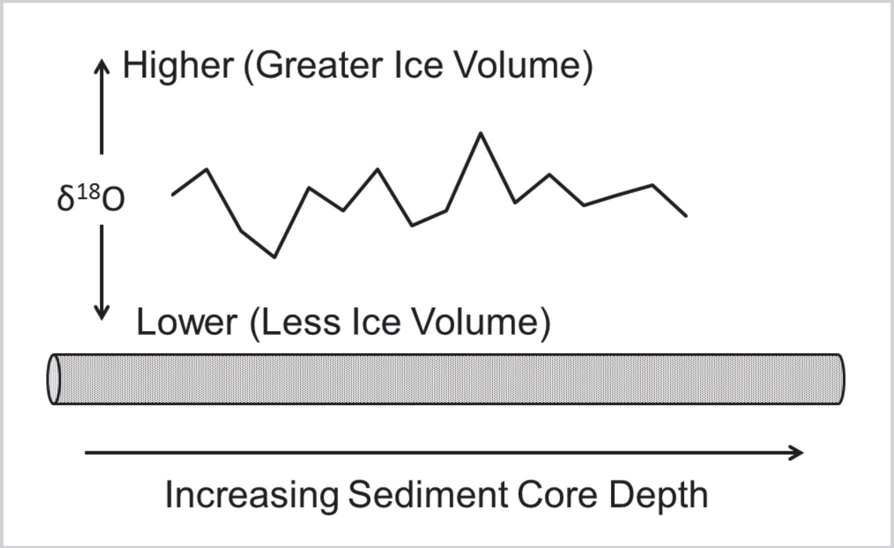

Figure 1. Secular scientists interpret variations in foraminiferal $\delta^{18}O$ values within the seafloor sediments as climate indicators.

in a laboratory, but there is no way to actually know these other two values. For this reason, secular scientists must make assumptions in order to attempt to "fill in" this missing information. Actually, there are multiple such empirical equations for foram $\delta^{18}O$ values (Grossman, 2012). Although these equations are generally similar, they take into account different temperature ranges, different crystal forms of calcium carbonate (such as aragonite), and differences between different foram species.

Another problem with interpretation of these foram $\delta^{18}O$ values is that seawater temperature is influenced, not just by global averages, but also by short-term spatial and temporal fluctuations. So how does one de-convolve which "part" of the temperature at the time of shell formation represents a global average temperature and which part represents short-term variations due to local hydrographical effects? This issue is especially problematic for oxygen isotope ratios obtained from free-floating planktonic forams, since one would expect surface water temperatures to be more variable than deep-water temperatures.

Hence, secular scientists have long attempted to separate these two effects. One way is to find other temperature-dependent signals that might also be contained within foraminiferal $CaCO_3$. For instance, magnesium ions can replace calcium ions within the $CaCO_3$, and this effect is temperature dependent. Theoretical and empirical data indicate that the Mg/Ca ratio depends exponentially upon the temperature at which the $CaCO_3$ was formed. In fact, planktonic foraminiferal Mg/Ca ratios are now viewed as the optimal paleothermometer for tropical waters (Kucera, 2009, p. 334).

However, a complication with this method is that magnesium is preferentially removed as $CaCO_3$ is being dissolved, a temperature-dependent effect that is thought to amount to a maximum bias of ~0.5° C for the three foraminiferal species most commonly used for such purposes (Kucera, 2009, p. 334).

Secular scientists have claimed to have used Mg/Ca ratios to separate the effects of ice volume and temperature within foraminiferal $\delta^{18}O$ values (Sosdian and Rosenthal, 2009, 2010), although this claim has been criticized by Yu and Broecker (2010). Elderfield et al. (2012) have made a similar but more recent claim.

However, separating these effects requires either long records of sea-level or deep-ocean temperatures or a model-dependent reconstruction of one or more of these variables (Bintanja et al., 2005). Of course, since such records and models are interpreted through the "deep time" paradigm, secular scientists have not achieved a separation of these two effects that is truly independent of old-earth, evolutionary assumptions.

Another problem with attempting to infer information about paleoclimates from foraminiferal chemistry is that the sediment records are nearly always at least partially disturbed by bioturbation, the reworking of sediments by living organisms (Shackleton, 1987).

A very good (albeit dated) early discussion of the many difficulties involved in secular interpretations of foram $\delta^{18}O$ values is found in Oard's work (Oard, 1984).

Background: The Astronomical Theory

Within the last thirty years or so, the astronomical (or Milankovitch) hypothesis of ice ages (Milankovic, 1941) has become extremely popular. This hypothesis holds that the Pleistocene glacial intervals ("ice ages" in popular speech) were caused by slow, subtle variations in the amount of summer sunlight falling on the northern high latitudes. It is thought that the northern, high-latitude ice sheets advanced during times of decreased (northern hemisphere) summer sunlight and retreated during times of increased sunlight. These variations in sunlight are thought to have been caused by subtle changes in the tilt and orientation of the earth's axis, as well as changes in the shape and orientation (relative to the background stars) of the earth's elliptical orbit around the sun. Despite the popularity of this hypothesis, it has a number of serious problems (Oard, 2007), many of which are acknowledged even in the secular literature (Cronin, 2010, pp. 130–139).

The astronomical theory received apparent support from a seminal paper (Hays et al., 1976) that used statistical analysis to purportedly show that earth's climate was responding to the dominant 100,000-year, 41,000-year, and 23,000-year Milankovitch cycles. Because the 100,000-year cycle seemed to be making the largest contribution to these climate responses, secular paleoclimatologists concluded that the 100,000-year cycle was the most important, despite the fact that, of the three cycles, it should theoretically have the weakest climatic effect (Cronin, 2010).

Likewise, there are other puzzling aspects to the astronomical hypothesis. For instance, there is a transition from 41,000-year cycles to 100,000-year cycles that takes place between 700 thousand and 1.25 million years ago. This so-called "mid-Pleistocene transition" does not correspond to any significant change in orbital forcing (Elderfield et al., 2012) and is as yet unexplained within the context of the model (Cronin, 2010, pp. 130–132).

Background: Orbital Tuning

How do secular scientists assign ages to seafloor sediments? Generally one cannot use radioisotope methods to date the sediments, so an age-depth model, which translates a depth down the sediment core into an age, is needed. The simplest possible (albeit unrealistic) age-depth model for a seafloor sediment core would assume that the seafloor sediments at that location have always been deposited at a perfectly constant rate (Herbert, 2010). Such a model would ignore compaction and possible reworking of the sediments. Instead, uniformitarian scientists use the Milankovitch hypothesis to assign ages to the sediments via a process called *orbital tuning* (Herbert, 2010).

Conceptually, the simplest way to perform orbital tuning is to visually inspect the $\delta^{18}O$ signal within a sediment core and to identify the highest peaks and deepest troughs within that signal. Recall that the highest "peaks" in $\delta^{18}O$ values are thought to indicate times of maximum glacial extent, while the deepest "troughs" are thought to indicate times of minimum glacial extent. Recall also that the presumed times for these periods of maximum and minimum glacial extent may be *calculated* from the Milankovitch hypothesis. Hence, the Milankovitch hypothesis assigns ages (in thousands or millions of years) to the highest peaks and deepest troughs within the $\delta^{18}O$ signal. This can be done either by direct calculation from the Milankovitch hypothesis or by "tying" these peaks and troughs to age assignments in *other* data sets that were *themselves* determined from the Milankovitch hypothesis. Once this has been done, the ages for the smaller "wiggles" between these dominant peaks and troughs may be obtained via interpolation.

Of course, these dominant peaks and troughs will occur at different depths within the core than would be predicted by an age-depth model that naively assumes a perfectly constant past sedimentation rate. This implies that the orbitally tuned timescale will *not* be linear: if one were to use tick marks to label intervals of, say ten-thousand years, at different depths within the core, the spacing between the "tick marks" would vary with depth, closer together in some sections and farther apart in others.

However, this is not a problem within the secular worldview, since even uniformitarian scientists do not believe that past sedimentation rates have been *perfectly* constant! As an example, suppose that in one section of the core, a (presumed) 100,000-year $\delta^{18}O$ cycle has been "stretched out" so that it corresponds to a greater-than-expected length down the core. This can be attributed to an interval during which the sedimentation rate at that location was higher than average, resulting in a greater depth of sediment deposited per unit time. Likewise, suppose that in another section of the core, a (presumed) 100,000-year cycle has been "squashed" so that it corresponds to a shorter-than-expected length down the core. This can be attributed to a lower-than-average sedimentation rate. Hence, the orbital-tuning method demands variable sedimentation rates, although the rates are still assumed to be "slow and gradual."

This implies that if one *were* to plot the $\delta^{18}O$ signal (as a function of time) on a linear timescale, this would be equivalent to selectively stretching and compressing different sections of the $\delta^{18}O$ signal within the core. Although different mathematical techniques may be used to facilitate this process, this is conceptually the heart of the orbital-tuning method.

Of course, one might expect there to be much local "noise" within the $\delta^{18}O$ signal of a single core, so a "globally averaged" signal using data from multiple cores is preferable to using only a single core. For this reason, secular researchers will often "stack" $\delta^{18}O$ data from multiple cores in an effort to produce a "cleaner" (and longer) global signal. In order to do this, however, the different $\delta^{18}O$ signals must be placed on a common vertical scale, since $\delta^{18}O$ values between different foraminiferal species can vary, even when their shells are formed under identical conditions. This can be accomplished by adding or subtracting the appropriate constant, as needed, to every measured $\delta^{18}O$ value within a particular core. Once all the different $\delta^{18}O$ records have been placed on a common vertical scale, the Milankovitch hypothesis is used to assign absolute ages to the prominent peaks and troughs within all the separate signals (this may be done either by visual inspection or via an automated computer program). This implies that corresponding $\delta^{18}O$ peaks and troughs within the different cores are all assumed to be the same age, even though they are usually found at different (sometimes dramatically different) depths below the seafloor. Once these key "tie points" within the different signals have all been assigned the same age, they are all placed on a common timescale, with the concomitant accordionlike "compression" and "expansion," as needed, of the different $\delta^{18}O$ signals (Figure 2). Once this has been done, the results are averaged to produce a stacked "global" signal (greater weight may be given to data sets of higher resolution). One of the best-known "stacked" records is that of Lisiecki and Raymo (2005), which consists of 57 different benthic $\delta^{18}O$ records and is thought to "cover" a total of 5.3 million years.

Pisias et al. (1984) present a good early discussion of this technique (their paper could be freely read online as of November 21, 2014). Their Figure 1 shows $\delta^{18}O$ values plotted as a function of depth and dramatically illustrates the compression and stretching of $\delta^{18}O$ signals that is demanded by orbital tuning: prominent troughs in two different cores (RC13–229 and Y7211–1) are assumed to be the same age, even though one is found at a depth of ~3 meters, and the other is found at a depth of 12 meters!

Since the orbital tuning method assumes the validity of the astronomical theory, there is much potential for circular reasoning, as has been pointed out even by secular scientists. Herbert noted, "The possibility clearly exists to produce a tuned sedimentary series that has been forced to resemble an orbital template by overenthusiastic correlation" (Herbert, 2010, p. 372). Moreover, secu-

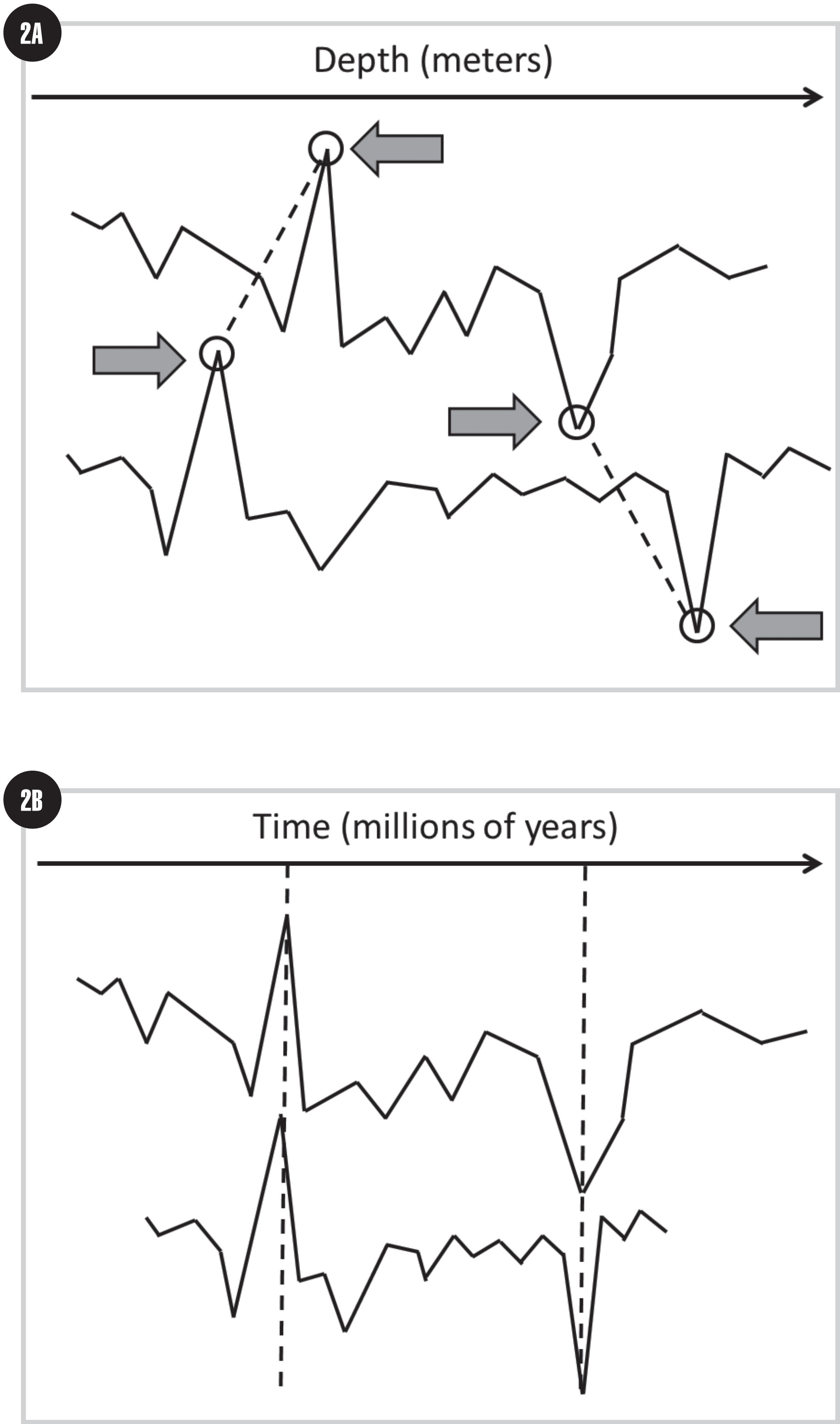

Figure 2. The Milankovitch hypothesis is used to assign the same ages to corresponding prominent δ^{18}O "peaks" and "troughs" within two different sediment cores, even though these peaks and troughs are almost always at different depths below the seafloor surface. This requires an accordion-like stretching and compressing (a) of different sections of the two δ^{18}O signals in order to (b) put the two signals on a common timescale.

lar researchers (Blaauw, 2010; Blaauw et al., 2010) have already demonstrated that it is possible to convincingly "tune" random signals that are unrelated to one another! Hence, despite the seemingly impressive correlations that secular scientists make between different paleoclimatological data sets, these correlations could very well be meaningless, even within the uniformitarian framework.

Additional factors give secular scientists even more "wiggle room" (pardon the pun!) when assigning ages to the deep-sea sediments. For instance, they can assume that the climate system takes a fixed amount of (lag) time to respond to a change in solar insolation (e.g., Shackleton, et al., 1990), or they can assume that this lag time can vary (e.g., Shackleton, 2000). They can also assume that the climate system is responding to insolation changes at different latitudes. Although most uniformitarian paleoclimatologists assume that it is summer insolation variations at 65° N that drive the ice ages, others have claimed better "fitting" of the data to insolation changes at other latitudes, as noted by Herbert (2010). Different assumptions can yield radically different conclusions about the past. "Depending on the latitude and season considered most significant, grossly different climatic records can be predicted from the same astronomical data" (Hays et al., 1976, p. 1121).

In fairness, secular scientists have recognized these potential dangers, and they make efforts to guard against them (Herbert, 2010). For instance, they sometimes use automated algorithms in the tuning process in an attempt to objectively find the optimal timescale for a stacked record. They may also code their algorithms to "penalize" timescales that require extreme or sudden changes in sedimentation rate (Lisiecki and Raymo, 2005, p. 3). However, their checks implicitly assume the validity of the astronomical theory and the old-earth timescale, so although these checks can perhaps distinguish between reasonable and unreasonable climate histories *within* the uniformitarian framework, they do not validate the choice of a uniformitarian model over a creation model. Moreover, the dates assigned to a sediment or ice core are often tied to dates that have been assigned to other cores, as discussed below.

A Case Study: New Zealand Core MD97–2120

The interconnectedness of age assignments for different cores can be illustrated by tracing the age-scale "pedigree" of the 36-meter-long MD97–2120 International Marine Past Global Changes Study (IMAGES) deep-sea sediment core, from the Chatham Rise east of New Zealand (45° 32.06´ S, 174° 55.85´ E, water depth of 1,210 meters).

The "MD" in the core designation refers to the French research ship, *Marion Dufresne*, which was used in its extraction. The "97" refers to the sediment hole from which the core was extracted, and the "2120" designates the particular core sample from within the hole. The dating of this core by Pahnke et al. (2003) was briefly mentioned by Hebert, (2014), but the more detailed examination presented here reveals the many assumptions involved in the dating of a deep-sea sediment core, as well as the interconnectedness between dates assigned to different cores.

Pahnke et al. (2003) explicitly describe the dating methods used for four different sections of the core, corresponding to presumed ages of 0–20 ky, 26.6–32.3 ky, 40–72 ky, and 72–340 ky BP (before present). An interpolation process was presumably used to assign "in between" dates that did not fall into one of these four date ranges. Before examining these methods in more detail, it should be noted that the timescale for this core has since been slightly revised for ages between 29 and 35 ky BP (Pahnke and Zahn, 2005, especially the caption on their Figure 2, and the "Age model" section of their online supporting material). Pahnke and Zahn used a new radiocarbon calibration data set (Hughen et al., 2004) to revise three radiocarbon dates in the upper portion of the core. This new calibration data set was itself tied to a well-known ice core in central Greenland, the GISP2 (Greenland Ice Sheet Project 2) core, which was itself a "follow-up" to another nearby core called the GRIP (Greenland Ice Sheet Project) core. Also, Shackleton et al. (2004) proposed a new age scale for both the GRIP and GISP2 cores, based upon ^{14}C dates for foraminifera within the deep-sea sediment core MD95–2042 that had been calibrated by means of ^{230}Th coral measurements. Because the dating of the MD97–2120 sediment core was tied to these other cores (as discussed below), Pahnke and Zahn acknowledged that acceptance of the new timescale of Shackleton et al. would also affect their absolute timescale for the MD97–2120 core, although they argued that this would not affect the previously determined correlations between the cores (i.e., one could presumably place the cores on a "floating" timescale while maintaining the relative "connections" between them).

Although this discussion focuses only on the original 2003 timescale of Pahnke et al., these chronological revisions illustrate two important points. First, the ice core and sediment core timescales are indeed interconnected: changes to the timescale of one sediment or ice core influence the chronologies for other cores. Second, one particular biblical critic (Seely, 2003) has claimed that the GISP2 ice core is the "ultimate proof" against a global, worldwide Flood (and by implication, the Bible's short chronology), since the long GISP2 timescale (Meese et al., 1997) was supposedly obtained "simply" by layer counting, independent of any doubtful old-earth assumptions. However, it has already been shown (Oard, 2004, 2005) that the GISP2 chronology was indeed subtly influenced by such assumptions. This proposed chronological revision by Shackleton et al. (2004) illustrates the tentative nature of secular age assignments: even this "ultimate proof" is subject to change! Furthermore, as pointed out by Skinner (2008), this proposed revision to the GISP and GISP2 timescales results in a potential contradiction to a new layer-counted chronology for the North Greenland Ice Core Project (NGRIP) core!

Dating of the Upper Core: 0 to 20 ky BP

The uppermost few meters of the core were assigned ages of 0 to 20 ky via a "marine calibration data set" that converted measured accelerator mass spectrometry (AMS) radiocarbon ages from within the core into "true" calendar ages (Pahnke et al., 2003 and online supplemental material). This calibration data set, which was obtained from dated tree rings, corals dated via the uranium-thorium method, and varves counted within marine sediments (Stuiver et al., 1998), was considered applicable to dates extending back to 24,000 years BP (0 years BP corresponds to AD 1950). This calibration process included a great many assumptions (in addition to the normal assumptions of radioisotope dating methods), as described by Stuiver et al. (1998), some of which were the following:

1. An extended tree-ring chronology (obtained by ^{14}C matching a "floating" German pine tree chronology to an "absolutely dated" tree chronology) is accurate to 11,857 years BP (p. 1041).
2. The C-14 "reservoir correction" was accurately determined for dates between 12,000 and 10,000 years BP (p. 1041). As a result of different amounts of carbon-14 in the ocean and atmosphere, the radiocarbon content of terrestrial and marine

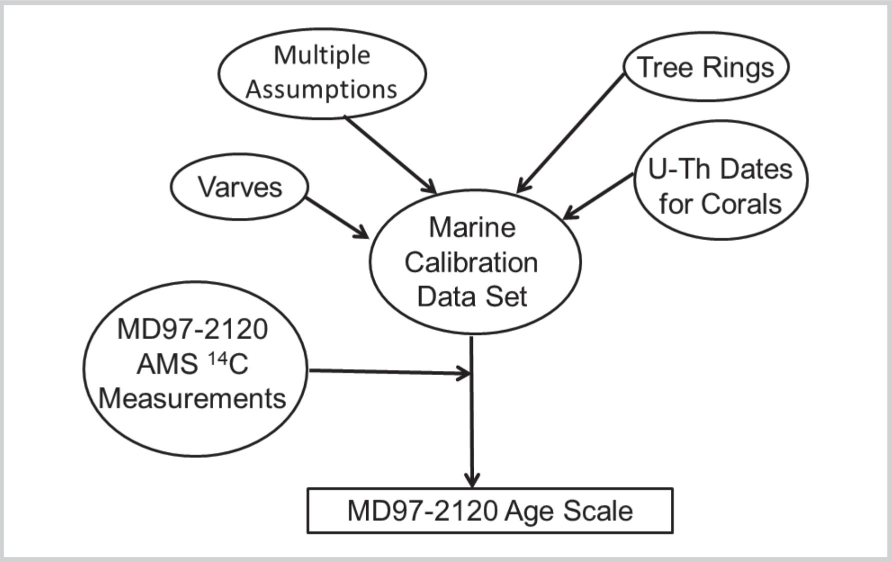

Figure 3. Schematic showing the logic used in dating the uppermost portion (0 to 20 ky BP) of the MD97–2120 New Zealand deep-sea sediment core. A marine calibration data set was used to convert accelerator mass spectrometry ^{14}C "ages" to calendar ages. The calibration data set was itself tied to varves, tree rings, radioisotope dates for corals, and multiple uniformitarian assumptions.

specimens will differ, even if they are of the same age. Hence, this effect must be taken into account when constructing a calibration that involves both "atmospheric" and "marine" samples.

3. The absolute times that had been attached to a "floating" marine varve chronology by matching with tree-ring ^{14}C ages (after taking into account the reservoir effect) were accurate (p. 1042).
4. An atmospheric transport model accurately determined differences in ^{14}C content for trees used in the calibration process that were from different geographic locations (pp. 1045–1046).

Pahnke et al. discarded two radiocarbon ages during their analysis, as they deviated from the overall linear age versus depth relation produced by the other radiocarbon data (Pahnke et al., 2003, online supplemental material, p. 2). The New Zealand Kawakawa ash (radiocarbon age of 22.59 ky BP; calendar age of 26.17 ky BP) also served as a constraint on the dating of the upper section of the core.

The methods used in the dating of the uppermost portion of core MD97–2120 are illustrated in Figure 3.

Dating of the Upper Core: 26.6 to 32.3 ky

Because the radiocarbon calibration of Stuiver et al. (1998) extended only to 24,000 years BP, Pahnke et al. (2003) needed some other means for presumed dates older than this to convert ^{14}C ages from within the core into calendar ages. For the portion of the MD97–2120 core dated as between 26.6 and 32.3 ky, Pahnke et al. (2003) used a calibration obtained by Voelker et al. (2000). In order to obtain their calibration points, Voelker et al. used the PS2644 sediment core from the western Iceland Sea (67° 52.02´ N, 21° 45.92´ W, water depth of 777 meters), tying planktonic δ^{18}O and δ^{13}C values from within this sediment core to Dansgaard-Oeschger cycles within the GISP2 ice core. Dansgaard-Oeschger cycles are fluctuations found within the supposed previous "interglacial" portion of the ice cores. Within the uniformitarian framework, these cycles are thought to be characterized by abrupt temperature increases within a decade or so, followed by slow, gradual cooling over several hundreds or thousands of years (Rahmstorf, 2010).

Since an age scale had already been assigned to the GISP2 ice core (Meese et al., 1997), this effectively transferred the GISP2 timescale to the PS2644 sediment core and allowed Voelker et al. (2000) to assign calendar ages to ^{14}C ages from within this Icelandic core. However, the transfer of the GISP2 timescale to the PS2644 sediment core required a great many selective expansions and contractions of the data: Figure 2 in Voelker et al. (2000) provides a classic illustration (the paper was accessible online, as of November 21, 2014) of the manner in which a data set can be "accordioned" via selective expansions and contractions in order to "correlate" it with another data set.

Voelker et al. (2000) argued that their calibration data set was confirmed by the correspondence between high excursions in ^{14}C and times of decreased geomagnetic intensity (one expects greater ^{14}C production during such geomagnetic "excursions"). It was this resulting calibration data set that Pahnke et al. (2003) used to date this section of the MD97–2120 core (Figure 4).

Dating of the Upper Core: 40 to 72 ky BP

Pahnke et al. (2003) assigned ages ranging from 40 to 72 ky BP to the section of the core between 6.8 to 10.6 meters in depth. They did this by tuning the core's benthic foraminiferal δ^{18}O values to the benthic δ^{18}O values within another

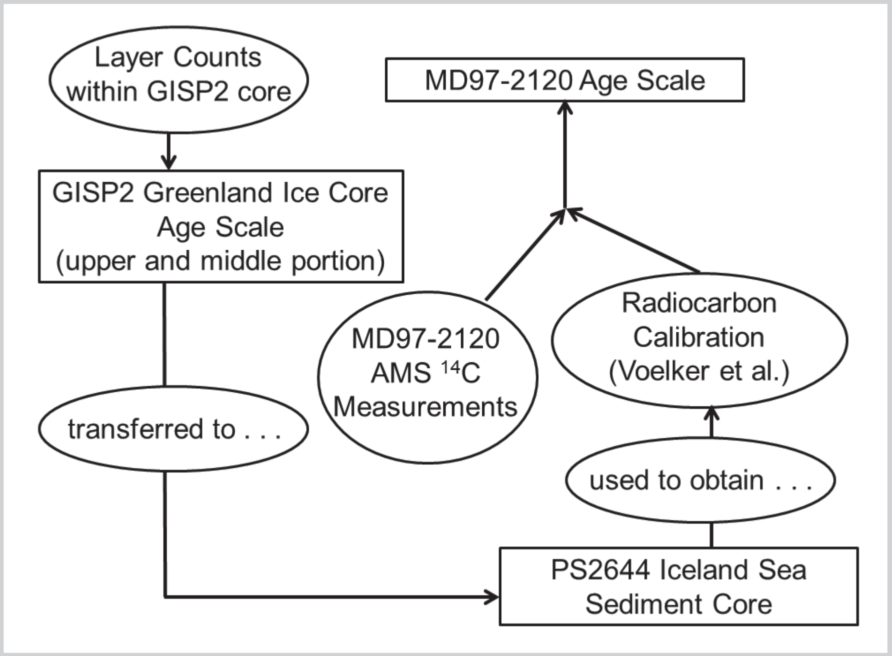

Figure 4. Schematic showing the logic used in dating the 26.6 to 32.3 ky BP section of the MD97–2120 New Zealand deep-sea sediment core. A second radiocarbon calibration data set was used to convert ^{14}C "ages" into calendar ages. But this radiocarbon calibration was tied to a sediment core from the Icelandic Sea, which was itself tied to the upper and middle portions of the GISP2 ice core chronology.

seafloor sediment core, the MD95–2042 core located off the coast of Portugal (37° 47.99´ N, 10° 09.99´ W, water depth of 3,146 meters). But the initial timescale for the 32-meter-long Portuguese sediment core was obtained from *another* sediment core, the nearby SU81–18 core (Shackleton et al., 2000, p. 565), and marine oxygen isotope values:

> *Cayre et al*. [1999] developed an age model for the core [the Portuguese MD95–2042 core] partly by correlation with nearby core SU81–18, which had been the subject of a very detailed AMS ^{14}C dating study [*Bard et al.*, 1987], and partly using the oxygen isotope stratigraphy. (Second set of brackets mine.)

From Cayre et al. (1999), one can see that the SU-18 core was used to date the upper portion of the MD95–2042 core, while ages for isotopic boundaries that had been assigned by Martinson et al. (1987) were used for assigning dates to the deeper parts of the MD95–2042 core. But Martinson et al. obtained these ages via orbital tuning. Hence, the astronomical theory played a significant role in the dating of the MD95–2042 core.

When the planktonic δ^{18}O values from MD95–2042 (dated according to this rough, initial timescale) were aligned with the δ^{18}O values from the GRIP (Greenland Ice Core Project) ice core, there was good agreement between their respective "wiggles" for ages between 0 and 100 ky BP. Hence, Shackleton et al. (2000) felt justified in transferring the higher resolution GRIP timescale to the MD95–2042 sediment core. However, as we shall see below, the astronomical theory *also* played a role in the dating of the GRIP ice core! Hence, good agreement between the timescales for their respective "wiggles" is not that surprising.

Shackleton, et al. (2000) noted that the GRIP ice core had been assigned a timescale by Johnsen et al. (1992). However, the timescale of Johnsen, which was obtained by stratigraphic methods, extended only to about 40 ky BP. Hence, some other means was required to extend this timescale to 100 ky BP before Shackleton et al. could make their comparison to MD95–2042. This was done (Anklin et al. 1993) via ice-flow modelling and was supposedly confirmed by correspondence between long-period (> 5 kyr) features in the Vostok ice core, a "standard" isotope curve for the SPECMAP (SPECtral MAping Project) marine timescale, and a vein calcite δ^{18}O record from Devil's Hole, Nevada.

This correspondence would superficially seem to validate the GRIP timescale. After all, the ages assigned by the flow model agreed with these previously determined age scales. However, the flow model for the GRIP ice core was *not* truly independent. (Dansgaard et al. acknowledge,

> The h and f_b values [flow model parameters, J. H.] are chosen so as to assign well-established ages to two characteristic features in the δ record: 11.5 kyr for the end of the Younger Dryas event[1,12] and 110 kyr for the marine isotope stage (MIS) 5d[4], which appears at depths of 1,624 m and 2,788 m, respectively, in the δ record. (Dansgaard et al., 1993, p. 219)

Thus, model parameters were "tweaked" to ensure an age scale that agreed with previous uniformitarian age expectations. Furthermore, Dansgaard et al. (1993) acknowledge that "orbital tuning" (see their Figure 2 caption) was used to assign the ages to the SPECMAP marine isotope curve!

Likewise, it should also be noted that the flow model Dansgaard et al. used to construct the GRIP chronology implic-

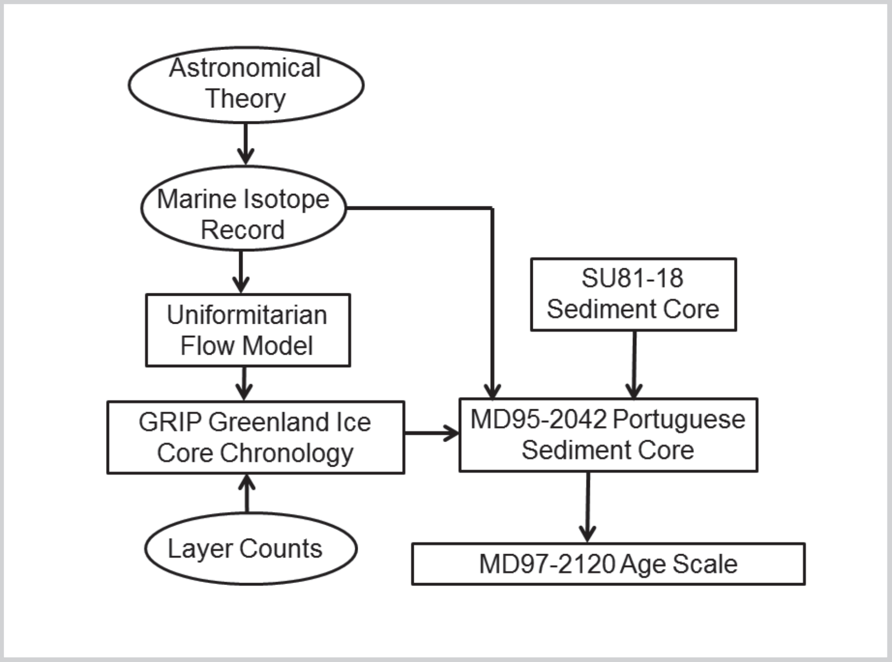

Figure 5. Schematic showing the logic used in dating the 40 to 72 ky BP section of the MD97–2120 New Zealand deep-sea sediment core. The age scale from another sediment core was transferred to the MD97–2120 core, but this age scale was itself tied to the age scale for still another (!) sediment core, as well as the GRIP ice core chronology. The GRIP chronology was in turn obtained via layer counts and a flow model that was calibrated, via the marine isotope record, to the astronomical theory of Pleistocene ice ages.

itly assumed the old-earth timescale, because such a "steady-state" model assumes that the thickness of the ice sheet has remained constant over extremely long ages (uniformitarians believe the ice sheets are millions of years old).

Note also that, because of light snowfall on the Antarctic plateau (Palerme et al., 2014), well-defined layering is not present in deep Antarctic ice cores like Vostok. Hence, glaciologists are especially dependent upon flow models in order to assign ages to the deep Antarctic cores, and these flow models are usually calibrated by the astronomical theory (e.g., Waelbroeck et al., 1995). Hence, the correspondence between the GRIP age-scale and that assigned to the Vostok core is not surprising either.

Although correspondence between the GRIP timescale and the Devil's Hole chronology supposedly helped to confirm the validity of the GRIP timescale, it should be noted in passing that the Devil's Hole chronology actually has been quite problematic for uniformitarian scientists, as it implies that the penultimate (second-to-last) deglaciation began at least 10,000 years before the changes in solar insolation that supposedly caused it (Winograd et al., 1992; Shakun et al., 2011)!

The methods used to date this section of the New Zealand sediment core are summarized in Figure 5.

Dating of the Lower Core: 72 to 338 ky BP

In order to obtain the age scale for depths within the MD97–2120 core greater than 10.6 meters, Pahnke et al. (2003) used Mg/Ca values measured within the MD97–2120 core in order to estimate sea surface temperatures via an empirically determined equation. These estimated sea surface temperatures were then correlated with chemical isotope data (and the associated timescale) of the Vostok ice core in order to establish an age scale. Specifically, the Mg/Ca-derived sea surface temperature values were correlated with Vostok values of the deuterium/hydrogen (D/H) ratio, which were thought to represent air temperatures at Vostok. As noted earlier, since ice is composed of water, one can calculate a "deuterium ratio," δD, for a given depth within the ice, in addition to an oxygen isotope ratio, $\delta^{18}O$.

One may wonder why Pahnke et al. used Mg/Ca values to establish a timescale for the bottom of the New Zealand core, rather than $\delta^{18}O$ values. Since they were attempting to construct a centennial-scale record of *surface* water hydrographic changes (Pahnke et al., 2003, p. 949), they would have needed to use values of $\delta^{18}O$ obtained from free-floating planktonic forams. However, they did not think that the MD97–2120 planktonic foraminiferal $\delta^{18}O$ values could really be used for this purpose, since they believed that these planktonic $\delta^{18}O$ values reflected global changes in ice volume, in addition to surface water effects (Pahnke et al., 2003, p. 949). In order to prevent complications from such global effects, they opted to use Mg/Ca rather than $\delta^{18}O$ values.

Likewise, why did they correlate these Mg/Ca values to Vostok δD values instead of to the high-resolution MD95–2042 timescale (which had been linked to the GRIP ice core)? There are likely a number of reasons for the use of the Vostok chronology, some of which are suggested by Shackleton et al. (2000). The most obvious reason is that the MD95–2042 chronology extended only to about 160 ky BP; hence, some other method was required to extend the MD97–2120 chronology beyond this

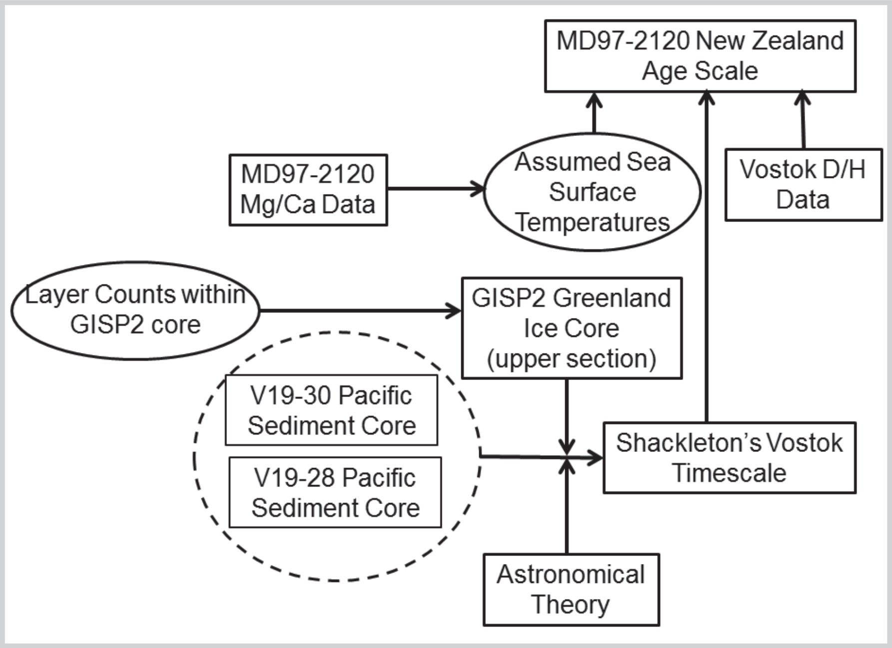

Figure 6. Schematic showing the logic used in dating the 70 to 338 ky BP section of the MD97–2120 New Zealand deep-sea sediment core. Mg/Ca data within the MD97–2120 core was used to infer presumed sea surface temperatures, which were correlated to Vostok δD values and a chronology for the Vostok core that was itself tied to the GISP2 ice core chronology, two other sediment cores, and the astronomical theory of Pleistocene ice ages.

point. Second, the age "control points" used to correlate the MD95–2042 chronology with the higher resolution GRIP chronology extended only to about 66 ky BP. Hence, Pahnke et al. probably did not feel justified in using the GRIP-tuned MD95–2042 chronology for presumed ages in the New Zealand core much greater than this.

The Vostok timescale Pahnke et al. applied to the bottom of the MD97–2120 core was constructed by Shackleton (2000). But Shackleton obtained his timescale by using the Eastern Pacific V19–30 sediment core (3° 21´ S, 83° 21´ W, water depth of 3,091 meters). After extending the sediment record somewhat by including $\delta^{18}O$ values from the nearby V19–28 (2° 22´ S, 84° 39´ W, water depth of 2,720 meters) sediment core, Shackleton then tuned benthic $\delta^{18}O$ values within these two cores to (presumed) 65° N summer insolation variations over the last 400,000 years. Hence, he assumed the validity of the astronomical theory and then used that assumption to assign an age scale to the V19–30 and V19–28 sediment cores, which was then applied to the Vostok ice core.

However, in order to determine the precession lag between the solar insolation signal and the V19–30 $\delta^{18}O$ values, Shackleton (2000) needed an "independent" age, which he obtained by assuming that the midpoint of the most recent glacial-to-interglacial transition occurred 13,000 years ago, on the basis of (presumed) annual layer counts in the upper portion of the GISP2 ice core. Once he obtained the value for this precession lag, he then inferred the value for the obliquity (axial tilt) lag.

Upon imposing this requirement and obtaining an age scale for the V19–30 core, Shackleton was able to transfer this timescale to the Vostok ice core data, including the D/H data. Pahnke et al. (2003) then correlated the assumed sea surface temperatures obtained from MD97–2120 to these variations in the Vostok D/H data, thereby transferring Shackleton's Vostok timescale to the bottom portion of the MD97–2120 sediment core.

It should be noted that Shackleton (2000) concluded, on the basis of his analysis, that the presumed 100,000-year cycle found in the seafloor $\delta^{18}O$ values was *not* the result (at least not directly) of changes in volume of the high-latitude ice sheets, as is generally assumed within the astronomical theory. Rather, he concluded that this 100,000-year cycle probably resulted instead from the influence of atmospheric carbon dioxide. This is interesting for two reasons. First, it suggests that part of the rationale for assuming that changing atmospheric CO_2 could dramatically influence climate is coming from old-earth interpretations of the climate data. Second, it was Shackleton himself (Shackleton, 1967) who argued that variations in sediment $\delta^{18}O$ values were caused mainly by variations in the amount of high-latitude ice, rather than by changes in sea temperature, as originally argued by Emiliani (1966). The fact that Shackleton reversed himself regarding the correct climatic interpretation of seafloor sediment chemistry is just one more example of the ever-changing nature of secular "origin stories."

The dating of this bottom section of the New Zealand core is summarized in Figure 6.

Discussion

Secular dates assigned to the deep seafloor sediments and ice cores are not independent but rather are tied to one another through a complex network of reasoning that assumes that the astronomical (or Milankovitch) hypothesis of ice ages is correct. This is demonstrated by examining in detail the methods used to date a single deep-sea sediment core, the MD97–2120 core off the eastern coast of New Zealand. It is worth noting that despite the interconnectedness between the different dating methods, there are still many contradictions between the different secular chronologies (e.g., the Devil's Hole chronology), although these are generally rather subtle and one has to "dig" into the literature in order to find them. Such contradictions are to be expected when a flawed paradigm is used to interpret the data.

Suggestions for Future Research

Due to the general lack of recent work on the seafloor sediments in the creation technical literature, this is an area that is "wide open" to creation researchers. Consideration of this topic suggests a number of avenues for future research. For instance, Vardiman (1996) has noted a trend of decreasing $\delta^{18}O$ values at greater sediment depths, consistent with postulated higher ocean temperatures during and after the Flood (Oard, 1990). However, Vardiman analyzed only three drilling sites: DSDP 277, 279, and 281. Given the wealth of sediment data available, it should be possible to confirm this trend for other cores. Likewise, Vardiman's model of seafloor sedimentation, though groundbreaking, was very preliminary, and there is a need to refine and expand it.

Also, there is a need to "tighten" up and revise a classic young-earth argument involving the seafloor sediments. Creation scientists have long pointed out that even if one assumes that sediment transport to the oceans has always been "slow and gradual," the many millions of years assumed by uniformitarian models imply that the ocean basins should now be choked with sediment (Roth, 1986; Nevins, 1973; Morris, 1994). However, these earlier arguments used old estimates of sedimentation rates, and there is a need to revisit this argument using the most up-to-date numbers. Snelling (2009, 2012) has already done this to some extent, although one online critic (Anonymous, 2014) has criticized his 2012 popular-level work. Snelling uses in his calculation a value of 20 billion tons of annual sediment discharge into the oceans, citing a figure from Milliman and Syvitski (1992). However, Milliman and Syvitski state that prior to 2000–2500 years ago, the rate of annual sediment discharge was probably less than half this number (< 10 billion tons per year). Hence, it could be argued that ~10 billion tons per year would have been the more appropriate number for the calculation, if one trusts Milliman and Syvitski's estimates. But it is also possible that their estimates could have been based on dubious old-earth assumptions. Either way, there is a real need to revisit and "tighten" this argument.

Also, Patrick (2010) has pointed out that the general scarcity of manganese and other polymetallic nodules within all but the shallowest seafloor sediments is a powerful argument that the bulk of the sediments were deposited rapidly, consistent with rapid Flood and post-Flood deposition of sediment but inconsistent with "slow and gradual" deposition over millions of years. Hence, geographical and depth variations in manganese nodule distribution might prove helpful in "fleshing out" the details of the Flood event, particularly its later stages as deposition rates slowed. In particular, they might help to determine how late-Flood and post-Flood sedimentation rates varied with location.

Much seafloor sediment data is publicly available, for example at ftp://ftp.ncdc.noaa.gov/pub/data/paleo/paleocean/. These data may provide a number of relatively inexpensive opportunities for the creation science community to strengthen and refine the Creation-Flood model.

References

Anklin, M., J.M. Barnola, J. Beer, T. Blunier, J. Chappellaz, H.B. Clausen, D. Dahl-Jensen, W. Dansgaard, M. De Angelis, R.J. Delmas, P. Duval, M. Fratta, A. Fuchs, K. Fuhrer, N. Gundestrup, C. Hammer, P. Iversen, S. Johnsen, J. Jouzel, J. Kipfstuhl, M. Legrand, C. Lorius, V. Maggi, H. Miller, J.C. Moore, H. Oeschger, G. Orombelli, D.A. Peel, G. Raisbeck, D. Raynaud, C. Schøtt-Hvidberg, J. Schwander, H. Shoji, R. Souchez, B. Stauffer, J.P. Steffensen, M. Stievenard, A. Sveinbjörnsdottir, T. Thorsteinsson, and E.W. Wolff. 1993. Climate instability during the last interglacial period recorded in the GRIP ice core. *Nature* 364(6434): 203–207.

Anonymous. 2014. "Best evidences for a young earth": Snelling and the ocean-sediment flux. Questioning Answers in Genesis blog. http://questioninganswers-ingenesis.blogspot.com/2014/05/best-evidences-for-young-earth-snelling.html

Bard, E., M. Arnold, J. Duprat, J. Moyes, and J. C. Duplessy. 1987. Reconstruction of the last deglaciation: deconvolved records of $\delta^{18}O$ profiles, micropaleontological variations and accelerator mass spectrometric ^{14}C dating. *Climate Dynamics* 1(2): 101–112.

Bintanja, R., R.S. W. van de Wal, and J. Oerlemans. 2005. Modelled atmospheric temperatures and global sea levels over the past million years. *Nature* 437(7055): 125–128.

Blaauw, M. 2010. Out of tune: the dangers of aligning proxy archives. *Quaternary Science Reviews* 36 (March 12): 38–49.

Blaauw, M., K.D. Bennett, and J.A. Christen. 2010. Random walk simulations of fossil proxy data. *The Holocene* 20(4): 645–649.

Cayre, O., Y. Lancelot, E. Vincent, and M. A. Hall. 1999. Paleoceanographic reconstructions from planktonic foraminifera off the Iberian Margin: temperature, salinity, and Heinrich Events. *Paleoceanography* 14(3): 384–396.

Cronin, T. M. 2010. *Paleoclimates: Understanding Climate Change Past and Present*. Columbia University Press, New York, NY.

Dansgaard, W., S.J. Johnsen, H.B. Clausen, D. Dahl-Jensen, N.S. Gundestrup, C.U. Hammer, C.S. Hvldberg, J.P. Steffensen, A.E. Sveinbjörnsdottir, J. Jouzel, and G. Bond. 1993. Evidence for general instability of past climate from a 250-kyr ice-core record. *Nature* 364(6434): 218–220.

Elderfield, H., P. Ferretti, M. Greaves, S. Crowhurst, I.N. McCave, D. Hodell, and A.M. Piotrowkski. 2012. Evolution of ocean temperature and ice volume through the mid-Pleistocene transition. *Science* 337(6095): 704–709.

Emiliani, C. 1966. Isotopic paleotemperatures. *Science* 154(3751): 851–857.

Grossman, E.L. 2012. Applying oxygen isotope paleothermometry in deep time. In Ivany, L.C., and B.T. Huber (editors), *Reconstructing Earth's Deep Time Climate—The State of the Art in 2012, Paleontological Society Short Course*, pp. 39–67. The Paleontological Society Papers 18 (November 3, 2012). GSA Annual Meeting, Charlotte, NC.

Hayes, J.D., J. Imbrie, and N.J. Shackleton. 1976. Variations in the earth's orbit: pacemaker of the ice ages. *Science* 194(4270): 1121–1132.

Hebert, J. 2014. Circular reasoning in the dating of deep seafloor sediments and ice cores: the orbital tuning method. *Answers Research Journal* 7:297–309.

Herbert, T.D. 2010. Paleoceanography: orbitally tuned timescales. In Steele, J.H. (editor), *Climates and Oceans*, pp. 370–377. Academic Press, Amsterdam, Netherlands.

Hughen, K., S. Lehman, J. Southon, J. Overpeck, O. Marchal, C. Herring, and J. Turnbull. 2004. ^{14}C activity and global carbon cycle changes over the past 50,000 years. *Science* 303(5655): 202–207.

Johnsen, S.J., H.B. Clausen, W. Dansgaard, K. Fuhrer, N. Gundestrup, C.U. Hammer, P. Iversen, J. Jouzel, B. Stauffer, and J.P. Steffensen. 1992. Irregular glacial interstadials recorded in a new Greenland ice core. *Nature* 359(6393): 311–313.

Kingston, P.F. 2010. Benthic organisms overview. In Steele, J.H. (editor), *Climates and Oceans*, pp. 416–424. Academic Press, Amsterdam, Netherlands.

Kucera, M. 2010. Determination of past sea surface temperatures. In Steele, J.H. (editor), *Climates and Oceans*, pp. 328–343. Academic Press, Amsterdam, Netherlands.

Lisiecki, L.E., and M.E. Raymo. 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic δ^{18}O records. *Paleoceanography* 20(1): PA1003

Martinson, D.G., N.G. Pisias, J.D. Hays, J. Imbrie, T.C. Moore Jr., and N.J. Shackleton. 1987. Age dating and the orbital theory of the ice ages: development of a high-resolution 0 to 300,000-year chronostratigraphy. *Quaternary Research* 27(1): 1–29.

Meese, D.A., A.J. Gow, R.B. Alley, G.A. Zielinski, and P.M. Grootes. 1997. The Greenland Ice Sheet Project 2 depth-age scale: methods and results. *Journal of Geophysical Res*earch 102, No. C12: 26411–26423. The depth-age scale for the GISP2 core has been archived at ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/gisp2/depthage/gisp2age.txt (accessed July 15, 2014).

Milankovic, M. 1941. *Canon on Insolation and the Ice-Age Problem* (in German). Special Publications of the Royal Serbian Academy, vol. 132, Belgrade, Yugoslavia.

Milliman, J.D., and J.P.M. Syvitski. 1992. Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers. *The Journal of Geology* 100(5): 525–544.

Morris, J. 1994. *The Young Earth*. Master Books, Colorado Springs, CO.

Mortyn, P.G., and C.D. Charles. 2003. Planktonic foraminiferal depth habitat and δ^{18}O calibrations: plankton tow results from the Atlantic sector of the southern ocean. *Paleoceanography* 18(2): 1037.

Nevins, S.E. 1973. Evolution: the ocean says no! *Acts & Facts* 8. Institute for Creation Research.

Oard, M.J. 1984. Ice ages: the mystery solved? Part II: the manipulation of deep-sea cores. *Creation Research Society Quarterly* 21:125–137.

Oard, M.J. 1985. Ice ages: the mystery solved? Part III: paleomagnetic stratigraphy and data manipulation. *Creation Research Society Quarterly* 21:170–181.

Oard, M.J. 1990. *An Ice Age Caused by the Genesis Flood*. Institute for Creation Research, El Cajon, CA.

Oard, M.J. 2004. Ice cores vs the Flood. *Journal of Creation* 18(2): 58–61.

Oard, M.J. 2005. *The Frozen Record*. Institute for Creation Research, Santee, CA.

Oard, M.J. 2007. Astronomical troubles for the astronomical hypothesis of ice ages. *Journal of Creation* 21(3): 19–23.

Pahnke, K., and R. Zahn. 2005. Southern Hemisphere water mass conversion linked with North Atlantic climate variability. *Science* 307(5716): 1741–1746. Online supplemental material at http://www.sciencemag.org/content/suppl/2005/03/16/307.5716.1741.DC1/Pahnke_SOM.pdf (accessed November 21, 2014).

Pahnke, K., R. Zahn, H. Elderfield, and M. Schulz. 2003. 340,000-year centennial-scale marine record of Southern Hemisphere climatic oscillation. *Science* 301(5635): 948–952. Online supplemental material at http://www.sciencemag.org/content/suppl/2003/08/14/301.5635.948.DC1/Pahnke.SOM.pdf (accessed November 21, 2014). Likewise, a summary of the age model applied to the core has been archived at http://ftp.ncdc.noaa.gov/pub/data/paleo/contributions_by_author/pahnke2003/pahnke2003.txt (accessed November 21, 2014).

Palerme, C., J.E. Kay, C. Genthon, T. L'Ecuyer, N.B. Wood, and C. Claud. 2014. How much snow falls on the Antarctic ice sheet? *The Cryosphere*

Discussions 8:1279–1304. http://www.the-cryosphere-discuss.net/8/1279/2014/tcd-8–1279–2014-print.pdf (accessed November 11, 2014).

Patrick, K. 2010. Manganese nodules and the age of the ocean floor. *Journal of Creation* 24(3): 82–86.

Pisias, N.G., D.G. Martinson, T.C. Moore Jr., N.J. Shackleton, W. Prell, J. Hays, and G. Boden. 1984. High resolution stratigraphic correlation of benthic oxygen isotope records spanning the last 300,000 years. *Marine Geology* 56(1–4): 119–136.

Rahmstorf, S. 2010. Abrupt climate change. In Steele, J.H. (editor), *Climates and Oceans*, pp. 41–46. Academic Press, Amsterdam, Netherlands.

Roth, A. 1986. Some questions about geochronology. *Origins* 13(2): 64–85.

Seely, P.H. 2003.The GISP2 ice core: ultimate proof that Noah's Flood was not global. *Perspectives on Science and Christian Faith* 55(4): 252–260.

Shackleton, N. 1967. Oxygen isotope analyses and pleistocene temperatures re-assessed. *Nature* 215:15–17.

Shackleton, N. 1987. Oxygen isotopes, ice volume, and sea level. *Quaternary Science Reviews* 6(3–4): 183–190.

Shackleton, N.J. 2000. The 100,000-year ice-age cycle identified and found to lag temperature, carbon dioxide, and orbital eccentricity. *Science* 289(5486): 1897–1902.

Shackleton, N.J., A. Berger, and W.R. Peltier. 1990. An alternative astronomical calibration of the lower Pleistocene timescale based on ODP Site 677. *Transactions of the Royal Society of Edinburgh: Earth Sciences* 81:251–261.

Shackleton, N.J., M.A. Hall, and E. Vincent. 2000. Phase relationships between millennial-scale events 64,000–24,000 years ago. *Paleoceanography* 15(6): 565–569.

Shackleton, N.J., R.G. Fairbanks, T. Chiu, and F. Parrenin. 2004. Absolute calibration of the Greenland time scale: implications for Antarctic time scales and for $\Delta^{14}C$. *Quaternary Science Reviews* 23(14–15): 1513–1522.

Shakun, J.D., S.J. Burns, P.U. Clark, H. Cheng, and R.L. Edwards. 2011. Milankovitch-paced Termination II in a Nevada speleothem? *Geophysical Research Letters* 38: L18701.

Skinner, L.C. 2008. Revisiting the absolute calibration of the Greenland ice-core age-scales. *Climate of the Past* 4:295–302.

Snelling, A.A. *Earth's Catastrophic Past*, volume 2. 2009. Institute for Creation Research, Dallas, TX.

Snelling, A. 2012. 10 best evidences that confirm a young earth: #1 very little sediment on the seafloor. https://answersingenesis.org/geology/sedimentation/1-very-little-sediment-on-the-seafloor/

Sosdian, S., and Y. Rosenthal. 2009. Deep-sea temperature and ice volume changes across the Pliocene-Pleistocene climate transitions. *Science* 325(5938): 306–310.

Sosdian, S., and Y. Rosenthal. 2010. Response to comment on "Deep-sea temperature and ice volume changes across the Pliocene-Pleistocene climate transitions." *Science* 328(5985): 1480d.

Stuiver, M., P.J. Reimer, E. Bard, J.W. Beck, G.S. Burr, K.A. Hughen, B. Kromer, G. McCormac, J. Van der Plicht, and M. Spurk. 1998. INTCAL98 radiocarbon age calibration, 24,000–0 cal BP. *Radiocarbon* 40:1041–1083.

Vardiman, L. 1996. The sands of time: a biblical model of deep sea-floor sedimentation. *Creation Research Society Quarterly* 33:191–198.

Voelker, A.H.L., P.M. Grootes, M.J. Nadeau, and M. Sarnthein. 2000. Radiocarbon levels in the Iceland Sea from 25–53 kyr and their link to the earth's magnetic field intensity. *Radiocarbon* 42:437–452.

Waelbroeck, C., J. Jouzel, L. Labeyrie, C. Lorius, M. Labracherie, M. Stiévenard, and N.I. Barkov. 1995. A comparison of the Vostok ice deuterium record and series from the Southern Ocean core MD 88–770 over the last two glacial cycles. *Climate Dynamics* 12:113–123.

Winograd, I.J., T.B. Coplen, J.M. Landwehr, A.C. Riggs, K.R. Ludwig, B.J. Szabo, P.T. Kolesar, K.M. Revesz. 1992. Continuous 500,000-year climate record from Vein Calcite in Devils Hole, Nevada. *Science* 258(5080): 255–260.

Wright, J.D. 2010. Cenozoic climate—oxygen isotope evidence. In Steele, J.H. (editor), *Climates and Oceans*, pp. 316–327. Academic Press, Amsterdam, Netherlands.

Yu, J., and W.S. Broecker. 2010. Comment on "Deep-sea temperature and ice volume changes across the Pliocene-Pleistocene climate transitions." *Science* 328(5985): 1480c.