ARTICLES

THE IMPACT OF TEKTITES UPON AN ESTIMATED 700,000 YEAR HISTORY OF DEEP-SEA DEPOSITS

Warren H. Johns*
Graduate Student in Paleontology
Michigan State University
East Lansing, Michigan

WHAT THIS ARTICLE IS ABOUT

In this sequel to an article that appeared in Origins *3:85-96, the author pursues further the matter of conflicting dates obtained by various lines of evidence. The controversy presented in this article centers around small unique glassy objects called tektites, whose implacement appears to have occurred less than 6000 years ago according to carbon-14 dating, while other dating techniques indicate that the same kind of object when found in the ocean appears to have been placed over one hundred times earlier. Dating of ocean sediments containing these unique objects by a number of techniques which appear to give consistent results does not agree with the dating of comparable terrestrial sediments.*

Small, glassy objects in a variety of shapes have been found scattered all across the surface of Australia and southeast Asia. Known as tektites, they were first thought to have originated from outside the earth's atmosphere because of their aerodynamically sculptured surface. Though much of their surface patterns are strikingly similar to the surficial etchings on meteorites, yet the chemical composition of tektites is quite different. Having only a trace of nickel as opposed to meteorites, they are especially rich in silica (SiO_2) and rarely are composed of less than 70% SiO_2. Thus tektites are not the waste products from meteorite showers.

On the basis of data on samples collected by five Apollo missions to the moon it is generally conceded that tektites were not formed from a shower of molten material ("moon drops") propelled toward the earth as a result of meteorite impacts on the lunar surface. Rather, it is now believed that they have originated from gigantic meteorite impacts on the earth itself.[1] It appears that drops of molten material were projected into a low orbit and then re-entered the atmosphere at high speed, finally resting over a wide area known as a strewnfield. Artificial tektites of the same chemical composition as Australian tektites (australites) have been fashioned at air speeds of 17,000 m.p.h. in a wind tunnel at the Smithsonian Institute. To the untrained eye the end product is indistinguishable from natural

---

* *Also Instructor in Religion,Columbia Union College, Takoma Park, Maryland*

tektites. Tektites from the Ivory Coast strewnfield have a chemical composition very similar to (if not identical with) the altered rocks of nearby Lake Bosumtwi, which has the main criteria of a meteorite impact site.[2] Recently a probable meteorite impact site, Elgygytgyn Crater, was identified from satellite photos and is now proposed as the source for australites.[3] The australite strewnfield is pie shaped and the apex points in the direction of Elgygytgyn in northeastern Siberia.

Australites have been dated concordantly at 700,000 years by two radiometric dating methods — fission track and potassium-argon (K-Ar). This represents a major challenge to conservative Christians wishing to hold to a short Biblical chronology. But these 700,000 year radiometric ages are now under question by the use of another radiometric method, radiocarbon dating. In the 1960's two independent teams of investigators[4,5] located australites *in situ* (see *Origins* 3:85-96). Since the publication of their findings, a third team working independently of the others has reached essentially the same conclusion: that the time of infall for the australites should be in terms of a few thousand years instead of the generally acknowledged radiometric age of 700,000 years.[6] These authors suggest an infall age of 6500 years based on a C^{14} date of 7300 years for wood fragments in the soil into which australites have fallen.

These conclusions place geologists and geochemists in a quandary. For those who have made first-hand field observations of australites, the evidence is in favor of a geologically young age, whereas those who work with them in the laboratory are convinced that the time when the tektites fell is the time of their last melting when the radiometric clock was re-set approximately 700,000 years ago.[7] According to one way of solving the dilemma, the older age represents their actual age of formation somewhere in space and the younger age represents their terrestrial age. This hypothesis has been ruled out by the fact that no cosmic ray tracks have been detected in tektites, as in meteorites; thus limiting their hypothetical journey in the solar system to less than 300 years.[8]

Another solution is to suggest that approximately 700,000 years ago the australites landed elsewhere than their present location and were subsequently washed into place as part of transported sediments a few thousand years ago. After reporting C^{14} ages of 5700 and 5350 years immediately adjacent to an australite, Gill notes that, if they were transported, neither the tektites nor the buckshot gravel which are always associated together at Port Campbell, Australia, "could have come far and both must have come gently because the edges are sharp on the australites, and the buckshot is not polished."[9] In a later publication Gill reaches the same conclusion: "The good preservation of the Port Campbell australites is against long residence in the soil, or long transport from one formation to another."[5]

More recently an author in commenting on Gill's conclusions notes that if the tektites were not transported, then the K-Ar age is under suspicion:

> *The Port Campbell australites as a geographical group are all astonishingly fresh and undegraded by terrestrial processes, as far as is known, and there seems little possibility that more than one shower is represented at Port Campbell. Hence, it is very difficult to accept Gill and Baker's conclusions, unless the K/Ar age date means something else than is commonly believed.*[10]

A 1976 study by a tektite expert confirms the fact that the dilemma has not yet been solved:

> *The papers of Gill and of Lovering et al. supply clear evidence that tektites are found on top of recent Australian soils whose ages, as given by carbon dating, are less than 20,000 years. The evidence is strong that they did not reach this position by reworking from older sediments at a higher elevation.¼ For example, a Czechoslovakian study shows that stream erosion will reduce glass objects of roughly tektitic character to about one-ninetieth of the original mass at a distance of 40 km downstream.*[11]

It is noted that in Lovering's study the nearest possible source for the tektites would be 15-20 km away. In commenting upon the 700,000 age for the flanges of tektites formed in their descent earthward, this expert concludes: "It appears that we must reject the very recent dates for the Australian tektites: something must be wrong, conceivably the dating of the hardpan."[12]

The Smithsonian study which was published in 1976 builds an even stronger case for the young age of australite infall, yet even it is unwilling to take that gargantuan leap and suggest that the fission-track and K-Ar ages may be in error. The report ends with these pointed observations:

> *No one who has seen the Port Campbell localities and examined the many perfectly preserved australites therefrom is likely to argue that these specimens are not being found essentially where they fell. The complete lack of solution etching, even on thin plates weighing as little as 0.03 gram, is a powerful argument against the australites having been subjected to terrestrial weathering, even in situ, for more than a few thousand years.*[6]

Evidence is against their having been transported as sediments, otherwise one would tend to find them concentrated in stream beds. They are found even on sand dunes, a fact which would rule out stream transport. They could not have been traveling through the universe over a period of 700,000 years and then come to earth 6000 years or so before the present (B.P.), otherwise the entry into the earth's atmosphere at high speed would have erased the fission tracks, which are sensitive to heat, and would have driven off the excess argon, thus re-setting the radiometric clocks. The concluding statement of the Smithsonian report aptly summarizes the dilemma:

Having reached an apparently irreconcilable impasse between the physical dating and the geographical dating of the australite fall, one can only turn to the third proposition — something else is wrong. Perhaps this can better be stated as something — some unsuspected factor — has been overlooked.[6]

To date, a proposed young age for australite infall has not been overthrown.

The last decade and a half have witnessed not only this epoch-making research come to light but also the discovery of tektites in deep-sea cores to the north, west and south of Australia. Because these marine tektites are never as large as their terrestrial counterparts, they are called microtektites, being the size of microfossils, such as foraminifera, which are less than 1 mm in diameter. Interestingly they retain the same general shapes as their larger relatives, ranging from spherical to tear dropped, disk and even dumbbell and spoon shaped.[13] These microtektites spread over a vast area of the ocean bottom are now undoubtedly linked with the influx of australites upon land because of the following salient facts:

1. They have identical refractive indices, which is a measure of the amount that visible light is bent passing from air into the glass, as their Australian counterparts.
2. They have the same range of chemical composition as australites.
3. The shapes of both are much alike.
4. They are dated at identically the same age by the fission-track method — 710,000 years.
5. Occasionally high-magnesium microtektites are found which would correspond with the less common high-magnesium australites.[13,14,15]

The evidence both from petrography and geochemistry strongly indicates that Australasian microtektites belong to the infall responsible for australites.[16,17] That being the case, a careful stratigraphic study of the deep-sea cores in which microtektites have been located should either deny or verify an identically young age for infall. Thus far nineteen Australasian deep-sea cores from widely scattered sites have yielded microtektites.[18,19] For eight of these cores a detailed magnetic stratigraphy has been determined.

Magnetic stratigraphy results from the fact that magnetic particles become oriented in the direction of earth's magnetic field as they fall out of suspension in the quiet water of ocean bottoms. Throughout geohistory the earth's magnetic field has frequently reversed so that the dominant field was not northward but southward. The boundaries between normal and reversed polarity are usually quite distinct in ocean sediments. The most critical boundary in our study is the Matuyama-Brunhes (M-B) boundary, which was first calculated by the K-Ar method to have been formed 690,000 years B.P.,[20] and more recently has been dated by fission tracks in volcanic ash.[21] Microtektites in large concentrations occur almost without exception in a very narrow stratigraphic range within 10 cm of the M-B boundary.

It appears to be more than a coincidence that microtektites, which have been dated at approximately 700,000 years by the fission-track and K-Ar methods, should be found in a narrow magnetic boundary zone that has been dated both on land and in the oceans at approximately 700,000 years by the same methods. It is for this reason that geologists reject the obvious terrestrial age of 5000-24,000 radiocarbon years as being embarrassingly too young.

The science of stratigraphy, which involves the correlation of cores drilled into the foraminiferal and radiolarian oozes of the ocean bottoms, has now achieved the reconstruction of climatic oscillation patterns on a worldwide basis. Such patterns can be developed irrespective of whether one accepts the validity of any of the dating systems, including C^{14}, applied to the cores. The criteria which are commonly used to match patterns from widely separated regions are described below.

1) *Oxygen isotope ratios*. The ratio of the heavier O^{18} isotope to the lighter O^{16} can be determined very accurately, and it is found that during times of the dominance of polar weather the ratio is higher. The current theory is that when increased amounts of snow accumulated in the far northern and far southern latitudes, the sea levels were lower and hence there would be a relatively higher ratio of O^{18} to O^{16}.[22] Conversely, the melting of the ice caps would release into the ocean the lighter O^{16} that had been incorporated into the snow, thus lowering the O^{18}-O^{16} ratio. The oxygen isotope ratio taken from foraminifera is directly a measurement of sea levels and only indirectly a measurement of paleotemperature. While on land oxygen isotope ratios in some cases seem to be positively correlated with temperature, as, for example, those from a sequence of 87 tree rings in Alberta, Canada, which correlates nicely with weather bureau records.[23] Just this year an 1800-year continuous sequence of Japanese cedar rings has been reported showing oxygen isotope patterns that match with an 800-year sequence from the Greenland ice cap.[24]

2) *Foraminiferal curves*. Foraminifera are one-celled organisms which have a calcium carbonate shell and are a major contributor to the deep-sea sediments. The percentage of polar species to temperate or tropical species can be plotted for the length of the core and a climatic curve developed that correlates nicely with the oxygen isotope curve.

3) *Coccolith curves*. Coccoliths are microfauna that contribute to the oceanic sediments, and, like the foraminifera, the ratios of polar fauna to temperate or tropical fauna can be plotted using the depth of the core as the Y-axis.

4) *Calcium carbonate percentages*. The amount of calcium carbonate ($CaCO_3$) in a given section of the deep-sea core can be accurately determined, and a plot of the percentages shows a good fit with the other factors related to climate. The reasoning is that during times of polar weather dominance the growth of marine organisms which are the major contributors of $CaCO_3$ is inhibited.

5) *Coarse fraction percentages*. This is not the measure of the amount of $CaCO_3$ but a determination of the average size of the calcareous clasts or fragments in the sediment. The theory is that during warm weather dominance the marine organisms grow larger and the percentage of coarse fragments would be higher.

Other methods have been developed and sometimes show a good correlation with oxygen isotope curves, such as the percentages of ice-rafted debris[25] and radiolarians,[26] as well as clay/quartz ratios,[27] quartz/mica ratios,[28] and the coiling ratios of foraminifera.[29,30]

One of the most intensively studied cores of all the thousands of deep-sea cores retrieved to date is the Caribbean V12-122. When the top four meters of the core are evaluated on the basis of the oxygen isotope, $CaCO_3$, coarse fraction and foraminiferal percentages, the resultant curves show fairly good parallelisms (Figure 1). Note that in this diagram as in all diagrams a fluctuation of the curve to the right denotes warm weather (W) dominance and to the left polar dominance (C).

Not only can paleoclimatic curves be developed for oceanic cores but also for terrestrial cores. One of the most problematic of all terrestrial cores has been that of Tenaghi Philippon, Macedonia, which was drilled through 120 m of lake bottom and marsh sediments. Large sections are composed of peat. It would be difficult to compress the amount of time needed for peat formation into a short chronology, unless one were to postulate that this particular peat were the product of diluvial action; in other words, an allochthonous peat. Also, more than a dozen radiocarbon determinations have been made on the top few meters of the core and a reading of 47,670±2700 years has been obtained at a depth of 16.75 m.[31] Assuming a constant sedimentation rate of 25 mm/10^3 years computed from the upper 17 m and extrapolating this rate to the base of the 120 m core, one would conclude that 342,857 years of time are represented. How can this be harmonized with a short chronology of just a few thousand years for post-diluvial time?

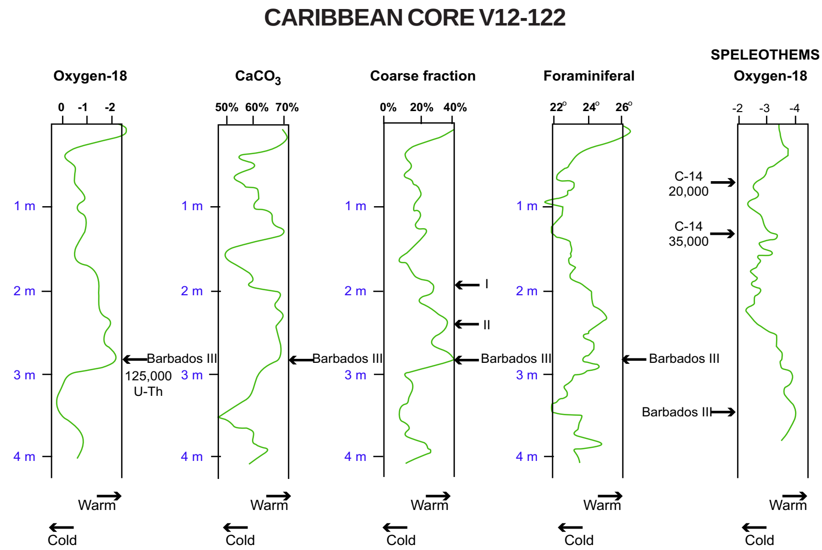


FIGURE 1. Four independent temperature curves for the Caribbean core V12-122 show similar fluctuations (W=Warm, C=Cold). The 3-m level has been dated at 127,000 years by Th^{230} and Pa^{231} (36) and has been correlated with Barbados terrace III which is dated at 125,000 years.[37] The fifth paleoclimatic curve is derived from two stalactites in New Zealand. (Re-drawn from references 45, 46, 33.)

Also of interest is correlating the climatic curve derived from this terrestrial core with various oceanic cores. To develop a climatic curve for land deposits one must use pollen as a temperature indicator. It has been discovered that the percentages of arboreal or tree pollen (AP) and of nonarboreal pollen (NAP), which is composed of grasses, herbs, and shrubs, are excellent climatic indices during historical times. Thus it is suggested that in pre-historic times the higher the ratio of AP to total pollen the warmer the climate would have been, and the higher the ratio of NAP to total pollen the cooler the climate. Thus a plot of AP and NAP percentages as a function of depth builds a climatic curve that can be cross-referenced with the deep-sea curves.

The question is whether it is feasible to match terrestrial curves with the deep-sea. A comparison of the two sets of curves indicates that the resultant curves have a very close fit, considering that they are constructed using different parameters. The Philippon core can be matched with the deep-sea core Al 189, which was retrieved from the central part of the Mediterranean Sea (Figure 2). Another terrestrial core that extends even longer than the Philippon core is the 190 m Sabana de Bogota core from

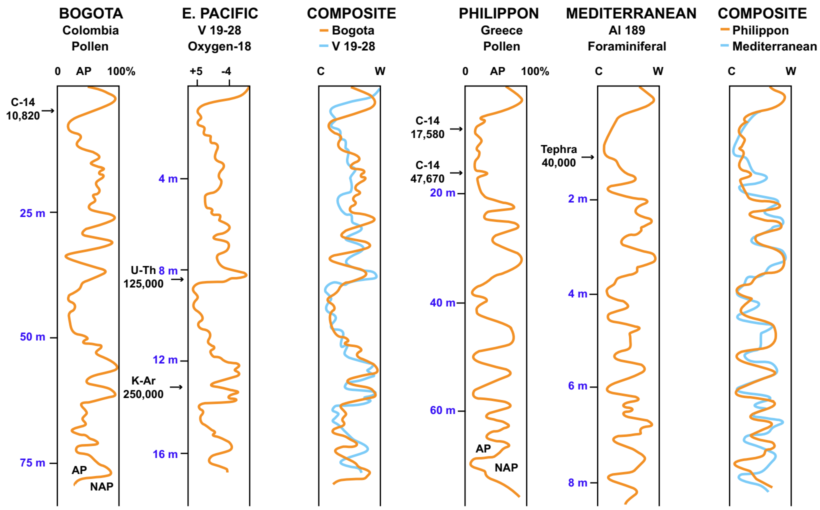


FIGURE 2. Correlation between two terrestrial pollen curves and two marine climatic curves from adjoining ocean basins is demonstrated. The Philippon core is dated with radiocarbon and V19-28 is dated stratigraphically by a distinct ash marker. AP=Arboreal Pollen, NAP=Nonarboreal Pollen. (Drawn from information in references 47, 32, 47, 48 respectively.)

Colombia, South America. Its climatic curve constructed out of AP/NAP ratios has a good fit with the deep-sea curve from core V19-28 which is based on oxygen isotope ratios (Figure 2). Located not far off the coast of Ecuador in the Panama basin, core V19-28 has an ash layer at 13.2 m that has been dated in the range of 225,000 to 250,000 years by four different methods, including K-Ar.[32]

Oxygen isotope curves can not only be derived from marine cores but also from terrestrial speleothems. A curve based on two stalactites from Waitomo, New Zealand, and dated by C^{14} dating is compared with the Caribbean V12-122 curve, indicating that matching can be done on a worldwide basis (Figure 1).[33] Short segments of speleothem oxygen isotope curves from North America that have been dated by Th^{230}/U^{234} match nicely with cores V12-122 and V19-28.[34]

Are such synchronizations of climatic curves mere coincidences? Hardly the case. If these curves were analyzed from the standpoint of probability theory there is only a very slight possibility that even two of the cores could be matched purely on the basis of chance alone. The probability that more than two cores could be coordinated if the curves were not climate dependent would be so small that it can be safely said such curves are indeed controlled by a common variable such as climate rather than by chance processes.

Correlation between widely separated curves can be achieved by noting faunal boundaries, relationships to magnetic reversals, and the presence of volcanic ash layers. Extinctions of certain deep-sea organisms occur at the same interval in matching cores on a worldwide basis. The most convincing example of this is the global extinction of the coccolith *Pseudoemiliania lacunosa* which occurs at the same interval on matching oxygen isotope curves from seven cores, including V28-238 and K708-7 (see Figure 3).[44] One would not expect such precision if the deposition patterns were catastrophic and non-uniform.

The best way for such cores to be matched is by postulating a fairly uniform rate of deposition. If the rate is apt to vary at certain segments of the core by a factor of more than 2 or 3 either below or above the average rate for the whole core, then the curves would not show a close fit. Thus it can be concluded that the sedimentation rates have varied from each other on an average less than a factor of 2 for any significant portion of the cores in Figure 2.

If the rates have been fairly uniform in order to produce a good fit for all these curves, then based upon the present rates of sedimentation the cores would depict a chronology many times longer than the traditional Biblically oriented chronology of 4300 to 5000 years for post-diluvial time. How does one solve this time problem if he wishes to maintain a conservative creationist approach to the subject? In probing for a solution, it is imperative that we first match these shorter core lengths with much longer sequences that extend to the M-B boundary. If that can be accomplished, we can take the tektite-determined age for the M-B boundary as a reference point for dating all deep-sea deposits that are above it.

What we have done is to select cores from widely scattered geographical areas to determine indeed if climates have fluctuated on a worldwide basis during the period of time which geologists have assigned to the Pleistocene. Of the eight cores represented in Figure 3 three extend to the M-B boundary. Of the other five, two are the longest terrestrial cores with a continuous pollen record — Sabana de Bogota of northern Colombia and Tenaghi Philippon of northern Greece. There is a very good match between the Bogota core and the North Atlantic K708-7, and another fine match between the Philippon core and the West Pacific V28-238, showing that terrestrial and deep-sea cores indeed can be correlated. Again it would be most difficult to argue that such matching is purely the product of chance. The sediments of these cores most likely accumulated *in situ* and provide a fairly reliable picture of temperature at the moment of their deposition. Otherwise, if they were not *in situ*, or autochthonous, then the temperature curves would show a scrambled picture due to catastrophic activities.

The most intriguing aspect of the cores is the variety of dating methods that have been applied to them. The most commonly used method, the C^{14}, exceeds its usual limit of 50,000 years at a depth of less than one-tenth of the way down to the M-B boundary. Core RC11-209 yields a radiocarbon date of 11,600±600 years at a depth of only 11 cm, which would give a sedimentation rate of 1 cm/10^3 years.[35] Extrapolating this average rate to the M-B paleomagnetic boundary which occurs at 6.9 m in this particular core, the result is a figure of 690,000 years. It should be noted, however, that generally C^{14} extrapolated rates do not harmonize so precisely with paleomagnetic data, which are based largely on K-Ar and fission-track dating of terrestrial lavas.

Other dating methods that have been used to determine the placement of the M-B boundary either through extrapolation or interpolation are uranium disequilibrium methods, fission tracks, K-Ar, obsidian hydration, and amino acid epimerization. The first three are radiometric, and the last two involve geochemical reactions with many variables. Two of the uranium disequilibrium methods involving Th^{230} and Pa^{231} have been applied to the Caribbean core V12-122 and yield concordant sedimentation rates of 2.35 cm/10^3 years.[36] It should be noted that uranium disequilibrium methods have not always yielded consistent results. This would date the end of the next-to-the-last polar dominance, known as Termination II, at 127,000 years (Figure 1). A recent report has correlated the high warm climatic peak that occurs immediately after Term II with a raised coral reef, which is called Barbados III and is dated at 125,000 years by Th^{230}/U^{234}.[37] The correlation is accomplished by an oxygen isotope analysis of mollusks from the raised coral reef and by a comparison with oxygen values from deep-sea cores, such as V28-238, which suggest a warmer climate than present and thus higher sea levels for that episode of reef growth. Actually there are three Barbados terraces, the other two being dated at 82,000 and 105,000 B.P. by the same method. These three terraces can be easily correlated with the three successive warm fluctuations just above Term II seen especially well in the Philippon and Bogota curves (Figures 2, 3).

Volcanic fragments in deep-sea cores have been dated by two methods; the fission-track method generally yields concordant results with the paleomagnetic age,[38,39] while the K-Ar results from a core that has microtektites are discordant with the paleomagnetic age.[40] Two other dating methods that as yet have not achieved the stature of the radiometric methods because of non-constant rates of chemical change are obsidian hydration and amino acid epimerization (racemization), the former having been applied to several Pacific cores,[41] and the latter to cores V12-122 and V28-238 which are dealt with in our study.[42,43]

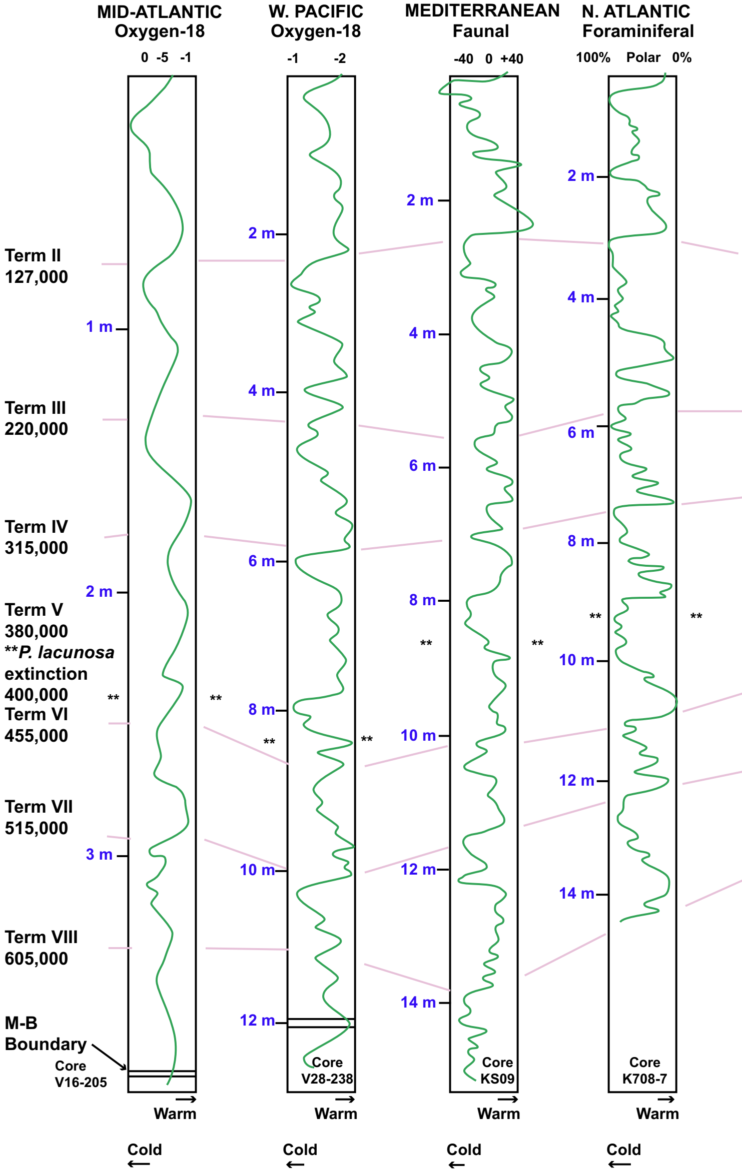
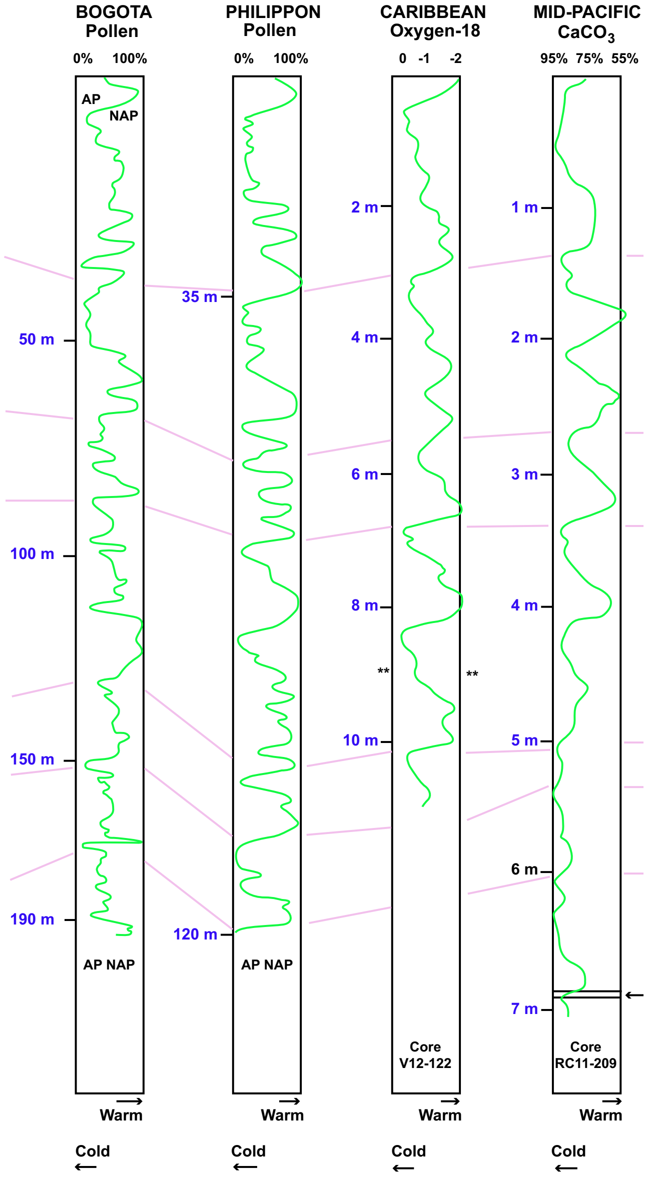


FIGURE 3. The possibility of worldwide correlation is shown by comparing paleoclimatic curves from six marine and two terrestrial cores which span most of the Brunhes magnetic era during which the earth's magnetic field showed normal polarity. The M-B, or Matuyama-Brunhes boundary, marks the transition from reversed to normal polarity. The transition form glacial-type conditions to



warm weather is denoted by "Terminations." The *Pseudoemiliania lacunosa* extinction occurs about midway in the Brunhes and serves as a worldwide stratigraphic marker. (Re-drawn from information in references 48, 50, 41, 52, 47, 47, 45, 35 respectively, left to right.)

If we simply take at face value the above-mentioned dating methods that have been applied to deep-sea cores, it confronts us with a strong case for the reliability of their conventional age interpretation. Thus it is important that some concrete, verifiable explanation be advanced in order to maintain a short chronology based upon Biblical data.

Since the first paleomagnetic boundary is worldwide and occurs at consistently the same location on the paleoclimatic curves, this can be utilized as a useful time marker. If the microtektites can be positively linked with the same event as australite infall and if radiocarbon dating serves to limit the age of infall to about 5000 or 6000 radiocarbon years ago, then we are forced into dating the M-B boundary at 5000 or 6000 radiocarbon years ago.

This tentative conclusion is valid only to the degree that our techniques of correlation are scientifically sound. Like a steel chain, correlation is no stronger than its weakest link. What we have done is to encircle the earth with our stratigraphic "chain" in the following way: first, link the australites on land with the deep-sea microtektites as part of the same infall of tektites; then the microtektites with the M-B boundary, which is usually placed at 690,000 years; the M-B boundary from cores in the Australasian area with the M-B boundary in cores around the world; and finally connect the deep-sea cores with the terrestrial.

If we assign an age of approximately 5000 B.P. for the M-B boundary, then the chronology for all Pleistocene paleoclimatic curves above that boundary would have to be compressed 140-fold from the conventional age of about 700,000 years. The most problematic Pleistocene core, that of Tenaghi Philippon, would likewise have to be reduced 140-fold. The C^{14} age of 47,670 at 16.75 m must be reduced accordingly to 340 years. Such a drastic reduction is not possible in light of the fact that C^{14} ages can be correlated with Egyptian chronology at least 3800 years into the past; thus at most there can be a 12-fold reduction if the figure of 3800 years is taken as the minimum time for major disagreement between C^{14} age and real time, as the evidence seems to indicate. This takes care of only the upper one-seventh or 17 m of the core, leaving more than 100 meters below. If we compress the C^{14} age at the 17 m level to the minimum allowable (3800 B.P.), then the age for the bottom of the core would be placed at approximately 26,600 B.P. (7×3800), which far exceeds the maximum age of 5000-6000 allowed by microtektite evidence. Therefore, the C^{14} stratigraphy at Philippon does not allow the compression of the Pleistocene time-scale to the degree demanded by C^{14} stratigraphy of australites found *in situ* in southeast Australia. It seems that we are confronted with two incontrovertible, yet incompatible, pieces of evidence.

Dilemmas such as this serve a much-needed purpose in forcing us to grapple with the problem and to begin earnest painstaking effort at working toward a solution. Further research is urgently needed to either eliminate or confirm any of the above. Let this study be a challenge to creationists to probe into the "uttermost parts of the sea" and the "recesses of the deep" (Psa 139:9; Job 38:16) to find adequate answers. In pursuing the footsteps of the Creator even into ocean depths, who knows whether a totally new solution may be uncovered that at present is overlooked! Only time will tell.

SUMMARY

If further research continues to validate the youthful age of australite infall, then six apparently interlocking dating methods applied to deep-sea cores must undergo complete revision, resulting in a drastic reduction of Pleistocene chronology and a greatly increased sedimentation rate for all but the uppermost deposits — at least 140 times above present rates. An acceptance of the australite infall age of 5000-6000 years B.P. determined by C^{14} and its worldwide application through paleomagnetic and paleoclimatic correlation has implications that would challenge virtually every radiometric and non-radiometric dating method applied to cave and sedimentary deposits. Thus the present dating methods based upon fission tracks, K-Ar decay, uranium-series disequilibrium (protactinium and thorium), amino acid epimerization, obsidian hydration, and paleomagnetism may stand or fall depending upon future studies into the vast shower of tektites and microtektites in the Australasian region.

ENDNOTES

1. King EA. 1977. The origin of tektites: a brief review. American Scientist 65:212-218.
2. Schnetzler CC, Pinson WH, Hurley PM. 1966. Rubidium-strontium age of the Bosumtwi Crater area, Ghana, compared with the age of the Ivory Coast tektites. Science 151:817-819.
3. Dietz RS. 1977. Elgygytgyn Crater, Siberia: probable source of Australasian tektite field. Meteoritics 12:145-157.
4. Lovering JF, Mason B, Williams GE, McColl DH. 1972. Stratigraphic evidence for the terrestrial age of australites. Journal of the Geological Society of Australia 18:409-418.
5. Gill ED. 1970. Age of australite fall. Journal of Geophysical Research 75:996-1002.
6. Chalmers RO, Henderson EP, Mason B. 1976. Occurrence, distribution, and age of Australian tektites. Smithsonian Contributions to the Earth Science No. 17. 46 p.
7. Fleischer RL, Price PB, Walker RM. 1965. On the simultaneous origin of tektites and other natural glasses. Geochimica et Cosmochimica Acta. 29:161-166.

8. Durrani SA. 1971. Origin and ages of tektites. Physics of the Earth and Planetary Interiors 4:251-260.
9. Gill ED. 1965. Quaternary geology, radiocarbon datings, and the age of australites. Geological Society of America Special Paper 84:415-432.
10. McCall GJH. 1973. Meteorites and their origins. NY: John Wiley, p 282-283.
11. O'Keefe JA. 1976. Tektites and their origin. NY: Elsevier Scientific, p 26.
12. Ibid., p 27.
13. Glass B. 1967. Microtektites in deep-sea sediments. Nature 214:372-374.
14. Cassidy WA, Glass B, Heezen BC. 1969. Physical and chemical properties of Australasian microtektites. Journal of Geophysical Research 74:1008-1025.
15. Glass BP. 1972. Bottle green microtektites. Journal of Geophysical Research 77:7057-7064.
16. Frey FA, Spooner CM, Baedecker PA. 1970. Microtektites and tektites; a chemical comparison. Science 170:845-857.
17. Glass BP. 1972. Australasian microtektites in deep-sea sediments. Antarctic Research Series, vol. 19. Antarctic Oceanology II: The Australian-New Zealand Sector, p 335-348.
18. Gentner W, Glass BP, Storzer D, Wagner GA. 1970. Fission track ages and ages of deposition of deep-sea microtektites. Science 168:359-361.
19. Zwart PA, Glass PB. 1976. Geographical distribution, age, and mass of microtektites in the Australasian, Ivory Coast and North American strewnfields. Meteoritics 11:397-398.
20. Cox A. 1969. Geomagnetic reversals. Science 163:237-245.
21. Izett GA, Naeser CW. 1976. Age of the Bishop Tuff of eastern California as determined by the fission-track method. Geology 4:587-590.
22. Shackleton N. 1967. Oxygen isotope analyses and Pleistocene temperatures reassessed. Nature 215:15-17.
23. Gray J, Thompson P. 1976. Climatic information from $^{18}O/^{16}O$ ratios of cellulose in tree rings. Nature 262:481-482.
24. Libby LM, Pandolfi LJ. 1977. Climate periods in tree, ice and tides. Nature 266:415-417.
25. Kent D, Opdyke ND, Ewing M. 1971. Climate change in the North Pacific using ice-rafted detritus as a climatic indicator. Geological Society of America Bulletin 82:2741-2754.
26. Keany J. 1973. New radiolarian palaeoclimatic index in the Plio-Pleistocene of the Southern Ocean. Nature 246:139-141.
27. Bonatti E, Gartner S, Jr. 1973. Caribbean climate during Pleistocene Ice ages. Nature 244:563-565.
28. Diester-Hass L. 1976. Late Quaternary climatic variations in northwest Africa deduced from East Atlantic sediment cores. Quaternary Research 6:299-314.
29. Ericson DB. 1959. Coiling direction of *Globigerina pachyderma* as a climatic index. Science 130:219-220.
30. Saito T. 1976. Geologic significance of coiling direction in the planktonic foraminifera *Pulleniatina*. Geology 4:305-309.

31. Wijmstra TA. 1969. Palynology of the first 30 metres of a 120 m deep section in northern Greece. Acta Botanica Neerlandica 18:511-527.
32. Ninkovich D, Shackleton NJ. 1975. Distribution, stratigraphic position and age of ash layer "L", in the Panama Basin region. Earth and Planetary Science Letters 27:20-34.
33. Hendy CH, Wilson AT. 1968. Paleoclimatic data from speleothems. Nature 219:48-51.
34. Harmon RS, Thompson P, Schwarcz HP, Ford DC. In press. Late Pleistocene paleoclimates of North America as inferred from stable isotope studies of speleothems. Quaternary Research.
35. Hays JD, Saito T, Opdyke ND, Burckle LH. 1969. Pliocene-Pleistocene sediments of the equatorial Pacific: their paleomagnetic, biostratigraphic, and climatic record. Geological Society of America Bulletin 80:1481-1514.
36. Broecker WS, van Donk J. 1970. Insolation changes, ice volumes, and the O^{18} record in deep-sea cores. Reviews of Geophysics and Space Physics 8:169-198.
37. Shackleton NJ, Matthews RK. 1977. Oxygen isotope stratigraphy of Late Pleistocene coral terraces in Barbados. Nature 268:618-620.
38. Seward D. 1974. Age of New Zealand Pleistocene substages by fission-track dating of glass shards from tephra horizons. Earth and Planetary Science Letters 24:242-248.
39. Macdougall D. 1971. Fission track dating of volcanic glass shards in marine sediments. Earth and Planetary Science Letters 10:403-406.
40. Dymond J. 1969. Age determinations of deep-sea sediments: a comparison of three methods. Earth and Planetary Science Letters 6:9-14.
41. Morgenstein M, Riley TJ. 1974. Hydration-rind dating of basaltic glass: a new method for archaeological chronologies. Asian Perspectives 17:145-159.
42. Wehmiller J, Hare PE. 1971. Racemization of amino acids in marine sediments. Science 173:907-911.
43. King K, Jr., Neville C. 1977. Isoleucine epimerization for dating marine sediments: importance of analyzing monospecific foraminiferal samples. Science 195:1333-1335.
44. Thierstein HR, Geitzenauer KR, Molfino B, Shackleton NJ. 1977. Global synchroneity of late Quaternary coccolith datum levels: validation by oxygen isotopes. Geology 5:400-404.
45. Imbrie J, van Donk J, Kipp NG. 1973. Paleoclimatic investigation of a Late Pleistocene Caribbean deep-sea core: comparison of isotopic and faunal methods. Quaternary Research 3:10-38.
46. Prell WL, Hays JD. 1976. Late Pleistocene faunal and temperature patterns of the Colombia Basin, Caribbean Sea. In: Cline RM, Hays JD, editors. Investigation of Late Quaternary Paleoceanography and Paleoclimatology. Geological Society of America Memoir 145:201-220.
47. van der Hammen T, Wijmstra TA, Zagwijn WH. 1971. The floral record of the Late Cenozoic of Europe. In: Turekian KK, editor. The Late Cenozoic Glacial Ages. New Haven: Yale University Press, p 391-424.
48. Ryan WBF. 1972. Stratigraphy of Late Quaternary sediments in the eastern Mediterranean. In: Stanley DJ, editor. The Mediterranean Sea: A Natural

Sedimentation Laboratory. Stroudsburg, PA: Dowden, Hutchinson & Ross, p 149-169.

49. van Donk J. 1976. O^{18} record of the Atlantic Ocean for the entire Pleistocene Epoch. Ibid., p 147-164.

50. Shackleton NJ, Opdyke ND. 1973. Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10^5 and 10^6 year scale. Quaternary Research 3:39-55.

51. Cita MB, Vergnaud-Grazzini C, Robert C, Chamley H, Ciaranfi N, d'Onofrio S. 1977. Paleoclimatic record of a long deep sea core from the eastern Mediterranean. Quaternary Research 8:205-235.

52. Ruddiman WF, McIntyre A. 1976. Northeast Atlantic paleoclimatic changes over the past 600,000 years. In: Cline & Hays (Note 46), p 111-146.