RADIOCARBON DATING OF THE NEWPORT TOWER

Rob Carter

Background

As of this writing it has been 13 years since a team of Danish scientists completed radiocarbon dating work on the Newport Tower. There has been some controversy concerning their conclusions regarding the age of the Tower, most of which centers not around the radiocarbon dating technique employed, but on how the resulting measurements were interpreted to support a date of origin (see references 1 and 2). Most of us trust radiocarbon dates appearing in articles without looking behind the technical veil that shrouds the technique. However, it turns out that in the case of the Newport Tower, even a small injection of knowledge on the subject makes the origin of the controversy very clear and points the way for future work. What follows is a short explanation of the principles and techniques behind radiocarbon dating, how they were applied in the case of the Newport Tower, and a brief review of the controversy in light of that knowledge.

Down To Earth - From The Cosmos To The Ecosphere

On any clear night you can walk out, look up, and see the origin of radiocarbon dating—the stars. As stars go through their natural life cycle, some eventually go through a rapid inward collapse, followed by an brief, bright obliterating explosion referred to as a supernova, which scatters nuclear particles and electromagnetic radiation in all directions. Supernova occurrences are randomly distributed throughout the universe and time, but there are enough of them to keep the earth under a bombardment of high energy nuclear particles from all directions at all times.

These particles are lumped together with high energy radiation and particles from all other sources under the term "cosmic rays," which is really a misnomer, since they come from random origins, angles, distances, and times. But the distribution of particles that arrive is not random. On average, 90% are protons, 9% are helium nuclei (alpha particles), and 1% are electrons. And the arriving protons are the "batteries" that make radiocarbon dating possible.

Speaking statistically, once a typical fast supernova proton arrives in the earth's upper atmosphere, it does not go far. Instead, it makes a violent impact with an oxygen or nitrogen nucleus, rendering it into its constituent protons and neutrons that, in turn, travel outward, but at a lesser velocity—just like a billiard table "break." (If you are wondering what happened to the electrons, they get scattered too, but they are too light to affect the nuclear interactions. They just become part of the upper atmosphere's "charge soup," available for pickup by naked nuclei.) Essentially, our single, very high energy proton generates a little upper atmosphere shower of lower energy protons and neutrons. Now, let's ignore the protons and follow the neutrons. Some of them impact a nitrogen-14 (^{14}N) nucleus, eject a proton, but remain in that nucleus forming a carbon-14 (^{14}C) nucleus, which is a radioactive isotope of carbon.[1] The ^{14}C nucleus will last on average only 5730 years before it decays back into ^{14}N. Before long, this nucleus scavenges its requisite electrons back out of the "charge soup" and subsequently undergoes a chemical reaction with available oxygen molecules (it "burns"). The result is a radioactive carbon dioxide molecule (CO_2) that is chemically stable enough to survive the ecosphere, but has an unstable ^{14}C nucleus at its heart, i.e., a clock!

Remember that all of this takes place in the upper atmosphere. By diffusion and air turbulence the radioactive CO_2 can make it down to earth's surface with plenty of its 5730 years to spare, mixing in with the CO_2 composed of non-radioactive carbons carbon-12 (^{12}C) and carbon-13 (^{13}C). So the situation is that the number of ^{14}C nuclei (call it $n^{14}C$) in the air is constantly being augmented by cosmic ray impact, but is also being depleted by radioactive decay. Over the eons the ratio of the number of ^{14}C nuclei to the total number of carbon nuclei in the atmosphere ($n^{14}C/(n^{12}C+n^{13}C+n^{14}C$, or simplified as $n^{14}C/n^{TOTAL}C$), has stabilized to a nearly constant value. ***This is the key to radiocarbon dating.***

From the air, ^{14}C enters the biosphere when its carrier

1 "The mass number, formerly placed in the superior position to the right of the element symbol, is now according to international agreement placed in the superior position to the left of the symbol. (Chicago Manual of Style)

CO_2 is drawn into a plant along with all the other non-radioactive CO_2s as part of the photosynthesis process. At that point, the oxygen goes bye-bye, but the ^{14}C, ^{12}C, and ^{13}C become a permanent part of the plant. When the plant gets eaten by insects, microbes, or mammals, all of the carbons similarly become incorporated into the ingesting body. The entire food chain of organisms is thus being continuously resupplied with a fresh carbon, carrying the same $n^{14}C/n^{TOTAL}C$ ratio as the atmosphere as long as they are alive.

Carbon Dating: the $n^{14}C/n^{TOTAL}C$ Counting Game

Now that we've established the *why* behind the presence of ^{14}C in our air, we have to work some numbers to get a grasp of *how* this applies to radiocarbon dating. Quantitatively, the CO_2 in our atmosphere is nearly all the non-radioactive carbon-12. Here is the actual breakdown:

- 99% carbon-12
- 1% carbon-13
- trace amount of carbon-14 (OK, 1.3 E-10 % if you really want to know)

When a living thing dies, its body is cut off from the fresh carbon supply chain. No more new carbons. However, it can still lose carbons. The ^{14}Cs present at the time of death begin to decay into ^{14}N + one electron. Careful empirical measurements in the laboratory have shown that the ^{14}C decay rate is such that any population will lose half its number every 5730 years (hence the term half-life).

Avoiding some "interesting" math by skipping straight to another measurement, in practical terms there will be fifteen ^{14}C decay events per minute for every one gram sample taken from any living thing. If we keep that sample in a vial, 5730 years later there will be 7.5 decays per minute; 11460 years later there will be only 3.75 decays per minute; and so on (**Figure 1**). (Incidentally, don't get worried about the radiation, it consists entirely of low energy electrons that can't even penetrate a sheet of paper). So, in principle, if we dug up an ancient charcoal sample, the radiocarbon dating procedure would go like this:

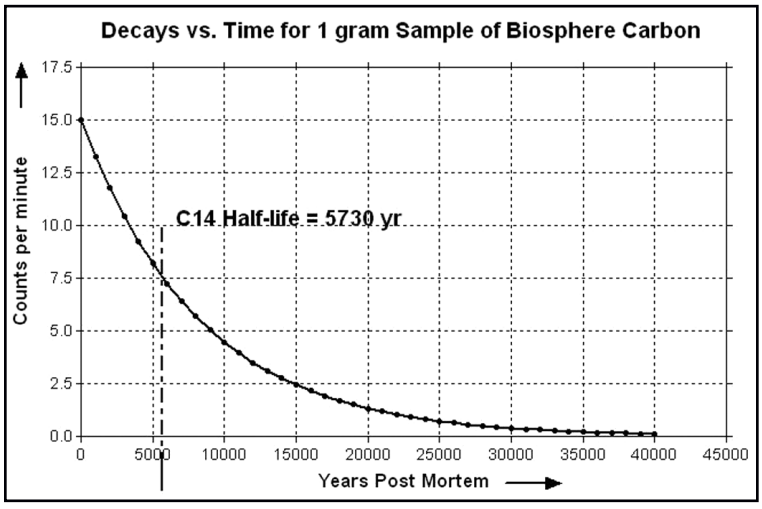


Figure 1. Graph of counts vs. time.

1. Extract the carbon from the charcoal (no impurities!). Need about 1 gm of carbon.
2. Weigh it accurately, in grams.
3. Use a Geiger counter to count the number of electrons ejected in a 24 hour period.
4. Look up the age on the graph.

Dr. Willard Libbey, of the University of Chicago, first demonstrated radiocarbon dating exactly that way in 1949. The demonstration netted him a Nobel prize. (All the more remarkable because carbon-14 was only discovered in 1940!) Now with that background established there are a few important nuances to absorb.

You can see from the graph that the count rate drops as time goes on, which means that the accuracy of the resultant data also drops. For material older than 30,000 years this technique is not considered reliable.

There is an improved counting technique called AMS (Accelerator Mass Spectrometry) Radiocarbon Dating. With some very expensive, large, and heavy equipment, the carbon atoms can be separated by their nuclear weight and literally counted as they arrive at detectors. This method does not just count the radioactive decays (representing only a fraction of the $n^{14}C$), it counts all of the ^{12}C's, all of the ^{13}C's, and all of the ^{14}C's. The numbers game is much better this way, because we are counting billions of events rather than hundreds of decays. Samples as small as one milligram can yield a trustable date. Using AMS on larger samples, some researchers have pushed the dating window out past 100,000 years.

Regardless of what past or future counting technique is utilized, the direct result of radiocarbon date measurement is referred to as "radiocarbon

years BP." Are these the same as actual solar years? Absolutely not! Ultimately, the reason for this is that the rate of proton influx from the cosmos is not rock steady, and this causes a variation in the $n^{14}C/n^{TOTAL}C$ ratio over the years. On top of that, the $n^{14}C/n^{TOTAL}C$ ratio is not exactly the same everywhere on the planet because diffusion and atmospheric currents that distribute the ^{14}C aren't truly random. And lastly, the advent of nuclear weapon explosions in the 1940s has resulted in a measurable differential between the northern and southern hemispheres (no kidding!).

Fortunately for archaeology, there is a nifty workaround for the vagaries of "radiocarbon years BP." The principle is to make a collection of tree ring samples that sufficiently overlap so that date-identified annual rings are available for every single year going back 10,000 years BP or more. (Note: Remember that the $N^{14}C/N^{TOTAL}C$ ratio varies over the surface of the planet, so these tree ring samples need to be from the same geographic area, e.g. North America). Radiocarbon dating is then done on a selection of wood samples from the date-identified rings, and a calibration chart is made (**Figure 2**). The creation and updating of these calibration charts is an ongoing effort.

Radiocarbon dating is the 'gold standard' of archaeological dating.

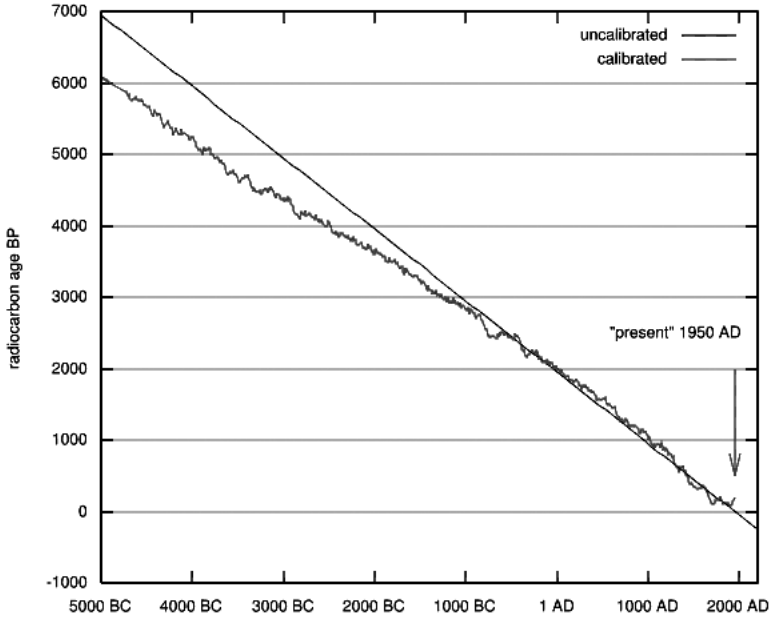


Figure 2. Tree ring calibration curve.

The Newport Tower Doesn't Eat Plants - Mortar And CO_2

Since the Newport Tower really is not and never was part of the biosphere, you might be wondering how radiocarbon dating could reveal anything about its age. It turns out that while the rocks contain no datable carbon, the mortar used between them actually does. Understanding how that carbon gets into the mortar is the real key to understanding the Newport Tower radiocarbon dating controversy.

Mortar making is an ancient and simple trade. Limestone and/or sea shells are burned in a furnace or at the heart of a large open fire. The resulting white powder is mixed with just the right amount of water, becoming quicklime powder. Quicklime is then mixed with sand and more water to the right consistency for masonry. That's it.

Limestone is calcium carbonate ($CaCO_3$). Sea shells are also calcium carbonate. When they are exposed to intense heat the carbon gets burned out into atmospheric CO_2, and what remains is CaO. The addition of the right amount of water converts it to $Ca(OH)_2$ powder. But when it is given an excess of water in the presence of air, it undergoes a chemical reaction in which it hardens by turning back into $CaCO_3$, and all of the "C" comes from the CO_2 in the surrounding air. Mortar has to have carbon dioxide to harden.

So the Newport Tower has no powers of photosynthesis, and it does not eat living things, but it did draw a single breath when it was built. And so, in principle, we can find out *when* that happened by radiocarbon dating.

Mortar Dating Is A Different Animal

Compared to the biochemical perfection of the photosynthesis process, human mortar making is very sloppy. In fact "carbon errors" can creep in via several different pathways. Let's consider some of the things that could shift the "radiocarbon years BP" reading on a mortar sample.

1. Lime gets contaminated with charcoal during furnace work. If the trees that made the charcoal were 100 years old, then the eventual mortar date looks older than actual.

2. Incomplete carbon burn-out from the limestone/shell. If the calcium carbonate ($CaCO_3$) is not fully burned some of the "C" from the limestone/shell is passed directly into the mortar. This also will result in a mortar date that looks older than actual. (Limestone is so old it generally has zero detectable ^{14}C).

3. "Sand and stuff" added to the lime at mix time contaminates mortar. This is yet another potential source of "old carbon" bearing substances (crushed shell for instance) entering into the mortar and shifting the carbon date older than actual.

4. Mortar takes a VERY long time to harden. Don't laugh. Samples have been taken from deep within 100+ year old structures and chemical tests have shown that the hardening was still going on! So carbon dates will be too young, smeared forward toward the present.

5. After hardening, fresh CO_2 from the air penetrates into the mortar and swaps its C with one of the original ones. This process is accelerated in the presence of moisture, and it also results in "too young" error. (This one is difficult to understand intuitively unless you have a feeling for chemistry, and it is the hardest of these error sources to document. It has, however, been confirmed by experiment as an significant error source.)

Radiocarbon dating of any mortar sample requires an assessment of the contributions of all of the above factors (so it can never approach the same position of trust as the dates obtained from organic samples). In fact, the Newport Tower radiocarbon controversy arises directly from that assessment.

Description Of Radiocarbon Dating Work Done On The Tower

In 1995 a Danish research team published a paper detailing their work on radiocarbon dating of the mortar in the Newport Tower (Heinemeier and Junger). This work was part of a larger effort to establish mortar dates on structures in Europe. The team was already experienced in mortar dating and all the intricacies of sample collection, storage, shipment, etc. They appear to have been both meticulous and thorough in their work, and here is what got done:

1. At various locations on the Tower they drilled 10 different holes, taking samples from different depths in the mortar.

2. They crushed and sieved the samples, keeping only the grains that were .0005 inch and smaller.

3. The samples were shipped to the University of Helsinki where they were prepared for AMS carbon dating. They were submerged in phosphoric acid in a vacuum. For each sample, the CO_2 that boiled out in the first few minutes was collected and kept separate from the CO_2 that came out for the remainder of the chemical reaction that continued.

4. The CO_2 fractions were then sent to the University of Aarhus in Denmark where Accelerator Mass Spectrometry was performed.

A graph of their raw results (already corrected by the tree ring trick) is shown in **Figures 3 and 4**.

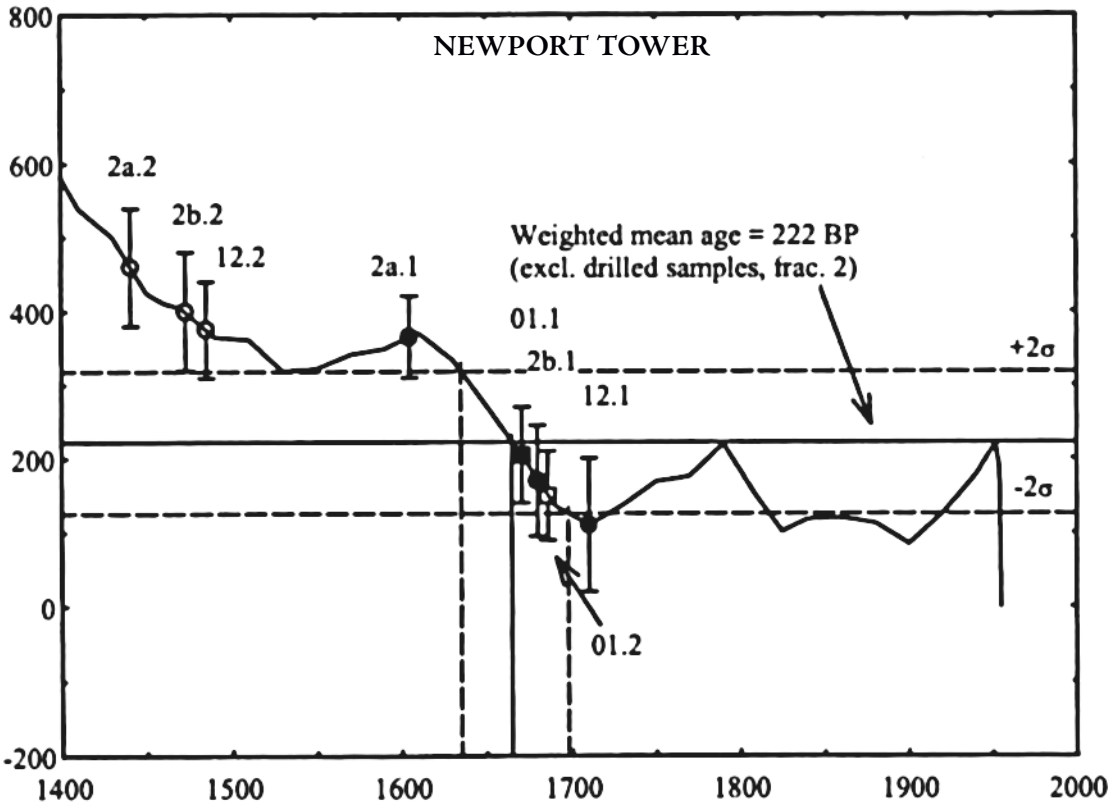
So you can see that there is a pretty big spread in dates. The earliest dates say the Tower was built before Columbus arrived, and the younger ones indicate that it was built in colonial times. (Perfect!)

Three Different Interpretations Of The Same Data

There were a total of about 25 separate samples taken from 10 different holes and bagged by the Danish team. Since they used the AMS technique, the count data for all three carbon isotopes ^{12}C, ^{13}C, and ^{14}C were available. Here is an oversimplified summary of three different conclusions reached by three different parties from that same data. If you've read this far, you are well prepared to understand the origin of this controversy.

First the original researchers that actually did the work, Heinemeier and Jungner

Sample taking was deliberately done in such a way as to eliminate the argument that CO_2 penetrated the mortar (error no. 5 above). Samples were only taken from



Position	Height above ground (cm)	Sample Depth (cm)	Sample No.	Lab. No. AAR-	Fraction of total sample (%)	Carbonate concentration (%)	^{14}C Age (BP)	δ^{13}C(‰) PDB
TOWER:								
Flue above fireplace	550	Surface	X.1	1284.1	45	42	205±65	-12.3
			X.2	1284.2	55		150±60	-11.5
Pillar 7	110	7-12	2a.1	1352.1	20	21	365±55	-12.9
			2a.2	1352.2	80		460±80	-9.4
			2b.1	1352.3	50	17	170±75	-10.7
			2b.2	1352.4	50		400±80	-9.7
			3a.1	1504.1	83	2.0	No meas.	-10.8
			3a.2	1504.2	17		No meas.	
			3b.1	1504.3	40	1.7	No meas.	-11.3
			3b.2	1504.4	60		No meas.	-10.4
Fireplace	420	10-20w	8.1	1353.1	57	5.8	(-110±70)*	-12*
			8.2	1353.2	43		(130±70)*	-11.6
Pillar 6	20	10-25	12.1	1286.1	37	52	110±90	-13.4
			12.2	1286.2	63		375±65	-9.7
Pillar 8	250	Plaster	Bulk (conv.)	Hel-3181			290±110	-6.4
Excavated 1949			Ox bone	1280			25±60	-19.7
WANTON-LYMAN-HAZARD HOUSE:								
Basement	30	Surface	H 23.1	1287.1	52	70	80±100	-16.3
			H 23.2	1287.2	48		160±60	-11.3
* Excluded due to low carbonate content								

Figures 3 and 4. Heinemeier and Jungner calibration curves and data table.

sites on the tower that were typically not water-soaked, i.e., above ground and well drained vertical surfaces. Additionally, only samples from several centimeters or more deep were kept. And they assumed the precautions were sufficient. They assumed that the mortar hardened completely within a few years of the tower construction (eliminating error no. 4).

Remember that they crushed the mortar samples (gently) and sieved them, accepting only small sized particles? This was to get rid of any large chunks of seashell that might make the date come out older than actual. They also looked at the sample powder under the microscope and did some impurity "weeding" based on color, attempting to only accept actual hardened mortar. This eliminated the "sand and stuff" contribution and the charcoal contamination (errors no. 1 & 3).

That left poor furnace burnout of the $CaCO_3$ (error no. 2) as the primary source of error. Based on all of the above, the contributing part of the sample would then be composed of a distribution of small grains (all smaller than .0005 inch) of actual mortar from the construction time, and the grains most likely to have incomplete carbon burnout would be at the large end of the distribution. So they argued that the actual date would be closest to the reading obtained from the *smallest* particles - which would be the *first* CO_2 fraction collected out of the phosphoric acid. Their final conclusion: *Tower constructed 1651-1679.*

Second, the interpretation of de Bethune

In a 1998 article appearing in *Journal of the Newport Historical Society* (reference 2), de Bethune made a strong argument (backed up by some painstaking physical chemistry calculations) that the penetration of air CO_2 over time into the mortar, even several inches into the mortar was likely, and that the quantitative contribution of that "fresh" ^{14}C renewal by ion exchange (error no. 5) would have to be significant, and in fact the most important. He was willing to assume that for particles as fine as .0005 inch there was little chance of poor furnace work and that Heinemeier and Jungner's sample preparation lowered the remaining errors to relative negligibility. The particles in the sample that would be least apt to be affected by carbon exchange error would be the *largest* particles—which would be represented in the *second* CO_2 fraction collected. Basically, he said that atmospheric CO_2 would penetrate the larger diameter particles less completely, and so their dates would be closer to actual (but still not correct). His final conclusion: *Tower already standing 1440-1480.*

Third, the interpretation of Alan Watchman

In 1996 Alan Watchman of Data-Roche Watchman, Inc. in Quebec, Canada made a detailed commentary on the Heinemeier and Jungner article in a private letter to James Whittall.

Like de Bethune, Watchman considered the primary potential dating error to be penetration and exchange of air CO_2 over the years since the tower construction. But he tossed in another interesting observation to support this: the published AMS data contained the measurements on all three carbon isotopes, and the ^{13}C data was inconsistent with the value typical of $CaCO_3$ of marine origin (i.e. of shell origin). Apparently, the biochemical process for making shell shifts the $n^{13}C/n^{TOTAL}$ C ratio in an identifiable fashion. That would eliminate poorly burned-out shell, or shells in the "sand and stuff" as error sources. (Note: Whether or not it eliminates poorly burned-out limestone is an open question). Watchman's conclusion: *Tower built around 1400.*

Conclusions And Indications for Future Work

That's how 25 little clumps of old mortar dust gave rise to the whole Newport Tower radiocarbon date controversy. Despite the degree to which the data delivered to us by Heinemeier and Jungner has been hashed over, there are two points regarding future radiocarbon dating work on the Newport Tower.

The first point arises from further reading on the subject of radiocarbon mortar dating. Other researchers working on this technique for dating stone structures in South America (for example see reference 4) report success at dating pre-Columbian mortared walls. There were no serious inconsistencies between the carbon dates and other corroborating evidence. What made their work different? Quantity. They had the luxury of taking kilogram samples from a large number of different locations. The abundance of samples permitted them to be much more selective during the "microscope screening" step. Were this approach applied to the Newport Tower it would require a deconstruction of perhaps a 2 ft. x 2 ft. section of the wall and removal of all mortar. It is unlikely that this would be undertaken until such time as restoration work is indicated.

The second point, made by Watchman in his letter, is that by using new samples of similar size to those taken by

Heinemeier and Jungner, a chemical technique could be applied which would essentially strip any post-construction carbons from the surface of the mortar particles. The basis for this technique is that the ion exchange of C's from air CO_2 with C's in the mortar CaO_3 are loosely bound, so it is expected that a specially tailored treatment could remove them from the picture without disturbing the original C's in the mortar. This could be proved out on mortar samples from New England structures of known construction date, and then applied to the Newport Tower.

In closing, here are the words of NEARA author and chemist Jim Guthrie who generously contributed his time to review and comment on the references cited in this article:

> "The radiocarbon data reinforce conclusions from several other lines of evidence that the Newport Tower is pre-Colonial. However, they do not provide conclusive evidence of antiquity because the methods of mortar and plaster dating are not yet well developed and the sampling was insufficient for proper statistical analysis. Nevertheless, the data generated by Heinemeier and Jungner contain valuable information and we should be grateful for their pioneering attempt."

References:

1. Heinemeier, J., H. Jungner, A. Lindroos, A. Ringbom, T. Von Konow and N. Rud. 1997. "AMS ^{14}C Dating of Lime Mortar." *Proceedings of the 7th International Conference on Accelerator Mass Spectrometry*. Tuscon, Arizona, May 1996. Nuclear Instruments and Methods B123 (1997) 487.
2. anon. 1998. "Newport History." *Journal of the Newport Historical Society*, Vol. 69, part I, No. 238.
3. Private letter communication to James Whittall, June 21, 1996 from Alan Watchman of Data-Roche Watchman Inc. in Quebec, CN.
4. Private letter communication to Sue Carlson, August 30, 2007, from Jim Guthrie.

Further Reading:

Hale, John, Jan Heinemeier, Lynne Lancaster, Alf Lindroos and Åsa Ringbom. "Dating Ancient Mortar." *American Scientist*, Volume 91, March-April 2003, pp. 130-137

Mathews, Jennifer P. "Radiocarbon Dating of Architectural Mortar: A Case Study in the Maya Region, Quintana Roo,Mexico." *Journal of Field Archaeology*, Vol. 28, No. 3/4. (Autumn - Winter, 2001), pp. 395-400.

Michniewiczi, Jacek, et al. "Issue Of Actual Chronology of a Romanesque Chapel at the Wlen Castle (Lower Silesia, Poland) in the Light of Mortar Radiocarbon Dating." *Geochronometria* 26 (2007), Pp 31-33, Doi 10.2478/v10003-007-0010-5.