The article below, published in the New York Times in the summer of 2014, describes a shift in scientists' thinking about when Neanderthals died out. The shift is largely due to recent improvements in radioactive carbon dating techniques. Read the article, and then begin working on the investigative questions that follow it. You'll be asked to report some of your findings as a graded assignment.

Neanderthals in Europe Died Out Thousands of Years Sooner Than Some Thought, Study Says

by Kenneth Chang
20 August 2014
The New York Times

Neanderthals, our heavy-browed relatives, spread out across Europe and Asia about 200,000 years ago. But when did they die out, giving way to modern humans?

A new analysis of Neanderthal sites from Spain to Russia provides the most definitive answer yet: about 40,000 years ago, at least in Europe.

That is thousands of years earlier than some scientists have suggested, and it narrows the period that Neanderthals and modern humans overlapped in Europe.

"After that, we don't think there are any Neanderthals on the continent anymore," said Thomas Higham, the deputy director of the radiocarbon accelerator unit at the University of Oxford in England.

On the other hand, the dating also argues against the view that modern humans overwhelmed the Neanderthals as soon as they arrived in Europe. While modern humans and Neanderthals do not appear to have intermingled in the same locales, the findings suggest they co-existed in neighboring regions for up to several thousand years.

The findings, reported Wednesday in the journal Nature, run counter to claims that pockets of Neanderthals persisted in Portugal, Spain, and Gibraltar until just 30,000 years ago, even as modern humans spread outward.

"This is a very strong compilation," said Chris Stringer, who leads research on human origins at the Natural History Museum in London and who was not involved in the research. "I think it kind of replaces the picture we had before."

In 1995, researchers including Jean-Jacques Hublin, now at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, announced fossil evidence of Neanderthals living 30,000 years ago in a cave near the southern Spanish city of Málaga.

Dr. Hublin said he had changed his mind as better radiocarbon dates became available. "To me, I'm ready to buy the new date," he said.

Modern humans migrated out of Africa at least 60,000 years ago, and anthropologists have been trying to figure out what happened when the two groups encountered each other.

One of the reasons some researchers think Neanderthals survived longer on the Iberian peninsula is that there are no signs of modern humans living there at that time.

A recent analysis of Neanderthal DNA shows that Neanderthals and modern humans not only crossed paths, but interbred. For non-African people living today, 1 to 4 percent of their genome has Neanderthal origins.

The genetics suggest that interbreeding occurred about 50,000 to 60,000 years ago, somewhere in western Asia.

"You've kind of got two parts of the story," Dr. Stringer said. "There must have been a western Asia coexistence, which included interbreeding. Then there was a later coexistence in Europe, for which we have no evidence of interbreeding but possible evidence of some cultural contact between the groups."

Dr. Higham, the lead author of the Nature paper, and his colleagues took advantage of advances in radiocarbon dating in testing samples of bone, charcoal and shell from 40 sites, mostly in Western Europe. The dating method takes advantage of unstable, radioactive carbon 14 atoms produced from the bombardment of the atmosphere by cosmic rays from outer space. The radioactive carbon combines with oxygen atoms to form carbon dioxide, and plants and animals take up some of it as long as they are alive.

But when they die, they absorb no additional radioactive carbon, and the carbon 14 disappears over time. The ratio of carbon 14 to carbon 12, which is stable, thus tells the age and can be used to date bones and artifacts up to about 50,000 years ago.

Contaminants containing younger organic molecules can distort that dating. Dr. Higham said that just 1 percent of modern carbon infiltrating a 50,000-year-old fossil would make it look 7,000 to 8,000 years younger. The researchers

prepared samples that would extract collagen in the bone and remove the contaminants.

"What we find is often the dates get older," Dr. Higham said. "We've managed to chip away at those erroneous younger Neanderthal dates to come up with a more refined, and we think accurate, estimate for when Neanderthals disappeared."

Dr. Higham said his team would like to expand the research to Neanderthal sites in Eastern Europe and across Russia to Siberia. It is possible that Neanderthals survived later in those areas.

Some of the conclusions are tentative because many of the sites do not have the bones of the actual inhabitants, and paleontologists are still debating whether it was Neanderthals or modern humans who made the tools found at some sites.

"This gives us a framework, basically, which allows us to ask more interesting questions," said William Davies of the University of Southampton in England, who wrote an accompanying commentary in Nature. "About what the tools might mean, how they were used, what they tell us about Neanderthal interactions."

The findings so far indicate that Neanderthals did not disappear all at once.

"I think we'll see patchy disappearance prior to extinction," Dr. Higham said.

What follows is a series of problems to solve using what you know about exponential decay. The problems build on one another, so do not try to solve later problems until you have satisfactorily solved the preceding ones. By solving the problems you will be able to assess the validity of, and expound upon, an important claim made in the article:

> "Dr. Higham said that just 1 percent of modern carbon infiltrating a 50,000-year-old fossil would make it look 7,000 to 8,000 years younger."

Preliminary Work

Before considering carbon dating at all, be sure you can answer the following questions, using your calculator as much as you like. The skills you use to solve these will be needed to consider carbon dating issues.

Light loses its intensity as it passes through water. For blue light passing through fairly clear ocean water, the light loses about 4% of its intensity for each additional meter of water that it passes through. (Red light loses intensity faster, which is why everything underwater seems so blue!) Define $L(d)$ to be the intensity of blue light at a depth d meters in the ocean, relative to its intensity on the surface. (So $L(0) = 1$.)

    A. Write an explicit expression for $L(d)$ in terms of d.
    B. Determine the relative intensity of blue light at a depth of 10 feet, which is about 3.05 meters.
    C. Use logarithms to determine to the nearest centimeter the depth at which the relative intensity of blue light drops below 0.01.
    D. A counterpart in this context to the half-life of C_{14} might be called the "half-dark distance". When blue light travels a certain distance through ocean water it loses exactly half of its intensity. What distance is that?
    E. Write an alternate expression for $L(d)$ that takes advantage of the "half-dark distance" you determined in the previous question.

More preliminary Work

A jeweler purchases pearls from two sources, A and B. Among the pearls purchased from source A, only 2% of them are flawless. Among the pearls purchased from source B, 100% of them are flawless. However, so few pearls are available from source B that the jeweler purchases 99% of her pearls from source A and only 1% from source B. Determine the percentage of all of the pearls she purchases that are flawless.

In the air we breathe and in the bodies of living things, the natural fraction of carbon that is the isotope C_{14} is extremely small—about 1.35×10^{-12}. So when a living thing dies, the fraction of carbon in its body that is C_{14} is 1.35×10^{-12}, or slightly more than one part in a trillion. Working with numbers so small is certainly possible, but you'll likely find it more comfortable working with numbers that are a little greater. In the light intensity problems above, we defined a function L that gave the intensity of blue light relative to what it would have been at the ocean's surface, such that $L(0)$ was equal to 1. We can do the same thing with C_{14}. Define $C(t)$ to be the amount of carbon 14 in a fossil after t years, relative to the amount that was in the organism when it died. (So $C(0) = 1$.)

The half-life of Carbon 14 is about 5,730 years.

1. Write an expression for $C(t)$ in terms of t, using any convenient equation form.

    $C(t) = $ _____

2. Compute $C(50{,}000)$ and interpret what it means.

    $C(50{,}000) = $ _____

    Interpretation:

3. Suppose that a scientist extracts a small amount of material from a 50,000-old-fossil. Unknown to her, the sample actually is 99% material from the original organism and 1% material from modern organisms. Relative to the amount of C_{14} in a newly-deceased organism, how much C_{14} is there in her sample? Show how you determine your answer.

4. The scientist doesn't know that her sample is contaminated. So when she estimates its age, she'll still use the function that you wrote for question 1 above. Using that function, how old would she estimate the fossil to be?

    Apparent age of fossil is _____ .

5. Assess the validity of the scientist's claim that "just 1 percent of modern carbon infiltrating a 50,000-year-old fossil would make it look 7,000 to 8,000 years younger."

Expounding, Investigating, Exploring...

When a mathematician or scientist wants to investigate a problem in some depth, he or she often considers generalizing an aspect of the problem that originally was constant. The quoted claim that you were assessing on the previous page included two such constants: the actual age of a fossil of interest (which was 50,000 years old in the example) and the amount of modern carbon infiltrating the fossil (which was 1 percent in the example).

6. First let's keep the "1 percent contamination" constant, but consider whether such contamination might create different errors in the age estimates of different fossils. Determine a function whose input x is the actual age of a fossil and whose output, $A_1(x)$, is the apparent age of the fossil if it is contaminated with 1% modern carbon. Note that $A_1(50,000)$ should be the same apparent age that you determined when working problem 4 on the previous page.

$A_1(x) = $ _____

Sketch a graph of your function over the age interval $0 \le x \le 100,000$, on the grid to the right.

Explain why the graph looks the way it does for relatively young fossils.
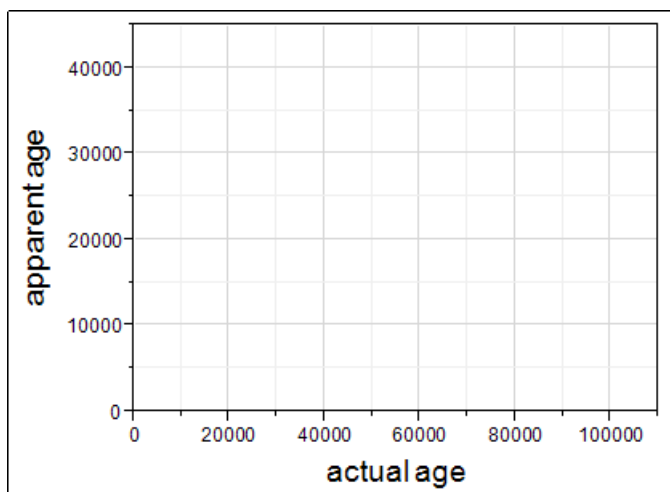
Explain why the graph looks the way it does for relatively old fossils.

7. Now let's keep the "50,000-year-old fossil" constant and consider the effect of different amounts of contamination. Write a function whose input x is the percent of contamination by modern carbon, and whose output $A_2(x)$ is the apparent age of a 50,000-year old fossil contaminated by x percent modern carbon. Note that $A_2(1)$ should equal $A_1(50,000)$, and both are equal to your answer to question 4 on a previous page of this document.

$A_1(x) =$ _____

Sketch a graph of your function over the inverval $0 \leq x \leq 100$, on the grid to the right.
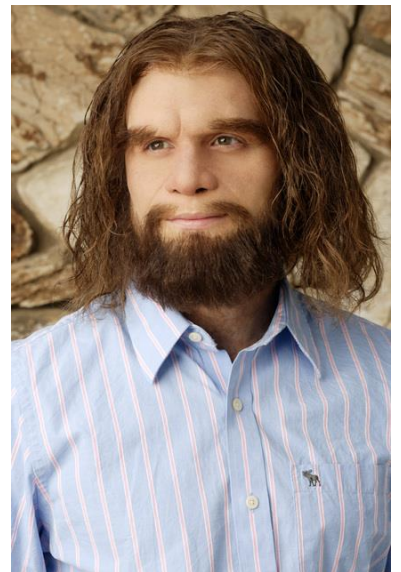
There are two particular points in the graph on the right that you could have plotted without knowing your function A_2. Which ones are they? Why are they easy to determine?
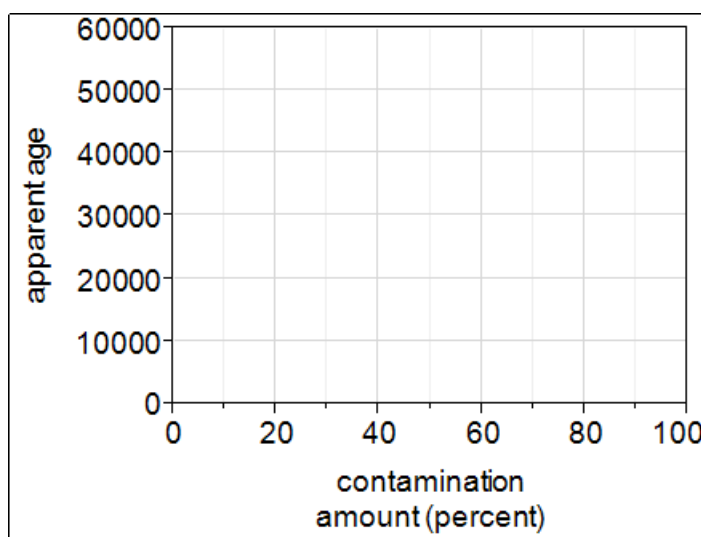
The newspaper article implies that recent improvements in carbon dating have come about because of techniques that help reduce contamination by modern carbon. ("The researchers prepared samples that would extract collagen in the bone and remove the contaminants.") Using the graph above, explain why even small improvements in contamination removal can make a big difference in the estimated age of a fossil. (Note that the contamination rate for fossils is typically less than 2 percent.)

Reflection

Reflect on the experience of working on this carbon-dating problem. This should be only a paragraph or two, and there are no right or wrong answers. Just describe what was most interesting, what you learned, whether it was frustrating, that kind of thing.

Less modern than he appears?