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BOMB CURVE RADIOCARBON DATING AS A FORENSIC TOOL FOR DATING IVORY

This document has been submitted by the United States of America at the request of the Wildlife Conservation Society in relation to agenda item 69 as well as proposals 10, 11, and 12.*

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Bomb-curve radiocarbon dating as a forensic tool for dating ivory

Overview

The age of ivory, or more specifically, the date of death of an elephant from which ivory comes, under some countries' domestic legislation determines whether commercial trade is legal or not. Under CITES, international trade of all elephant ivory for primarily commercial purposes has been prohibited since 1990 (the African elephant was transferred to Appendix I in 1989; the Asian elephant was already on Appendix I), with some trade allowed in the past from populations included in Appendix II (but no international commercial ivory trade is allowed now). In some countries, domestic trade is only legal for ivory obtained before 1989 or 1990. Regulations related to the age of ivory have been difficult to enforce, however, primarily because, until very recently, there was no way accurately to determine the age of ivory.

In 2013, a paper was published to validate a method for dating recent ivory using radiocarbon (Uno et al., 2013). The method relies on the anthropogenic spike of radiocarbon, known as the "bomb-curve", released into the atmosphere through above-ground nuclear weapons testing from 1952-1962.

Bomb-curve radiocarbon dating can be used to determine the year that ivory formed between *ca.* 1955 to present, to within several months to 3 years of the true date, depending on the year of death. The method can also detect if ivory was formed before 1955, but it cannot determine the year in which pre-1955 ivory formed because of the Suess Effect.

The most robust application of the method is to whole tusks. Dating of worked ivory, especially small pieces, can be highly ambiguous or misleading. The technique is also expensive, especially if applied at scale.

Anatomy of a Tusk

Tusks are highly modified incisor teeth made of dentin that grow throughout an elephant's life (Figure 1A). The tip of the tusk is the oldest part and the base is the youngest. The interior of the base of the tusk is called the pulp cavity, which is a cone-shaped space filled with soft issue. New ivory is continuously forming at the interface of the pulp cavity tissue and the tusk.

Ivory stops forming when an elephant dies. The ivory at pulp cavity surface is the last ivory to form. Therefore, a radiocarbon date from the ivory at the pulp cavity has the potential to reveal the year of death.

Figure 1B shows some radiocarbon dates measured in a tusk from a zoo elephant that died in 2008. Each dot on the center line represents the time at which that part of the tusk formed. The oldest ivory at the tip of the tusk formed in 1993.

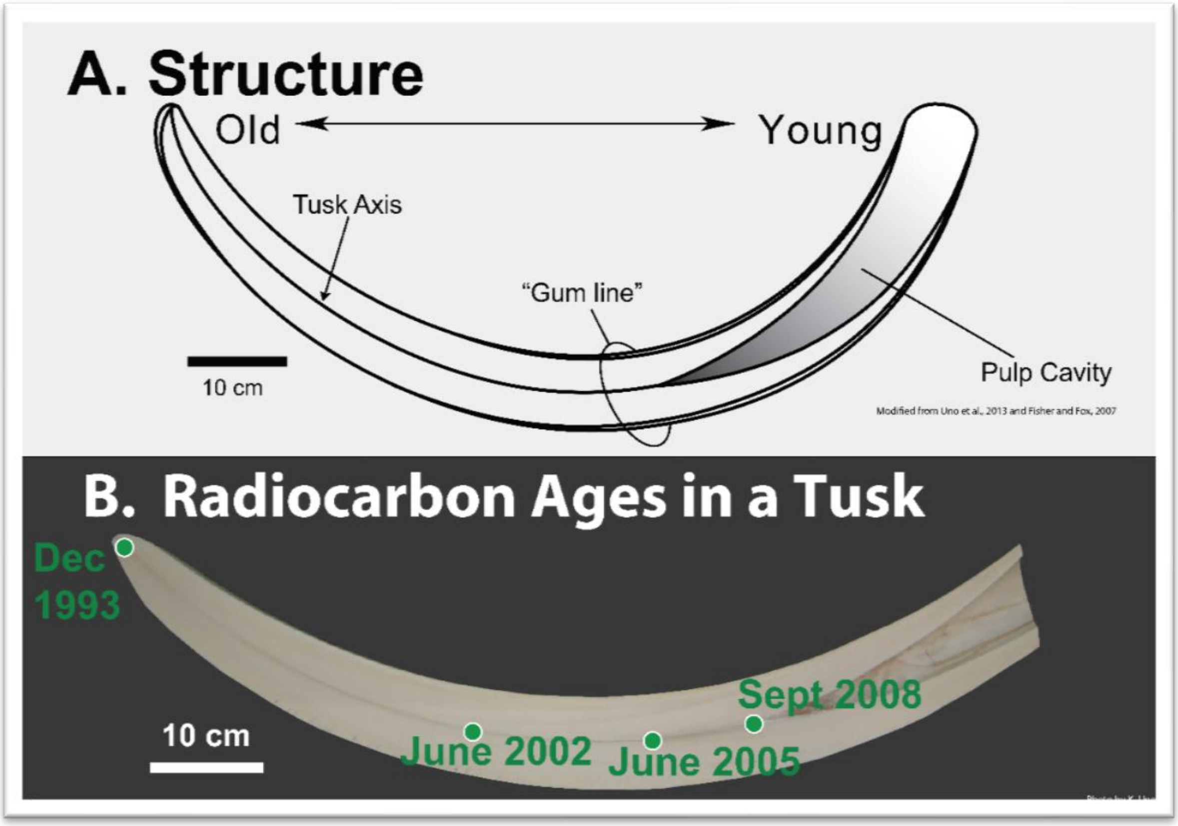

Figure 1. A) A schematic of a longitudinally-cut elephant tusk showing its internal structure and B) a photo of a real tusk cut in the same orientation with radiocarbon ages shown along the tusk axis. Schematic in A) is modified from Uno et al. (2013) and from Fisher and Fox, 2007.

Bomb-curve Radiocarbon Dating of Ivory

Unlike traditional radiocarbon dating, which relies on radioactive decay, Uno et al.'s method simply uses the known concentration of radiocarbon in the atmosphere over the last 60 years. Above-ground nuclear weapons testing from the mid-1950's to 1963 nearly doubled the concentration of radiocarbon in the atmosphere (Figure 2).

The abrupt rise and steady fall of radiocarbon in the atmosphere is known as the bomb-curve. The Partial Test Ban Treaty of 1963 ended above-ground testing and with this, anthropogenic production of radiocarbon in the atmosphere virtually ceased. After the treaty, the radiocarbon concentration in the atmosphere began to decrease as it was absorbed by the oceans and plants. As a result, each year has a different radiocarbon concentration relative to the previous year.

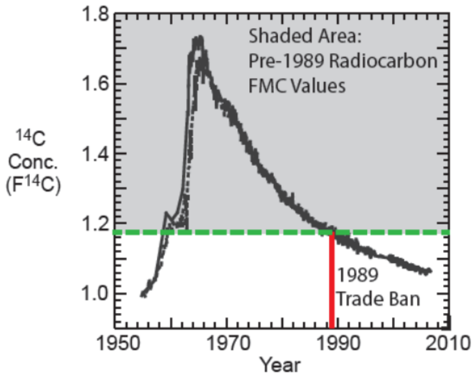

Figure 2. Concentration of ^{14}C in the earth's atmosphere from the start of nuclear testing in 1952 onwards. The shaded area is defined by elevated radiocarbon concentrations that are above the 1989 level. Note that there is a brief period up to ~1956, where radiocarbon concentrations are similar to post-1989 values.

The reason that the radiocarbon concentration in the atmosphere can be used to date certain animal tissues is because you are what you eat: Radiocarbon produced by nuclear blasts quickly oxidizes to carbon dioxide in the atmosphere. Carbon dioxide is taken up by plant leaves during photosynthesis. Thus, plant leaves lock-in the radiocarbon concentration of the atmosphere during the year in which they form. Herbivores such as elephants then eat these leaves. Elephants use this dietary carbon to build tusk ivory, and in turn, lock in the radiocarbon concentration of the atmosphere into their tusks.

Using the Technique to Determine the Age of Ivory

The radiocarbon concentration can be accurately measured from any piece of ivory. However, not all ivory will yield a conclusive age. This is because most radiocarbon concentrations measured have two corresponding dates on the curve—if you draw a horizontal line across the bomb-curve, the line intersects the curve twice, once on the rising side of the curve (1955 to 1963) and once on the falling side (1963 to present) (Figure 2). To determine which is the true date, two additional pieces of information are required: a second radiocarbon analysis from another point on the tusk; and the relative position of the two samples along the tusk axis (which one is older). This is not a problem for whole tusks, but can be difficult or impossible for worked ivory, especially small pieces.

If taking two samples is not feasible, the result is not necessarily entirely inconclusive. If the radiocarbon concentration corresponds to a pre-1989 level, then the piece itself is "pre-ban" in age (but not pre-Convention). That does not mean that the elephant died before 1989, however. Figure 3 shows the tusk of an elephant that died in Kenya in 2006. If the tusk is worked into smaller pieces, ivory derived from the distal or older end of the tusk would yield an age of 1978, even though the animal did not die until 28 years later. Hence, the technique is only truly reliable in determining the time of death of the elephant if two measurements are taken from a whole tusk.

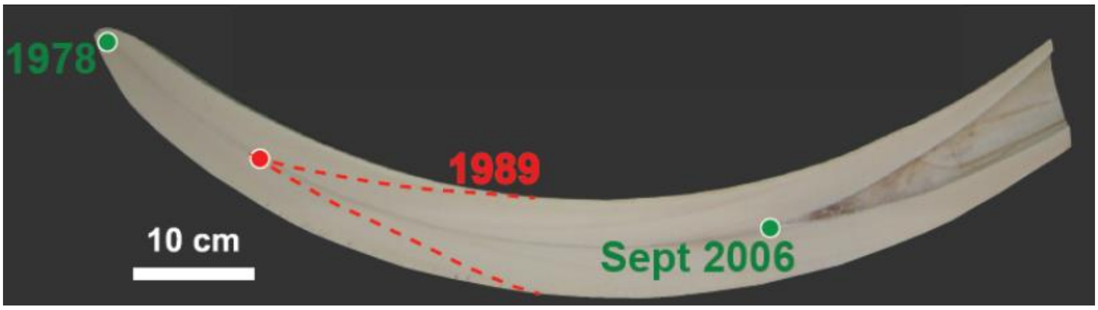

Figure 3. Ages of different parts of a tusk of an elephant that died in September 2006.

Cost

The amount of ivory required for a single measurement is about 50 milligrams, which is equivalent to a pinch of salt. The easiest way to obtain a sample is to drill a small area at the pulp cavity of a tusk i.e., the part laid down shortly before the animal died. It takes about a week in a suitable lab to prepare the sample for analysis on an Accelerator Mass Spectrometer.

Obtaining a radiocarbon date currently costs about $300 and, for accurate aging, two samples are generally needed. This cost is trivial in comparison to the value of a shipping container full of tusks or even a single carved tusk. However it might be viewed as prohibitive when verifying the age of a $200 bracelet.

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