CHRONOLOGY

Teacher's Manual

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Subjects:
Archaeology, Earth Sciences, Chemistry

Duration:
3 class periods

Class size:
up to 40 students

Summary

Overview:

In this module, students will be introduced to the radiocarbon dating method, which archaeologists and geologists frequently use to determine when the events which interest them occurred. During this lesson, the teacher will instruct the students about the concepts foundational to the radiocarbon dating method. This lesson will require students to identify suitable and unsuitable materials for radiocarbon dating, use a graph to determine the age of samples based on the amount of radiocarbon that is present in them, and do a take-home writing assignment in which they will design a plan for constructing a timeline of events at an archaeological site.

Objectives:

- To understand the difference between timelines based on relative dating and absolute dating.
- To understand how radiocarbon dating works, what objects can be dated, and what the limitations of the method are.
- Understanding how archaeologists use radiocarbon dating to reconstruct human history and investigate links between natural hazards and human occupation

Material Included in the Box:

- Slide Show to assist in the presentation of the information.
- Digital and hard copies of illustrations to be used while instructing.
- Digital and hard copies of the lesson packet to be distributed to students.

Vocabulary

Absolute Dating:

The process of determining when an event occurred along a calendrical timeline.

Biosphere:

The component of the Earth system which consists of all life on earth, including all avian, terrestrial, and aquatic species. The biosphere can be understood in terms of the abundance of living organisms on earth (global biomass) and in terms of its internal organization or systemic process (ecosystems).

Carbon-12 (^{12}C):

The most abundant stable carbon isotope occurring in nature. ^{12}C contains 6 protons and 6 neutrons.

Carbon-13 (^{13}C):

A naturally occurring, stable carbon isotope, which is considerably less abundant in the atmosphere than is ^{12}C but considerably more abundant than ^{14}C. ^{13}C contains 6 protons and 7 neutrons.

Carbon Cycle:

The process by which carbon flows throughout and is exchanged between various physical and biological systems (for example, the atmosphere, the oceans, and the biosphere). Because carbon is an essential ingredient for life on earth, it is critical that carbon be continuously available to organisms, so understanding how carbon is recycled through the carbon cycle is of central importance for biologists.

Carbon dioxide (CO_2):

A molecule consisting of two oxygen atoms and one carbon atom. Carbon dioxide molecules form in the atmosphere, and their carbon atoms can be either ^{12}C, ^{13}C, or ^{14}C atoms.

Dated event:

An event which is directly dated by a particular dating method. In the case of radiocarbon dating, the dated event is the time of death of an organism from which a sample is taken. The dated event may or may not be of direct interest to archaeological research.

Isotope:

A variant form of an element. Different isotopes of the same element have different numbers of neutrons in their atomic nuclei. For example, a ^{12}C atom has six neutrons in its nucleus, ^{13}C has seven, and ^{14}C has eight, yet all three are still carbon atoms and interact in the same chemical reactions in the same way.

Vocabulary
Continued

Law of superposition:
A principle of geology which states that, in a sequence of geological layers, a lower layer of sediments was deposited before, and therefore is older than, overlying layers. This law only applies in cases where such layers have not been disturbed or mixed since the time of their deposition.

Neutron:
A subatomic particle which has no charge. Together with protons, neutrons are one of the building blocks of the nuclei of atoms, but they can also occur free in nature.

Nitrogen-14 (^{14}N):
A common, naturally occurring, stable nitrogen isotope. ^{14}N contains 7 protons and 7 neutrons.

Radiocarbon (^{14}C):
A naturally occurring, radioactive carbon isotope, which is considerably less abundant than both ^{12}C and ^{13}C.

Relative dating:
The process of determining whether an event came before or after another event in time, without consideration for how much time intervened between the two or how long ago in the past they occurred.

Stratigraphy:
A sequence of layers at an archaeological site or a geological locale that represents the depositional history of that location.

Stratum (plural: strata):
A layer in a geological deposit having characteristics (age, color, composition) that make it distinguishable from other layers.

Target event:
An archaeological term used to refer to the event which is of interest to an archaeologist and for which they would like to estimate a date. Linking a particular "dated event" to the "target event" is one of the biggest challenges of historical sciences like archaeology and geology.

Years BP (years before present):
The amount of time which has passed between the occurrence of an event and the year A.D. 1950. To prevent confusion, radiocarbon scientists defined A.D. 1950 as the 'present' so that radiocarbon ages always refer back to this same fixed point in time. For example, 537 years BP will always refer to the year which preceded A.D. 1950 by 537 years, in other words A.D. 1413.

Background Information

When cosmic rays excite atmospheric neutrons, some of these neurons collide with atmospheric nitrogen-14 (^{14}N), which is transformed into radiocarbon (^{14}C) as a result (see Figure 1). This ^{14}C constitutes a miniscule proportion of atmospheric carbon, alongside two considerably more abundant carbon isotopes: carbon-12 (^{12}C) and carbon-13 (^{13}C). All three of these carbon isotopes combine with atmospheric oxygen atoms to form carbon dioxide molecules. Through the process of photosynthesis, plants incorporate carbon from these carbon dioxide molecules into their tissues, maintaining a ^{14}C to ^{12}C ratio in equilibrium with the atmosphere as long as they are alive. In turn, animals eat plants or other animals, and the carbon in the plant or animal tissues that they consume is incorporated into their own tissues. When plants and animals die, they cease incorporating new carbon into their tissues and the "radiocarbon clock" starts ticking.

Radiocarbon is a radioactive isotope which decays back into ^{14}N at a constant rate: after approximately 5,700 years, half of the amount of ^{14}C which was originally in the sample converts back into ^{14}N. After another ~5,700 years, half of the remaining ^{14}C converts into ^{14}N. This process of radioactive decay continues indefinitely through time, but the amount of ^{14}C remaining in a sample becomes so small after approximately 50,000 years that laboratory machines have a hard time detecting it. Conversely, ^{12}C is a stable isotope, so the amount of ^{12}C that is present in a sample at the time of its death should remain constant over time.

Technicians who work at radiocarbon laboratories measure the amount of ^{14}C and ^{12}C remaining in a sample of organic material (such as wood, charcoal, bone collagen, shell, hair, seeds, or plant fibers). If they assume that the ratio of ^{14}C to ^{12}C that was originally present in the sample is identical to the ratio of modern atmospheric ^{14}C to ^{12}C, then they can use their measurement of the amount remaining in a sample to estimate the amount of time that has passed since the death of the organism that the sample came from, assuming a constant rate of radiocarbon decay.

If an archaeologist or geologist has good reason to believe that the death of a sample (the "dated event") corresponds closely in time with its deposition at an archaeological or geological site (the "target event"), they can use this sample's date to determine when it was deposited at the site, allowing them to begin to construct a timeline for the archaeological or geological history of that site.

^{14}C (pronounced "radiocarbon" or "carbon 14") is a radioactive isotope of carbon.

An isotope is a variant form of an element. Different isotopes of a single element have the same number of protons in their nuclei but vary in the number of neutrons they have. A carbon atom, for example, has six protons in its nucleus, but there are three naturally occurring carbon isotopes — ^{12}C, ^{13}C, and ^{14}C — which have six, seven, or eight neutrons in their nuclei, respectively.

What makes some isotopes such as radiocarbon radioactive is that they are "unstable," meaning that the ratio of neutrons to protons in their nuclei is too high above 1.0 and as a result they end up "giving up" parts of their nuclei, resulting in a more stable atom. This process is called radioactive decay or simply radioactivity. Radioactive isotopes contrast with stable isotopes, whose neutron-to-proton ratios are close enough to 1.0 that they stay in their form barring external intervention.

The formation and radioactive decay of ^{14}C

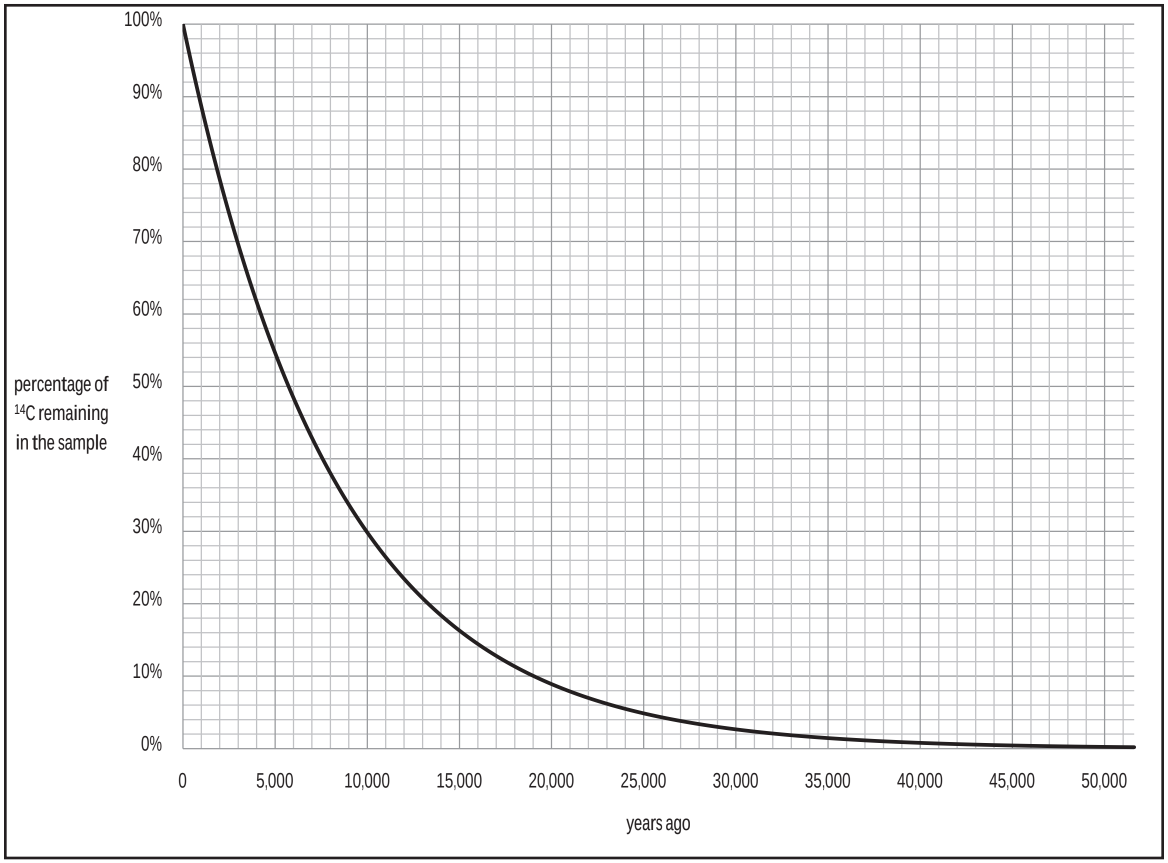
In the upper atmosphere, nitrogen atoms are bombarded by cosmic rays. As a result of this bombardment, the stable isotope ^{14}N (pronounced "Nitrogen-14"), which has seven protons and seven neutrons in its nucleus, loses one of its protons and gains an extra neutron, converting it into ^{14}C (six protons, eight neutrons).

Over time, ^{14}C decays back into ^{14}N through a process called ß emission (ß is pronounced "beta"). A ß particle is a negatively charged electron, located in the nucleus of the atom, and each ß emission event involves not only emitting a ß particle from the nucleus of the ^{14}C atom but also an exchange of its eighth neutron for an additional proton. As a result, the nucleus of the atom is balanced back to the seven neutrons and seven protons that constitute ^{14}N (n:p ratio = 1.0).

^{14}C decays to ^{14}N at a constant rate, which can be expressed in different ways:
The most common expression of this decay rate refers to a radioactive element's "half-life" (labeled $t_{1/2}$). A $t_{1/2}$ is the amount of time it takes for one half of a given amount of a radioactive element to decay, leaving the other half in the radioactive isotope form. Willard Libby, the creator of radiocarbon dating, thought that ^{14}C's $t_{1/2}$ was approximately 5,568 years long, but we now know that it is closer to approximately 5,730 years long.

A less common way of talking about radioactive decay is to talk about its annualized decay rate (labeled λ, pronounced "lambda"). λ refers to the amount of the radioactive isotope that decays in a single year, expressed as a percentage of the amount existing at the beginning of the year. In other words, the amount of the radioactive isotope at the beginning of the year is reduced by a certain percentage by the end of the year. For example, the λ associated with the Libby $t_{1/2}$ of 5,568 years is 0.0124488% lost per year, while the λ associated with the Oxford $t_{1/2}$

of 5,730 years is 0.0120968% lost per year.



Knowing these decay rates, it is possible to graph the relationship existing between the amount of ^{14}C present in a sample at the time of its death and the amount of time that has elapsed since then.

Assuming that we know how much radiocarbon was originally present in the sample, we can calculate the amount of time which has elapsed based on the amount of radiocarbon remaining in the sample.

Radiocarbon in the carbon cycle:

Approximately one out of every one trillion carbon atoms in the atmosphere is a ^{14}C atom. Just like other atmospheric carbon, most atmospheric ^{14}C atoms bond with oxygen atoms to create carbon dioxide (CO_2).

Most of this carbon dioxide enters the oceans, but terrestrial plants consume some of it through the process of photosynthesis, fixing the carbon in their tissues. In turn, animals that eat these plants fix the plant's carbon in their tissues, and predators that prey upon these animals in turn fix the prey's carbon in their tissues.

As long as the plant or animal is alive, it continually rejuvenates the carbon in its tissues, exchanging old carbon for newly consumed carbon, and thereby insuring that the ratio of ^{14}C out of all carbon in its tissues is in equilibrium with (in other words is more or less identical to) the ratio of ^{14}C out of all carbon in the atmosphere.

When the organism dies, however, it can no longer rejuvenate the carbon in its body. The ^{14}C fixed in its tissues at the time of death begins to decay into nitrogen, as discussed earlier.

Measuring radiocarbon in samples and calculating radiocarbon ages:

Because we know that there was approximately one ^{14}C atom for every 999,999,999,999 carbon atoms in an organism's tissues when it died, we can determine the percentage of ^{14}C lost through radioactive decay, if we can also measure the current ratio of ^{14}C to all other kinds of carbon in a sample taken from a deceased organism's tissue. If we can take such a measurement and calculate the percentage of ^{14}C remaining, we can then use this knowledge to calculate the amount of time that has elapsed between the organism's death and the present, and can thereby determine its time of death.

There are two ways of measuring the amount of ^{14}C present in a sample, labeled conventional dating and AMS dating. *Conventional* dating involves counting the number of ß particle emissions that occur over a given amount of time and using this to calculate the amount of ^{14}C necessary to produce ß emissions at the measured frequency. *AMS dating* uses a machine called an accelerator mass spectrometer (or AMS for short) to directly measure the mass of ^{14}C and of all other kinds of carbon present in a sample.

Typically, after about eight or nine half-lives (approximately 45,840 to 51,570 years), there is too little ^{14}C left in a sample to reliably measure. When a sample which is submitted to a dating lab comes back with an undetectably small amount of ^{14}C remaining in it, we say that it is "radiocarbon dead" or has "infinite age" (meaning that we know that it can be no less than eight or nine half-lives old but that we don't know how much older than eight half-lives it is).

Limitations in a radiocarbon date's accuracy and precision:

An archaeologist's or geologist's ability to make effective use of a ^{14}C date is limited in important ways.

First of all, there is an issue of precision in measurement. Precision refers to how close a measurement comes to the value that the researcher is trying to measure. All instruments that scientists use to make measurements of the phenomena that interest them have limited precision. In other words they rarely get exactly the right measurement. For example, if you were to measure the width of your desk with a ruler to the nearest millimeter or the nearest sixteenth of an inch, and if you were to do this multiple times, you would probably come up with multiple nonidentical measurements. Yet, your measurements would also come close to each other, and this allows you to estimate what the width of your desk is within a certain margin of error. Similarly, both conventional and AMS dating methods involve some measurement error. When radiocarbon laboratories report an age

Background (in more detail)

The Physics of ^{14}C Formation and Decay - continued

estimate for a particular sample, the estimated age is always reported along with a margin of error, called an standard error, for example 5,000±50 (read "5,000 plus or minus 50") years before present. The standard error is associated with a 68% probability, so we can say that the real date of the sample falls between 4,950 and 5,050 years before present, with a 68% probability (in other words, a 32% chance of being wrong). If the standard error is doubled (e.g., to ±100 years in our example), the resulting margin of error is associated with a 95% probability, so in our example we can say that the date of the sample falls between 4,900 and 5,100 years before present, with a 95% likelihood (in other words a 5% chance of being wrong).

Secondly, there is an issue of accuracy. Accuracy refers to the connection between the date estimated for a given sample and the date of the phenomenon that the researcher actually wants to date. Recall that the method calculates the amount of time elapsed since the organism died. Yet, archaeologists and geologists are usually not interested in the organism's time of death. They are usually interested in knowing such things as when a particular village was occupied, when people manufactured a particular style of pot, when a certain volcano erupted, or when a particular stratigraphic layer was deposited. We refer to the organism's time of death as the dated event, whereas we refer to the time that the researcher actually wants to date as the target event. The fact that the two events are not the same does not, however, mean that we cannot use the dated event to infer the age of the target event. But in order to do so we must demonstrate that the two events lie very close to each other in time. In some situations, this is not easy. For example, when people use driftwood as fuel for fire, there is a possibility that the driftwood they burn had died a long time before they burned it. If an archaeologist then wants to know when that fire was made and collects a charcoal sample from its ashes for ^{14}C dating, the date which the archaeologist gets back from the lab may in fact be older than the date at which the fire was made because of the driftwood problem. If the archaeologist has good reason to suspect that the prehistoric people whom they are studying harvested driftwood for fire-making purposes, they may therefore not want to use charcoal as a material to date. On the other hand, if the archaeologist has no reason to believe that driftwood was an important resource, or to believe that the driftwood which was available could have been very old by the time that past people harvested and used it, then he or she may choose to date wood or charcoal samples with confidence. The trick is therefore to pick the right kind of material to date in order to reliably date the target event.

Lesson Activity 1: The Basics

Students learn the Law of Superposition and the difference between absolute and relative dating used by archaeologists and other earth scientists.

Warm up:

Review what archaeologists study. Ask students why time and dating might be an important component in an archaeological project (answer: archaeologists want to know when a village was occupied, when a specific type of tool was used first, when some change in technology happened, etc.).

Procedure:

1. Ask students to think of 5 events from their life; for some of these events they should remember the exact date (example: sibling's birth), but for others they should not remember the exact date, but be able to place it into sequence relative to the events they do know exact dates for (example: a play at school, an important sports game, an injury, family vacation, visit from a relative). Ask the students to write them in a column, with the oldest event on the bottom and the most recent event on the top.

2. Explain the difference between absolute and relative dating (just like with the events in our lives, sometimes we can put a specific number on the age of some event (absolute date), and other times we can only say that something is older than, younger than, or same age as something else (relative date).

3. Ask students which of their events would fall under relative or absolute dating. As a class, discuss examples provided by several students.

4. Introduce the Law of Superposition.

5. Ask students to discuss the law using a trash can activity: have students draw a trash can and fill it with the remains of three meals in the order in which they went in. Ask students which of these objects could provide them with absolute dates (newspaper, yogurt container – expiration date), and how you could use relative dating for the rest of the items. You may decide to do this as a demonstration with an actual trash can.

6. Give students the Rasshua Island stratigraphic profile (laminated handouts) and ask them to work in small groups to explain the sequence of deposition according to the Law of Superposition (which layer is oldest and which came after?). Ask them if they could tell without absolute dating if object #6 or object #2 was older.

Wrap Up:

Ask students what they already know about dating methods used by archaeologists (from movies, documentaries, or books). Make a transition to radiocarbon dating – one of the most useful and most often used absolute dating methods.

Lesson Activity 2:

Students learn the environmental chemistry of carbon, from the formation of radiocarbon in the atmosphere, to its introduction into the bio-sphere, to its transmission throughout the bio-sphere, to the decay of radioactive carbon.

Procedure:

1. Use the powerpoint provided on CD or online to explain how radiocarbon dating works. The teacher may choose to include more detail in their explanation of the process to the class, depending on the students' interest and knowledge of molecular physics and chemistry [Slides 1-7]. After these slides, students should be able to identify items that are ^{14}C datable.

2. Use the "Dating Game" [Slides 7-20] to solidify the understanding of what can be used for radiocarbon dating: the students are shown a series of photographs depicting different objects, and they are asked whether these objects can be ^{14}C dated and why. Here are the answers:

Rock: Because stone does not contain organic carbon, we cannot use the radiocarbon method to date it. However, there are other dating methods which can provide dates for some types of stone.

Bone: Bone was part of a living organism and contains organic carbon, so it can be radiocarbon dated. However, before this can be done the organic portion of the bone, called collagen, has to be isolated from the inorganic portion, called bone apatite.

Pure Beach Sand: Because beach sand consists of inorganic mineral grains, it does not contain organic carbon, so we cannot use the radiocarbon method to date it.

Charcoal: Charcoal is burned wood and contains organic carbon, so it can be dated using the radiocarbon method. In fact, it is probably the material most commonly dated by archaeologists to establish the age of human settlements.

Seed: Though rarely recovered in archaeological sites because they are fragile, seeds are organic and can be dated using the radiocarbon method.

Shell: Shell can be radiocarbon dated because it contains calcium carbonate.

Metal Artifact: Metal does not contain carbon, so it cannot be radiocarbon dated. However, sometimes rust on metal tools contains organic carbon, which can be used to indirectly date the metal artifact.

Stone Projectile Point: Just like unmodified stone, artifacts made out of stone do not contain organic carbon, so we cannot use the radiocarbon method to date them. However, stone tools sometimes have organic residues on them, which can be used to indirectly date the stone artifact.

Hair: Hair was a part of a living organism and contains organic carbon, so it can be radiocarbon dated. Technological advances in radiocarbon dating allow as little as 20 micrograms of carbon (about 2–4 cm of hair) to be radiocarbon dated.

Wood: Wood contains organic carbon and can be dated using the radiocarbon method. However, in most cases unburned wood does not preserve as well as does charcoal, so archaeologists encounter wood less often than charcoal.

Plastic Bottle: Plastic is a petroleum-based product. Petroleum is an organic substance, containing organic carbon from organisms that

Lesson Activity 2 (continued):

lived hundreds of millions of years ago. However, because these organisms lived so long ago, any radiocarbon that was once in their tissues has effectively disappeared. The commercial use and mass manufacture of bottles also did not begin until the mid-20th century A.D., so while the material from which plastic bottles are made is too old to be dated using the radiocarbon dating method, the plastic bottle itself is also too young to be dated using the method.

Cotton Fabric: Cotton is made from organic fibers from cotton plants belonging to the genus *Gossypium*. It can be dated using the radiocarbon method.

Pottery: Pottery itself cannot be radiocarbon dated because it consists of inorganic clay and sand minerals. However, if there is organic residue, for example remains of food that was cooked or stored in the vessel, then these materials can be dated and used to indirectly date the pot's manufacture.

3. Discuss the results of the Dating Game

4. Demonstrate the dynamics of ^{14}C and ^{12}C after the organism dies using the online or hardcopy Decay Illustration of a seal [Slide 21]. This series of drawings shows how many atoms of each isotope are contained in the bones after each half-life (5,730 years). Please note that the condition of bones does not determine the amount of ^{14}C present, i.e. the deterioration of bones is illustrated to represent time, not the amount of radiocarbon present. The illustration also shows that the radiocarbon method is not reliable for objects older than about 50,000 years because too few ^{14}C atoms are present to accurately detect and measure them. However, many archaeologists are interested in human activities within this period and organics preserve at many sites, so radiocarbon is a very popular method of dating, especially in North America.

5. The teacher will illustrate how to "reflect" lines against the radiocarbon decay curve (get x from y or y from x) to determine the age of a sample based on how much radiocarbon is left in it, using the decay curve illustration [Slide 22]. The teacher can then ask questions based on this curve:

a. What is the approximate age of an organic sample with 75% radiocarbon remaining?

Answer: approximately 2,500 years.

b. How much radiocarbon remains in a sample after 3 half-lives?

Answer: $3 \times 5730 = 17{,}190$ years. Approximately 12%

c. What is the approximate age of an organic sample with 1/512 of the original radiocarbon remaining?

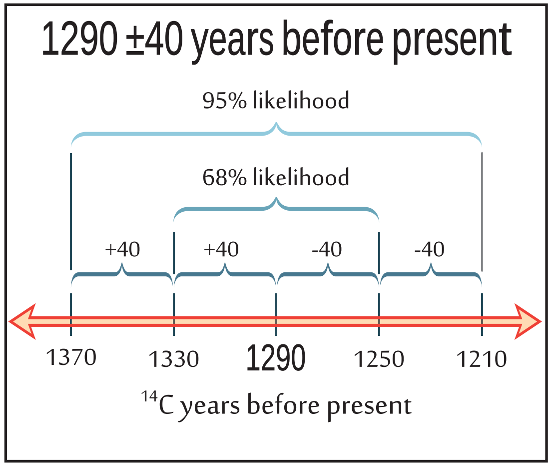
Answer: $1/512 \approx 0.2\%$. 1/512 is associated with 9 half-lives ($2^9 = 512$). However, this amount of remaining radiocarbon is too small for most laboratories to measure or detect, so no reliable date can be obtained; all we can say is that it is >9 half-lives old, in other words >51,570 years old).

d. How much radiocarbon remains in a sample after 25,000 years?

Answer: approximately 5%.

6. Show the students what a radiocarbon date looks like when the lab sends the result back to

the researcher using an illustration like this one.



Explain what Before Present means (before 1950) and why there is a +/- (standard error measurement) attached to the date -- our instruments are not perfect, there is some uncertainty to each measurement. We leave it up to the teacher to decide in how much detail to cover this concept in class, but students should understand that radiocarbon dating does not determine the age of events with exact precision but instead provides a restricted range of possible ages, which can be efficiently communicated using the central date and standard error as a shorthand for this range. However, for the sake of simplicity, students should use the central estimate in any exercise that requires the manipulation of radiocarbon dates throughout the modules in this box. Then give students another random date (for example 5,275+/-60) and have them explain what the date means (the true radiocarbon age has a 68% chance of lying somewhere between the measured age plus the standard error and the measured age minus the standard error).

Conclusion:

Have students summarize and review how radiocarbon dating works in their own words (you can display the fox illustration to help them).

Lesson Activity 3: Interpreting radiocarbon dates

Students use their knowledge of dating methods to interpret an archaeological site.

Warm up:

Review the Law of Superposition, Absolute and Relative Dating, and the principles of Carbon Dating. Ask students to give examples of how each is used.

Procedure:

1. Ask students to think about whether archaeologists are interested in when an organism died. Ask them to think about the definition of archaeology – study of people. Discuss the idea that archaeologists are more interested in human activities than when an organism died. Consider what archaeologists call the target events and dated events, using the illustration as a visual aid that emphasizes the difference between target and dated events [Slide 23]. Students should understand that

a. While archaeologists date layers and objects, what they are really interested in dating are the human behaviors or events that might have influenced humans.

b. The death of an organism is a "dated event." Human behaviors or geological events of interest are "target events."

c. Archaeologists have to make arguments to link dated events and target events for example, the wood is found in the same layer and it's a short-lived twig.

2. Use the Rasshua test pit illustration (laminated handouts) to talk about whether things that can be dated on that illustration will provide dates close to target dates. For example, bone is usually a good way to get a date close to target date of human occupation, because people normally eat animals soon after they kill them, whereas wood could provide a date older than human occupation if, for example, old driftwood was being used (for firewood or tools).

3. Tell the class that they will now use this Rasshua Island site to interpret using what they've learned about dating.

4. Hand out the Research Plan worksheets (you can print out the Rasshua stratigraphy and radiocarbon dates for each student on the last two pages of the Research Plan worksheet or use the laminated handouts). Ask students to answer the questions and write a narrative about the site layers. The narrative should include how people lived at the site and what events they experienced. You may decide to do this as a small group activity:

A. Divide the class into small groups of 2-3 students. Hand out the first worksheet and the Rasshua Test Pit profile. Ask students as a small group to complete the first worksheet and to identify what levels they want to date and why.

B. Discuss the answers to worksheet as a class. Ask students to report on which layers they would like to date and why.

C. Distribute Worksheet Two and the Test Results. Ask students to answer the questions relating to their test results in their small group. Reconvene the class to discuss the answers and what they might tell us about the people who lived at the Rasshua site.

Conclusion:

As individuals (or in small groups), students will write a site report describing who lived at the site, how they lived at the site and what they experienced. Tell students that they should use evidence from their study to support their narrative. Discuss the findings as a class.

Quick Reference:

^{14}C in the Carbon Cycle

How ^{14}C works

1. Cosmic rays enter the earth's atmosphere and collide with atoms there, creating energized neutrons.
2. If one of these energized neutrons collides with a nitrogen atom (^{14}N, having seven protons and seven neutrons), this atom turns into a ^{14}C atom by capturing the energized neutron and losing a proton.
3. Both ^{14}C and ^{12}C combine with oxygen in the atmosphere to form carbon dioxide molecules, which are then absorbed into the tissues of plants during photosynthesis.
4. Animals eat plants or other animals and absorb the ^{14}C and ^{12}C into their tissues continuously throughout their life.
5. Following the death of a plant or animal, it no longer absorbs ^{14}C or ^{12}C into its tissues, and its tissues begin to lose ^{14}C atoms because these atoms change back into ^{14}N by losing a neutron and regaining a proton. This process is called beta emission.

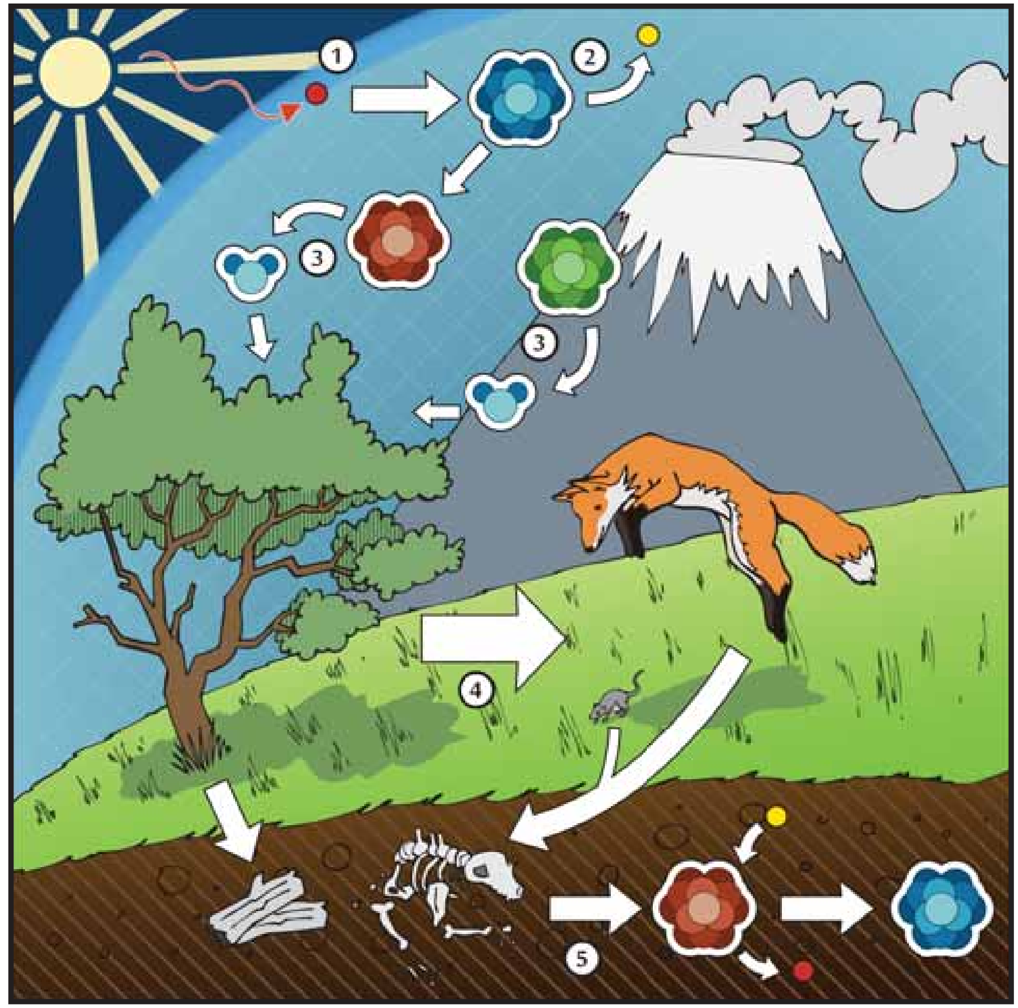
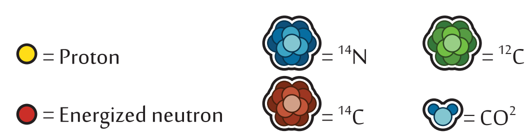


Figure 1



The Kuril Biocomplexity Project: www.kbp.org

Questions to ask in class:

- What is the approximate age of an organic sample with 75% radiocarbon remaining?

  Answer: approximately 2,500 years.

- How much radiocarbon remains in a sample after 3 half-lives?

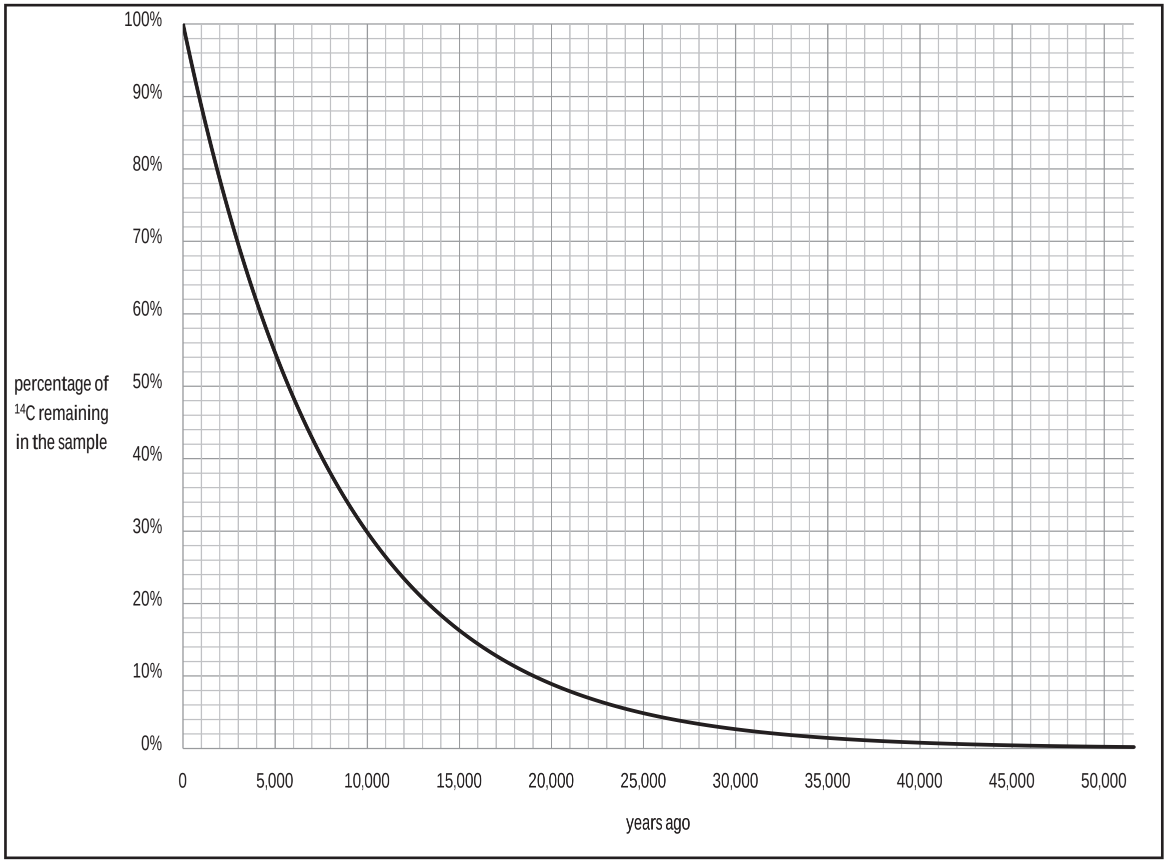
  Answer: 3 × 5,730 = 17,190 years. Approximately 12%

- What is the approximate age of an organic sample with 1/512 of the original radiocarbon remaining?

  Answer: 1/512 ≈ 0.2%. 1/512 is associated with 9 half-lives ($2^9 = 512$). However, this amount of remaining radiocarbon is too small for most laboratories to measure or detect, so no reliable date can be obtained; all we can say is that it is >9 half-lives old, in other words >51,570 years old).

- How much radiocarbon remains in a sample after 25,000 years?

  Answer: approximately 5%.



Dated Event

A radiocarbon date approximates the time of death of an organism, because this is the point in time when that organism stops incorporating new ^{14}C into its tissues and the ^{14}C already in its tissues begins to decay. For example, a radiocarbon date on wood or wood charcoal indicates when a tree died, either from natural causes or when it was cut by people for use. Similarly, a radiocarbon date on an animal bone indicates when that animal died, either from natural causes or when it was killed by people for use. This date is referred to as the "dated event." In the case of radiocarbon dating, the dated event always refers to the time of an organism's death

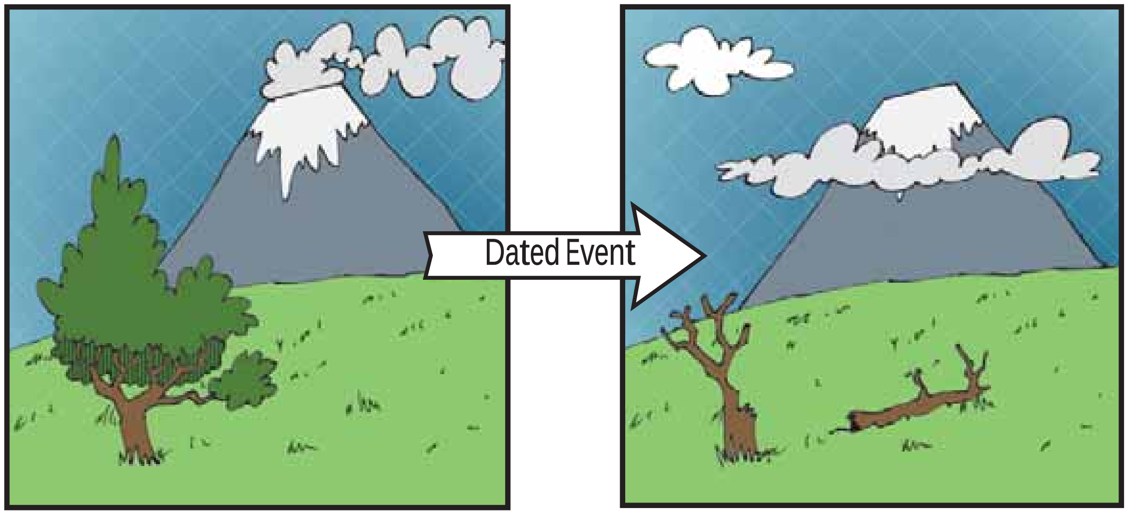


Figure 3

Target Event

Archaeologists are actually interested in dating when humans occupied certain locations or when they engaged in particular activities in the past. The activities that humans undertook when they occupied particular locations often involved the use of organic materials (bones, wood, shell, etc.), which were then thrown away nearby. If these materials have been preserved (in other words, did not decompose, were not eaten or carried away by animals, etc.), they can be collected by archaeologists and dated. Human activities are referred to as "target events," and their age can be approximated by the age of the dated event. In some situations, the dated event and the target event occurred very close in time to one another, for example if people cut wood from a tree to burn it. In other situations, the dated and target events may be separated by a few centuries (or more), for example if people use old driftwood from a beach as fuel for fire. Because of this possibility, archaeologists have to develop convincing lines of reasoning to justify using a particular sample to estimate a date for a target event, and they should check their dates by dating several samples and dating different materials (bones and charcoal, for example). Geologists struggle with these issues too, because organic materials contained in geological layers may be anomalously old or young, for example if burrowing rodents have disturbed the layers.

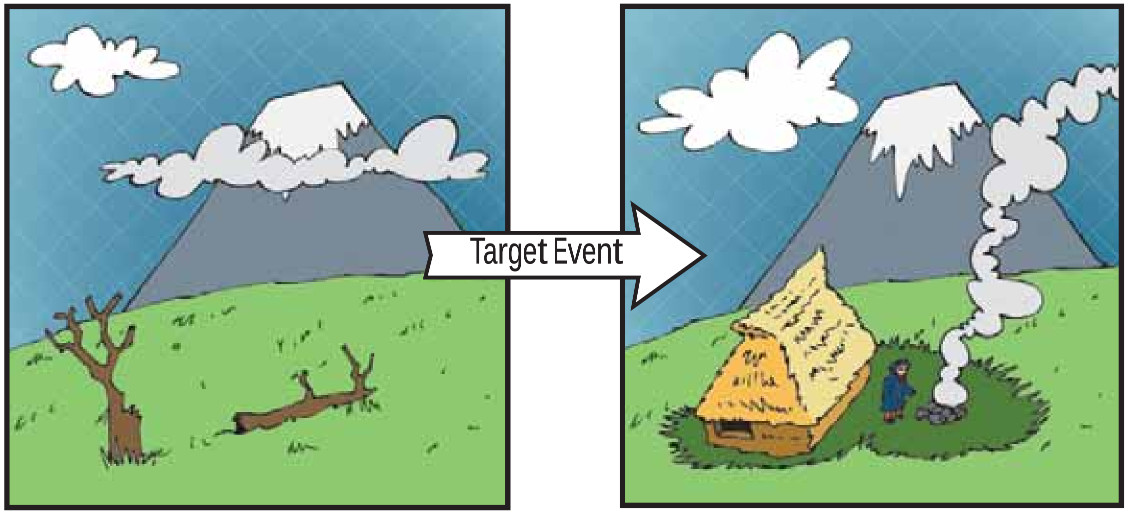
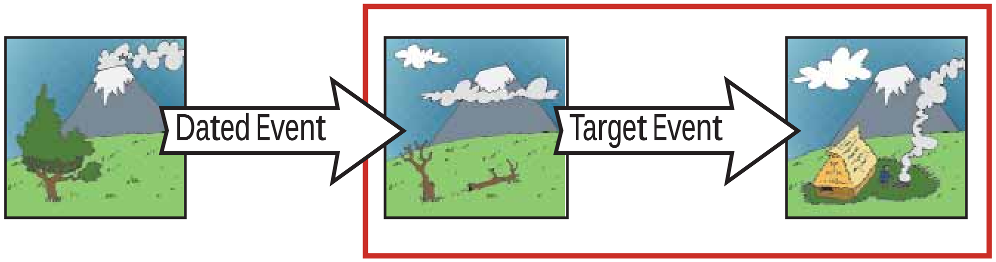


Figure 4



Student Worksheet guide

The Research Plan

Part One:

You are the head of an archaeology crew. You and your crew just returned from an excavation of a Test pit (Test Pit 1) at the Rasshua 1 site on Rasshua Island in the Kuril Island chain. After the excavation, your field assistants drew the stratigraphic column of one of the walls of the excavation. Using the drawing of the stratigraphy, you now have to answer the following questions in order to decide how you are going to establish the chronology, or the sequence of events, of this site.

Written questions:

1. Which layers can you date using ^{14}C? Why do you think so?
2. What materials would you date to find out the age of cultural occupations? Why?
3. What would you date to find out the age of Layer B?
4. What materials would you date to find out the age of Ushishir tephra (Layer C)?
5. How would you test the idea that volcanic eruptions had a devastating consequence for human occupation?

Part Two:

After you answered these questions and decided which levels you wanted to date, you sent your radiocarbon samples to a radiocarbon dating laboratory. Take a look at the table of results that they sent back. Now answer the following questions to interpret what events took place at this site and how they are related to each other in time.

Written questions:

1. Are there any dates which are out of order? How would you explain them? (**Hint:** Think back to target and dated events and human or natural activities that can disturb certain levels).
2. How long did humans occupy the site? Were there any gaps in occupation?
3. What is the age of artifact X? How did you determine it? What are the dated and target events for this sample?

Part Three:

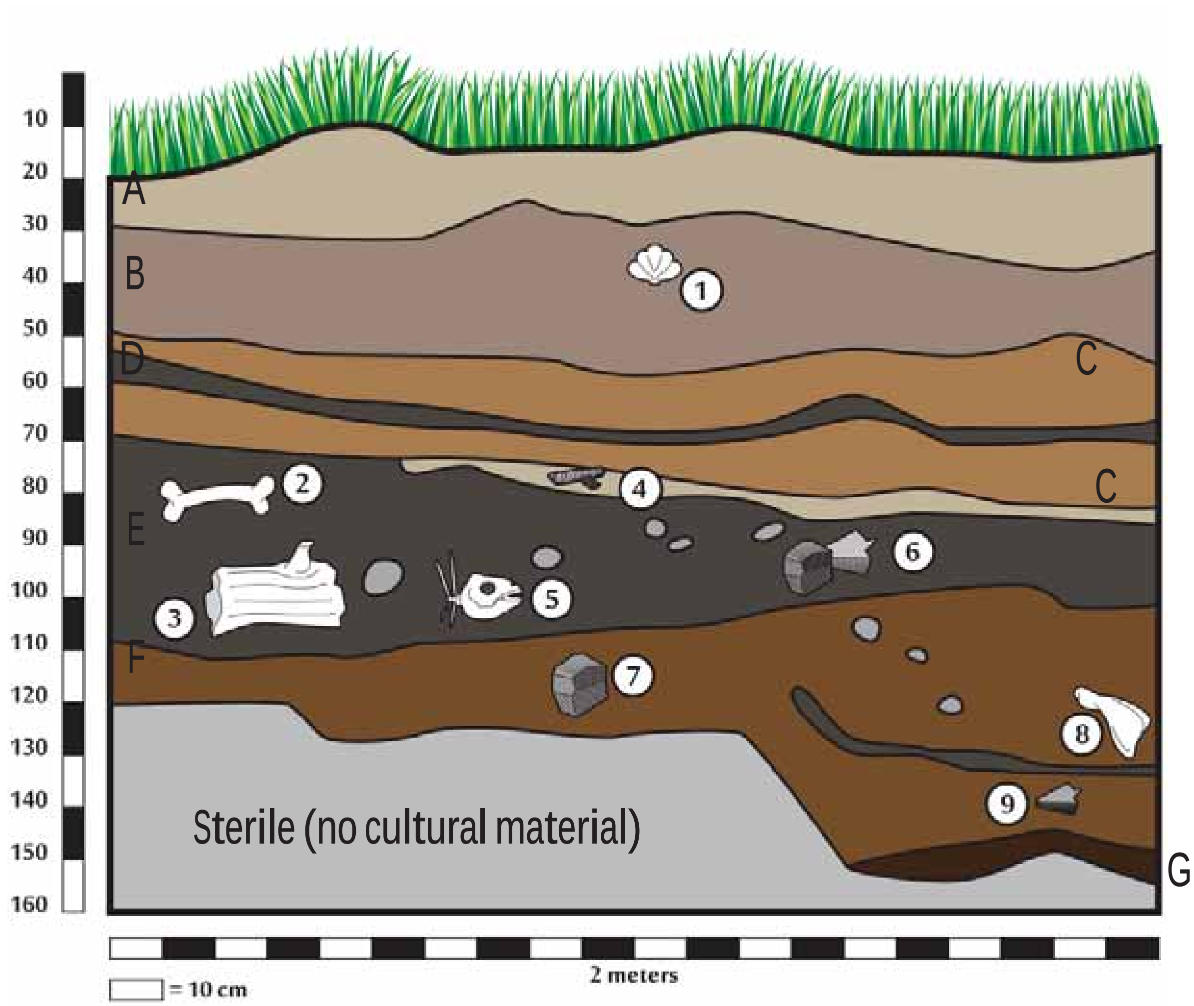
The last step in the process of archaeological analysis of a site is to write a narrative about how the layers of the site got there. This is the story about how people lived there and what events they experienced. In the space below, write the history of people at Rasshua 1 as you understand it from the dates you obtained and the stratigraphic sequence. Start from the bottom and explain how each layer formed, as well as what its chronolgical relationships are with other layers. (In other lessons in this education kit, you will learn more about the artifacts and food remains discovered at this site and will be able to better understand the everyday lives of the people who once lived here.)

Material 1

Rasshua 1 Test Pit 1 Excavation Profile

July 15, 2008

Erik Gjesfield and Molly Odell



Material 2

Results of the Radiocarbon Dating of Rasshua 1 - Test Pit 1 Samples

Site	Lab Number	^{14}C Age (years BP) reported with standard error	Material	Stratigraphic position
Rasshua 1	OS - 79668	1,950 ± 25 years BP	Shell	Position #1
Rasshua 1	OS - 79669	2,080 ± 25 years BP	Bone	Position #2
Rasshua 1	OS - 79865	2,020 ± 30 years BP	Wood	Position #3
Rasshua 1	OS - 79670	2,110 ± 25 years BP	Charcoal	Position #4
Rasshua 1	OS - 79671	2,210 ± 25 years BP	Bone	Position #5
Rasshua 1	OS - 79720	2,430 ± 25 years BP	Charcoal	Position #6
Rasshua 1	OS - 79665	2,860 ± 25 years BP	Charcoal	Position #7
Rasshua 1	OS - 79666	2,480 ± 35 years BP	Bone	Position #8
Rasshua 1	OS - 79667	2,660 ± 25 years BP	Charcoal	Position #9