

**October/November 2016 Teacher's Guide**

**Background Information**

**for**

***How SUE Became a Rock Star***

**Table of Contents**

[About the Guide 2](#_Toc461457367)

[Background Information 3](#_Toc461457368)

[References 25](#_Toc461457369)

[Web Sites for Additional Information 26](#_Toc461457370)

[More Web Sites on Teacher Information and Lesson Plans 30](#_Toc461457371)

# About the Guide

Teacher’s Guide team leader William Bleam and editors Pamela Diaz, Regis Goode, Diane Krone, Steve Long and Barbara Sitzman created the Teacher’s Guide article material.   
E-mail: [bbleam@verizon.net](mailto:bbleam@verizon.net)

Susan Cooper prepared the anticipation and reading guides.

Patrice Pages, *ChemMatters* editor, coordinated production and prepared the Microsoft Word and PDF versions of the Teacher’s Guide.   
E-mail: [chemmatters@acs.org](mailto:chemmatters@acs.org)

Articles from past issues of *ChemMatters* and related Teacher’s Guides can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains the entire 30-year publication of *ChemMatters* issues, from February 1983 to April 2013, along with all the related Teacher’s Guides since they were first created with the February 1990 issue of *ChemMatters*.

The DVD also includes Article, Title, and Keyword Indexes that cover all issues from February 1983 to April 2013. A search function (similar to a Google search of keywords) is also available on the DVD.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558. Purchase information can also be found online at <http://tinyurl.com/o37s9x2>.

# Background Information

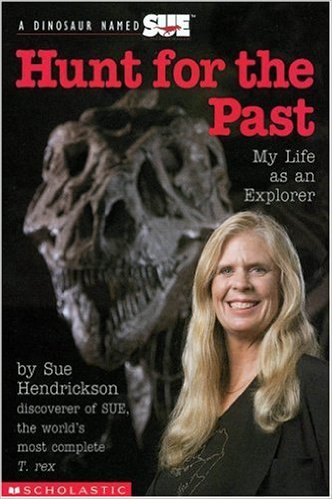
**(teacher information)**

**Sue Hendrickson**

According to her autobiography Sue Hendrickson has chosen an adventurous life, one that paved her way to paleontology and the discovery of SUE. She spent her early years in a small town in Indiana, a shy independent child who read a great deal. A strong swimmer, she won many races but detesting competition, she quit the swim team. At age 16, Sue convinced her parents to allow her to live with her aunt and uncle in Florida. She was soon bored with school, dropped out, taught herself to dive and used her swimming ability to collect and sell tropical fish to aquariums and pet stores. Her travels took her hop scotching across the country to California to live on a boat, and then back to the Florida Keys as a lobster fisherman.

Sue passed her GED in Seattle and enrolled in a marine biology program at the University of Washington. Soon she dropped this program, returned to Florida to help salvage a cargo freighter and became interested in exploring shipwrecks. On a trip to the Dominican Republic she began working with archeologists in amber mines. Here she found perfect butterflies embedded in the amber. These 23 million-year-old specimens that became one-half of the world’s total collection.

Meanwhile, Sue taught herself paleoentomology and become an expert at identifying fossilized insects. While excavating Miocene baleen whales in Peru, she met Peter Larson and joined his team from the Black Hills Institute of Geological Research based in South Dakota. The team was digging for fossils on the property of a local South Dakota rancher, Maurice Williams. August 12, 1990 was a foggy morning and the 1975 Chevy Suburban carrying the Black Hills team had a flat tire. Impatient Sue couldn’t wait for a tire change. Instead she walked to the ranch and discovered SUE. She said, “Anybody who had any idea what a fossil versus rock (looked like) would have seen it.” The Black Hills Institute, a for-profit enterprise that finds, restores and sells fossils to scientists, is housed in a little museum on the ranch belonging to Larson’s parents. Larson said, “And finding Sue, the *Tyrannosaurus rex* – here’s the anchor for our museum.”



*(*[*https://www.amazon.com/My-Life-Explorer-Hunt-Past/dp/0439271916*](https://www.amazon.com/My-Life-Explorer-Hunt-Past/dp/0439271916)*)*

In 2000, Hendrickson—the high school dropout—received an honorary Ph.D. from the University of Illinois, Chicago. Additional excerpts from Sue’s autobiography are located on these sites: <https://en.wikipedia.org/wiki/Sue_Hendrickson> and <http://www.sue-hendrickson.info/biography.asp?iframe=True>. Information on Sue’s published autobiography is given in the “References (non-Web-based information sources)” section of this Teacher’s Guide and can be purchased from Amazon.

**“When the Feds seized a *T.* *rex*”**

In January 2014, CNN Films Lionsgate introduced a documentary, “Dinosaur 13” at the Sundance Film Festival in Park City, Utah. “Dinosaur 13” tells the story of Sue Hendrickson’s discovery and the aftermath tangles involving the legal custody of SUE. In early December 2014, CNN broadcast their documentary. The film received positive reviews, such as “engrossing”, “a story of scientific discovery and petty politics” and “both awe-inspiring and tragic”. (<https://en.wikipedia.org/wiki/Dinosaur_13>) And on September 29, 2015, “Dinosaur 13” was awarded an Emmy for the News and Documentary category. (<http://cnnpressroom.blogs.cnn.com/2015/09/29/cnn-films-and-dinosaur-13-win-news-documentary-emmy-award/>)

But after the film aired, the *New York Times* labeled it a “scientific soap opera” and a group of professional academic paleontologists, The Society of Vertebrate Paleontology, issued a statement that in part said:

The film Dinosaur 13 erroneously implies that the regulations impede paleontological science by placing onerous and confusing restrictions on field collecting. Not so. Federal law embodies the same principles and ethics adopted by professional paleontologists themselves. These same principles are part of the Society’s Bylaws (Article 12, Code of Ethics). The Federal permitting process helps ensure that field collecting is well planned and professionally conducted, that the scientific context of fossils is documented, and that the fossils are placed in established research repositories with a demonstrated commitment to preserving them in perpetuity for scientific research and public enjoyment.

(<http://vertpaleo.org/the-Society/Governance-Documents/On-Dinosaur-13.aspx>)

Upon discovery of SUE, the Black Hills Institute team paid the delighted land-owner Williams $5,000 and began the arduous task of recovering more than 80% of SUE. On May 12,2002, almost two years later, the team had finally brought all the bones to their “museum” for cleaning and preserving. As they finished the delicate reclamation process by successfully separating the *T.* *rex* pelvis from its skull, FBI agents and the National Guard arrived at their door, seized SUE and many documents from the Black Hills’ office. They claimed that SUE was stolen from Federal land. To further complicate matters, before rancher Williams died in 2011, his wife said that he claimed ownership of the fossil. She said that Peter paid her husband $5,000 to disturb his land not as payment for SUE. In addition, Williams didn’t tell Larson that he was a member of the Cheyenne Tribe and his “private ranch” was on Indian Trust land, further complicating the ownership of SUE. A nasty civil dispute ensued between the Black Hills business, Williams’ wife and the Cheyenne River Sioux Tribe of South Dakota.

SUE went on Sotheby’s auction block and was sold to the Field Museum of Natural History in Chicago for an unheard of $8.3 million. Another bidder, The Smithsonian, ended up accepting a 50 year loan of a smaller *T. Rex* from the Montana Army Corps of Engineers for their new Hall of Fossils slated to open in 2019.



*“SUE,” a 41-foot-long Tyrannosaurus rex, is on permanent display at the Field Museum in Chicago*

*(Sue Ogrocki/Reuters)*

*(*[*https://www.washingtonpost.com/news/post-nation/wp/2014/12/08/dinosaur-13-broadcast-on-cnn-unearths-old-drama-over-a-t-rex-named-sue/?utm\_term=.12b5f954eb79*](https://www.washingtonpost.com/news/post-nation/wp/2014/12/08/dinosaur-13-broadcast-on-cnn-unearths-old-drama-over-a-t-rex-named-sue/?utm_term=.12b5f954eb79)*)*

As a paleontologist for the National Park Service, Vincent Santucci had been investigating fossil thefts from public land for 10 years. Black Hills, a for-profit business specializing in the excavation and preparation of fossils for sale to research paleontologists and museums, was on his watch list. Thus, the seizure of files went well beyond the problems of SUE ownership. Ultimately Larson and Black Hills were accused of international fossil theft and sale, plus related offenses. He and other employees were convicted. Larson served an 18-month prison sentence for “fossil theft, money laundering and false statements to government agencies”. Sue Hendrickson was given immunity because she was a Black Hills volunteer and the legality of SUE ownership was not involved in these accusations. Williams’ estate received $7.6 million. Sue Hendrickson was present at the 2000 unveiling of SUE at the Field Museum in Chicago. (<https://www.washingtonpost.com/news/post-nation/wp/2014/12/08/dinosaur-13-broadcast-on-cnn-unearths-old-drama-over-a-t-rex-named-sue/?utm_term=.849829ab6148>)

**Physical characteristics of *T. rex***

As the name implies, *Tyrannosaurus rex* means “king of the tyrant lizards”. *T. rex* is the largest member of the tyrannosauroidea family of huge carnivorous dinosaurs that lived during the last part of the Cretaceous Period, 85 to 65 million years ago. SUE was estimated to be approximately 28 years old at the time of death. As reported in the Emilsson/Tinnesand SUE article, Sue (Hendrickson) discovered a huge specimen, 40.5 feet long and 13 feet tall at the hips (*T-rex* did not stand erect). Scientists estimate that SUE may have weighed from 9.3 to 10.4 tons. The tyrannosauri are characterized by three-foot-long arms with two-fingered hands. Scientists doubt that they could feed themselves with these tiny limbs. Speculation remains regarding their usefulness. Strong thighs and tails, plus six-inch serrated teeth made them powerful predators. (<http://www.livescience.com/23868-tyrannosaurus-rex-facts.html>, <https://en.wikipedia.org/wiki/Sue_(dinosaur)> and <http://www.ucmp.berkeley.edu/diapsids/saurischia/tyrannosauridae.html>)

*Sue Hendrickson at the unveiling of T. Rex “SUE”*

*(*[*http://www.cnn.com/2014/12/11/us/dinosaur-fossil-tyrannosaurus-rex-sue/*](http://www.cnn.com/2014/12/11/us/dinosaur-fossil-tyrannosaurus-rex-sue/)*)*



Researchers now challenge the assumption that the three-foot-long arms of *T. rex* were useless. A 1990 study by Matthew Smith of the Museum of the Rockies at the University of Montana, Bozeman, suggests that evidence shows that the arms of *T. rex* were short but very powerful. The thickness and size of *T. rex* bicep muscle was estimated from the large patterns left by attached muscle in the arm bones. These impressions suggest that the dinosaur had the ability to lift 400 pounds. In comparison, CAT scans of human athletes show that the bicep can hold only 19 pounds. Further, the dinosaur’s hands had two opposing claws (a digit and a finger) that could act like meat hooks to grasp and trap struggling prey.

(<http://www.nytimes.com/1990/07/02/us/researchers-challenge-ideas-on-dinosaur-arms.html>)

Approximately 30 *T. rex* fossils have been found in Montana, Texas, Utah and Wyoming, as well as in Canada and Mongolia. In July 1998 while excavating around a *T. rex* discovery in Saskatchewan, Canada, an enormous piece of fossilized dung was found. Its size suggests that it was much too large to have come from a smaller dinosaur. In addition, the specimen contained fossilized bones from a plant-eating dinosaur. To paleontologists, this suggests the last meal of a carnivorous *T. rex.* (<http://www.enchantedlearning.com/subjects/dinosaurs/news/Trexdung.shtml>)

Until recently, the debate remained as to whether *T. rex* was a predator or scavenger. “Physical evidence of predatory behavior in *Tyrannosaurus rex*” was published in the *Proceedings of the National Academy of Sciences* (PNAS) on May 21, 2013. The authors note that many fossils contain puncture wounds and teeth drag marks but it is difficult to predict the type of predator that inflicted this damage. In a fossil from the Hell Creek Formation of South Dakota, a *T. rex* tooth crown was found embedded in the tail of a giant duck-billed dinosaur, a plant-eating hadrosaurid. The tooth was surrounded by vertebrae bone growth, suggesting that the duck survived the *T. rex* assault. This strengthened evidence of the predatory nature of *Tyrannosaurus rex*. The confrontation occurred between two living animals. “Moreover, the position of the injury—the tail—suggests that *T. rex* could possibly have engaged in pursuit predation.” The full text of their work is available at <http://www.pnas.org/content/110/31/12560.full>.

Below is a classification scheme for *T. rex*. Students may have studied this in their biology classes.

|  |  |
| --- | --- |
| [**CLASSIFICATION**](http://www.enchantedlearning.com/subjects/dinosaurs/dinoclassification/Classification.html)**:** | * **Kingdom** Animalia (animals) * **Phylum** Chordata (having a hollow nerve chord ending in a brain) * **Class** [Archosauria](http://www.enchantedlearning.com/subjects/dinosaurs/glossary/Archosaur.shtml) ([diapsids](http://www.enchantedlearning.com/subjects/dinosaurs/glossary/indexdi.shtml) with socket-set teeth, etc.) * **Order** [Saurischia](http://www.enchantedlearning.com/subjects/dinosaurs/dinoclassification/Saurischian.html) - lizard-hipped dinosaurs * **Suborder** [Theropoda](http://www.enchantedlearning.com/subjects/dinosaurs/glossary/Theropod.shtml) - bipedal carnivores * Tetanura - advanced theropods * **Infraorder** [Coelurosauria](http://www.enchantedlearning.com/subjects/dinosaurs/glossary/Coelurosaur.shtml) - lightly-built fast-running predators with hollow bones and large brains * **Superfamily** Maniraptoriformes - advanced coelurosaurs with a fused wrist bone * **Family** Tyrannosauroidea - huge predators with small arms and two-fingered hands (the third finger was very tiny). Tyrannosaurids include [T. rex](http://www.enchantedlearning.com/subjects/dinosaurs/dinos/trex/), [Albertosaurus](http://www.enchantedlearning.com/subjects/dinosaurs/dinos/Albertosaurus.shtml), Alectrosaurus, Alioramus, Chingkankousaurus, Daspletosaurus, [Eotyrannus](http://www.enchantedlearning.com/subjects/dinosaurs/facts/Eotyrannus/), Gorgosaurus, Nanotyrannus, Prodeinodon, Tarbosaurus, etc. * **Genus** [Tyrannosaurus](http://www.enchantedlearning.com/subjects/dinosaurs/dinos/trex/) * **Species** *T. rex* (type species named by Osborn, 1905) |

*(*[*http://www.enchantedlearning.com/subjects/dinosaurs/facts/Trex/print.shtml*](http://www.enchantedlearning.com/subjects/dinosaurs/facts/Trex/print.shtml)*)*

***T. rex* becoming a giant fossil—burial**

How did SUE develop into the Field Museum’s “centerpiece”? The chance of becoming a fossil is very slim; some say one million to one! Fossil formation is a long, slow environmentally determined process. The conditions of death and the environment where it occurred are essential for preservation. A good *T. rex* specimen must die with healthy, intact bones at a location where it is gently buried by sediments, such as mud in North America, or sand in Mongolian deserts. Death and covering must occur quickly, before the bones decompose or are picked apart, scattered and eaten by other animals. Surrounded by soft sediment, the carcass is protected from scavengers, but decomposers are free to work on all except the hard bones. (<http://www.scientificamerican.com/article/what-are-the-odds-of-a-de/>)

Climate and soil conditions have to be correct: Fossil formation did not occur when the dinosaur died in a jungle, where extremely moist, acidic soil would exacerbate quick decomposition of bones as well as soft tissue. In addition, raging rivers and strong winds break bones before they can be gently covered for slow decomposition.

***T. rex* becoming a giant fossil—decomposition**

Initially, gentle decomposition is primarily the work of fungi and bacteria. Later, beetles, flies, maggots, worms and their larvae feed on the soft tissue. Digestive enzymes released at death expedite breakdown of materials and digest dead cells.

(<https://www.reference.com/science/petrified-fossils-form-2ef7f679ac18d768>)

When animal death occurs, organic material decomposes, but inorganic substances such as bone remain. As stated in the Emilsson/Tinnesand SUE article, within hours of death, iron, calcium and digestive enzymes are released. Since the “life” of bone depends upon oxygenated blood, when it stops flowing:

* iron rich hemoglobin is leaked from collapsing red blood cells.
* muscle contraction sends impulses down the spinal cord reaching the neuromuscular junction and acetylcholine is released.
* acetycholine causes membrane channels to open allowing sodium ions to be released and calcium ions to enter pores in the bone.
* digestive enzymes are released to catalyze these processes.

(<http://serendip.brynmawr.edu/biology/b103/f02/web2/wcarroll.html>)

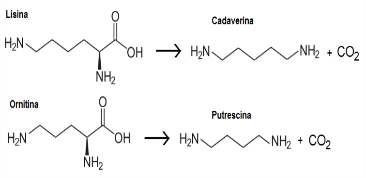
(<http://science.howstuffworks.com/environmental/earth/geology/fossil3.htm>)

Within hours after an animal’s death, putrid gases cadaverine and putrescine, along with compounds related to hydrogen sulfide, are released from the body. Insects and other scavengers attracted by their odor rush in to aid the decomposition process. First identified in 1885 by the German chemist Ludwig Brieger, these compounds have similar structures. Both are diamines, which means that they contain two amino groups (–NH2). The chemical name for putrescine is tetramethylenediamine; the IUPAC name is butane-1,4-diamine; the molecular formula is: NH2(CH2)4NH2. The chemical name for cadaverine is pentamethylenediamine; the IUPAC name is pentane-1,5-diamine; the molecular formula is: NH2(CH2)5NH2.

The structural and ball-and-stick formulas below show the four methyl groups bracketed by two amino groups for putrescine and the similar amino brackets for the five methyl groups on the cadaverine structure.

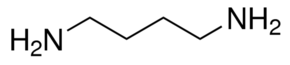
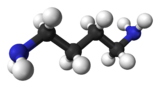
*Cadaverine*

*(*[*https://en.wikipedia.org/wiki/Cadaverine*](https://en.wikipedia.org/wiki/Cadaverine))

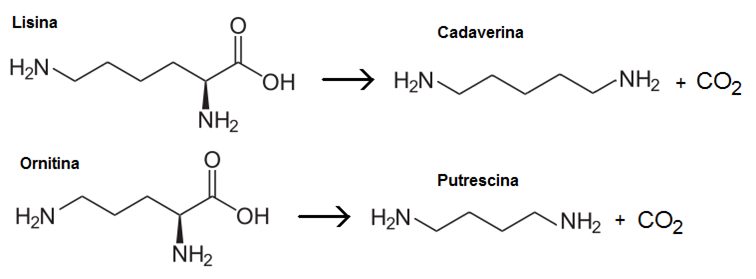


*Putrescine*

*(*[*https://en.wikipedia.org/wiki/Putrescine*](https://en.wikipedia.org/wiki/Putrescine)*)*



These unpleasant-smelling compounds are products of the breakdown of fatty acids present in the tissue of dead animals. During this process, putrescine is synthesized from the amino acid arginine and cadaverine, from lysine. Both arginine and lysine are alpha-amino acids used by the body in the synthesis of proteins.



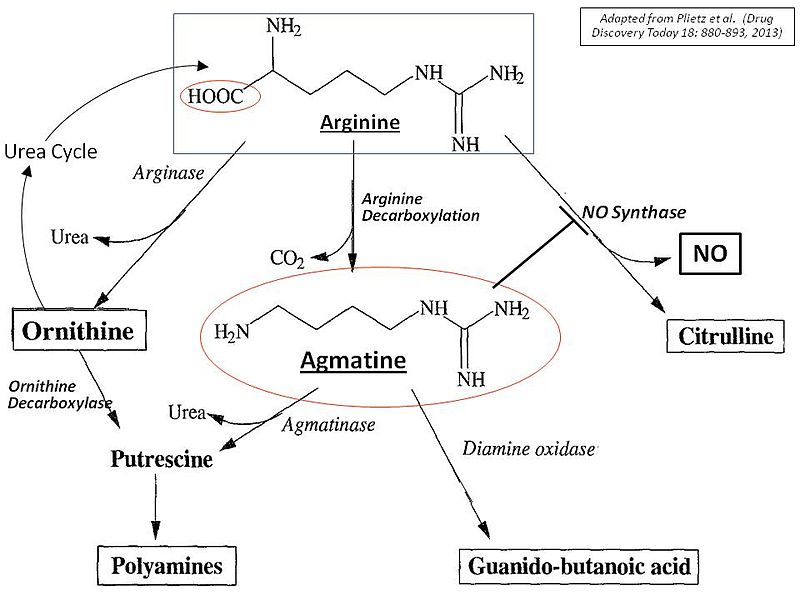
*(*[*https://cienciaetecnologias.com/en/quimica-dos-fedores-mal-cheiro-quimica/*](https://cienciaetecnologias.com/en/quimica-dos-fedores-mal-cheiro-quimica/)*)*

Note: The illustration above is from a Spanish publication. “Lisina” is lysine in English and “ornitina” is the amino acid ornithine in English. As shown in these reactions, cadavarine can be produced through the process of decarboxylation, removal of the carboxyl group   
(–COOH) from the amino acid lysine; in a similar process putrescine is a decarboxylation product of arginine or ornithine. ([http://jb.asm.org/contehttp://science.howstuffworks.com/environmental/earth/geology/fossil3.htmnt/163/3/933.short](http://jb.asm.org/content/163/3/933.short))

Cadaverine and putrescine are not only signs of death, they are also produced in living bodies, where their odor may be detected in urine, halitosis, sweat, rancid butter and strong cheese such as blue or feta. The production of putrescine involves two different pathways; both begin with arginine as described and illustrated below:

* In one pathway, arginine is converted into [agmatine](https://en.wikipedia.org/wiki/Agmatine), with a reaction catalyzed by the enzyme [arginine decarboxylase](https://en.wikipedia.org/wiki/Arginine_decarboxylase) (ADC); then agmatine is transformed into   
  [N-carbamoylputrescine](https://en.wikipedia.org/w/index.php?title=N-carbamoylputrescine&action=edit&redlink=1) by [agmatine imino hydroxylase](https://en.wikipedia.org/wiki/Agmatine_deiminase) (AIH). Finally,   
  N-carbamoylputrescine is converted into putrescine.
* In the second pathway, arginine is converted into [ornithine](https://en.wikipedia.org/wiki/Ornithine) and then ornithine is converted into putrescine by [ornithine decarboxylase](https://en.wikipedia.org/wiki/Ornithine_decarboxylase) (ODC).

(<https://en.wikipedia.org/wiki/Putrescine>)



*The production of putrescine*

*By Gmgilad - Own work, CC BY-SA 3.0, (*[*https://commons.wikimedia.org/w/index.php?curid=33087914*](https://commons.wikimedia.org/w/index.php?curid=33087914)*)*

Cadaverine is produced by the decarboxylation and the release of CO2 from the amino acid lysine. Lysine decarboxylase (LDC) is the catalyst for the reaction below:

[Cadaverine synthesis.svg](https://en.wikipedia.org/wiki/File:Cadaverine_synthesis.svg)

*(*[*https://en.wikipedia.org/wiki/Polyamine*](https://en.wikipedia.org/wiki/Polyamine)*)*

**Cadaver Dogs**

A dog’s sense of smell is estimated to be one thousand to ten thousand times greater than humans, making their work in major disasters and crime solving extremely valuable. Cadaver dogs are trained to pick up the scent of decomposing human tissue, blood and bone, and to ignore scents emitted by bodies of other decaying animals, as well as the odors of other chemicals. Labrador retrievers and German shepherds are usually trained as cadaver dogs, but handlers say that good hunt drive, strong nerves and confidence are more important than breed.

As puppies, cadaver dogs are trained to ignore noise, including crashing, burning buildings and sirens, and to maneuver easily amidst debris and general chaos. A square of carpet contaminated from contact with a corpse within 3 hours of death can be used for scent detection training. These dogs hasten the process of finding bodies amongst the rubble following disasters such as tsunamis, earthquakes, forest fires and avalanches. They are also invaluable in crime detection, especially when the victim’s body is hidden.

This cadaver dog is searching for human remains in homes burned by the June 2016 wildfire in Kern County, California. Two people died while trying to escape this fire.



*A cadaver dog searching for survivors*

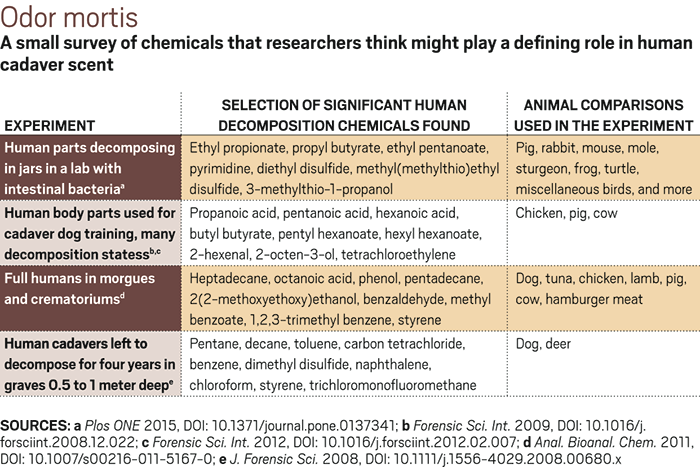
*(Gina Ferazzi Los Angeles Times 6/27/16)*

*(*[*http://www.latimes.com/topic/disasters-accidents/fires/wildfires/T03004001-topic.html*](http://www.latimes.com/topic/disasters-accidents/fires/wildfires/T03004001-topic.html)*)*

A well trained dog can detect as little as 15 mg of human remains and can pick up the scent as far as one kilometer from the body. Since molecules migrate through the environment, the dog may detect the scent at various places. By studying the pattern of spots identified by a dog, the point source (human body) can be located as the area of most concentration with other areas radiating from it.

(<http://cen.acs.org/articles/94/i14/Scientists-search-deaths-aroma.html>)

Identification of the odor emitted by human decomposition is not a simple process. In addition to cadaverine and putrescine, close to 500 other chemicals are released during the various stages of microbial degradation. The mix of these chemicals depends upon the time following death, the rate of decomposition, and the physical environment surrounding the corpse. Some of these chemicals are identified in the table of “Odor Mortis” (smell of death) shown below:



*(*[*http://cen.acs.org/articles/94/i14/Scientists-search-deaths-aroma.html*](http://cen.acs.org/articles/94/i14/Scientists-search-deaths-aroma.html)*)*

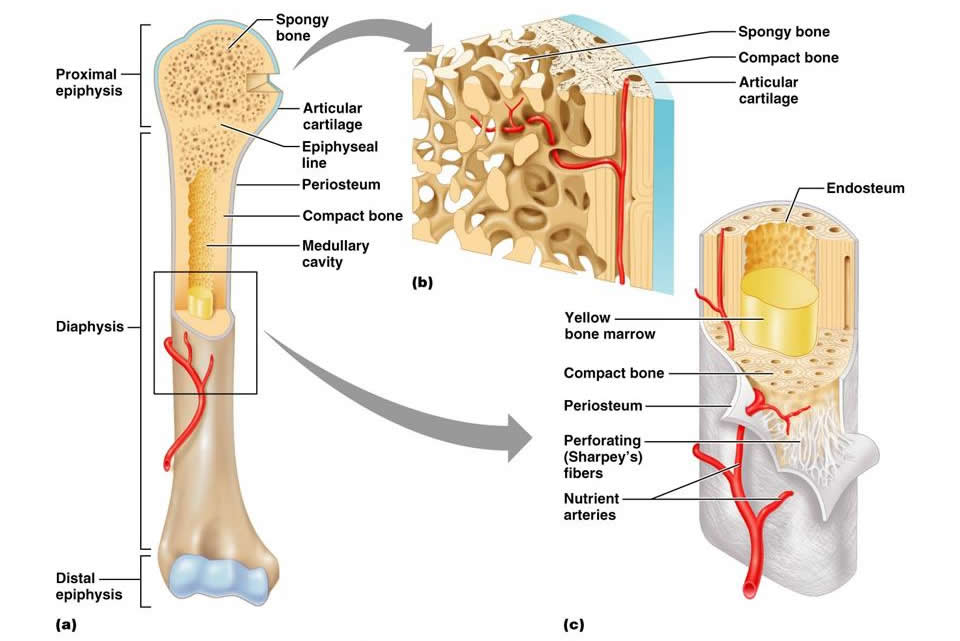
Although researchers continue their quest to identify and characterize these compounds in an effort to develop instruments to detect the odors of human remains, their efforts fall short of achieving the sensitivity and selectivity of cadaver dogs. Additionally, one of the primary limitations of this research is the inability to obtain samples of human decomposition and/or human tissues that can be legally decomposed for chemical study in the laboratory.

***T. rex* becoming a giant fossil~~—~~anatomy of bone**

As shown in the Emilsson/Tinnesand SUE article, the bones of vertebrates like SUE are surrounded by a compact outer layer. The “spongy” internal portion of the bone is porous and holds the arteries that transport nutrients while the animal is living.

In the diagram below, (a) and its enlarged wedge (b), show bone with a dense, smooth textured outside that resists compression and an inside that provides the area and channels for nerve connections and blood flow. In (c), yellow bone marrow occupies the central cavity of the bone.

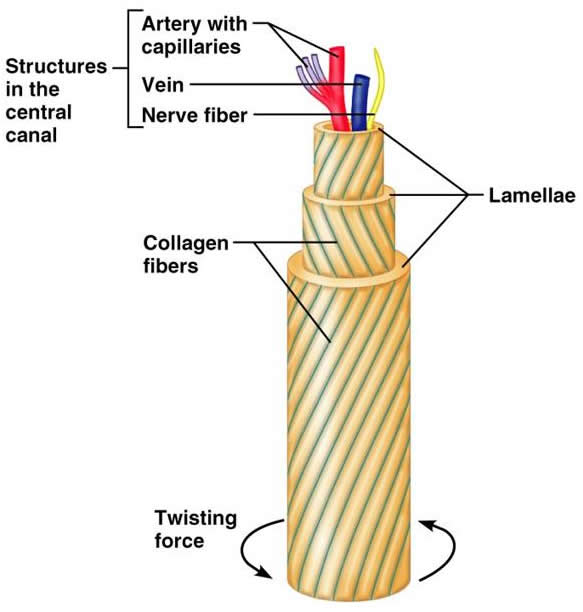
Bone marrow is soft spongy tissue containing many blood vessels and capillaries. There are two types of bone marrow. The yellow produces fat, cartilage and new bone. Red bone marrow produces both red and white blood cells, as well as blood platelets. A low red-blood-cell count indicates anemia; low white blood cell count leads to infections and may suggest leukemia; and a low platelet count is related to excess bleeding. A bone marrow transplant can be performed to introduce healthy donor blood cells as replacements for cells that have been damaged. In infants red bone marrow is found in most bones in the body to satisfy the high need for red blood cells to carry oxygen to developing tissues. As people age, much of the red marrow is replaced by yellow. (<http://www.conversantbio.com/blog/red-bone-marrow-vs.-yellow-bone-marrow-what-is-the-difference>)



*Bone texture*

(<http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html>)

**Bone texture**

 Concentric tubes (lamellae) lie within the spongy portion of the bone. They form around a central “canal” to provide space and a passageway for veins and nerves, as seen in the illustration to the right. Collagen is fibrous protein material that provides bone strength and cushioning.

**Microscopic anatomy of a bone**

About 20% of human bones are “spongy”. Like the name implies, microscopically they resemble a sponge, primarily solid material filled with tiny pores. These pores provide life to the bone. They are filled with blood vessels, nerves and marrow, the soft tissue birth place for stem cells.



*Illustration of compact bone structure*

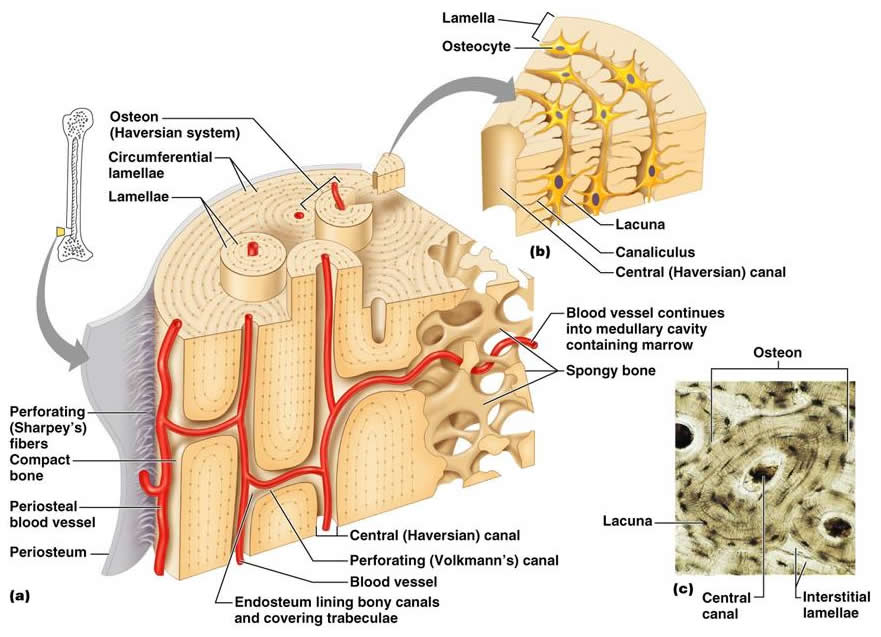
*(*[*http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html*](http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html)*)*

*Microphotograph of sponge-like structure of bone*

*(*[*https://askabiologist.asu.edu/bone-anatomy*](https://askabiologist.asu.edu/bone-anatomy)*)*

The diagram of the bone’s interior, below, is designed to illustrate the structure of the spongy tissue of bone.

1. The lamellae are layers of concentric tubes of bone that surround the central canal, to form a secure place where blood vessels and nerves thread through the bone.
2. The organic part of the bone, the osteoid, is shown in the diagram below. Star shaped osteocytes are connected to each other by long cytoplasmic extensions that provide an avenue for exchange of nutrients and waste. As these organic structures become saturated with inorganic mineral material, they adhere to adjacent bones cells that gradually become new bone.
3. This diagram shows a cross section of spongy tissue.



*Interior structure of bone*

*(*[*http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html*](http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html)*)*

***T. rex* becoming a giant fossil—permineralization**

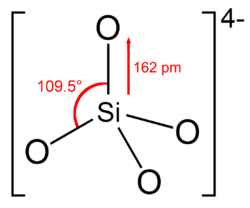
Permineralization is the term used to define the process of fossilization, wherein living tissues are replaced by minerals. First the living tissue is decomposed, leaving space within the bony structure. This provides a path for ions to migrate from damp ground, lakes and oceans. They seep in and fill the open areas. As water laden with dissolved minerals evaporates, ionic compounds with low solubility such as calcium carbonate and calcium phosphate are deposited. Thus formed, fossils retain the shape of the original bones but are denser, due to the ionic crystals occupying their pores. In addition, the process of permineralization hardens the buried bones, preventing breakage by compression from the weight of covering sediments.

The University of California, Berkeley Museum of Paleontology distinguishes between three subgroups of permineralization based on the environment at the time of their permineralization:

* Silicification—The mineral silica precipitates on cells and cell structures as it moves through the animal’s internal structure. Silica comes from rocks and volcanoes, thus indicating the type of environment at the time of death. The silica anion combines with cations in the bone mineral to form a gel that dehydrates with time. Silicification results in much internal structure detail.

*Basic (ortho-)silicate oxoanion  
(SiO44-) structure*

*(*[*https://en.wikipedia.org/wiki/Silicate*](https://en.wikipedia.org/wiki/Silicate)*)*



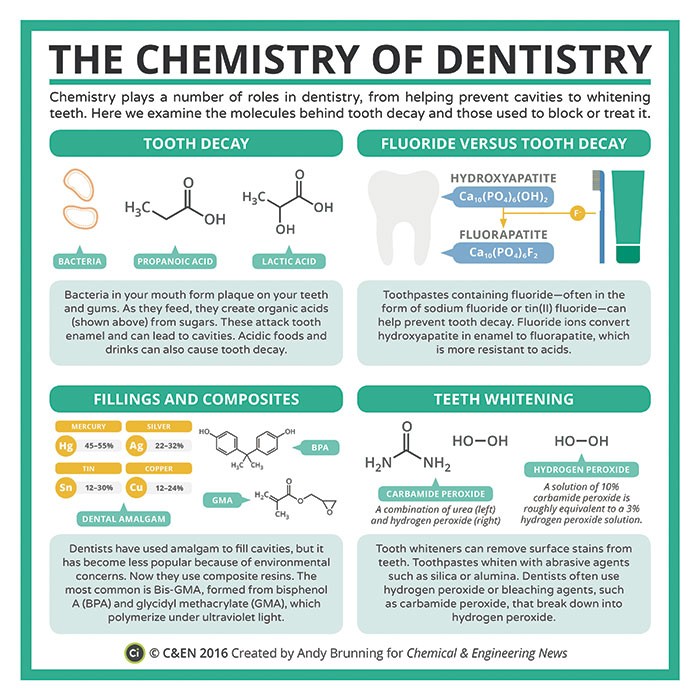
* Pyritization—Pyrite is iron sulfide (FeS2). When organic matter decomposes, sulfides are released that readily combine with iron cations dissolved in water. Pyrite easily replaces carbonate compounds in the shells of sea animals. Pyritization usually indicates that the animal was buried in a marine environment or possibly buried in clay.
* Carbonate mineralizations—Calcium and magnesium carbonates form round balls in marine and acidic peat environments. Fine cellular detail is present in the fossil that remains within the ball.

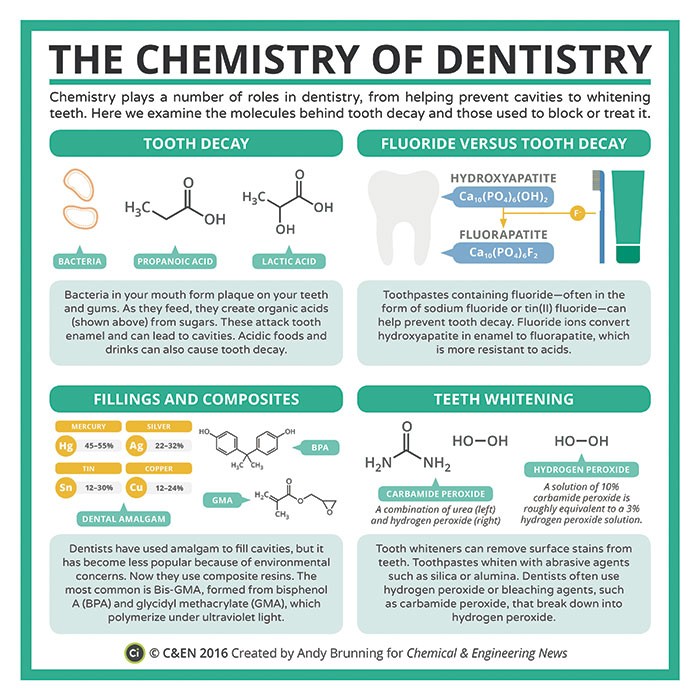
(<http://www.ucmp.berkeley.edu/paleo/fossilsarchive/permin.html>)

The chemical composition of living bone lends itself to permineralization. By mass, the living bone of an adult human is composed of approximately 25% water, 10% collagen (fibrous protein material) and 65% bone mineral along with small amounts of inorganic salts. This bone mineral contains 99% of the calcium and 85% of the phosphorous found in the body. The chemical formula for hydroxyapatite in the Emilsson/Tinnesand SUE article shows a Ca:P mole ratio of 5:3 (1.67); the actual ratio in adult bone mineral ranges from 1.37–1.87. The University of Cambridge reports that these ratios differ because actual bone mineral is more complex than hydroxyapatite. The structure of bone mineral contains additional ions including silicon, carbonate, bicarbonate, magnesium and zinc. (<http://www.doitpoms.ac.uk/tlplib/bones/structure.php>) (<https://depts.washington.edu/bonebio/ASBMRed/structure.html>)

Hydroxyapatite is formed geologically under high temperatures and pressures. Laboratory procedures have been designed to produce synthetic hydroxyapatite using high temperature and pressure to mimic the natural process. Since hydroxyapaptite can be dissolved and absorbed in the body, it makes it a good choice for bone and teeth repair. A synthetic paste of a hydroxyapatite composite can be used to fill tooth cavities. Unlike the traditional dental method that requires removal of natural, healthy tooth enamel to prepare the area for insertion and adhesion of metal or resin, the hydoxyapaptite composite can be directly inserted into the (cleaned) cavity without the loss of healthy enamel. (<http://www.sciencedirect.com/science/article/pii/0142961291901303>)

*Chemical and Engineering News* publishes “Periodic Graphics” in some issues. This page shows the substitution of fluoride ions in some toothpastes and water systems for hydroxide ions. The resulting fluorapatite’s resistance to acids helps prevent tooth decay.



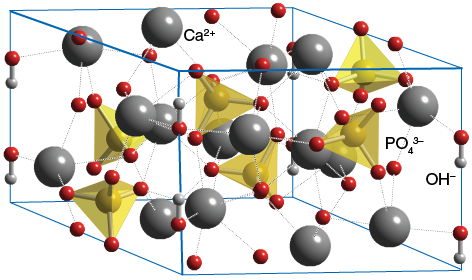


Created by Andy Brunning for *Chemical and Engineering News*

(<http://cen.acs.org/articles/94/i24/Periodic-Graphics-chemistry-dentistry.html>)

To repair damaged bone, engineers must use biocompatible materials that support new bone formation. Success has been achieved in filling a two- by three-centimeter hole in the tibia of a rabbit. When hydroxyapatite-tricalcium phosphate was inserted with osteoblast (bone forming) cells, new bone formed. (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3614259/>)

Note the amount of open space available and the large surface area shown in the three-dimensional structure of a hydroxyapatite crystal below. This structure is ideally suited for permineralization by cation exchange.



*Crystalline structure of hydroxyapatite*

[*http://www.chemtube3d.com/solidstate/SShydroxyapatite.htm*](http://www.chemtube3d.com/solidstate/SShydroxyapatite.htm)

During fossilization the bone mineral crystal undergoes continual exchange of ions with its environment. This alteration or replacement of ions in the hard parts of the original bone, by minerals such as calcite, silica, pyrite and hematite, occurs slowly. Note that pyrite and hematite both contain iron, but hematite is the more stable mineral. In a pyrite crystal, sulfur has a -1 charge so the iron is Fe2+, while in hematite the ion is Fe3+ creating a more stable situation.

**Minerals involved in fossilization**



*Calcite—calcium carbonate (CaCO3)*

*(*[*http://www.dakotamatrix.com/mineralpedia?page=2&name=C*](http://www.dakotamatrix.com/mineralpedia?page=2&name=C)*)*



*Silica—silicon dioxide (SiO2)*

*(*[*http://geomaps.wr.usgs.gov/parks/rxmin/mineral.html*](http://geomaps.wr.usgs.gov/parks/rxmin/mineral.html)*)*



*Pyrite—iron(II) oxide (FeS2)*

*(*[*https://www.amazon.com/s/ref=nb\_sb\_ss\_i\_5\_6?url=search-alias%3Daps&field-keywords=pyrite+crystal&sprefix=pyrite%2Caps%2C272&rh=i%3Aaps%2Ck%3Apyrite+crystal*](https://www.amazon.com/s/ref=nb_sb_ss_i_5_6?url=search-alias%3Daps&field-keywords=pyrite+crystal&sprefix=pyrite%2Caps%2C272&rh=i%3Aaps%2Ck%3Apyrite+crystal)*)*



*Hematite—iron(III) oxide (Fe2O3)*

*(*[*http://www.trinityminerals.com/elba/hemspc.shtml*](http://www.trinityminerals.com/elba/hemspc.shtml)*)*

***T. rex* becoming a giant fossil—surface exposure**

While permineralization is occurring, the fossilizing material is being continuously covered and compacted by additional layers of sediment. After millions of years, the fossil is completely formed. Meanwhile the earth’s continental plates are moving and crashing into one another. These collisions push the layers of sediment up as mountains are formed and former sea floors are lifted, exposing lower layers of sediment with their fossilized dinosaurs. Finally, erosion from wind and rain exposes the fossil.

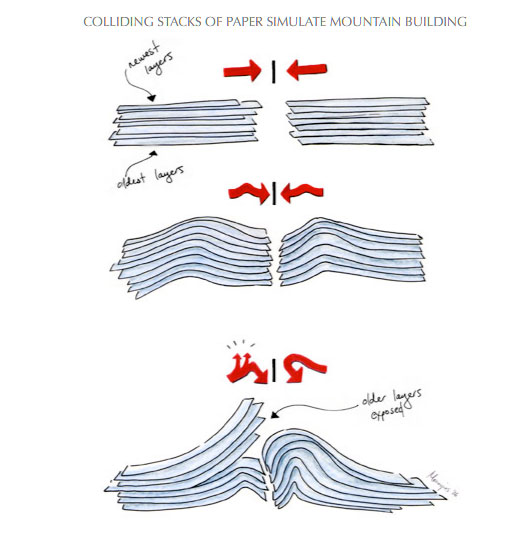
The University of Chicago fossil education program uses a diagram to model the surfacing of a *T. rex* fossil. They explain the three steps involved in constructing this model, corresponding to those shown in the diagram below:

**[Step One:]** Imagine that the layers of sediment covering our fossil are sheets of paper that keep stacking up. Now imagine your stack of paper gets rammed by another stack of paper. The layers are going to buckle and the first sheets of paper you laid down, were hidden from view, will be pushed up and visible at the surface now.

**[Step Two:]** The same thing happens when continents collide. All those layers of sediment get bent out of shape as the continents shift around and bump into each other. Older layers of sediment that were previously buried deep in the earth get pushed to the surface.

**[Step Three:]** Then over the course of millions of years, water wears away at the rock, and if we’re lucky enough for those layers to contain fossils, then it’s only a matter of going out and finding them!

(<http://tiktaalik.uchicago.edu/fossils101.html>)



*(*[*http://tiktaalik.uchicago.edu/fossils101.html*](http://tiktaalik.uchicago.edu/fossils101.html)*)*

**Dinosaur extinction**

Dinosaurs, as well as all land animals weighing over approximately 55 pounds, became extinct during at the boundary between the Cretaceous and Tertiary geologic time Periods. This is called the K/T mass extinction. K stands for kreide (the German word for chalk), describing the layer of chalky sediment at the end of the Cretaceous Period, and T is for the Tertiary Period.

 At right is a map of North America during the late Cretaceous era. Note that the large Western Interior Seaway split the continent. *T. rex* fossils are found in Laramidia, the western section, from Alaska to Mexico. Fossil evidence shows that *T. rex* shared this region with other dinosaurs.

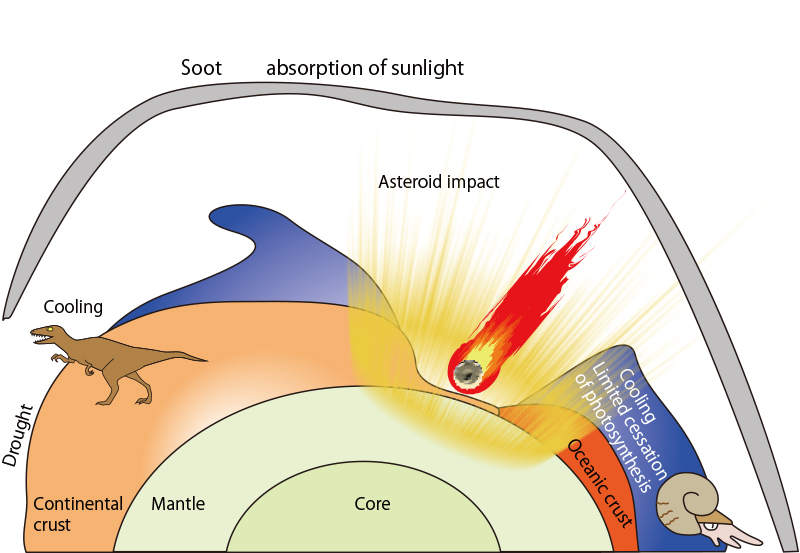
*Image by the U.S. Geological Survey*

*(*[*http://www.fossilguy.com/gallery/vert/dinosaur/tyrannosaurus/tyrannosaurus.htm*](http://www.fossilguy.com/gallery/vert/dinosaur/tyrannosaurus/tyrannosaurus.htm)*)*

Numerous theories persist to explain the death of so many animals. Some are silly, such as “mammals ate all the dinosaur eggs” or “dinosaurs ate poisoned weeds and killed each other”; others are backed by at least some scientific evidence. Scientific theories have been categorized as “intrinsic” or “extrinsic”. Intrinsic models are those that involve dramatic earth changes such as volcanoes or earthquakes. Extrinsic refers the bombardment of earth by huge objects from outer space. All scientists seem to agree that, whether the cause was intrinsic or extrinsic, climate change severe enough to eliminate food sources was probably involved. (<http://www.ucmp.berkeley.edu/diapsids/extinctheory.html>)

Kunio Kaiho, a paleontologist at Tohoku University, Japan, and his team studied the site where the enormous Chicxulub asteroid hit the coast of the Yucatan Peninsula about 66 million years ago. Chicxulub, estimated to be 10 km wide, created a gigantic crater with a diameter of 180 km and a depth of 12 km. Kaiho’s team collected and analyzed samples of the sediment layer representing the K/T boundary from Haiti (near the chicxulub impact) and from Spain. They found a layer corresponding to this Period that is primarily composed of organic molecules burned when the asteroid hit. The assumption is that this material was emitted during the impact of the asteroid with a huge oil field in the Yucatan. In data released in July 2016, they calculated that the massive amount of soot arising from the burning of this material would block 85% of the sun from the Earth. Without the sun’s energy, photosynthesis in the ocean would cease for two years; rain would be blocked causing severe drought; and global cooling would occur. The team hypothesized that this drastic change in climate was a major cause of dinosaur extinction. Further extinction of animals weighing 55 pounds or more eventually led to macroevolution and the emergence of the human species. (<http://www.tohoku.ac.jp/en/press/soot_may_have_killed_dinosaurs.html>)

Below is a model developed by Japan’s Meteorological Research Institute to represent the climate change resulting from massive amounts of soot blocking the sun at the end of the Cretaceous Period (the K/T boundary).



*Global climate change caused by soot aerosol at the K-Pg boundary*

*Journal: Scientific Reports DOI:* [*10.1038/srep28427*](http://www.nature.com/articles/srep28427)

*(*[*http://www.tohoku.ac.jp/en/press/soot\_may\_have\_killed\_dinosaurs.html*](http://www.tohoku.ac.jp/en/press/soot_may_have_killed_dinosaurs.html)*)*

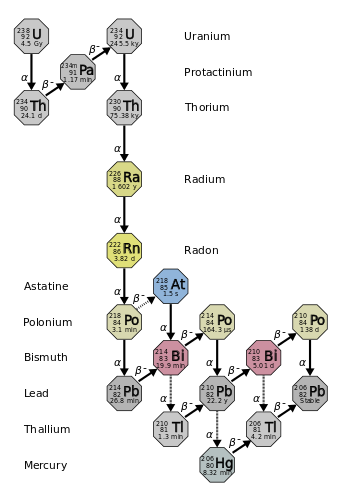
**Fossil dating**

While living, organisms constantly consume radioactive carbon-14 (C-14), because during photosynthesis, plants use C-14 from atmospheric carbon dioxide to produce glucose. As the animals consume plants, the C-14 undergoes natural radioactive beta decay to nitrogen-14 (N-14). But the living animals continue to replace C-14 by eating more plants and/or animals. This maintains a constant ratio between C-14 and nonradioactive C-12. At death, bodies no longer take up C-14. While the amount of C-12 stays the same, C-14 continues to decay, decreasing the 14C/12C ratio. This relationship can be used to estimate the age of once living organic material and can date carbon-containing material up to 45,000 to 55,000 years old. Now, with modern mass spectroscopy, the limit is extended to 100,000 years. Since the half-life of C-14 is 5,730 years, theoretically no C-14 would remain in the bones of a dinosaur that lived 65 million years ago. Thus the age of dinosaurs could not be estimated using C-14 dating.

(<http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/cardat.html>)

Instead, the radioactive decay of uranium to lead (U–Pb) is used to date rocks. The diagrams below show that radioactive U-238 decays to stable Pb-206 and U-235, to Pb-207.   
U-238 has a half-life of 4.47 billion years; the half-life of U-235 is 704 million years. Uranium undergoes radioactive decay until only lead remains. Since the two uranium isotopes decay at different rates, they act like a cross-check to validate the estimation of the age of rocks. U–Pb dating can be used to determine the age of the sediment and rocks surrounding fossil bones. The assumption is made that the sediment indicates the age of the fossil within its midst. (<http://study.com/academy/lesson/radioactive-dating-methods-uses-and-limits-of-radioactive-decay-as-a-dating-tool.html>)

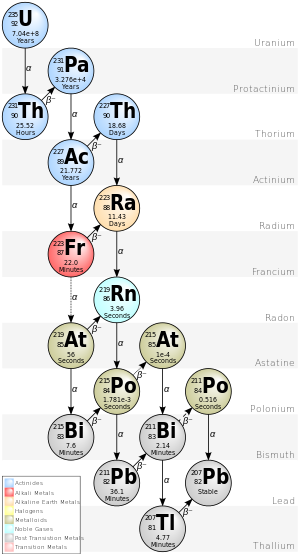
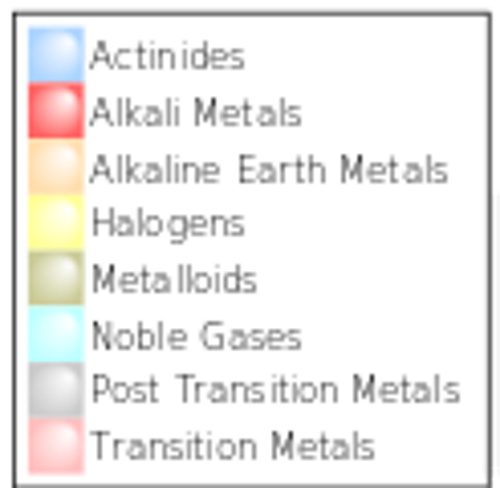
(<https://en.wikipedia.org/wiki/Decay_chain>)



*U-238 Decay Chain*

*By User:Tosaka - File:Decay chain(4n+2, Uranium series).PNG, CC BY 3.0,*

*(*[*https://commons.wikimedia.org/w/index.php?curid=33293646*](https://commons.wikimedia.org/w/index.php?curid=33293646)*)*



*U-235 Decay Chain*

*Diagram above by Edgar Bonet - Own work, CC BY-SA 3.0,*

*(*[*https://commons.wikimedia.org/w/index.php?curid=30259749*](https://commons.wikimedia.org/w/index.php?curid=30259749)*)*

During the years between *T. rex*’s death and current U–Pb dating analysis of surrounding sediments, geological forces such as collisions between plates and uplifts by volcanoes may have caused fossils to move away from the original material that buried them. This may invalidate the use of data from U–Pb radiometric dating on sediments as a tool to estimate the age of a fossil. To avoid this problem, scientists have employed U–Pb ratio techniques on minute particles of dinosaur bone removed by laser. Little uranium is present in living material so this can be used as a baseline. When permineralization begins following death, uranium from rocks and soil is incorporated into the bone mineral along with other ions. Thus, the radioactive decay of uranium to lead can be assumed to begin at death.

New data from bone analyses has created major disagreements among paleontologists. In a February 16, 2011 paper published in *Geology*, researchers from the Universities of Notre Dame and Alberta described their use of U–Pb to analyze the femur bone of a giant hadrosaur found in New Mexico. The bone age was estimated at 64.8 million years. Current theory suggests that dinosaurs became extinct (due to the impact of the asteroid) 65.5 million years ago. Did this hadrosaur die 700,000 years after Chicxulub? Is a new extinction theory needed to explain this discrepancy?

(<http://phys.org/news/2011-02-dinosaur-dating-technique-paper.html>)

**Dinosaur protein**

Almost 20 years ago when Mary Schweitzer was working in her North Carolina State University paleontology lab, she thought that she saw red blood cells in a fossil! Using a microscope to study a piece of *T. rex* leg bone, she had found evidence of soft tissue within the bone. Her discovery was questioned and initially attributed to contamination because it was considered impossible that organic material could survive the many years of fossilization.

This bone was buried 20 meters deep, so contamination was unlikely. Schweitzer worked with John Asara from Harvard Medical School to sequence seven pieces of the soft tissue. This tissue was found to be collagen, protein connective tissue. The amino acid sequence matched that of chickens and reacted to chicken collagen antibody. This fit because birds are close relatives of *T. rex*. Asara concluded that *T. rex’s* bones contained protein that survived fossilization. Jack Horner, Montana State University, who also worked on the analysis said, “If we can get as deep as possible into sediment where there has been little contamination, I think we’ll find many specimens like this.” In 2007, he suggested that paleontologists must “dig deeper” to locate fossils that are better preserved. (<https://www.newscientist.com/article/dn11591-tyrannosaurus-rex-fossil-gives-up-precious-protein/>)

In 2015, Sergio Bertazzo and colleagues at the Natural History Museum in London found soft tissue in fossils that had been in storage for over 100 years. The picture below from a color scanning electron microscope shows the long collagen fibers that have been mineralized.



*Scanning microscope photo of mineralized collagen fibers*

*(*[*http://www.dailymail.co.uk/sciencetech/article-3117137/Blood-skin-cells-75-million-year-old-dinosaur-bones-Tissue-extracted-fossils-left-storage-century.html*](http://www.dailymail.co.uk/sciencetech/article-3117137/Blood-skin-cells-75-million-year-old-dinosaur-bones-Tissue-extracted-fossils-left-storage-century.html)*)*

Dr. Bertazzo used ion beams for internal observation of fossil structures. He found material that resembled red blood cells. Some speculate that since these fossils have yielded amino acid sequences, perhaps *T. rex* could be cloned. Paleontologists note that red blood cells do not contain DNA and the pieces of collagen found are far too small to construct the complete genome required for cloning.

This article from the U.K. *Daily Mail*, contains additional color scanning microscope images. Click on the large arrow in the supplementary video (second-to-last image) to see a 3D reconstruction of red blood cells found in the fossilized bone. (<http://www.dailymail.co.uk/sciencetech/article-3117137/Blood-skin-cells-75-million-year-old-dinosaur-bones-Tissue-extracted-fossils-left-storage-century.html>)

# References

**(non-Web-based information sources)**

**The references below can be found on the   
*ChemMatters* 30-year DVD, which includes all articles   
published from the magazine’s inception in October 1983 through April 2013, all available Teacher’s Guides, beginning February 1990, and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [**http://ww.acs.org/chemmatters**](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab directly under the *ChemMattersonline* logo and, on the new page, click on “Get the past 30 Years of *ChemMatters* on DVD!” (the icon on the right of the screen).**

**Selected articles and the complete set of   
Teacher’s Guides for all issues from the past three   
years are available free online at the same Web site, above. Click on the “Issues” tab just below the logo, *“ChemMattersonline”*.**



***30* Years of *ChemMatters !***

Available Now!

Iridium is rarely found on earth but is more common in asteroids. This article describes how the concentration of iridium at the K/T Boundary provides evidence for the impact of the Chicxulub meteorite at the time of dinosaur extinction. (Withgott, J. Dinosaurs and Iridium—Traces of an Impact. *ChemMatters*, 2001, *19* (1), pp 12–13)

This article provides details including molecular and structural formulas and chemical reactions as tooth decay is discussed. Also shown is how hydroxyapatite is broken down by bacteria and how fluorine forms fluorapatite. (Rohrig, B. Demystifying Gross Stuff. *ChemMatters*, 2001, *19* (3), pp 12–14)

The structure of bone including osteocytes is pictured and described in this article. Hydroxyapatite is introduced as a calcium phosphate compound. (Stone, C. Bones—The Living Skeleton. *ChemMatters*, 2000, *18* (3), pp. 12–13)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Hendrickson, S. *Hunt for the Past: My Life as an Explorer;* Scholastic, Inc.: New York, NY, 2001. Hendrickson’s autobiography contains many references to her self-taught accomplishments from painting boats to diving for ship wrecks to paleontology. She leads an exciting adventurous life of nonconformity. This will probably appeal to students.

# Web Sites for Additional Information

**(Web-based information sources)**

**Sue Hendrickson**

This site provides some information about the life of Sue Hendrickson, the high school dropout, after she found SUE. (<http://articles.chicagotribune.com/2000-05-08/news/0005080126_1_specimen-dinosaur-high-school-diploma>)

**“Dinosaur 13”**

The film critique was published by the *Chicago Reader*. It goes beyond “Dinosaur 13” to discuss the deep problems involved in the commercialization of fossil recovery. (<http://www.chicagoreader.com/chicago/dinosaur-13-review-todd-douglas-miller-peter-larson-tyrannosaurus-rex-fossil-sue-field-museum-of-natural-history/Content?oid=14690513>)

The documentary “Dinosaur 13” (1:35:00) is available for rent or purchase. (<https://itunes.apple.com/us/movie/dinosaur-13/id889020430>) This YouTube video (38:39) includes clips and a trailer of the film. (<https://www.youtube.com/watch?v=K66ja5WJurk>) The 3:00 minute official trailer can be found at <https://www.youtube.com/watch?v=XZywsT8Sy-c>.

Film critics gave positive responses to the film:

* Dennis Harvey, [*Variety*](https://en.wikipedia.org/wiki/Variety_(magazine)): "engrossing"
* Duane Byrge, [*The Hollywood Reporter*](https://en.wikipedia.org/wiki/The_Hollywood_Reporter)*,* "story of scientific discovery and petty politics"
* Eric Kohn, [Indiewire](https://en.wikipedia.org/wiki/Indiewire), "A subset of the recent scientific-documentary-as-thriller tradition epitomized by [*The Cove*](https://en.wikipedia.org/wiki/The_Cove_(film)) and [*Blackfish*](https://en.wikipedia.org/wiki/Blackfish_(film))”
* Todd Douglas Miller, “both awe-inspiring and tragic”

(<https://en.wikipedia.org/wiki/Dinosaur_13>)

Others in the scientific community call ”Dinosaur 13” a very slanted anti-government approach that ignores U.S. Federal laws written to protect fossils on public land.

Writing for *Slate*, Don Lessem provides a thorough review of the documentary “Dinosaur 13” from his perspective: “Don’t Believe the Anti-Government Tale Spun by This New Dinosaur Documentary”. This may provide information useful if your students are gathering material for a debate on the ethics of for-profit fossil hunting or to present an alternative view if you show the film. (<http://www.slate.com/blogs/browbeat/2014/08/22/dinosaur_13_review_movie_about_peter_larson_spins_a_bogus_tale.html>)

The *Chicago Reader* critique of the documentary reviews the film and speaks about the frustration of academic paleontologists when excavations become commercial. (<http://www.chicagoreader.com/chicago/dinosaur-13-review-todd-douglas-miller-peter-larson-tyrannosaurus-rex-fossil-sue-field-museum-of-natural-history/Content?oid=14690513>)

**The Field Museum purchase of SUE**

This *Washington Post* story: “The *T. rex* that Got Away” describes the drama and secret bidding involved in the purchase of SUE. (<https://www.washingtonpost.com/local/the-t-rex-that-got-away-smithsonians-quest-for-sue-ends-with-different-dinosaur/2014/04/05/7da9a73c-b9a6-11e3-9a05-c739f29ccb08_story.html>)

On March 21, 2014, Christina Rose published an article in the tribal newsletter, *The Indian Country Today*, titled, “After T-Rex Troubles, Dinosaurs Stay on the Rez”. The judge’s decision favoring Maurice Williams in the SUE case was based on the premise that, “… fossils are actually part of the ground, which meant the dinosaur was tribal land.”

(<http://indiancountrytodaymedianetwork.com/2014/03/21/after-t-rex-troubles-dinosaurs-stay-rez-154111>)

**The anatomy of *T. rex***

This site gives “Fast Facts on *T. rex*” and provides many details of the assumed physical anatomy, physiology and behavior of *T. rex*. The information may help answer student questions about theories regarding the life style of huge dinosaurs. (<http://www.fossilguy.com/gallery/vert/dinosaur/tyrannosaurus/tyrannosaurus.htm>)

***T. rex* growth and behavior**

George Erickson, Florida State University questioned how dinosaurs became gigantic so quickly. His research attributes enormous growth rates for *T. rex* between 14 and 18 years due to voracious eating habits. (<http://news.nationalgeographic.com/news/2004/08/0811_040811_trex.html>)

*Wikipedia* provides detailed information and references on the feeding and predatory behavior of T-rex. (<https://en.wikipedia.org/wiki/Feeding_behaviour_of_Tyrannosaurus>)

**Scientific evidence of *T. rex* predation**

*PLOS* is an open access journal of the *Public Library of Science*. This article describes and shows photos of teeth marks that suggest the cannibalistic behavior of *T. rex.* (<http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0013419>)

**Types of animal preservation**

The *Virtual Fossil Museum* Web site posting, “Fossilization - How Fossils Form”, lists and explains fossil formation under different environmental conditions. This informative site includes some of the chemistry involved in processes including drying, freezing and immersion in tar that leave evidence such as fossils, molds and casts of ancient animal habitation. (<http://www.fossilmuseum.net/fossilrecord/fossilization/fossilization.htm>)

Paleosol is the type of soil that was preserved many years ago through burial under sediments. This soil, conducive to fossil formation, is discussed in a soil science blog from the University of Oregon. (<http://blogs.uoregon.edu/gregr/files/2013/07/Retallack-1997-dinosaurs-and-dirt-17ef2dj.pdf>)

**Steps to fossil formation**

This site contains a concise step by step, easy to follow procedure for the formation of a fossilized animal. (<https://www.papertrell.com/apps/preview/The-Handy-Dinosaur-Answer-Book/handy%20answer%20book/How-likely-is-it-that-an-organism-becomes-a-fossil/001137014/content/SC/52cafef582fad14abfa5c2e0_Default.html>)

The Australia Museum in Sydney shows pictures with a description of the four stages of fossil development in “How fossils are formed”. There are links to sedimentary processes and the types of fossils found in the Sydney Basin.

(<http://australianmuseum.net.au/how-are-fossils-formed>)

**Cadaver dog training**

This article describes the training of cadaver dogs and the situations that they must experience in their work. (<https://www.theguardian.com/lifeandstyle/2015/sep/08/cadaver-dogs-trained-to-smell-death>)

**Bone mineral**

Smithsonian Institute researchers describe the reactivity of bone mineral and how its formula changes over time. The high surface area of the crystal readily lends itself to cation exchange.

(<http://rimg.geoscienceworld.org/content/48/1/489>)

**Bone repair**

This paper, **“**Collagen-Hydroxyapatite Composites for Hard Tissue Repair (bone repair)”, describes the work of researchers at Oxford University, UK. Their work involves the use of a bioresorbable collagen-hydroxyapatite composite for bone repair. (<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.655.1594&rep=rep1&type=pdf> )

**Bone marrow transplants**

The U.S. National Library of Medicine published this description of three types of transplants to replace bone marrow damaged by chemotherapy or radiation. Hopefully, healthy donor white blood cells may continue the process of eradicating cancer cells. (<https://www.nlm.nih.gov/medlineplus/ency/article/003009.htm>)

**Permineralization**

This technical paper describes studies of the chemical analysis of bone mineral and synthetic hydroxyapatite, including discussion of the crystalline structure and the Ca:P ratio in these compounds. (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2760485/>)

**Dinosaur extinction**

This article, “After asteroid hit, a giant cloud of smoke led to dinosaur’s demise.” from the July 23, 2016 *Los Angeles Times* reports data from the release of Professor Kaiho’s research. The newspaper report is clear and very readable.

(<http://www.latimes.com/science/sciencenow/la-sci-sn-dinosaurs-asteroid-soot-20160714-snap-story.html>)

The *Scientific American* article, “A Theory Set in Stone: An Asteroid Killed the Dinosaurs, After All” contains additional information about Chicxulub and Kaiho’s research and how the impact led to destruction of the food chain. And, it discusses the less plausible explanation that multiple volcanic eruptions caused the extinction. (<http://www.scientificamerican.com/article/asteroid-killed-dinosaurs/>)

The Smithsonian National Museum of Natural History site lists several references and two URLs that discuss, “Why did they go extinct?” (<http://paleobiology.si.edu/dinosaurs/info/everything/why_7.html>)

**Fossil dating**

Studies by geologists at the University of California, Berkeley Geochronology Center present how uranium/lead (U/Pb) ratios can be used to date geological events up to 100 million years ago with a precision of within 250,000 years (1 in 400, or 0.25%). This article also discusses the advantages of using uranium decay as compared to argon (Ar/Ar) dating. (<http://www.berkeley.edu/news/media/releases/2004/09/16_uranium.shtml>)

When U–Pb dating techniques were used on fossil bone, the data caused scientists to question previous proposed dates of dinosaur extinction. This article, “Uranium technique raises dinosaur question” describes the collection of this data and the controversy surrounding it. (<http://www.world-nuclear-news.org/EE-Uranium_technique_raises_dinosaur_question-0202117.html>)

These are “class notes” on a lesson on radioactive dating, including an explanation of half-life. There are questions for students and they are asked to graphically analyze data. I don’t see this as a lesson in itself, but there is some material (particularly the problems) that could be used to challenge students. (<http://eas2.unl.edu/~tfrank/History%20on%20the%20Rocks/Teachers/Plan%20files/Planansky_geochronology.pdf>)

**Dinosaur** **protein**

Additional information is given on the molecular analysis by Mary Schweitzer on the soft tissue found in a *T. rex* bone. This article provides details of analyses and findings using mass spectrometry techniques to sequence the amino acids in dinosaur protein. Protein antibody bonding is discussed, as well as the data from tests that show a strong similarity between the dinosaur tissue and that of modern birds. (<http://www.nature.com/news/molecular-analysis-supports-controversial-claim-for-dinosaur-cells-1.11637>)

# More Web Sites on Teacher Information and Lesson Plans

**(sites geared specifically to teachers)**

These are “Teacher Resource Activities for Education and Fun”, including Earth Science lessons, that include details on how to build a volcano model. Many links are shown on each margin that take you to general information as well as lessons to use for studying the formation of fossils. (<http://www.fossils-facts-and-finds.com/how_are_fossils_formed.html>)

The Emilsson/Tinnesand SUE article contains a sidebar, “Types of Fossils”, with brief explanations of different types of fossil evidence. Supported by the National Science Foundation (NSF), the University of California, Berkeley, Museum of Paleontology has produced an extensive Web page on this subject. In conjunction with *PBS Learning Media*, they present pictures (in series) of the different types of fossils, a NOVA video on the Grand Canyon, questions for students and links to the specific *Benchmarks for Science Literacy* (National Standards). This site is rich with possibilities for student lessons. (<http://www.pbslearningmedia.org/resource/ess05.sci.ess.earthsys.fossiltype/types-of-fossils/>)