NOAA Ship *Okeanos Explorer:* America's Ship for Ocean Exploration. Image credit: NOAA. For more information, see the following Web site: *http://oceanexplorer.noaa.gov/okeanos/welcome.html*

Section 3: Key Topic – Climate Change

The Methane Circus

Focus
Methane hydrates, climate change, and the Cambrian Explosion

Grade Level
5-6 (Life Science/Earth Science)

Focus Question
How might methane hydrates have been involved with the Cambrian Explosion?

Learning Objectives
- Students will describe the overall events that occurred during the Cambrian Explosion.
- Students will explain how methane hydrates may contribute to global warming.
- Students will describe the reasoning behind hypotheses that link methane hydrates with the Cambrian explosion.

Materials
- Copies of *Cambrian Explosion Investigation Guide*, one for each student group
- (Optional) Materials for making model fossils
  - Copies of *Model Fossil Construction Guide*, one for each student group
  - Oven-bake modeling clay
  - Dowel, rolling pin or other cylindrical object for rolling out clay
  - Flat-sided toothpicks and a spatula
  - Aluminum baking pan (approximately 4 – 5 inch diameter)
  - Tile grout, plaster, or other water-based filler that sets hard
  - Scissors
  - Latex paint (see Steps 9 and 10 for colors)
  - Brushes
  - Paper towels
  - Corrugated cardboard or poster board
  - Oven (see modeling clay instructions for specific directions)

Audiovisual Materials
- None

Teaching Time
Two or three 45-minute class periods plus time for student research

Seating Arrangement
Groups of four to six students

Maximum Number of Students
32

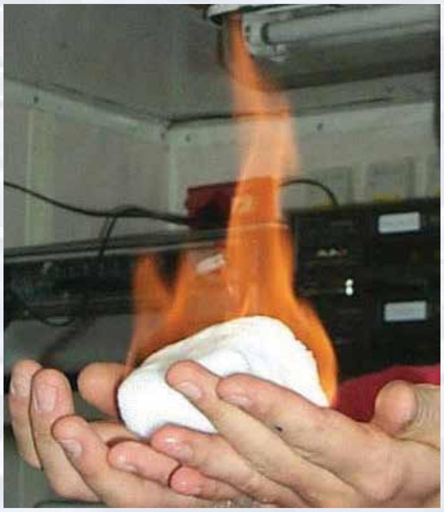
Key Words and Concepts
Methane hydrate
Cambrian Explosion
Burgess Shale
Fossil
Continental drift

Background Information
NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

"They are grubby little creatures of a sea floor 530 million years old, but we greet them with awe because they are the Old Ones, and they are trying to tell us something."

Stephen Jay Gould

Methane is produced in many environments by a group of Archaea known as the methanogenic Archaea. These Archaea obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep-ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form. Scientists are interested in methane hydrates for several reasons. A major interest is the possibility of methane hydrates as an energy source. The U.S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. In addition to their potential importance as an energy source, scientists have found that methane hydrates are associated with unusual and possibly unique biological communities. In September, 2001, the Ocean Exploration Deep East expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials and other useful natural products.



Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

While such potential benefits are exciting, methane hydrates may also cause big problems. Although methane hydrates remain stable in deep-sea sediments for long periods of time, as the sediments become deeper and deeper they are heated by the Earth's core. Eventually, temperature within the sediments rises to a point at which the clathrates are no longer stable and free methane gas is released (at a water depth of 2 km, this point is reached at a sediment depth of about 500 m). The pressurized gas remains trapped beneath hundreds of meters of sediments that are cemented together by still-frozen methane hydrates. If the overlying sediments are disrupted by an earthquake or underwater landslide, the pressurized methane can escape suddenly, producing a violent underwater explosion that may result in disastrous tsunamis.

Iceworms *(Hesiocaeca methanicola)* infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image credit: Ian MacDonald. *http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg*

The release of large quantities of methane gas can have other consequences as well. Methane is one of the greenhouse gases. In the atmosphere, these gases allow solar radiation to pass through but absorb heat radiation that is radiated back from the Earth's surface, thus warming the atmosphere. A sudden release of methane from deep-sea sediments could increase this greenhouse effect, causing Earth's surface to become significantly warmer.

Methane-induced greenhouse warming has been linked to one of the most striking events in Earth's geologic history. In the summer of 1909, Charles Walcott, head of the Smithsonian Institution, made an amazing discovery in a small limestone quarry 8,000 feet above sea level in the Canadian Rockies: beautifully preserved fossil remains of hundreds of animals that had never been seen before. The Burgess Shale, as the quarry came to be called, turned out to be the record of the "Cambrian Explosion;" a period of geologic history 542 - 488 million years ago during which life on Earth became much more diverse. Many different multicellular animals appeared, including most of the major groups alive today, such as mollusks, arthropods, echinoderms, corals, sponges, and chordates. For the first time, many animals had hard outer skeletons, which eventually became fossilized. Prior to the Cambrian Period, most living organisms were small or microscopic with soft bodies that usually do not form recognizable fossils. In addition to the ancestors of familiar groups, many other animals appeared during the Cambrian Explosion that do not resemble any animals living today.

In 2003, Joseph Kirschvink and Timothy Raub theorized that the Cambrian Explosion might be linked to methane hydrates. According to their hypothesis, Archaea in pre-Cambrian times produced large amounts of methane from decaying organisms in Earth's tropical regions. Methane-rich sediments from tropical areas were carried into polar regions by continental drift. Colder conditions favored methane hydrate formation which created a cap under which methane gas was trapped as the Archaea continued their work. Eventually, continental drift returned the capped methane deposits back toward tropical latitudes where warmer conditions caused methane hydrates to become unstable. Periodically, large volumes of trapped methane were released into the sea and then into the atmosphere resulting in a greenhouse effect and rapid warming. Warmer temperatures stimulated invertebrate metabolism, resulting in rapid evolution of new species. In the words of Kirschvink and Raub, "A methane 'fuse' ignited the Cambrian Evolutionary Explosion."

This activity guides a student investigation into how methane hydrates may have been involved with the Cambrian Explosion, and into some of the animals that appeared during that event.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*….
   - Visit the Smithsonian Institution's Cambrian Explosion Web page (*http://paleobiology.si.edu/burgess/cambrianWorld.html*) and review information about the Burgess Shale Fauna and The Age of Trilobites.
   - Review questions on the *Cambrian Explosion Investigation Guide*.
   - Review procedures on the *Model Fossil Construction Guide*, and gather necessary materials.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include further understanding of climate change.

   Briefly describe methane hydrates. You may want to use a model of a methane hydrate molecule as part of this discussion (the *Animals of the Fire Ice* lesson includes directions for making this kind of model).

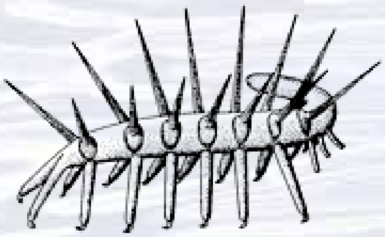
   Tell students that they are going to investigate the possible connections between methane hydrates, global warming, and a dramatic event in the history of life on Earth that took place about 530 million years ago. Assign each student group one of the following animals from the Burgess Shale:

Thaumaptilon	*Canadaspis*	*Olenoides*
Aysheaia	*Perspicaris*	*Naraoia*
Sidneyia	*Waptia*	*Opabinia*
Pikaia	*Leanchoillia*	*Amiskwia*
Canadia	*Hallucigenia*	*Anomalocaris*
Choia	*Haplophrentis*	*Wiwaxia*
Ottoia	*Marrella*	

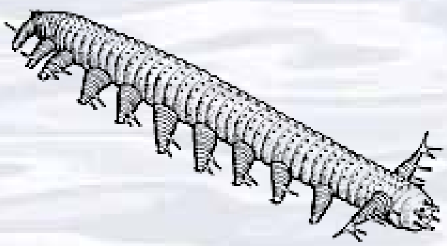
   Provide each student group with a copy of the *Cambrian Explosion Investigation Guide*. You may want to provide the link to the Smithsonian Institution's Burgess Shale Fossil Specimens Web page (*http://paleobiology.si.edu/burgess/burgessSpecimens.html*).

3. Lead a discussion of students' responses to questions on the *Guide*, and have each group present information about their assigned animal.
   a. The Cambrian Explosion was a geologic period 542 - 488 million years ago during which a great diversity of multicellular animals appeared. Most of the major animal phyla alive today appeared during this period, as well as other animals that do not resemble any animals living today.
   b. The Burgess Shale is a rock formation in the Canadian Rockies that contains fossils of many animals that appeared during the Cambrian Explosion. These fossils are unusually well-preserved and show fine details of soft parts as well as shells and similar hard structures. While many of the Burgess Shale fossils appear to be early ancestors of modern animals, others do not seem related to any living forms and reasons for their disappearance are not known.
   c. Methane hydrates are molecules of methane gas surrounded by a lattice of frozen water molecules, and are formed under conditions of high pressure and cold temperature in the deep ocean (methane hydrates are also found in some areas of arctic permafrost).
   d. Methane is a greenhouse gas. If methane hydrates become unstable due to high temperatures or mechanical disruption (*e.g.*, earthquakes) large quantities of methane gas can be released to the atmosphere where they intensify the greenhouse effect. Heat that would otherwise be radiated into space is retained by the greenhouse effect, and the result is higher temperatures in the atmosphere and on Earth's surface.
   e. In addition to the Kirschvink/Raub theory discussed above,
      - Increasing concentrations of oxygen in Earth's atmosphere and ocean may have allowed larger animals to develop;

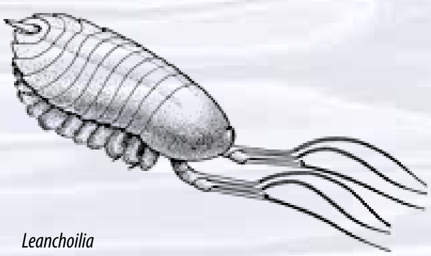
Sample illustrations from the Smithsonian Institution's Web site



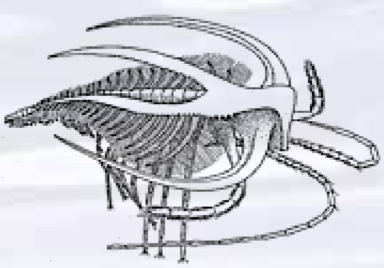
Hallucigenia



Aysheaia



Leanchoilia



Marrella

http://paleobiology.si.edu/burgess/burgessSpecimens.html

- A mass extinction event preceding the Cambrian Period may have eliminated competing organisms and allowed new species to evolve and become successful;
- The appearance of predation as a means of obtaining food might have created new ecological roles for new species, as well as making shells and other forms of armor an evolutionary advantage; more animals with more hard parts would have increased the likelihood that recognizable fossils could be formed.

Notes on Burgess Shale fauna

[*All images and pronunciations can be found on the Smithsonian Institution's Burgess Shale Fossil Specimens Web page* (*http://paleobiology.si.edu/burgess/burgessSpecimens.html*)]

Thaumaptilon – a sea pen, similar to sea pen species alive today; the animal resembles a leaf, attached to the seafloor by a structure called a hold-fast; relatively large for Cambrian animals, up to eight inches long; modern sea pens are colonial soft corals, and the surface of *Thaumaptilon* is covered on one side by tiny spots that may have been individual coral polyps; probably fed on plankton and particulate material. Phylum: Cnidaria

Aysheaia – nicknamed "velvet worm;" ten pairs of stubby tapered appendages; spines and grasping arms near the head; largest specimens are slightly over two inches long; thought to be a parasite living on sponges or a sponge predator, since *Aysheaia* fossils are often found with sponge remains. Phylum: Onychophora

Sidneyia – segmented body and tail resembling modern arthropods; two to five inches long; probably a predatory bottom-feeder that consumed molluscs, small crustaceans, and trilobites. Phylum: Arthropoda

Pikaia – elongated, flattened body with a central notochord and expanded tail fin; average length about one and one-half inches; probably swam eel-like near the seafloor, possibly feeding on particulate material. Phylum: Chordata

Canadia – worm-like; short appendages covered with stiff bristles could be used for swimming or walking; one to two inches long; its gut could be turned inside out to form a feeding organ; may have been a carnivore or scavenger. Phylum: Annelida

Choia – small, thin disc-shaped sponge with spines radiating from the middle of the body; about one inch in diameter; filter-feeder. Phylum: Porifera

Ottoia – a burrowing worm similar to modern priapulid worms; one to six inches long; carnivorous predator, possibly cannibalistic. Phylum: Priapulida

Canadaspis – crustacean-like with segmented body, walking legs, and head appendages; about one inch long; bottom-feeder. Phylum: Arthropoda

Perspicaris – a bivalved arthropod, with two sides of the carapace joined by a hinged joint along the back; about one inch long; feeding habits uncertain, may have been a swimmer or a bottom feeder. Phylum: Arthropoda

Waptia – a bivalved arthropod; about three inches long; capable of swimming but probably was a sediment feeder. Phylum: Arthropoda

Leanchoillia – an arthropod with conspicuous head appendages; often described as blind, but recent reports suggest that delicate (and consequently, rarely preserved) stalked eyes were present as well as light sensitive ocelli that are inconspicuous in most specimens; about two inches long; possibly carnivorous. Phylum: Arthropoda

Hallucigenia – elongated body with paired appendages on the lower surface and sharp spines along the back; slightly more than one inch long; probably a scavenger. Phylum: possibly Onychophora

Haplophrentis – long, flat-bottomed, conical shell with a small lid (operculum) closing the front end, and two curved appendages sticking out sideways at the front; one-tenth to one and one-quarter inches long; fed on organic material in bottom mud. Phylum: possibly Mollusca

Marrella – heart-shaped arthropod, with two pairs of large spines curved from the head back over the body; 20 body segments with long, thin appendages; two pairs of antennae on head; one-tenth to three-quarters inch long; possibly carnivorous and/or particulate feeder. Phylum: Arthropoda

Olenoides – a trilobite with smooth head shield, thorax with seven segments, and short tail; long, curved antennae; legs with spines used for grasping prey; up to four inches long; carnivorous predator and scavenger. Phylum: Arthropoda

Naraoia – A trilobite with two body shields covering the head and thorax; up to one and one-half inch long; carnivorous predator and scavenger. Phylum: Arthropoda

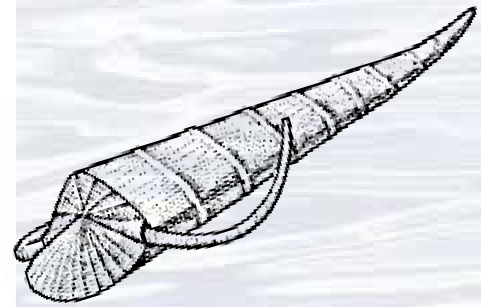
Opabinia – segmented animal with five eyes, and a long, flexible feeding organ with grasping spines; lobe-shaped appendages on the side of each segment; possibly carnivorous; up to four inches long including the feeding organ. Phylum: unknown

Amiskwia – elongated swimming animal; head with two prominent tentacles; body with stubby side fins; flattened tail; up to one inch long; feeding habits unknown. Phylum: unknown

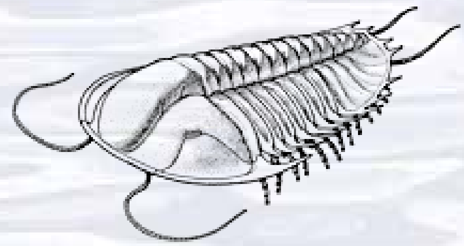
Anomalocaris – the T-rex of the Burgess Shale; large eyes, muscular swimming lobes on each side of a flattened body; large grasping limbs in front for holding prey; mouth like a garbage disposal on underside surrounded by sharp teeth; up to three feet long, some specimens from China up to six feet long; carnivorous. Phylum: unknown

Wiwaxia – oval-shaped body, upper surface covered with hard plates; two rows of long spines along the back; mouth with two rows of teeth on bottom

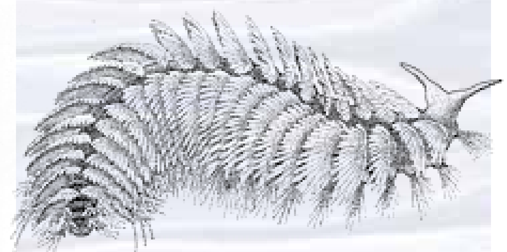
Sample illustrations from the Smithsonian Institution's Web site



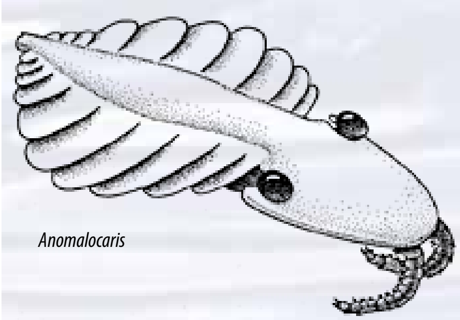
Haplophrentis



Olenoides



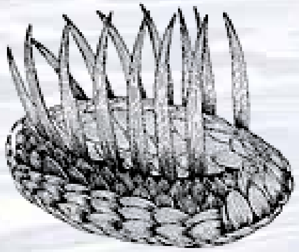
Canadia



Anomalocaris

http://paleobiology.si.edu/burgess/burgessSpecimens.html

Sample illustrations from the Smithsonian Institution's Web site



Wiwaxia

http://paleobiology.si.edu/burgess/burgessSpecimens.html

Methane gas hydrate forming below a rock overhang at the seafloor on the Blake Ridge diapir. This image, taken from the DSV *Alvin* during the NOAA/OER Deep East Expedition in 2001, marked the first discovery of gas hydrate at the seafloor on the Blake Ridge. Methane bubbling out of the seafloor below this overhang quickly "freezes," forming this downward hanging hydrate deposit, dubbed the "inverted snowcone." Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03windows/background/plan/media/hydrate2.html

This mother polar bear and two cubs were spotted leaping between ice floes early in the cruise. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/02arctic/logs/aug25/media/bears_three.html

surface; up to two inches long; bottom feeder, possibly carnivorous. Phylum: unknown

4. (Optional) Have your students construct a model fossil of their assigned animal, following directions on the *Model Fossil Construction Guide*.

The BRIDGE Connection

www.vims.edu/bridge/ – Enter "paleontology" in the Search box for links to resources about geology and paleontology.

The "Me" Connection

Read the quotation from Stephen Jay Gould at the beginning of the Background section. Have students write a short essay on what the "Old Ones" might be trying to tell us.

Connections to Other Subjects

English/Language Arts, Fine Arts

Assessment

Students' responses to *Investigation Guide* questions and class discussions provide opportunities for evaluation.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Have students research other events in the history of life on Earth that have been linked to methane hydrates.

Other Relevant Lesson Plans from the Ocean Exploration Program

(All of the following Lesson Plans are targeted toward Grades 5-6)

The Big Burp: A Bad Day in the Paleocene
(from the 2003 Windows to the Deep Expedition)
http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_badday.pdf

Focus: Global warming and the Paleocene extinction (Earth Science)

Students will describe the overall events that occurred during the Paleocene extinction event, describe the processes that are believed to result in global warming, and infer how a global warming event could have contributed to the Paleocene extinction event.

Polar Bear Panic! (from the 2002 Arctic Exploration Expedition)
http://oceanexplorer.noaa.gov/explorations/02arctic/background/education/media/arctic_polarbears.pdf

Focus: Climate change in the Arctic Ocean (Earth Science)

Students will identify the three realms of the Arctic Ocean and describe the relationships between these realms; graphically analyze data on sea ice cover in the Arctic Ocean and recognize a trend in these data; and discuss possible causes for observed trends in Arctic sea ice and infer the potential impact of these trends on biological communities in the Arctic.

The Ocean Unicorn (from the 2006 Tracking Narwhals in Greenland Expedition)
http://oceanexplorer.noaa.gov/explorations/06arctic/background/edu/media/unicorn.pdf
Focus: Narwhals (Life Science)
Students will describe key elements of the life history and ecology of narwhals, including overall morphology, preferred habitat, geographic range, and feeding habits; and identify and explain three possible explanations for the apparent decline in the size of narwhal populations.

The 2006 Tracking Narwhals in Greenland Expedition used satellite-linked time-depth-temperature recorders to track whale movements, diving behavior, and ocean temperature structure during the fall narwhal migration from north Greenland to Baffin Bay. This information is needed to help understand how Arctic climate change may affect the deep-ocean thermohaline circulation, sometimes known as the "global conveyor belt." Image credit: Mads Peter Heide-Jorgensen.
http://oceanexplorer.noaa.gov/explorations/06arctic/background/hires/male_narwhals_hires.jpg

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.
Please send your comments to:
oceanexeducation@noaa.gov

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Cambrian Explosion Investigation Guide

Long before dinosaurs, Earth's ocean contained strange animals that are unlike anything living today. Many of these animals first appeared during an event known as the Cambrian Explosion. Your assignment is to investigate the Cambrian Explosion, and find out more about at least one of the animals that appeared during this event. In addition to the references and resources provided by your teacher, key word searches on the Internet will produce all the information you need to answer the following questions:

1. What and when was the Cambrian Explosion?

2. What is the Burgess Shale?

3. What are methane hydrates?

4. How might methane hydrates be involved with global warming?

5. What are some theories about what might have caused the Cambrian Explosion?

The following questions refer to the animal assigned by your teacher.

6. What did your animal look like? [Hint: Use your animal's name in an image search on the Internet and copy the best picture you can find]

7. How big was your animal?

8. What did your animal probably eat?

9. To what phylum does your animal belong?

Model Fossil Construction Guide

NOTE: These directions are adapted from "Make a fossilized Dinosaur Egg;" http://www.instructables.com/id/Make_a_fossilized_Dinosaur_Egg/

Materials

- Oven-bake modeling clay
- Dowel, rolling pin or other cylindrical object for rolling out clay
- Flat-sided toothpicks and a spatula
- Aluminum baking pan (approximately 4 – 5 inch diameter)
- Tile grout, plaster, or other water-based filler that sets hard
- Scissors
- Latex paint (see Steps 9 and 10 for colors)
- Brushes
- Paper towels
- Corrugated cardboard or poster board
- Oven (see modeling clay instructions for specific directions)

Procedure

1. Find several images of your assigned animal. The Smithsonian Institution's Burgess Shale Fossil Specimens Web page (*http://paleobiology.si.edu/burgess/burgessSpecimens.html*) has line drawings as well as photographs of actual fossils. You may also want to do an Internet search for images of your animal to see other views. You want to get a good idea of what the animal probably looked like when it was alive, and then imagine how it would look if it were lying on very soft sediment. Obviously, most animals will appear differently depending upon whether they are lying on their back, side or front. Choose the most interesting view for your fossil.
2. Roll out a piece of modeling clay until you have a flat disk about 1/16-inch thick, and a diameter that is at least twice the maximum size of your animal (for example, if the maximum length of your animal is one inch, you should have a disk with a diameter of at least two inches). It's better to have a piece of clay that's too big than one that's too small. If your animal seems too small to make a good model, then make a model of the very rare GIANT form of this animal (in other words, just pretend the animal was bigger than presently known fossils suggest). If your animal is *Anomalocaris*, you will have to make a very rare DWARF fossil.
3. With a toothpick, outline the major pieces of your animal that will be visible on your fossil. Carefully cut out each piece with the flat side of a toothpick. Lift the pieces with a spatula, or one or two toothpicks for small pieces and place them on an aluminum baking pan.
4. Follow your teacher's instructions for baking the pieces of your fossil.
5. Cut a piece of corrugated cardboard or poster board so there will be at least one inch on all sides of your fossil when it is completed.
6. Mix grout, plaster, or filler according to instructions on the package so that you have a mix that is flexible but stiff enough not to run off of a flat piece of cardboard.
7. Make a puddle of grout, plaster or filler on the piece of cardboard you cut in Step 5. Arrange the pieces of your fossil on the puddle, and push them slightly down into the puddle before the material hardens.
8. When the filler is almost dry, but before it is completely hard, scrape or brush some of the filler away from the hardened clay pieces until enough of the fossil is revealed.
9. When the filler is completely dry and hard, spray or brush paint over the entire surface of your model. Gray, brown, or reddish colors are best, depending upon the type of rock that surrounds your fossil.
10. Thin a darker color of paint with some water. When the first layer of paint is completely dry, brush the thinned paint onto the model, then wipe most of it off with a paper towel. The thinned paint will fill in cracks and lower portions of your model, enhancing the contrast and making the model look old. After the model is completely dry, you can repeat this step again with other colors until you have the effect you want.

Your model fossil is finished!

Notes: