The Burgess Shale: historic and scientific explorations.

Age Range:

Grade 10 (secondaire 4): 14,15 years Grade 11 (secondaire 5): 15,16 years Grade 12 (CEGEP): 16,17 years

Subjects:

- Geology
- Ecology
- Natural Sciences
- General Science
- Earth Science

Contents

Introduction

High on a mountain ridge in Canada's spectacular Yoho National Park in British Columbia is one of Earth's most important fossil deposits: the Burgess Shale. Preserved with exquisite detail within the rock layers for the last half-billion years are the remains of soft-bodied and often bizarre animals and algae dating from the Cambrian period.

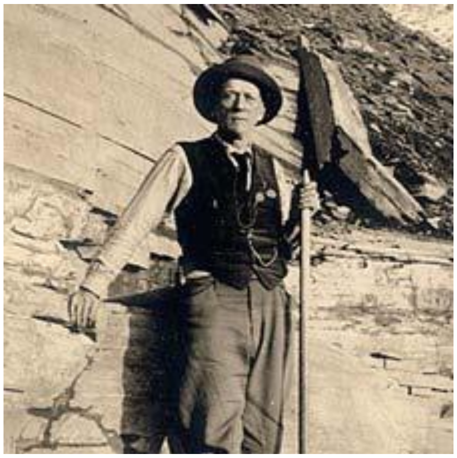
By studying the fossilized remains of animals such as *Anomalocaris, Opabinia*, and *Marrella* , your students are able to explore the circumstances leading to the formation of such unusual fossils, reconstruct Cambrian food webs, examine the Earth's first great predators and the concomitant evolution of new defensive structures, and discover the origin of the diversity of modern animals.

The historic explorations connect events, places and people which made the discovery of the Burgess Shale possible. It also looks into a technological innovation, in this case the panoramic camera and its application. Your students are invited to reflect on the significance and implications of the connections.

A tale of western expansion and scientific exploration

What do the story of Canada's western expansion, the building of the railroad, the discovery of a major fossil deposit and the beginning of tourism in the Canadian Rockies, have in common? History is often described as a chain of events. Here is one tale which intertwines all of the above in a web of people and places all converging together for different reasons.

As the fledgling country of Canada developed, it was united by a grand project: the railroad linking east to west. Geological explorations and the development of a tourism industry led to the discovery of the first fossils in the Canadian Rockies during the 1880s. The discovery of the Burgess Shale by Dr. Charles Walcott, an American geologist and palaeontologist, in 1909 depended heavily on these earlier finds.



Charles Walcott posing with a pry-bar at the Burgess quarry 1912 (?)

Importance of the Canadian Pacific Railroad

Part of Prime Minister John A. Macdonald's "National Policy" was a railway linking Canada's four eastern provinces (Nova Scotia, New Brunswick, Quebec and Ontario) to the Pacific Ocean. The CPR was a bargaining tool to persuade the Northwest Territories and British Columbia to join the new Confederation (in 1870 and 1871, respectively). After its completion in 1885, the railroad not only bound the young country together, it also opened up vast areas for exploration and exploitation.

Train steaming along Kicking Horse Bridge with Mount Stephen in the background, British Columbia, 1901.

The role of the Geological Survey of Canada

The Geological Survey of Canada (GSC) was established in 1842 by the Legislature of the Province of Canada (roughly the area representing the southern parts of Ontario and Quebec today) as its first scientific organization. The Survey played a critical role in evaluating Canada's vast geological resources, and helped unify the country by demonstrating that its economy could be sustained by a healthy mining industry.

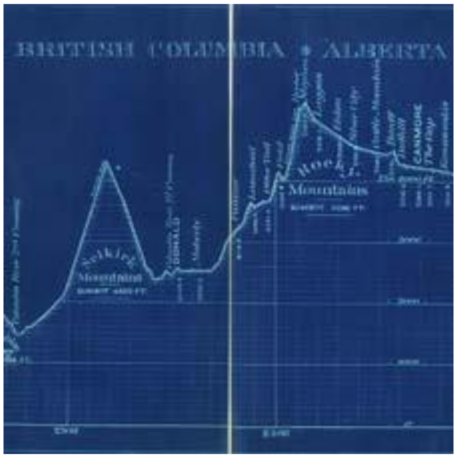
During the first 60 years of its history, the Survey was actively involved in exploring and mapping the vast reaches of the country, including the new lands added when the Northwest Territories and British Columbia joined the Confederation.

The Survey originally assisted in developing mining in Canada by identifying deposits of valuable minerals, but its role also included the collection of specimens (rocks, minerals, plants, animals, artifacts, and fossils) from across the country. Parts of these collections became the heart of the Canadian Museum of Nature in 1856. The GSC retains large collections of minerals, rocks and fossils today.

The railroad project became a pressing reason for the Government to expand geological explorations in western Canada. Many of the GSC geologists brought back fossils, including some from Mount Stephen in the Rocky Mountains which would go on to play a key role in the later discovery of the Burgess Shale.

Prospecting for a suitable route

The Geological Survey of Canada (GSC) and Canadian Pacific Railway (CPR) survey crews collaborated to locate various potential routes for the railroad and mineral resources that might prove useful for the project (such as coal or iron deposits).



© 2011, The University of British Columbia, Rare Books and Special Collections. All Rights Reserved.

The final route

Final CPR route through the Canadian Rockies, showing elevation of different mountains. Contrary to its previous plan (proposed by Sandford Fleming in 1871), the CPR opted to complete the last, most challenging section of tracks through the Kicking Horse Pass instead of going by an easier (but much longer) northern route. This decision led to the need for more geological surveys of the area around the pass.

Tinted souvenir postcard showing Mount Stephen House (mentioned above) and Mount Stephen. C. 1909.

Discovery of the first fossils

At the same time, a group of CPR construction workers and engineers migrated into the area around the nearby village of Field, at the foot of Mount Stephen, to build the palatial Mount Stephen House. It was at this time that key fossils (now considered to belong to the same formation as the Burgess Shale) would be discovered on Mount Stephen by local labourers, catching the attention of GSC geologists working in the area and eventually of Charles Walcott.

**

Train arriving in front of Field Hotel, British Columbia, 1887 or 1888.

Had the rail line not been built, or if the railway had used a different route to the Pacific, who knows how long these fossils would have remained unrevealed? The 1909 discovery of the Burgess Shale by Charles Walcott is deeply rooted in these earlier finds from Mount Stephen.

**

A burgeoning tourism industry

Even as the tracks were being completed, the CPR was launching an ambitious program to bring tourists to the area. The company built a series of lodges and hotels based on those found throughout the European Alps. The company even brought over experienced Swiss mountain guides (seen in photo at Glacier House, British Columbia, 1899) to help tourists make their way through the Rockies.

**

Tourism – natural beauty

The scenic beauty of the mountains and their natural wonders (including fossils) were at the forefront of a burgeoning tourist industry. Here we see a view of Takakkaw Falls from Lookout Point, British Columbia, 1901.

Tourism – outdoor activities

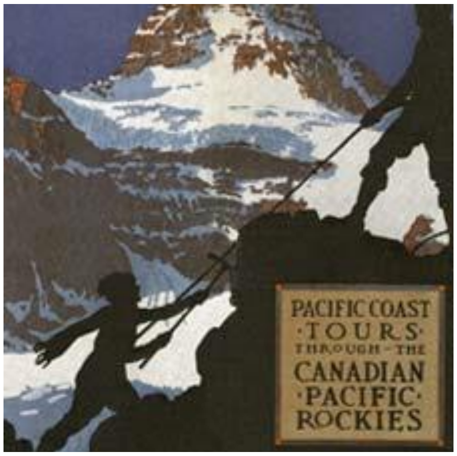
Glacier climbing, unknown location in the Canadian Rockies, 1905

Tourism – natural wonders

Falling avalanche, British Columbia, between 1894 and 1912.

Early fossil collecting

Man possibly looking for fossils, Mount Stephen, British Columbia, 1900.



Promotional poster produced by Canadian Pacific Railway to promote tourism in the Canadian Rockies, 1910.

Fossils in the spotlight

In a 1910 promotional booklet untitled The Challenge of the Mountains the Canadian Pacifique specifically listed the trilobite fossil discovery site on Mount Stephen as a tourist destination:

"The lower slopes of the mountain have one spot well worth visiting, the fossil bed, where for 150 yards the side of the mountain, for a height of 300 or 400 feet, has slid forward and broken into a number of shaly, shelving limestone slabs, exposing innumerable fossils."

The first female tourists in the Canadian Rockies

Mary Vaux photographing flowers in the Rocky Mountains, date unknown. One of the first tourists to the area was Mary Vaux of Philadelphia (who later married Charles Walcott). Vaux was a prominent artist and naturalist who took many photographs in the Canadian Rockies.

The Burgess Shale protected by Parks Canada

There is another reason we can thank the “iron horse” (the steam locomotive) for the Burgess Shale fossils. Today, the Burgess Shale (including the Mount Stephen Trilobite Beds) is located within Yoho National Park, under the protection of Parks Canada and closed off from casual visitors and fossil-hunters. This helps ensure the fossils are preserved for scientific research while remaining accessible to the public through special guided hikes (the area was added to the UNESCO World Heritage list in 1980)

But if it had not been for the railway, there might not have been any national parks in this area. The CPR’s focus on tourism and recognition of the huge economic potential of the region gave the company a strong incentive to keep the scenery pristine. As the CPR’s general manager, William Van Horne said, "Since we can’t export the scenery, we’ll have to import the tourists."

The economic importance of the tourist trade led the CPR to encourage the federal government to set aside huge swaths ofthe Rockies as reserves or national parks. This included the Mount Stephen reserve in 1886 — which eventually becameYoho National Park in 1901.

Timeline 1867 to 1909

- 1867, July 1: British North America Act: four provinces join to form Canada.
- 1870 Canada acquires the Northwest Territories.
- 1871 British Columbia joins Canada on the promise made by Sir John A. Macdonald to link B.C. to the rest of Canada by railroad within 10 years; Sir Sandford Fleming preliminary survey of the railway routes: 7 possible destinations on the Pacific coast.
- 1876 Prime Minister John A. Macdonald introduces his "National Policy", including a series of tariffs on imported goods and a renewed focus on a national railway.
- 1880, October 21: Contract for the completion of the Pacific Railway is signed.
- 1881, February 15: Canadian Pacific Railway is officially incorporated; search for an alternative passage through the Rocky Mountains begins.
- 1881, May 29: Discovery of the Rogers Pass.
- 1884 Railway reaches Kicking Horse Pass.
- 1885 North West Rebellion.
- 1885, November 7: Last spike at Craigellachie, B.C.; the CPR is officially finished.
- 1886 CPR builds Field Hotel (later renamed Mount Stephen House) and receives its first guests in the summer.
- 1886, Summer: First collections from the Trilobite Beds; CPR publishes first tourist pamphlet.
- 1886, July 4: The first passenger train from Montreal/Toronto arrives in Monroe, B.C.
- 1886, October 10: Creation of Mount Stephen Dominion Reserve.
- 1888 Charles Walcott’s first publication on fossils from the area.
- 1892 Whiteaves publication of Anomalocaris canadensis from the Trilobite Beds.
- 1897 First excursion by the German-Austrian Alpine Club up the Yoho valley.
- 1899 June: First arrival of Swiss guides.
- 1901 Mount Stephen Dominion Reserve is renamed Yoho National Park.
- 1902 CPR builds two log cabins on the shore of Emerald Lake.
- 1906, March 27: Creation of the Alpine Club of Canada; first annual camp at Yoho Pass in July.
- 1907 Walcott visits the Trilobite Beds.
- 1908 Walcott publishes an account of his discoveries in the Canadian Alpine Journal.
- 1909 Spiral Tunnels are completed, replacing the Big Hill; Discovery of the Burgess Shale fossils by Walcott

Learning activities: A Tale of Western Expansion and Scientific Exploration

Learning Objectives

1. Students explore how the history of the region has influenced Canadian culture and identity.
2. Students examine factors that led to the settlement of the Canadian west and explore technological achievements.

Since the construction of the CPR through the Rockies, Canadian, federal and provincial governments have taken a number of steps and measures to protect specific areas. From reserves to parks, portions of the Rocky Mountains in Alberta and B.C. are now designated as parks and managed by Parks Canada, and their provincial counterparts. The Burgess Shale has been on the list of the UNESCO World Heritage sites since 1980 and is now part of a broader designation as Canadian Rocky Mountain Parks.

Research and report on the following:

1. What are the criteria on the UNESCO World Heritage list that justify the designation of the Canadian Rocky Mountain Parks as a protected site?
2. Discuss the role that the Burgess Shale fossils play in the designation as a World Heritage site.
3. In the Burgeoning Tourism Industry section, there are a number of black and white photographs from the Mary Vaux collection. Describe her experience of having traveled in this region based on these photos.
4. Compare these actual photographs to the CPR promotional material. Is the promotional information representative of the actual tourist experience? Justify your answer.
5. Look at the colour souvenir postcard of Mount Stephen House. Imagine that you are recipient of this postcard. What does it convey about the tourist experience in the region?
6. What do you suppose is the economic impact:
    a. Of the CPR traveling through this region
    b. Of designating the Rocky Mountain Parks (including the Burgess Shell) as a UNESCO world heritage site .

Timeline section

Look at the timeline and pull out the events related to the construction of the railroad. How are these related to the discovery of the Burgess Shale fossils? Which event is most significant in making this discovery possible?

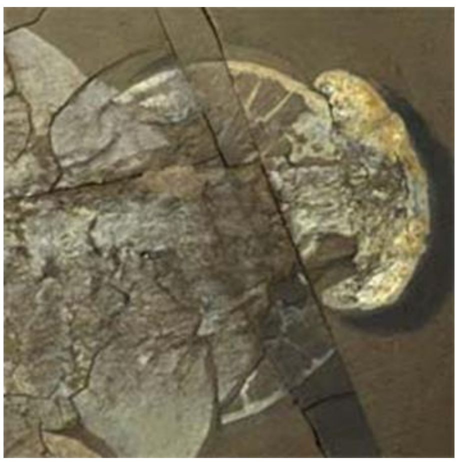
In the following section: A Late Decision and the First Fossil Discoveries examine the schematic showing the CPR line through the Rocky and Selkirk mountains. Identify the Kicking Horse pass. Discuss the challenges the CPR engineers had in designing a railroad through this kind of landscape.

The photograph showing the steaming train along the Kicking Horse Bridge with Mount Stephen in the background is evocative of the experience the visitors have of being on this train and of the challenges the CPR had in taking this path through the Rockies. Explain this statement from examining this photograph.

Anomalocaris canadensis - one hundred years of interpreting the Burgess Shale fossil record

The *Anomalocaris canadensis* jigsaw puzzle

Anomalocaris canadensis, whose name means "unlike the other shrimp, from Canada," at first seems to have little in common with shrimp we are familiar with today. First described in 1892, this 505 million year old animal from British Columbia's Burgess Shale has a complex history of description because parts of its body were described in isolation before it was realized they all belonged to the same animal. Trying to reassemble Anomalocaris fossils was like trying to put together a jigsaw puzzle where no one has seen the picture on the box for 505 million years.



1 Photo: Jean-Bernard Caron

The complete *Anomalocaris*

Anomalocaris canadensis (ROM 51211).The most complete specimen ever found was collected in 1991 by the Royal Ontario Museum. You can see from right to left, the pair of eyes, claws, lateral lobes along the body and the posterior fan. Specimen length = 222 mm. (Raymond Quarry).

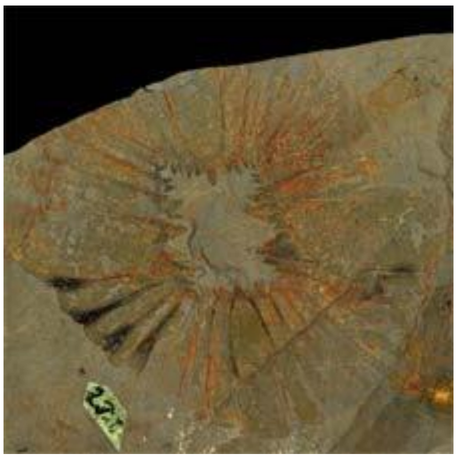
Confusion in the fossil record

The frontal appendage of Anomalocaris was initially described as the body of a shrimp. The mouth parts (or oral ring) were described as a jellyfish (*Peytoia nathorsti*). And a decomposed full body anomalocarid specimen was originally described as a sea cucumber (it is now known as *Laggania cambria*). Upon re-examination of this particular specimen, it was then incorrectly decided that it was actually a superimposition of a jellyfish on top of a sponge.

An appendage once thought to be a shrimp

Anomalocaris canadensis (GSC 3418) – Holotype. Individual claw. Specimen length = 76 mm. Mount Stephen Trilobite Beds (McConnell collection).

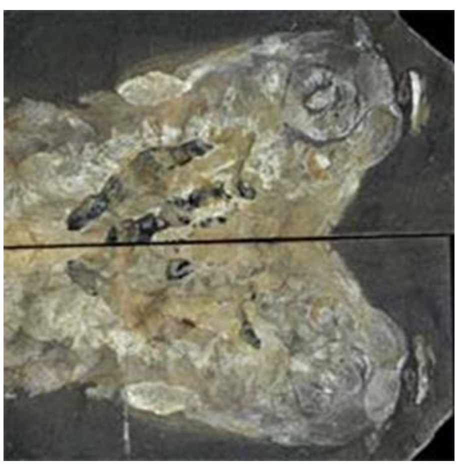
Photo: Jean-Bernard Caron © 2011, Geological Survey of Canada. All Rights Reserved.



A mouth once thought to be a jellyfish

Anomalocaris canadensis (USNM 57538) – Part and counterpart. Mouth parts originally described by Walcott as the holotype of Peytonia nathorsti, but this species is now invalid. Specimen diameter = 64 mm. Walcott Quarry.

Photo: Jean-Bernard Caron



A body once thought to be a sea cucumber

Laggania cambria (USNM 57555) – Holotype – Part and counterpart (top and bottom). Ventral view of an incomplete individual showing the mouth parts and eyes. Specimen length = 100 mm. Walcott Quarry. Photo: Jean-Bernard Caron © 2011, Smithsonian Institution – National Museum of Natural History. All Rights Reserved.

A scientific breakthrough

In the early 1980s, palaeontologist Harry Whittington was preparing a Burgess Shale fossil when he solved the mystery of *Anomalocaris*'s identity. Much to his surprise, Whittington uncovered two Anomalocaris “shrimps” attached to the head region of a large body, which also had the jellyfish *Peytoia* as its mouth apparatus. Collecting at the Burgess Shale by the Royal Ontario Museum in the early 1990s led to the discovery of several complete specimens, which allowed for the reconstruction of *Anomalocaris canadensis* with greater accuracy. *Anomalocaris* is now classified as a kind of primitive arthropod, a group that contains modern insects, arachnids, and crustaceans.

Why are only fragments of *Anomalocaris canadensis* fossils so often found? It is possible that as *Anomalocaris* decayed, body parts fell off and may have been fossilized in different locations. Mouth parts and claws were made of chitin (the same material composing the exoskeletons of insects) which made them more susceptible for preservation. It is equally (or perhaps even more) likely that individual body components were separated during regular moulting, and only the more resilient exoskeletal elements of the feeding apparatus (claws and oral ring) were preferentially preserved. Less resilient parts were probably rapidly degraded. The claws and complete oral ring would also behave differently in currents, and end up being deposited in different places. Claws, consisting of a single more-or-less continuous sheath, would survive much more commonly than complete oral rings, which would separate fairly quickly into smaller elements.

Anomalocaris uncovered

Anomalocaris canadensis (GSC 75555) – Part and counterpart. The specimen prepared by Harry Whittington that unlocked the mystery. It shows a pair of claws and part of the mouth (left). Specimen length = 127 mm. Raymond Quarry. (GSC 1966-1967 collection).

Photo: Jean-Bernard Caron

Ecological interpretation of *Anomalocaris canadensis*

We now know that *Anomalocaris* was a carnivore reaching a maximum length of 100 cm. *Anomalocaris*'s streamlined body would have been ideal for swimming. Undulatory movements of the side flaps propelled the animal through the water column. While swimming*, Anomalocaris*'s frontal appendages would hang below the body, but it would thrust its head and appendages forward 180° to attack prey as needed.

Dietary habits are usually inferred from preserved gut contents (directly showing what the animals ate) and from specialized body structures, such as those used in feeding. Anomalocaris had large eyes, grasping limbs with sharp pointed spines, mouthparts with numerous blade-like teeth, and lateral lobes used for swimming (see above animation). Together with its large size, these features strongly suggest Anomalocaris was a predator. But what kind of prey did this animal feed upon? There is no evidence of gut contents in the few known complete bodies of Anomalocaris, indicating that perhaps it only fed on soft-bodied prey. "Soft" prey is less likely to be preserved in the gut than the remains of "shelly" animals with hard mineralized exoskeletons.

Shelly remains have been found within the gut of other predatory animals known from the Burgess Shale, such as the priapulid worm *Ottoia prolifica*, and the arthropod *Sidneyia inexpectans*.

Anomalocaris recreated

A digital animation of an *Anomalocaris canadensis* swimming through an assemblage of sponges. This giant predator belongs to a primitive group of arthropod and probably swam with formidable speed using the numerous lobes along its body. The non-mineralized bodies of many Burgess Shale animals were no protection against the powerful, spine-edged claws.

The first great predator

The Burgess Shale records what life was like during the "Cambrian Explosion". The Cambrian Explosion refers to the sudden appearance in the fossil record of complex animals starting about 540 million years ago. It may represent the most important evolutionary event in the history of life on Earth. The "explosion" is particularly remarkable because all major animal phyla (representing different body plans) appeared during this time, changing the biosphere forever.

Despite being separated by 505 million years, the structure of the food web from the Burgess Shale ecosystem is surprisingly similar to what we see in modern marine communities, although the individual species involved are clearly quite different. This suggests that basic feeding relationships were quickly established during the Cambrian Explosion and have remained relatively unchanged to the present.

Various feeding strategies are known in the Burgess Shale, including herbivory, detritus feeding (consuming decaying organic matter), suspension feeding (straining food particles suspended in water), and predation and scavenging. The accurate reconstruction of Anomalocaris canadensis led to the recognition that other large predators akin to Anomalocaris existed during that time (*Laggania cambria* first described as a sea cucumber and *Hurdia victoria*). The evolution of predation is regarded as one of the most significant feeding strategies to appear during the Cambrian Explosion. Today, predators play an important role in structuring animal communities by controlling prey populations. Although *Anomalocaris* was relatively rare in the Burgess Shale, its position in the food chain as a top predator made it an important part of the ecosystem.

Top of the food chain

Reconstruction of the Burgess Shale food web. Spheres represent taxa. The taxa at the bottom of this network are primary producers and the taxa at the top are predators. (modified from Dunne et al.). Graphic: Jacquie Jeanes © 2011, Royal Ontario Museum. All Rights Reserved

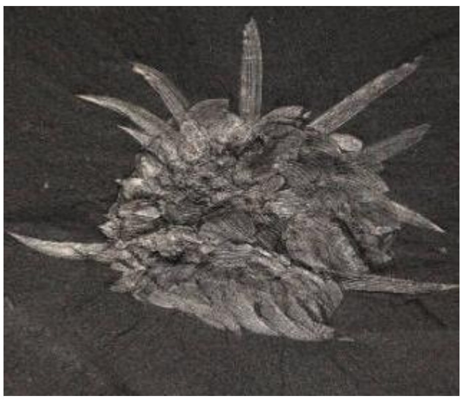
Bite marks?

Olenoides serratus (ROM 54365). Nearly complete individual; presumed carcass with healed injury on left thorax. Specimen length = 65 mm. Specimen dry – direct light (left) and coated with ammonium chloride sublimate to show details (right). Trilobite Beds on Mount Stephen.

Photos: Jean-Bernard Caron

Defenses against predators must evolve

Predation was likely an important driving force for the diversification seen in the Cambrian Explosion, as animals evolved new strategies to eat and avoid being eaten. The development of swimming as a means of escape or the emergence of hardened exoskeletons and defensive features is also thought to have been a response to increased pressure from predators like *Anomalocaris canadensis*. Trilobites like *Olenoides* had hard mineralized exoskeletons. Some *Olenoides* fossils show unmistakable evidence of healed injuries, suggesting they may have been preyed upon, likely in their “soft-shell” growth phase, by larger arthropods such as *Anomalocaris.* The development of rows of spines on the back of *Hallucigenia* and the body armour of small, overlapping scales and blades on *Wiwaxia* are both examples of potential defensive mechanisms against predators.



Spines and body armour

The lobopod animal *Hallucigenia* (top, size = 2 cm) and the armoured slug-like animal *Wiwaxia* (bottom, size = 3 cm). *Hallucigenia* possesses rows of spines on the back of its body while *Wiwaxia* developed a body armour of small, overlapping scales and blades. Both traits may have evolved as a defensive mechanism against predators. Photos: Jean-Bernard Caron © 2011, Royal Ontario Museum. All Rights Reserved.

Learning activity: mixed up fossils

Learning Objectives

- Learn about our current interpretations of the largest known predator from the Burgess Shale - Anomalocaris canadensis.
- Explore the challenges faced in interpreting the fossil record of the Burgess Shale.
- Discover the importance of predators like Anomalocaris canadensis in driving the diversification seen in the Burgess Shale community.

When attempting to reconstruct the 505 million year old Burgess Shale ecosystem, researchers must consider how the Burgess Shale fossils formed. Reconstructing the original anatomy of fossilized organisms is often based on fragmentary or incomplete material and often requires assumptions. Failing to understand the connection between the original organism and how it became a fossil may lead to a misinterpretation of some anatomical characters, or the improper classification of a fossil. Over the past one hundred years, our view of *Anomalocaris* has gone from it being a strange shrimp, to the largest known Cambrian predator. Changes in our interpretation of *Anomalocaris canadensis* fossils have radically altered both our view of this animal and its role in its environment.

Select an animal, extinct or extant (still living today), and imagine its remains were scattered during the process of fossilization.

1. Describe how isolated body parts might be interpreted by palaeontologists (i.e. in Anomalocaris canadensis the isolated mouth was considered to be a jellyfish).
2. If some body parts were missing, how might the ecology of this animal be reconstructed differently (i.e. if we did not have *Anomalocaris*'s grasping claws we might not know that it was a predator)? Let's consider the ramifications of mistakes made when interpreting the fossil record. Consider the animal you selected above.
3. What ecosystem does your animal belong to?
4. What is the niche (ecological role) of your animal?
5. If you were to remove your animal from its ecosystem, how would the ecosystem function differently (i.e. if we remove *Anomalocaris canadensis* from the fossil record we lose the largest predator in the ecosystem)?

Innovative photography in the Rocky Mountains

The Discovery of the Burgess Shale by Charles D. Walcott

A horse train carries supplies along the trail to the Burgess Pass, 1910. © 2011, Whyte Museum of the Canadian Rockies. All Rights Reserved

Charles Doolittle Walcott (1850–1927), geologist and fourth Secretary of the Smithsonian Institution, is best remembered for discovering the main Burgess Shale site between Wapta Mountain and Mount Field, in 1909. This rock formation in Yoho National Park of British Columbia contains many unique fossils, including rare soft-bodied forms; it is one of the most important finds in paleontology, revealing much about marine life on earth during the Cambrian Period, 505 million years ago. For its importance to evolutionary studies, the Burgess Shale was inscribed on the UNESCO World Heritage List in 1980, and is now part of the Canadian Rocky Mountain Parks World Heritage site.

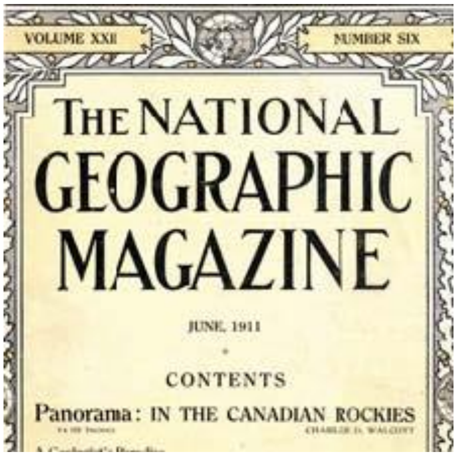
2C.D. Walcott taking pictures using a Cirkut Camera (undated). © 2011, Erin Younger Family Collection. All Rights Reserved.

Walcott and panoramic photography

Walcott began experimenting with panoramic photography in 1905. This was cutting edge technology at the time, as the Irkut Camera had been patented only in 1904 and manufactured by Kodak in 1905. By the time of his last field expedition in 1925, he had created more than 650 photographic panoramas of the Canadian Rockies. His images offer both the scenic grandeur of the Rockies and the documentary evidence of a geologist at work.

In an article from the National Geographic magazine (see below), it was said of Walcott's work in the Rockies:

"NO ONE would be more surprised and delighted with Mr. Walcott's beautiful panoramic view, which is published as a Supplement to this number, than the American scientist whose discoveries gave a practical value to Daguerre's invention of photography (...) Mr. Walcott's panorama is the most marvelous mountain view that has ever been published, and is remarkable not only for its exceeding beauty, but also because of the many lessons in geography learned from studying it." (National Geographic magazine, June 1911).



Announcing the discovery to the world

Front page of the June 1911 issue of National Geographic with Walcott's article on the Burgess Shale called "A Geologist's Paradise."

Panorama of the Burgess Shale, c. 1910

The National Geographic article included this supplement featuring a panoramic image of the area. The image folded out to a size of 2.5m (8 feet), making it the single largest photograph ever included in the magazine. About 100,000 copies were printed at the time; few of these copies remain today.

The Burgess Shale locality

Detail of the Panorama (shown above) showing the main Burgess Shale locality (now the Walcott Quarry), marked by an "X".

Walcott in the Canadian Rockies

The number 3 on the map corresponds to the panoramic photograph shown above. Other numbers on the map show some other locations to which Walcott traveled and photographed using the Cirkut camera.

This Cirkut camera is of a similar model and age as the one used by Charles Walcott to photograph the Canadian Rockies in the early twentieth century. Photo: Jean-Bernard Caron © 2011, Royal Ontario Museum. All Rights Reserved.

Photographing in the Canadian Rockies

To document his scientific work Walcott mainly used a Cirkut camera, bringing enough photographic equipment to load a pack horse. In the early 1900s, photography in the field was no simple matter. The metal and wood camera itself weighed 4kilograms (9 pounds). If you count the complete outfit, with tripod, top and cases, it weighed 20 kilograms (44 pounds).Walcott preferred glass-plate negatives, which meant hauling heavy, fragile glass over the mountains. Plastic film often faded before Walcott could get it developed. Early film was made of nitrocellulose plasticized with camphor which is highly flammable. It was also less stable under extreme temperature changes. Although lighter in weight, plastic film proved to be problematic for Walcott.

It was hard to tell if the camera needed adjusting in the field. At the start of each expedition, Walcott took a few test shots and shipped the negatives to Washington. The Smithsonian's official photographer, T.W. Smillie, made prints and sent a telegram to Walcott, advising him on technical problems and exposure. Walcott then made adjustments before proceeding to more remote locations.

Walcott on photography in the Rockies

Getting these shots required patience and skill. Walcott himself commented: "Often in the Canadian Rockies days will pass in which atmospheric conditions are unfavorable for an extended view — dust blown in from the plains, smoke from forest fires . . . the best conditions usually occur after a heavy storm of either snow or rain has cleared the air." (National Geographic magazine, June 1911).

Walcott's family at Wapta Falls (Yoho National Park), July 1910 (left to right: Stuart, Helena, Sidney, Charles, Helen).

A family affair

Walcott's wife, Helena, and three of their four children often accompanied him on his earlier expeditions to the Rockies, where the children joined in the work of splitting rocks in search of fossils. Walcott named one of the Burgess Shale animals *Sidneyia,* after his son Sidney, who discovered the first specimen in 1910. Helena died in 1911 in a train wreck, and three years later Walcott married Mary Vaux, a talented artist, photographer, and mountaineer. She took an interest in the botany of the Rockies and assisted Walcott in the field.

Photograph of Sidneyia inexpectens *specimen, the first of which was discovered by Walcott's son, Sidney, for whom it was named. Right, retouched photograph of the same specimen published by Walcott.*

Panoramic photography: more Canadian connections

Two Canadians, John Connon and William J. Johnston were involved in the development of the Cirkut camera used by Walcott in the Canadian Rockies. As reported by Charles Long in his article In the Round, published in The Beaver(April/May 2000), these Canadians played an important pioneering role which eventually made it possible for a camera to take a 360º panoramic view in one continuous exposure.

An experienced photographer, John Connon designed the modifications on a camera to make this kind of photograph possible. His first 360º panoramic view was of the town of Elora, Ontario taken from the top of the town's tallest building in February 1887. Although he succeeded in patenting his design, it was never manufactured.

Eventually another Canadian, William J. Johnston, took Connon's design a step further. "The same basic design surfaced again in 1904 as the Cirkut Camera, patented by (...) William J. Johnston, and manufactured by the Rochester Panoramic Camera Company. Two quick mergers and two years later, that too became part of the American company Eastman Kodak. The Kodak Cirkut would become the most successful workhorse of the industry, sold continuously until 1949, and still in use today." (Charles Long, The Beaver, April/May 2000).

Summary of an Interview with Dr. Caron

Dr. Jean-Bernard Caron talks about the Cirkut Camera and the panoramic photographs taken by Walcott.

Walcott photography

SUMMARY: Jean-Bernard Caron, Curator of invertebrate Palaeontology at the Royal Ontario Museum, discusses Walcott's use of the Kodak Cirkut Camera to take panoramic views of the landscapes in the Rockies. (2:35)

DESCRIPTION: Caron shows what the Kodak Cirkut Camera looked like Walcott used photography to study the rocks and the rock formations in the Canadian Rockies while he was exploring. Andin particular he used this type of camera, called a Kodak Cirkut camera, which is a panoramic camera, which is basically a camera which is set on a tripod, which eventually is on a rotating plate, so you can actually take panoramas up to 360degrees.

DESCRIPTION: Panorama taken by Walcott that shows the Burgess Shale and this is one of the most famous panoramas taken by Walcott himself, showing the Burgess Shale, which is located around here. Walcott's camp will have been around here, so every day he will have walked and used his horses to go to the quarry, which would have been located around here. This is an image that was taken probably in 1910, and eventually was published by National Geographic in 1911. And to this day it remains the largest picture ever published by any magazine anywhere in the world. It's more than 2 metres in width. The actual panorama was offered as a supplement to all the subscribers of National Geographic and we have a copy here that is relatively rare. And this is an original reprint of this particular picture.

DESCRIPTION: Copy of National Geographic magazine with large foldout panoramas taken by Walcott But most of these images were used to do some serious geological work. And many of these images were actually published in this monograph, describing the rocks of the Canadian Rockies. In fact, if you open this volume, in many places you are going to have large panoramas of many landscapes. So once again he used these images to do his work, there's usually a description at the bottom of these images about what he sees on these images, and it's a way to quickly take information in the field knowing that in the Canadian Rockies, the weather can change very quickly, and it's very hard to stay in one place and probably draw all these mountains without being rained on. So usually photography still today is the best way to study the rocks.

Learning activity: Innovative Photography

Learning Objectives

- Students examine technological advances that promoted changes to Canada.

Panoramic photography started in 1843, but as camera technology evolved, so did the ways in which the method was used. New applications included shots of cities, landscapes, and large groups of people.

Read the above, and do additional research if necessary to explain:

1. Why was the panoramic camera important to Charles Walcott in the Canadian Rocky Mountains.
2. How does the design of the camera help to take panoramic pictures?
3. What record did Walcott set with a Cirkut camera?
4. Considering where Walcott did his research, list the inconveniences and challenges associated with using this camera.

Marrella splendens - recreating life during the Cambrian Period

The beautiful lace crab

Marrella splendens was one of the first Burgess Shale fossils found by palaeontologist Charles Walcott, and sketchesappear in his notebook as early as August 31st, 1909 (see picture below). Walcott informally named them “lace crabs” atthe time.

The next summer, on August 9, 1910, Walcott and his son Stuart found the “lace crab beds” marking the discovery of thefossil-bearing horizon of the Walcott Quarry in British Columbia’s Burgess Shale.

Of the hundreds of thousands of fossil specimens subsequently obtained from the Burgess Shale, *Marrella* splendens is one of the most common species, with more than 25,000 specimens collected.

The genus was named *Marrella* after Dr. John Marr, a palaeontologist at Cambridge University and friend of Walcott. Thespecies name comes from the Latin word splendens for beautiful or brilliant.

Walcott's notebook: The discoveries

Meet *Marrella*

In his 1909 field notebook Charles Walcott mentioned the discovery of soft-bodied fossils from the "Stephen Formation" (today's Burgess Shale). Here he sketched fossils depicting three arthropods and one sponge. The sketch on the top left, would later be known as *Marrella* splendens.

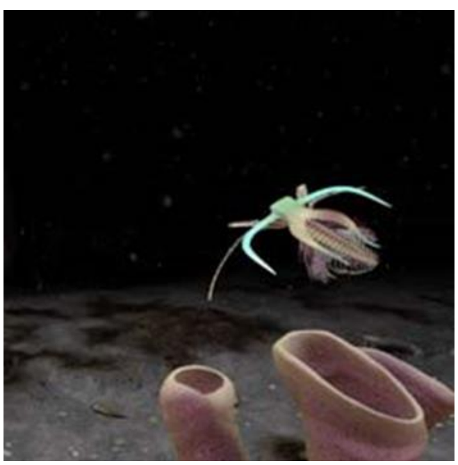
Photo: Brian Boyle

Marrella splendens, (size = 16 mm) a common fossil from the "Phyllopod bed". Photo: Jean-Bernard Caron

The morphology of *Marrella* splendens

Marrella is a small arthropod (maximum size 3 cm) with a wedge-shaped head shield bearing two pairs of prominent spines that extend back along most of the length of the body. The head has a pair of long, thin, segmented antennae projecting towards the front, and a pair of paddle-like appendages with numerous bushy bristles along their edges positioned more laterally.

Behind the head, the body consists of 26 segments, each bearing a pair of two-branched appendages. The lower branches were used for walking, and the upper branches bore many long filaments which functioned mainly as respiratory organs called gills. The lower branches of the last twelve pairs of appendages curve inwards, forming a tapering net-like structure below the body that was used to trap food particles in water currents and pass them towards the mouth which was positioned near the front of the animal on the ventral side (see 3D animation). *Marrella* walked along the sea floor while deposit feeding; swimming was achieved in part by “rowing” with the paddle-like head appendages and also by swinging the upper branches of the appendages sequentially to create undulatory movements. Its antennae would be used to sense the environment and locate food items.



Marrella swimming

Digital animation of *Marrella* splendens swimming near an assemblage of sponges. This small arthropod erupts in front of camera, and swims away using a pair of paddle-like antennae and numerous specialized swimming appendages along its body.

How did the Burgess Shale form?

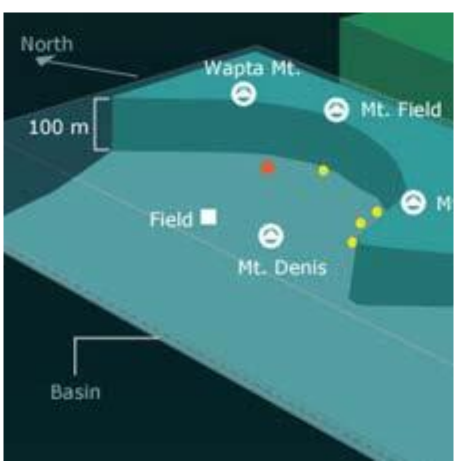
The original Burgess Shale site refers to a fossil-rich horizon in the Rocky Mountains of British Columbia. The most important excavations were done within a two-metre-thick rock section made up of a series of thin layers containing the exquisitely preserved soft-bodied fossils. This section was named the "Phyllopod bed" by Walcott, in reference to the leaf-like structure of the appendages of certain abundant arthropods, including *Marrella* .

The limits of the Phyllopod Bed in the Walcott Quarry are indicated by a double arrow. Photo: Desmond Collins © 2011, Royal Ontario Museum.

The Burgess Shale fossils are preserved in a type of sedimentary rock known as shale. Shale is a variety of mudstone (originally formed from deposits of fine mud) that can be easily split apart. The different fossil layers of the Burgess Shale represent different mud deposits, originally laid down in sheet-like horizontal beds ranging from a few millimetres up to several centimetres in thickness. The individual beds can still be seen in the Burgess Shale today, but the layers are now much thinner due to dewatering and compression caused by the accumulated weight of hundreds of metres of sediments deposited on top of them. Compression is most easily grasped by looking at the fossils themselves, which show how the animals have lost their original three dimensionality and are squashed almost flat.

The compressed seafloor muds of the Burgess Shale were transformed into shale when they encountered increased temperature and pressure during their geological history. It was during the main stage of the formation of the Rocky Mountains (about 65 million years ago, at the end of the age of dinosaurs!) that most of the transformations occurred.

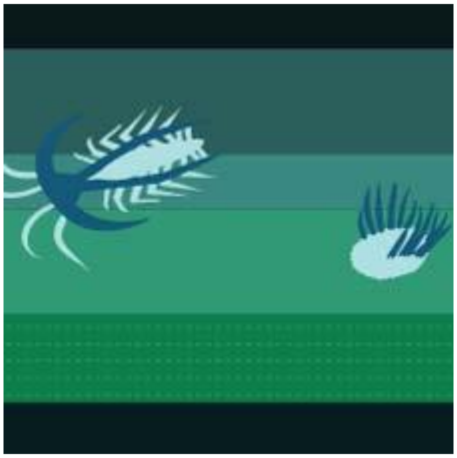
During these changes, the original mudstone minerals and parts of the fossils which were originally preserved as carbon were secondarily replaced by different minerals with flatter structures which aligned with each other to form parallel layers. The resulting shale tends to split apart into thin sheets. The presence of a fossil in the shale creates a zone of weakness between layers, so when the rock is broken open it is more likely to split along a plane containing a fossil, leaving some of the fossil on each mirror-imaged surface (as part and counterpart).



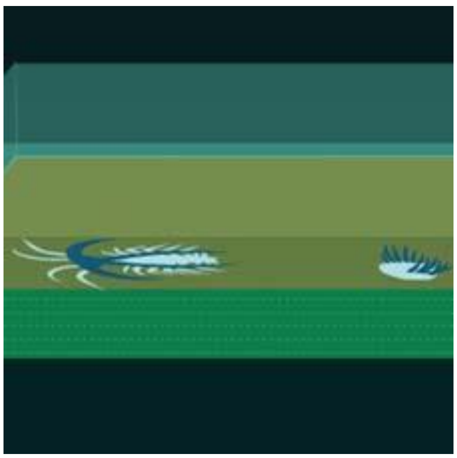
A 3 dimensional reconstruction of the palaeoenvironment of the Burgess Shale showing the the underwater topography along with the relative positions of the modern-day mountains and fossil localities. Graphic: Jacquie Jeanes

How the Burgess Shale organisms fossilized

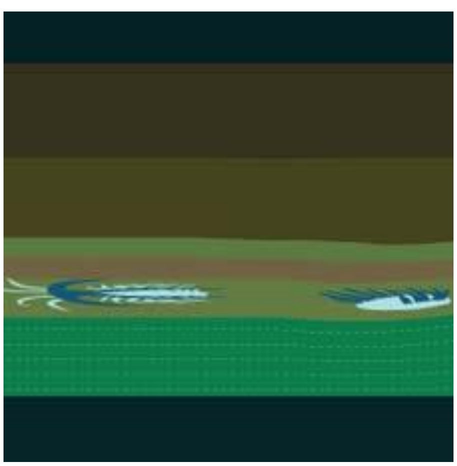
The creatures found in the Burgess Shale lived 505 million years ago during the Cambrian Period near the start of the Paleozoic Era. These organisms lived in a relatively deep water basin at the base of a large submarine cliff known as the Cathedral Escarpment. The Escarpment was about 200 metres high before mud and other sediments began to fill in the basin. Periodically, the calm sea floor would be overwhelmed by torrents of mud – rapidly burying living and dead organisms in a disorganized mass. This process continued for perhaps hundreds of thousands of years, with successive layers of sediment eventually filling the original



The process of fossilization: Step 1 – death Graphic: Jacquie Jeanes © 2011, Royal Ontario Museum. All Rights Reserved.



The process of fossilization: Step 2 – burial Graphic: Jacquie Jeanes © 2011, Royal Ontario Museum. All Rights Reserved.



The process of fossilization: Step 3 – fossilization Graphic: Jacquie Jeanes © 2011, Royal Ontario Museum. All Rights Reserved.

basin. This rapid burial accounts, in part, for the exceptional preservation of the Burgess Shale fossils.

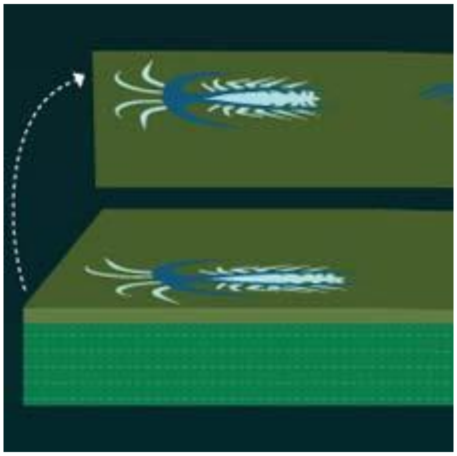
What makes the Burgess Shale fossils different from other fossils?

The Burgess Shale is famous for the exquisite preservation of its soft-bodied fossils. It is exceptional to find nearly complete animals fossilized, especially ones like priapulid worms or ctenophores (comb jellies) that had only soft tissue and no mineralized structures. Typically it is only the hard parts of organisms (e.g. shell or bone) that become fossils. When soft tissues fossilize, palaeontologists can gain a tremendous amount of ecological and biological information about a particular time in the Earth's history. The Burgess Shale is such a site, providing the best window on animal communities during the middle part of the Cambrian. For more information about why soft body parts were preserved in the Burgess Shale click here.

In modern marine settings, animals with mineralized body parts (e.g. shells or carapaces) account for only a minor component of the total diversity. This is also the case in most Burgess Shale deposits where the shelly assemblage usually represents a small percentage of specimens collected. Thus, without the fossilized remains of soft-bodied organisms, especially from the Burgess Shale, our knowledge of Cambrian ecosystems would be extremely limited.

Burgess Shale-type deposits around the world

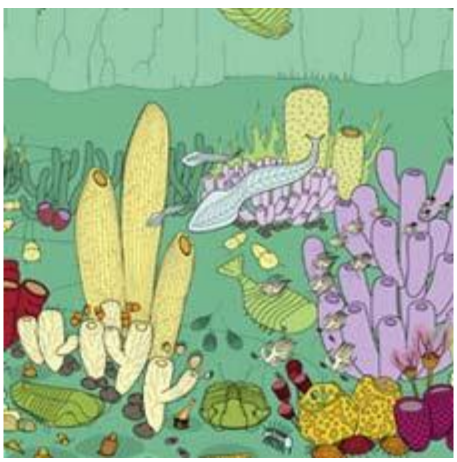
Exceptionally well-preserved soft-bodied fossils dating from the Cambrian were first found from the Burgess Shale in British Columbia over 100 years ago. Today, dozens of Burgess Shale-type deposits with comparable assemblages of fossils have been found around the world. These deposits are characterized by a similar mode of preservation called "Burgess Shale-type preservation".



The process of fossilization: Step 4 – Exhumation and discovery of the fossils Graphic: Jacquie Jeanes © 2011, Royal Ontario Museum. All Rights Reserved.

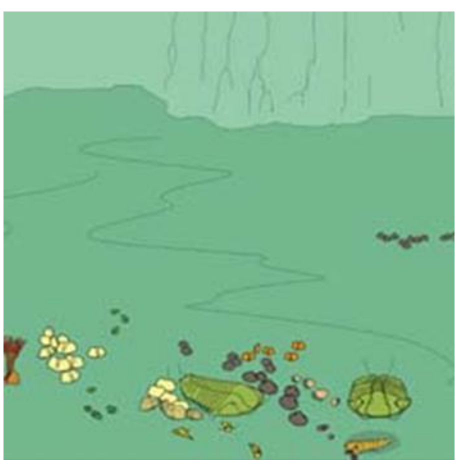
The most notable sites for Burgess Shale-type preservation are the Burgess Shale localities in British Columbia (Walcott Quarry – the original site, Raymond Quarry, and Collins Quarry in Yoho National Park), along with the Maotianshan Shales of China. Other significant occurrences include the Kaili deposit in China, sites in the western United States of America (Spence Shale and Marjum and Wheeler Formations in Utah, Pioche Formation in Nevada), Greenland (Sirius asset), and Australia (Emu Bay Shale).

Similarities among various Burgess Shale-type deposits around the world suggest that the deep marine ecosystem was geographically uniform. Similar types of animal fossils have been recovered through this whole interval, spanning at least15 million years. The characteristic assemblage of organisms is often referred to as the Burgess Shale-type biota.



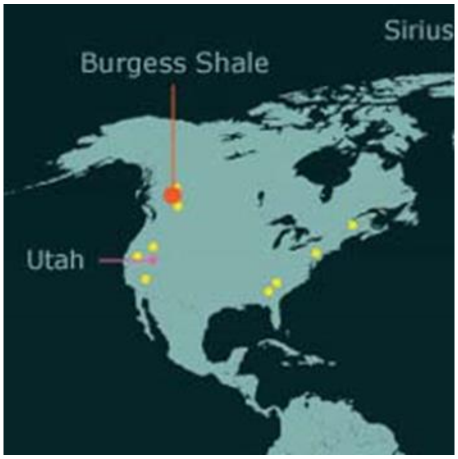
The Burgess Shale community

Reconstruction of the Burgess Shale community (as seen in the Walcott Quarry).



The Burgess Shale community - without soft-bodied animals

The reconstruction shows how the community would look if only animals with mineralized parts were present.



Mapping the world's Burgess Shale-type deposits

Locations of Main Burgess Shale-Type Deposits. Graphic: Jacquie Jeanes Yoho National Park of Canada, British Columbia, CANADA © 2011, Royal Ontario Museum. All Rights Reserved.

View taken along the trail leading to the Middle Cambrian Kaili locality, Guizhou Province, China. Photo: Jean-Bernard Caron © 2011, Royal Ontario Museum. All Rights Reserved.

Chinese Burgess-Shale type locality

Marrella is not only found in Canada

Fossils of *Marrella* are not limited to the Walcott Quarry. Other Burgess Shale locations with *Marrella* fossils include the Raymond Quarry, Mount Field, Mount Stephen, and Mount Odaray. Recently, *Marrella* species have also been found in the Kaili Biota of southwest China.

Marrella specimen from Kaili

Specimen of the arthropod *Marrella* (size = 6.4 cm) from the Kaili Biota in Ghuizhou Province (China). This is the only occurrence of *Marrella* outside the Burgess Shale localities in Yoho National Park. Photo: Jih-Pai Lin © 2011, Nanjing Institute of Geology and Palaeontology. All Rights Reserved.

Learning activity: key fossil sites around the world

Learning Objectives

- Learn about our current interpretations of the common Burgess Shale arthropod *Marrella splendens*.
- Explore how the Burgess Shale formed.
- Describe how fossils are formed and why the fossilization seen in the Burgess Shale is extremely unusual and why sites like the Burgess Shale provide a wealth of biological and ecological information about ancient life.

For palaeontologists, the Burgess Shale provides the best window on animal communities during the middle part of the Cambrian. Other fossil sites around the world provide rare glimpses to other important times in the Earth's past.

Pick one of the following significant fossil sites:

- Ashfall Fossil Beds
- Auca Mahuevo
- Dinosaur Provincial Park
- Florissant Fossil Beds
- Green River Formation
- La Brea Tar Pits
- Messel Oil Shale
- Mistaken Point
- Solnhofen Limestone

Conduct research to answer the following questions:

1. What time period does this fossil site represent?
2. What types of organisms are found at this location? Are any specimens famous?
3. How did the organisms fossilize? What makes the preservation at this site significant?
4. What clues does this fossil site provide about the history of the Earth?
5. What steps been taken to protect this site and to manage how the fossils are collected, maintained, and studied?

Opabinia regalis - classifying the bizarre creatures found in the Burgess Shale

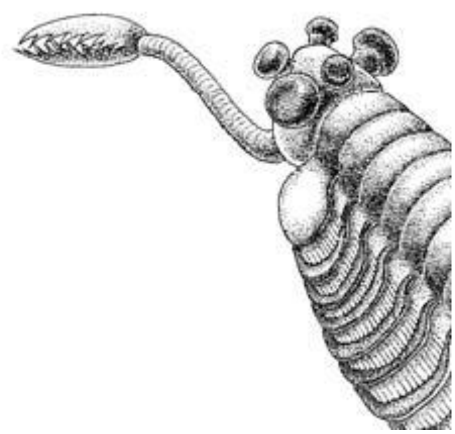
Opabinia regalis *(USNM 57683) – Lectotype. Complete specimen preserved laterally showing the proboscis, mouth and gut, four of the five eyes and lateral lobes. Specimen length (with proboscis) = 72 mm. Walcott Quarry.*

Opabinia regalis is no laughing matter

Opabinia regalis was first described in 1912 by its discoverer Charles Walcott. Because of its clearly unique morphology,505 million year old *Opabinia* became one of the most iconic fossils from the Burgess Shale. With such an unusual body, speculation about its affinities and lifestyle soon followed.

It wasn't until a major redescription in 1975 that *Opabinia* was revealed to be truly one of the most enigmatic of all fossils. It was so unusual, in fact, that when palaeontologist Harry Whittington, an expert on the Burgess Shale, showed an early version of his reconstruction in a meeting of palaeontologists in 1972, the whole room burst out laughing!

The importance of the Burgess Shale to understanding the Cambrian explosion



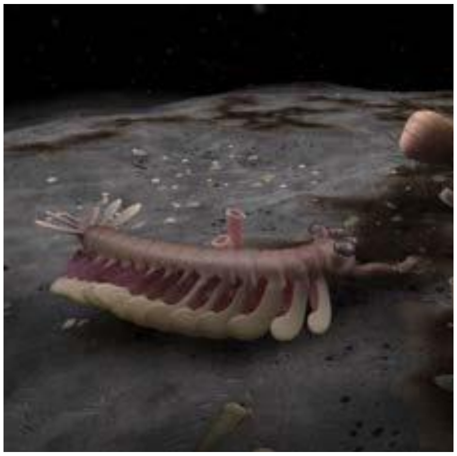
3Reconstruction of Opabinia regalis.

Opabinia regalis lived near the close of the "Cambrian Explosion". The Cambrian Explosion refers to the sudden appearance in the fossil record of complex animals. It may represent the most important evolutionary event in the history of life on Earth.

The beginning of the "Explosion" is generally placed about 542 million years ago, during the Cambrian Period at the start of the Palaeozoic Era. The Burgess Shale, at 505 million years old, records the tail end of this event. By the end of the Cambrian, every major animal phylum (i.e. different body plans) was firmly established, and life after the Cambrian was radically different from what had gone before. So it is safe to call this event an "Explosion" - it was crucial to the evolution of life on Earth as we know it.

Why did the Cambrian Explosion happen when it did, and why was it such a unique event? While there is no current consensus among scientists, most researchers agree the Explosion cannot be ascribed to a single, simple mechanism. The potential triggers can be classified in three main categories: environmental, genetic, and ecological. Deciphering the impact of each of these factors remains one of the most important challenges faced by palaeontologists today.

How do palaeontologists classify strange animals like *Opabinia regalis*?



A digital animation of an Opabinia regalis *swimming around an assemblage of sponges. This primitive arthropod with five eyes and a "trump" was probably an efficient predator.*

Like *Opabinia,* many fossils found in the Burgess Shale are difficult to classify. Part of the problem is that some species are poorly known - i.e., there is not enough well-preserved fossil material to describe the anatomy of the animals with certainty. *Opabinia* fossils are rare, with only 42 specimens currently (as of 2011) known from all collections, but overall its anatomy is relatively well preserved. Thus difficulties in interpreting the affinities of *Opabinia* are more related to its bizarre anatomy: *Opabinia* displays only some of the traits associated with familiar groups and possesses a combination of traits that remains at odds with what we know for any living or extinct organisms.

Because of the jointed claws on its proboscis, *Opabinia* is classified, along with another iconic animal from the Burgess Shale, Anomalocaris canadensis, as a primitive arthropod in a group called the anomalocaridids (see learning object *Anomalocaris canadensis*). Today, arthropods are the most diverse of all animal groups, a distinction they have probably held over the last 500 million years. Characterized by a segmented body, a rigid, articulated external covering(exoskeleton), and jointed limbs, arthropods are represented today by spiders, shrimps, insects, and millipedes. While *Opabinia regalis* does not closely resemble modern arthropods, it is believed to represent one of the most primitive species in the evolution of this group.

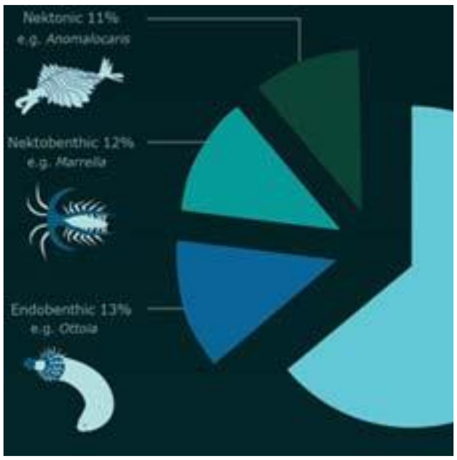
Opabinia regalis – *Commemorative stamp showing the famous animal on the top right corner as part of a series on prehistoric life. Photo: Jean-Bernard Caron*

The bizarrest of the bizarre

Opabinia is quite unlike any animal on our planet today. It had five compound eyes (each mounted on a short stalk), a frontal “nozzle” or proboscis, a body with repeated lobes and gills, and a prominent tail fan. Body length ranged between 4.3 and 7.0 cm - excluding the proboscis, which was four times longer than its head.

Opabinia was a swimmer. Rippling waves along its lobes propelled it forward, while it used its tail fan to steer or maintain stability. The proboscis was highly flexible, ending with two opposing claws each with five or six spines. *Opabinia* was likely a carnivore and used the claws on its proboscis to grasp soft food items and carry them towards its mouth, which was located under the base of the proboscis.

Why is *Opabinia* regalis so strange?



This pie chart illustrates the relative abundance of different lifestyles in the Burgess Shale: Nektonic (swimmers), Nektobenthic (swimmers/crawlers), Endobenthic (burrowers) and Epibenthic (crawlers). Graphic: Jacquie Jeanes © 2011, Royal Ontario Museum

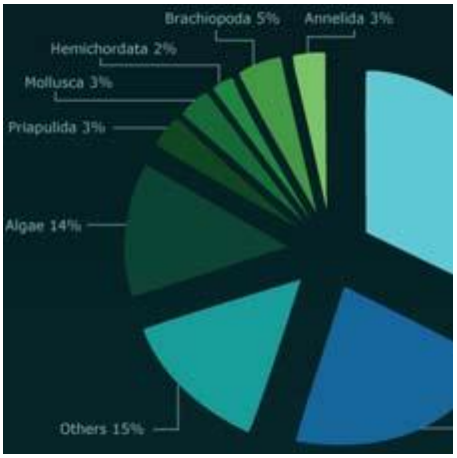
Cambrian seas teemed with animals of various sizes, shapes, and ecologies. Strategies for obtaining nutrients expanded to include suspension feeding (filtering particles of food out of the water), deposit feeding (gathering particles of food that settled on the sea floor), predation (actively capturing and devouring other animals), scavenging (finding and eating dead organisms), and grazing (munching algae and microbial mats). Some lived on or in the sea floor (benthic), while others (including *Opabinia* regalis) actively swam in the water column, but were still dependent on the benthos for foraging(nektobenthic). The rapid appearance of such a wide variety of animals during the Cambrian Explosion led to the development of radical new ecological interactions. As the number and variety of organisms increased, they occupied a variety of newly created marine environments and habitats.

New ecological niches (particular spaces in an ecosystem) would have been created by the organisms interacting with their environment. Moving into previously-unexploited environments would have allowed even a poorly-adapted animal to survive, perhaps with one of the more "exotic" body plans. For example, the emergence of predators like *Opabinia* might have stimulated the evolution of hardened exteriors for protection, or swimming as a means of escape. Before predation became widespread, early "experiments" in different body plans could have briefly thrived because species interactions were probably more limited.

Animal phyla – 500 million years ago and today

By the end of the Cambrian, every major animal phylum known today was firmly established. Primitive members of animal phyla found in the Burgess Shale include the following:

Annelida: These elongate, many-segmented animals are represented today by earthworms and leeches. The annelid body is covered by a thin flexible cuticle that is not moulted after the adult stage is reached.



This pie chart illustrates the relative abundance of groups of related species, such as the arthropods, in the Burgess Shale of the Walcott Quarry. Graphic: Jacquie Jeanes © 2011, Royal Ontario Museum. All Rights Reserved.

Arthropoda: Today, arthropods are the most diverse of all animal groups. Characterized by a segmented body, rigid exoskeleton, and jointed limbs, this group is represented today by insects, spiders, centipedes, and crustaceans. Arthropods grow by shedding their exoskeleton (a process called moulting), which can harden or even mineralize in some cases (such as in crabs).

Brachiopoda: Brachiopods are bottom-dwelling marine suspension-feeding animals enclosed in a two-part shell. Most forms attach to a surface (either the sea floor or on other organisms) via a flexible cylindrical organ called a pedicle. Although some species still survive, the phylum was hit hard by the Permian mass extinction about 250 million years ago.

Chordata: Chordates are a group of animals united by the possession of a notochord. Members of this phylum include mammals, fish, and reptiles with their defining backbone and spinal chord.

Ctenophora: Ctenophores are radially organized animals with a simple body plan superficially resembling that of jellyfish. Living representatives are termed "comb jellies" because they have 8 comb-like rows of cilia (small elongated extensions of cells which can reach up to 2 mm) to propel them through the water.

Echinodermata: The echinoderms form a distinctive group of mostly benthic animals characterized by a mineralized skeleton. Almost all adult echinoderms exhibit fivefold symmetry. Modern groups include sea stars, sea urchins, and sea lilies (crinoids).

Mollusca: A large group of animals, today characterized by a cavity-forming mantle. Modern molluscs include snails, squids, and clams.

Onychophora (Lobopoda): Worm-like animals with unspecialized pairs of non-jointed limbs. The modern onychophorans(velvet worms) are all terrestrial.

Porifera: The sponges are among the most primitive animals; their simple body is not organized into true tissues. Sponges are mostly bottom-dwelling suspension feeders, and many forms possess a supporting mesh-work of fine needle-like spicules composed of various minerals.

Learning activity: Burgess Shale classification key

Learning Objectives

- Learn about our current interpretations of the bizarre Burgess Shale predator *Opabinia regalis*.
- Discover the significance of the fossils of the Burgess Shale as related to the diversity of life found within their Cambrian sea-bed community, and their relevance to living animals today.
- Investigate and classify the animal populations of the Burgess Shale.

When paleontologists examine animal fossils they must determine which animal phyla they belong to. Since fossils are not found with labels attached, different techniques are used to help with identification. One such method is a dichotomous key, which simplifies the identification of an unknown organism. The key consists of a series of two mutually exclusive statements that describe characteristics of various organisms. At each step the user determines which statement is correct and is led to the next step in the dichotomous key. The last step ends with the name of the organism.

If you were trying to identify a Tiger, a Gray Wolf, a King Cobra, and a Bald Eagle, the key might read as follows:

1. a) Animal is covered in feathers……………………………………………………Bald Eagle

   b) Animal is not covered in feathers…………………………………………………go to 2

2. a) Animal has long narrow body covered in scales………………………………King Cobra

   b) Animal is covered in fur……………………………………………………………go to 3

3. a) Animal has black and orange stripes………………………………………………Tiger

   b) Animal has fur which is not striped black and orange…………………………Gray Wolf

Your task is to create a dichotomous key for six of the following organisms (the list contains animals from ten different phyla). Researching their names will lead you to information and pictures to help with the creation of your key: *Anomalocaris, Canadia, Choia, Ctenorhabdotus, Echmatocrinus, Hallucigenia, Micromitra, Nectocaris, Olenoides, Opabinia, Pikaia*.

Acknowledgements

The Royal Ontario Museum wishes to express its gratitude to the following individuals and organizations who contributed to the development of this learning resource.

To Sarah Stauderman from the Smithsonian Institution Archives for allowing the use of images and text originating from the exhibition *Beauty in service to Science*, The Panoramas of Charles D. Walcott – a Smithsonian Institution Archives exhibit presented in 2003 at the Canadian Embassy in Washington, D.C. For more information on the panoramas, please visit: siarchives.si.edu/techsvcs/walcott/index.htm

To Erin Younger, the great grand-daughter of Charles Walcott, for allowing use of her family images.

To Elizabeth Kundert-Cameron from the Archives and Library of the Whyte Museum of the Canadian Rockies for providing historical images from the Vaux family fond. https://www.archivesalberta.org/findingaids/whyte/Vaux/Vaux_main.htm

To Jaimie Miller at the University of British Columbia Rare Books & Special Collections (Irving K. Barber Learning Centre) for allowing archival access and support.

To Bob Kennell at the Canadian Pacific Archives for contributing historical images.

To Alexandre Béchard, student at the Collège Français in Toronto for testing the content of the learning activities. To Doug Erwin from the Smithsonian Institution (National Museum of Natural History), and Jean Dougherty from the Geological Survey of Canada in Ottawa for images of fossils.

To Jilli and Lars Fields (Phlesch Bubble) for digital animations and Jacquie Jeanes for graphics.

Murielle Frenette-McCabe et Dominique Picouet, for French translation. P

eter Fenton and Amanda Govan for inputing the Agora site

Publisher: Government of Canada, Department of Canadian Heritage, Canadian Heritage Information Network Creator

Contributor(s): Bethany Kempster; Jacques Lavoie; Jean-Bernard Caron

References

- Main source of information

Learning Objects:

- *Anomalocaris canadensis* - One hundred years of Interpreting the Burgess Shale Fossil Record
- *Marrella splendens* - Recreating Life During the Cambrian Period
- *Opabinia regalis* - Classifying the Bizarre Creatures Found in the Burgess Shale

Additional References

- Briggs, D. E. G., D. H. Erwin, and F. J. Collier. 1994. *The fossils of the Burgess Shale*. Smithsonian Institution Press, Washington.
- Conway Morris, S. 1998. *The Crucible of Creation, the Burgess Shale and the Rise of Animals*. Oxford University Press. Whittington, H. B. 1985. The Burgess Shale. Yale University Press, New Haven. Learning objects:
- Innovative Photography in the Rocky Mountains
- A Tale of Western Expansion & Scientific Exploration
- Smithsonian Institution Archives: https://siarchives.si.edu/techsvcs/walcott/main_article.htm
- Berton, P. 1972. *The Great Railway Illustrated*, Toronto:
- McLelland and Steward. Hart, E.J., *Trains, Peaks & Tourists 2000. The golden age of Canadian travel*, EJH Literary Enterprises ltd.
- Jones, David, L. 2006*. Famous Name Trains, Travelling in Style with the CPR*, Fitzhenry & Whiteside.
- Lavallée, O. 1977. *Van Horne's Road: An Illustrated Account of the Construction and Early Operation of the CPR, A Railfare Book*, Montreal.
- Long, C. 2000. *In the Round*. In: "The Beaver" April/May, Vol. 80:2, pp. 28-33.
- Walcott, C. D. 1911. *Geologist's Paradise*, In "National Geographic Magazine". June, Vol. XXII (No. 6).

Other Websites of Interest:

Parks Canada www.pc.gc.ca

Smithsonian Institution, National Museum of Natural History http://paleobiology.si.edu/burgess/

Canadian Pacific Railway www.cpr.ca/cms/English/General+Public/Heritage/

UNESCO World Heritage Convention whc.unesco.org

Whyte Museum of the Canadian Rockies www.whyte.org

A History of Photography by Robert Leggat, 1995 www.rleggat.com/photohistory/index.html