U3A International Geological Phenomena

The Burgess Shale

Introduction

- Cambrian fossils had been recognised since the 1830s, but the spectacular discovery of the Burgess Shale in Canada by Dr Charles Walcott in 1909 showed the extraordinary diversity of well-preserved soft-bodied animals
- the fossils were first located in rock fragments in 1907
- rocks hosting the well-preserved fossils are Cambrian Shales*
- the animals are soft-bodied animals that lived some 508Myr ago

Charles Doolittle Walcott (1850-1927)

- Charles Walcott → American palaeontologist, administrator of Smithsonian Institute and a director of the USGS
- discovered outcropping Burgess Shale in 1909
- he collected more than 65,000 specimens from the Burgess Shale (1910-1924)
- Walcott's original phylum classifications of Burgess Shale fossils → no longer accepted*

Charles Doolittle Walcott

Cathedral Formation

- Burgess shale – located on Burgess Ridge near Field, British Columbia, Canada at the base of a submarine escarpment

- escarpment rocks belong to the Cathedral Formation

- Cathedral Formation → a thick unit (up to 610m) of limestone and dolomite located in the Canadian Rockies

- cliff-forming carbonate rocks formed in shallow marine environment

Burgess Shale at base of Cathedral Formation

Cathedral escarpment

- The Cathedral Escarpment is a massive 508Ma submarine cliff acting as the edge of Cathedral formation adjacent to Burgess Shale deposits
- extends for ~100km, approximately 100-300m in height
- escarpment provided a unique often anaerobic environment that aided in preservation of soft bodied organisms
- at base of escarpment, Early Cambrian sands were covered by black muds allowing soft-bodied organisms to be preserved

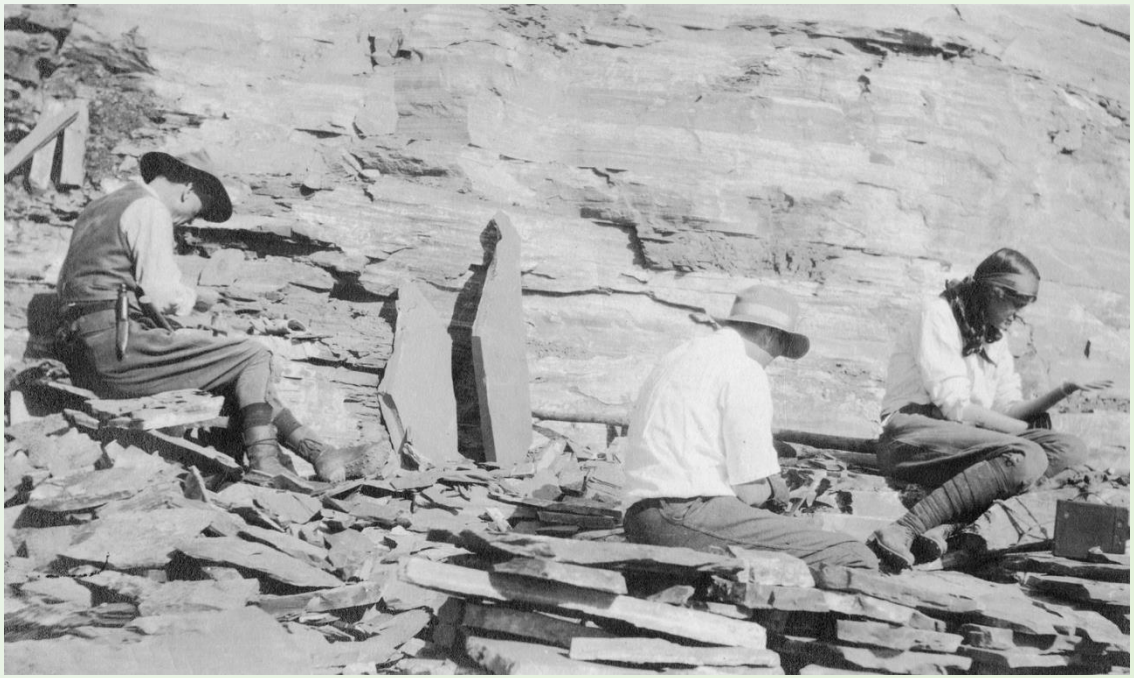
Geology of the Burgess Shale

- Fossil-bearing deposits of the Burgess Shale belong to Stephenson Formation composed of slightly calcareous dark mudstones ~508Myr
- the beds were deposited at the base of a submarine cliff 160m high
- the vertical cliff was composed of calcareous cliffs of the Cathedral Formation deposited shortly before the Burgess Shale
- precise formation mechanism unknown for certain
- widely accepted that edge of Cathedral Formation became detached from rest of reef and slumped → transported away from reef edge

The Walcott Quarry

- The Walcott Quarry is the most famous quarry of the Middle Cambrian Burgess Shale opened by Dr Charles Walcott in 1910

- the quarry's proximity to the Cathedral escarpment led to preservation of spectacular samples in the Burgess Shale



Fossil collecting in Walcott Quarry

Burgess Shale biota

- The Burgess Shale contains species of trilobites, sponges, brachiopods, molluscs and echinoderms all of which have hard parts
- in addition to diverse skeletonised fauna, there is a very large fossil assemblage of soft-bodied animals usually not so well-preserved
- there are more than 70 genera of organisms with at least 130 species of preserved soft-bodied animals
- the Burgess Shale reveals the evolutionary stage that life had reached by the Cambrian

Burgess Shale biota

- Animals whose preserved fossil remains are found in Burgess Shale, lived on banks formed along top of escarpment
- periodically sediments on this unstable area would slump and slide down the escarpment
- at base of escarpment, mud and animals carried with it were deposited in a deeper water anaerobic environment
- bacterial degradation did not destroy buried animals that were compressed by weight of overlying sediments

Burgess Shale biota

- Life was highly diverse in the Cambrian as it is today
- the reason that many members of the Burgess Shale look so strange to us → no living organisms possess their basic body plan
- many orgnisms that were thought to have represented new phyla have subsequently been placed in extant phyla*
- if these reassignments are correct, then no new extinction events followed the Cambrian explosion

Cambrian explosion

- The Cambrian Explosion ~540Ma was a rapid evolutionary event
- up until the evolution of multicellular, soft-bodied Edicaran fauna, in Late Proterozoic, Earth was populated by single-celled organisms
- at beginning of Palaeozoic Era animals with hard parts appeared abruptly in the fossil record marking the appearance of most major phyla in the fossil record
- Cambrian explosion lasted 13-25Myr

Cambrian explosion

- Up until recently it appeared that there was a fairly long time between extinction of Ediacaran and first Cambrian fossils
- the gap has narrowed significantly in recent years with the discovery of new Proterozoic fossil assemblages
- recent discoveries in Namibia indicate that Ediacaran-like fossils are ever present above first occurrence of Cambrian fossils
- it appears likely that the "Cambrian explosion" had its roots planted in the Late Proterozoic glaciations
- global warming during the Cambrian may have stimulated evolution contributing to the Cambrian explosion

Appearance of Burgess Shale biota

- In recent years, reconstruction, classification and interpretation of many Burgess Shale fossils has led to new theories of "Cambrian explosion"
- it was during Late Proterozoic that multicellular animals evolved and shortly after, animals with hard parts made their first appearance
- for years palaeontologists placed the bulk of Burgess Shale organisms into existing phyla
- only a few were assigned to phyla that are now extinct
- discoveries of new Cambrian fossils in Greenland and China resulted in reassignment of some specimens back into extant phyla

Study of Burgess Shale fossils

- Charles Walcott recognised that the significance of soft-bodied preservation and range of organisms was new to science
- until 1924 he amassed >65,000 specimens
- it was revealed that fauna present were more diverse and unusual than those that Walcott had previously recognised
- many of the animals had bizarre anatomical features with only a slight resemblance to other animals
- British palaeontologist Simon Conway Morris proposed that almost all Cambrian fauna could be classified in modern day phyla

Environment of deposition of Burgess Shale

- It was originally thought that the Burgess Shale was deposited in anoxic conditions
- subsequently shown that oxygen was continually present in the sediment
- organisms found in Burgess Shale are thought to have been rapidly entombed by sediment-rich water currents before they could decay
- currents may have transported organisms relatively long distances before they were finally buried
- fossils are preserved as very thin (<1μm) carbonaceous films on black shales

Preservation of Burgess Shale fossils

- The Burgess Shale has contributed significantly to the fossil record because of the large number of well-preserved fossils within its layers
- in the Burgess Shale organisms lived in underwater mudbanks known as phyllopod beds*
- in most forms of fossilisation, bodies of dead organisms settle to bottom of sea, lake or river with sediment slowly covering bodies
- at the base of the escarpment, water currents would periodically cause sediments to flow in the form of mudslides, quickly burying living organisms in moving water

Preservation of Burgess Shale biota

- Burgess Shale fossils are in random orientation indicative of a violent mudslide burial and instant death
- there is also other evidence that these organisms died instantly
- in the presence of an anaerobic environment such as mud, animals normally curl up when dying
- fossils in Burgess Shale locality do not exhibit coiling
- no evidence of any attempt by organisms to burrow out of their mud prison
- being killed instantly by mudslides, preservation began immediately

Burgess Shale biota

- Biota of the Burgess Shale appear typical of Middle Cambrian deposits → comprise a diverse range of organisms
- animals with hard parts comprise as little as 14% of community → same organisms found in similar proportions in other Cambrian localities
- free swimming organisms → relatively rare with majority of organisms bottom dwelling or sessile
- about two-thirds of Burgess Shale organisms lived by feeding off organic content in muddy sea floor
- about one third filtered particles from water column, <105 organisms were predators or scavengers

Burgess Shale fossils

- The Burgess Shale fauna contains many fossils of soft-bodied animals as well as those with hard parts
- dominant fossils are arthropods but other types are found in great abundance (e.g. worms, crinoids, sea cucumbers chordates etc.)
- soft-bodied fossils are rarely found elsewhere, as such organisms are usually destroyed before preservation as fossils*
- when an organism is completely soft → body usually rots away before fossilisation, hard parts are more easily preserved

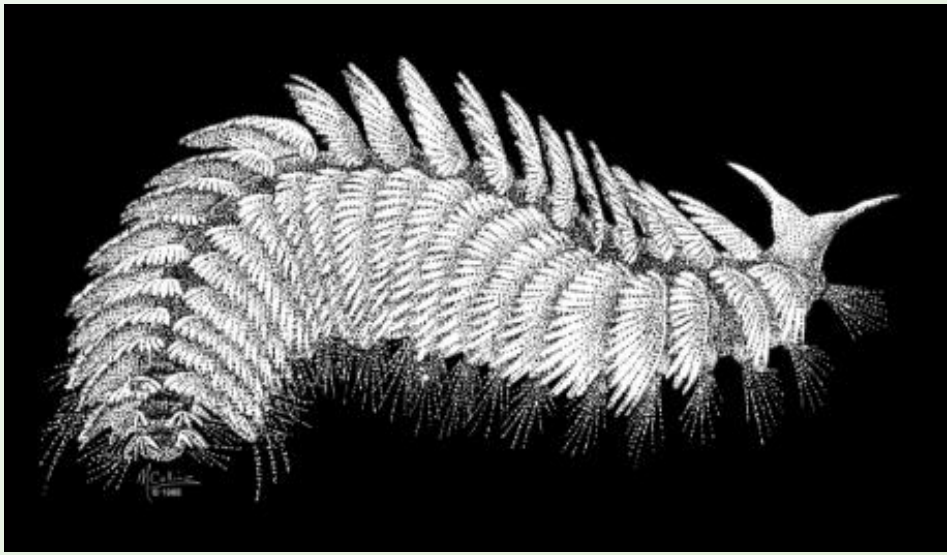
Phylum annelida (segmented worms)

- Annelids are elongate many segmented bodies e.g. earthworms, leeches
- many Burgess Shale fossil annelids show evidence of parapodia (flap-like structures) and bristles
- bristles (setae) are rigid and extend from dorsal branches characteristic of polychaete worms
- some may have lived in or on mud on sea bottom
- 5 species are recognised in Burgess Shale

Canadia spinosa

- *Canadia spinosa* is a genus of extinct annelid worm
- body consists of 20-22 trunk segments each bearing a pair of parapodia, all parapodia bear bristles
- the animal had a straight gut and soft proboscis

Canadia spinosa fossil Burgess Shale



Artist impression of *Canadia spinosa*

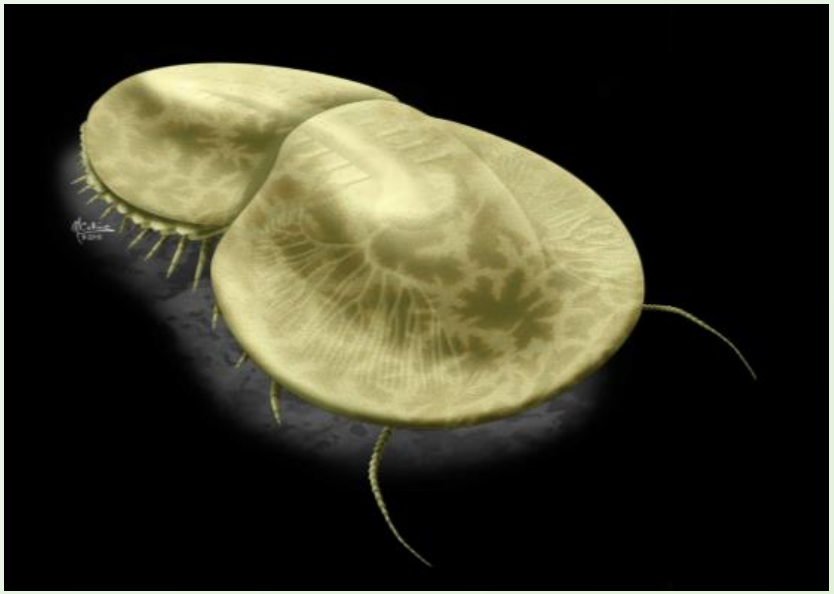
Phylum Arthropoda

- The most diverse of the animal groups, arthropods are characterised by a segmented body, an exoskeleton and jointed limbs e.g. insects, spiders and crustaceans
- the Burgess Shale contains a wide range of fossil arthropods that have two dorsal shields (head shield, elongate body shield)
- 53 species of arthropods are known from the Burgess Shale

Naraoia compacta

- Naraoia compacta is one of the most populous of the Burgess Shale arthropods, it is a mobile carnivorous bottom dweller
- a pair of multi-jointed antennae emerge from beneath the head shield
- behind the antennae are 4 pair of cephalic appendages and 14 pairs of trunk appendages

Naraoia compacta fossil Burgess Shale

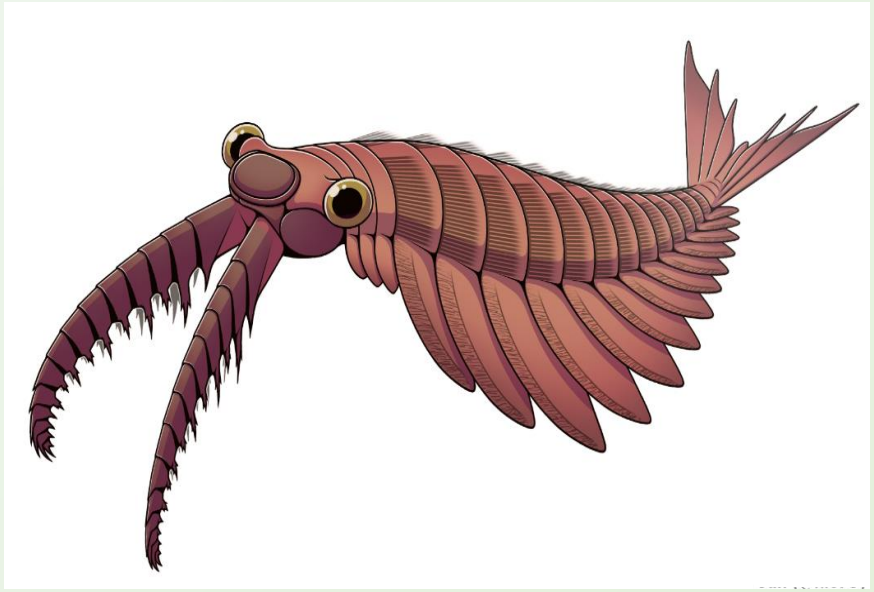


Artist impression of Naraoia compacta

Anomalocaris canadensis

- Dorso flattened animal with flexible exoskeleton
- frontal appendages are elongated and have 14 spiked segments
- one of the largest animals of the Cambrian (~36cm long), an active predator

Anomalocaris canadensis from Burgess Shale



Artist impression *Anomalocaris canadensis*

Phylum Brachiopoda

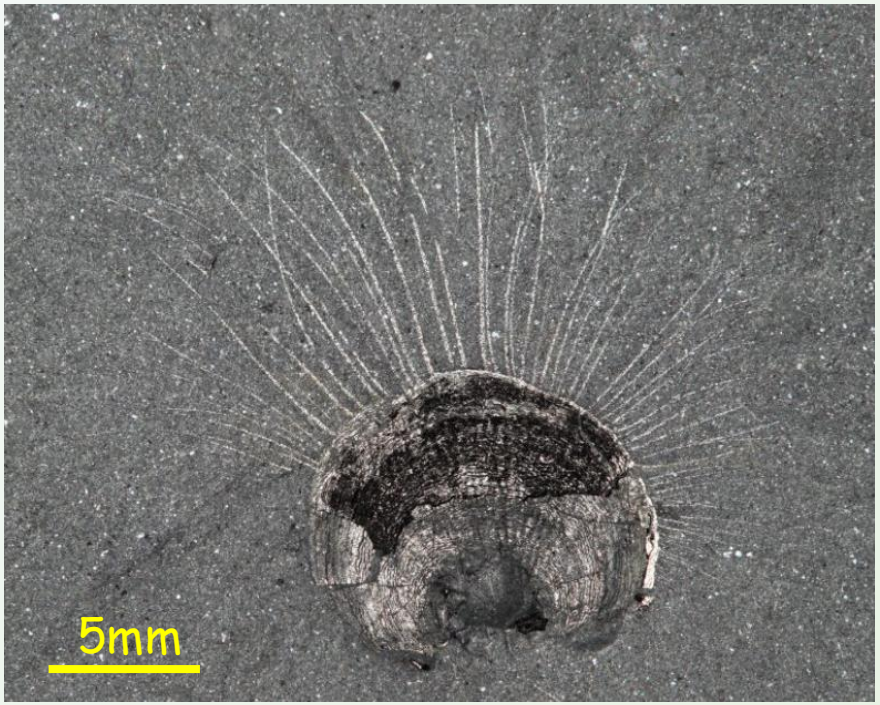
- Brachiopods are bottom dwelling marine suspension feeding animals enclosed in a two part shell
- unlike bivalves, brachiopod valves are bilaterally symmetrical*
- most forms attach to the seafloor
- in the Burgess Shale, some forms are preserved with soft tissues
- there are 7 species identified in the Burgess Shale

Bivalve

Brachiopod

Micromitra burgessensis

- *Micromitra burgessensis* → extinct form of brachiopod
- most ornamented of Burgess Shale brachiopods
- most striking feature of the organism → long slender bristles (setae) that extend from margins of shell



Micromitra burgessensis fossil Burgess Shale

Artist impression of Micromitra burgessensis

Phylum Chordata

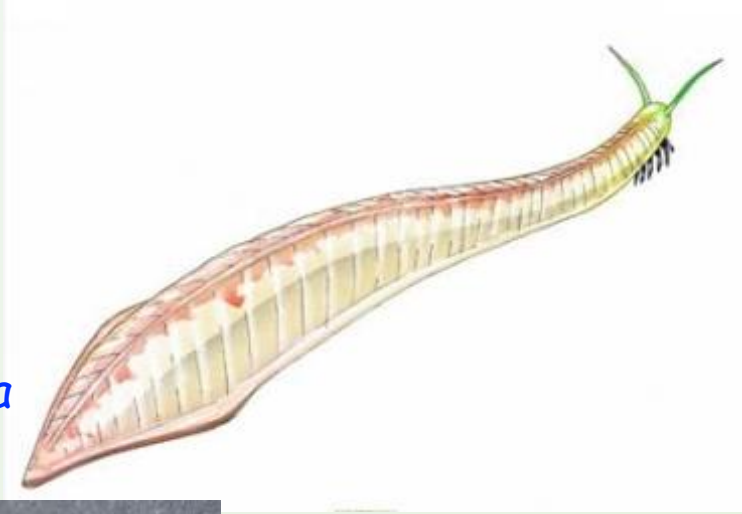
- Chordates are a group of animals that possess at some stage during their larval or adult stages a notochord and hollow nerve cord

- chordates are divided into three subphyla:
  - Vertebrata (fish, amphibians, reptiles, mammals)
  - Cepholochordata (lancelets) that resemble jawless fish (no gills)
  - Tunicata (sea squirts, larvaceans) that only possess a notochord and hollow nerve cord in larval stage

- there are 2 species identified in the Burgess Shale

Pikaia gracilena

- Body resembles that of a lancelet
- has a pair of antennae like tentacles on head similar to snails
- narrow dorsal structure that runs the length of the organism may represent a notochord



Artist impression of *Pikaia gracilena*

Pikaia gracilena fossil in Burgess Shale

Phylum Cnidaria

- The phylum Cnidaria includes soft-bodied stinging animals such as sea anemones, corals and jelly fish
- the animals are radially symmetrical with two basic lifestyles, swimming jellyfish and sessile polyp-like forms e.g. corals
- group includes modern jellyfish and corals
- various tubular fossils in Walcott Quarry have been attributed to primitive sessile cnidarians
- four species are recognised in the Burgess Shale

Cambrorhytium fragilis

- *Cambrorhytium fragilis* is conical with markings on walls parallel to the base
- interpreted as cnidarian polyp with the animal in the tube extending tentacles from an aperture

Cambrorhytium fragilis fossil in Burgess Shale

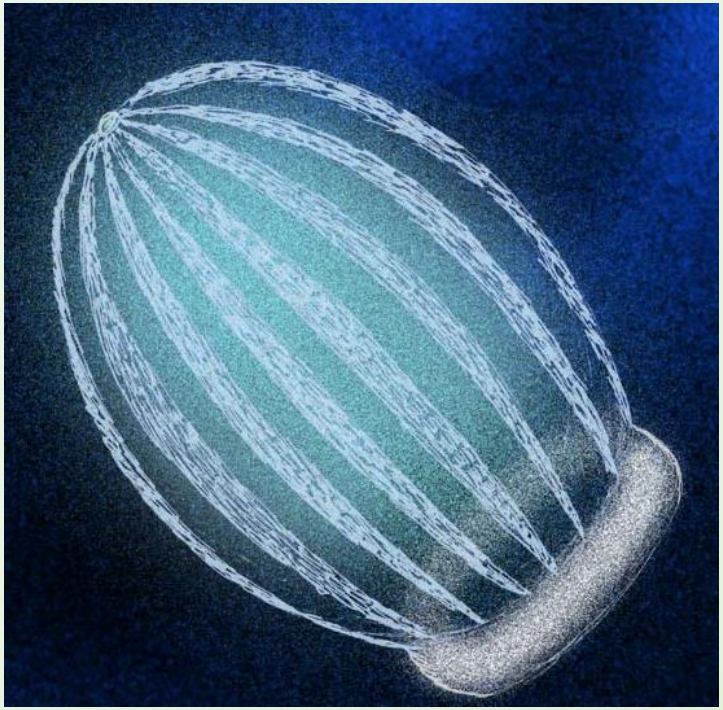
Phylum Ctenophora

- Ctenophora is a phylum of marine invertebrates known as "comb jellies"
- they are noted for having groups of cilia commonly known as combs that they use for swimming
- they are the largest animals to swim with the help of cilia
- almost all ctenophores function as predators on small crustaceans and microscopic larvae
- 2 species are known from the Burgess Shale

Ctenorhabdotus capulus

- Ctenophores → ovoid in shape and bears 24 comb rows organised in 8 sets of 3
- each group of 3 rows converge towards aboral side to form 8 strands
- top and bottom surfaces are relatively flat

Ctenorhabdotus capulus fossil in Burgess Shale



Artist impression of *Ctenorhabdotus capulus*

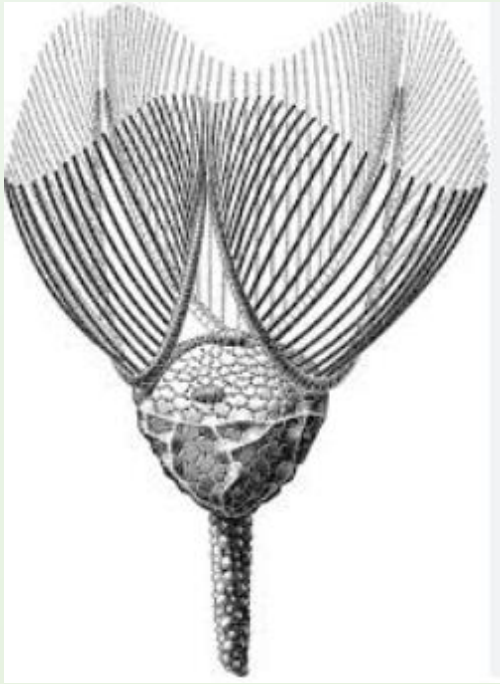
Phylum Echinodermata

- Phylum Echinodermata includes starfish, sea urchins, sea cucumbers and crinoids ("sea lilies")
- echinoderms have bilateral symmetry as larva and as adults acquire 5-fold symmetry
- they are equipped with a water vascular system that mobilises tube feet, spines and arms
- there are 4 species recognised in the Burgess Shale

Lyracystis reesi

- Sessile animal that attaches by stalk to the sea floor
- up to 21cm in length, features long, thin stem and main body topped by 3 wide V-shaped arms,
- the arms (brachioles) are used to capture food

Lyracystis reesi fossil from Burgess Shale



Artist impression of Lyracystis reesi

Phylum Hemichordata

- Hemichordata → phylum of relatively small invertebrates
- two branches → Acorn worms and Pterobranchia
- closely related to echinoderms and chordates
- possess some characteristics of chordates but lack a true notochord
- 3 specimens identified in Burgess Shale

Chaunograptus scandens

- This species belongs to a primitive group of graptolites
- small colonial organism comprising several slender and straight limbs that branch at the base
- short conical structures (thecae) are attached to either side of the stem at regular intervals

Chaunograptus scandens fossil from Burgess Shale

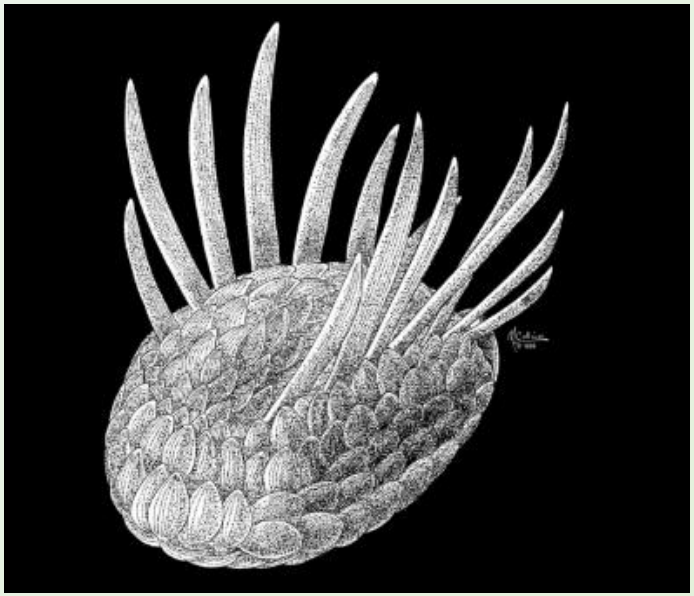
Phylum Mollusca

- Mollusca → phylum of soft-bodied invertebrates usually wholly or partly enclosed in a $CaCO_3$ shell
- one of the largest and most diverse groups in the animal kingdom, includes snails, oysters, cuttlefish, squid etc.
- inhabit diverse environments including marine, freshwater and terrestrial habitats
- 5 species are known from the Burgess Shale

Wiwaxia corrugata

- Organism almost entirely covered with array of chitonous over-lapping, scale-like elements (sclerites) and spines
- sclerites are arranged in about 60 rows with two rows of spines
- Wiwaxia's feeding apparatus consists of toothed plates (c.f radula)

Wiwaxia corrugata fossil in Burgess shale



Artist impression *Wiwaxia corrugata*

Phylum Onychophora

- Onychophora → commonly known as velvet worms, is a phylum of soft-bodied animals
- in appearance they have commonly been compared to worms with legs, caterpillars and slugs
- velvet worms are segmented animals with flattened cylindrical body cross-sections and rows of stubby feet
- 2 species are known from the Burgess Shale

Hallucigenia sparsa

- Hallucigenia has a worm-like body and a small head at the end of a long neck
- the trunk bears 7 pairs of slender leg-like lobes and spine pairs
- each leg terminates in a pair of claws and rigid spines have base plates

Hallucigenia sparsa fossil from Burgess Shale

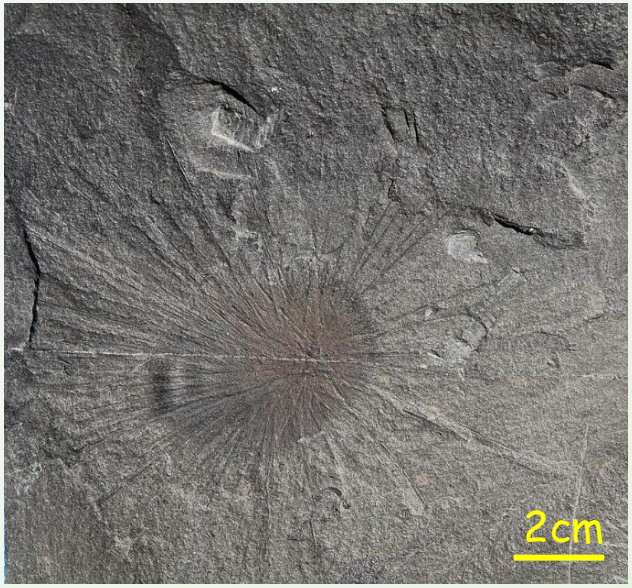
Artist reproduction of *Hallucigenia sparsa*

Phylum Porifera (sponges)

- Porifera → scientific name for sponges that are sessile animals characterised by their porous bodies
- there are over 10,000 species of sponge today, most are marine
- Porifera filter food and oxygen from water drawn through tiny pores and expelled via a large opening (osculum)
- There are 34 species recognised in the Burgess Shale

Choia carteri

- *Choia carteri* is an early branch of siliceous sponge
- it consists of a flattened disc (up to 5cm) formed by fine radiating spines from which stronger spicules (up to 30mm) radiate
- *Choia* was suspended above sea floor attached via stalk-like spines



Choia carteri fossil from Burgess Shale

Artist impression *Choia carteri*

Phylum Priapulida

- Priapulids → phylum of unsegmented worms, likely major predators of the Cambrian Period
- worm-like animals with a median anterior mouth devoid of tentacles
- the adult body is divided into main trunk or abdomen and somewhat swollen proboscis region
- Family Priapulidae have species with a tail or caudal appendages
- 5 species are identified in the Burgess Shale

Selkirkia columbia

- *Selkirkia* lived in a tube up to 6cm in length
- body was similar to most priapulids with a trunk and an anterior mouthpart called a proboscis
- the proboscis had a series of spines along its length and was radially symmetrical

Selkirkia columbia fossil from Burgess Shale

Artist impression of Selkirkia columbia

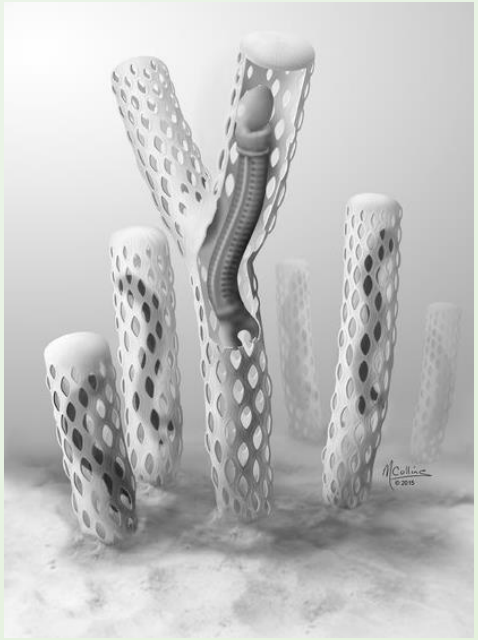
Burgess Shale algae

- Burgess Shale fossils include diverse algae both microscopic (like cyanobacteria) and macroscopic (like Margaretia, MarpLoia)
- algae are preserved as delicate carbon films in mudstone layers showing different forms from branching to frond-like structures
- these algae include potential red, green and blue-green types
- 12 species have identified in the Burgess Shale

Margaretia dorus

- *Margaretia dorus* generally thought to be a fossil, green algae
- axes of *Margaretia dorus* exceed 2cm in diameter and more than 1metre in height
- fronds reach 10cm → peppered with length parallel oval holes

Margaretia dorus fossil from Burgess Shale



Artist impression *Margaretia dorus*