Ctenophora

Urochordata

Nemertea

Echinodermata

Platyhelminthes

Kamptozoa

Nematomorpha

Porifera

Phoronida

Brachiopoda

Acoela

Arthropoda

Annelida

Mollusca

Bryozoa

Onychophora

Acanthocephala

Cnidaria

Tardigrada

Nematoda

Hemichordata

How are phyla related?

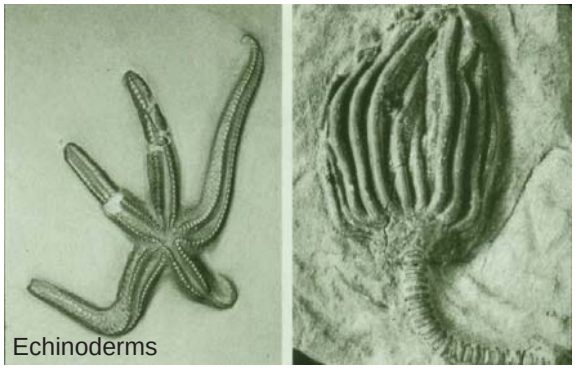
When did they appear?

How has diversity changed?

What mechanisms underlie diversification?

Variable preservation among taxa

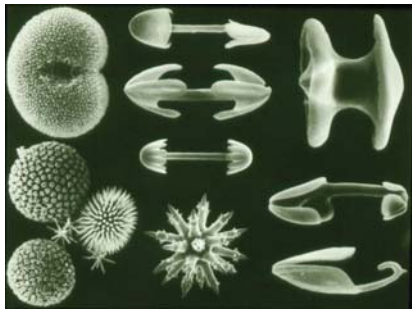
Which phyla are more likely to leave informative records?



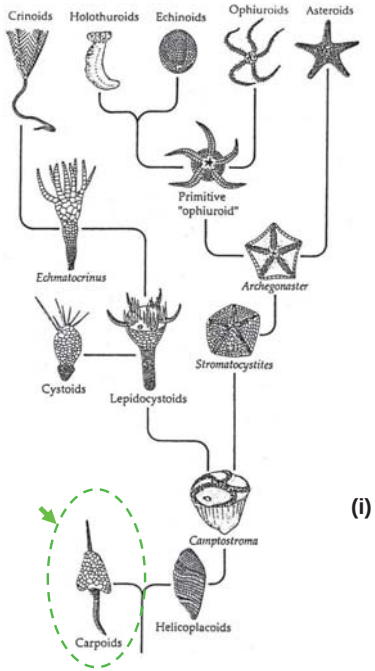
Echinoderms

Molluscs

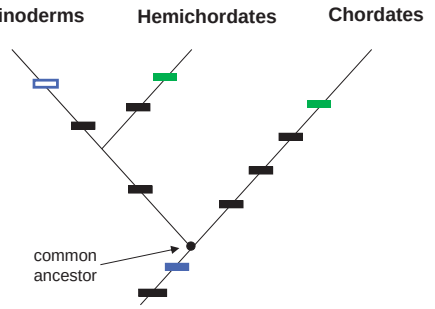
Sponges



1. Analysis of fossil taxa
eg. Echinoderm classes



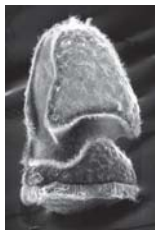
2a. Cladistics: phenotypes of extant taxa
eg. Deuterostomes



b. Cladistics: phenotypes of larval forms

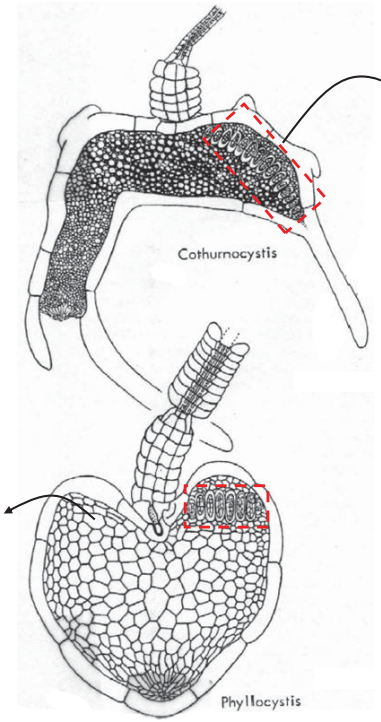
(i) "dipleurula" type larva

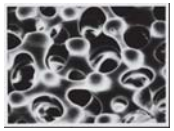
holothuroid echinoderm auricularia



hemichordate tornaria

Carpoids



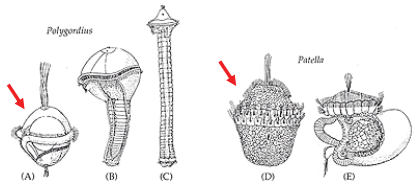


stereom

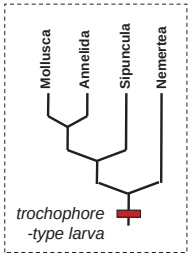
pharyngeal slits?

Are larval forms always reliable cladistic characters?

(ii) Trochophore-type larva: molluscs, annelids, sipunculans, nemerteans



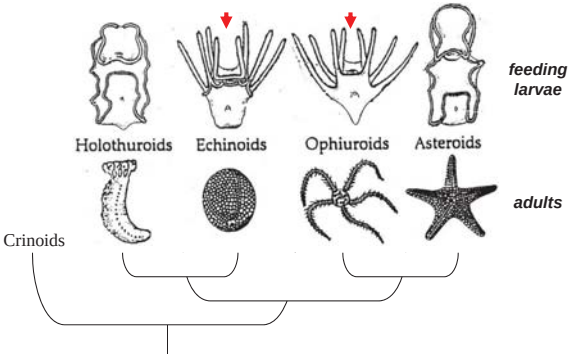
polychaete annelids gastropod molluscs



(iii) "Pluteus" larva: echinoid and ophiuroid echinoderms

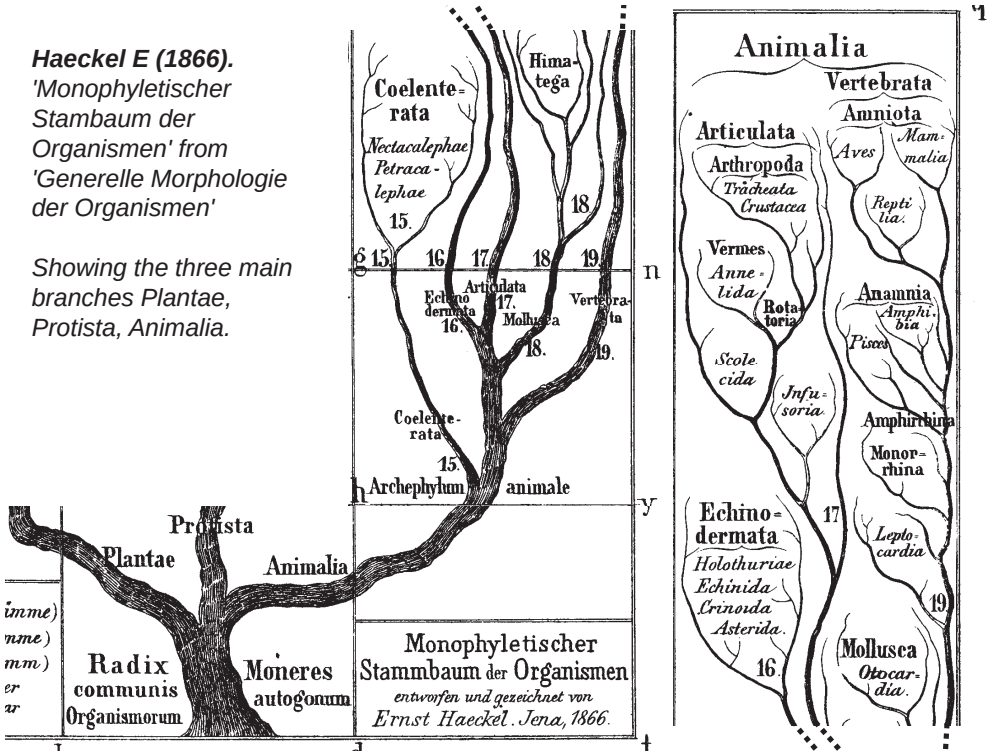
Echinopluteus

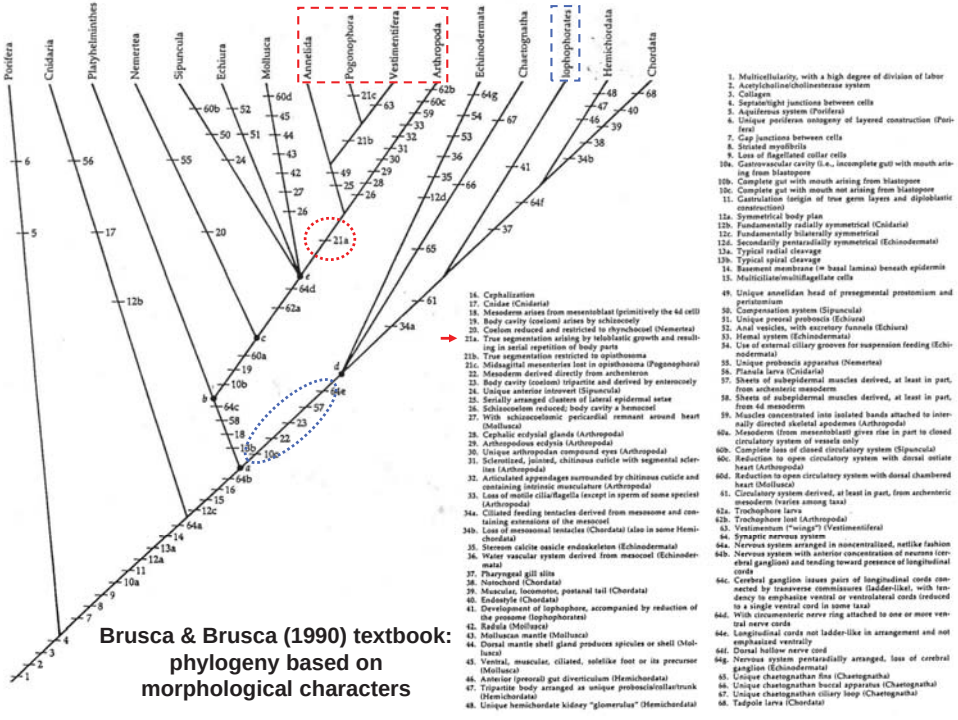
Ophiopluteus



Haeckel E (1866).
'Monophyletischer Stambaum der Organismen' from 'Generelle Morphologie der Organismen'

Showing the three main branches Plantae, Protista, Animalia.



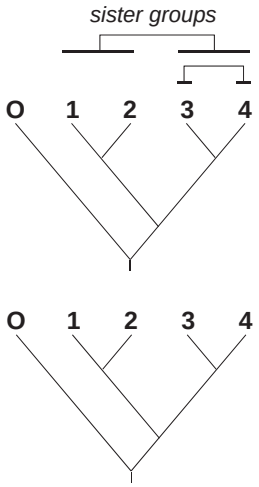


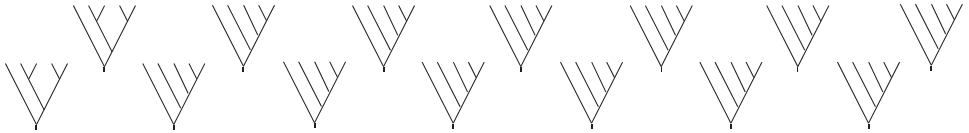
Brusca & Brusca (1990) textbook: phylogeny based on morphological characters

2b. Cladistics: molecular characters

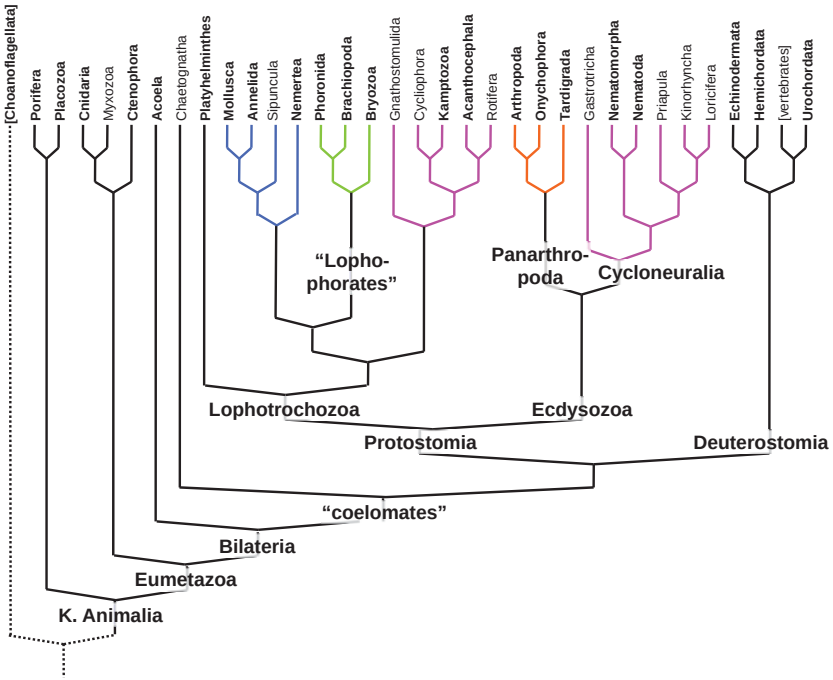
DNA base	1	2	3	4	5	6	7	8	9	10	11	12
sp "O"	A	C	G	C	G	G	T	C	A	T	T	A
sp 1	.	G	.	.	.	.	.	.	.	.	.	T
sp 2	.	G	.	.	A	.	.	.	.	.	.	T
sp 3	.	.	.	.	T	.	C	.	.	A	.	T
sp 4	.	.	.	.	T	.	C	.	.	.	.	T

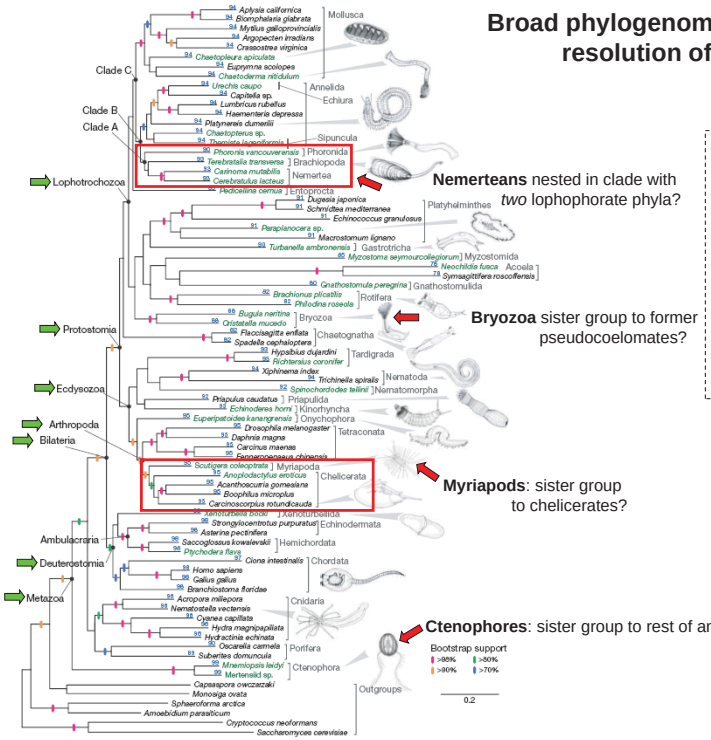
sister groups





Our phylogenetic roadmap: a consensus view





Nemerteans nested in clade with *two* lophophorate phyla?

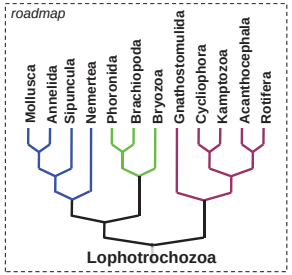
Bryozoa sister group to former pseudocoelomates?

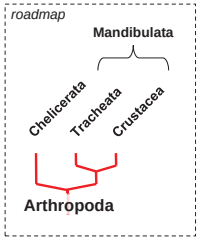
Myriapods: sister group to chelicerates?

Ctenophores: sister group to rest of animals?

Broad phylogenomic sampling improves resolution of the animal tree of life

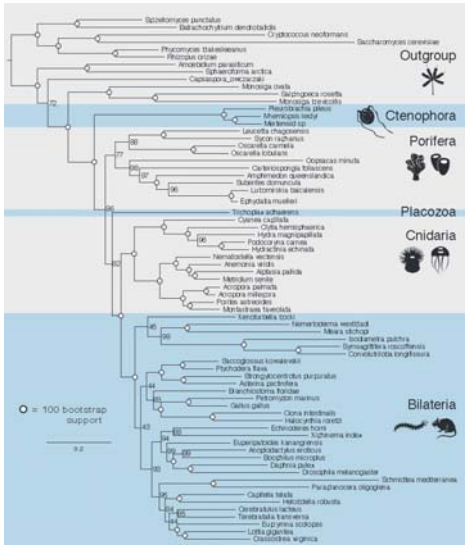
Dunn et al. 2008
(+17 coauthors!)





The Genome of the Ctenophore *Mnemiopsis leidyi* and Its Implications for Cell Type Evolution Science (2013)

Joseph F. Ryan, Kevin Pang, Christine E. Schnitzler, Anh-Dao Nguyen, R. Travis Moreland, David K. Simmons, Bernard J. Koch, Warren R. Francis, Paul Havlak, NISC Comparative Sequencing Program, Stephen A. Smith, Nicholas H. Putnam, Steven H. D. Haddock, Casey W. Dunn, Tyra G. Wolfsberg, James C. Mullikin, Mark Q. Martindale, Andreas D. Baxevanis*



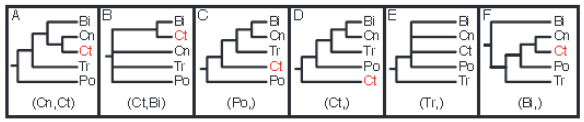
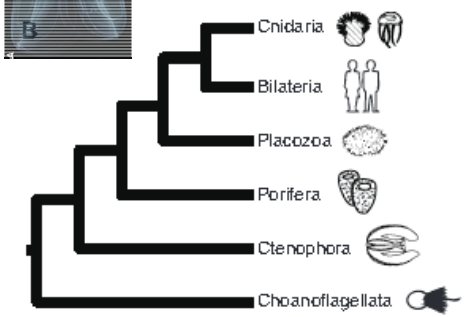


Fig. 2. Previously proposed relationships of the five deep clades of animals. The label at the bottom of each pane corresponds to the header of Table 1. (A) Coelenterata hypothesis. (B) Ctenophora as sister to Bilateria. (C) Porifera as sister group to the rest of Metazoa. (D) Ctenophora as sister group to the rest of Metazoa. (E) Placozoa as sister group to the rest of Metazoa. (F) Diploblastica hypothesis. We see no support in any of our analyses for the hypotheses in (A), (E), and (F) and very little support for (B) (see Table 1). Ct, Ctenophora; Po, Porifera; Tr, Placozoa; Cn, Cnidaria; Bi, Bilateria.

The phylogenetic position of the ctenophore *Mnemiopsis leidyi* and its implications regarding the origin of mesodermal cell types. (**A**) Adult *M. leidyi*. (**B**) Summary of the relationships of the five main branches of animals and the outgroup Choanoflagellata.

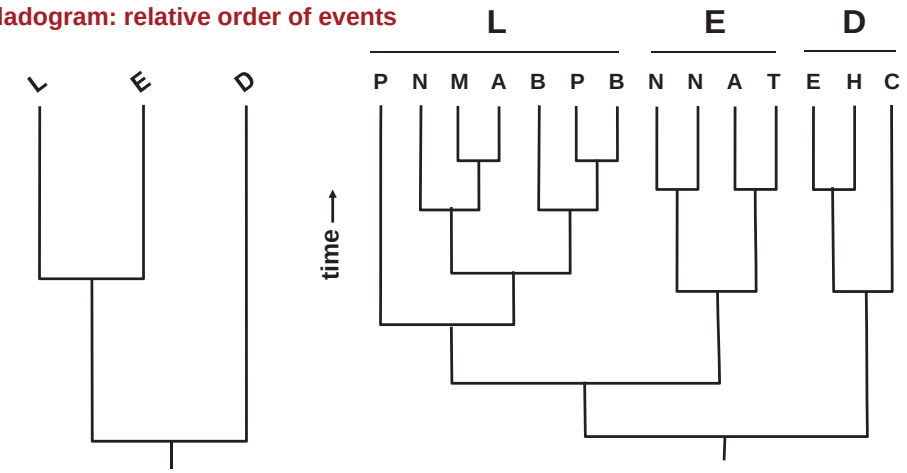


muscles? nerves? epithelia? axes?

Ctenophora
Urochordata
Nemertea
Echinodermata
Platyhelminthes
How are phyla related?
Nematomorpha
Sipuncula
Kamptozoa
When did they appear?
Porifera
Phoronida
Brachiopoda
How has diversity changed?
Acoela
Arthropoda
Annelida
Bryozoa
Mollusca
What mechanisms underlie diversification?
Onychophora
Acanthocephala
Chidaria
Tardigrada
Nematoda
Hemichordata

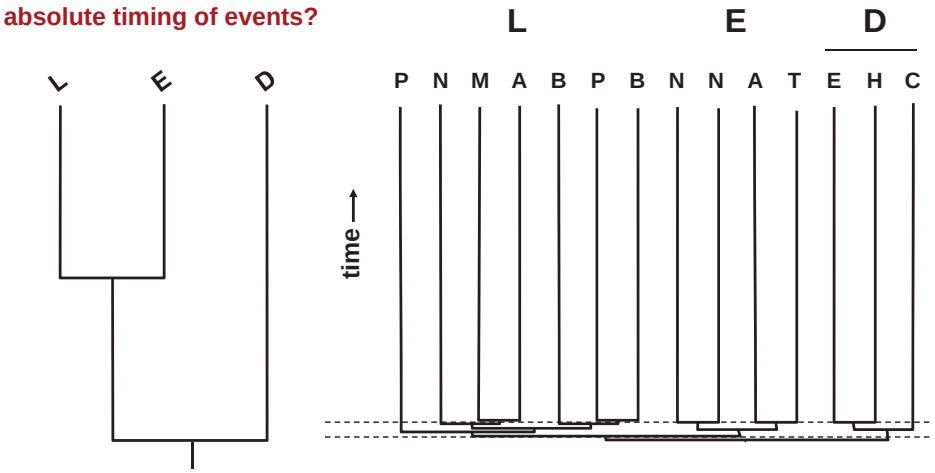
Pattern of evolutionary relationships

cladogram: relative order of events



Timing of evolutionary divergences?

absolute timing of events?



The major Pre-Cambrian and Cambrian *Lagerstätten*

Pre-Cambrian		
Bitter Springs	1000–850 Ma	South Australia
Ediacara Hills	630-542 Ma	South Australia
Doushantuo Formation	600–555 Ma	Guizhou Province, China
Cambrian		
Maotianshan Shales (Chengjiang)	525 Ma	Yunnan Province, China
Sirius Passet	518 Ma	Greenland
Emu Bay shale	517 Ma	South Australia
Kaili Formation	513–501 Ma	Guizhou province, south-west China
Wheeler Shale (House Range)	507 Ma	Western Utah, US
Burgess Shale	505 Ma	British Columbia, Canada
Kinnekulle Orsten and Alum Shale	500 Ma	Sweden
Öland Orste and Alum Shale	500 Ma	Sweden

Pre-Cambrian seas?

The Ediacaran (named after the hills in Australia, the site of a major pre-Cambrian fossil deposit) featured soft-bodied life - no bones, shells, teeth or other hard parts. Most of the life forms bear no resemblance to modern day animals, and may have become the eventually extinguished prey of more modern forms. The world's first ever burrowing animals evolved in the Ediacaran but left only trace fossils (burrows).

Enigmatic Ediacaran biota (630-542 mya)

Dickinsonia costata, an iconic Ediacaran organism, displays the characteristic quilted appearance of Ediacaran enigmata

Spriggina superficially resembled a segmented animal but the apparent segments are isomers (alternating on left and right sides).

Charniodiscus, probably a stationary filter feeder, was a frond anchored by a holdfast to a sandy sea bed.

Kimberella may have had a predatory or grazing lifestyle.

Archaeonassa-type trace fossils

Charnia, the first accepted complex Precambrian organism, once interpreted as a relative of the sea pens.

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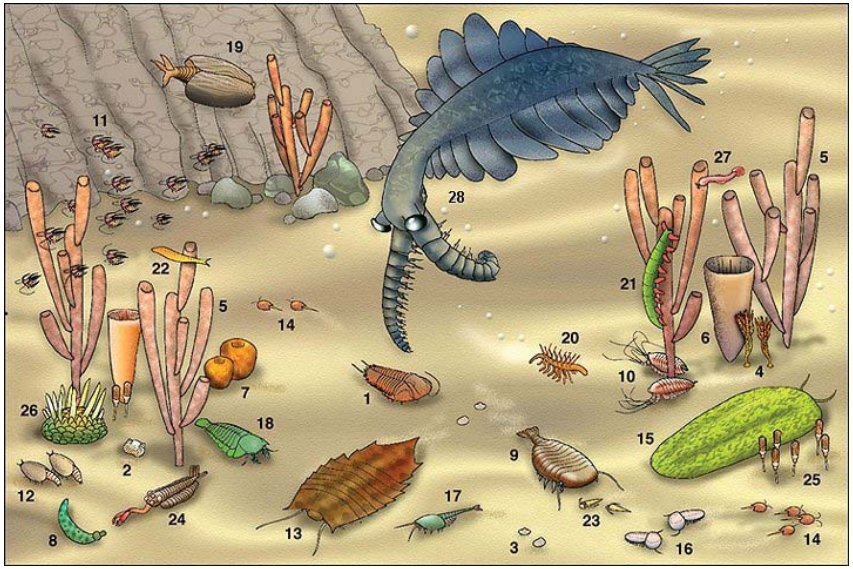
Cambrian seas?

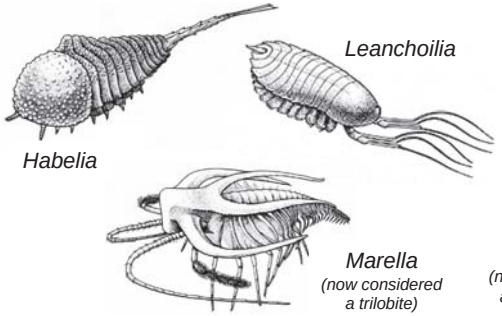


Some of the diversity of the Burgess Shale biota is depicted in the drawing above by Sam Gon III and John Whorrall. Trilobites such as *Olenoides serratus* (1) were a minority among a diversity of arthropods such as *Sidneyia* (9), *Waptia* (17), *Helmetia* (13), *Sanctacaris* (18), *Tegopelte* (15), *Naraoia* (16), *Leanchoilia* (10), *Canadaspis* (12), *Odaraia* (19), *Marrella* (11), and *Burgessia* (14), as well as oddities such as *Opabinia* (24), *Wiwaxia* (26), *Hallucigenia* (20), and the giant predator, *Anomalocaris* (28).

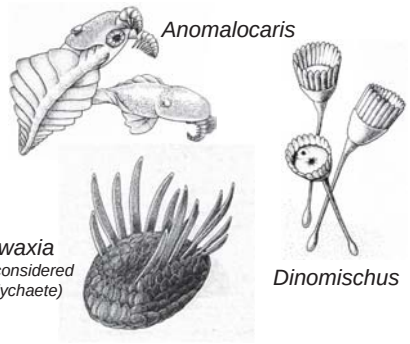
Problematic taxa of the Burgess Shale (525-505 mya)

Wonderful Life, Gould (1990)

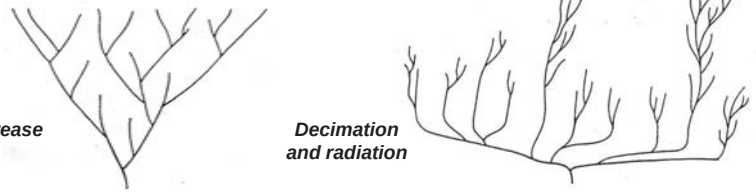
Unique arthropod subphyla?



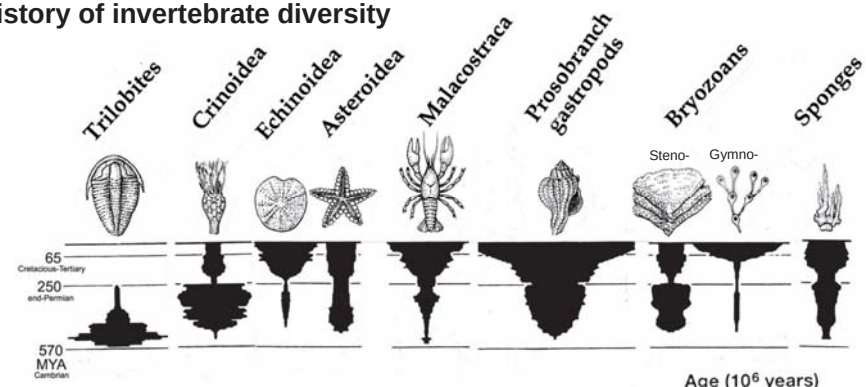
Unique phyla?

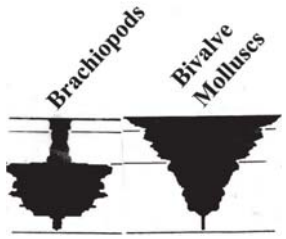


Two models of the history of diversity



History of invertebrate diversity





Mass extinctions of marine families