29–1 Invertebrate Evolution

Until recently, the origins of invertebrates were shrouded in mystery. This was because few fossils old enough to shed light on this period in Earth's history had been found. But ongoing discoveries around the world are shedding new light on the origins of invertebrates. Treasure troves of beautifully preserved invertebrate fossils, dating between 575 and 543 million years ago, have been discovered in the Ediacara Hills of Australia and in Chengjiang, China. These fossils join those known from the Burgess Shale deposits in the Canadian Rockies to show a fascinating history of early multicellular life.

Guide for Reading

Key Concept
- What are the major trends in invertebrate evolution?

Vocabulary
radial symmetry
bilateral symmetry
cephalization
coelom

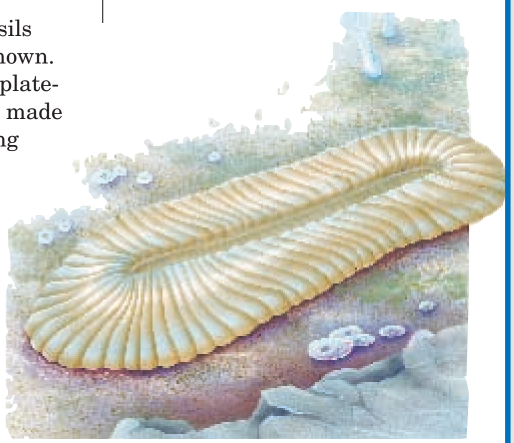
Reading Strategy: Using Visuals Before you read, preview **Figure 29–4.** As you read, notice how the evolutionary trends in the cladogram are discussed in the text.

Origin of the Invertebrates

The Ediacaran fossils brought to light a strange group of ancient invertebrates. These peculiar fossils puzzled paleontologists for years because they seemed quite different from any modern invertebrates. More recently, paleontologists have identified beautifully preserved, microscopic fossils, between 610 and 570 million years old, that seem to be the developing embryos of early multicellular animals. From the same time period, they also identified what are called trace fossils. Trace fossils are tracks and burrows made by soft-bodied animals whose bodies were not fossilized.

Molecular biologists and paleontologists have also created a new field called molecular paleontology. This research uses cutting-edge studies in genetics to understand how different animal body plans evolved. DNA comparisons among living invertebrates help determine which phyla are most closely related. In addition, geneticists are studying how small changes in certain genes can cause major changes in body structures.

The First Multicellular Animals The Ediacaran fossils include some of the earliest and most primitive animals known. Most, like the animal shown in **Figure 29–1,** were flat and plate-shaped and lived on the bottom of shallow seas. They were made of soft tissues that absorbed nutrients from the surrounding water. Some may have had photosynthetic algae living within their bodies. These animals were segmented and had bilateral symmetry. However, they show little evidence of cell specialization or organization into a front and back end. Some of these early animals may have been related to soft-bodied invertebrates such as jellyfishes and worms. Their body plan, however, is distinct from anything alive today. Regardless of their relationships to other organisms, these animals were probably simple and had little internal specialization.



▼ **Figure 29–1** The drawing is an artist's conception of what an early invertebrate might have looked like. **Applying Concepts** *In what environment did most early invertebrates live?*

SECTION RESOURCES

Print:
- ***Teaching Resources,*** Lesson Plan 29–1, Adapted Section Summary 29–1, Adapted Worksheets 29–1, Section Summary 29–1, Worksheets 29–1, Section Review 29–1, Enrichment
- ***Reading and Study Workbook A,*** Section 29–1
- ***Adapted Reading and Study Workbook B,*** Section 29–1

Technology:
- ***iText,*** Section 29–1
- ***Transparencies Plus,*** Section 29–1

Section 29–1

1 FOCUS

Objectives

29.1.1 ***Explain*** what the Cambrian Explosion was.
29.1.2 ***Describe*** the major trends in invertebrate evolution.

Guide for Reading

Vocabulary Preview
Suggest that students preview the meanings of the Vocabulary terms in the section by skimming the text to find the highlighted, boldface words and their definitions.

Reading Strategy
Students have already learned about specific invertebrate phyla and should remember the basics of the history of life from Chapter 17. Ask students to write a paragraph describing what they already know about the origin and evolution of invertebrates. Then, as they read the chapter, they should revise these paragraphs as needed.

2 INSTRUCT

Origin of the Invertebrates

Make Connections

Earth Science Explain that a fossil like the drawing in Figure 29–1 was probably found in a rock formation. Ask: **How would you describe the process by which this fossil might have formed?** *(Some students might correctly describe a process in which the organism died and was buried in sediment, which hardened into sedimentary rock, leaving a mold, cast, or imprint of the original organism.)* Point out that this organism had no hard body parts. **Why is it remarkable that such an organism left fossil remains?** *(Most soft tissue deteriorates more quickly than sediment hardens into rock, leaving no fossil evidence behind.)* Explain that fossils of relatively few of these earliest multicellular animals have been found because of their lack of hard parts. L2 L3

Answer to . . .

Figure 29–1 *Early invertebrates lived on the bottoms of shallow seas.*

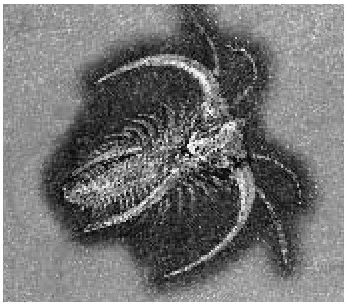
29–1 (continued)

Use Visuals

Figure 29–3 Have students examine the illustration of Burgess Shale animals, and then direct their attention to the trilobite shown, *Olenoides.* Point out that this organism is the earliest known example of a trilobite, which students know from Chapter 28 is an ancient form of marine arthropod. Have students turn back to the subsection Evolution of Arthropods in Section 28–1 and review what they read about trilobites. Then, ask: **What can you say about this Burgess Shale trilobite in terms of body symmetry, skeleton, segmentation, cephalization, and appendages?** *(This trilobite had bilateral symmetry, an exoskeleton, many body segments, a head with compound eyes, and appendages.)* Point out that these features, or similar ones, are characteristic of living arthropods. Then, ask: **In what ways is this organism different from the animal shown in Figure 29–1?** *(Although the animal was segmented, it had no anterior and posterior end, no skeleton, and no appendages.)* Emphasize that the animals of the Burgess Shale represent the first appearance of almost all the major groups of modern animals. The illustration shows an early sponge, early arthropods, and an early annelid. L2

Make Connections

Earth Science To help students place the Burgess Shale fossils in proper context, display a geologic time scale from an encyclopedia or an Earth Science text. Note significant events in the history of life on Earth. For example, have students recall that they learned about trilobites in Chapter 28, and then point out that trilobites became extinct at the end of the Paleozoic Era. Also note the extinction of dinosaurs at the end of the Mesozoic Era. Point as well to the appearance of *Homo sapiens* in very recent time. Show students where on the scale the Cambrian Period begins, and emphasize that it was more than 500 million years ago that the Burgess Shale animals thrived. L2



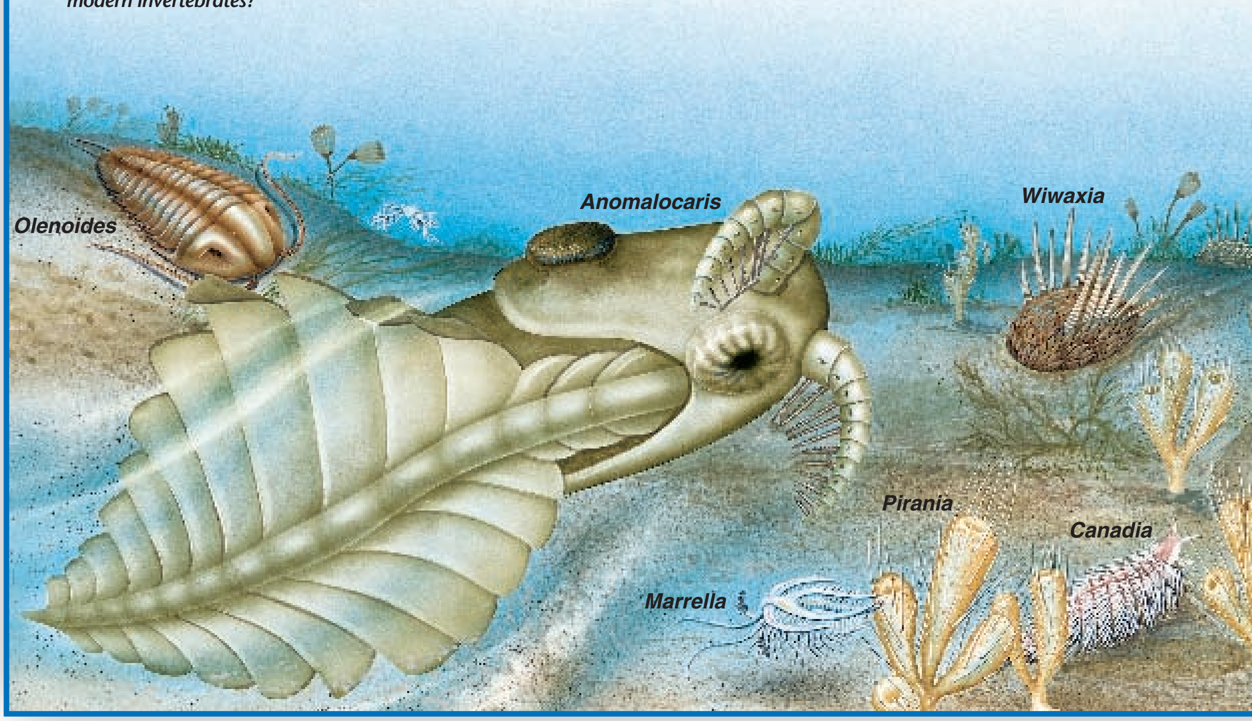
▲ **Figure 29–2** The fossilized arthropod *Marrella splendens* had body symmetry, segmentation, a skeleton, a front and a back end, and appendages adapted for many functions. **Applying Concepts** *What type of symmetry does this fossil exhibit?*

Beginnings of Invertebrate Diversity Fossils from a few million years later—a short period in geological time—paint a radically different picture of invertebrate life. The Cambrian Period, which began 544 million years ago, is marked by an abundance of different fossils. Why the difference from earlier periods? By the Cambrian Period, some animals had evolved shells, skeletons, and other hard body parts—all of which are readily preserved in fossils. Suddenly, the fossil record provided a wealth of information about animal diversity, body plans, and adaptations to life. One of the best-known sites of Cambrian fossils is the Burgess Shale of Canada. A fossil from the Burgess Shale is shown in **Figure 29–2.**

You can see what some of the Burgess Shale animals may have looked like in **Figure 29–3.** Note the wide variety of body shapes and appendages. Trilobites such as *Olenoides* moved along the ocean floor. *Wiwaxia* had two rows of long, pointed spikes. The annelid *Canadia,* like many annelids today, had prominent setae. *Anomalocaris,* the largest Burgess Shale fossil, had fearsome-looking forelimbs that were probably used to grasp prey. The animals of the Burgess Shale are far more numerous and diverse than anything that lived earlier.

In just a few million years, animals had evolved complex body plans. They acquired specialized cells, tissues, and organs. Because of the extraordinary growth in animal diversity, events of the early Cambrian Period are called the Cambrian Explosion. During that time, the ancestors of most modern animal phyla first appeared in the fossil record.

▼ **Figure 29–3** This illustration shows what some of the Cambrian organisms found in the Burgess Shale may have looked like. **Observing** *What body features of these animals are similar to those of modern invertebrates?*

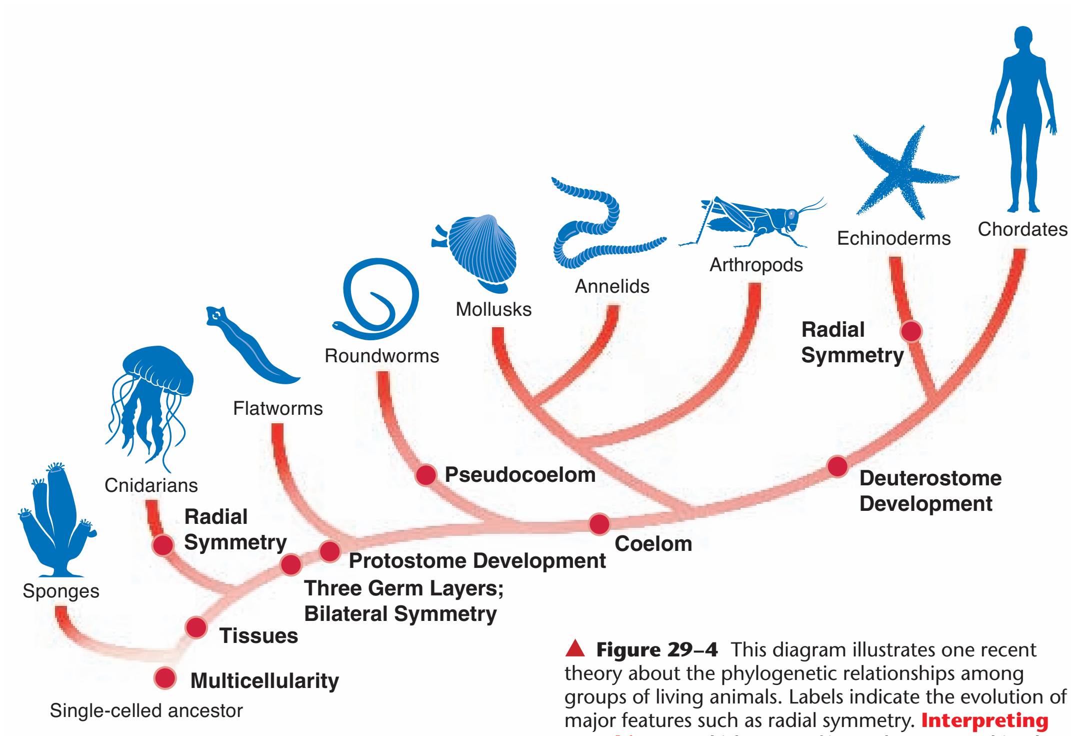


BIO INSIGHTS

HISTORY OF SCIENCE

Creatures of the Burgess Shale

In 1909, Charles Doolittle Walcott, then secretary of the Smithsonian Institution, discovered a section of rock on the side of Mt. Stephen in British Columbia, Canada, that is possibly the most important fossil find ever. From this rock unit, about 60 m long and 2.5 m thick, Walcott collected more than 65,000 fossils. *Marrella,* a 2.5-cm-long swimming arthropod with long antennae and at least 24 pairs of legs and gills, is the most common Burgess shale organism. *Wiwaxia*, 2–5 cm long, is a bottom feeder covered by hard plates and two rows of upright spines. *Olenoides*, a bottom predator as large as 10 cm long, is the earliest example of a trilobite. *Canadia,* 2.5–5 cm long, is an annelid with two slender tentacles and a body covered with short bristles. *Pirania* is an early sponge.



▲ **Figure 29–4** This diagram illustrates one recent theory about the phylogenetic relationships among groups of living animals. Labels indicate the evolution of major features such as radial symmetry. **Interpreting Graphics** *To which group of invertebrates are echinoderms least closely related?*

What features of the Cambrian animals made them so successful? One way of determining this is to find their common features—especially those that are present in animals today. The anatomies of Burgess Shale animals typically had body symmetry, segmentation, some type of skeleton, a front and a back end, and appendages adapted for many functions. These features are characteristic of most invertebrates living today.

Invertebrate Phylogeny

The diagram in **Figure 29–4** shows the evolutionary relationships among major groups of living invertebrates. It also indicates the sequence in which some important features evolved. These features include tissues and organs, patterns of early development, body symmetry, cephalization, segmentation, and the formation of three germ layers and a coelom. Many of these features, which have persisted up to modern times, evolved in animals of the Cambrian Period. As you review the major trends in invertebrate evolution, consider how each feature might have contributed to the evolutionary success of animals.

CA
a

CHECKPOINT *What groups of animals are deuterostomes?*

Word Origins

The word *germ* in the term *germ layers* comes from the Latin word *germen,* which means “embryo” or “sprout.” **If the suffix *-ate* means “to become,” what happens to a seed when it germinates?**

a 7 3.c

Invertebrate Phylogeny

Build Science Skills

Inferring Construct a classroom display of as many invertebrates as possible, using photos as well as live and preserved invertebrates. Try to provide a diverse assemblage, including at least one from each of the groups studied in previous chapters. Label each animal with its common or species name. Then, ask students: **Which of these invertebrates do you think are closely related to one another?** *(Accept all reasonable responses, but challenge students to think about relationships across phylum lines.)* **What further information would you need to be sure about how closely these invertebrates are related to one another?** *(Anatomical, behavioral, and molecular information about these animals.)* L2

Go Online
active art

For: Invertebrate phylogeny activity
Visit: PHSchool.com
Web Code: cbe-8299
Students build their own cladogram online.

Word Origins

When a seed germinates, it sprouts and begins growing. L2

UNIVERSAL ACCESS

Inclusion/Special Needs
Point out the heading on page 748, Evolutionary Trends. Then, discuss with students what a trend is, using examples from their everyday lives. For instance, have students identify trends in popular music, hairstyles, or fashion. Emphasize that a trend is a general movement over the course of time and that there are often exceptions to trends. Point out that *evolutionary trends* include the ways that invertebrates have evolved in general over time. L1

Advanced Learners
Encourage students to investigate further the remarkable fossils of the Burgess Shale and prepare a presentation to the class. For resources, suggest that they look for Web sites and library books on paleontology and prehistoric animals. Perhaps the best book on these fossils is *Wonderful Life: The Burgess Shale and the Nature of History* by Stephen Jay Gould (New York: Norton, 1989). L3

Answers to . . .

CHECKPOINT *Echinoderms and chordates*

Figure 29–2 *Bilateral symmetry*

Figure 29–3 *Asymmetry and pores in the spongelike animals; bilateral symmetry in the other animals; segmentation; cephalization; appendages, including antennae*

Figure 29–4 *Sponges*

29–1 (continued)

Evolutionary Trends

Address Misconceptions

Many students believe that the more-complex animals evolved from simpler animals, and thus are somehow "better" in an evolutionary sense than simpler animals. Point out that each phylum evolved as animals changed through adaptation to changing environmental conditions. Simpler animals have shown that they are quite well adapted to many environments and have persisted in much the same forms for millions and millions of years. L2

Use Visuals

Figure 29–5 Have students study the table of major characteristics, and also have them compare the table with the cladogram in Figure 29–4. Then, ask: **From the information in the table, what can you say about the differences between sponges and cnidarians?** *(Cnidarians have germ layers and body symmetry, whereas sponges have neither.)* Have students look back to the cladogram and confirm that those differences are reflected on that arrangement of phyla. Continue this strategy of providing connections between the information presented in the two figures. L2 L3

Evolutionary Trends

The appearance of each phylum in the fossil record represents the evolution of a successful and unique body plan. Features of this body plan typically change over time, leading to the formation of many new traits. The major trends of invertebrate evolution are summarized in **Figure 29–5.**

Specialized Cells, Tissues, and Organs Modern sponges and cnidarians have little internal specialization. They carry out essential functions using individual cells or simple tissues. As larger and more complex animals evolved, specialized cells joined together to form tissues, organs, and organ systems that work together to carry out complex functions. Flatworms have simple organs for digestion, excretion, response, and reproduction. More complex animals, such as mollusks and arthropods, have organ systems.

Body Symmetry Sponges lack body symmetry. **All invertebrates except sponges exhibit some type of body symmetry.** Cnidarians and echinoderms exhibit **radial symmetry**—body parts extend from the center of the body. Worms, mollusks, and arthropods exhibit **bilateral symmetry,** or have mirror-image left and right sides.

Cephalization Most invertebrates with bilateral symmetry rely on movement for feeding, defense, and other important functions. The evolution of this body plan and lifestyle was accompanied by the trend toward **cephalization,** which is the concentration of sense organs and nerve cells in the front of the body. **Invertebrates with cephalization can respond to the environment in more sophisticated ways than can simpler invertebrates.** In most worms and arthropods, nerve cells are arranged in structures called ganglia. In more complex invertebrates, nerve cells form an organ called a brain.

CHECKPOINT *How does cephalization benefit an animal?*

Comparing Invertebrates

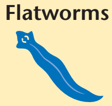
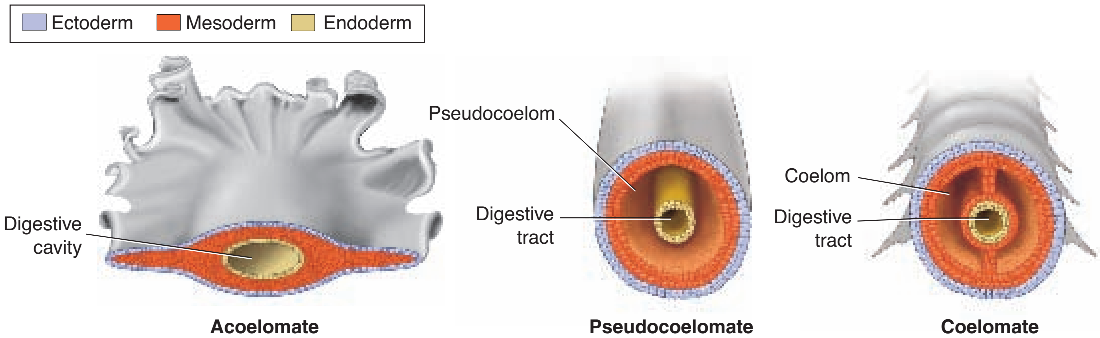
	Sponges 	Cnidarians 	Flatworms 
Germ Layers	Absent	Two	Three
Body Symmetry	Absent	Radial	Bilateral
Cephalization	Absent	Absent	Present
Coelom	Absent	Absent	Absent
Early Development	———	———	Protostome

Figure 29–5 This table shows the major characteristics of the main groups of invertebrates. **Germ layers, body symmetry, cephalization, and development of a coelom are more common in complex invertebrates than in simple ones.** Mollusks, for example, have all of these features, but sponges have none of them.

TEACHER TO TEACHER

When I introduce invertebrate evolution, I ask the students to come up with various environments in which invertebrates live. List on the board the environments (ponds, lakes, dry land, air, and so forth), and have students determine what structures are needed by invertebrates in order to survive in each particular environment. As you go over the lists, have students compare structural similarities and differences among the various groups and between the simple and complex invertebrates. This is a good start for student discussion on evolution.

—*Wendy Peterson*
Biology Teacher
Velva High School
Velva, ND



▲ **Figure 29–6** Acoelomates do not have a coelom, or body cavity, between their body wall and digestive cavity. Pseudocoelomates have body cavities that are partially lined with tissues from mesoderm. **Most complex animal phyla are coelomates, meaning that they have a true coelom that is lined completely with tissues from mesoderm.**

Segmentation Most invertebrates with bilateral symmetry also have segmented bodies. Over the course of evolution, different segments have often become specialized for specific functions. Because the same structures are repeated in each body segment, segmentation also allows an animal to increase in body size with a minimum of new genetic material.

Coelom Formation Cnidarians have a simple construction in which a jellylike layer lies between ectoderm and endoderm tissues. Other invertebrates develop from three germ layers, the endoderm, mesoderm, and ectoderm, as shown in **Figure 29–6.** Flatworms are acoelomates, meaning that no **coelom,** or body cavity, forms between the germ layers. Pseudocoelomates, such as roundworms, have a body cavity lined partially with mesoderm. **Most complex animal phyla have a true coelom that is lined completely with tissue derived from mesoderm.**

Embryological Development In most invertebrates, the zygote divides repeatedly to form a blastula—a hollow ball of cells. In protostomes, the blastopore, or the opening of the blastula, develops into a mouth. In deuterostomes, the blastopore forms an anus. Worms, arthropods, and mollusks are protostomes, and echinoderms (and chordates) are deuterostomes.

	Roundworms	Annelids	Mollusks	Arthropods	Echinoderms
	Three	Three	Three	Three	Three
	Bilateral	Bilateral	Bilateral	Bilateral	Radial (adults)
	Present	Present	Present	Present	Absent (adults)
	Pseudocoelom	True coelom	True coelom	True coelom	True coelom
	Protostome	Protostome	Protostome	Protostome	Deuterostome

Use Visuals

Figure 29–6 Review with students the names of the three germ layers, as discussed in Section 26–1. Then, ask: **What difference can you see between an acoelomate and a pseudocoelomate?** *(In the pseudocoelomate, there is a cavity between the gut and body wall, while in the acoelomate there is no cavity.)* **What difference can you see between the pseudocoelomate and the coelomate?** *(The cavity in the coelomate is lined completely with mesodermal tissue, while the cavity in the pseudocoelomate is only partially lined with mesodermal tissue.)* L2

Build Science Skills

Using Models Divide the class into small groups and give each group three colors of modeling compound. Then, ask each group to make models of an acoelomate, a pseudocoelomate, and a coelomate, using the illustrations in Figure 29–6 as examples of each kind of organism. L2 L3

Use Community Resources

Invite an expert to visit the classroom and speak about how scientists determine the relationships among invertebrate phyla. A university professor who has done research in molecular biology will be able to explain modern methods of biological investigation and answer questions about how molecular data can be used to confirm phylogenetic relationships. L2

BIO INSIGHTS — FACTS AND FIGURES

Advantages of a coelom

The coelom is a fluid-filled cavity between the gut or digestive tube and the outer body wall, creating a tube-within-a-tube construction. The coelom has a number of functions. This cavity serves as a buffer between the outer wall and the inner organs, cushioning them against harm. It allows for the growth of internal organs without distorting the body's outer wall. It serves as a storage place. For invertebrates with an open circulatory system, it provides a place for circulation to occur. Also, the fluid in the cavity serves as a hydrostatic skeleton for many animals. There are several theories about when and how the coelom evolved. Some zoologists think that it evolved twice, once in protostomes and again in deuterostomes. One thing is certain—there is great adaptive advantage for a crawling or burrowing organism to have a coelom.

Answer to . . .

CHECKPOINT *Because sense organs and nerve cells are concentrated in the head end, animals with cephalization can respond to the environment in more complex ways than can animals that lack cephalization.*

29–1 (continued)

Problem Solving

Defining the Problem Have students write a detailed description of the habitat they have chosen.

Organizing Information Make sure students consider all relevant features as they pick the body systems that would work best in the chosen environment.

Creating a Solution Advise students to write a general description of the invertebrate they create and then describe as many body systems as they can in detail.

Presenting Your Plan Have students present their "perfect invertebrates" to the class, or provide bulletin board space for students to display their plans. L2 L3

3 ASSESS

Evaluate Understanding

Call on students at random to explain the major trends of invertebrate evolution.

Reteach

Have students look at Figure 29–4. Help students write a paragraph that explains how the groups of invertebrates are related to one another, indicating what major feature appears each time the cladogram branches.

Focus on the BIG Idea

Students should compare animals such as those in Figure 29–3 with animals described on pages 745–747. Students should emphasize that many of the Burgess Shale animals had hard body parts, complex body plans, segmentation, and organ systems, whereas the earlier animals did not.

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 29–1.

Problem Solving

Creating an Imaginary Invertebrate

The moth in the photo is a real animal, but you may think that it looks like a science-fiction monster. Several of the most frightening "monsters" dreamed up for the science-fiction films of the past 20 years have actually been based on bits and pieces of anatomy and behavior of real invertebrates. Now that you have studied all the invertebrate phyla, try to create the "perfect invertebrate" for a habitat of your choice.

Defining the Problem First, choose a habitat: a temperate zone desert, a tropical coral reef, or inside the body of a mammal. Depending on which habitat you chose, define the environmental challenges (such as heat, cold, or lack of water) and the biological needs (such as food and oxygen) that your organism must meet.

Organizing Information Once you have defined the problem, look back over the characteristics of all the invertebrate groups you have studied, and pick the kind of body systems that you think would work best in your chosen habitat.

Creating a Solution Assemble the body systems you have chosen into an imaginary animal. Make sure that the systems you use can work in harmony. You could not, for example, expect an animal to breathe through its skin if it had an impermeable exoskeleton covering its entire body! Make sure that you have considered all the organism's needs. Give your animal an appropriate name.

Presenting Your Plan Create external and cutaway diagrams of your animal, including any larval stages. Label the diagrams, including the name of the real-life invertebrate system that fulfills each essential function. Conclude by describing the complete life cycle of your organism.

29–1 Section Assessment

1. **Key Concept** Describe three major trends in the evolution of invertebrates.
2. Compare the first multicellular animals with those of the Burgess Shale.
3. How was the evolution of internal specialization important to invertebrate form and function?
4. Compare the body structures and other characteristics of cnidarians and mollusks.
5. **Critical Thinking Observing** Observe the fossil of *Marrella splendens* in **Figure 29–2.** What evidence does the fossil exhibit of anatomical (structural) characteristics similar to those of present-day arthropods?

Focus on the BIG Idea

Unity and Diversity
Imagine that you are one of the first paleontologists to find fossils in the Burgess Shale. Suppose that you have studied the fossils and compared them with earlier animal fossils such as the one in **Figure 29–1.** Write a report for a scientific journal about your discovery and its significance.

29–1 Section Assessment

1. Three of the following trends: specialized cells, tissues, and organs; body symmetry; cephalization; segmentation; coelom formation; and patterns of early development
2. The first multicellular animals were soft-bodied and show little evidence of cell specialization or cephalization. Animals of the Burgess Shale had hard parts as well as cephalization and specialized cells, tissues, and organ systems.
3. Specialized cells, tissues, organs, and organ systems work together to carry out complex functions.
4. Cnidarians have two germ layers and radial symmetry. Mollusks have three germ layers, bilateral symmetry, cephalization, a true coelom, and protostome development.
5. Students should mention a segmented body, an exoskeleton, jointed appendages, bilateral symmetry, and cephalization.