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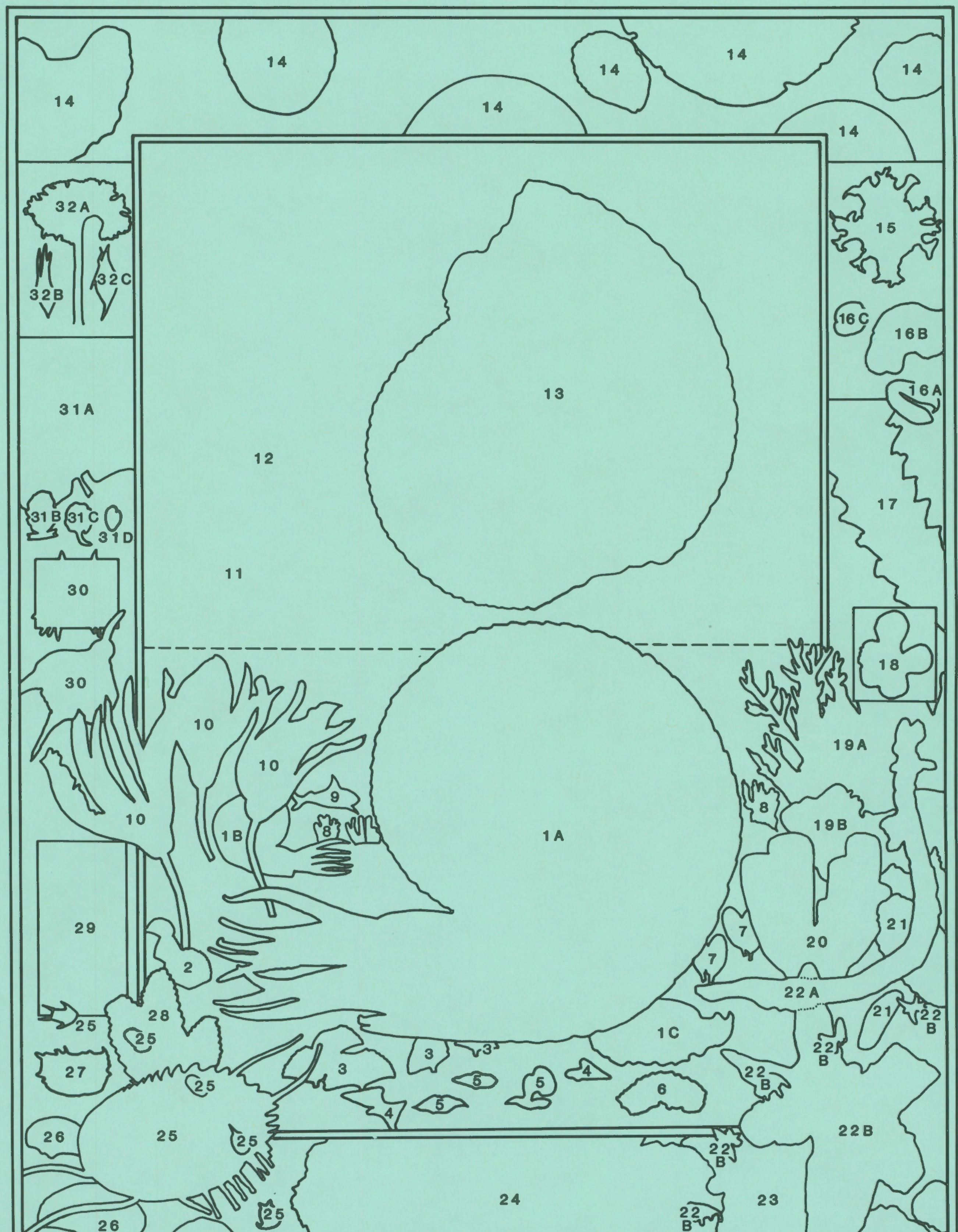

EXPLANATORY NOTES TO ACCOMPANY POSTER ENTITLED "FOSSILS"

PRODUCED BY THE GEOLOGICAL SURVEY OF CANADA,
Natural Resources Canada

INTRODUCTION

This poster illustrates fossils of plants and animals that have inhabited the earth over the course of its history. The Earth formed over 4 500 million years ago, but the first life, probably bacteria, did not appear until about 3 500 million years ago. Since that time life has evolved on Earth through a process that has given rise to a great variety of plants and animals. Most of these organisms are now extinct and known only from the fossil record. The study of animals and plants that have lived in the past is called *paleontology* and scientists who study fossils are known as *paleontologists*. In order to become a professional paleontologist, a person must study geology and biology, but anyone can have fun collecting and identifying fossils in their own area. Fossils occur in sedimentary rocks which are present in most regions of Canada. To find out what rocks are present in your area consult a geological map or report dealing with your region. Collectors should take care to learn the rules and regulations that apply in their region, to respect the property rights of landowners, and to take safety precautions. Good specimens should be shown to professional paleontologists because they may represent a species new to science or provide other valuable scientific information.

THERE ARE MANY REASONS TO STUDY FOSSILS

A. Paleontological study of fossil assemblages makes possible the dating and comparison of fossiliferous rocks throughout the world. Organisms that are abundant, evolve quickly, have a wide distribution and are relatively tolerant of a wide range of environments make the best time indicators. Species that have these characteristics are likely to be used for definition of short intervals of time called zones and they are referred to as index or guide fossils. Many paleontologists, particularly those employed by oil companies and government agencies, are involved in this branch of paleontology which is called *biostratigraphy*.

B. The appearance and disappearance of different fossils through time tells a story of changing environmental conditions. One of the main objectives for study of sedimentary rocks is the reconstruction of the environment in which the sediments that form the rocks were deposited. Accurate reconstruction of environments can lead to the discovery of natural resources such as coal, many metals, salt, oil and gas. A study of the environmental requirements of organisms that become fossils provides the most accurate information on the ancient environment in which they lived. Studies of this type are referred to as *paleoecology*.

C. Without the study of fossils we would know nothing about the history of life on Earth and the connections of various groups of organisms in the chain of biological evolution. Even though the fossil record is imperfect because organisms have different potential for preservation as fossils (only some are preserved), it is the only record of life on Earth. Detailed studies of fossils are primary components of research on *evolution*.

D. Unusual patterns in the distribution of fossils were one of the first reasons that scientists began to suspect that the continents had not always been in the same positions. Now that it is well established that continents have moved over the surface of the Earth, the present-day distribution of fossils is used as one line of evidence to reconstruct the position of continents and oceans in the geological past. Just as the distribution of animals and plants on the Earth today is affected by various environmental conditions, so were the organisms on the ancient Earth. The use of fossils for this purpose is termed *paleobiogeography*.

E. Knowledge of the history of life provides important information for the understanding of processes that have taken place, and still are taking place on the Earth's surface. The existence of life on Earth has affected the chemistry of the oceans and atmosphere over the past 3 500 million years. The fact that organisms began to secrete shells and skeletons of substances (mainly calcium carbonate, silica and organic compounds) has had a significant effect on the distribution of important elements on Earth, especially calcium, carbon, silicon, and oxygen. The appearance of land plants and their continued existence has a profound effect on the composition of the atmosphere. For all these reasons it is important to study the impact of the history of life on the *geochemistry* of the Earth.

ABOUT THE POSTER

The central image is divided into two halves. The lower half represents how a sea bottom may have looked during the Jurassic Period, some 150 million years ago, dominated by a large shellfish called an ammonite (1A). The upper half depicts how the ammonite (13) might look when preserved as a fossil dug from rock strata such as those illustrated in the background landscape. Around the margin of the poster are illustrations of fossil groups that are important in the geological record. In the text that follows, the specimens identified by number in the silhouette diagram, are described and important aspects are highlighted. A standard geological column containing the names and sequence of time periods and a list of suggestions for further reading are included at the back. It is hoped that this text will be of value to the general public, particularly school teachers and students.

SEA-FLOOR DIORAMA

01. AMMONITES

Ammonites were marine animals that belong to the Class Cephalopoda, meaning "head-footed". Modern cephalopods include the squids, cuttlefish, octopus, and the *Nautilus*, a coiled shellfish that lives in the seas off southern and southeast Asia. They are predators, cruising the seas and sea bottom, grabbing fish and other prey with their tentacles, and crushing them with their beak. Cephalopods have a complex eye structure, and can swim rapidly by jet propulsion, as they expel water from their siphon in any direction. Some escape from enemies by exuding a cloud of dark ink into the sea water. Some cephalopods, such as

Nautilus and the ammonites, have a hard outer shell. Others have an inner hard support structure - the cuttlebone or pen of modern species.

The ammonoids are an extinct group of cephalopods, known primarily from preserved shell remains. Because they evolved rapidly, have many distinctive features, and spread widely with the ocean currents, these shells are important index fossils from Late Paleozoic through Mesozoic time. Figure 1A shows an artist's interpretation of how the animal might have looked in its shell, using analogies from the modern, distantly related *Nautilus*. Note the arms with suckers, the prominent eye, the colour banding of the shell and the protective covering on top of the soft parts. This is the aptychus, which folds down and seals the shell's opening when the animal retracts into its shell. Details of the life style of ammonites are uncertain, but they probably did some swimming and some crawling on the ocean floor in search of prey. Figure 1B shows another specimen living on the sea-floor, and lC a dead shell lying on the sea-floor. See also explanation for 13.

02. BRACHIOPODS

Brachiopods are a group of animals that form shells, but which are poorly known to most people because of their scarcity in modern oceans. Many have stalks (pedicles) with which they live attached to firm objects in the sea, such as rocks on the bottom, or wharves and piers. They occur on both the Atlantic and Pacific coasts of Canada, where they are rarely seen. There are many different kinds of brachiopods, most of which are extinct. Those illustrated are rhynchonellids, a common component of some Jurassic faunas and a hold-over, to the present day, from the Paleozoic Era, when they were exceptionally abundant. Beginning about Middle Jurassic time, their dominant position on the sea-floor was taken over by the bivalves, which are the main form of shelled organism in modern oceans. Because of their highly specialized forms and rapid evolution, many brachiopods are exceptionally good index fossils, as well as indicators of ancient environments and the geographic configuration of ancient oceans.

03. BRACHIOPODS

Another major group of brachiopods that survives today since Paleozoic time is the spiriferinids, shown here attached to a Jurassic sea-floor by their pedicles. See explanation for 02.

04. SHARKS' TEETH

Sharks' teeth are a rare component of Canadian Jurassic fossil faunas, but occasionally occur in some unusual fossil assemblages of other ages. They are illustrated here to show that fossil assemblages are an imperfect indicator of the life that existed in ancient times. Certain plant and animal communities are preserved in the fossil record much more commonly than others, for reasons related to their living environments and the processes of deposition and preservation after death. The presence of a shark's tooth on the sea-floor amongst animals that actually lived there is an anomaly - the remains of an animal that swam in the seas above, and dropped to the sea-floor upon its death. It is the small reminder of the passage of a large animal that is otherwise un-noticed. It is also a reminder to the paleontologist that his collections are incomplete records of ancient communities, and may be a mixture of species that lived together as well as some that are there due to death, and thus not a real community at all. See also 09.

05. MOUNDS AND BURROWS

Sandy and muddy sea-floors, as well as beaches in the intertidal zone may support an abundance of animals that live in burrows and therefore are rarely seen. The openings of their burrows can often be seen however, and many of them throw or push sediment into mounds. The most dominant burrowing animals are the crustaceans (certain shrimps and crabs) and bivalves (e.g. clams). A large number of bivalves live below the surface of the sea-floor, and filter microscopic animals and plants for food from the seawater that they circulate through their siphons.

Sedimentary rocks commonly show extensive evidence of burrowing. An entire branch of paleontology deals with these burrows (trace fossils) of which there is a great variety. Sometimes the burrows are obvious, cutting the lamination, and sometimes cross-cutting each other. In other cases, the original lamination is destroyed and only a homogeneous layer of mixed clay and sand indicates the extensive burrowing and mixing of what were originally different layers. Bivalves can be found in growth position, oriented vertically across the bedding, with their siphons pointed upward (called a life assemblage). Other burrowing organisms are rarely found.

More commonly, however, fossils are found strewn on the surface of a rock bed, indicating that burrowing species were excavated and redistributed on the sea-floor. This indicates that a current or storm occurred, with a strength that was greater than normal for the area. Thus periods of gentle wave or current activity that allowed for colonization of the sea-floor by organisms alternated with rougher periods when the colonies were disrupted. The shell beds that result from excavation of burrowing organisms generally also contain a variety of other species that lived on, rather than below, the sea-floor. They are a mixed death assemblage. See also 04, 06 and 24.

06. BIVALVE

This species of bivalve, belonging to the genus *Myophorella* is characteristic for many Jurassic marine strata in Canada. It originally burrowed in the sand or mud of a Jurassic sea-floor, and was excavated by currents or waves so that it lies beside a variety of other species, some dropped from the open water above (04), some actually colonizing the sea-floor (02, 03). For detailed discussion of bivalves, see 26.

07. LINGULA

One large group of brachiopods (see 02, 03) has existed throughout most of the Phanerozoic Eon with little change in form. They are simple shells with few characteristics to differentiate them, and have no value as index fossils. The shells illustrated, belonging to the genus *Lingula*, occur in Canada in rocks of all ages. Like oysters, *Lingula* is not specialized for any particular environment within the shallow marine realm and can colonize niches from which more specialized species are excluded.

These generalists or opportunists, may dominate certain environments because they have no competition from other organisms. They have come to be thought of (wrongly) as having special adaptations to these difficult conditions, for example brief periods of exposure to the atmosphere, and fresh (low salt content) or hypersaline (high salt content) water.

08. SPONGES

Sponges are shown living on a Jurassic sea-floor (see also 20). They are not normally preserved as three-dimensional fossils in the Canadian Jurassic, but extensive sponge reefs are characteristic of much of the Upper Jurassic of Germany. More commonly in Canada, the soft material of the sponges decayed, and scattered microscopic silica fragments (spicules) scattered on the sea-floor are the only record of their existence. See also 20.

09. SHARK

Although fossils of sharks are rare and almost entirely represented by teeth, their record is ancient, extending back to the Devonian. Sharks, like the rays and skates, have skeletons made of cartilage rather than bone, so that they are rarely preserved as fossils. These earliest of fishes dominated some Paleozoic seas, and perhaps also Mesozoic seas, to at least the extent that they do today, but their soft skeletons left little record. Only fossil teeth mark their passing; presumably the remainder of the body was consumed by predators or rotted away. See also 04.

10. CRINOIDS

Crinoids or sea lilies are animals that form a complex hard skeleton consisting of many small articulated plates. Each small plate is a crystal of calcite and is attached to the adjoining plate by a glue of soft organic material. The most conspicuous parts of the crinoid are the calyx (like the head of a flower), the arms and the cirri (fine feathery parts of the arms). Species that live attached to the sea-floor have stalks; others swim freely in the ocean. See 23.

FOSSILS AND STRATIGRAPHY

11. BIOSTRATIGRAPHY AND THE GEOLOGIC COLUMN

Biostratigraphy is the science of creating a record of the earth's history through study of the fossils contained in sedimentary rocks. By carefully observing the sequence in which different fossil species occur in many parts of the world, and splicing them together from one place to another, generations of paleontologists have produced a composite record of the life of the past. This record, the geologic or fossil record, is subdivided into a hierarchical system of eons, eras, systems, and stages. For example, the Phanerozoic Eon is the record of the earth's history since about 570 million years ago, when the first organisms with hard skeletons appeared in abundance.

The Phanerozoic Eon is subdivided into the Paleozoic (meaning ancient life), Mesozoic (middle life) and Cenozoic (recent life) eras. The Mesozoic Era, extending from about 250 to 65 million years ago, is the age of the great reptiles - the dinosaurs on land, the flying pterosaurs and the aquatic mosasaurs and plesiosaurs - and of the ammonites. The name Mesozoic indicates that the plants and animals of this time are a mixture of some essentially modern forms, and some that are ancient.

The Mesozoic Era is subdivided into the Triassic, Jurassic and Cretaceous systems or periods. The Jurassic Period, extending from about 208 to 140 million years ago, is further subdivided (primarily on the basis of the sequence of ammonite fossils in marine deposits) into 11 stages, each about 5 million years in duration. A sequence of 4 stages, ending with the Callovian, is grouped together as the Middle Jurassic, and the younger series, beginning with the Oxfordian, as the Upper Jurassic. The ammonites in Figures 1A and 13 are index fossils for the Upper Callovian Lamberti Zone, an interval of about 1 million years duration or less, which is about the finest precision that can be recognized in geology.

12. SEDIMENTARY ROCKS IN THE FIELD

Fossils occur in sedimentary rocks, formed of sediments laid down by wind or water. By studying the fossils in these layered rocks, and details of their texture and bedding structures, geologists can determine how and where the original layers of sediment were deposited. The strata are studied by the field geologist, who records all details about each bed, including its relation to lower and higher layers, its thickness, composition, the types and size of particles or grains, and its fossil content. The geologist will usually collect samples for later preparation and analysis in the office and laboratory.

The landscape illustrated is the badlands near Drumheller, Alberta. The rocks are horizontal, and have been cut by erosion in the last 12 000 years, first by the enormous quantities of water that melted from the retreating glaciers of the last ice age, and then by the periodic downpours that are interspersed with arid conditions that continue today. Differential resistance of the sandstone, siltstone and shale layers to the forces of erosion result in undercutting of the hard layers. The result is a complicated system of hoodoos, gullies and small underground tunnels.

The strata illustrated are Late Cretaceous and earliest Tertiary in age, and are mainly nonmarine lake and river deposits, although a few layers contain fossils that indicate the occasional presence of seas. These strata contain the Cretaceous-Tertiary boundary, when the last of the dinosaurs, ammonites, and many other creatures disappeared, perhaps due to a cosmic body colliding with the earth. Dinosaur bones, marine and nonmarine shells, and plant remains can be found in abundance at Drumheller. These strata also contain coal deposits which were mined until recently. The slippery nature of the hillsides when wet is the result of bentonite in the rocks, a volcanic ash which indicates the presence of distant volcanoes during the time of deposition of the sediments.

FOSSILS

13. AMMONITES

The shell of the animal shown in Figure 1A has been reversed in a mirror image by the artist, and the shell broken and stained by minerals to indicate the way in which these fossils are often found in marine strata. No soft parts remain, and imperfect shells or impressions are often the only material the paleontologist has available to work with. These specimens are a species of the genus *Quenstedtoceras*, which occurs in rocks of about 152 million years old (Late Callovian), around much of the world including western Canada.

Ammonites are one of several fossil groups in which distinct sexes are thought to have existed, based on the different size and structure of individuals that are found together.

14. CORALS

Corals are simple aquatic animals with hard limy skeletons which makes them important rock builders. Modern reefs occur in areas where the water is warm such as Australia and the Caribbean because they like water temperatures above 20°C. The presence of fossil coral reefs in the Arctic and Antarctic indicates that climatic conditions in the past were very different from the present. Many fossil reefs are important reservoirs of oil and gas such as the Devonian reefs of Alberta.

Corals are studied by cutting slices so thin that they are transparent. In this way the internal structure is revealed and the differences found allow the paleontologist to identify many different species. The illustrations poster are of thin sections of a variety of corals of Devonian age, about 400 million years old. See 19 for other discussion of corals.

15. DINOFLAGELLATES

Living dinoflagellates are tiny unicellular (single-celled) protozoans that live in both fresh and salt water. Their name means whirling whips because the majority are equipped with long whip-like processes called flagellae that thrash about and enable the organism to move. The phenomenon of red tide is a result of the presence of huge numbers of dinoflagellates in areas rich in food. The natural colour of the tiny creatures makes the sea water turn red. Red tides can be dangerous because the dinoflagellates produce poison which is accumulated by shellfish and makes them hazardous to eat. Modern dinoflagellates are also responsible for most of the luminescence (shimmering lights) in the sea such as that seen in the wake of ships. They provide food for larger organisms including the whales, the largest mammals ever to have lived.

Dinoflagellates are common as microscopic fossils (microfossils) in strata of Triassic to Recent age (about 250 million years ago to the present). They occur in the form of tiny cysts (0.02-0.15 mm long) made of a resistant organic material and are extracted from rocks using strong acids. The swimming whip-equipped phase in the life cycle of dinoflagellates is not usually preserved as fossils. Dinocysts are present in a variety of shapes, many with spines such as the specimen illustrated on the poster. Dinoflagellates are useful for telling the age of rocks because they evolved rapidly and allow paleontologists to recognize successive zones. These zones are used extensively in the exploration for oil and gas deposits where they provide information on the relative age of rocks penetrated by drilling rigs.

16. SPORES AND POLLEN

Spores are formed by bacteria, fungi, algae and vascular plants, but only those produced by land plants are common as fossils. A spore is a single- or few-celled structure produced by the plant in order to reproduce. Spores and pollen are very small ranging in size from 0.02-0.1 mm in length. They are produced in vast numbers and can travel widely in wind and water, ending up in rivers, lakes, seas and oceans. Spores are produced by vascular plants such as mosses and horsetails, including the giant clubmosses such as those represented by *Lepidodendron* (32), and ferns (16C). Seed-bearing plants produce pollen grains which serve the same purpose as spores but are composed of many cells. The specimens illustrated as 16A and 16B are pollen grains from a flowering plant (e.g. poplar tree, and a spruce, respectively). Spores and pollen provide important information for study of the origin and development of land plants. When plants die they generally rot quickly and thus they are not often preserved as fossils. Pollen and spores tend to be preserved much more commonly because they are produced in great numbers and covered in a tough coating.

The study of spores, pollen and dinoflagellates is called *palynology*. For the study of the Quaternary (the time of the most recent ice age), palynology contributes significant information about past climatic and plant migration patterns. In a more ancient geological context, palynology illustrates the evolution of plants. This information is put to practical use to determine the ages of sedimentary rocks, an application important to exploration for oil, gas and coal, and to geological mapping.

One of the special applications in petroleum exploration is based on the observation that spores and pollen change colour when they are heated. Like most organic materials, they tend to darken in colour as they are heated, eventually turning black. The changes in colour are progressive and irreversible and different colours can be assigned to known temperature ranges. Some heat is important to the formation of oil and gas. Relatively low heat is necessary for the formation of oil, but with increasing temperature gas is formed. Above certain temperatures only carbon is left and no oil or gas will be found. The colour of spores and pollen are sensitive, permanent indicators of the maximum temperature to which the rock has been heated. Data from this type of analysis is called the Thermal Alteration Index (TAI) and is used widely in the search for oil and gas. The specimens illustrated on the poster show a variety of TAI levels: specimen 16A is natural (unheated) colour, 16B is darker brown and 16C is almost black representing an even higher temperature ("cooked").

17. GRAPTOLITES

Graptolites are extinct marine colonial organisms that are very common as fossils in rocks of Ordovician and Silurian age from about 518 to 410 million years ago. The colonies were thin linear arrangements of short tubes connected internally by a common canal. An individual animal lived in each tube and presumably shared responsibility for food gathering. The specimen shown on the poster has a row of tubes on both sides of the common canal. The animals that lived in the tubes are not shown because they were composed of soft tissue and not preserved. Graptolites are most commonly preserved as flattened impressions on rock surfaces and this gave rise to their name because they look like lead (actually graphite) pencil marks on the rocks. Sometimes graptolites are preserved without being compressed and much has been learned about their structure and evolution from these three dimensional specimens. Although there are no living graptolites, it is likely that they belong to the group called Phylum Hemichordata, a group of animals related to the vertebrates (animals with backbones) to which human beings belong. Graptolite colonies varied greatly in size, but commonly ranged from a few millimetres to 10 cm in length.

Graptolites show many changes during the Early Paleozoic (about 500 to 387 million years ago) and this has made it possible for paleontologists to recognize many zones of worldwide extent, each with distinctive graptolite species as index fossils.

18. FORAMINIFERA

The Foraminifera are a group of single-celled microscopic organisms that live either on the sea-floor or floating in the water column as marine plankton. The soft tissue is enclosed in a shell of organic material and minerals (e.g. calcium carbonate) secreted or gathered from the sea-floor by the organism. Foraminifera are small (usually less than 1 mm in diameter). The shell commonly consists of a number of chambers each connected by an opening. These microorganisms presently live in the ocean from 5 to 5 000 m depth. Bottom-dwelling Foraminifera have existed since the Cambrian and those living in the water column have been known since the Mesozoic.

Foraminifera have been studied in great detail because of their abundance, wide distribution and diversity. They are widely used in determining the age of the rocks, especially rocks from the Mesozoic and Cenozoic. Evidence from Foraminifera has been used to determine that the modern Atlantic Ocean began to form about 120 million years ago. The shells of Foraminifera can be so abundant in marine sediments that they sometimes make up the bulk of the rock, such as in certain chalks oozes from the modern sea-floor.

Rarely, Foraminifera make larger shells which grow to several millimetres in size. Such large Foraminifera are common in the rocks of which the pyramids of Egypt are made and ancient travellers believed them to be lentils eaten by the slaves who built the pyramids.

19. CORALS

The branching form of the corals illustrated as 19A is typical of many that form the framework construction of reefs. The form of the colony depends on its environment. Massive rounded corals such as that illustrated as 19B tend to live in the surf zone whereas the more delicate branching form in 19A (the staghorn coral) live at greater depths out of range of the surf's action. The rate of growth of corals varies with environment and season, but may be very rapid, up to 10 cm per year in branching corals.

In well preserved specimens, fine successive lines may be visible. These lines represent daily growth, and groupings of them represent monthly and annual growth. Studies of these growth lines in Devonian corals have shown that there was an average of 400 days in a Devonian year, compared to only 365 now. This observation is in agreement with astronomers' estimates that the Earth's rotation has been slowing down due to friction by about 2 seconds per 100 000 years. Since the Earth was spinning faster during the Devonian, there were more days in the year but they were shorter. See also 14.

20. SPONGES

Although most bathroom sponges are now made of plastic, it is still possible to buy a natural sponge which is actually the remains of an organism. Sponges are multicellular (many celled) organisms but the cells are not organized into distinct tissues and in many ways they represent a level of organization between unicellular (single-celled) animals and true multicellular organisms. Details of fine structure are used to identify species of sponges but the form of a sponge can vary greatly, and the same species can adopt different shapes in different environments. Most sponges have a skeleton composed of either organic material or tiny silica spikes (spicules), or both. The spicules are the parts most commonly preserved as fossils and are crucial to identification of species.

Sponges are sometimes preserved as body fossils such as the branching form *Vauxia* from the Burgess Shale (illustrated). The Burgess Shale is Cambrian in age and occurs in Yoho National park near the town of Field, British Columbia. It contains a diversity of extremely well preserved fossils representing arthropods (trilobites), molluscs, brachiopods, sponges, echinoderms, worms of all sorts, chordates, as well as a substantial number of forms that are not readily accommodated in any of the known major groups of animals. The site of the Burgess Shale is a UNESCO World Heritage Site and there is an interpretation centre on the Trans Canada Highway near Field.

Sponges are also preserved as fossils in reefs. Stromatoporoids, an extinct type of sponge, are a very important component of reefs in the Paleozoic, particularly the Devonian reefs of Alberta that are host to major oil and gas resources. Spaces within the skeletons of the corals and stromatoporoids provide the porosity necessary for accumulation of oil and gas. Sponges are also important in reefs of Permian and Jurassic age. See also 8.

21. BIVALVES

See comments under 26.

22. CONODONTS

The conodonts are among the most mysterious of fossil organisms. First discovered in 1856 as tiny tooth-like fossils, many years passed before the fossil impression of the animal from which these hard parts came was discovered. The conodont animal (22A) was discovered, not at a field collecting site, but in the cabinets housing fossil collections at the British Geological Survey. The organism had been collected in the 1920's from Carboniferous strata as part of a major collection of shrimp fossils that are abundant in the same beds. Demonstrating the importance of preserving collections, the specimen remained unrecognized until 1983 when its description rocked the paleontological community.

Conodonts are most commonly minute (typically 0.1-1 mm) tooth-like fossils. They are tough microfossils because they are made out of bony material (calcium phosphate) and are readily preserved. Several different forms of tooth occurred together in each animal. For example, all the elements illustrated in the poster as 22B belonged in a single organism common in rocks of Ordovician age. These hard structures formed the feeding apparatus for the organism which was probably a free-swimming type of complex worm, perhaps a protochordate. Conodonts are extinct but they had a long and successful history on Earth from Cambrian through Triassic times. Like graptolites (17) and Foraminifera (18), they are very useful as index fossils for telling the age of rocks in which they are found.

Conodonts, like spores and pollen (16), change colour with increasing temperature and are thus valuable "paleothermometers". Conodonts survive a much greater range of heating than spores and pollen and are still identifiable until they have been subjected to a temperature of about 600°C. Conodonts change from a natural amber colour to dark brown to black and eventually to grey then white. This change is like that observed on a barbecue where cooking will turn meat (organic matter) black; if burned all the way to ashes, the organic matter consumed and the ashes are white.

23. CRINOID STEMS

Crinoids, or sea lilies, are found only rarely as whole fossils where conditions of deposition were very quiet, and there were no predators, so that the parts did not become separated. These conditions commonly characterize sea-floors with low oxygen and little circulation. No organisms lived on the sea bottom, and those that fell down from the water above when they died remained untouched by predators.

Most commonly crinoids occur as individual plates (ossicles) in the fossil record, or as small fragments of stalks with several plates still attached. In western Canada, entire rock formations, such as some in the Carboniferous of the Rocky Mountains, are made up of crinoid ossicles. Crinoids, which range through most of the Phanerozoic, are not good index fossils because of their normally fragmented preservation. Distinctive patterns resembling stars or flowers with 5 points or petals ornament some Jurassic species however, as seen in 23. Five-fold symmetry in nature is restricted to the crinoids and other echinoderms (meaning spiny skins), such as the starfish, brittle stars and sea urchins.

24. DEATH ASSEMBLAGE

This figure shows several ammonites and bivalves that were broken and brought together to be found as a fossil death assemblage, the most common kind of fossil accumulation. It includes a mixture of species that lived in the sea water, on the sea-floor, and in the sediment beneath it. Strong waves and currents caused by storms may have caused the shells to be concentrated, mixed and broken. Depending on the size and shape of different species and the conditions of deposition, these shell concentrations or shell beds will have differing compositions, even when the same basic components are involved. The ammonites shown are all oriented in the plane of the poster. Storms may jumble shells so that they lie in random orientations throughout a layer of sediment, whereas gentler currents tend to lay shells flat on the sea-floor.

25. TRILOBITES

Trilobites are an extinct group of marine arthropods, a major group that includes the modern crabs and insects, and is characterized by segmented bodies, paired, jointed limbs, and a hard outer covering with flexible joints. They are known in marine rocks of Cambrian through Permian age. They are characterized by three distinct regions of the body: head, thorax and tail and by three-lobed appearance over much of their length. Throughout their 320 million year history, they maintained a constancy of overall form but with many variations. The most common part of a trilobite to be preserved as fossils is the hard covering, and because trilobites, like modern crabs, shed their skin in order to grow, there are often fragments of heads, thoraxes and tails on a slab of rock. The limbs (legs and antennae) are only rarely preserved because they are much more delicate.

One of the most interesting features of many trilobites is their eyes. They represent the most ancient visual system known. Trilobite eyes are compound, like those of insects, being composed of many small lenses that commonly give a wide field of view. The eyes on the specimen illustrated on the poster are the narrowly oval brown areas on either side of the head. The faint ridges that run from the eye to the margins of the specimen represent the lines along which the shell cracked and from which the trilobite animal emerged as it shed its old shell.

Trilobites are important index fossils in the Cambrian and Ordovician. Global distribution patterns of trilobites are used to recognize what are known as faunal provinces. On the Earth today animals and plants have restricted distributions due to environmental conditions. In the same way it is possible to delineate regions of the ancient Earth based on the fossils that they contain. The recognition of regions with similar faunas suggests that those areas were adjacent prior to continental drift, or at least in the same general climatic belt, or connected by ocean currents.

In Cambrian time the trilobites that occur in the western part of Newfoundland are similar to those found over much of North America, but those in the eastern part of Newfoundland are much more similar to those in Europe. The two different groups of fossils are described as separate faunal provinces and the difference between them supports other evidence of an ancient ocean (Iapetus, the ancestor of the modern Atlantic) that closed along a line that runs through central Newfoundland.

26. BIVALVES

This group of organisms (also called pelecypods) includes the oysters, mussels, scallops and clams that are commonly used as food. They live mainly in the sea but there are some that live in fresh water. A visit to the seashore will often reveal the remains of hundreds of shells of bivalves. The two shells, usually similar in shape, are joined along a hinge by teeth and elastic ligament. The inside surface of the shells bears the scars or impressions of muscles. The shells are kept open during feeding and tubes (siphons) bring in food and exhaust waste material. The shells can close quickly if the bivalve senses danger and one may often see the spurt of water as a bivalve living in a burrow beneath a sandy beach closes its shells (see 5C).

Bivalves live on the bottom of lakes or seas, burrow in sand and mud, or cement themselves to rocks. The shape of a bivalve shell can provide hints as to the mode of life of a particular species: for example some that live on the sea-floor may have broad shells to prevent them sinking into the soft bottom (26).

Bivalves originated in the Cambrian but did not diversify much until the Ordovician. They are not as common as brachiopods (3, 7) in Paleozoic rocks, however, in the Mesozoic to Recent bivalves are common fossils and some are important as index fossils. When a bivalve dies, the two shells, which are essentially spring loaded, fall apart. In contrast brachiopod shells (5, 7) tend to stay together because they lack the elastic ligament. See also 5, 6 and 21.

27. OSTRACODES

At first glance ostracodes might not seem to be members of the same group as trilobites (arthropods) because the body is enclosed between two shells, but they are similar in having jointed appendages and segmented bodies. Ostracodes are commonly called seed shrimps because of their shells' resemblance to a seed and their body to that of a shrimp. They are small, usually less than 1 mm long, but large forms up to 30 mm long are known. The shell is hinged along the upper margin and one side commonly overlaps the other. Shells have lobes, pits, spines and ribs and may be quite ornate such as the one illustrated from Silurian strata of the Northwest Territories.

Ostracodes, like trilobites, moult as they grow and each cast-off shell may be fossilized leading to an abundance of fossil material. Ostracodes live in a variety of settings: in the water column, on the sea-floor, in fresh water lakes and even in humid forest soils. They are abundant as fossils, particularly in the marine setting.

Male and female ostracodes are distinguishable on the basis of shell size and shape. The females, like the one illustrated, have prominent rounded bulges called brood pouches within which the eggs are stored.

Ostracodes have a long and well documented fossil record from the Cambrian to the Recent and are important index fossils. They are also very useful for determining the position of ancient shorelines, salinities of ancient oceans and relative sea-floor depths because they are very sensitive to their environment. Like other microfossils, their small size allows them to be identified in the rock fragments brought to the surface by drilling of wells. This makes them an important tool for oil and gas exploration.

28. BRYOZOA

Bryozoans (meaning moss animals) are aquatic, colonial organisms in which each individual of the colony secretes tubes or boxes that partially enclose the soft parts. They grow as encrusting, branching or fan-like forms. Bryozoans superficially resemble corals but the animals are more complex and represent a higher grade of cellular organization than coral polyps (14, 19). Bryozoans are commonly delicate and tend to be noticed less than many fossil groups. They are in fact quite abundant and diverse with a long record from the Ordovician to the Recent.

The specimen illustrated is one of the genus *Archimedes* and it looks like a fossilized screw. Actually it represents the spirally arranged sheet of a colony that stood on the sea-floor supported by spines. This type is well known from rocks of Carboniferous age.

29. NUMERICAL TECHNIQUES

Dealing with large numbers of specimens makes paleontology a natural subject for statistical treatment. Statistical techniques can be applied to the distribution of fossils within a rock layer or from one layer to another, to their geographic distribution, to their morphology, and to their biological evolutionary relationships.

In the example shown, a succession of rock strata (12) is on the left and the abundance of a species of fossil pollen (16) in each layer is on the right. In the rock column (an example from the Late Cretaceous of Alberta), sandstones are shown by the stippled pattern, shales are dashed lines, and coal is black. This succession is typical where shores, rivers, deltas, lakes and swamps with abundant vegetation occur. The abundance of pollen from a species of plant is shown in the graph to be related to the type of sediment - they are most abundant in the shales, less so in the other rock types. The preservation of material as small as pollen grains is dependent on a lack of current activity which would wash it away, the same factors that are critical for the deposition of mud, from which shale is produced. The abundance of the species is relative - it is the percentage of the species that occurs in the entire sample, so that some of the spikes suggesting high abundance, are instead related mainly to a low abundance of other forms.

30. RADIOLARIA

Single-celled radiolarians are microfossils averaging 0.1-2.0 mm in diameter. They have intricate glassy skeletons made of silica that are enclosed within the soft body. Spines projecting from the skeleton support thin fingers of body tissue that serve to collect food. Radiolarians mainly live in oceanic conditions beyond the edge of the continental shelf. They are most abundant in regions close to the Equator, particularly where nutrients are brought to the surface by upwelling ocean currents. Different species occur at different water depths depending on the temperature of the water. Species that occur in cold waters at the surface in polar regions may occur in equally cold water at depth near the Equator.

Calcium carbonate, the substance of which many shells are made (bivalves, ammonites, brachiopods, most Foraminifera) dissolves in the ocean at depths of about 3 000 to 5 000 m because of its greater solubility in cold water. Radiolaria, being composed of silica, are more commonly preserved at greater depths although silica can also dissolve in seawater. Indeed, when some of the more delicate types of radiolaria die, their skeletons are dissolved before they reach the sea-floor. Nevertheless, many deep sea sediments are so rich in radiolarian skeletons that they are known as radiolarian oozes and may contain as many as 100 000 skeletons per gram of sediment. Fossil radiolarians are commonly found in rock made mainly of silica and known as chert. Cherts of this type can be interpreted as products of greater depth than adjacent limestones which are made mainly of calcium carbonate.

31. METASEQUOIA

Specimens of *Metasequoia*, the Dawn Redwood tree, were first described in 1941 from fossil remains found in sediments of Pliocene age, but later living trees were found in a very restricted part of central China. It is now widely cultivated in China and in many botanical gardens elsewhere. It was a common component of North American forests during the late Cretaceous and early Tertiary. One of the most remarkable occurrences of fossil *Metasequoia* is in extremely well preserved fossil forests of Tertiary age in the Canadian Arctic Islands. In this site on Axel Heiberg Island tree stumps are preserved in growth position and the wood is so well preserved that it looks like modern wood despite the fact that it is about 45 million years old. The leaves and cones of the trees are also almost perfectly preserved, their tissues practically unaltered. The occurrence of mature forests so close to the North Pole in Tertiary time indicates that climate was much warmer. The degree to which climate has changed in the past is significant for our understanding of current global climatic change. The study of fossils and the ancient rock record is crucial to understanding the ancient changes.

The poster shows a branch with needles, cones and a seed of the *Metasequoia* plant (31A-D).

32. LEPIDODENDRON

A reconstruction of the common Carboniferous plant *Lepidodendron* (32A) shows a large tree. The fossil is a representative of a group called Lycopods or scale trees. Modern lycopods, the club mosses, are only a few centimetres in height, but their ancient ancestors grew to heights of about 30 m and had trunks up to a metre in diameter. The pattern of leaf scars (places where leaves were attached) on the trunks of these trees serves to distinguish different types. The pattern of scars (32B) and the form of an individual scar (32C) on the trunk of *Lepidodendron* is shown.

These types of trees dominated swamps in the Carboniferous Period and the accumulation of their remains and those of other plants gave rise to the formation of coal. The major coalfields of eastern North America including those in Nova Scotia provide a major natural resource. The fossil cliffs at Joggins, Nova Scotia on the Bay of Fundy form a site of international importance for the study of fossils of this age.

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ABOUT THE ARTIST

Dennis Budgen is a native of Alberta who undertook training as an illustrator at the Alberta College of Art (1974-1979) and the Illustrators Workshop, New York (1979). He is currently a Visual Communications instructor at the Alberta College of Art in Calgary and has participated in a wide range of illustration projects pertaining to significant cultural and environmental sites in western Canada including the Burgess Shale interpretation centre in British Columbia and the Head-Smashed-In Buffalo Jump in Alberta.

SUGGESTIONS FOR FURTHER READING

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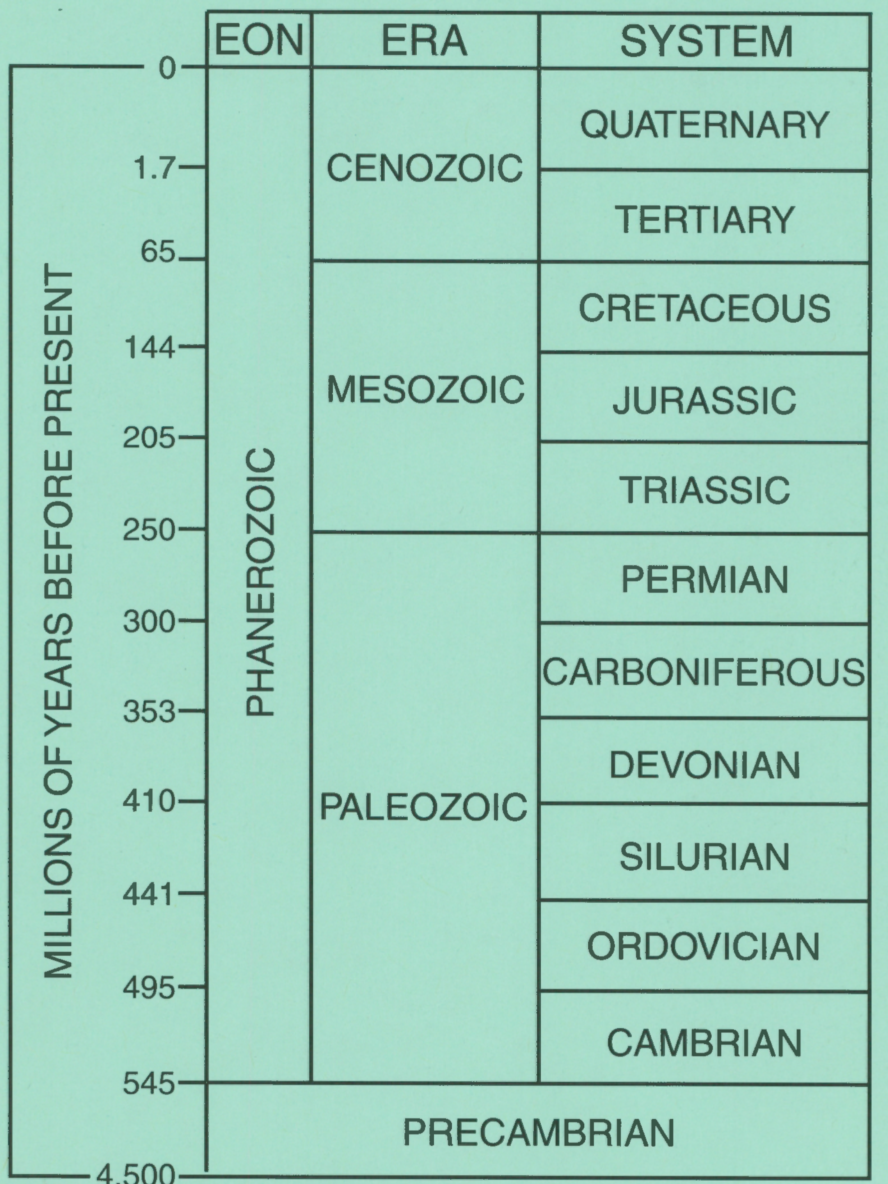

GEOLOGICAL TIME SCALE