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Onyx


Aquamarine


Spider trapped in amber


Howlite


Amethyst


Marble statue


Rose quartz


Orpiment


Diamond


Common spirula

Emerald-encrusted dagger

THE ROCK & GEM BOOK

...AND OTHER TREASURES OF THE NATURAL WORLD


Hornblende


Scapolite


Fossilized coral


Stone quartz


Graphite


Limestone sphinx


Rhodochrosite

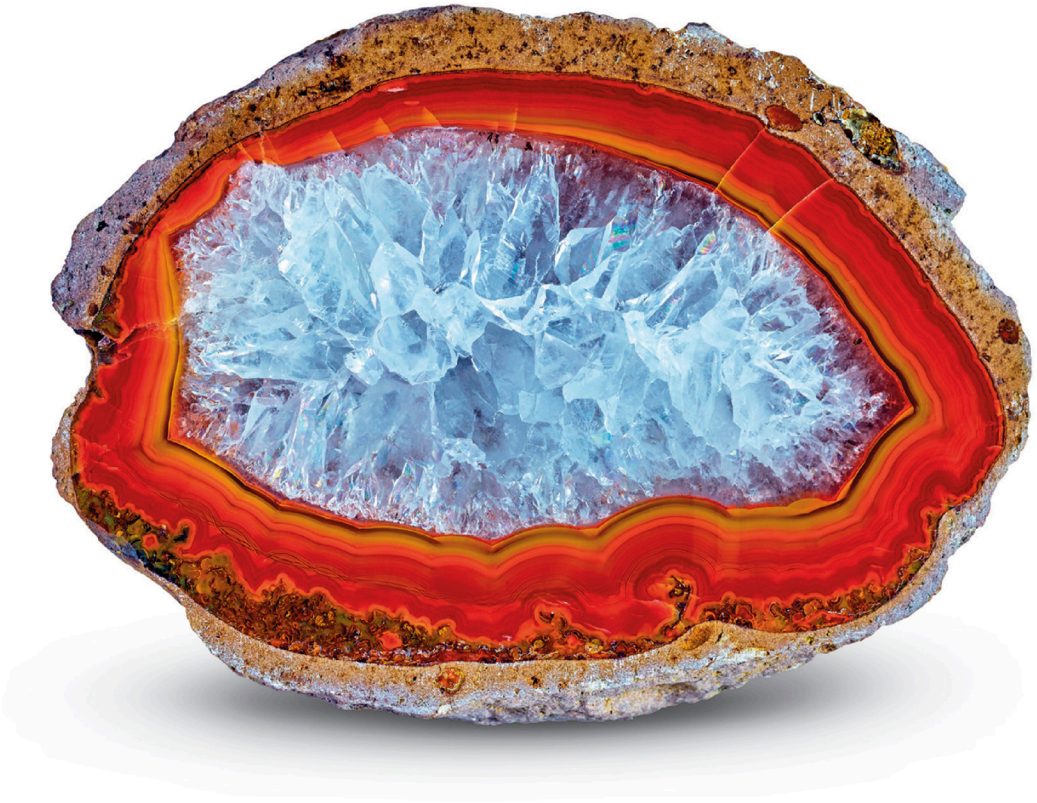

Sulfur


Chrysoprase


Blue sapphire

THE ROCK & GEM BOOK

...AND OTHER TREASURES OF THE NATURAL WORLD



SMITHSONIAN

THE ROCK & GEM BOOK

...AND OTHER TREASURES OF THE NATURAL WORLD

WRITTEN BY **DAN GREEN**

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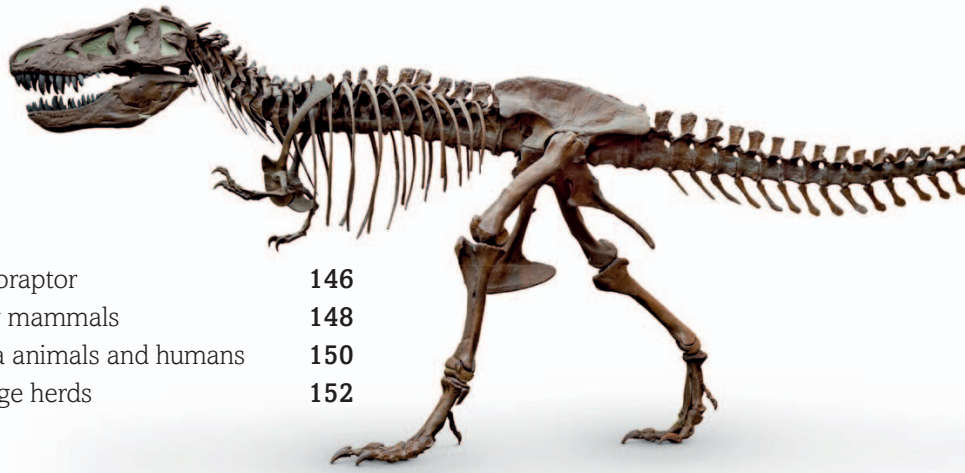
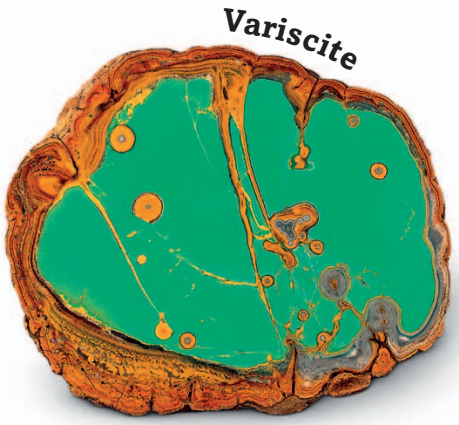
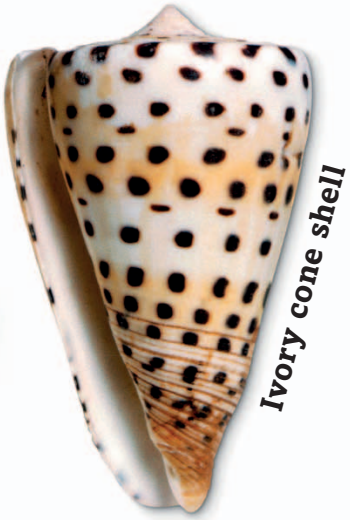
CONTENTS







Foreword

Our planet is bursting with wonders of nature. The rocks that make up Earth's surface hide countless surprises, from colorful minerals to glittering gemstones, and valuable metals. This book is a fascinating collection of natural treasures, along with amazing fossils and beautiful shells.

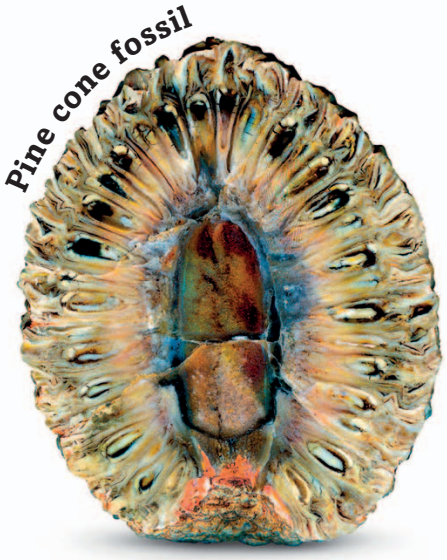
Growing up by the sea in Wales, I was fascinated by the things that the tide brought in. With my sisters, I would scour the beach looking for treasures, collecting shiny stones, patterned pebbles, and shells. The hills around were dotted with lead mines, and I was obsessed with the idea of finding gold in local rivers. I never did find any gold, but sometimes I would turn up a rock with small fossil shells embedded in it, which was almost as exciting.

I went on to study geology at university. There I learned that, as well as being irresistible for their beauty and rarity, minerals tell us a story about how the planet formed and how it changes over time. Fossils record the tale of how life on Earth has coped with the challenges of living on our ever-changing planet. Rocks and minerals are important in our everyday lives, too. Many of the raw materials we depend on are dug out of the ground.


Hessonite


Moon rock

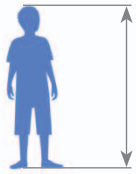

Azurite heart


Pine cone fossil

Inside this book you'll discover rocks and gemstones, encounter important mineral ores, come face to face with astounding fossil organisms, trace the history of life, and marvel at pretty shells. Along the way, you will see some of the most amazing landscapes and natural wonders. I hope it will inspire you with curiosity about the world around you and maybe even set you off on your own journey of discovery.

Dan Green

Throughout this book you will find scale boxes that show the sizes of examples of rocks, minerals, gems, fossils, and shells compared to a child, a school bus, or a human hand.

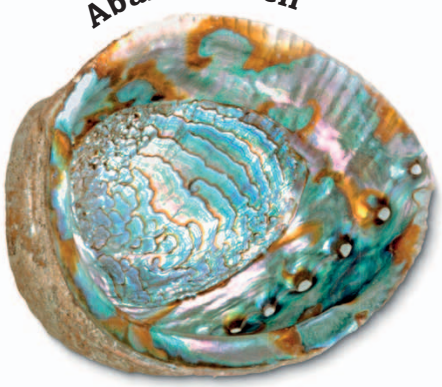


Child = 4 ft 9 in (1.45 m) tall

School bus = 36 ft (11 m) long

Hand = 6 in (16 cm) long

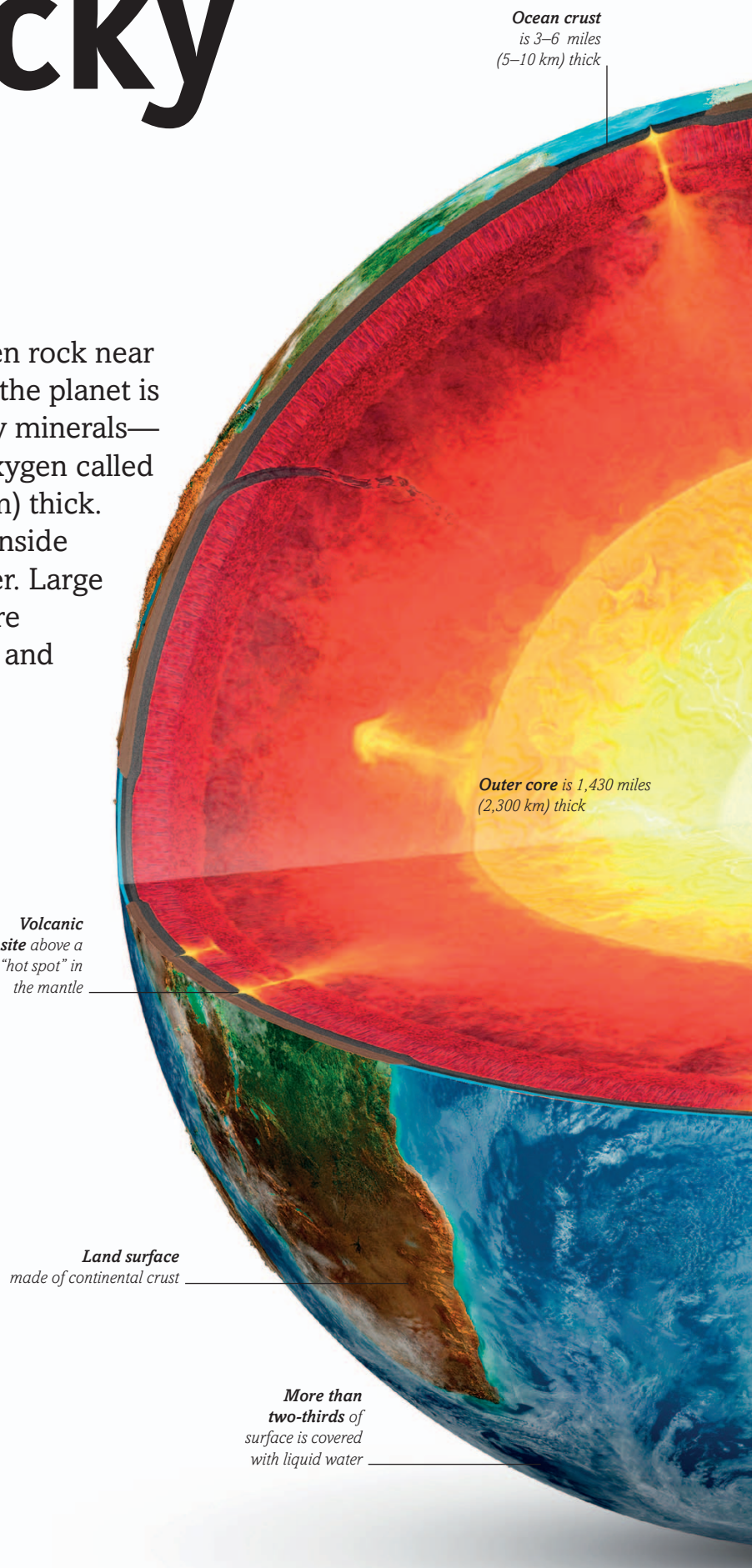

Lazurite in marble


Abalone shell


Bornite

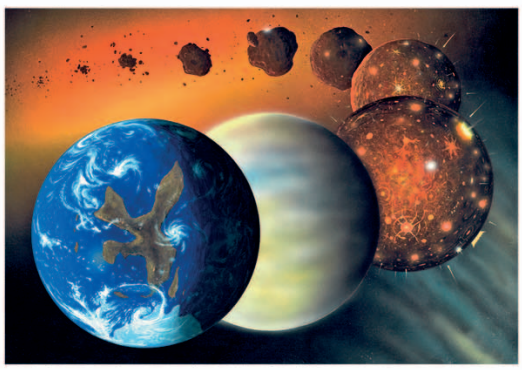
Our rocky planet

Earth is a rocky ball, with thick, molten rock near its center. Only a thin surface shell of the planet is fully solid. This crust is made of rocky minerals—mainly combinations of silicon and oxygen called silicates—and is up to 30 miles (50 km) thick. Earth is not a quiet place. Heat from inside the planet keeps the crust turning over. Large slabs of rock, called tectonic plates, are shunted around, causing earthquakes and fiery volcanic eruptions, and heaving up mountain ranges, as they bump and crash into each other.



How Earth formed

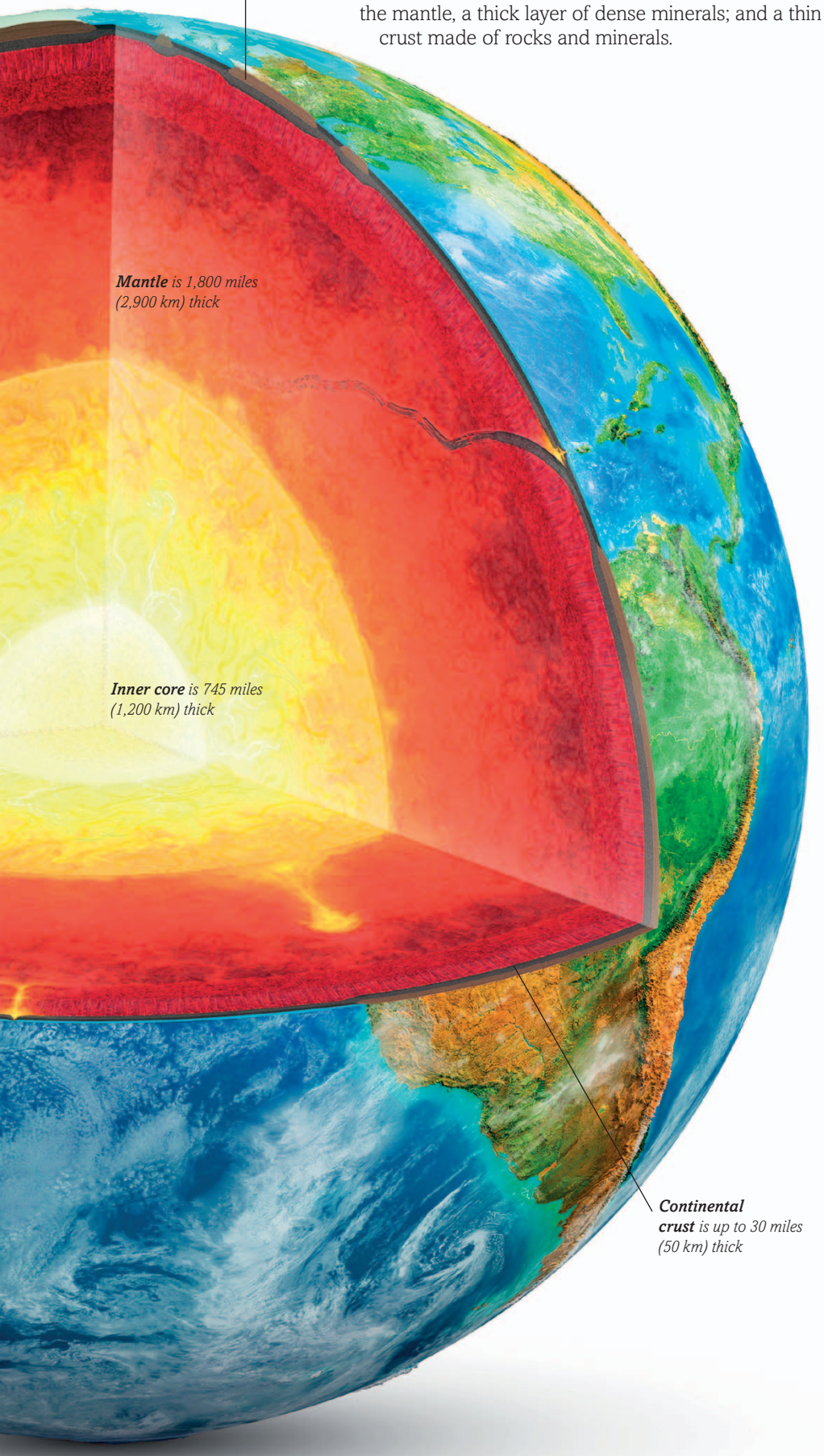
The planets of the solar system formed at the same time, about 4.6 billion years ago, from the cloud of dusty rubble orbiting the Sun. Over millions of years, small clumps of this debris grew larger and were pulled into spheres by the force of their own gravity. As the sphere grew, it attracted more and more debris, accelerating the growth of our planet.



This artwork shows a sequence of how Earth formed—from small fragments of rock and dust sticking together to a planet that had its own atmosphere.

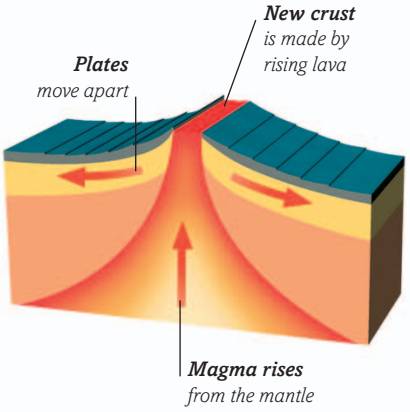
Inside Earth

Earth has three distinct layers: a core, consisting of a solid inner core and a fluid outer core, which together make up more than half the planet's diameter; the mantle, a thick layer of dense minerals; and a thin crust made of rocks and minerals.

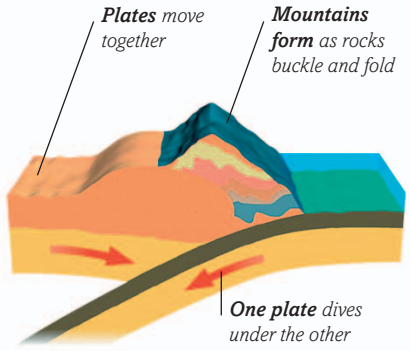


Moving plates

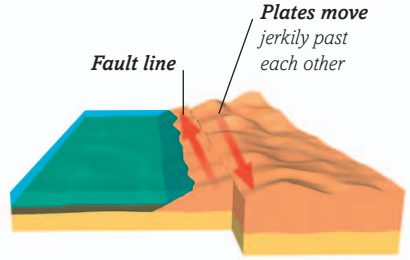
Earth's surface is divided into a jigsaw puzzle of interlocking slabs of crust and solid mantle. These huge blocks, called tectonic plates, move on the syrupy mantle beneath the surface. There are eight major plates and many smaller ones.



Spreading
New crust is created where movement pushes plates apart. As the crust thins, magma rises to the surface and spreads lava over the surface. This happens along the Mid-Atlantic Ridge.



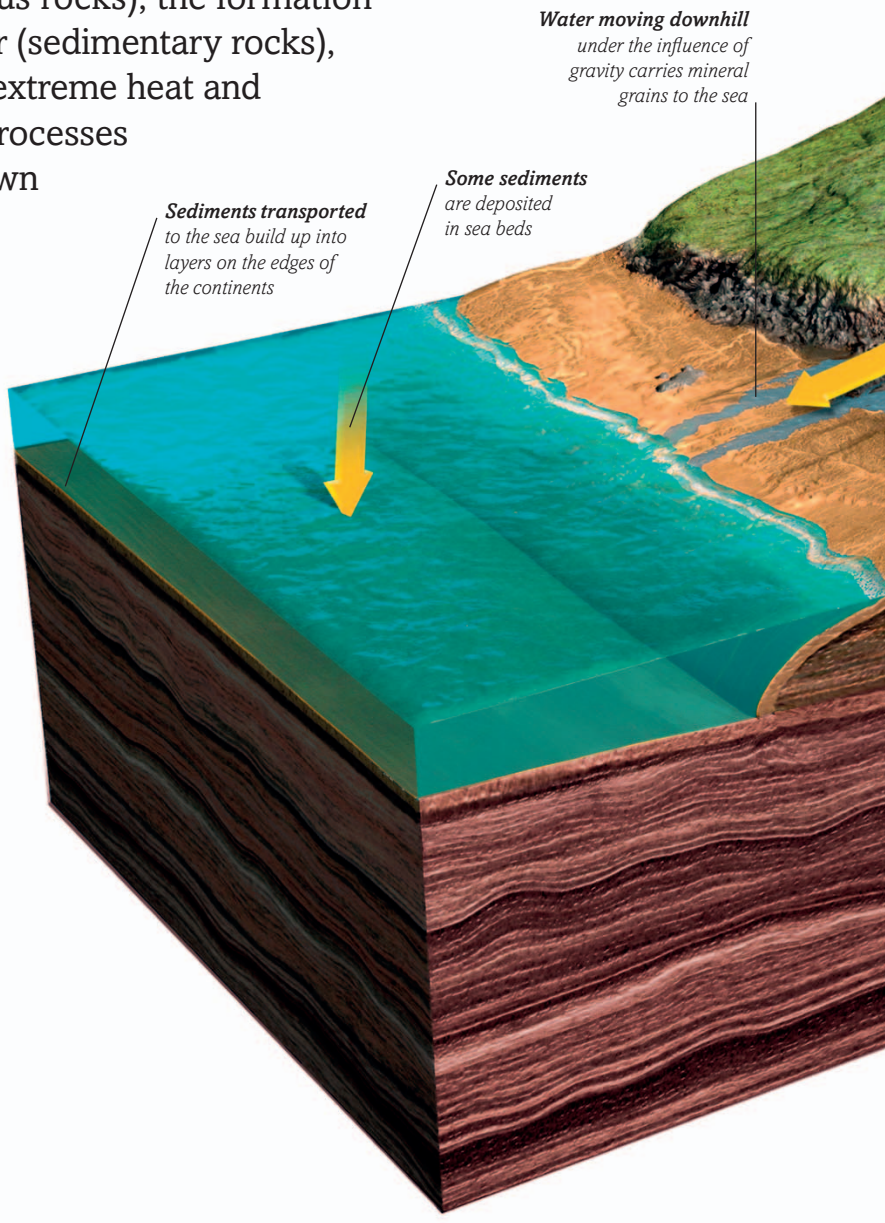
Crunching
Crust is destroyed where plates come together. The higher plate rides up over the other as the lower plate dips down into the mantle. This pushes up mountain ranges, such as the Himalayas and the Andes.



Sliding
When plates move sideways, no crust is created or destroyed. The friction between the two plates builds up tension, which may release with a snap, causing earthquakes.

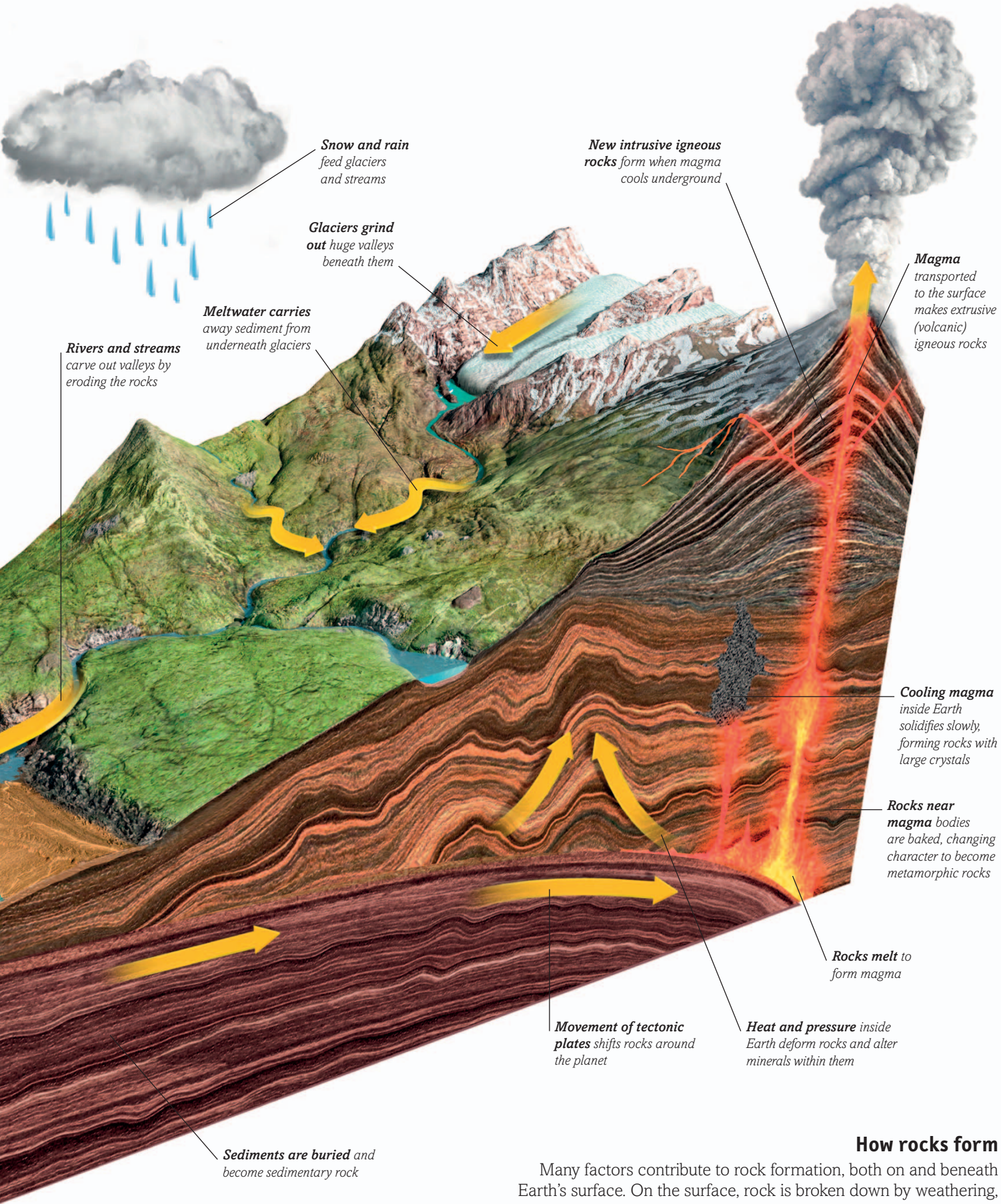
The rock cycle

Most of Earth's rocks are hidden beneath the surface, but in some places they are visible in the landscape: mountains, canyons, and coastlines, for example. Many different types of rocks have developed over billions of years through a variety of processes. These include volcanic activity, which creates rocks at or near the surface (known as igneous rocks), the formation of sediments in places like the sea floor (sedimentary rocks), and changes in form brought about by extreme heat and pressure (metamorphic rocks). These processes are linked in a never-ending cycle known as the rock cycle.



Rock recycling

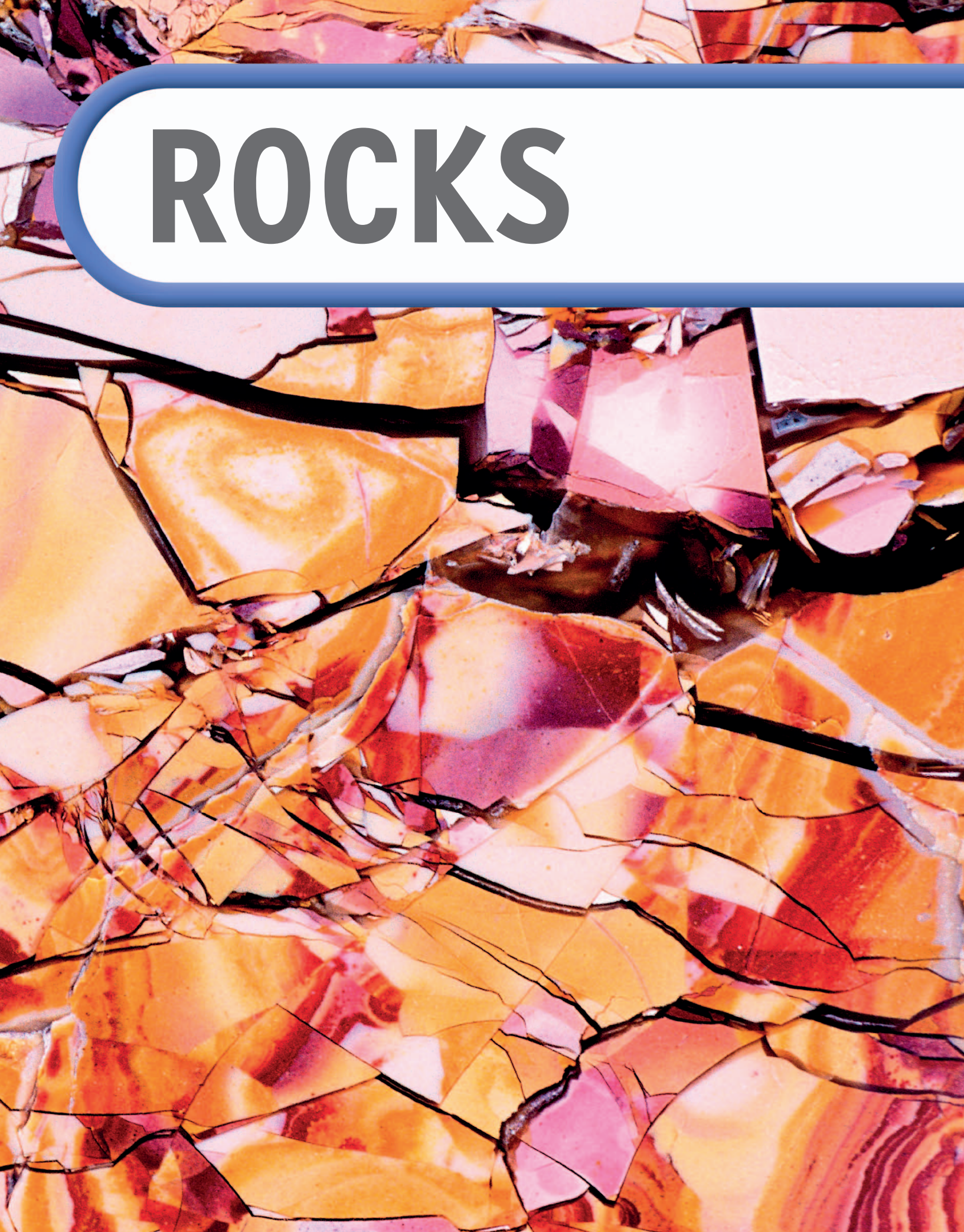
The planet endlessly recycles its rocks. Mineral grains worn off igneous rocks are deposited to form sedimentary rocks. Pressure and heat inside Earth alter minerals to make metamorphic rocks. When rocks melt, a new generation of minerals crystallizes out of the magma, creating new igneous rocks.



How rocks form

Many factors contribute to rock formation, both on and beneath Earth's surface. On the surface, rock is broken down by weathering, glaciers, and rivers, and wind erodes rocks by carrying particles of them away. Sediments made of tiny particles of rock and mud form in places like lake bottoms, coasts, and sea beds. Inside Earth, heat, pressure, and melting change sedimentary and igneous rock into metamorphic rock, and volcanoes are formed that create new igneous rock.

ROCKS



Rocks

A rock is a naturally occurring material consisting of one or more minerals, although a few rocks are made of other substances, such as decayed vegetation (coal, for example). There are three major classes of rocks—igneous, sedimentary, and metamorphic—and each of these classes is further divided into groups and types, mainly based on their mineral composition and texture.

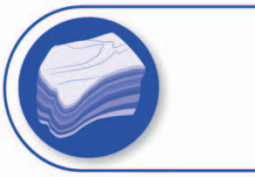
Crystal size › A striking feature of pegmatite is the size of the crystals it contains. The crystals are usually more than 2 in (5 cm) in size, but examples over 30 ft (10 m) have been found in this type of rock.

Formation › Pegmatite is an extreme igneous rock that forms during the final stage of magma's crystallization. It is called extreme because it contains exceptionally large crystals, and because it often contains minerals that are rarely found in other type of rock.

Types of rocks

Igneous
• Formed from molten rock (magma), which solidifies either underground or after it flows to the surface.

Sedimentary
• Generally formed from mineral grains deposited on Earth's surface by water, wind, or ice.



Metamorphic
• Formed from existing rocks that change when subjected to extreme temperatures and pressures underground.

ROCKS IN THE LANDSCAPE

Devil's Tower, Wyoming. A rock that cooled within a volcanic vent and has been exposed over time by erosion.

The Grand Canyon, Arizona. The Colorado River has cut a 1-mile- (1.6-km) deep canyon through layers of sedimentary rock.

Taigh Bhuirgh Beach, Harris, Scotland. Gneiss, a metamorphic rock, has distinct bands of minerals of different colors.

Igneous rocks

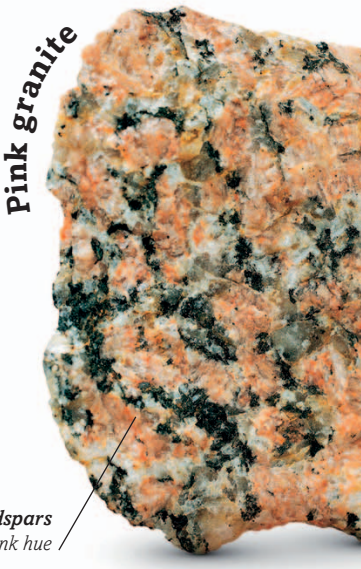
Deep inside Earth, it is hot enough to melt rock. At searing temperatures of 2,280°F (1,250°C), the red-hot, syrupy melted rock, called magma, forces its way up through the solid layers of Earth's crust along cracks and other lines of weakness.

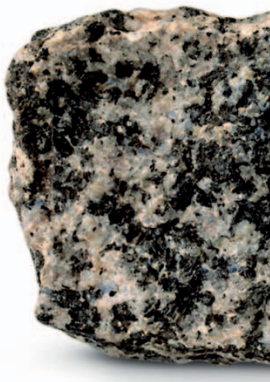
Intrusive igneous rocks form when magma cools slowly beneath Earth's surface. Under immense pressure, the magma crystallizes and hardens into rock. Made of interlocking crystals, it is tough and durable. Intrusive rocks have larger grains than volcanic rocks because they take

longer to cool and the crystals have more time to grow. Coarse-grained **granite** is the most common intrusive rock. **Pegmatite**, a source of rare metals and gemstones, has the largest crystals of all. **Porphyry** forms when large, slowly growing crystals are cooled quickly and are surrounded by small crystal grains. Sometimes whole lumps of rock from Earth's upper mantle—the layer underneath the crust—form intrusive igneous rocks. These **pyroxenites**, **dunites**, and **peridotites** all contain lots of the mineral olivine, while some **kimberlite** rocks contain diamonds.

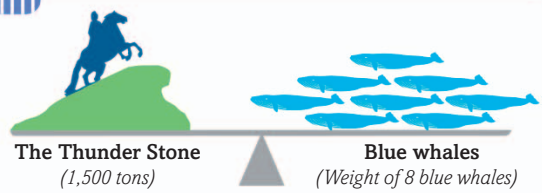
Granite

No two **slabs** of granite are **alike**, making each countertop **unique**.





THE THUNDER STONE



Mammoth rock

The Thunder Stone is the granite pedestal for the Bronze Horseman statue in St. Petersburg, Russia. Weighing an estimated 1,500 tons, the equivalent of eight blue whales, it is thought to be the largest stone ever moved by man.

Granite is the bedrock of our planet's crust. The foundations of the continents are underpinned almost entirely by this coarse-grained, intrusive igneous rock. Granite makes up no less than 70 per cent of Earth's crust.

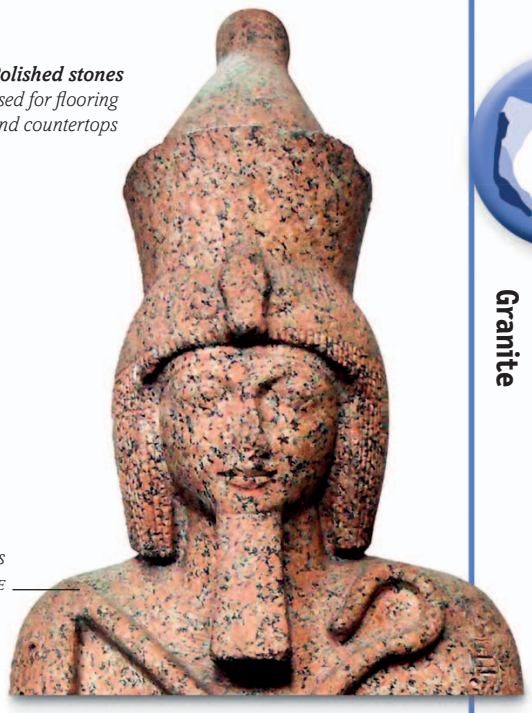
Granite is the symbol for strength and durability. The most common intrusive rock on Earth, it crystallizes slowly from silica-rich magma deep underground. Magma is often injected into the crust in enormous quantities. These rock masses are called batholiths. They often remain as tall

Made from *Cheesewring granite from Cornwall, England*

Tower Bridge, London

Polished stones *used for flooring and countertops*

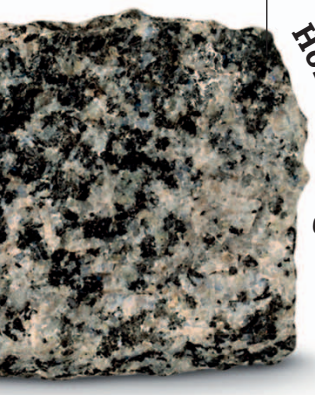
Granite slabs



Granite statue *dates to around 1250 BCE*

Bust of Ramses II

Black specks *of hornblende produce a mottled appearance*

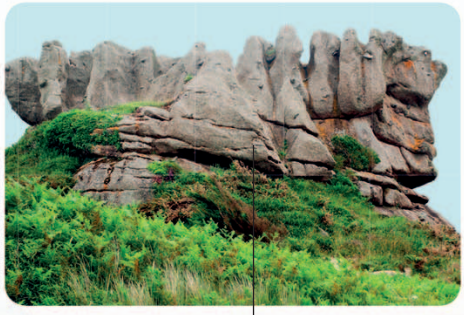


Hornblende granite

Porphyritic granite

Large crystal *of plagioclase feldspar*

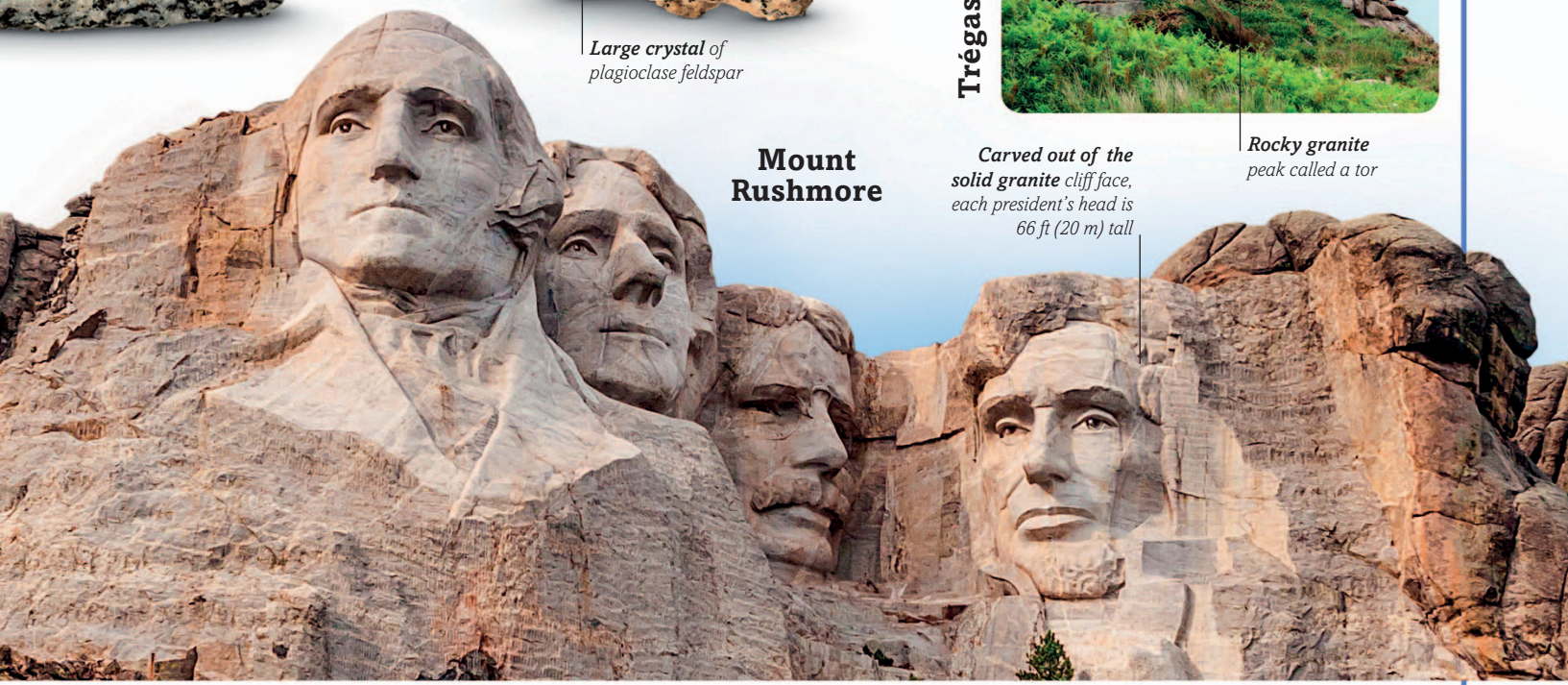
Trégastel, France



Rocky granite *peak called a tor*

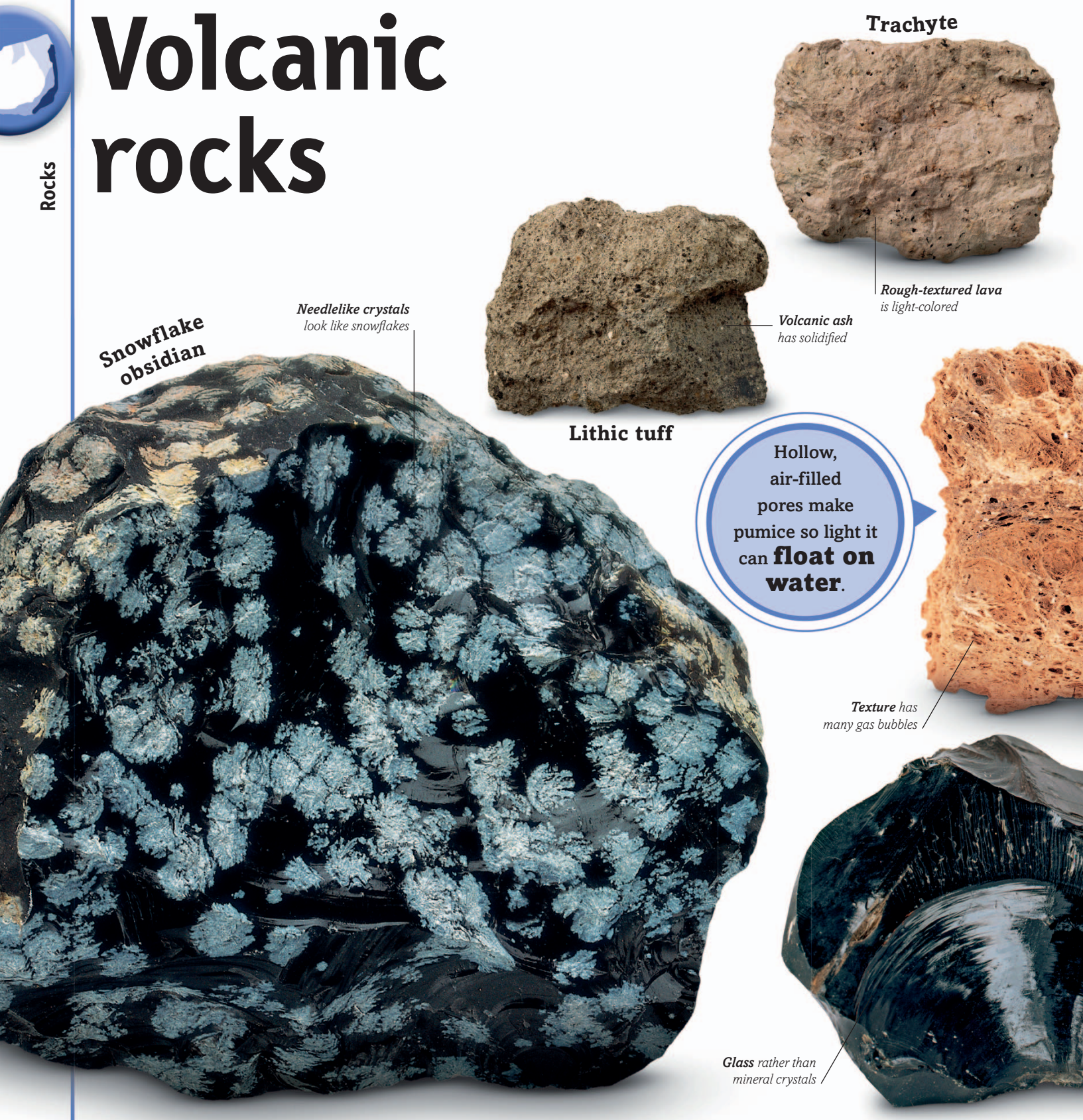
Mount Rushmore

Carved out of the solid granite *cliff face, each president's head is 66 ft (20 m) tall*



buttresses after the cover of country rock has eroded. **Mount Rushmore** and **Trégastel, France**, are examples. Granite is a mix of three main mineral crystals—feldspar, quartz, and mica. The type of feldspar and the mix of minor minerals give the rock its distinctive colors, of mottled white, gray, and even **pink**. When polished, granite's large crystals glitter from countertops and the facades of buildings. This unyielding rock has been used throughout history for making **stone tools**, **statues**, and **busts**. Rough-hewn **slabs** are used as cobblestones and cut as building blocks.

Volcanic rocks



Volcanic, or extrusive igneous, rocks are born of fire. Magma hits the surface at temperatures of 2,190°F (1,200°C). Bubbling and fizzing with dissolved gas, it explodes violently through volcanoes or oozes slowly from a vent or fissure.

Volcanic rocks form when lava cools and solidifies. They have small grains because they cool quickly, giving crystals little time to grow. **Basalt**, **andesite**, and **trachyte** are the most common lavas on Earth. Because it is so thick, **rhyolite** magma can cause the most violent

Pele's hair

Molten lava *is spun out by the wind into long, hairlike strands*

Mount Fuji, Japan

The core of Mount Fuji *is composed of andesite*

Andesite

Light-colored crystal

Basalt

Rich *in iron and magnesium*

Rhyolite

Pink banding *is not common*

Pumice

Bread crust volcanic bomb

Hard outer crust *like a loaf of bread*

Obsidian

Edge on arrowhead *is sharper than steel*

Arrowhead

VIOLENT VOLCANOES

Yellowstone, Wyoming, 640,000 years ago
A massive eruption, it produced 2,500 times as much ash as Mount St. Helens.

Mount Tambora, Indonesia, 1815
The largest eruption in recorded history, it caused a year-long winter around the world.

Mount Pinatubo, Philippines, 1991
Second-biggest eruption of the 20th century. Many people were evacuated before the eruption.

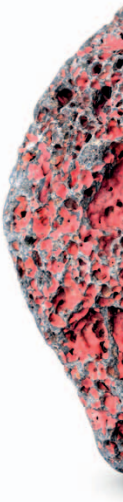
Krakatoa, Indonesia, 1883
Made the loudest boom ever recorded. This massive eruption triggered tsunamis, killing many people.

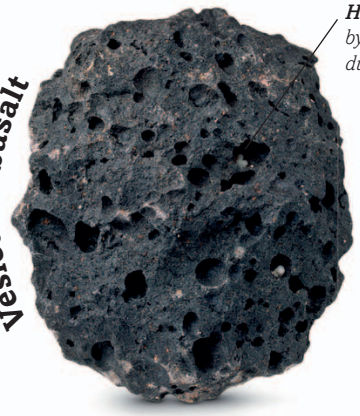
Mount St. Helens, Washington, 1980
Deadliest eruption in American history. The explosion blew the top off the mountain.

eruptions. Most lavas are made up of silicate minerals including feldspars, olivine, amphiboles, micas, and quartz. **Tuff** is rock formed of volcanic ash, which is sometimes hot enough to weld together. **Obsidian**, a black volcanic glass, cools too quickly to form crystals. During volcanic eruptions, volcanoes may shoot out lumps of lava called **bombs**. Dissolved gases pump **pumice** full of frothy bubbles. **Pele's hair**—named after the Hawaiian fire goddess—is made of long, wispy, mineral fibers that are drawn out in the air as liquid rock erupts.

Basalt

Basalt volcano, Hawaii





Calendar stone, 11 ft (3.5 m) wide, carved by the Aztec people of Mexico

TYPES OF LAVA

As volcanoes explode, magma either blows apart as tiny ash particles or seeps out as red-hot lava flow. This lava can be of different kinds.

A'a lava
Thick a'a lava breaks into jagged blocks that cool and then ride on top of the lava flow.

Pahoehoe lava
Runny "pahoehoe" lava moves like candle wax. Its surface cools into a solid skin that buckles.

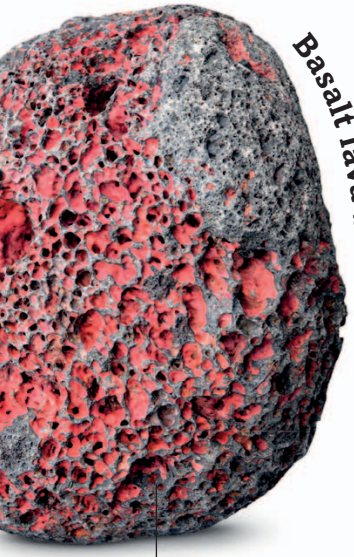
Pillow lava
Basalt erupted underwater forms rounded "pillows." The front of the pillow cools as it hits the water.

Mysterious mushroom stones *carved by Central America's Mayan people more than 1,000 years ago*

Gas bubble *later filled with minerals such as silica or calcite*

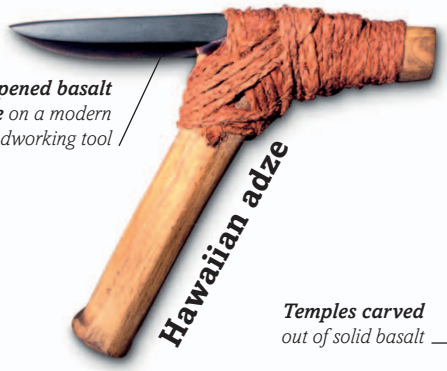
A dark stone made up of fine crystal grains, basalt is the most common extrusive igneous (volcanic) rock on the planet. It pours out of volcanoes under the seas at mid-ocean ridges and forms the bulk of Earth's oceanic crust.

Although most of Earth's **basalt volcanoes** are below water, several are on the surface. The volcanoes of the Hawaiian Islands and the African Rift Valley are basaltic shield volcanoes. They create huge quantities of lava. Eruptions in India around 66 million years ago covered 0.6 million



Basalt lava bomb

Iron-containing *minerals in the basalt turn red as they rust*



Hawaiian adze

Sharpened basalt blade *on a modern woodworking tool*

Temple at Ellora Caves, India

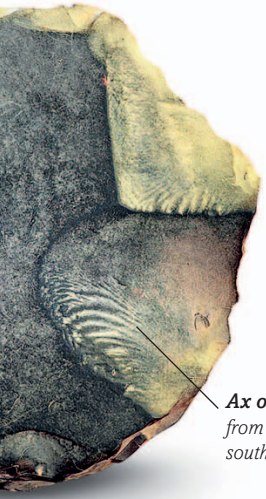
Temples carved *out of solid basalt*

Head of Yarim-Lim

Carved bust *in dark basalt of ancient Persian king, c. 1785 BCE*

The **tallest basalt** columns at Giant's Causeway stand **40 ft (12 m)**.

Giant's Causeway, Ireland



Ax or digging tool *from Pueblo culture, southern US, 750–900 CE*

The largest lava plateau *in Europe, Giant's Causeway consists of 40,000 basalt columns*

Lunar basalt rock

"Mare basalt" *sample brought back from the Moon*

sq miles (1.5 million sq km) to a depth of 1.2 miles (2 km). At **Ellora**, 34 majestic temples and monasteries have been carved out of the very same lava flow. Basalt volcanoes produce different types of lava (see box), including **a'a lava**. They also throw out bubbly **vesicular basalt** and **lava bombs**. On land, basalt lava forms hexagonal columns as it cools and cracks. **Giant's Causeway** in Ireland is a classic example. The dark patches on the Moon are **lunar basalt**—lava flows that date back to after the Moon formed in a giant asteroid smash with Earth.

VIOLENT EARTH Kilauea Volcano on Big Island, Hawaii, erupts in a frenzy of red-hot lava. Its fiery central crater is the traditional home of Pele, the Hawaiian fire goddess. Kilauea is one of the world's most active volcanoes and has been erupting continuously since 1983. It produces a runny basalt lava, which pours out of the crater and the vents along the sides of the volcano and flows over the island to the sea.

Volcanoes are a vital part of the planet's rock cycle. Fed from magma chambers below Earth's surface, they recycle old rocks, and create new igneous rocks. Most volcanoes sit close to the margins of Earth's tectonic plates, points at which the edges of Earth's crust grind and bump against each other. Hawaii's volcanoes, however, sit right in the middle of the Pacific plate. Scientists think these volcanoes form as the plate inches slowly over the top of a "hot spot" in the underlying mantle. The volcano may have started its life 300,000–600,000 years ago, far beneath the waves. It grew and grew until, around 50,000 years ago, it finally emerged from the sea.

Metamorphic rocks

Splits easily into thin sheets

Slate roof

Fine grain size

Slate

Marble

Interlocking grains of calcite

Rock has snakeskin texture

Serpentinite

Band of granite rock

Migmatite

Amphibolite

Coarse-textured rock

Alternate light and dark layers

Gneiss

Red garnet crystals

Skarn

Dark band of minerals

Earth is not a quiet, calm planet. Its outer crust turns itself over, replacing, recycling, and renewing itself endlessly. Rocks caught in this churning mill are squeezed and heated until they turn into new metamorphic rocks.

Metamorphic rocks are shapeshifters—transformed from igneous and sedimentary rocks by heat and pressure underground. Pressure within the planet builds as it shifts and buckles. These stresses push on mineral crystals within the rocks, forcing them to align

into discrete layers. This turns mudstones into **slate**. Slate minerals are stacked up like the pages of a book, allowing them to break easily into flat sheets. Intense pressure also creates new minerals within the rock, forming the striped bands of **gneiss**. **Migmatites** have recrystallized bands of granite swirling through them, while **eclogite** contains red garnets formed under extreme temperature and pressure. Intense pressure also creates **schist**, a flaky rock in which nearly all the mineral grains are parallel.

Marble

Green marble

Green color *comes from the mineral serpentine*

Marble columns *adorn the facade of this marvelous church in Lucca, Italy*

San Michele church, Italy

Statue *was carved from one big block of white marble*

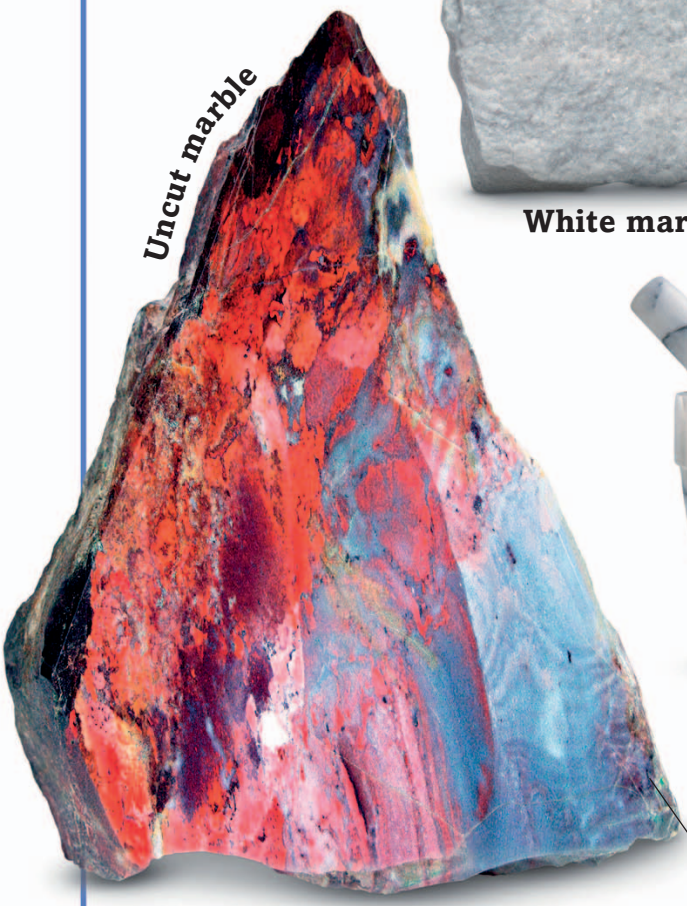
Statue of David

Marble *made up of coarse crystals*

White marble

Michelangelo's *David* is a **massive** nude, standing **17 ft** (5.17 m) tall.

Uncut marble



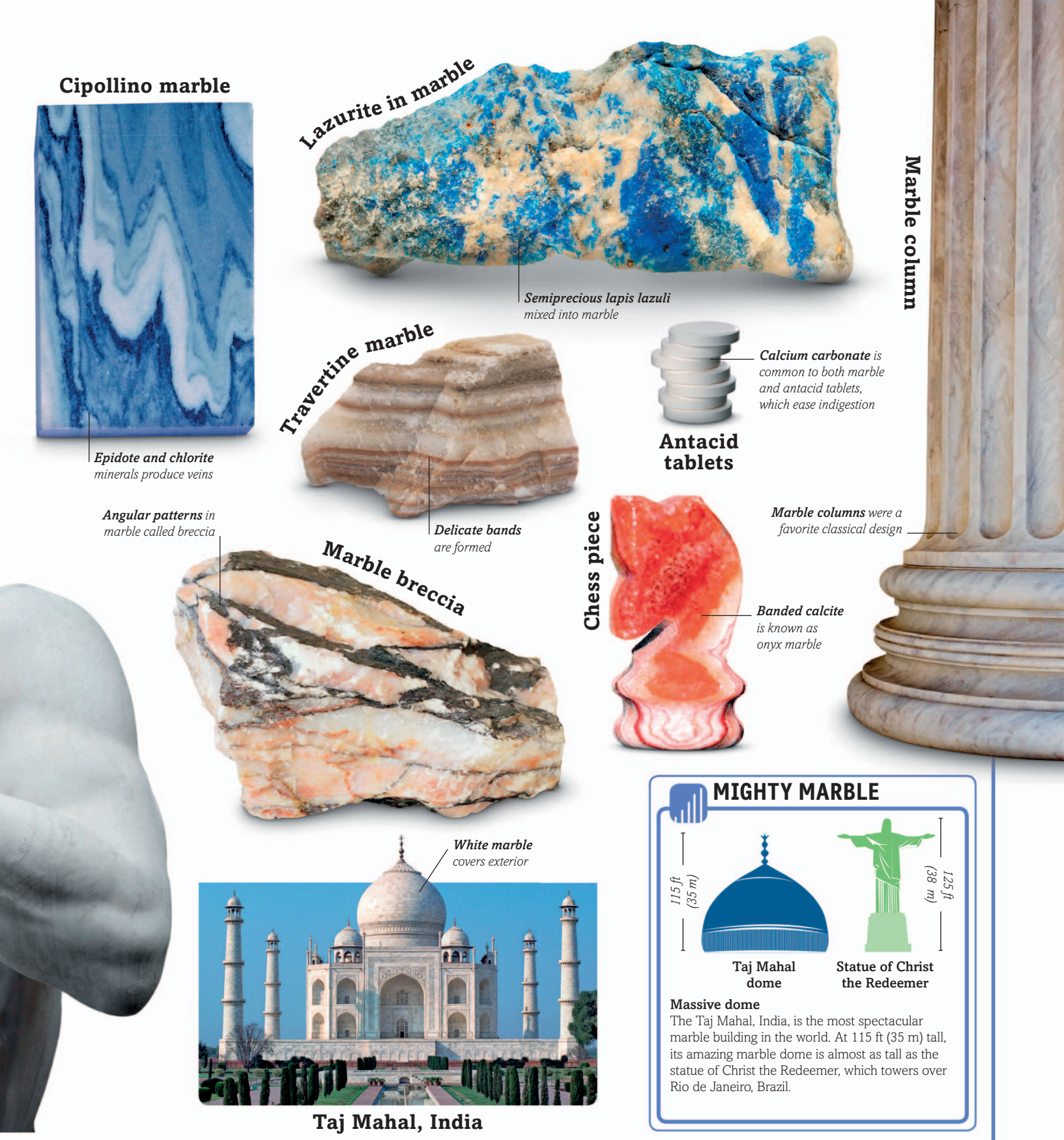
Veins of clay *in original limestone rock*

Marble mortar and pestle

Polished marble *has waxy look*

Marble is a metamorphic rock derived from limestone or dolomite. It is formed under the influence of extreme heat and pressure. It is not as soft as its appearance would suggest. This beautiful rock has been much loved by artists and architects.

Marble's combination of toughness and good looks is a product of metamorphism. When carbonate rocks, such as limestone or dolomite, are heated and put under pressure inside Earth's crust, calcium carbonate minerals recrystallize. This creates interlocking grains that scatter light



Taj Mahal, India

MIGHTY MARBLE

Massive dome

The Taj Mahal, India, is the most spectacular marble building in the world. At 115 ft (35 m) tall, its amazing marble dome is almost as tall as the statue of Christ the Redeemer, which towers over Rio de Janeiro, Brazil.

and give the rock its creamy appearance. The classic color is seen in **white marble**, which is often shot through with dark veins, as seen in this **mortar and pestle**. Italian artist Michelangelo (1475–1564) loved Carrara marble and carved his masterpiece ***David*** from it. Marble comes in a huge range of colors and textures. **Cipollino marble**, also known as onion stone, has swirling bands of metamorphic minerals. **Travertine marble** comes from limestone deposited in hot springs, while **marble breccia** is a striking mix of rock fragments and marble cement.

Sedimentary rocks

Micaceous sandstone

Iron oxide patches

Greywacke

Fine-grained *matrix of sand deposited in sea*

Feldspathic gritstone

Around one-quarter *of this rock is made up of feldspar minerals*

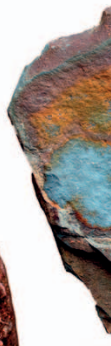
Shale

Layers *of shale visible*

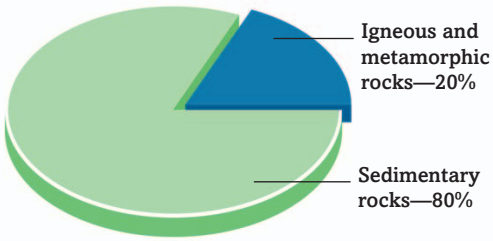
Angular fragments *show that grains have not been transported far*

Breccia is often found along **fault lines** in rocks.

Breccia



MAKEUP OF EARTH'S SURFACE



In abundance
Approximately 80 percent of Earth's surface is covered by sedimentary rocks. However, it is a very thin layer—they make up barely one-tenth of the planet's crust.

When rain, wind, and weather beat against exposed rock, tiny grains wash away. Carried by streams and rivers, these sediments settle in thick beds at the bottom of lakes and oceans. Over time, minerals cement the grains together, forming sedimentary rock.

Sandstones are made from small grains of hard quartz. The mineral is tough and makes a hard-wearing rock. All grains wear as they are moved, so the farther sediments are transported, the smaller the grains and the rounder they are. **Breccia** is made from broken

Kata Tjuta domes, Australia

fragments of other rocks. Its grains are sharp and angular, rather than smooth and rounded. Coarse-grained **gritstone** is a sandstone renowned for its toughness—it was once used to make millstones for grinding wheat and sharpening tools. **Siltstone**, **shale**, and **mudstone** are all formed from fine particles of silt and clay. Mudstone has extremely fine grains that can only be seen with a microscope. Conglomerate rocks have the biggest grains of all. This **puddingstone conglomerate** has grains the size of cobblestones.

Limestone breccia

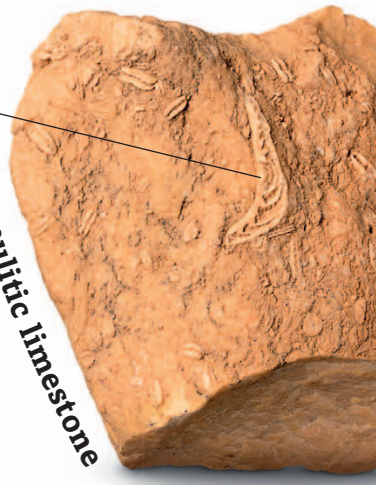
Gray, silica-rich fragments

Calcareous tufa

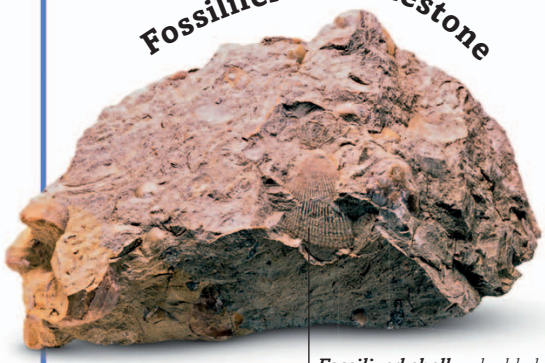
Strange shapes form when water evaporates

Nummulitic limestone

Nummulite fossils can be as large as 2 in (5 cm)



Fossiliferous limestone



***Fossilized shell** embedded in a calcium carbonate matrix*

Soft, white powdery texture

***Limestone** mixed with muddy sediment*

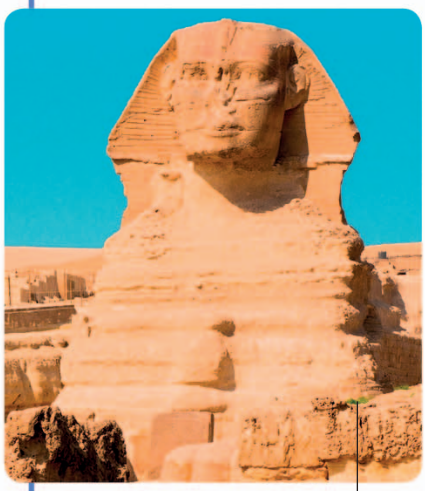
Marl

Blackboard chalk

***Chalk sticks** are made of gypsum, although they were traditionally made from natural chalk*

Red chalk

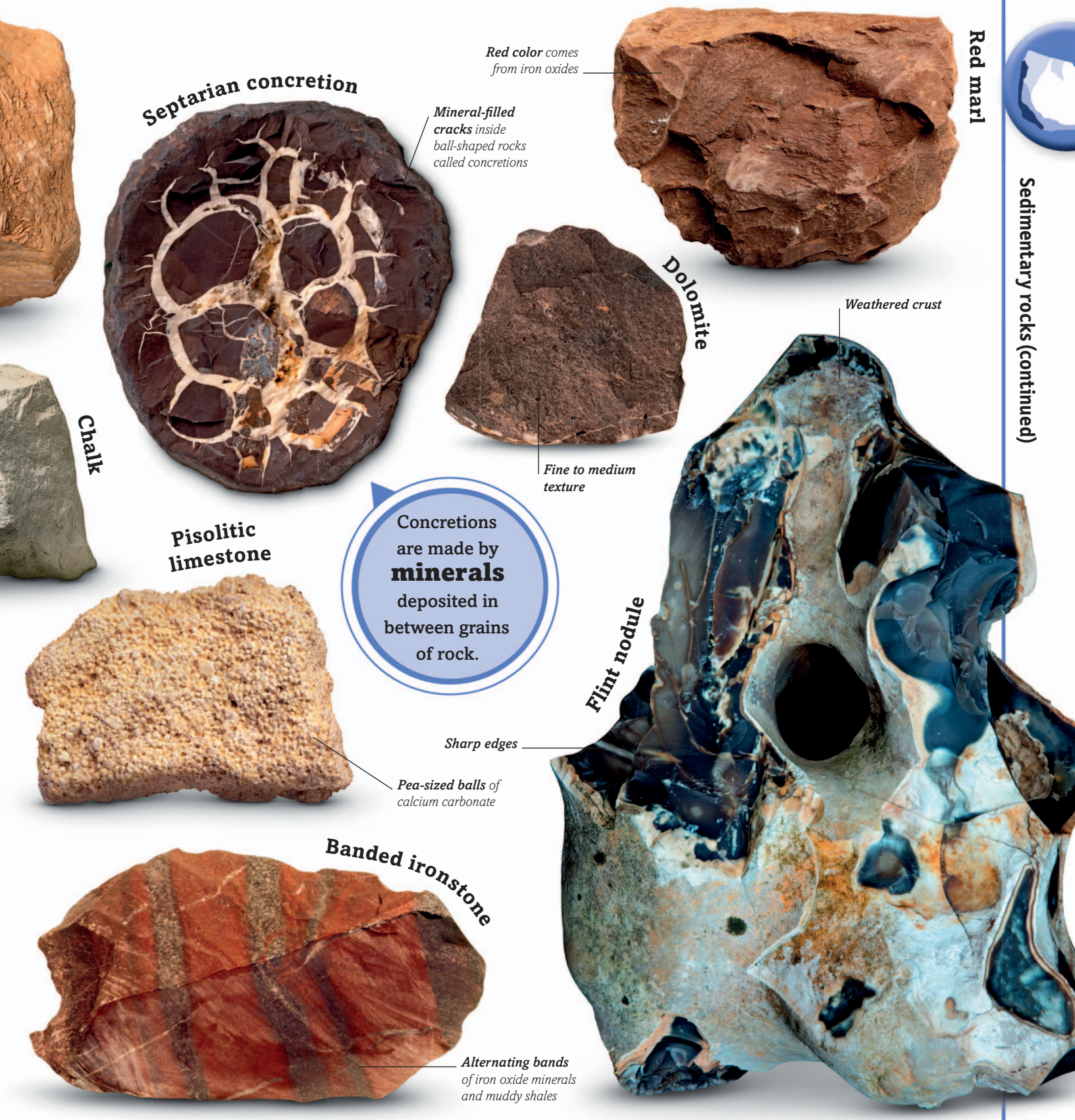
***Red color** comes from hematite*



Sphinx, Egypt

***Great Sphinx at Giza,** Egypt, carved out of hillside of marl rock*

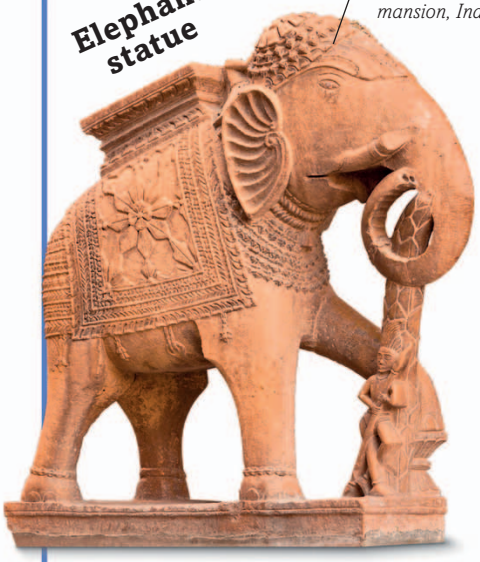
Clastic sedimentary rocks are composed of fragments of preexisting materials. Certain **limestones** are formed from the remains of seashells and coral reefs. These are often full of fossils and make a beautiful building stone. Hot springs and geysers deposit **tufa** limestone in weird shapes. **Nummulitic limestone** contains small round fossils called nummulites, but some sedimentary rocks are made entirely of fossils. **Chalk** is made of microscopic coccolith fossils, the remains of plankton algae. Although they are incredibly tiny, massed remains can build up into



vast white cliffs. Warm, shallow tropical seas roll calcium carbonate minerals into the little balls that make up **pisolitic limestones**. **Concretions** are rounded masses that form when water circulating through rocks replaces the cement minerals sticking sedimentary grains together.

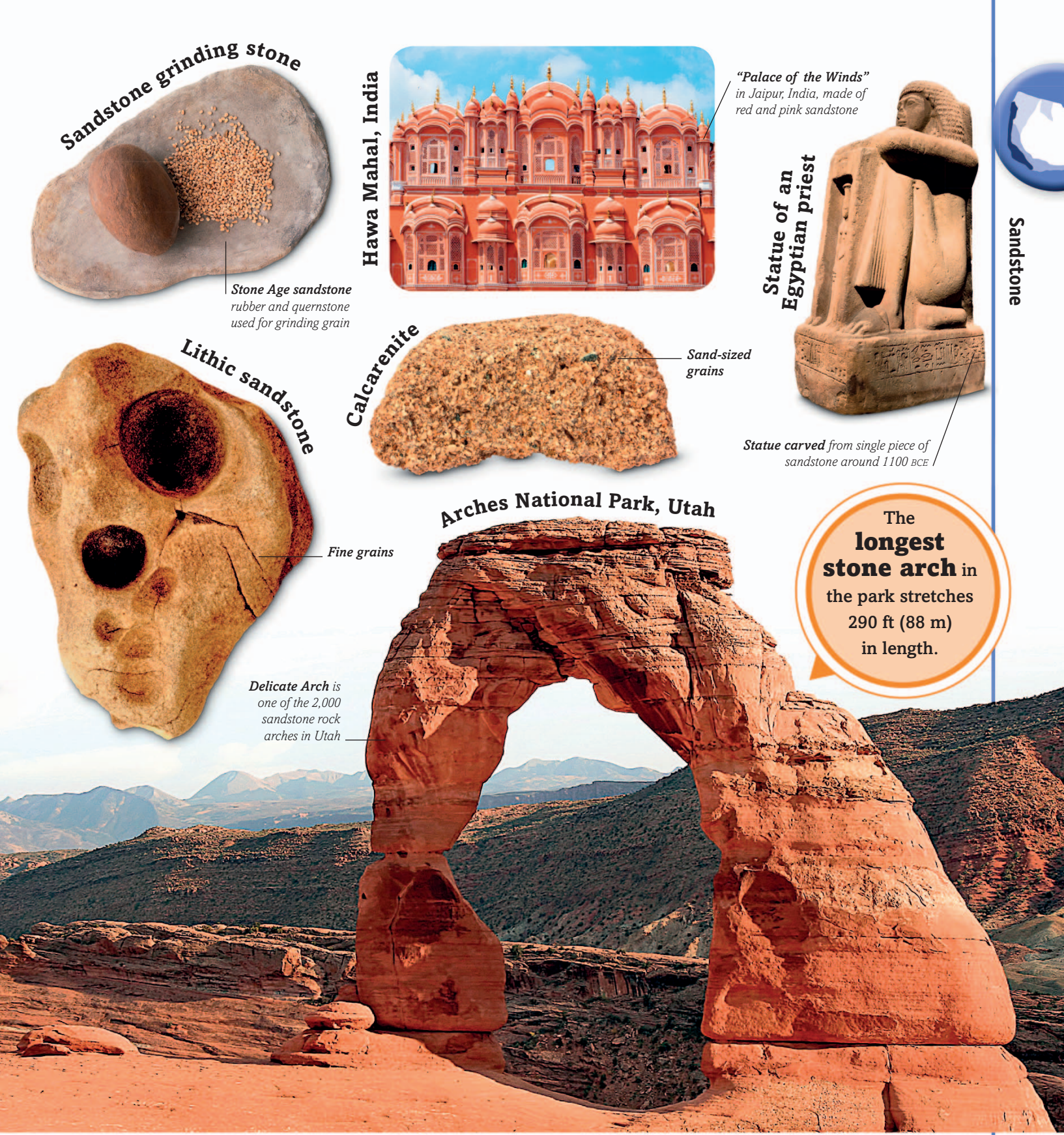
Chemical sedimentary rocks develop when dissolved minerals form from water as solid grains. This process creates the iron-rich red bands in **ironstone**. **Flint** forms in hard nodules that break to give a sharp edge. Stone Age people used this to make tools.

Sandstone



A heap of sand is not a sedimentary rock. Sand turns into a hard stone as the individual grains are glued together with a mineral cement, such as silica or calcium carbonate. The classic sandstone rock is a tan, dun, or yellow color.

Sandstones develop from fragments of other rocks. They are mostly composed of quartz and feldspars. The cement has a big influence on sandstone color—**red sandstone** cement contains iron oxide. **Greensands** are greenish sandstones containing glauconite mica. **Desert**



sandstone can be coarse- or fine-grained, while **lithic sandstones** contain lots of poorly sorted rock fragments. **Calcarenite** is a carbonate (limestone) type of sandstone, made up of sand-sized carbonate grains. Sandstone carves well and is used for ornaments and decorative features for buildings and has been a popular material for making statues. Perhaps its most common use, however, is as a building stone. Some of the world's most iconic buildings, such as the **Hawa Mahal** palace in Jaipur, India, are made from sandstone blocks.

RAINBOW MOUNTAINS

These candy-striped mountains may look like an optical illusion, but they actually consist of sandstone rock, built up by layer after layer of blue-gray, magenta, maroon, and lemon-colored stone. One of the most beautiful landforms in China, they form part of the Zhangye Danxia Geological Park in Gansu Province, in the northwest of the country.

The sandstones of Gansu were deposited around 80 million years ago. Originally, the sediments would have settled on the beds of rivers and lakes, forming horizontal layers that lay one on top of the other. However, mighty changes were happening far to the south, as the Indian subcontinent plowed into the Eurasian plate, crumpling and heaving up Earth's crust to create the Himalayan plateau. About 23 million years ago, these disturbances lifted up the Chinese sandstone beds and tilted them on their sides. Rain and water then eroded them, carving out hills. This weathering process created spectacular colors as different minerals in the sandstone reacted in different ways. The end result is a stunningly unique landscape.

Rocks from outer space

Hoba meteorite

This massive lump of iron *crashed down in Namibia 80,000 years ago*

Crosshatched mineral pattern *of iron-nickel crystals*

Iron meteorite

Iron-nickel *mixture resistant to weathering*

This rock fell to Earth *about 13,000 years ago*

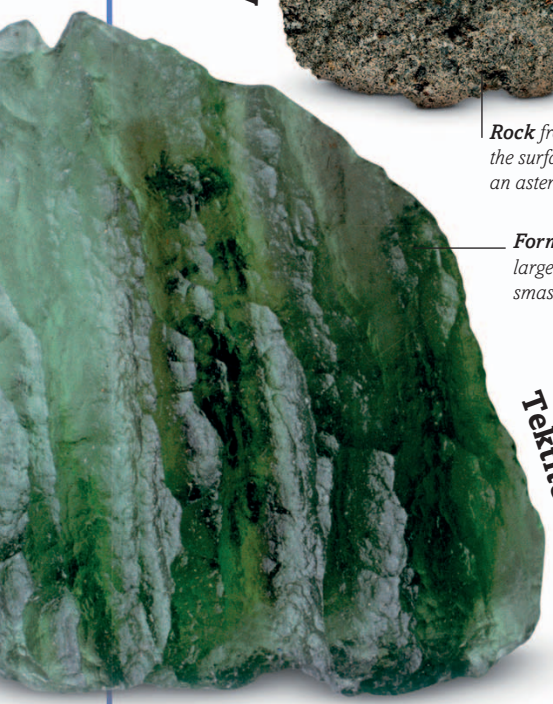
Martian meteorite

Achondrite

Rock *from the surface of an asteroid*

Polished tektite

Green moldavite *formed in meteorite impacts*

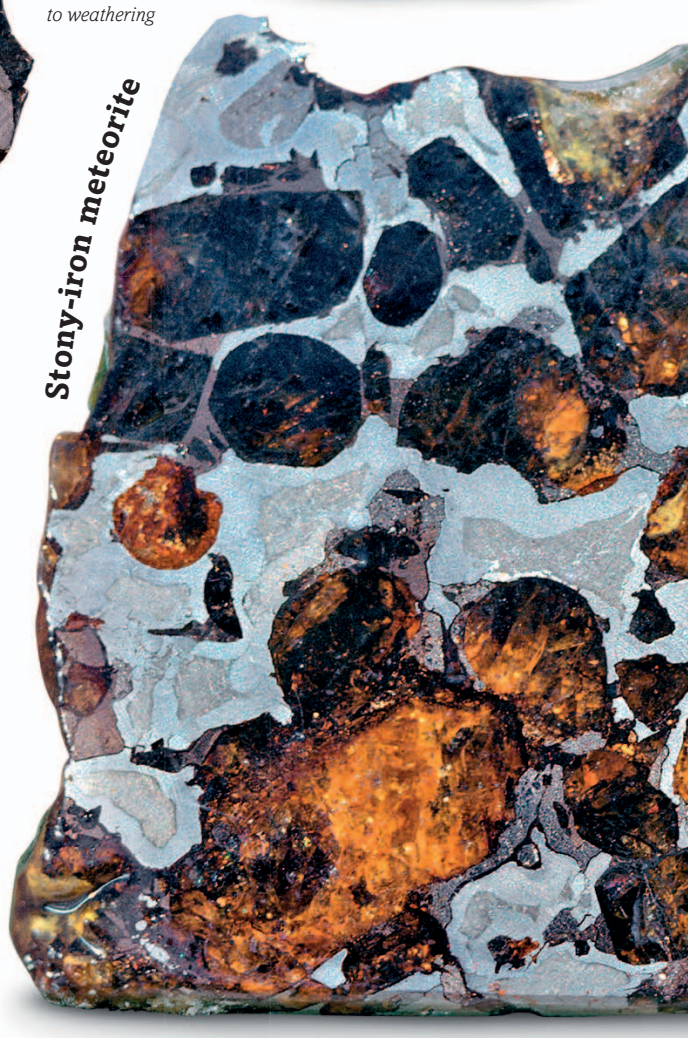


Tektite

Formed *when a large meteorite smashed into Earth*

Meteorite ring

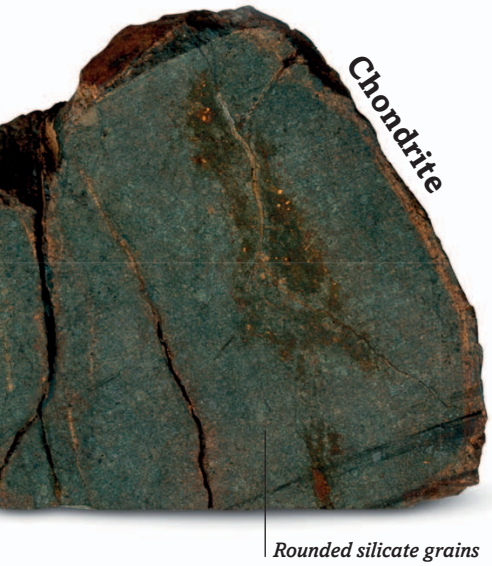
Meteorite *cut for jewelry*



Stony-iron meteorite

Look up at the sky on a clear night and you may see a shooting star. More than 100 tons of dust and rocky fragments blaze in from space every day. They heat up as they punch through Earth's atmosphere, and most of them burn away with a streak of light.

Some space rocks called meteoroids enter Earth's atmosphere and burn up, creating a streak of light known as **meteor**. The meteoroids that survive and land on the ground are called **meteorites**. These are of three types—**iron**, **stony-iron**, and **stony meteorites**. Iron meteorites are almost



Chondrite

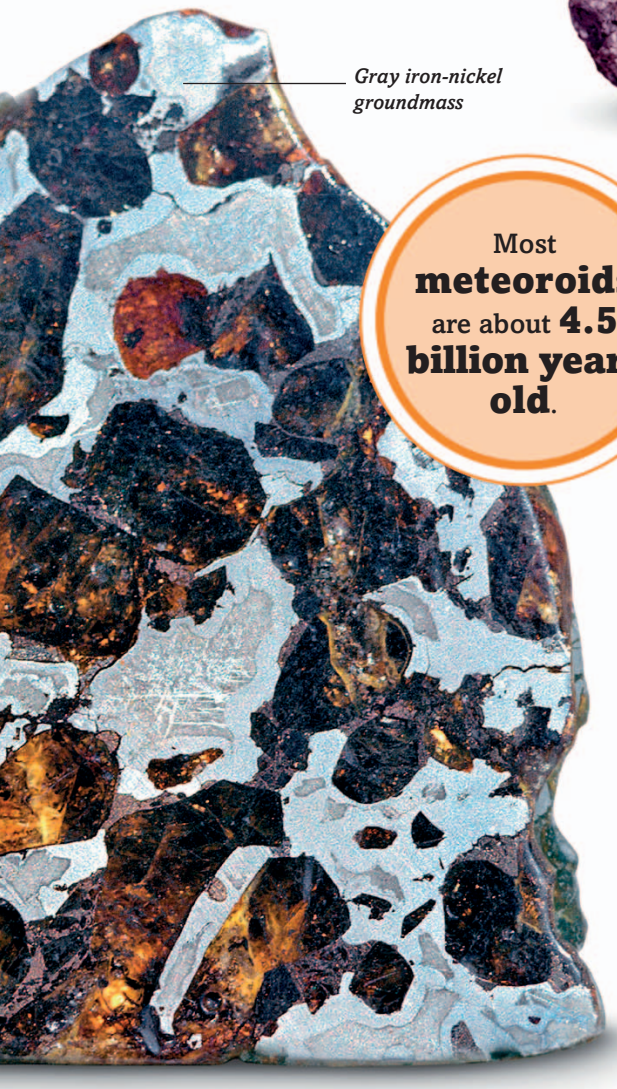
Rounded silicate grains

Moon rock

Rock fragment *blasted off the Moon by meteorite impact*

Meteor shower

Meteor showers *happen when a cloud of debris left by a passing comet hits Earth's atmosphere*



Gray iron-nickel groundmass

Most **meteoroids** are about **4.5 billion years old**.

Beads *made from iron meteorite*

Gerzeh beads

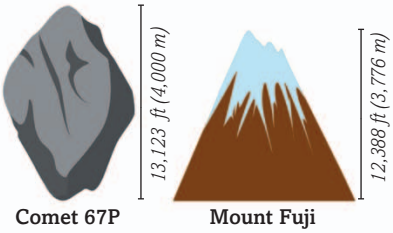
The Iron Man statue

Statue *carved from the Chinga meteorite that fell to Earth 15,000 years ago*

Stony meteorite

Dull interior *mostly made up of olivine and pyroxene minerals*

COMET 67P



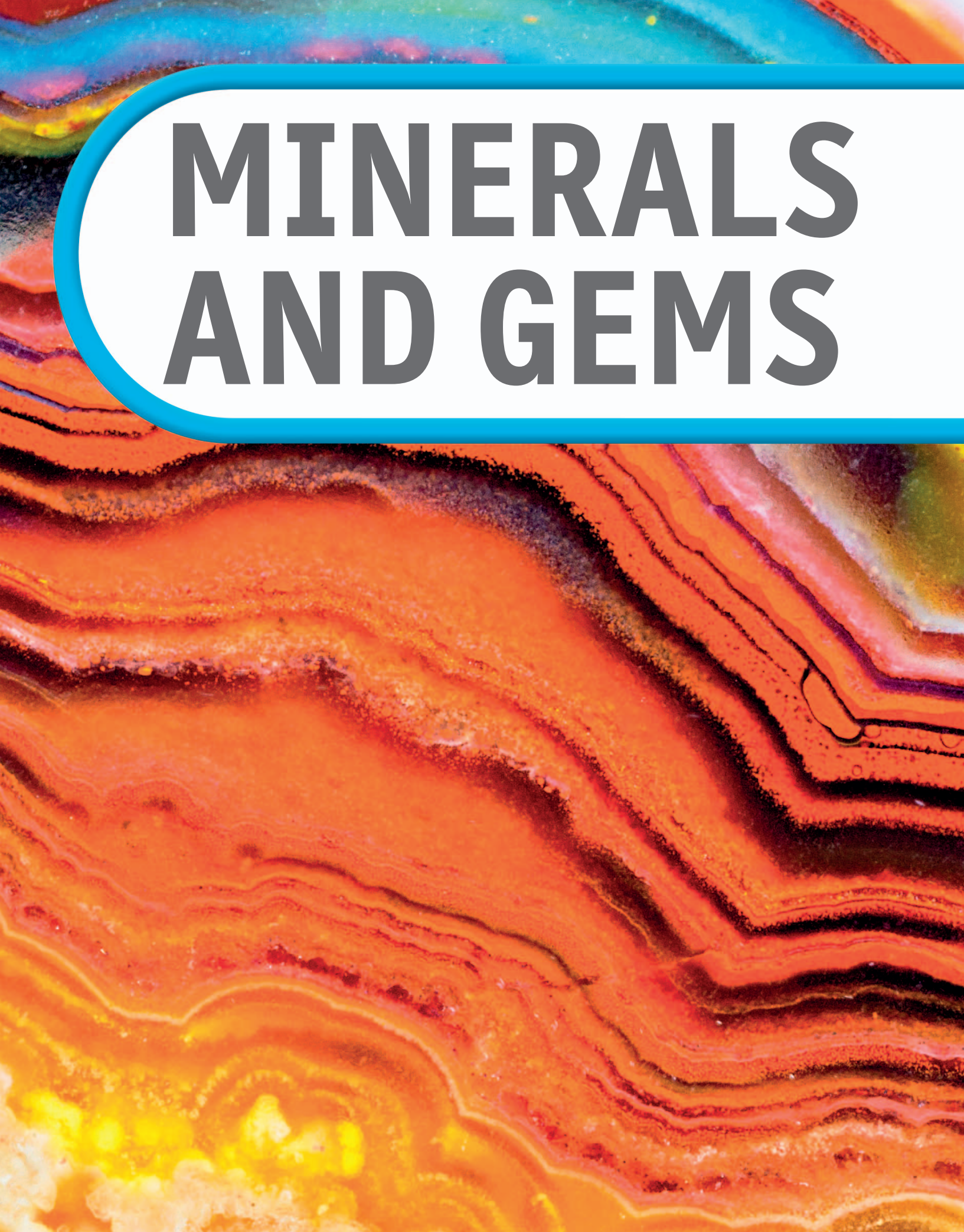
Chasing space rocks
This 2.4-mile- (4-km-) tall comet is bigger than Mount Fuji in Japan. A space probe landed on its surface in 2014. It was the first such landing in history.

pure iron, mixed with nickel. Weighing 60,000 tons, the **Hoba meteorite**, in Namibia, is the largest example ever found. The **Gerzeh beads**, made by the ancient Egyptians, are also thought to be made of iron meteorite since the people of that time had not developed the smelting techniques required to separate iron from its mineral ore. A group of meteorites are thought to have come from Mars. These are called **Martian meteorites**. Stony-iron meteorites are the most common. They come from near the cores of large asteroids. Achondrites and chondrites are two types of stony meteorites.

IMPACT CRATER Gosse's Bluff is a massive meteor crater in Australia's Central Desert. Known by the Aboriginal name "Tnorala," this scar on the landscape records the moment when a giant object came crashing out of the skies and collided with Earth's surface. Interestingly, both Aboriginal and scientific explanations as to how the Bluff was formed are very similar.

According to the traditional Aboriginal story, at the dawn of time a group of women danced across the sky, creating the Milky Way as they twisted and twirled. One of the mothers put her baby down to rest, but the cradle toppled out of the sky and crashed to Earth, creating the hollow of Tnorala, surrounded by circular rock walls. Scientists believe that, around 143 million years ago, a meteoroid blazed in from outer space on a collision course with our planet. It smashed into the surface, blasting a crater 12 miles (20 km) across. Today only the central part of this vast crater remains in the middle of the desert. It is up to 3 miles (5 km) in diameter.

MINERALS AND GEMS



Minerals and gems

Naturally occurring mineral ›
Minerals are naturally occurring solids. Some form solid crystals as molten liquid rock cools; others crystallize out of fluids loaded with dissolved minerals trickling through rocks.

Minerals are the basic building blocks of solid Earth. All rocks are made out of tiny, mixed mineral grains. Each mineral has a definite chemical recipe, and can be identified by its crystal form (known as its habit), color, hardness, surface shine (luster), and the way in which it breaks. Gems are cut and polished mineral crystals. These stones are highly prized for their beauty and rarity.

Amethyst

Mineral crystal › A definite chemical composition and an ordered internal arrangement of atoms give minerals the flat faces and sharp edges of crystals.

Cut gem › Gems are exceptionally beautiful crystals that are shaped and polished to enhance their appearance.

Crystal systems

Crystals can be divided into six groups based on their shape.

Tetragonal
- Have three axes of symmetry, all at right angles, two of which are of equal length.

Orthorhombic
- Similar to monoclinic system, but all three axes are at right angles. Habits are tabular and prismatic.

Monoclinic
- Have three unequal axes of symmetry, only two at right angles. Tabular and prismatic shapes are common.

Trigonal/hexagonal
- Both systems are similar, with four axes of symmetry. Crystals are often six-sided with tops like a pyramid.

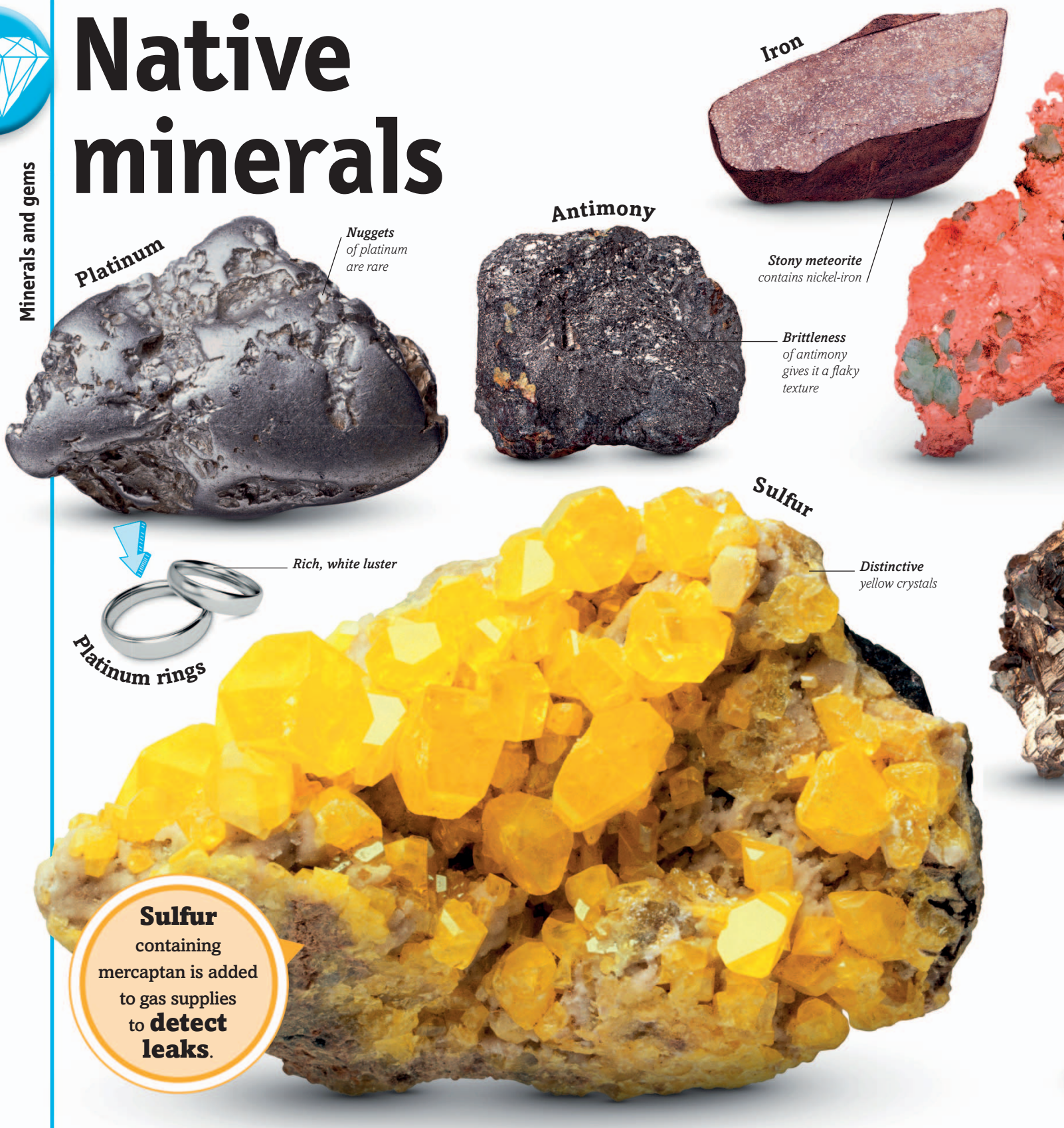
Cubic
- Are common and easily recognized. Have three axes at right angles, and shapes can be four- or eight-sided.

Triclinic
- Have a low degree of symmetry, because three axes are unequal in length and are not at right angles.

CARATS

A carat is the standard measure of weight for precious stones and metals. One carat is equal to 0.007 oz (0.2 g). It is also used as a measure of the purity of gold—pure gold being 24 carats (0.16 oz/4.8 g).

Native minerals

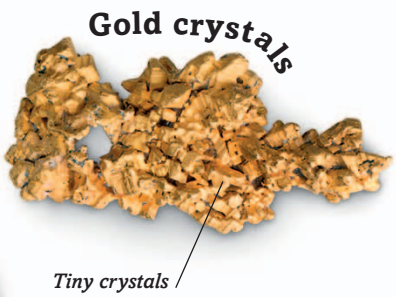


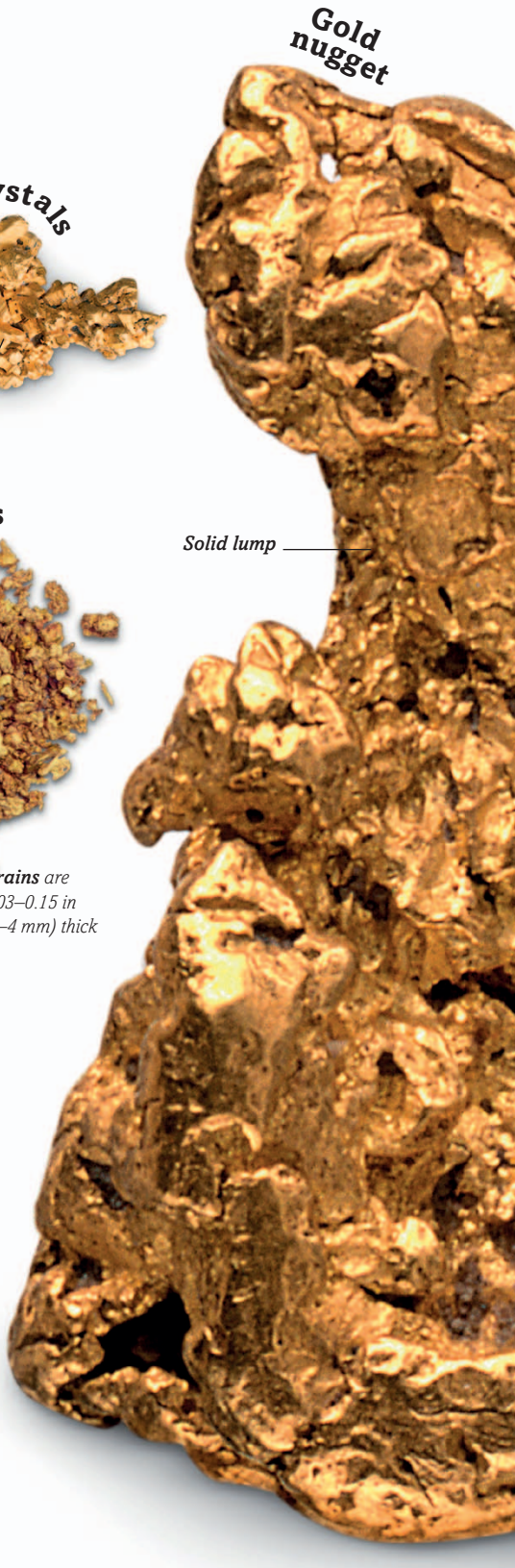
Most minerals are made of two or more chemical elements bonded together. A small handful, however, are not combined with anything else and are found in their natural, or native, state. Some of these minerals are highly valued precious metals.

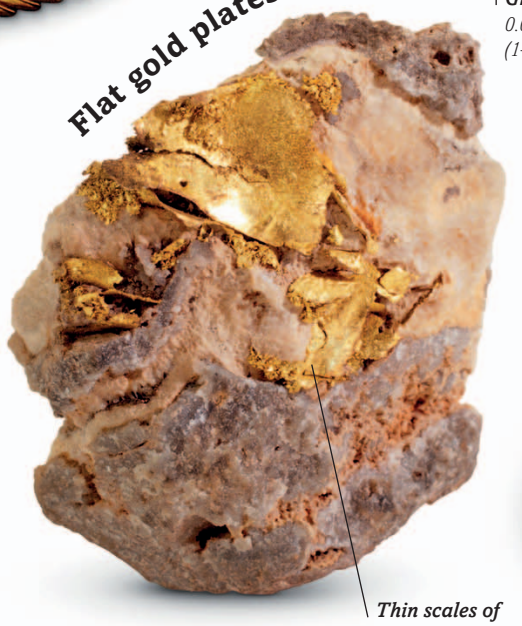
Gold is the most highly prized of all metals and is so unreactive that it is typically found in a relatively pure form. It is used to make ornaments, jewelry, money, and for numerous industrial applications. **Platinum** is usually found in its native metallic form in alloys. The metal is often

used to make jewelry and in industry. **Copper** and **silver** are usually found combined with other minerals. Native **iron** is found in weathered iron ore deposits or arrives on Earth in meteorites from space. Bright yellow crystals of native **sulfur** are sometimes found around volcanoes and hot springs. These crystals are used in the production of sulfuric acid—one of the most important industrial chemicals. The element carbon is found in two forms: **diamond** is the hardest known mineral in the world, while **graphite** is a soft, greasy mineral that has many different uses.

Gold







Gold is the most sought-after mineral on Earth. Its beauty and rarity make this precious metal extremely valuable. Gold keeps its soft, yellow sheen because it does not corrode or tarnish easily.

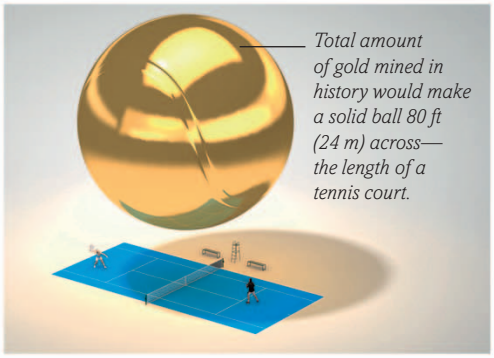
Although some lucky people find **gold nuggets** or **crystals**, most gold is found as flakes or **grains** in river silt, where it has washed out of rocks. It is taken out from these deposits by panning—washing the silt through a sieve. Throughout history,

Gold coins

British sovereign coins

The **largest gold nugget** ever found weighed 156.5 lb (71 kg).

RARE RESOURCE



Total amount of gold mined in history would make a solid ball 80 ft (24 m) across—the length of a tennis court.

The hunt for gold
An estimated 183,600 tons of gold have been mined in human history—around 80 percent of Earth's total mineable reserves of gold.

Intricate design in gold leaf

Gold leaf

Ceremonial gold cup from Chimú culture (1100–1470), in modern-day Peru

Chimú cup

Gold medal

***Medal** from the 1972 Olympic Games*

Ram's head engraved in gold

Medieval signet ring

Gold bullion

*Bars of solid **gold** weighing 2.2 lb (1 kg) each*

Superthin layer of gold on visor

Astronaut's visor

Satellite parts

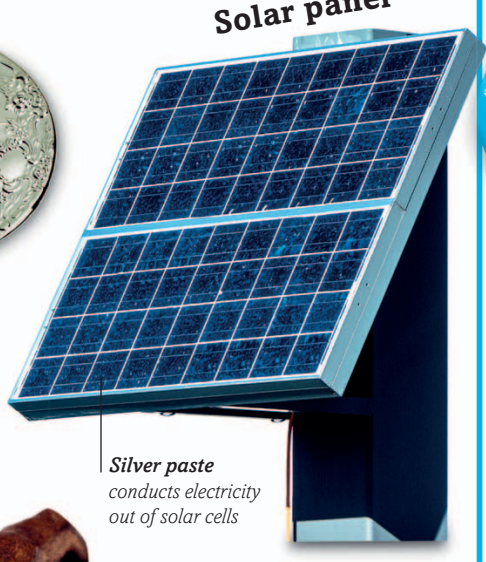
Gold covering

the sight of even a small speck of gold has been enough to spark a gold rush. It has been used for centuries as a store of wealth—as **jewelry**, **coins**, or **gold bullion**. An Olympic **gold medal**, such as this one from the 1972 Summer Olympic Games in Munich, West Germany, is made of 92.5 percent silver with a thin coating of 0.2 oz (6 g) of gold. A thin layer of gold on an **astronaut's visor** provides protection from the Sun's glare and heat. Gold foil is used to cover **satellites** because it keeps out harmful radiation.

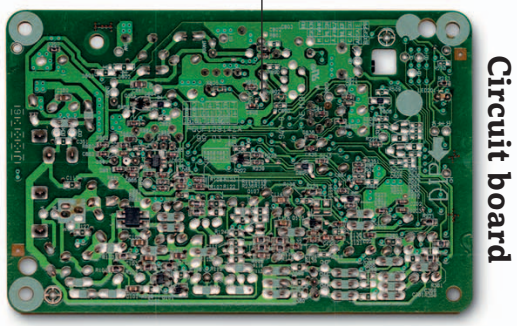
Silver

Silver is a pale, beautifully shiny precious metal. Found in our planet's crust as both an ore mineral and in its pure, native form, it has been mined since ancient times. However, unlike gold, silver nuggets are relatively rare.

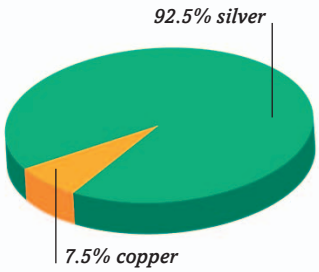
Although most silver is found in ores, native silver forms as crystals and as attractive twisted **wires** in veins in rocks. Silver is highly prized as a decorative metal, and is used for jewelry and **coins**. Ancient Greek *tetradrachm* coins and Roman *denarii* are hugely valuable collector's



One million **cell phones** contain about **770 lb (350 lb)** of silver.



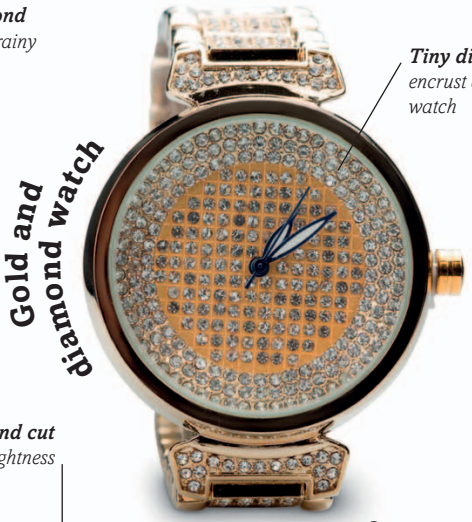
STERLING SILVER

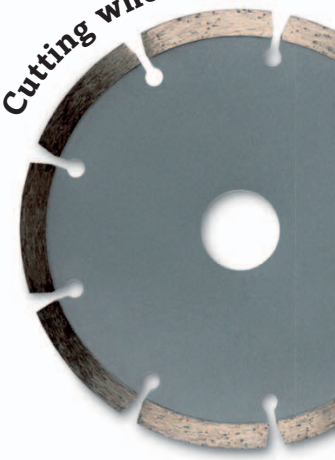


Popular alloy
Jewelry and silverware are traditionally made from sterling silver. This alloy contains a mix of silver (92.5 percent) and copper (7.5 percent).

items. High-quality musical instruments, such as **flutes** and trumpets, are made of silver alloy or silver-plated metal. In legend, **silver bullets** kill werewolves, but despite its mythical power, the metal is rather too expensive for bullets. Silver was once an active ingredient in **photographic film**, but digital cameras have made it a thing of the past. **Silver foil** just micrometers thick, called vark, is sometimes used to cover candy or other food items. Silver is also a natural conductor of electricity, and is used in **circuit boards** and **solar panels**.

Diamond





Mirny diamond mine, Russia

Diamond is the hardest known material in the world. It is lustrous, bright, and resistant to dulling or scratching. Diamonds are formed in Earth's mantle, 87–118 miles (140–190 km) underground. They make beautiful gems and are highly desirable.

Diamonds are so precious that they are used almost exclusively for jewelry—inlaid in **watches**, worn as **earrings**, or set in **rings**. Most diamonds are slightly yellow to brown, due to nitrogen impurities or other defects. Pure diamonds are colorless. One of the most famous gems, the

Diamond necklace

Pear-shaped diamond

Rough diamond embedded in kimberlite

Glass-cutting tool

Small diamond *set in the tip of cutting tool*

Diamond ring

Cluster diamond *on engagement ring*

Hope Diamond

Blue color *caused by tiny amounts of boron*

Marie Antoinette's earrings

Large, pear-shaped diamonds *that once belonged to the French queen*

Diamonds *embedded around the edge of grinding wheel*

The **Koh-i-Noor** diamond was recut in 1852 to make a **105.6-carat** stone.

Koh-i-Noor diamond

Queen Mother's crown

Powdered diamond *on head of tool can cut gem diamonds*

Diamond-coated tools

GIANT GEM

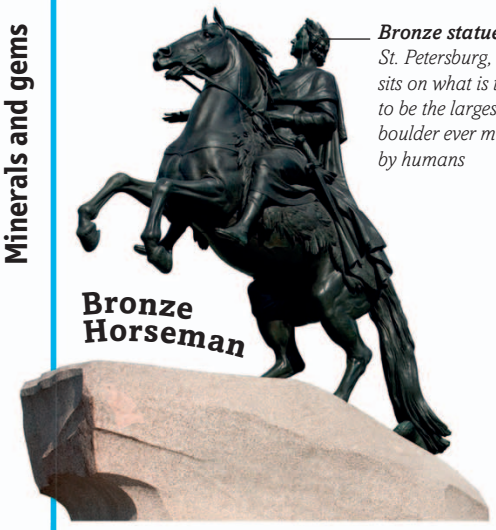
Cullinan Diamond

4 in (10 cm)

Record breaker
The Cullinan Diamond, discovered in 1905 in South Africa, was twice the size of any other diamond ever found. It was split into 9 large pieces and 96 smaller stones.

Hope Diamond, is a beautiful deep blue. Not all diamonds are precious. **Bort** is an industrial-grade, non-gem diamond that is crushed to make **cutting tools** and **wheels**. Diamonds reach the planet's surface by being carried by molten rock in special volcanic eruptions that originated deep in Earth. They are also found embedded in certain types of igneous rock. Sites where these rocks are found can be mined, such as the **Mirny diamond mine** in Russia. They are also found in gravel deposits in riverbeds, because the rock around them has been eroded by the water.

Copper

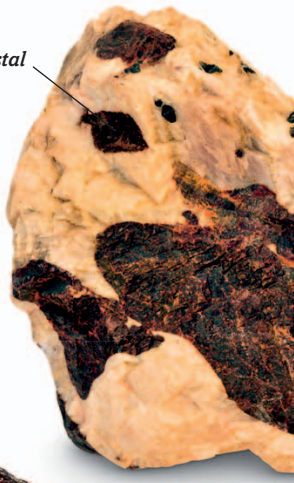


Bronze Horseman

***Bronze statue**, in St. Petersburg, Russia, sits on what is thought to be the largest boulder ever moved by humans*

***Fingerlike crystals** of copper*

Native copper

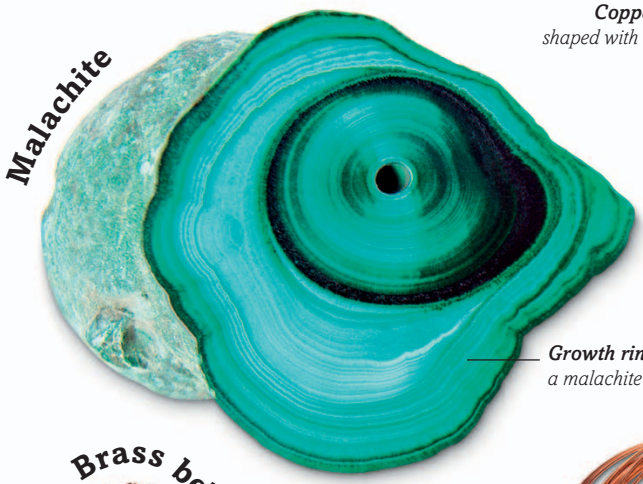


Cuprite crystal

Cuprite

Chalcopyrite

***Crystals** normally have triangular shape*



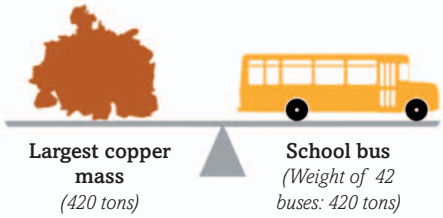
Malachite

***Growth rings** inside a malachite stalactite*

***Copper** is easily shaped with a hammer*

Copper pot

COPPER CRYSTAL



Largest copper mass
(420 tons)

School bus
(Weight of 42 buses: 420 tons)

Copper giant
The largest single chunk of native copper ever found was in Michigan in 1857. It weighed 420 tons, as much as 42 school buses.

Brass bells

***Bright brass** is an alloy of copper and zinc*

***Wire** carries electrical current*

Copper wire

Copper is a metal element that has been used since ancient times. Soft and easily shaped, this metal forms a variety of useful alloys when mixed with other metals. It is an excellent conductor of electricity and is used to make electrical wire.

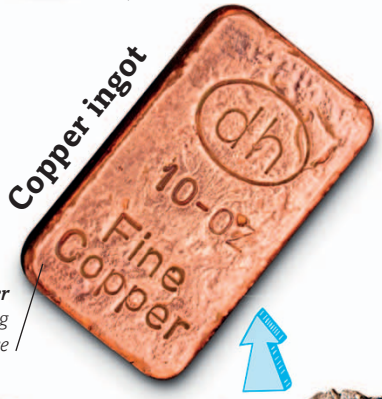
This reddish-brown metal is found as a native mineral or is extracted from its many ores. **Malachite** was the very first copper ore mined. Although the oxide mineral **cuprite** contains much more copper, it was easier to extract from malachite. **Chalcopyrite** is the most important

ore today. Although it has a lower copper content, it occurs in vast deposits and the copper can be easily extracted. Copper mixed with tin makes bronze. Discovered around 2500 BCE, bronze is tougher than pure copper. In the Bronze Age, people used it to make swords, **helmets**, and **spearheads**. The **Nebra Sky Disc**, from Germany, is a 3,600-year-old sky map made of bronze. Today, copper is used for roofing and for making **pipes**, **wire**, electronic components, energy-efficient motors, and **coins**. The **Statue of Liberty** is the world's largest copper statue.

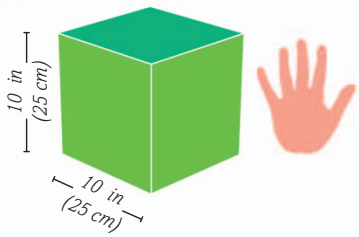
MIGHTY MINE In open-pit mining, the land covering a deposit of mineral ores is removed and an immense hollow is gouged into the ground to extract the metal-containing rocks. This results in the world's deepest human-made holes, some of which are visible from space. To limit the danger of rock falls, a series of steps are dug into the walls of the mines.

The Morenci mine in Arizona, first opened in 1872, is one of the world's largest open-pit copper mines. Reserves of an estimated 3 billion tons of copper ore lie in these hills, in copper porphyry deposits. The excavation is undertaken on a giant scale. Dynamite blasts apart the pit's steep, stepped sides, loosening entire hillsides of rock. Then gigantic bucket-wheel excavating machines move in, taking huge bites of earth and stone and loading them into monster trucks. The copper ore is taken to a mill, where it is crushed into a fine powder. The mine produces over 380,000 tons of copper every year and employs approximately 2,000 people.

Sulfides



GIANT GALENA



Colossal crystal
The largest galena crystal ever reported is a cube with sides measuring 10 in (25 cm). It was found in the Great Laxey Mine, Isle of Man, UK.

Among the most important metal ores in the world, sulfides are a group of commonly dark, dense minerals made of sulfur combined with metal. Sulfides do not usually make good gemstones because they are too soft.

Galena is a typical sulfide mineral. Soft, shiny, and heavy, this sulfide forms striking six-faced (cubic) or eight-faced (octahedral) crystals. Galena, one of the main sources of lead, is often found alongside other ores, such as marcasite, **pyrite**, **chalcopyrite**, and sphalerite. Marcasite,

Copper is the **third-most-used metal** in industries around the world.

an iron ore, shares the same composition as pyrite, but it has a different structure. **Cinnabar** is an unusual, brightly colored sulfide. It is the principal ore of mercury, and sometimes releases beads of the liquid metal. Indigo-blue **covellite** is a copper ore, first found on the famous volcano Mount Vesuvius in Italy. Purple **copper ore**, also called peacock ore, is one of the most colorful minerals in the world. This mix of bornite and chalcopyrite minerals can form dull **chalcocite**, another ore mineral that has the highest copper content perhaps of all sulfides.

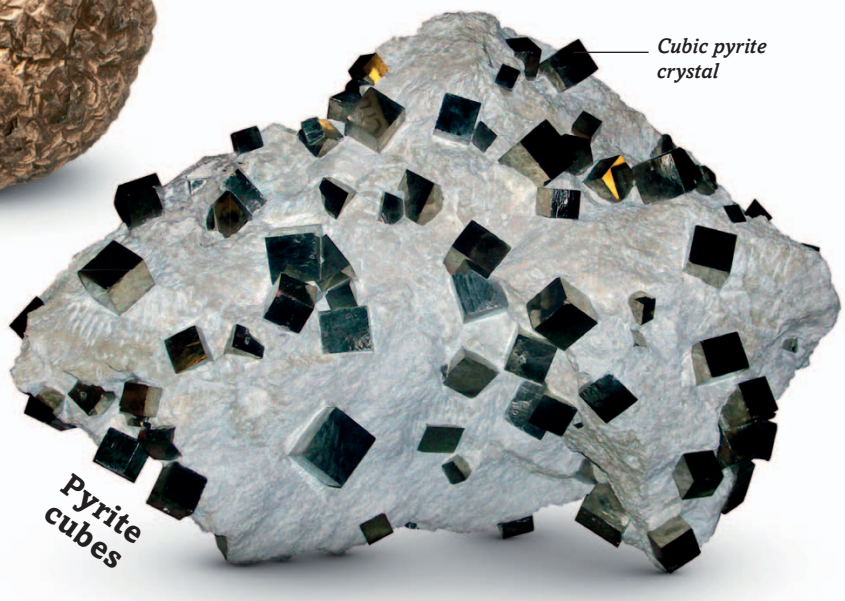
Some sulfide minerals masquerade as other minerals and are easily misidentified. **Pyrite** is the most notorious—it is also known as "fool's gold" and "brazzle" because its dazzling shine can fool the unwary into thinking they have found pure gold. Fool's gold, however, contains no real gold, just iron and sulfur. It is harder and more brittle than gold and is less dense. **Sphalerite** can also deceive the unwary. This mineral has several different forms and contains zinc. **Nickeline** is rarely used as a source of nickel because it often contains the deadly poison

The Germans called nickeline "***copper nickel***" though it contains no copper.

arsenic. **Realgar** is sometimes called ruby sulfur, and it is a soft mineral that crumbles easily. Its partner in crime is **orpiment**. Both of these minerals form around volcanic vents, were once used to make paint pigments, and also contain arsenic. Sometimes associated with realgar and galena, **stibnite** is the principal ore of the metal antimony. Sulfosalts are a rare group of minerals that contain a metal and a semimetal, such as arsenic. **Proustite**, also called ruby silver, and **pyrargyrite** are important sources of silver.

Pyrite

Pyrite is the most **abundant** sulfide mineral in Earth's crust.



Pyrite is a bright and shiny pretender. If you are not careful, it will trick you into thinking that you have struck gold. However, pyrite will not make you rich. It contains nothing of value, except, perhaps, some iron.

Pyrite gets its name from the Greek word *pyr*, meaning "fire," because pyrite emits sparks when struck by iron. Its gleaming gold crystals of pyrite are known as **fool's gold** because of their power to dazzle. However, it is easy to tell the difference between the precious metal and

Wheel-lock rifle

Firing mechanism *uses a piece of pyrite*

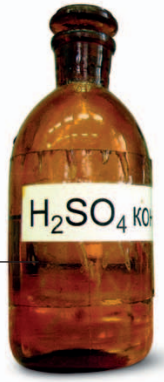
Pyrite *was one of the first minerals to be mined here*

Rio Tinto mines, Spain

Pyritized ammonite fossil

Pyrite *replaces shell's minerals during fossilization*

Sulfuric acid



Important industrial chemical *made with pyrite*

Dodecahedral pyrite

Crystal faces *are of different sizes, unlike a regular dodecahedron*

Pyrite nodules

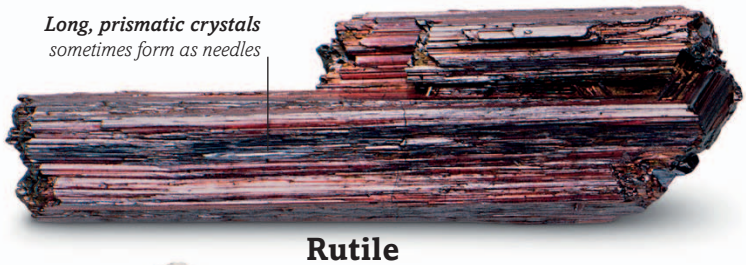
Hard, spherical mass

Pyrite sun discs

Radiating crystals *inside a pyrite nodule*

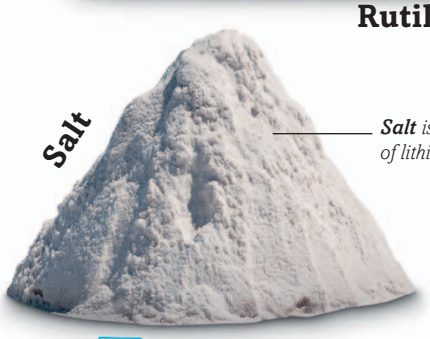
this worthless iron sulfide. Pyrite is less dense and harder than gold and forms perfect cubic crystals. Another test is to scrape the mineral down a scratch plate—pyrite leaves a streak of greenish-black powder rather than flakes of gold. As well as cubes and **octahedrons** (eight-faced shapes), pyrite forms **dodecahedron** crystals with 12 faces. It also forms **nodules**, some of which have radiating crystals inside. Pyrite is used to make **sulfuric acid**, and because it makes sparks when struck, it was also used to ignite gunpowder in **wheel-lock rifles**.

Ore minerals



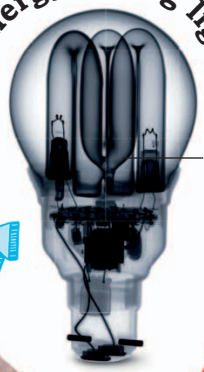
Long, prismatic crystals *sometimes form as needles*

Rutile



Salt

Salt *is a source of lithium*



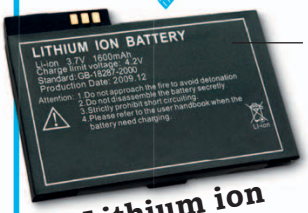
Energy-saving light

X-ray image *reveals tubes of mercury vapor*

Tiny red crystals *contain mercury*

Cinnabar

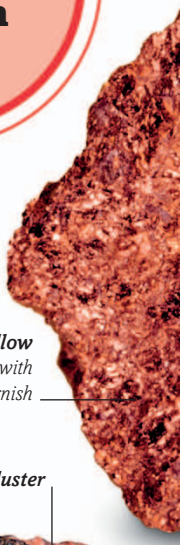
Cinnabar takes its name from the Arabic for "dragon blood."

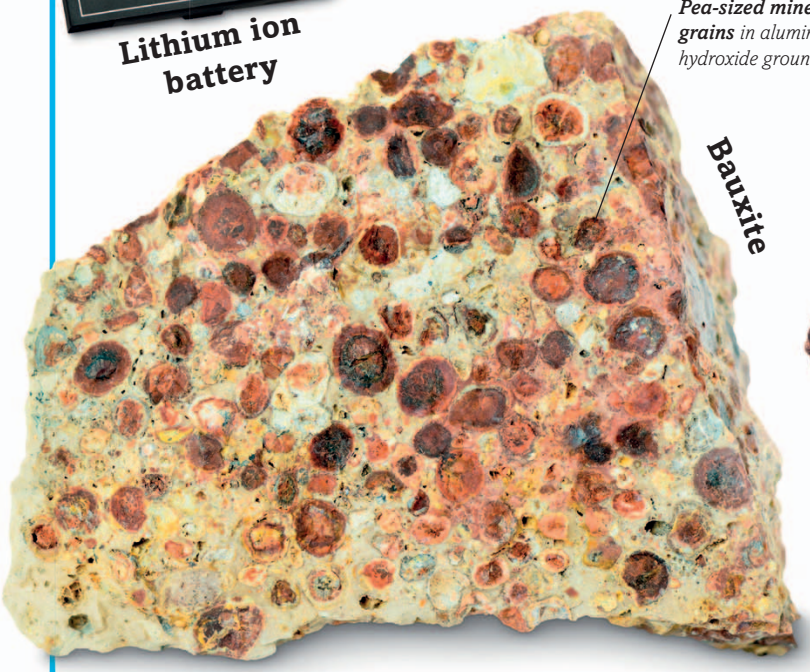


Lightweight, *rechargeable battery*

Lithium ion battery

White calcite





Pea-sized mineral grains *in aluminum hydroxide groundmass*

Bauxite

Cassiterite

Metallic yellow color *with bronzelike tarnish*

Dull luster

Uraninite

Prismatic crystals, *rich in tin*

Ores are minerals that contain valuable metals or other materials in large enough amounts to be worth mining. Many of them are oxides and sulfides, and contain oxygen or sulfur. Ores are mined and then refined to extract the metals they carry.

Important metals such as iron and copper are extracted from their ores in a chemical process called smelting, which requires high temperatures. The three main iron ores are the oxides hematite, **magnetite**, and ilmenite. Iron is often turned into steel, which is used in the construction

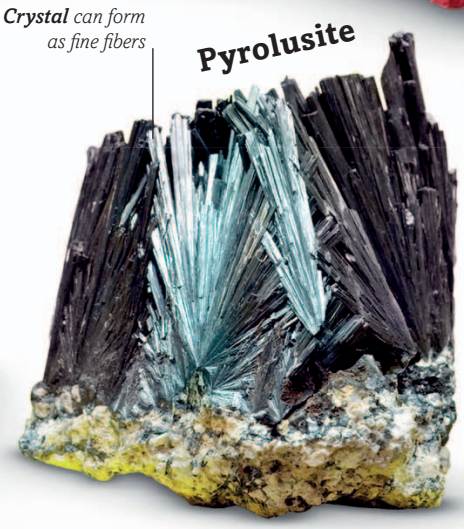
BINGHAM CANYON MINE

Largest human-made hole
The Bingham Canyon Mine in Utah is an open-pit copper mine nearly half a mile (1 km) deep. Two Empire State Buildings stacked on top of each other inside it would not even reach the top.

industry to build skyscrapers and bridges. **Bornite**, a major source of copper, is also called peacock ore because of its multicolored appearance. **Rutile** is a source of titanium, a light, strong metal, often used to make aircraft parts and added to steel to make it stronger.

Uraninite is refined to produce uranium, the metal that is used to power a nuclear reactor. **Bauxite** is the main source of aluminum. As well as being a source of fluorine, **fluorite** is also used during smelting, helping to speed up the process.

Oxides



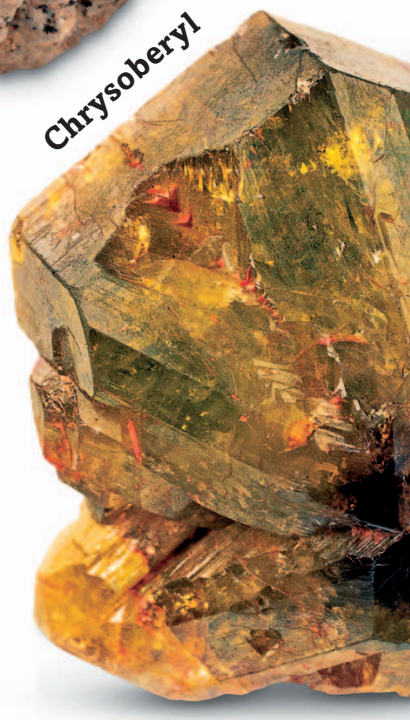
Many minerals contain oxygen, but oxide minerals are specifically those formed by one or more elements teamed with oxygen. Oxides are often stunning, and this group features some of the most gorgeous, glittering gemstones.

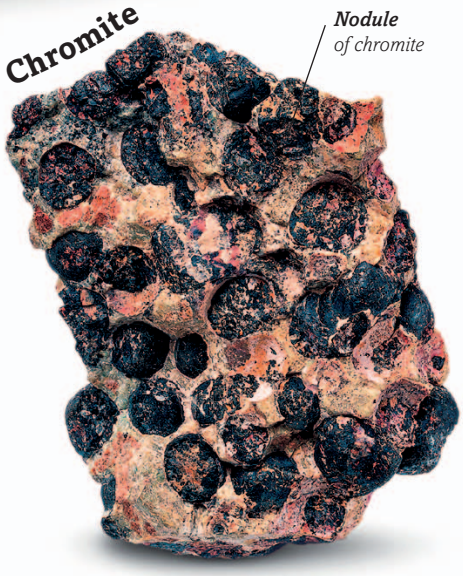
Many oxides are important ores of metals because they contain metal elements in their crystals. **Cuprite** is a source of copper, while uranium is extracted from **uraninite**. **Pyrolusite**, the most common ore of manganese, forms in lumps as well as in fibrous crystals. **Spinel** is the name for

Uraninite is highly **radioactive** and must be handled with care.

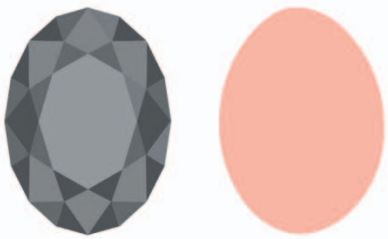
both a single mineral and a group of more than 20 minerals. Blood-red spinels are often mistaken for rubies. The Black Prince's ruby, set into the British Imperial State Crown, is actually a 170-carat (1.2 oz/34 g) spinel the same size as a ping-pong ball. Zinc-containing **gahnite** is a brown-gray spinel, while iron-rich **franklinite** is black. **Brookite, rutile**, and **anatase** are titanium oxides that share identical chemical compositions, but have different atomic arrangements. Minerals containing tin are rare; **cassiterite** is the only known commercial source of tin.

The finest sapphires come from **Sri Lanka**, **Myanmar**, and **India**.





GEMSTONE RECORD-BREAKER



Super sapphire
About the size of a hen's egg, the 733-carat (5.1 oz/146.6 g) Black Star of Queensland is the world's largest star sapphire.

Aluminum oxide may not sound exciting, but it forms no fewer than three highly prized gemstones. Pink and clear- to blue-colored varieties of corundum are known as **sapphires**, while **rubies** are blood red. A third, pink-orange form, called padparadscha, is even more rare.

Chrysoberyl is an aluminum oxide that also contains beryllium. Its most rare variety—a gem called alexandrite—changes color under electric lighting. **Chromite** is the world's most important source of chromium. It is used to make gleaming, chrome-plated faucets, car parts, and kitchen

appliances, and is also added to steel to make it super-hard. Chromite occurs in sedimentary layers or in weathered nodules within a rock. **Magnetite** is an iron oxide related to spinel. A naturally magnetic mineral, it is also known as **lodestone**. Magnetite and **hematite** are major ores of iron—a key ingredient of steel. **Ilmenite** is another black mineral, which resembles magnetite or hematite. It is an iron, titanium oxide, so is a major source of titanium, the wonder metal with the highest strength-to-weight ratio of all metals.

Ice

Iceberg floats *in water, the liquid form of ice*

Polar bear stranded on Arctic iceberg

Perito Moreno Glacier, Argentina

Blocks of ice *break off, or calve, from front edge of glacier*

Ice *sawn and chiseled into this shape*

Ice castle on Lake Louise, Canada

Castle *built on surface of frozen lake*

Snowflake

Symmetrical*, six-pointed pattern*

Ice cores in freezer

Tubes *cut from ancient ice are stored for analysis*

Hubbard Glacier, Alaska

River of ice *flows very slowly*

Iceberg

Around 90 percent *of iceberg is under water*

Minerals are any natural solids with a definite crystal structure, and ice is one of the most abundant minerals on Earth's surface. It exists naturally only in cold areas, such as on mountain peaks and in the polar regions, or as hail or snow.

Like iron ore, ruby, and cuprite, ice is also an oxide. Unlike the other oxides, however, it exists mostly in its liquid form, as water. As a solid, it is found as ice crystals (which form **snowflakes**, **glaciers** and ice caps), **icicles**, hailstones, and frost. Most of the world's ice is in the polar regions. Antarctica

Halo effect

Glowing ring *around Sun caused by ice crystals in atmosphere*

Icicles

Dripping meltwater *refreezes into long spikes*

Igloo

Temporary shelter *built out of blocks cut from ice and covered in snow*

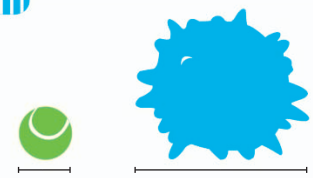
Natural ice sculpture

Huge chunk *of ice can float for weeks on the ocean*

Strange, curving shapes *formed as the ice is melted by the Sun*

The temperature at the **core** of an iceberg can be as low as **–4°F** (–20°C).

HUGE HAILSTONE



Tennis ball
2.75 in (6.8 cm)

Giant hailstone
8 in (20 cm)

Large ball
The largest hailstone ever seen fell in South Dakota in 2010. It measured 8 in (20 cm) across, roughly three times the size of a tennis ball.

is covered in a layer of ice about 1.2 miles (2 km) thick. The ice in this layer has been deposited over many thousands, if not millions, of years. Scientists drill into the ice to cut long, tube-shaped samples, called **ice cores**. These reveal what conditions on Earth were like in the past. In winter, most of the Arctic Ocean is covered in a 10–13-ft- (3–4-m-) thick sheet of ice, but much of this melts in summer, cracking up into **icebergs**. Snow houses called **igloos** are built by inhabitants of the Arctic region. Rivers of ice called **glaciers** move slowly down mountains, cutting valleys as they go.

UNDER THE ICE An explorer stops to take in the wonder of an ice cave. Meltwater flowing underneath the Muir Glacier in Alaska's Glacier Bay National Park has carved a spectacular cavern. We do not often think of ice as a mineral, but it meets all the criteria—it occurs naturally, is not formed by living things, is solid, and has a regular, internal crystal arrangement.

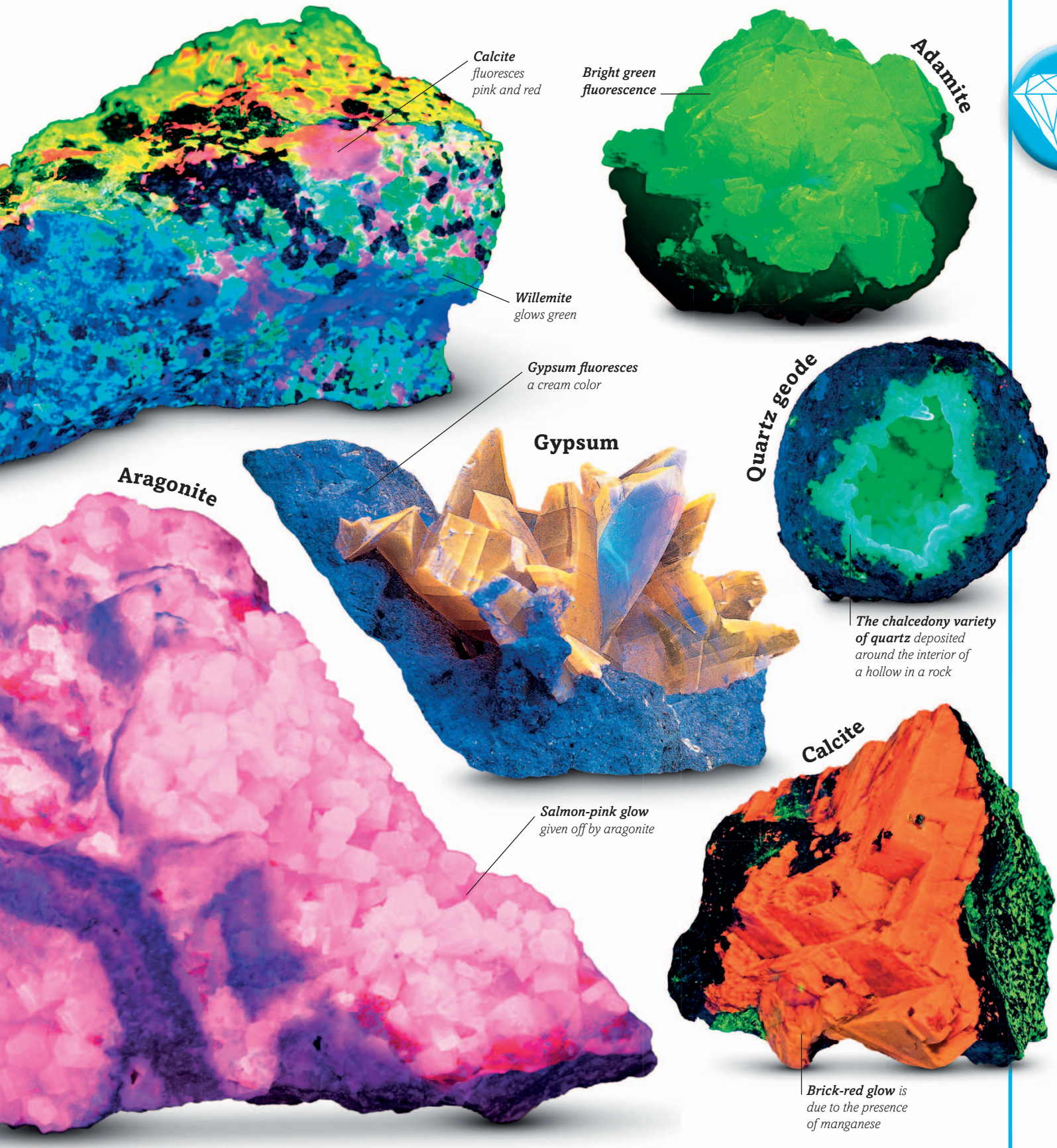
Ice occurs in vast deposits at Earth's poles—in fact, it is one of the most common minerals on the planet's surface. As snowfall builds up, ice crystals are compressed and compacted until they accumulate and form large, light blue masses. When it forms over land, ice can remain for thousands of years. In some places, an ice cap can be more than a mile (2 km) thick. Very few minerals can be said to last forever, but ice is particularly unstable—it turns into liquid water at temperatures over 32°F (0°C). In the Arctic, an expanse of sea ice the size of Australia melts every summer, but each winter, less ice is forming. As global temperatures rise, melting ice caps add water to the oceans, raising sea levels and affecting global weather patterns.

Fluorescent minerals

Benitoite was discovered by the **San Benito River** in California.

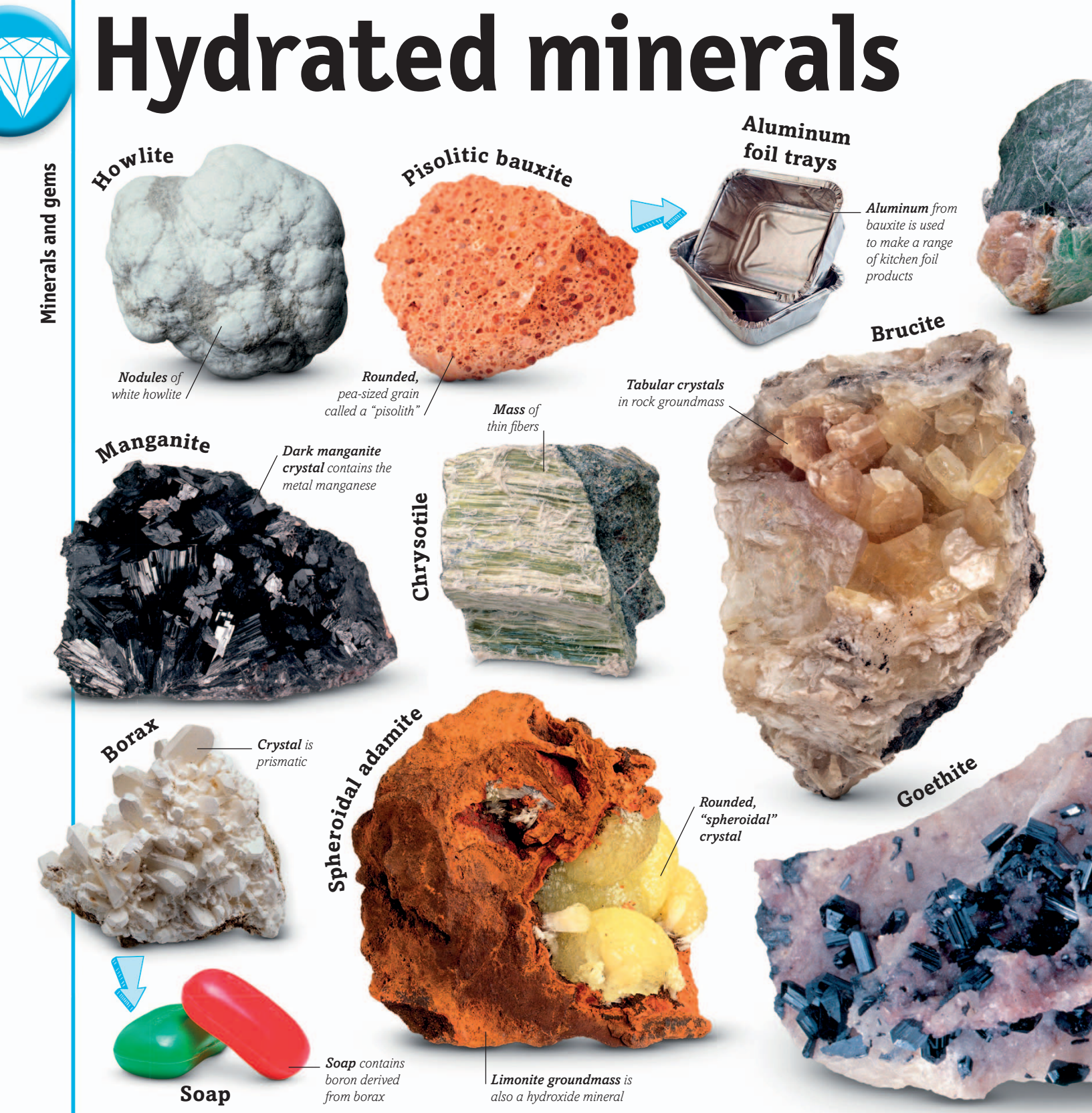
A chunk of zinc ore looks plain in dull browns and black, but turn off the lights and flick on an ultraviolet (UV) lamp and it bursts into an array of bright colors. Known as fluorescence, this phenomenon is common to all fluorescent minerals.

Many minerals sparkle and shimmer in wild colors when viewed under UV light. This "fluorescent" effect gets its name from **fluorite**—the mineral in which it was first observed, in 1852. Lots of common minerals change their colors totally under UV light.



Adamite, a zinc arsenate, shines bright green. **Calcite**, one of the most abundant minerals on the planet, is normally colorless, but the crystals fluoresce a bright, deep orange. What is needed for this strange glow is an "activator"—an element whose atoms absorb the energy of UV light, and then reemit it as visible light. A small amount of manganese acts as an activator for both **aragonite** and calcite. Iron, on the other hand, can be a "quencher," meaning that it suppresses fluorescence in some minerals.

Hydrated minerals

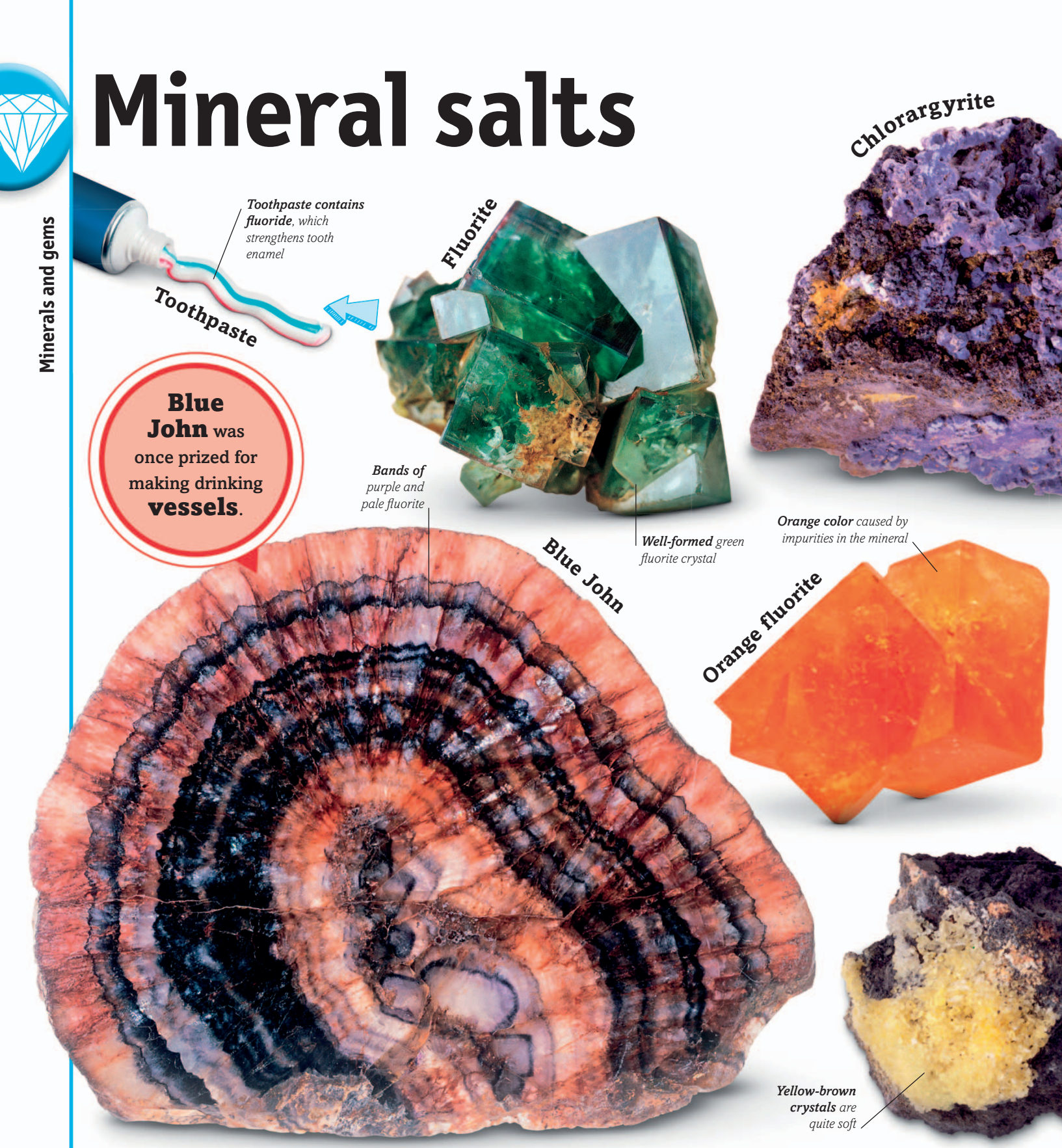


Hydroxide minerals are typically "secondary minerals" that form when water reacts with existing rocks and minerals. Other mineral groups can become "hydrated", when water molecules are incorporated into the crystal structure.

Bauxite is a source of the metal aluminum, which is used to make everything from aircraft bodies to windows and kitchen foil and has an unusual texture. **Pisolitic bauxite** consists of grains and concretions of aluminum-rich minerals. **Diaspore** also contains aluminum, but has

long, thin crystals. **Borax** is used in household cleaning products and laundry **soap**, and is added to glass to make it heatproof. Flameproof asbestos used to be made from thin, hairlike crystal fibers of **chrysotile**, but its use in buildings is banned today because breathing in the tiny dust particles it creates causes fatal health problems. **Talc** is one of the softest known minerals. As well as talcum powder that keeps babies' bottoms rash-free, it is used as a filler to bulk out **paints**, plastics, and rubber, and is even added to some foods, such as bread.

Mineral salts

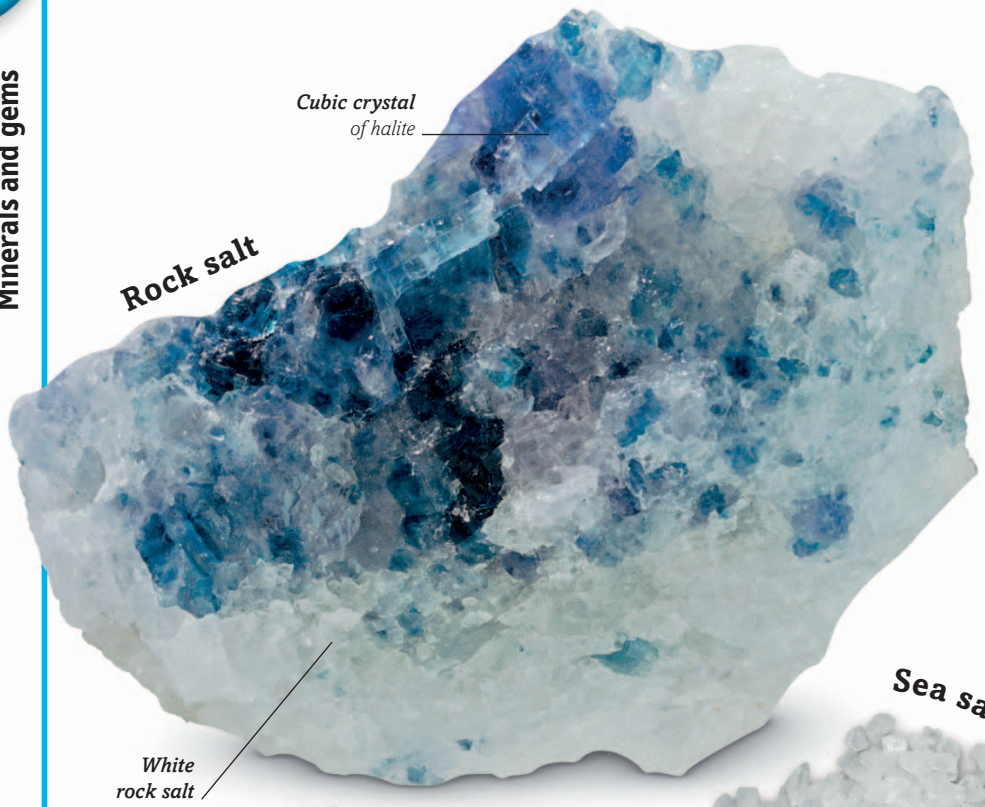


Mineral salts, or halides, are a group of sometimes brightly colored minerals that form when metals pair up with one of the halogen elements—fluorine, chlorine, bromine, or iodine. Many dissolve in water and are left behind when saltwater evaporates.

Fluorite is calcium fluoride and comes in many strikingly beautiful colors—purple, orange, and green are the most common. **Blue John** is a stunning and rare purple-, yellow-, and white-banded fluorite. When metals are smelted, fluorite is used as a "flux"—a substance that

lowers the melting point of impurities, which makes them runnier and easier to separate from the metals. Other halides include the silver ore **chlorargyrite**, **sylvite** (used to make potassium fertilizer), and **sal ammoniac** (a rare aluminum chloride mineral used in the salty Nordic liquorice salmiakki). But by far the most common halide mineral, and one of the most important minerals on Earth, is rock salt, or **halite**. As well as being used to flavor and preserve food, it is spread on roads in winter to prevent icing and is also an important industrial chemical.

Salt



Maras Salt Mines, Peru

Salt crystals *form as water in artificial ponds evaporates*

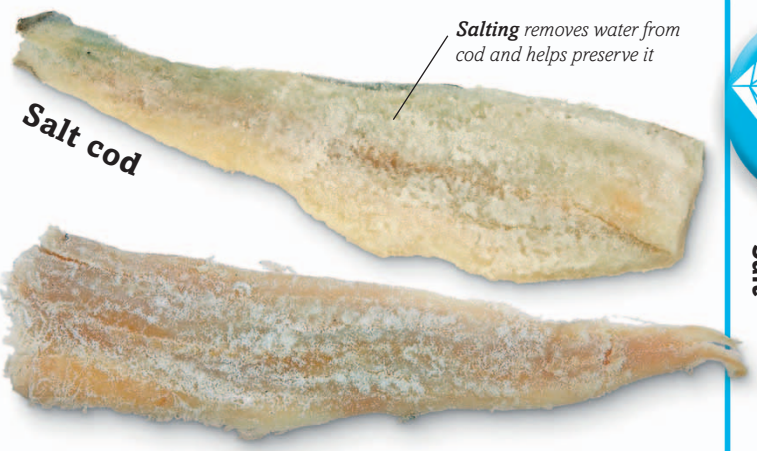
Pure white crystals of salt are abundant on Earth. Essential for all animal life, salt can be extracted from rock deposits or salty waters. Salt is a halide mineral made of sodium chloride, which has been mined and traded since ancient times.

Rock salt, also known as **halite**, is found in vast deposits underground. The **Wieliczka Salt Mines**, in Poland, have been mined for a thousand years. Since most halides dissolve in water (they make seawater salty), deposits of these minerals occur in dry places where

Regular, cubic crystals

Halite

Up to **900 tons** of salt per hour can be extracted from large salt mines.



Salt cod

Salting *removes water from cod and helps preserve it*

Wieliczka Salt Mines Chapel, Poland

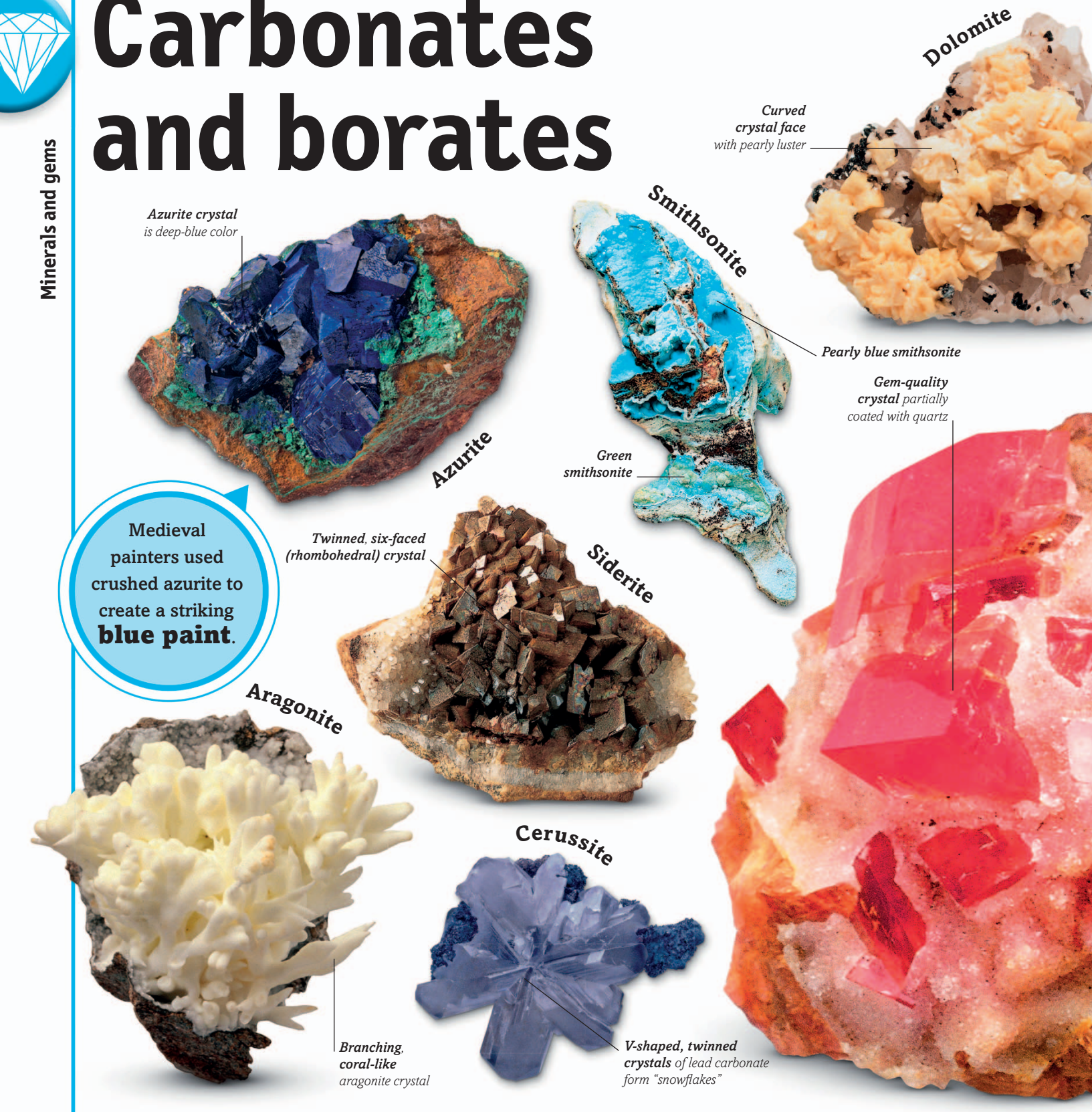
Church *carved from solid salt 1,300 ft (400 m) underground*

Salt *is scraped into small mounds to evaporate the water*

Salar de Uyuni, Bolivia

water evaporates. The **Salar de Uyuni**, in southwest Bolivia, is the world's largest salt flat. Evaporating salty water in shallow artificial ponds also produces salt. The **Maras Salt Mines** in Peru have produced salt for over 600 years. Salt is **spread on roads** in the winter to stop ice from forming. It is also used to **preserve food**, as well as to flavor it. Small amounts of salt are an essential part of the diet, but if you consistently eat too much of it, it can cause health problems later in life.

Carbonates and borates



Medieval painters used crushed azurite to create a striking **blue paint**.

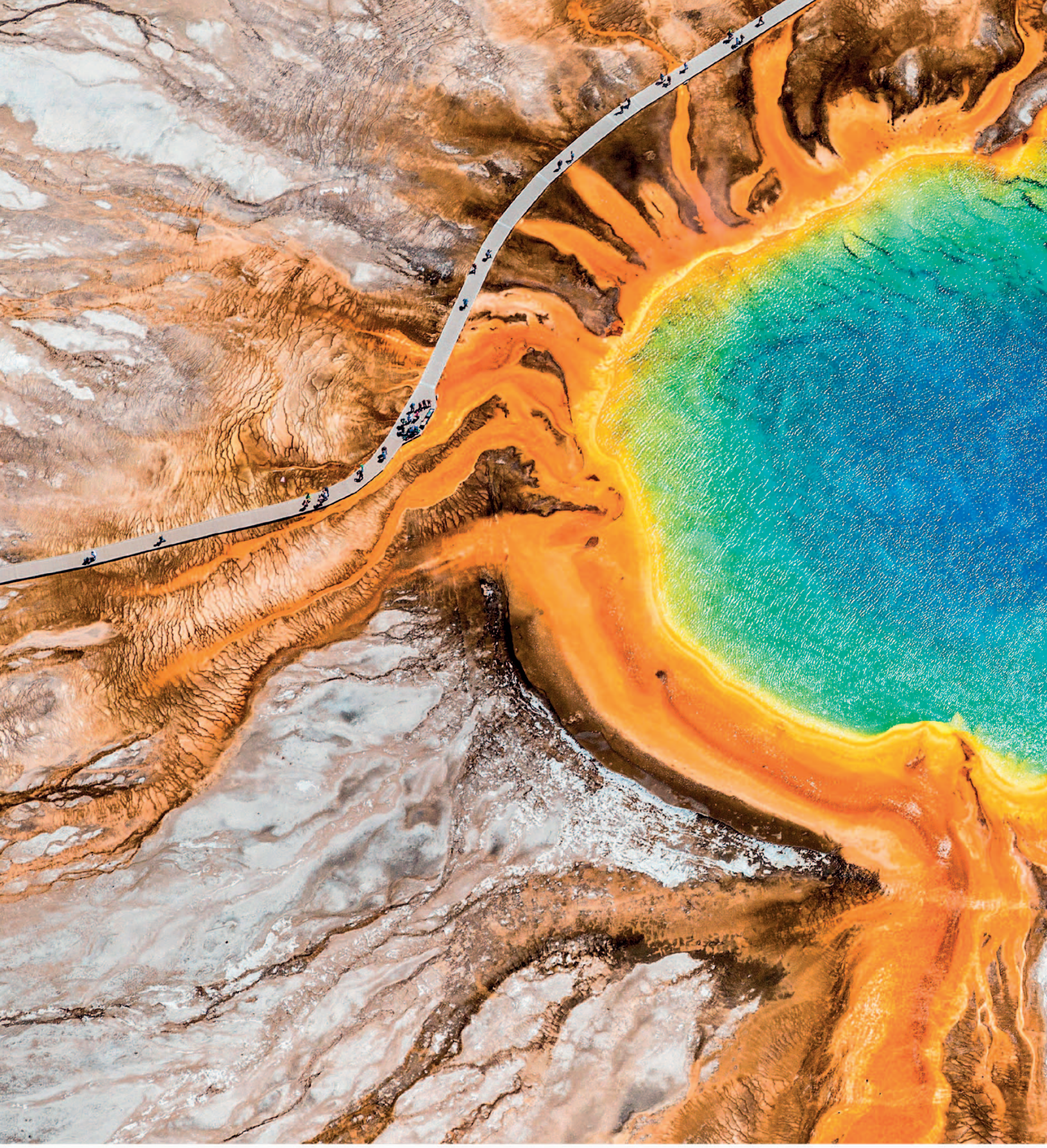
The carbonates are a family of relatively soft minerals that are formed of metal elements, along with carbon and oxygen. Carbonates are abundant in sea water, and some sea creatures such as mollusks and snails are able to use carbonate minerals to build their shells.

The three main rock-forming carbonate minerals are **calcite**, **aragonite**, and **dolomite**. The most common is calcite—a calcium carbonate mineral. It has more than 1,000 shapes—more than any other mineral—including Iceland spar, which was once used to make lenses, and jagged **dogtooth**

COLOSSAL CALCITE

Monster mineral
Some calcite crystals are giants. The largest single crystal ever was found in Iceland. It weighed 280 tons, approximately the weight of 28 school buses.

spar. Carbonates can be a source of metals—**smithsonite** contains zinc and **magnesite** contains magnesium. **Rhodochrosite** is a manganese ore, the color of which varies from rose pink to a deep crimson red, depending on how much **siderite** (iron carbonate) is mixed with it. Both **azurite** and **malachite** are weathered hydroxide minerals that often form together. Malachite is both a decorative stone and an important copper ore. Azurite is sometimes used in jewelry, but it is too soft to make a good gemstone.



SPECTACULAR SPRING Grand Prismatic Spring in Yellowstone National Park is the third largest hot spring in the world. It dazzles with color: from deep blue at the center, where the water is hottest, to orange and red at the edges, where it is cooler. This kaleidoscope of colors is caused by different types of bacteria living in each of the temperature zones and by the presence of certain minerals (such as sulfur).

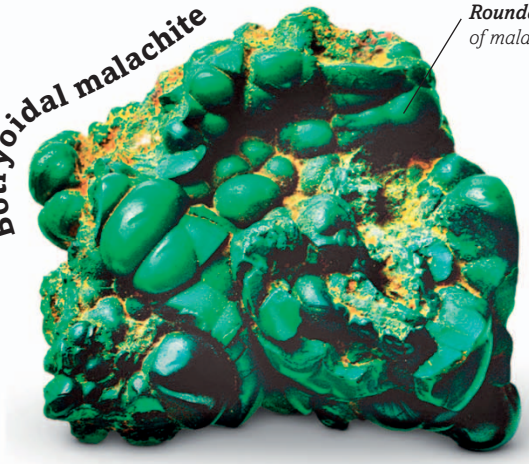
Water with a temperature of up to 185°F (85°C) constantly wells up in the center of the Grand Prismatic Spring. The energy to generate this hot water, and nearly 10,000 other springs, mudpots, and geysers in the area, comes from a supervolcano sitting below the park, which last erupted 640,000 years ago. The supervolcano's vast magma chamber heats water to more than 750°F (400°C), slowly transforming the rocks underneath as extremely hot fluids from the volcano dissolve the minerals contained in them. These fluids deposit new minerals in cavities and cracks, and cause minerals within the rock to change.

Malachite

Urn and base carved from malachite

Malachite urn

Botryoidal malachite



Rounded lumps of malachite

Growth rings show how the mineral builds up in layers

Statue carved from malachite

Malachite statue

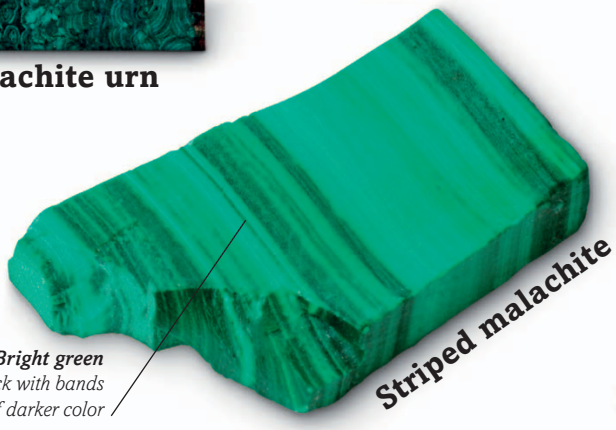
St. Isaac's Cathedral, Russia

Column clad in carved malachite

Radiating crystals

Jewelry box

Jewelry box clad with thin veneers of malachite



Striped malachite

Bright green block with bands of darker color

The name malachite comes from a Greek word meaning green, and it is easy to see why. This deep-green mineral is the natural form of copper carbonate hydroxide. It has been used for centuries as a source of copper and for making ornaments.

A green crust of malachite is a sign that other copper minerals are present below the surface, and prospectors look for this sign as they survey an area for valuable minerals. Malachite typically forms when copper ores react with acidic water containing carbonate. The larger specimens

Malachite pendant

Polished surface shows bands inside stone

Ancient Egyptian painting

***Blue color** in this ancient wall painting comes from malachite pigment*

Malachite

Some malachite **forms as stalactites** in cave formations.

Malachite stalactite

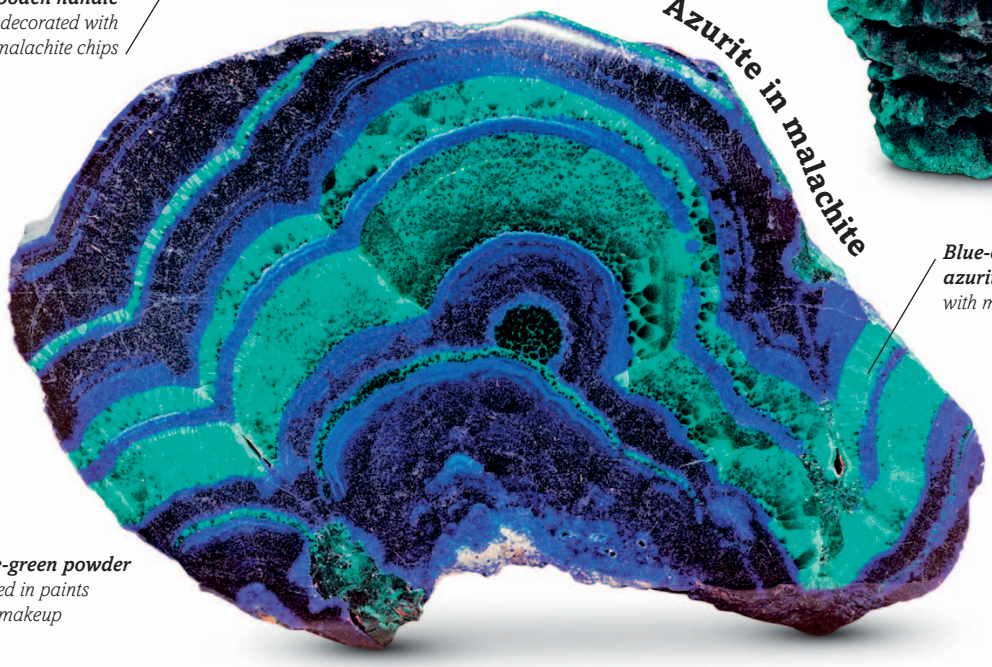
Group of radiating, fibrous crystals

Aztec knife

***Wooden handle** decorated with malachite chips*

Fibrous malachite

Azurite in malachite



***Blue-colored azurite** is often mixed with malachite*

Malachite pigment

***Blue-green powder** is used in paints and makeup*

form as **botryoidal** (grapelike) masses made up of lumps and bumps. Each bump contains many layers of crystals, so when the mineral is cut and polished, it takes on a rippled, flowerlike finish. Malachite is quite soft and is easily carved into **statues** and other ornaments.

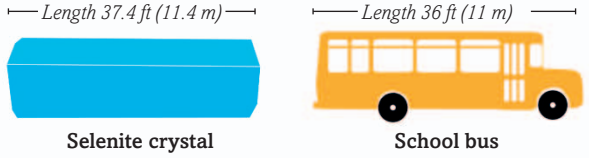
About 35,000 lb (16,000 kg) of malachite was used to decorate various features at **St. Isaac's Cathedral** in Russia. Powdered malachite mixed with water or oil was an early source of **pigments** and was used by artists in many ancient paintings.

Sulfate minerals

The sulfates, tungstates, chromates, and molybdates are minerals that show a similar chemical structure. Oxygen combines with sulfur, tungsten, chromium, and molybdenum, respectively, to form these minerals. Sulfates are most common.

Many of the sulfate minerals are important sources of useful metals. **Anglesite**, named after the Welsh island of Anglesey, is a lead sulfate. **Celestine** is a source of the metal strontium. Powdered strontium is added to fireworks to make red sparks when they explode.

GIGANTIC GYPSUM

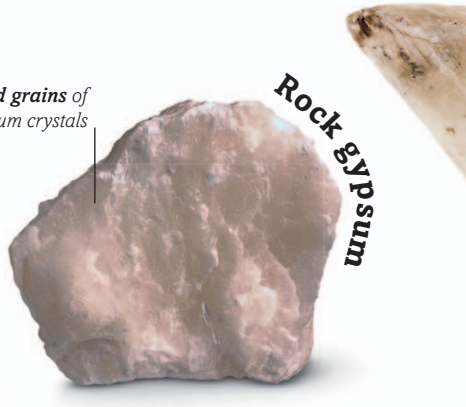


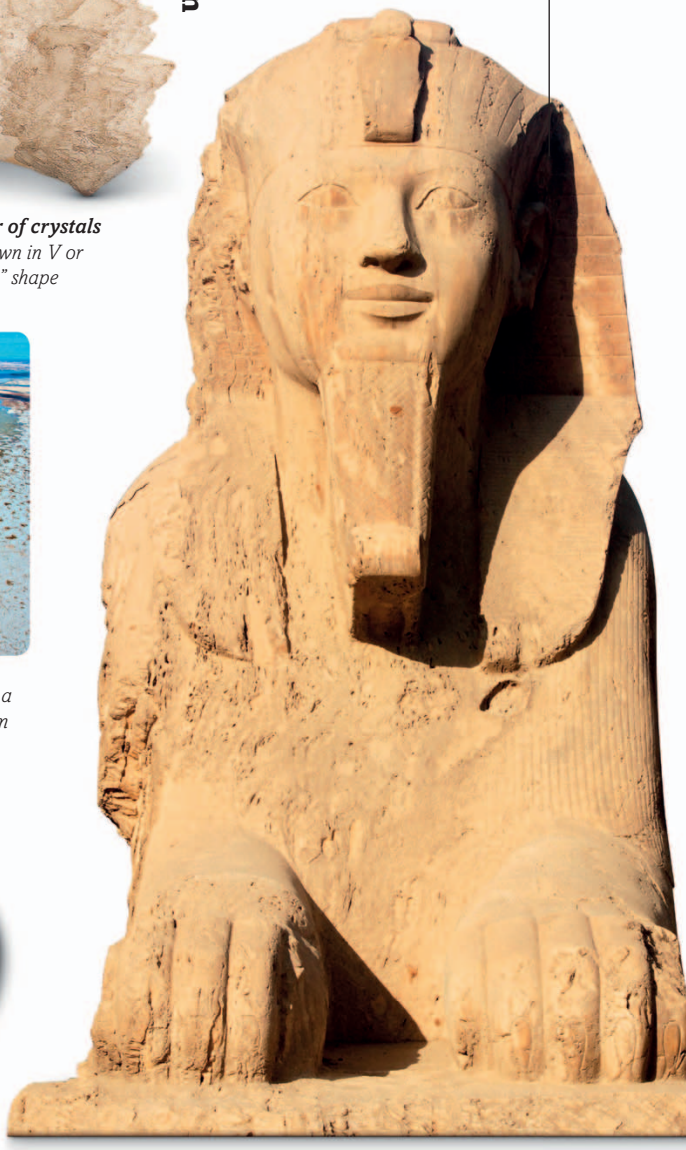
Longest crystal
The longest selenite gypsum crystal ever found was discovered in the Cave of Crystals, Mexico. It measures 37.4 ft (11.4 m) in length—as long as a school bus and weighs 50 tons.

Celestine is also sought after for its beautiful, pale-colored crystals. **Wulfenite** is purified into molybdenum, which is a metal used to make hardened steel. Tungsten is refined from **scheelite**—named after the Swedish chemist Carl Scheele, who discovered the metal in 1781.

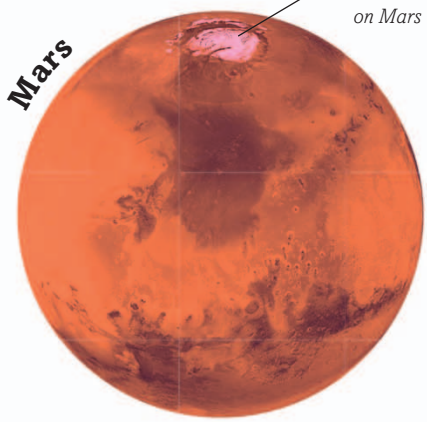
Tungsten has the highest melting point of any metal and is used in heaters and light bulbs. In medicine, patients with gastrointestinal problems swallow "barium meals" (of which powdered **baryte** is an ingredient) so that their intestines will show up on X-rays.

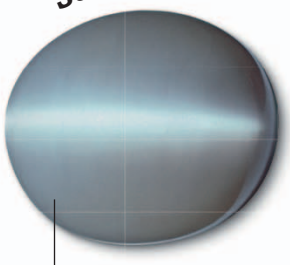
Gypsum





Alabaster sphinx



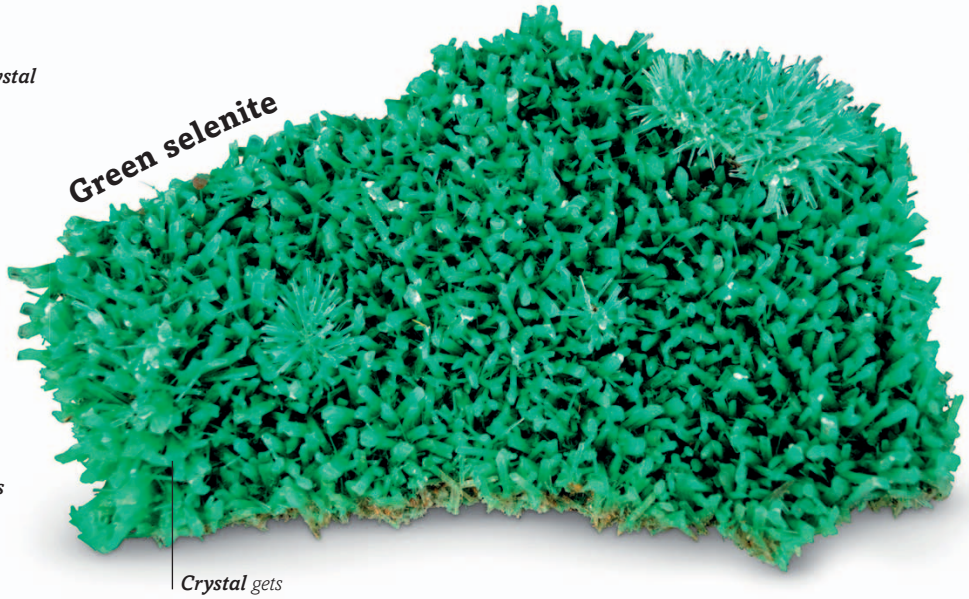


Gypsum is the natural form of calcium sulfate and is one of the world's most useful minerals—200 million tons of it are dug up every year. Gypsum is used mostly to make the drywall or sheetrock that covers the inside walls of our homes.

Gypsum crystals form when water containing dissolved calcium and sulfate ions evaporates. As a result, gypsum is common in desert areas, where lakes often dry out, and in deep caverns that were once filled with water. Large crystals of gypsum are called **selenite**, and they are

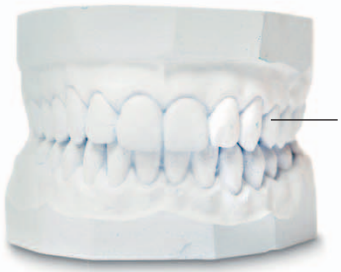
Colorless crystal

Gypsum



Green selenite

Crystal *gets its color from copper impurities*

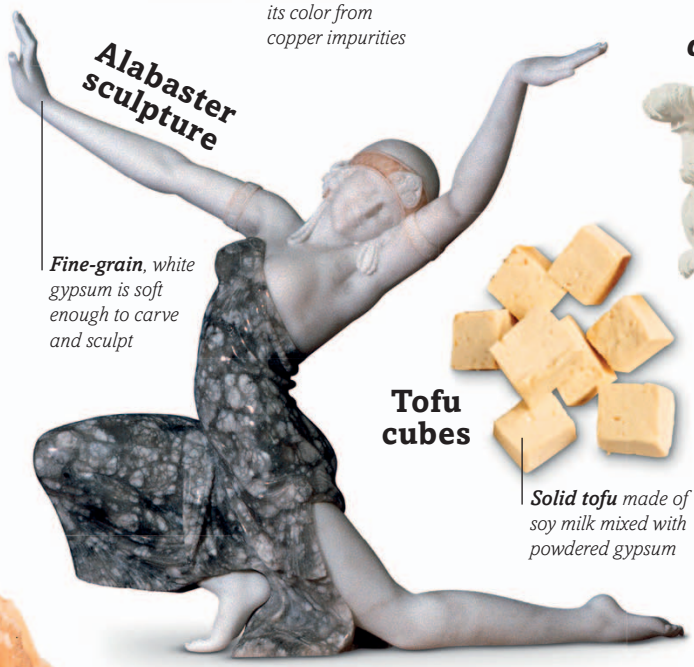


Plaster of Paris *teeth for making dentures*

Plaster of Paris teeth

Desert rose gypsum is found in dry areas once covered by seas or lakes.

Alabaster sculpture



Fine-grain*, white gypsum is soft enough to carve and sculpt*

Plastered, decorative pillar

Plaster of Paris *carved into intricate shapes*

Tofu cubes

Solid tofu *made of soy milk mixed with powdered gypsum*

Flowerlike plates *form from mineral-rich water*

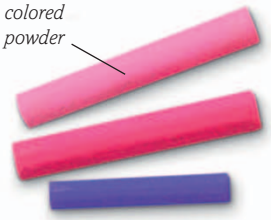
Desert rose

White dunes *are made of gypsum crystals*

White Sands National Monument, New Mexico

Drawing chalk

Chalk *made from colored gypsum powder*



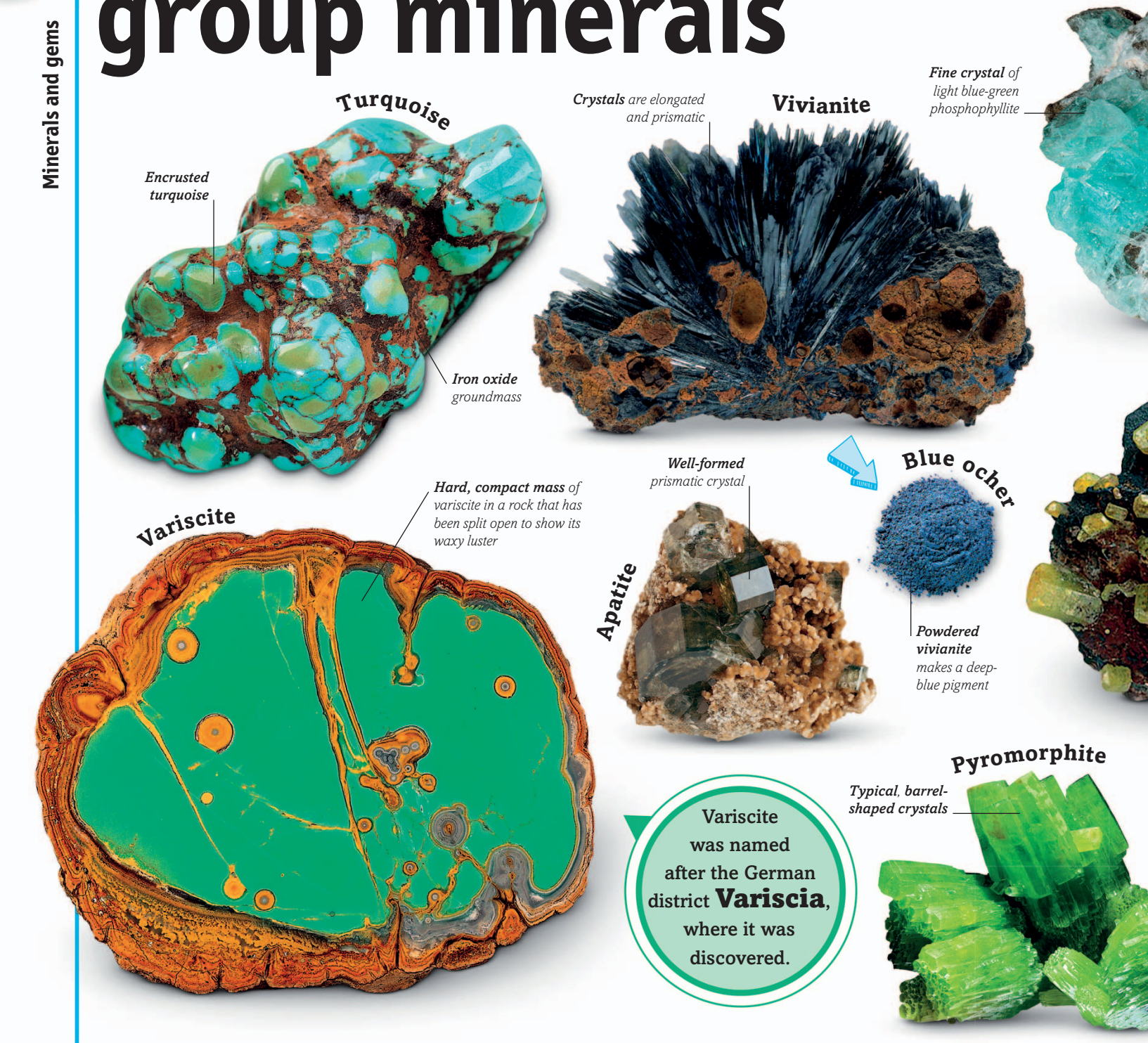
mostly transparent and milk-colored. Smaller crystals of gypsum make a white rock called gyprock, or **rock gypsum**. When the crystal grains are even finer, the mineral is known as **alabaster**, which is easy to carve and is used to make small statues and sculptures. Gypsum crystals have water trapped inside them. Heating the crystals drives out the water, making a dry powder called **plaster of Paris**. Adding water to plaster makes a paste that can be molded and spread. As it dries, the water goes back into the crystals, making a hard, solid substance.

CAVE OF CRYSTALS

In 2000, some miners drilling more than 1,000 ft (300 m) below the surface in the Naica mines of northern Mexico made an incredible discovery. Breaking through a cave wall, they discovered a chamber never seen by human eyes. The Cueva de los Cristales, or Cave of Crystals, was filled floor to ceiling with monumental gypsum crystals that had grown undisturbed for millions of years.

The giant, translucent crystals in the cave are made of a type of gypsum called selenite. This is a commonplace mineral, but their sheer size makes the crystals a wonder of nature. Some of them are more than 30 ft (10 m) long. For millions of years, these caves were flooded with groundwater rich in calcium sulfate. Kept warm by heat from a magma chamber below, the colossal pillars of selenite crystals grew steadily. When the mines were drained of water, the crystals were revealed. However, once the mines are exhausted and the water pumps are turned off, the cave will be flooded once again. For now, 100 percent humidity and temperatures reaching 122°F (50°C) keep this natural wonder stable.

Phosphate group minerals



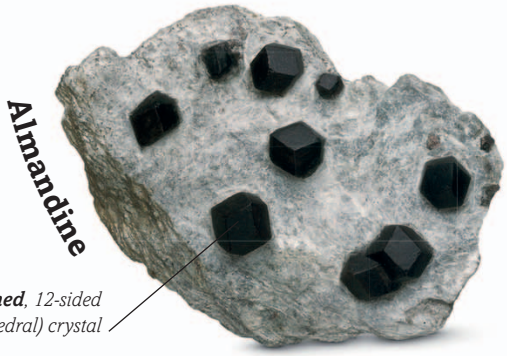
Variscite was named after the German district **Variscia**, where it was discovered.

The phosphates are a family of minerals that contain phosphorus and oxygen. They are part of a large and varied group that includes the arsenates and vanadates. Bright colors are characteristic of this group of minerals.

Turquoise has been mined for thousands of years and was a very important mineral for many ancient cultures. Semiprecious **variscite** is often mistaken for turquoise, but is greener. **Vivianite** turns pale blue to dark greenish-blue when exposed to light. **Apatite** is

the most common phosphate mineral. In the body, it builds our teeth enamel and bones. In rocks, it occurs as a group of related minerals including chlorapatite and fluorapatite. The main use of phosphate minerals is as fertilizer—200,000 tons of phosphate-containing rocks are crushed every year to make fertilizer. The phosphate family includes vanadates (with vanadium) and arsenates (with arsenic). Cobalt-containing **erythrite** is an arsenate. The vanadate **carnotite** is an important source of radioactive uranium, used to generate nuclear power.

Silicates



Hessonite is named after the Greek word for **inferior** because of its softness.

The silicates are the most common minerals on Earth. They are made up of silicon and oxygen combined with other elements, mostly metals. These minerals are the main ingredients in sands and clays, and are found in almost all rocks.

The silicate minerals are divided into different groups based on their structure. The ones seen here are nesosilicates or sorosilicates. **Peridot** belongs to a subgroup of nesosilicates called olivine. It is one of the major minerals that make up the Earth's upper mantle. **Almandine** and

hessonite are members of the garnet group of nesosilicates. These minerals are harder than most minerals, but are softer than the gem minerals corundum, diamond, beryl, and topaz, which is why they were used in jewelry in ancient times. The nesosilicates **staurolite** and **kyanite** are valuable sources of the metal aluminum. **Vesuvianite**, a sorosilicate, is named after Mount Vesuvius, a volcano in Italy, where it was first discovered. **Epidote** is another sorosilicate but it is only rarely used as a gem material.

Rhodonite

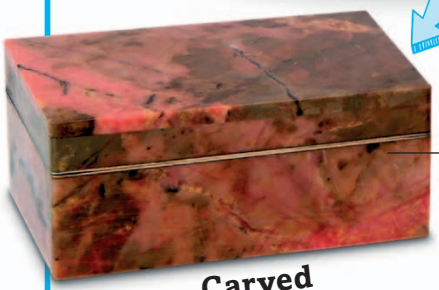
Rose-colored crystals *form brittle plates*

Wollastonite

Fibrous layers *of crystals splinter easily*

Astrophyllite

Golden crystals *crack into leafy flakes*

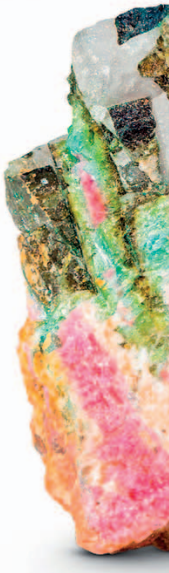


Rhodonite *can be carved into many shapes, such as this box*

Carved rhodonite box

Augite

Dark crystal *is nearly opaque*



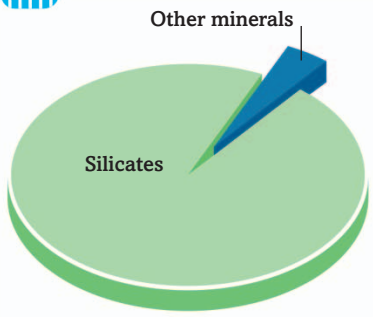
Black tourmaline

Dark, prismatic crystal

Indicolite

Large, blue crystal

SUPER GROUP



Minerals in Earth's crust

Widespread silicates
There are about 1,000 kinds of silicate. They make up 90 percent of the minerals in Earth's rocky crust and mantle.

Inosilicate minerals take their name from the Greek word for "thread," because of the chainlike structure of the crystals. They include **augite**, which is one of the most common minerals in basalt and other dark-colored igneous rocks. **Wollastonite** forms when limestone is heated by magma underground. **Rhodonite** gets its name from the Greek word for rose. Its pink color comes from manganese in its crystal structure. A common inosilicate called **hornblende** was often mistaken for a valuable ore mineral. The cyclosilicate

minerals have crystal structures made up of rings of silicate groups. Tourmaline is one of the most common cyclosilicates and comes in many color varieties, most of which are used as gems. The most abundant type is **black tourmaline**. Another colorful cyclosilicate is beryl.

Morganite is its pink form, while **heliodor** is a yellow variety. Vivid green beryl is more famous—it is called emerald. **Dioptase** is sometimes mistaken for emerald, but its crystals are much more fragile and break too easily to use in jewelry.

COLOSSAL QUARTZ

Largest single quartz crystal | **African elephant**

Crystal tower

The largest quartz crystal ever found is from Itapore in Brazil. It is approximately 20 ft (6.1 m) high and weighs more than 50 tons—10 times the mass of an African elephant.

Quartz is one of the most common minerals on the surface of Earth. Sand is made up mostly of grains of quartz crystals, and the mineral is found in common rocks, such as granite and sandstone. Quartz is the main example of a tectosilicate, a type of silicate in which the crystal structure consists of a spiral-like arrangement of silicate groups. There are many color varieties of quartz. **Amethyst** is purple quartz and gets its color from iron impurities. It is named after the maiden Amethyst from Greek mythology. Many

Scientists have discovered traces of **opal on Mars**.

amethysts and similar kinds of crystalline quartz form as geodes—air bubbles inside rocks that become filled with mineral-rich water, from which crystals slowly form. **Agate** is microcrystalline, meaning that the crystals are tiny, giving the mineral a smooth texture. **Opal** is made up of silica and water, and typically does not have a crystal structure. **Albite** and **orthoclase** are examples of feldspars, which are the main silicates in rocks. **Stilbite** crystals are tabular in shape, have a pearly luster, and can exceed 4 in (10 cm) in length.

Topaz

The word topaz comes from Sanskrit, an ancient Indian language, and means "fire"—a reference to its golden-yellow color. In the past, many yellowish gems, such as peridot and garnets, were called topaz. The gem was used in ancient Egypt, Greece, and Rome.

The earliest source of topaz was an island in the Red Sea called Zabargad, which was known as Topazios in ancient times. However, it is thought the gems found there were actually peridot. In Sri Lanka, topaz crystals are found among the pebbles of river beds, where the gems have been

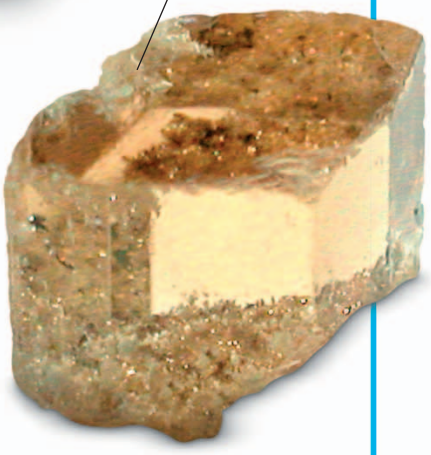
Blue topaz is made **darker** by exposing it to radiation.

Topaz necklace

Small, blue topaz stone *polished to give it a curved surface*

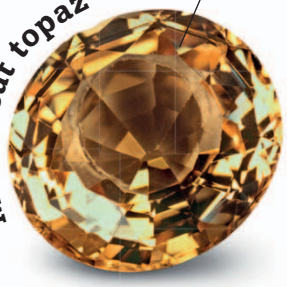
Golden brown variety *is called sherry topaz*

Sherry topaz



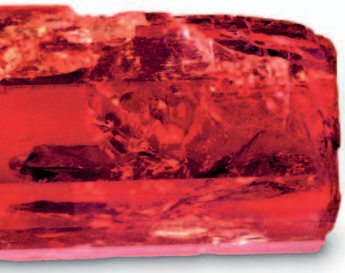
Cut *shows off color and shine*

Mixed-cut topaz



Topaz in gold

Natural blue topaz *can be very pale*



Orange sections *made of topaz*

Topaz inlay in marble

Bluish-gray specimen *formed as magma-rich water cooled*

Topaz on muscovite

Figure wearing blue topaz

Blue topaz *was mined in Sri Lanka*

MEGA CRYSTAL

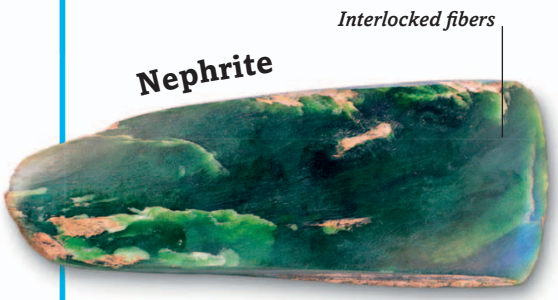
6.9 in (17.53 cm)

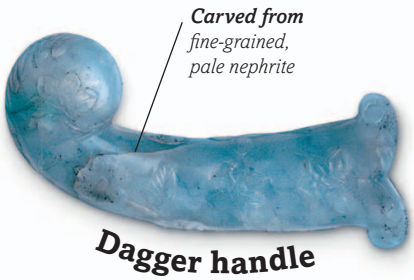
American Golden Topaz

Topaz king
Dug up in the Minas Gerais area of Brazil, the American Golden Topaz is one of the largest cut yellow topaz crystals in the world. It is a 172-faceted gem weighing 10 lb (4.58 kg).

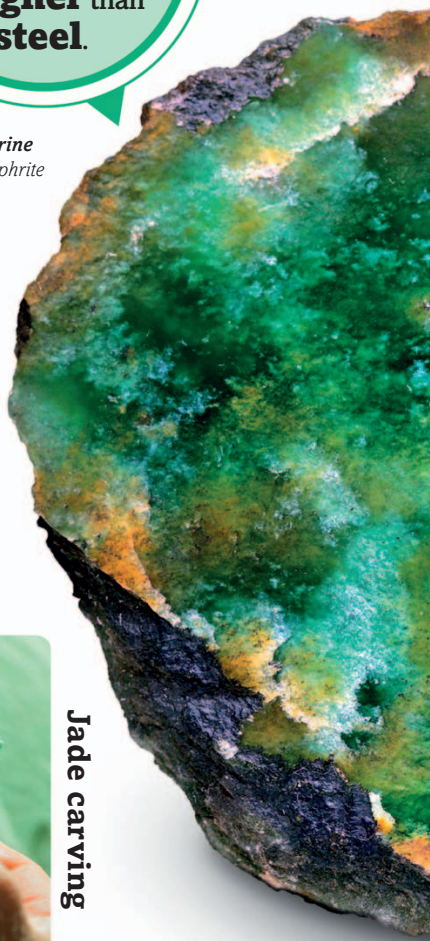
rounded as a result of being knocked together by water currents. In other parts of the world, topaz has formed inside igneous rocks that cooled slowly underground. Topaz occurs in granite, rhyolite, and **pegmatite** cavities. Most topaz specimens are yellow and brown. Colorless or gray stones are also common, while **pink** and blue ones are rarer. Orange-yellow **sherry** stones from Brazil are particularly valuable. As well as its typical use in **necklaces** and **rings**, topaz is also used in **marble inlays** or other decorative objects, such as the **Russian chalice** shown above.

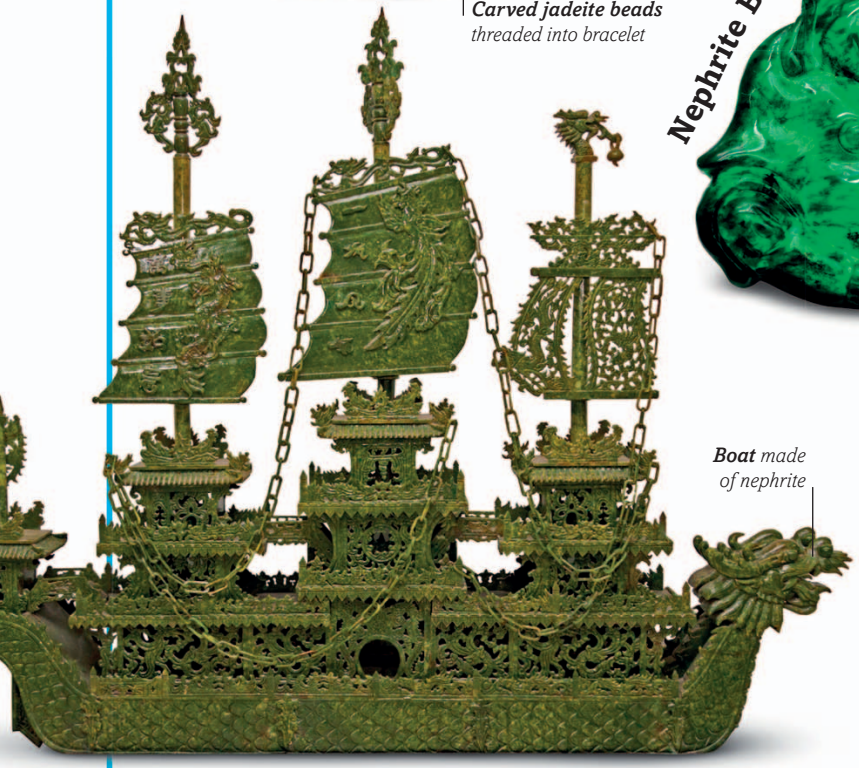
Jade





Tightly interlocked **fibers** mean nephrite can be **tougher** than **steel**.

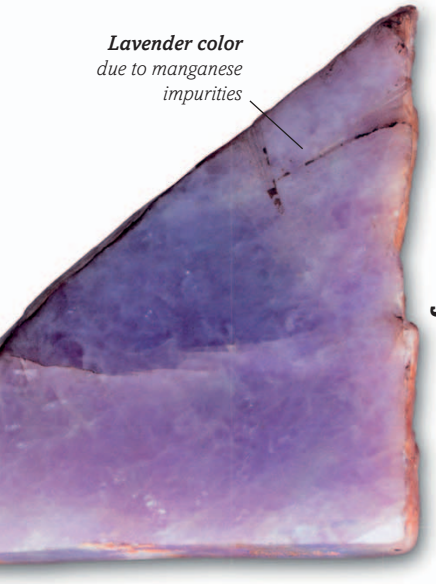




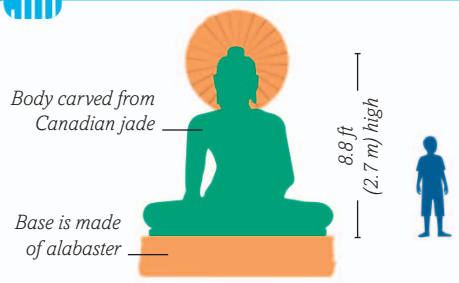
Chinese dragon boat

Jade is a mostly green stone made of tiny crystals. It is very hard, but can be carved and polished into beautiful, smooth ornaments. Cultures all over the world have used it for many centuries to make jewelry.

Jade is not a single mineral, but a group of many. Green serpentine objects are often mistaken for jade. True jades are either **jadeite** or **nephrite**. Jadeite is an inosilicate containing sodium, aluminum, and iron, and occurs in fine crystals that interlock to form a waxy-looking



GIANT JADE BUDDHA



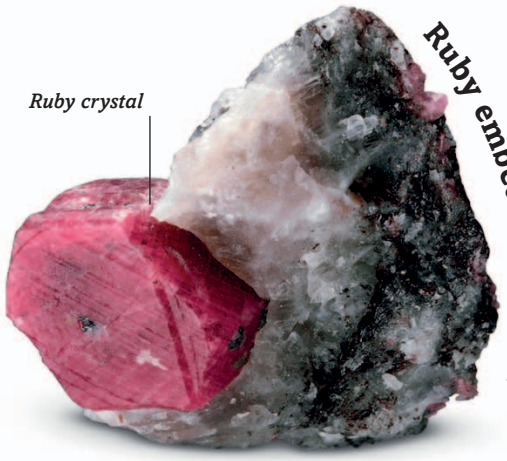
Jade Buddha for Universal Peace
Carved from a single piece of nephrite, this 4-ton statue of the Buddha is based in Australia but is taken around the world for Buddhists to see.

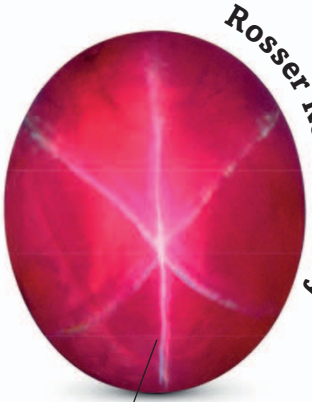
mass. In its pure form, jadeite is creamy white, but impurities give most specimens their color. Green comes from iron, **lilac** from manganese, and **yellow** forms have a range of extra elements. In ancient China, jade was believed to protect the dead from demons and ensure immortality, and extraordinary jade **burial suits** were created for kings and queens. Older Chinese jade objects are mostly made from nephrite, such as in the case of this **dragon boat**, but more recent objects, after the discovery of jadeite in Burma, are jadeite.

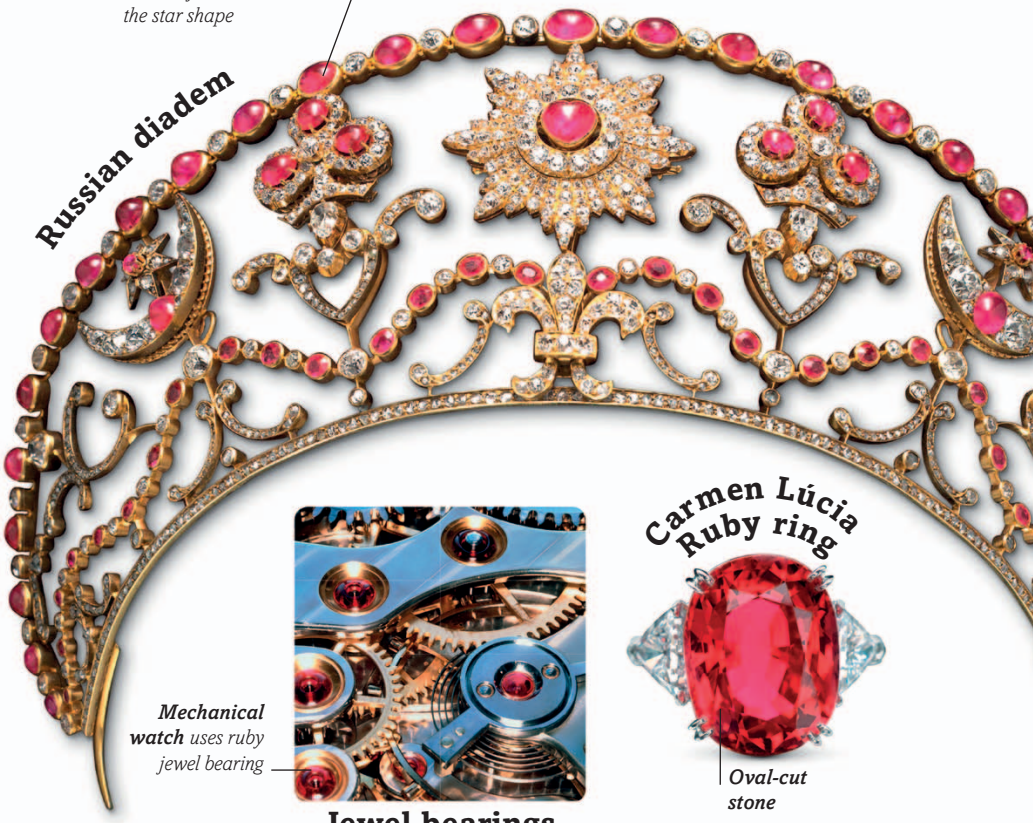
JASPER FALLS In the southern Venezuelan state of Bolívar, in Canaima National Park, water flows over a red and black, tiger-striped river bed. Known as Kako Parú in the language of the indigenous Pemón people, these small cascades ripple and splash over solid jasper. The dappled sunlight shining through the jungle foliage sparkles on the semiprecious stone, creating a stunningly beautiful wonder of nature.

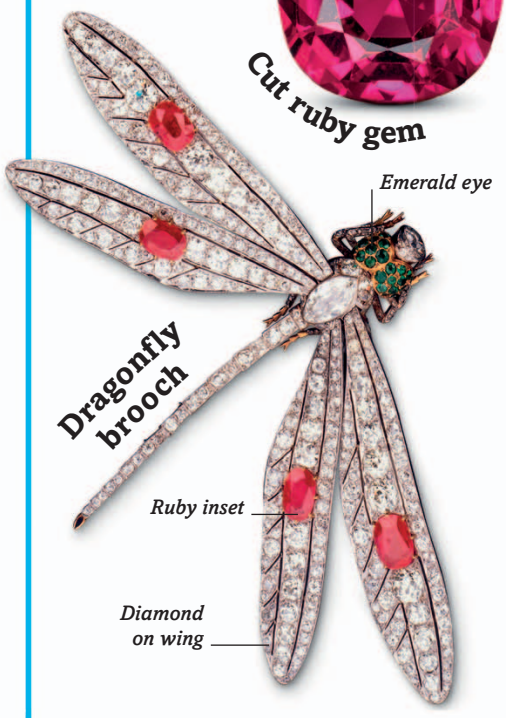
Some of the oldest sandstones in the world are found in the Guiana Shield, a vast block of rock that forms highlands in the northern parts of South America, dotted with strange table mountains called *tepuis*. Contained in these 2-billion-year-old rocks are younger minerals deposited by mineral-rich fluids in cracks and fissures. Jasper is a cryptocrystalline form of quartz—its crystals are intergrown and can only be seen with a microscope. Its red color comes from iron impurities, while darker bands contain more iron. The way the tiny crystals absorb and reflect light gives the surface a waxy sheen and a shimmery depth. When the angle of the light is just right, the jasper stream bed glows golden.

Ruby and sapphire









Rubies are red, sapphires are blue, but both are the made of the same mineral—corundum. Impurities give these aluminum oxide minerals their colors. Rubies tend to be small (stones of more than 10 carats are rare), while sapphires can grow large.

Rubies are gorgeous red stones found in marbles and metamorphosed limestones. The majority of gem-quality rubies, including the **Carmen Lúcia Ruby**, come from Myanmar. Chromium impurities give ruby its red color. Symmetrically-arranged titanium-containing needles of rutile

grow inside rubies, such as in the beautiful **Rosser Reeves Ruby**. While rubies are only ever red, sapphires can be many colors. The most common color is **blue**, while **pink sapphires** are also found. The 733-carat (5.1 oz/146.6 g) **Black Star of Queensland** is rare because of its size. Sapphires and rubies can also be produced artificially in laboratories. Today, the **jewel bearings** used to keep mechanical watches running smoothly are made of synthetic corundum.

Emerald

Emerald and diamond tiara

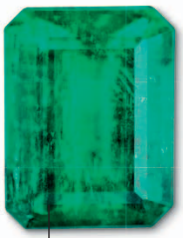
Aquamarine

Impurities give ***the hexagonal*** *(six-sided) prism a blue-green color*

Emerald in rock

Emerald crystal in pegmatite

Cut emerald



Rectangular cut *makes the gemstone sparkle*

Emerald crystal

Smooth, polished emerald *set in gold*

Hexagonal (six-sided) crystal

Turban ornament

Emerald from Carnaiba mine, Brazil

Crystal *has the same structure and color as natural emerald*

Synthetic emerald

Emerald is one of the most valued gemstones, famed for its deep green color. It is often cut into a rectangle or square shape with angled edges. Emeralds form within thin veins of white calcite or quartz, in dark shale, and limestone.

Emerald is a variety of a mineral called beryl. Beryl is a silicate mineral that contains aluminum and beryllium. The word beryl means "pale" and pure specimens are see-through. A blue-green version is called **aquamarine**. Emerald, which gets its green coloring from tiny amounts of

Emeralds were a symbol of **fertility** and **life** in ancient Egypt.

AWESOME EMERALD

Duke of Devonshire Emerald

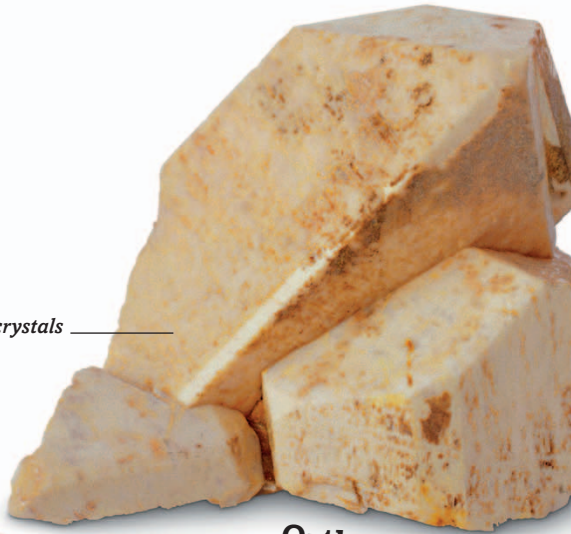
Glittering gift
Given as a gift by the emperor of Brazil to the English Duke of Devonshire in 1831, this emerald is one of the largest ever found. The stone is 2 in (5 cm) long and weighs 8 oz (277 g).

chromium or vanadium impurities in the crystals, is the most valued form of beryl. Emeralds have been highly prized since they were first mined in Egypt in 1300 BCE. Egypt was the main site for mining emeralds for a thousand years. Later, the finest specimens, including the **Chalk Emerald** and the emeralds set in the **Spanish Inquisition necklace**, came from Colombian mines in the 18th and 19th centuries. **Synthetic** emeralds are formed from hot water filled with dissolved minerals that are allowed to crystallize slowly, but they are not considered to be minerals.

Feldspars

Ancient pottery jug

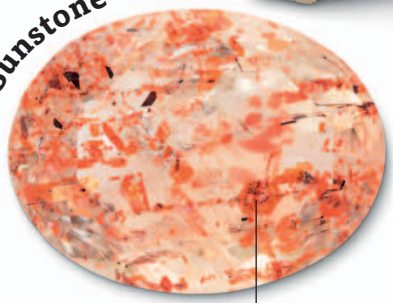
Animal mask *decoration on jug from ancient Nazca culture of Peru (100 BCE–1 CE)*



Three intergrown crystals

Orthoclase

Sunstone



Red color *comes from hematite inclusions*

About **20 million tons** of feldspar were produced in 2010.

Moonstone

Brilliant-cut stone *has opal-like sheen*

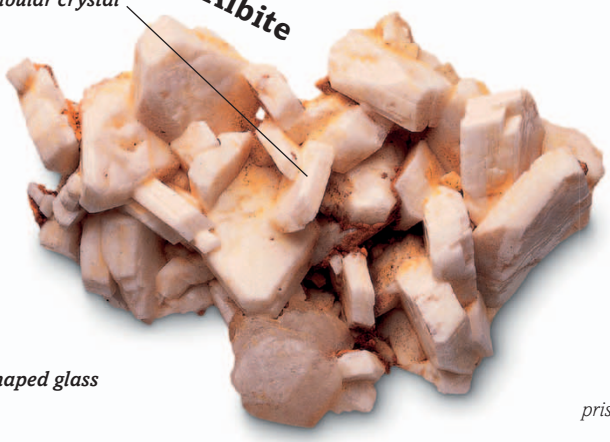
Molten glass

Shaped glass

Glassmaking

Twinned, tabular crystal

Albite



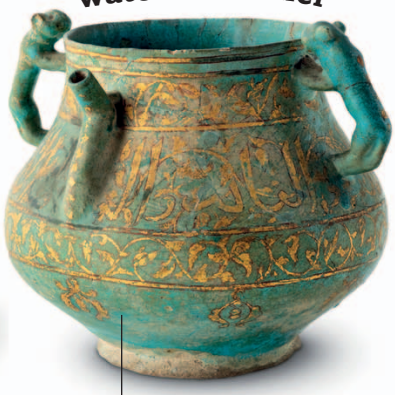
Microcline in rock

Blocky, *prismatic crystal*

Feldspars are the most abundant minerals in Earth's crust. These aluminosilicates (silicates with aluminum) make up the major part of igneous rocks. Beyond Earth, feldspars are also the most abundant minerals on the surface of the Moon.

Feldspars are not flashy minerals. They are almost never found in bright colors, and are generally seen in dull browns and tans. But this group of minerals plays a crucial role in forming rocks. They fall into two groups—the alkali feldspars and the plagioclase feldspars. Minerals in both groups

Persian ceramic water container

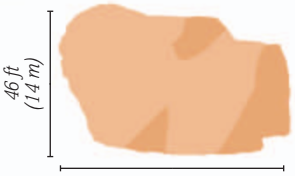


Water container *made of ceramic*

Cleaning products

Cleaning powder *contains crushed feldspar*

MONSTER MICROCLINE



Largest microcline crystal

Olympic-size swimming pool

Phenomenal crystal

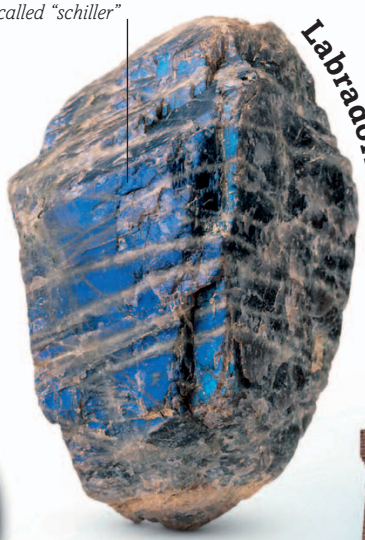
The largest single crystal of microcline ever found was about as long as an Olympic-size swimming pool. Discovered in the Devils Hole Beryl Mine in Colorado, it is one of the largest crystals in the world.

Amazonite

Blue-green microcline*, or amazonite*

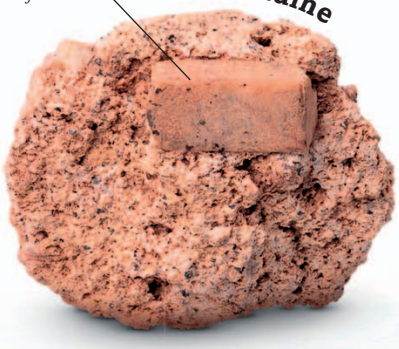
Color play *on shimmery surface is called "schiller"*

Labradorite



Well-formed crystal *of sanidine*

Sanidine



Andesine

Rare, red, *gem-quality andesine*

Large, well-developed *plagioclase feldspars form in granite rocks*

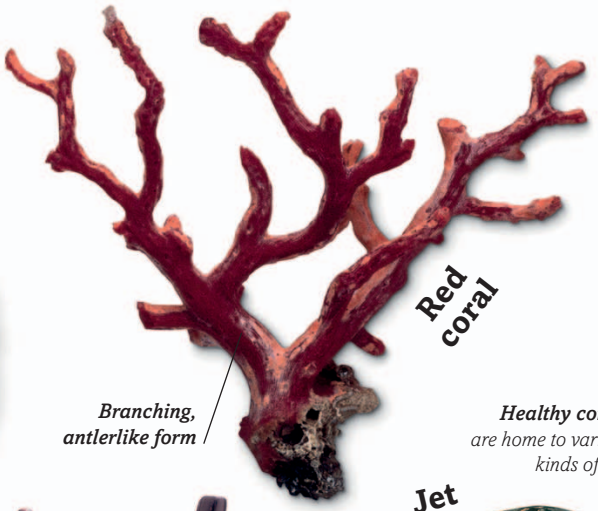
Pink granite coast, Brittany, France

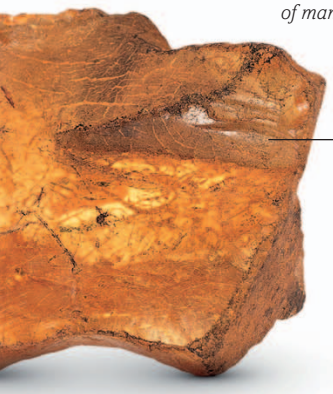
have the same crystal structure, but their chemical composition varies. Alkali feldspars include potassium-rich **orthoclase**, **microcline**, and sodium-rich **sanidine**. **Andesine** contains a high percentage of calcium and sodium, while **labradorite** is considered a semiprecious plagioclase. Intergrown, tiny feldspar crystals make **moonstone**, which comes in blues and whites. Feldspars are used in **glassmaking** and **ceramics**, where they help to lower the melting temperature of a mixture. They are also used in **cleaning products**, and ground to make concrete.

Mineraloids

Organic minerals, or mineraloids, are often hard substances made by living things. Unlike minerals that have an ordered internal crystal arrangement, mineraloids may or may not have a regular crystal structure.

Pearls are one of the most desirable organic minerals. Made inside the shells of mollusks, they grow in layers around a small piece of grit or other foreign particle. Some of the most beautiful **mother-of-pearl** comes from the abalone shell, with its silvery layers and





COAL CONSUMPTION

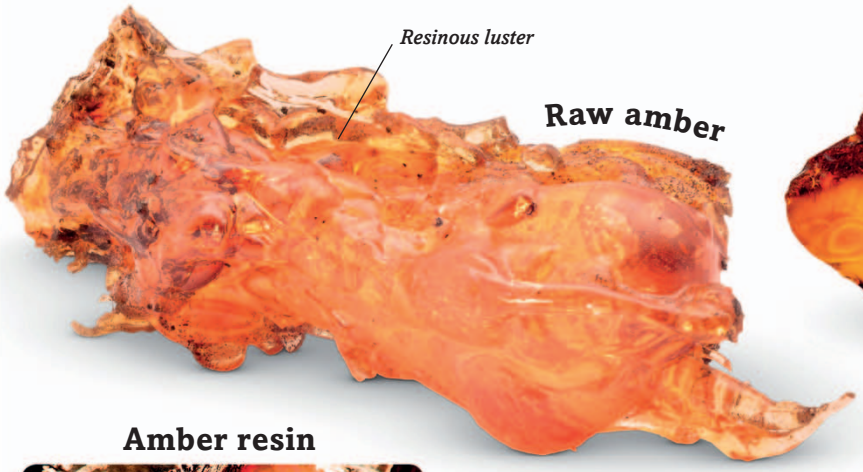
Coal
(21 million tons, used globally in one day)

Pyramids of Giza
(Weight of 3 pyramids: 21 million tons)

Burning bonanza
Coal is burned to provide power for industry and generate electricity. The amount of coal burned daily around the world weighs as much as the three pyramids of Giza.

iridescent, multicolored interior. As well as jewelry, mother-of-pearl from giant oysters is used for human bone implants. **Coral** is another hard structure made by living things. Tiny animals, called polyps, secrete a hard calcium carbonate skeleton to live in. Tough and compact, **red** and **black** coral can be used to create complex carvings. **Jet** and **anthracite** are forms of coal that are burned as fuel, but which can also be carved and polished. **Vegetable ivory**, from certain palm trees, is used in carvings and to make jewelry.

Amber



Resinous luster

Raw amber

Mixed amber

***Impurity in amber**, suggesting it fell to the ground*

Amber resin

***Sap running down** the trunk of a tree*

Amber nodule

***Nodule** is transparent to translucent and golden-yellow in color*

Sun-spangled bead

***Polished bead** contains cracks caused by trapped water droplets*

Oil of amber is produced by heating amber above **400°F** (200°C).

***Wood polished** using oil of amber*

Violin with amber polish

Amber Room, Russia

***This room in the Catherine Palace** in St. Petersburg, Russia, is a recreation of the original amber-laden room, which was looted during World War II*

Amber pebble

***Amber** shows a distinct flow pattern*

Sticky, golden-yellow sap from conifer trees can sometimes harden and crystallize to form a hard organic gem called amber. According to the ancient Greeks, this substance contained trapped sunlight.

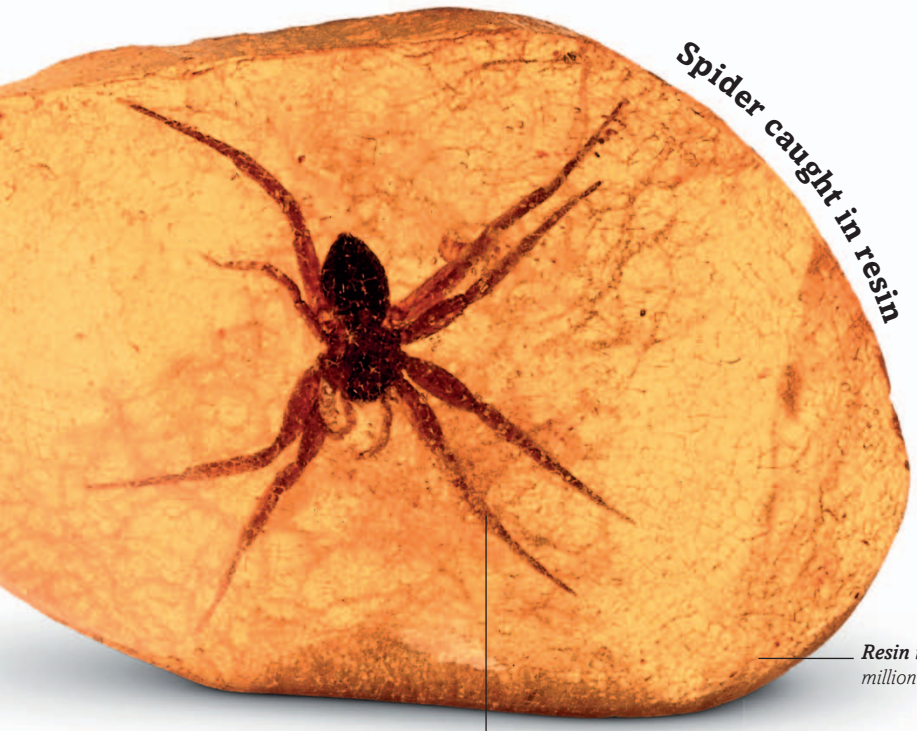
Amber is actually a fossil. Like preserved pollen or a pine cone, it is part of an ancient tree that lived millions of years ago. Amber forms from hardened **resin** that oozes from inside a tree. **Raw amber** can be found on the sea floor in large, rough-shaped **amber nodules** and **pebbles**. Water

ENORMOUS AMBER

Largest amber piece *(150 lb/68 kg)*

Children *(Weight of 2 children: 154 lb/70 kg)*

Asian all-star
The largest piece of amber ever found came from Borneo. It weighed 150 lb (68 kg)—about the same weight as an average adult human.



Spider caught in resin

***Resin** is 40–60 million years old*

***Spider** encased in resin globule*

***Resin from kauri tree** shows flow pattern*

***Necklace** made from cut and polished amber beads*

Amber bead necklace

Dominican amber

***Rare**, deep-blue color*

Carved elephant

***Elephant made** of amber, which is relatively easy to carve*

Kauri gum

***Bracelet** made of carved amber*

Unpolished gem

Clear gem

Amber bracelet

caught in the resin creates a "**sun-spangled**" effect. Amber may even contain trapped fossils. Most amber comes from Russia and Scandinavia, but there are deposits in Asia, Africa, and the Caribbean. This gem is made into **polished beads** for jewelry or carved into decorative ornaments.

Amber mainly comes in warm sunset and honey colors, but it can also be green, red, and even blue, in the case of **Dominican amber**. King Frederick I of Prussia liked amber so much he created an **Amber Room** out of it—which was called the "Eighth Wonder of the World."

Opal

PRECIOUS OPAL

Australian opal
The largest and most valuable opal ever found is called the Olympic Australis. It is 11 in (280 mm) long, 5 in (120 mm) thick, and 4 in (115 mm) wide—as big as a loaf of bread.

Opal is a precious stone made from hardened silica gel. It is a mineraloid and lacks a regular internal crystal structure. Even though it is not a true mineral, its swirling colors and pearly sheen have been prized since ancient times.

Common opal, often called **potch opal**, comes in a variety of colors, including off-whites, dull reds and yellows, and even **rose**. Precious opal is semi-transparent and has a glittering shimmer caused by tiny silica balls that break the light into colors, and make it appear to play over the gem's

surface. Microscopic cracks, called crazing, also reflect light. The major source for opal today is Ethiopia. The Lightning Ridge opal field in New South Wales, Australia, produces the rare **black opal**. **Fire opal** is the most prized form. **Boulder opal** forms inside rocks, where circulating, mineral-rich fluids deposit silica in cavities and cracks. Precious opal also replaces bone, wood, and other hard parts, to form opalized fossils. The massive **Roebling opal**—an extraordinary specimen found in Nevada—was deposited in a hole where a buried tree rotted away.

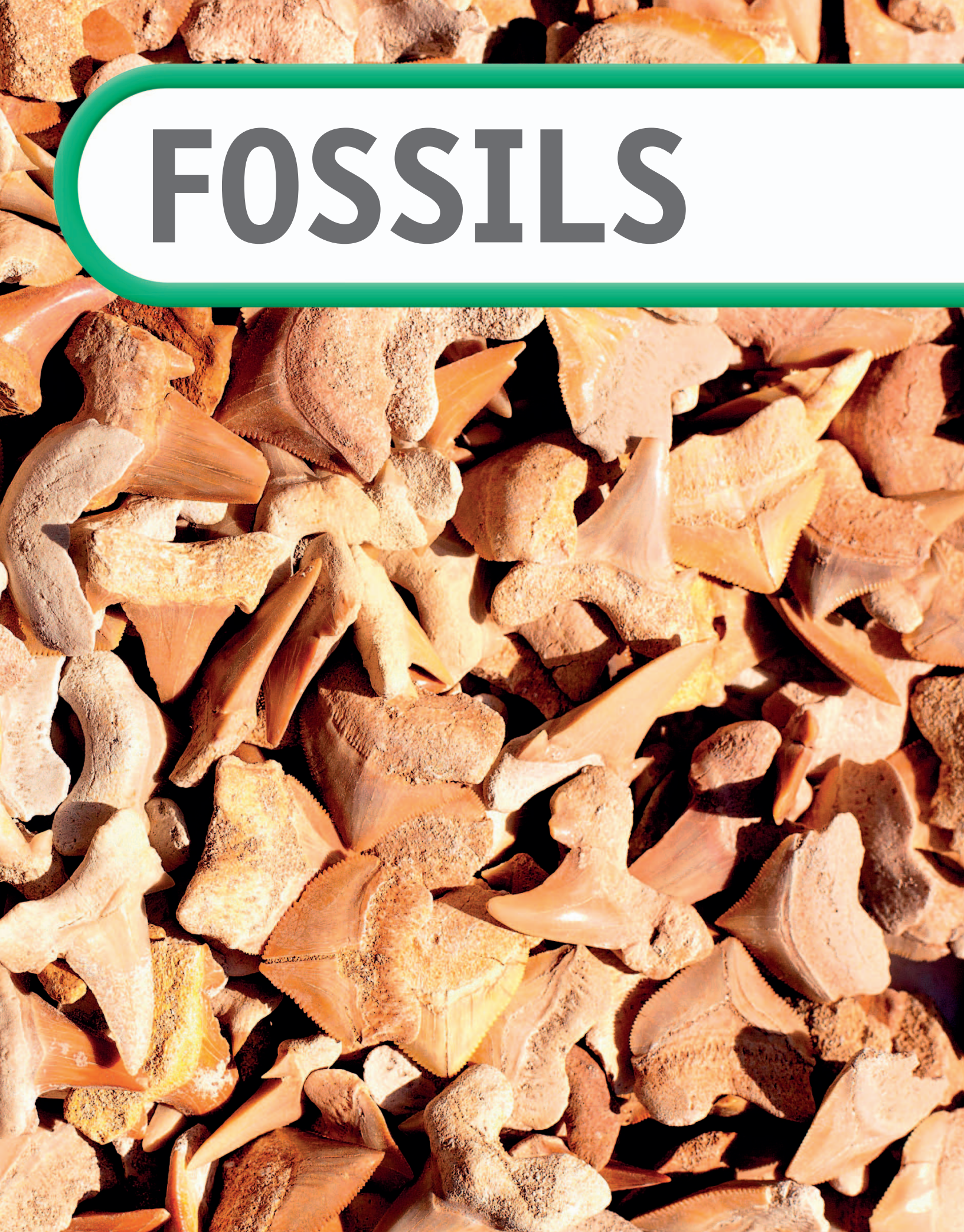
Decorative stones

Decorative stones are colored minerals that look beautiful when polished. Although only a few are rare, they are at times more highly valued than precious metals. Turquoise and lapis lazuli were thought to be sacred by ancient cultures.

Agate is a microcrystalline form of quartz, also known as chalcedony. Agates form when circulating, mineral-rich fluids deposit silica in cavities in the rock. Quartz is deposited around the inside surface and builds up in layers that follow the shape of the cavity. When sliced, it

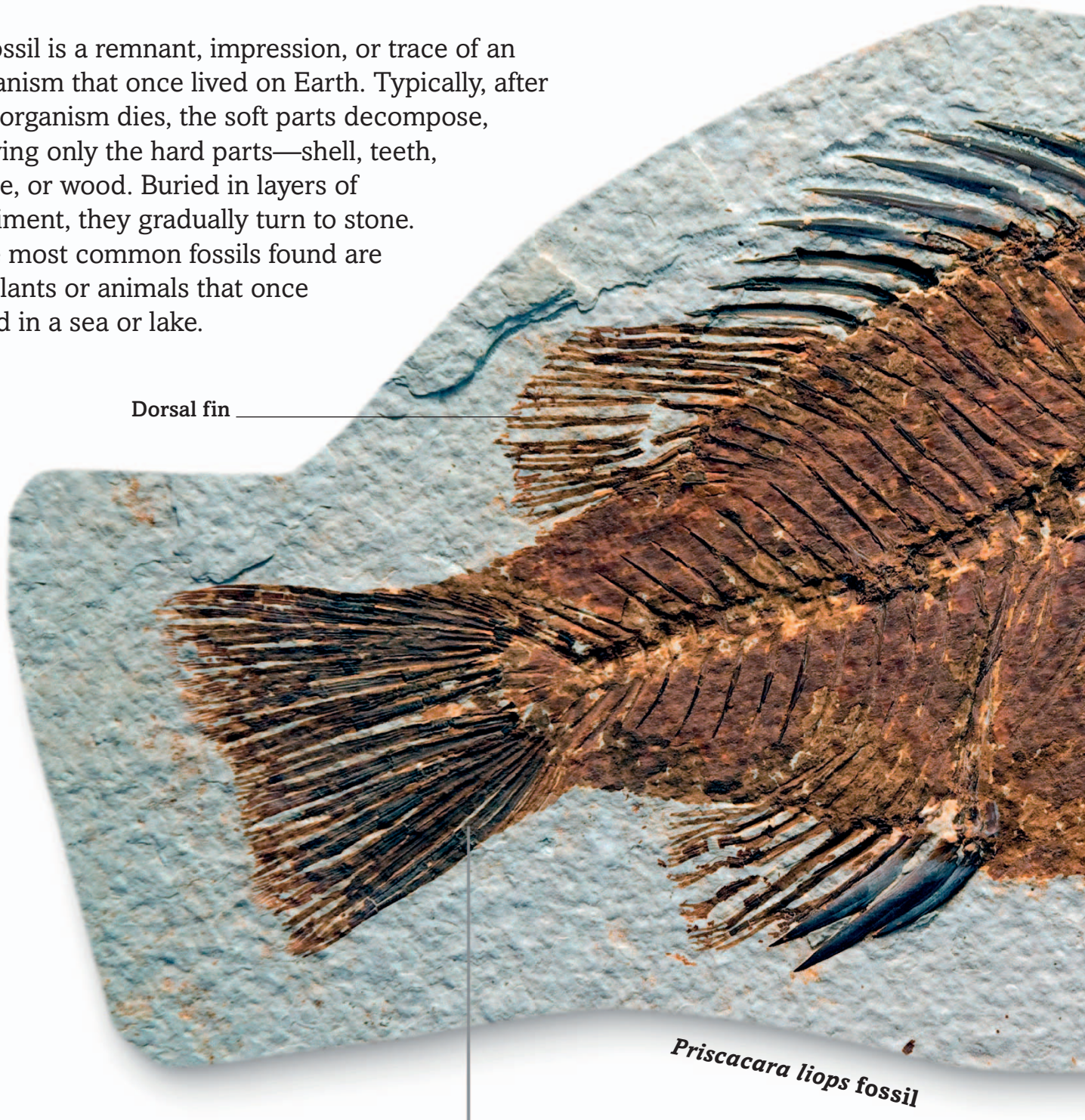
gives a banded appearance. Impurities give agate lovely colors, such as **fire agate**, which gets its reddish-brown color from hematite. Manganese oxides and chlorite make the greenish markings in **moss agate**. **Lapis lazuli** is a precious stone whose main component—the mineral lazurite—gives it an intense blue color. Just like **turquoise**, lapis lazuli was highly prized in ancient times. Precious, apple-colored **serpentine** can be mistaken for jade, but it is much softer. **Moonstone** and **labradorite** are both feldspar gemstones used for jewelry and ornaments.

FOSSILS



Fossils

A fossil is a remnant, impression, or trace of an organism that once lived on Earth. Typically, after the organism dies, the soft parts decompose, leaving only the hard parts—shell, teeth, bone, or wood. Buried in layers of sediment, they gradually turn to stone. The most common fossils found are of plants or animals that once lived in a sea or lake.



Preserved in ash › This complete *Priscacara liops* skeleton was recovered from the Paleogene lake bed that covered much of western Wyoming. Fine volcanic ash fell into the lake and smothered the fish, then buried and preserved its skeleton.

Recent relative › *Priscacara liops* is an extinct species of fish from the middle of the Paleogene period, 66–23 million years ago (MYA). Similar to a modern-day perch, it was around 6 in (15 cm) in length and had strong protective spines on its back and tail.

Types of fossils

Preserved soft tissue
- Soft tissue can be preserved in substances such as amber (insect) or ice (woolly mammoth).

From wood to stone
- Water deposits minerals into the pores of a shell or the cells of a piece of wood, fossilizing the remains.

Leaving an impression
- Sediment buries an object, such as a leaf. The leaf decays as the sediment hardens, but leaves its imprint.

Natural cast
- Some organisms, such as shells, can be fossilized in an entirely unaltered state.

Trace fossil
- Some living things leave traces behind them, such as footprints preserved in rock.

GEOLOGICAL TIME

Earth's geological timescale is divided into divisions called "periods." Multiple periods form a division called an "era."

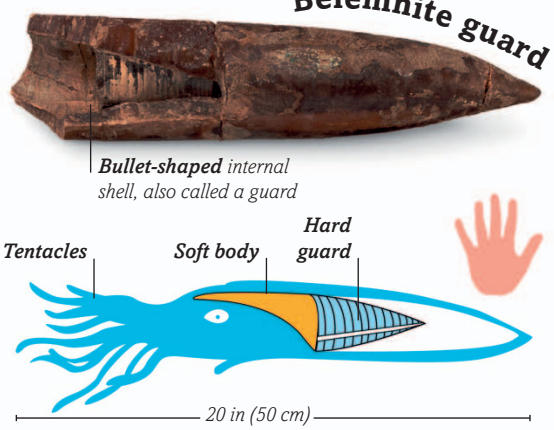
Precambrian (4.6 BYA–541 MYA)	EARLY EARTH
Cambrian (541–485 MYA)	PALEOZOIC ERA
Ordovician (485–444 MYA)	
Silurian (444–419 MYA)	
Devonian (419–359 MYA)	
Carboniferous (359–298 MYA)	
Permian (298–252 MYA)	
Triassic (252–201 MYA)	MESOZOIC ERA
Jurassic (201–145 MYA)	
Cretaceous (145–66 MYA)	
Paleogene (66–23 MYA)	CENOZOIC ERA
Neogene (23–2.6 MYA)	
Quaternary (2.6 MYA–present)	

Life in the ancient seas

The world's oldest fossils are tiny, floating, bacteria-like cells that lived in the oceans about 3.8 billion years ago. Over millions of years, more complex sea creatures gradually evolved. These animals were invertebrates (animals without backbones).

The most common fossils found today are the remains of the animals that lived in the ancient seas that once covered most of Earth. Creatures lurking on the sea bed were the most likely to fossilize because they would become buried in mud before they rotted away. Bacteria, worms,

FOSSILIZED INSIDES



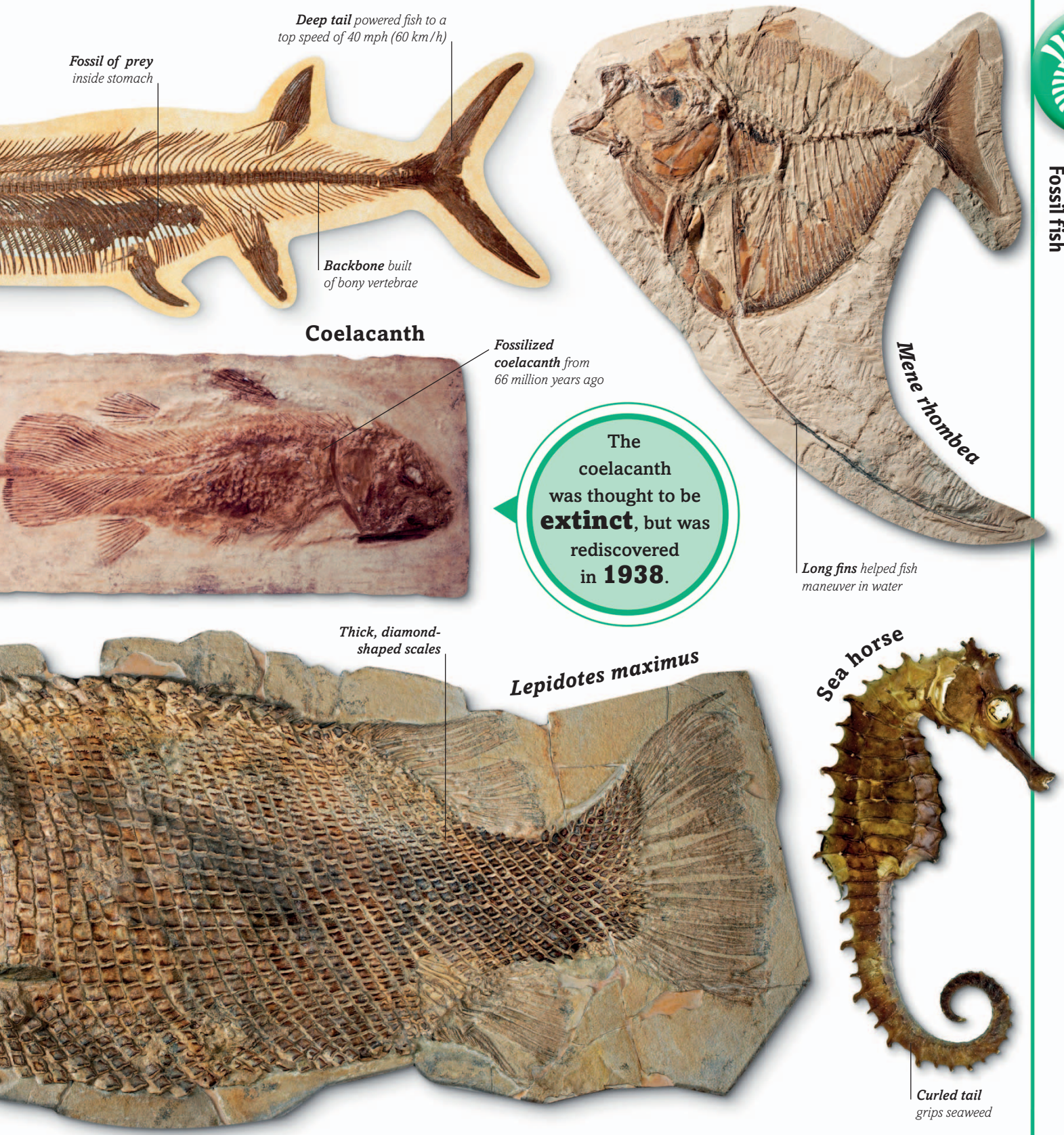
Insides out
Belemnites were squidlike creatures that died out at the same time as the dinosaurs. They had a hard, cone-shaped internal shell called a guard, which is a commonly found fossil.

jellyfish, and other animals with soft bodies do not fossilize well. What looks like fossil **worms** are, in fact, the hard tubes in which the animals lived. Invertebrates with protective shells and hard inner parts preserve better, such as the **trilobites** that lived 520–250 million years ago, roaming across the sea bed protected by their outer shell. **Graptolites**, like **coral**, were homes for colonies of small soft-bodied animals. **Crabs**, **starfish**, and **sea urchins** look similar to present-day species found in rock pools. **Ammonites** are the shells of ancestors of the octopus and squid.

Fossil fish

The first vertebrates—animals with backbones—were fish. A backbone, or vertebral column, supports a bony skeleton inside the body. Amphibians, reptiles, mammals, and birds are all vertebrates descended from fish.

The first fish were jawless. They sifted through the ooze and soft sediment on the sea floor, sucking up tasty morsels. Fish developed the first bones, cartilage (the tough, flexible tissue in your joints), and enameled teeth. Early jawed fish such as ***Bothriolepis*** had head and fins



covered in heavy bony armor, to serve as protection from the hungry mouths of predators roving the seas. Instead of bone, the skeletons of sharks and rays are made of cartilage. The sharklike ***Helicoprion*** had 180 teeth set in a strange spiral, like a circular saw. Rays such as ***Heliobatis*** date from around 56 million years ago and are nearly flat. Their whiplike tails had up to three wickedly barbed spikes loaded with poison. But perhaps most impressive of all was ***Megalodon***, at 60 ft (18 m) long the largest shark that has ever lived.

Plant fossils

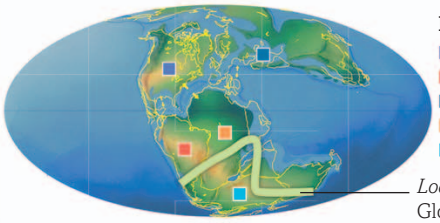
The evolution of the first land plants was a major event in Earth's history. It cleared the way for the development of animal life on land, and was the starting point for the wide variety of plants we see today.

All plants convert sunlight into sugar (a process called photosynthesis) and use this energy to build their bodies. The earliest plants to learn this trick were algae (microscopic plankton and seaweed) living in the oceans. Hardy **liverworts** and **lichens** first appeared on land around 450 million years

FOSSIL EVIDENCE

Evidence for a supercontinent

Scientists have found *Glossopteris* fossils from around 200 million years ago across five continents. This shows that they must have been part of the supercontinent Gondwana at the time.

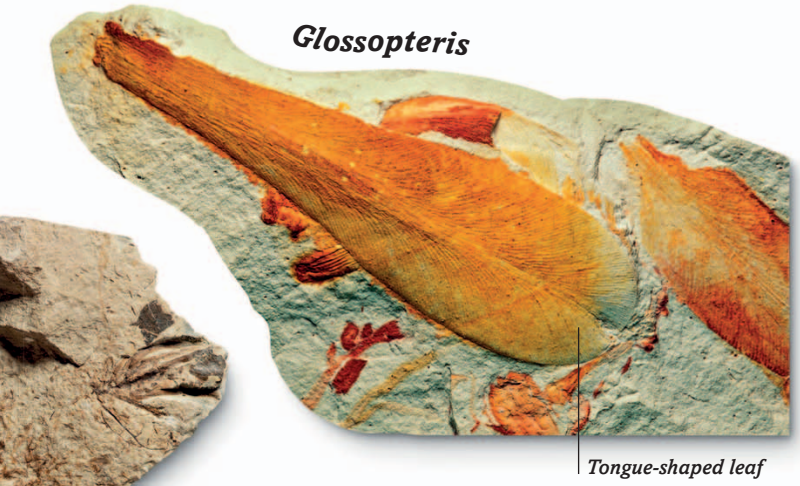


Key

- *North America*
- *South America*
- *Eurasia*
- *Africa*
- *Antarctica*

Locations of Glossopteris *fossils*

Glossopteris



Tongue-shaped leaf

Zamites

Impression fossil *created when leaves were pressed into soft sediment*

Woody tissues *replaced by hard minerals*

Oak tree

Petrified trunk

Pine cone

Seed-producing *pine cone replaced by silica minerals*

ago. With no leaves, early plants like ***Cooksonia*** transported fluids around their bodies using internal tubes. Clusters of light-sensitive cells developed into leaves around 360 million years ago. Prehistoric swamps were full of mosslike plants, such as ***Lepidodendron***, and tree ferns like ***Archaeopteris***. They grew into trees, thanks to woody tissues that supported their weight, and spread by producing spores. Palmlike cycads, such as ***Zamites***, developed the first seeds, which were able to survive drought. Flowering plants, such as the **oak**, evolved around 130 million years ago.

TREES OF STONE

The morning sunlight catches loglike pieces of solid rock lying on the ground as though they were trunks sawn for firewood. These are the petrified remains of a prehistoric forest in Arizona's Painted Desert. Petrification is a process by which organic material turns to stone over time. Minerals, which replaced the trees' organic matter and turned it into stone, glow in warm reds and browns.

About 225 million years ago, what is now the state of Arizona stood on the southwestern edge of a supercontinent called Pangaea. Situated near the equator, it had a humid climate that produced a huge variety of ferns, cycads, ginkgoes, and tall conifer trees. Streams flowing from the mountains across the plains passed through these large forests, depositing silt and burying fallen trees and vegetation. Every so often, volcanoes would deposit ash over the region. Groundwater dissolved silica from the ash and washed through the buried trunks as it trickled through the wet sediment. Slowly, quartz crystals grew inside the trees, replacing the organic structures of the wood, until it became totally petrified.

The first land animals

About 395 million years ago, tetrapods (animals with four limbs) evolved from fish. These would be the first vertebrates to move from water to land. The study of fossils has helped scientists understand how animals adapted to live in this new environment.

To survive on land, animals need lungs for breathing air and limbs for walking. This means a skeleton to support their body weight and limbs strong enough to move around. About 385 million years ago, lobe-finned "fish with legs," such as ***Eusthenopteron***, had evolved many of these

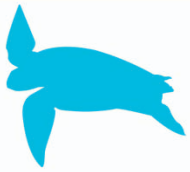
Strong fins *enabled this fish to haul itself onto land, though it lived in water*

Typical length 3.3 ft (1 m)

***Proganochelys* skull**

Oldest known extinct turtle

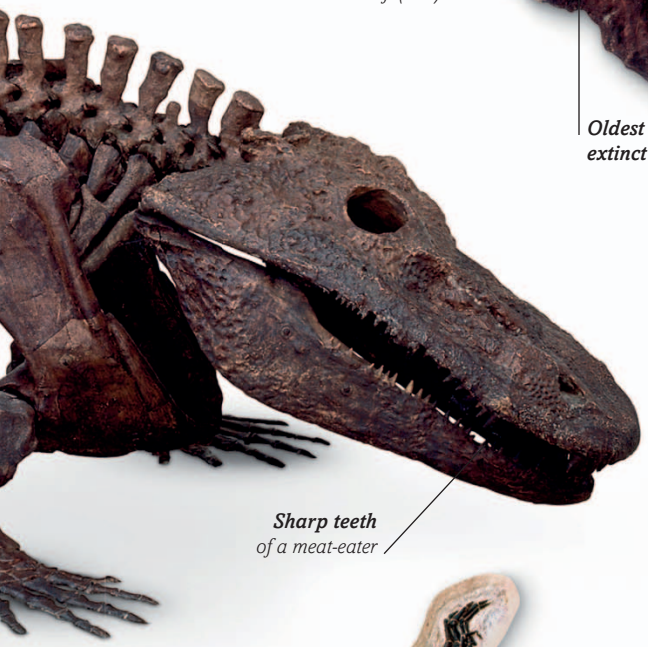
GIANT TURTLE



Leatherback sea turtle
Largest turtle alive
Shell length: 6.6 ft (2 m)

Stupendemys
Largest turtle ever
Shell length: 10.8 ft (3.3 m)

Big flipper
Fossils of *Stupendemys*, a prehistoric species of freshwater turtle, have been found in South America. It was more than one-and-a-half times bigger than any turtle alive today.



Sharp teeth *of a meat-eater*

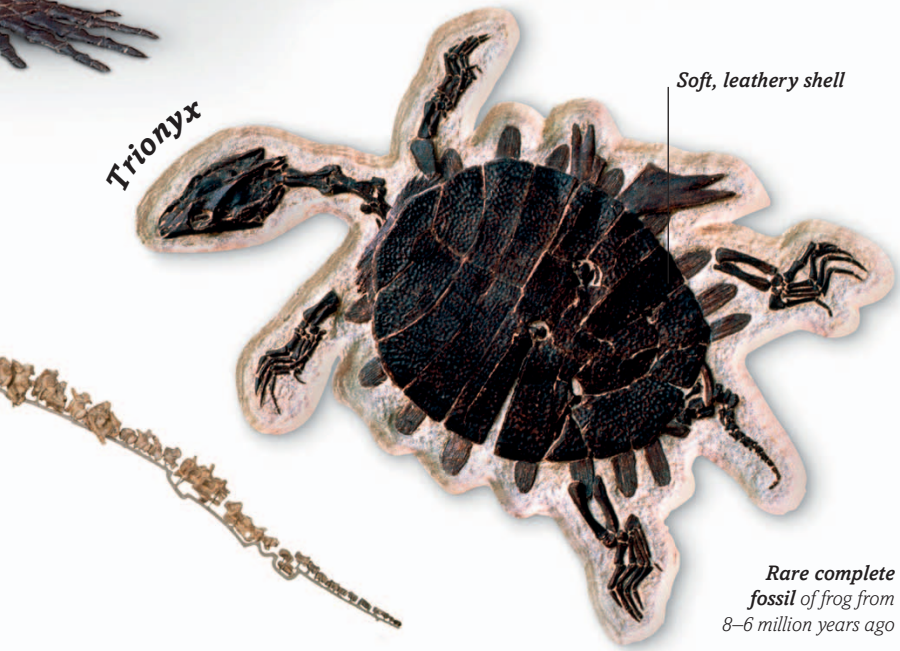
***Deinosuchus* skull**

This extinct crocodile *grew up to 40 ft (12 m) long—that's longer than a bus*

Typical length 40 ft (12 m)

The **jaws** of *Deinosuchus* had a **bite force** comparable to that of a *T. rex*.

***Triony*x**

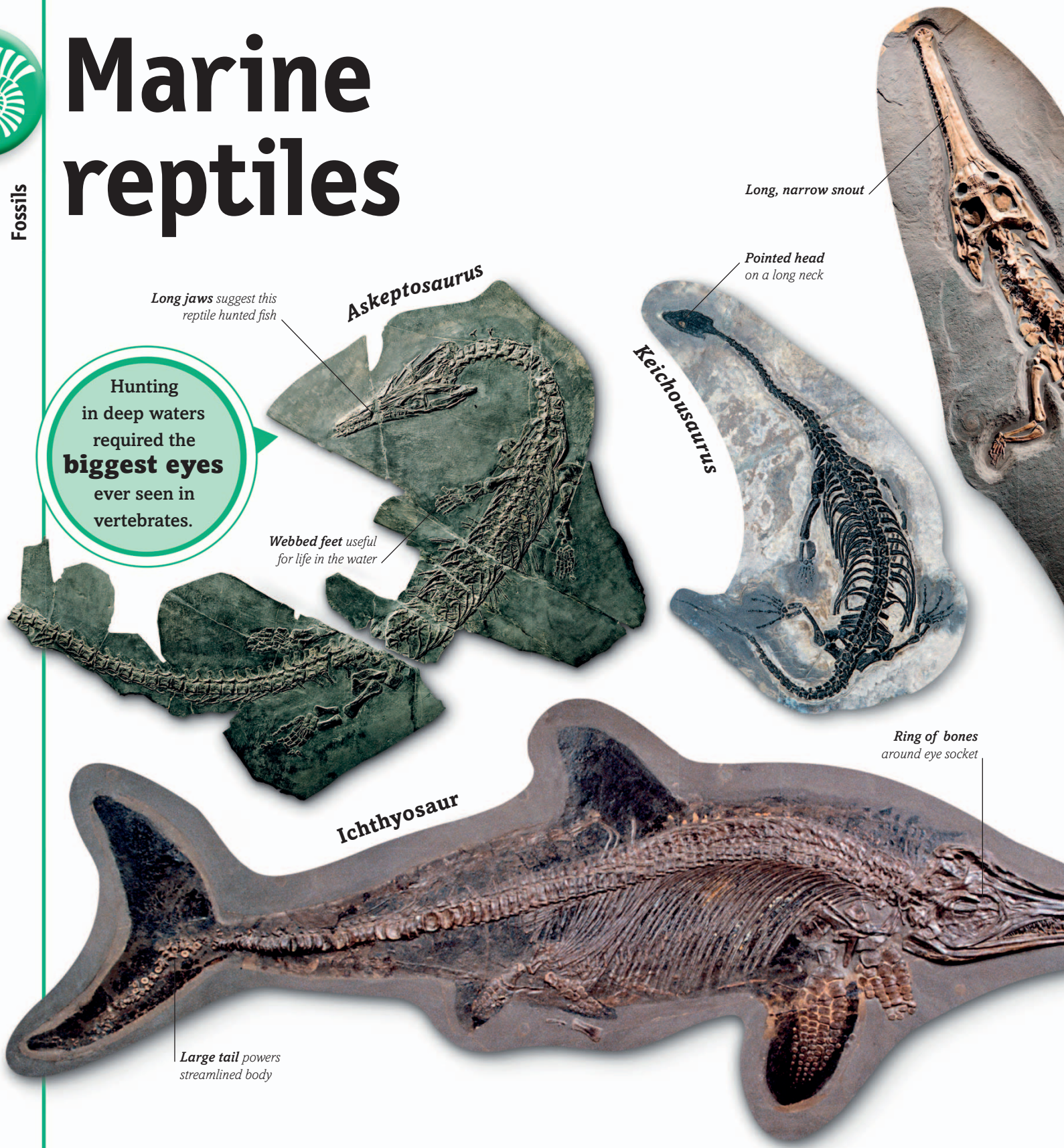


Soft, leathery shell

Rare complete fossil *of frog from 8–6 million years ago*

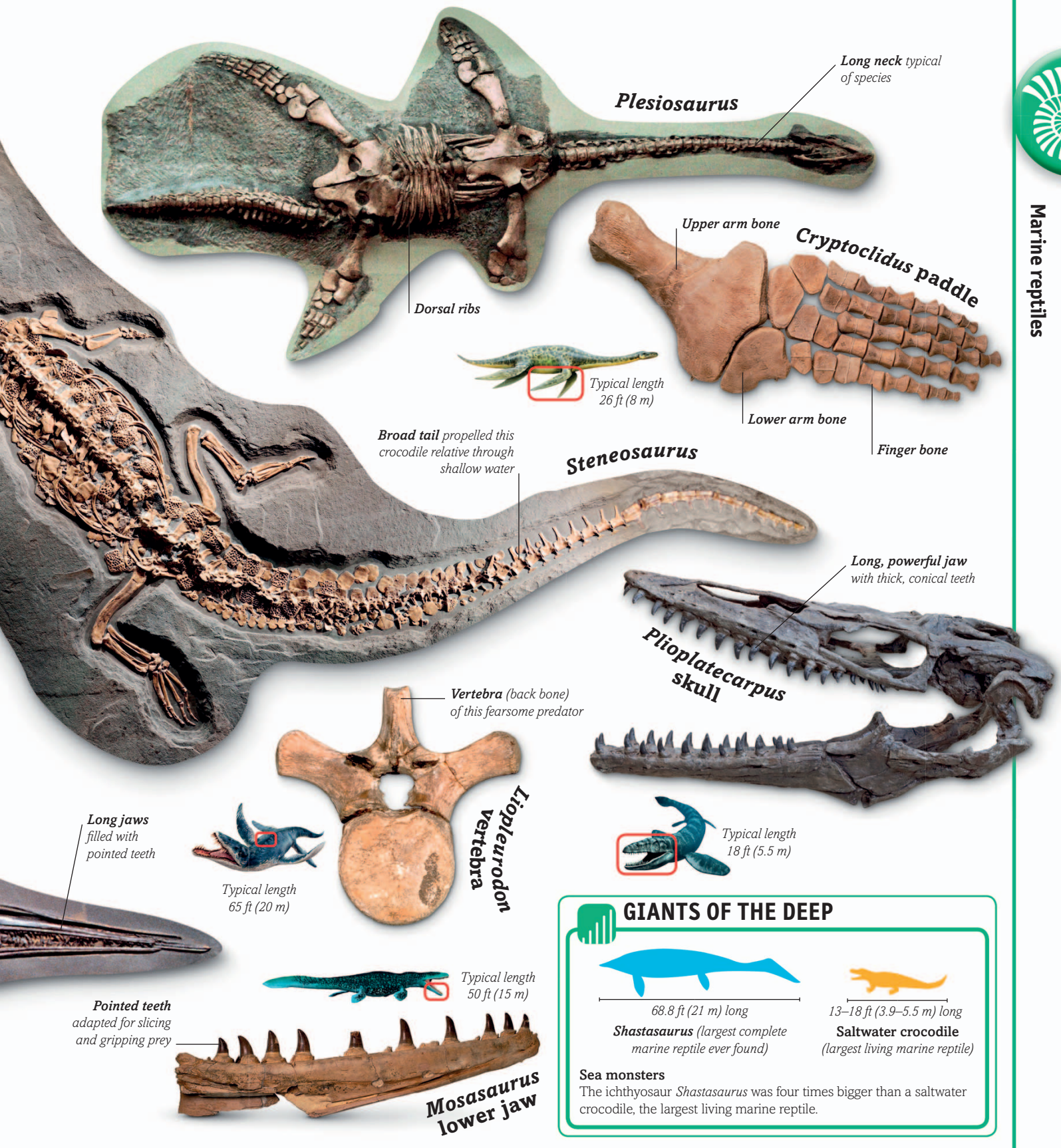
features. Halfway between a fish and an amphibian, four-legged ***Ichthyostega*** was capable of short spells above water, but lived a mostly aquatic life in shallow swamps. ***Microsaur*** was an early amphibian, with small legs that enabled it to live on land. ***Eryops*** was happy on dry land, but relied on water for laying and hatching its eggs. Modern amphibians, such as **frogs**, still live semiaquatic lifestyles. Early tetrapods like these evolved to become the ancestors of dinosaurs (***Hyperodapedon***), crocodiles (***Deinosuchus***), and even mammals (***Cynognathus***).

Marine reptiles



The shallow seas of the Jurassic period were full of terrifying monsters. Giant reptiles stalked the waters hunting fish, chasing shellfish, and eating each other. Preserved in fine-grained marine muds, they make beautiful fossils.

Ocean lizards, such as ***Askeptosaurus***, were some of the first reptiles to take to the oceans in the Triassic period. Growing up to 6.5 ft (2 m) long and with a strong paddlelike tail, they were swift predators. The nothosaurs were another group of marine reptiles. They included the



GIANTS OF THE DEEP

68.8 ft (21 m) long

Shastasaurus *(largest complete marine reptile ever found)*

13–18 ft (3.9–5.5 m) long

Saltwater crocodile
(largest living marine reptile)

Sea monsters
The ichthyosaur *Shastasaurus* was four times bigger than a saltwater crocodile, the largest living marine reptile.

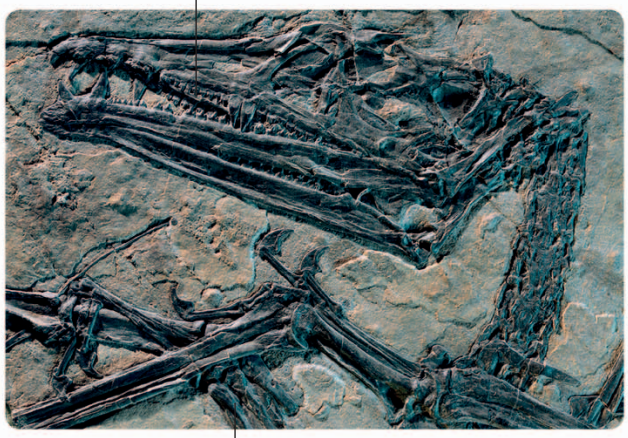
fish-eating ***Keichousaurus*** and lived like today's seals, hunting in the water, but coming out to bask in the sunshine on rocks. Meanwhile, "fish-lizard" **ichthyosaur**, shaped like modern sharks and dolphins, torpedoed through the water. Long-necked plesiosaurs, such as ***Cryptoclidus***, had the classic "Loch Ness Monster" look. There were also short-necked ones, such as ***Liopleurodon***, which was bigger than a sperm whale. These amazing animals went extinct at the same time as the dinosaurs, 66 million years ago.

Flying reptiles

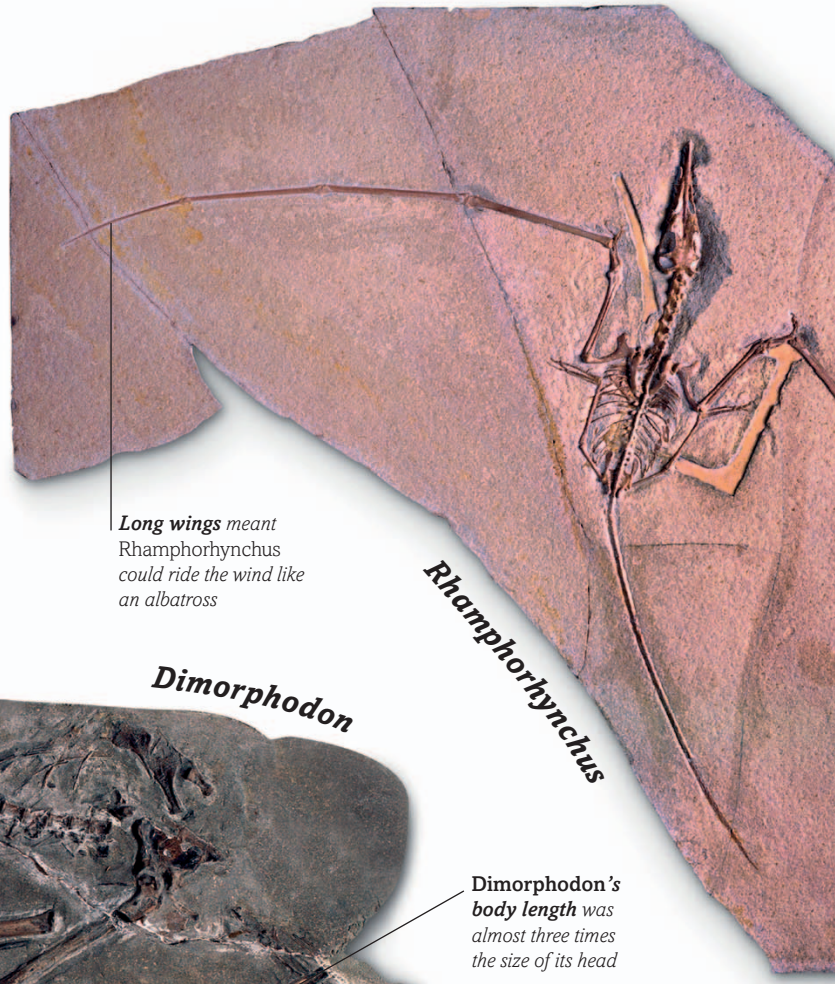
Toothless beak

Teeth *with three cusps helped slice up prey*

Eudimorphodon



Sharp claws *helped grasp*



Long wings *meant* Rhamphorhynchus *could ride the wind like an albatross*

Rhamphorhynchus

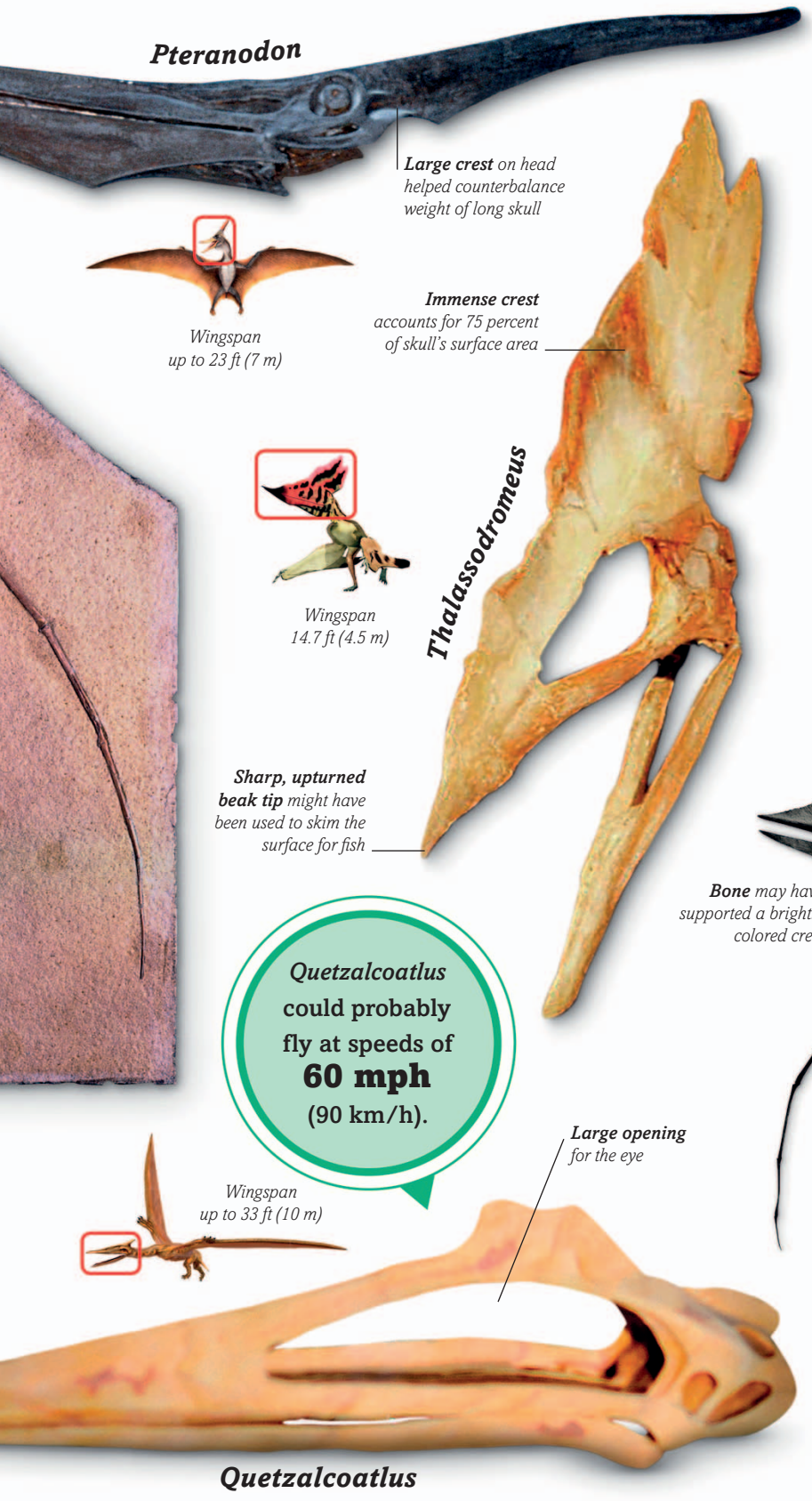
Dimorphodon

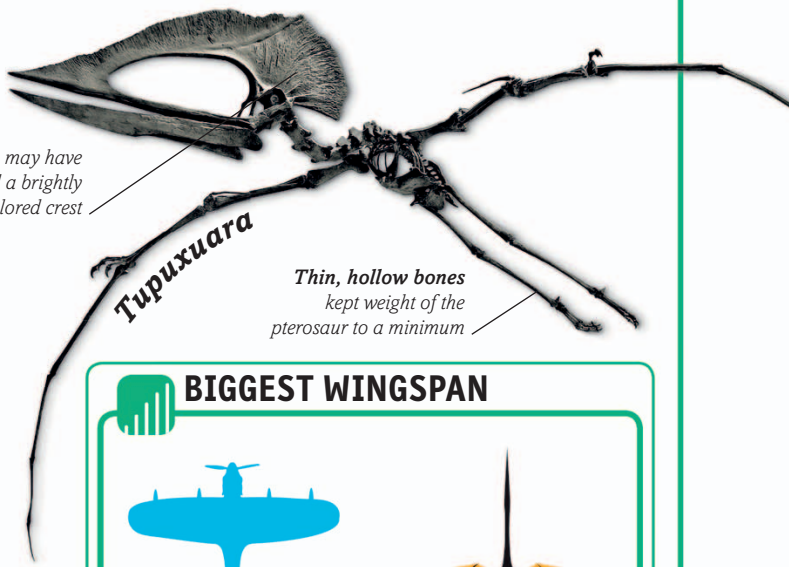
Dimorphodon*'s body length* *was almost three times the size of its head*

Wingspan 4.6 ft (1.4 m)

Swooping and soaring on leathery skin, pterosaurs, or winged lizards, ruled the Jurassic skies. Before birds evolved, they were the only flying vertebrates. They were related to the dinosaurs and lived between 225 and 66 million years ago.

One of the oldest known flying reptiles is ***Eudimorphodon*** from 210 million years ago. This small pterosaur had a wingspan of 3.3 ft (1 m). An agile flier, it may have hunted insects on the wing. ***Rhamphorhynchus*** had a long tail and wings but a short head.



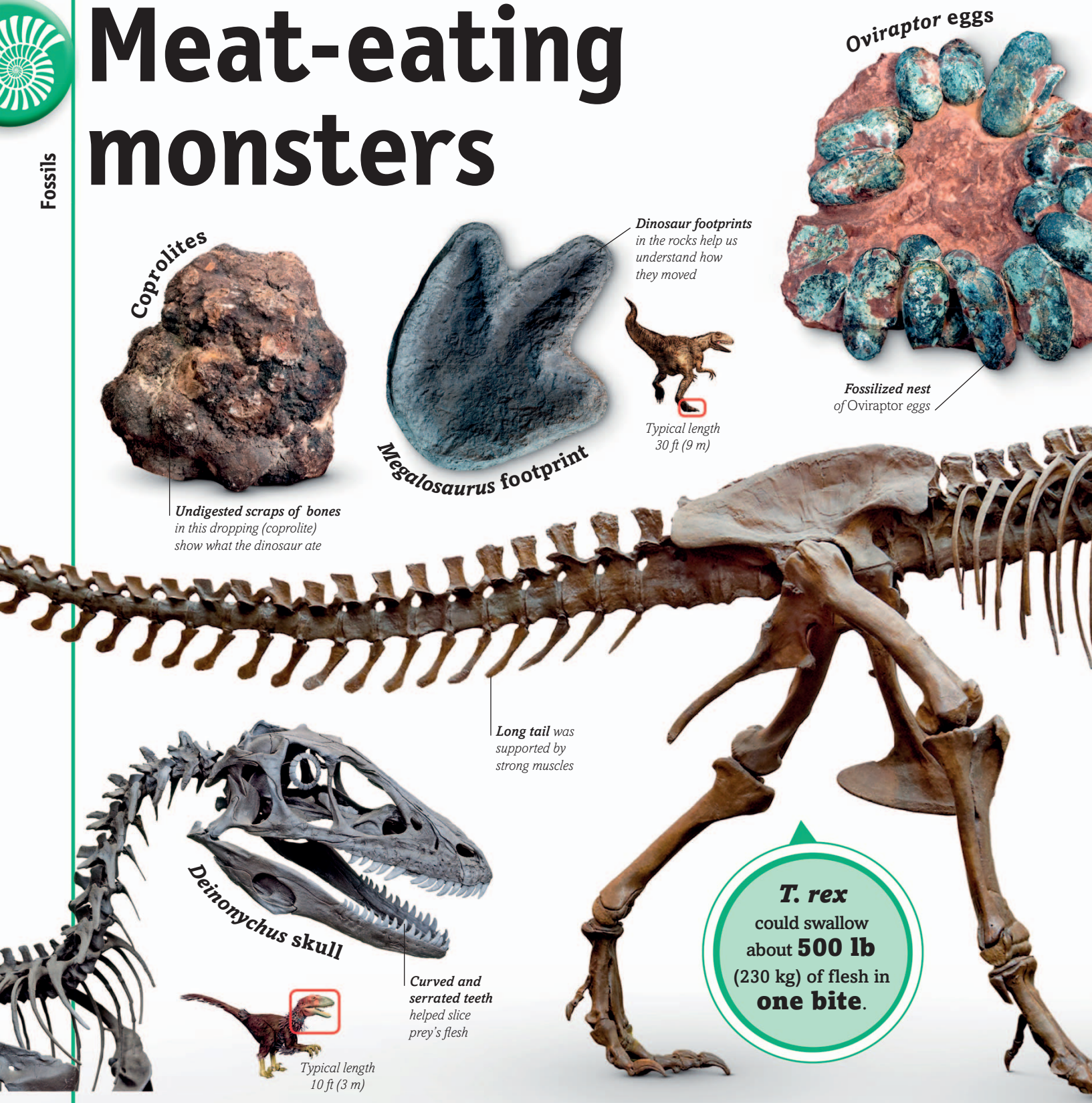


BIGGEST WINGSPAN

Widespread
The wingspan of *Quetzalcoatlus* was almost as broad as that of the World War II Spitfire fighter aircraft.

Pteranodon was huge, with wings that stretched 23 ft (7 m). Pterosaurs such as ***Thalassodromeus*** and ***Pterodactylus*** had short tails, long limbs, and large heads and necks, and were masters of flight. Their wings were a flap of skin stretched between a very long fourth finger and rear limbs. On these leathery wings, they wheeled out over the ocean, diving and snapping fish out of the water. The biggest pterosaur was ***Quetzalcoatlus***, with a wingspan of around 33 ft (10 m) in length.

Meat-eating monsters

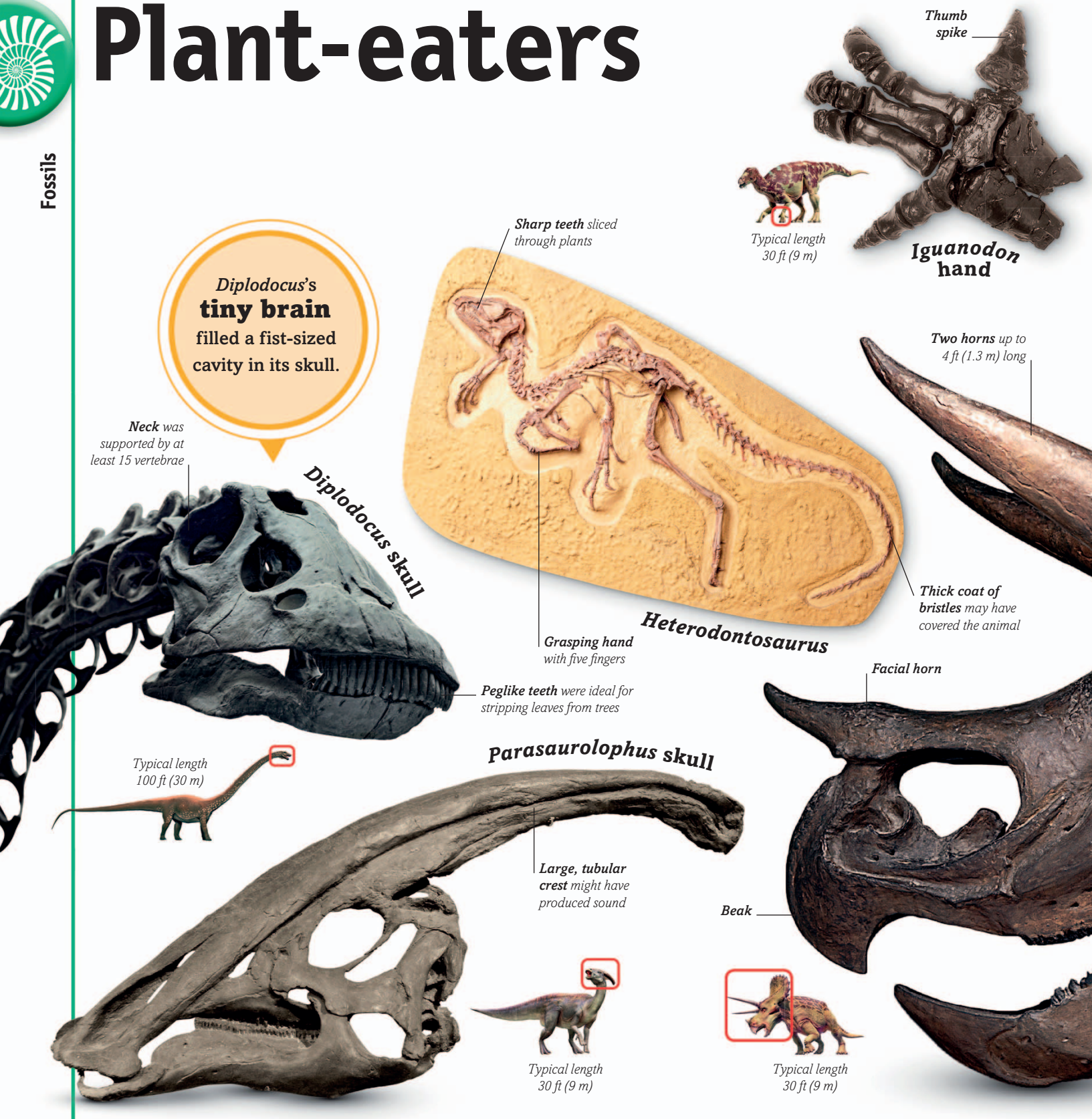


When people first discovered dinosaur fossils, they thought they must be the bones of living animals. But as they studied the jigsaw of bones, they began to realize that fossils were the remains of animals that had long been extinct.

The first fossil hunters named these animals dinosaurs, which means "terrible lizard." ***Megalosaurus*** was the first to be identified, and had the long, curved teeth of a meat-eater. One of the most powerful land predators that has ever lived was ***Tyrannosaurus***. Agile and

able to run fast on two legs, *Tyrannosaurus* had bone-crushing teeth that made it a fearsome hunter. The teeth of ***Allosaurus*** were more like knife blades, while those of ***Baryonyx*** were pointed for piercing the slippery skin of fish. Not all the most vicious meat-eaters were big. ***Coelophysis*** was a lean, lightweight hunter about 10 ft (3 m) long. ***Velociraptor*** was even smaller, but had killer claws for attacking prey such as small dinosaurs, mammals, and lizards. *Velociraptor* was covered in feathers but could not fly, and is an ancient relative of birds.

Plant-eaters



As well as ferocious dinosaur predators, much gentler giants also once roamed Earth. The largest and longest dinosaurs were plant-eaters. These beasts would have had to graze almost constantly to consume enough energy to keep their bodies working.

Fossils have revealed plant-eating dinosaurs of all shapes and sizes, and with curious features and habits. Many, including ***Triceratops***, had a beak to tear at leaves and stems. ***Euoplocephalus*** was a solitary animal with thick armor and a mighty tail club to swing at attackers, while

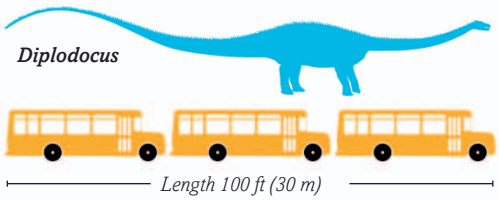
Baby Maiasaura

Fossil skeleton *is about 30 ft (9 m) long*

Ducklike bill

Front legs *were half as long as back legs*

INCREDIBLE LENGTH



Three school buses

Lengthy giant
With an unbelievably long neck for gathering leaves from the tops of trees, and an equally long tail, fossil bones of *Diplodocus* suggest it could have been up to 108 ft (33 m) long.

Pachycephalosaurus skull

Typical length 15 ft (4.5 m)

Thick, domed skull *was covered with knobby bones and spikes*

Triceratops skull

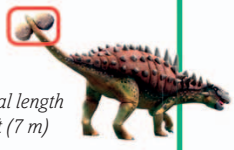
At up to 8 ft (2.4 m) long, *Triceratops* has one of the **biggest** dinosaur skulls.

Bony frill

Battery of teeth *helped in shredding plants*

Euoplocephalus tail club

Heavy, bony club



Typical length 23 ft (7 m)

Plates *arranged in double row down back*

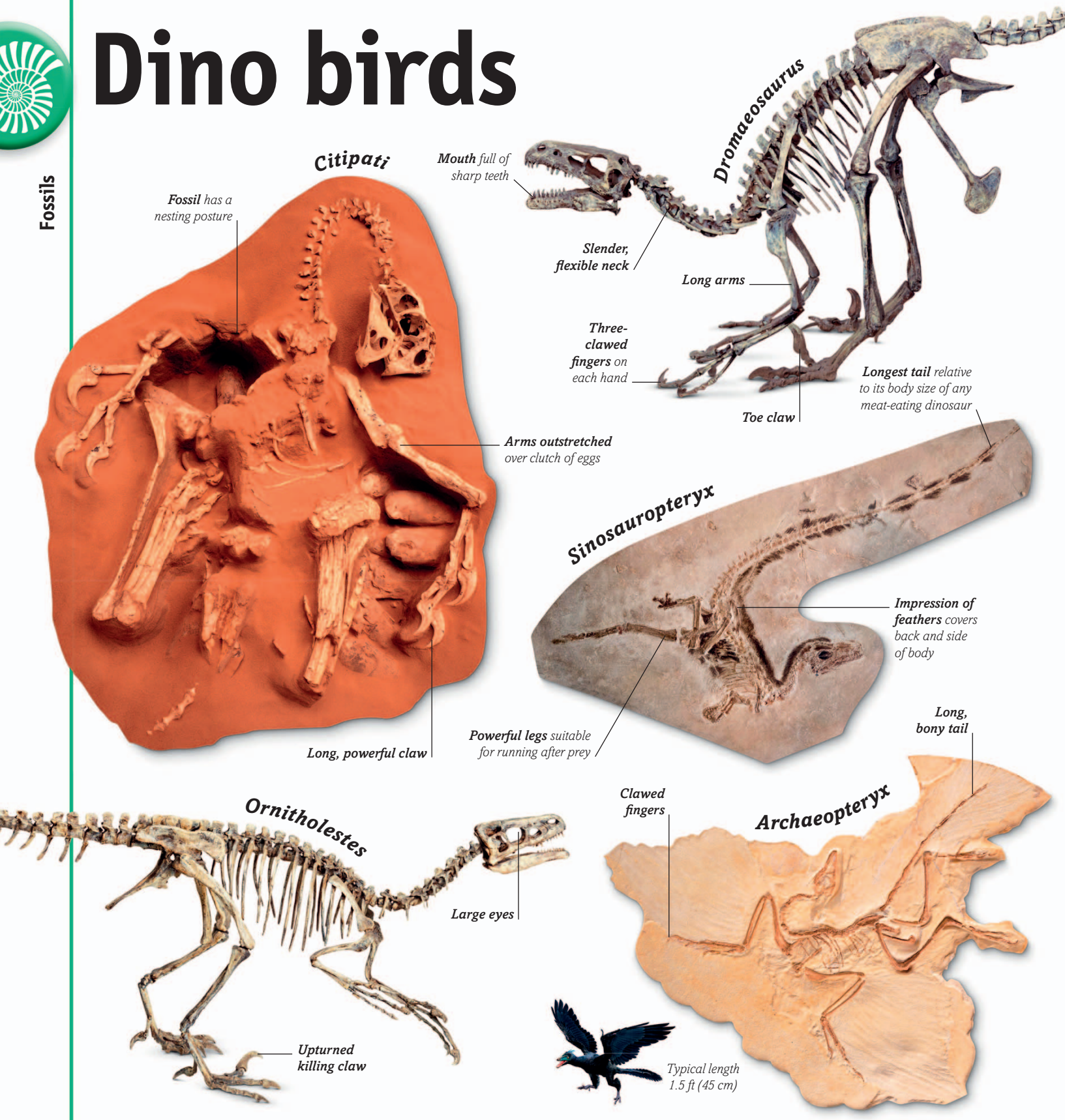
Stegosaurus

Tiny head

Spiked tail club *is called a thagomizer*

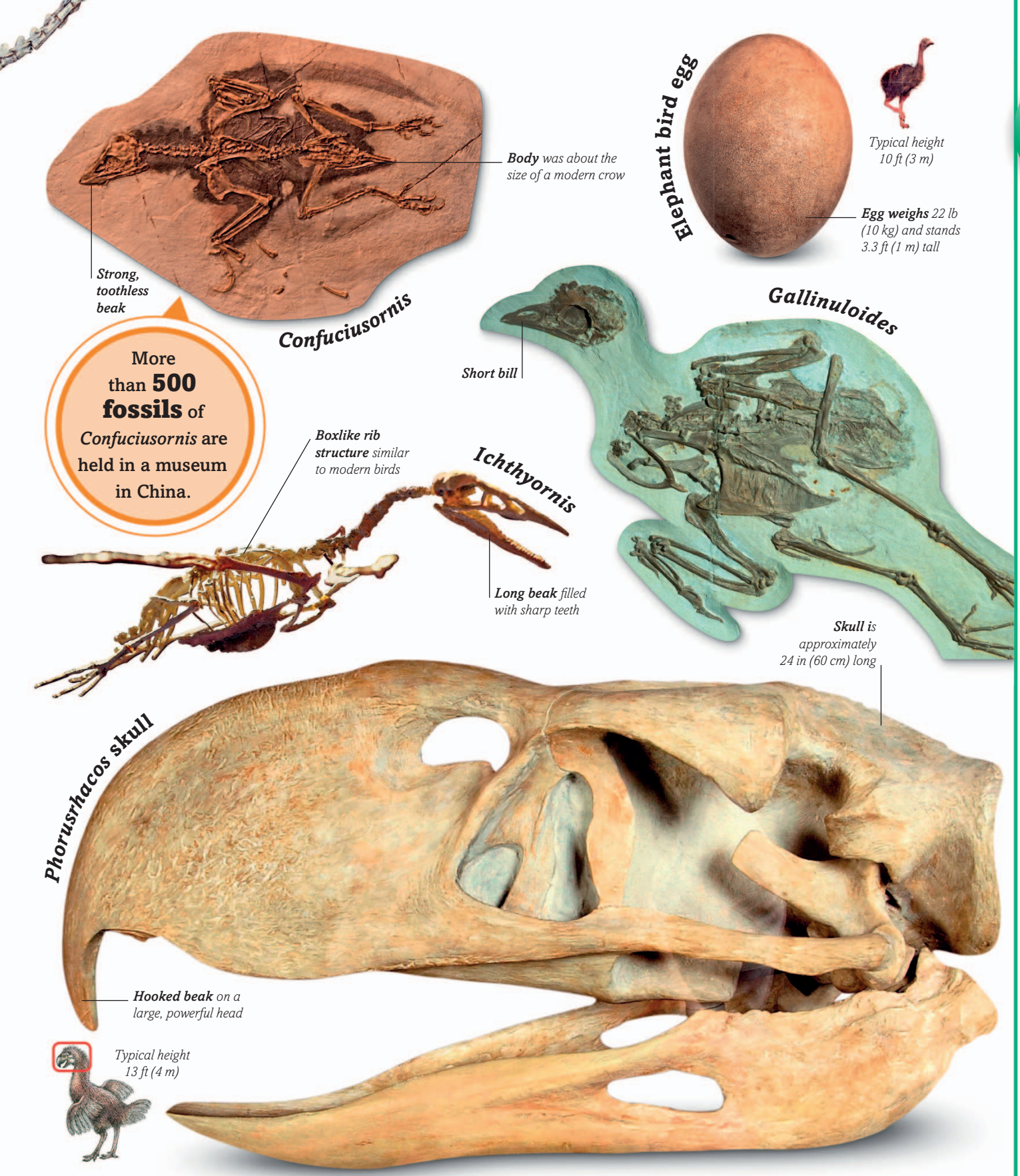
Maiasaura and ***Iguanodon*** sought safety in numbers and grazed in herds. Sometimes scientists can only guess how dinosaurs behaved. Were the enormous plates along the back of ***Stegosaurus*** for show, or to make it look bigger? ***Pachycephalosaurus*** had a domed skull at least 8 in (20 cm) thick. Some think this may be because rival males had head-butting competitions to decide which one was dominant. And perhaps ***Parasaurolophus*** was able to communicate using its tubular crest to produce a trumpeting sound, like an elephant.

Dino birds



If you think the dinosaurs died out 66 million years ago, you had better think again. There are so many similarities between theropod dinosaurs and birds that scientists think theropods were the ancestors of birds.

Birds evolved from lightly built dinosaurs with raptorlike claws, such as ***Dromaeosaurus***. Emu-sized ***Citipati*** fossils are often found sitting on eggs. Like in birds, this brooding behavior used the warmth of the body to hatch the eggs. Turkey-sized ***Sinosauropteryx*** was the first



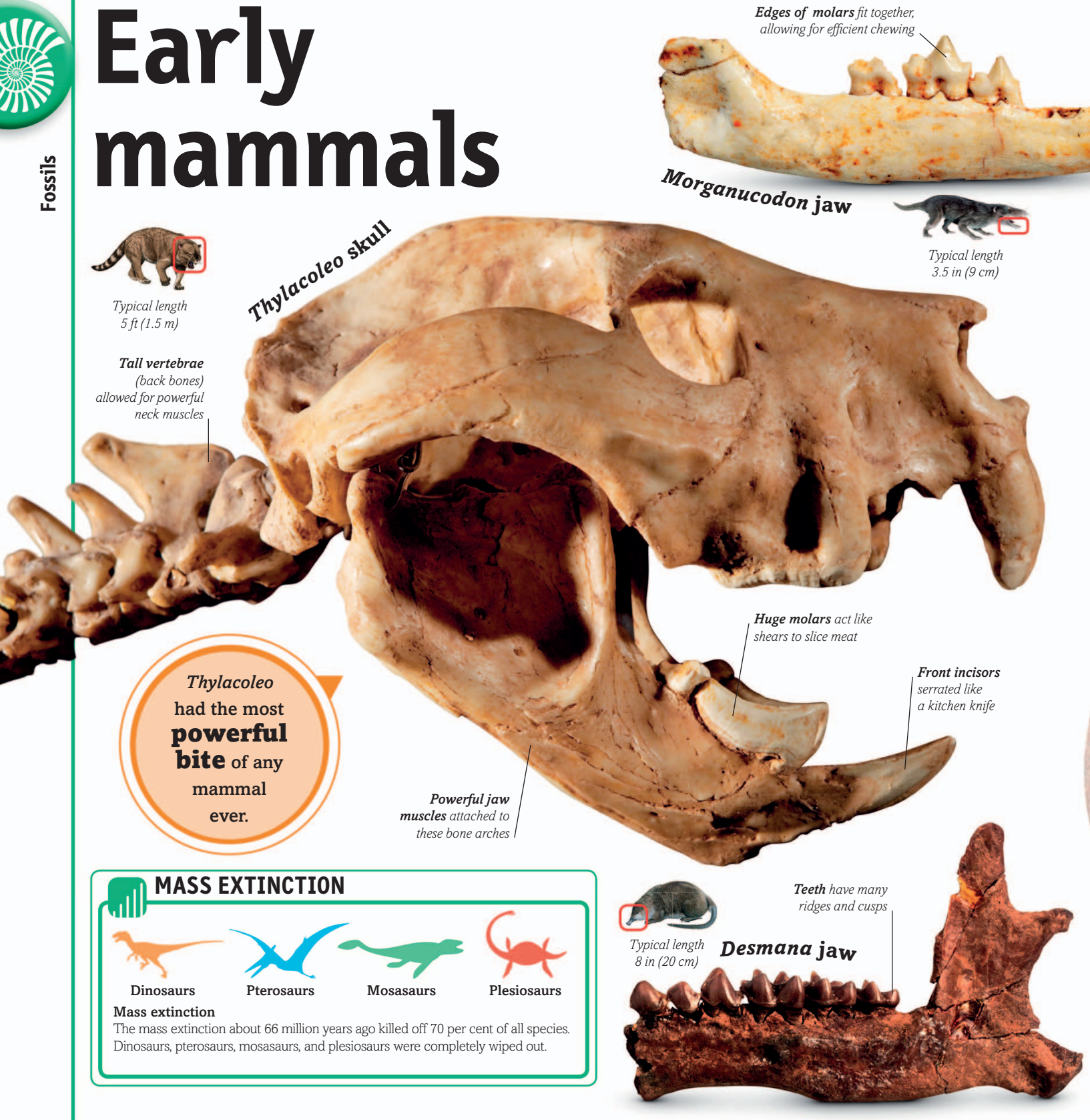
dinosaur to be found with feathers. Color pigments in the feathers even show that it had dark reddish and light stripes along its tail. ***Archaeopteryx***, from 150 million years ago, has a mix of both reptilian and birdlike features. It had flight-ready, feathered wings like birds, but a toothy beak, clawed fingers on the wing, and a long, bony tail, like dinosaurs. A later bird, ***Ichthyornis***, was the Cretaceous equivalent of a seagull, and would fly over the water looking for fish. Most modern birds are small songbirds, a long way from flightless giants such as ***Phorusrhacos***.

MICRORAPTOR This beautifully preserved fossil *Microraptor* from Liaoning Province, China, shows off the remains of its thick plumage of feathers. There was something special about these feathers, however. Unlike the body coverings of other feathered dinosaurs, these feathers were not for warmth. They were long, slender, aerodynamic, and built for one purpose—gliding.

This tiny raptor dinosaur lived 130 million years ago in a dense forest. *Microraptor* went one better than modern birds—with feathered front and back legs, it had no less than four wings! It was a glider, lacking the muscles for powered flight. The slim, off-center feathers had microscopic hooks called barbules linking each to the next to form a smooth flight surface.

Beyond these flight feathers, *Microraptor* had a thick covering of feathers all over its body and running down its tail. A diamond-shaped fan at the end of the tail provided extra stability during flights. In 2012, scientists found pigments at the base of the feathers that showed that, in life, *Microraptor* was dark, with iridescent black feathers like a grackle or a starling.

Early mammals

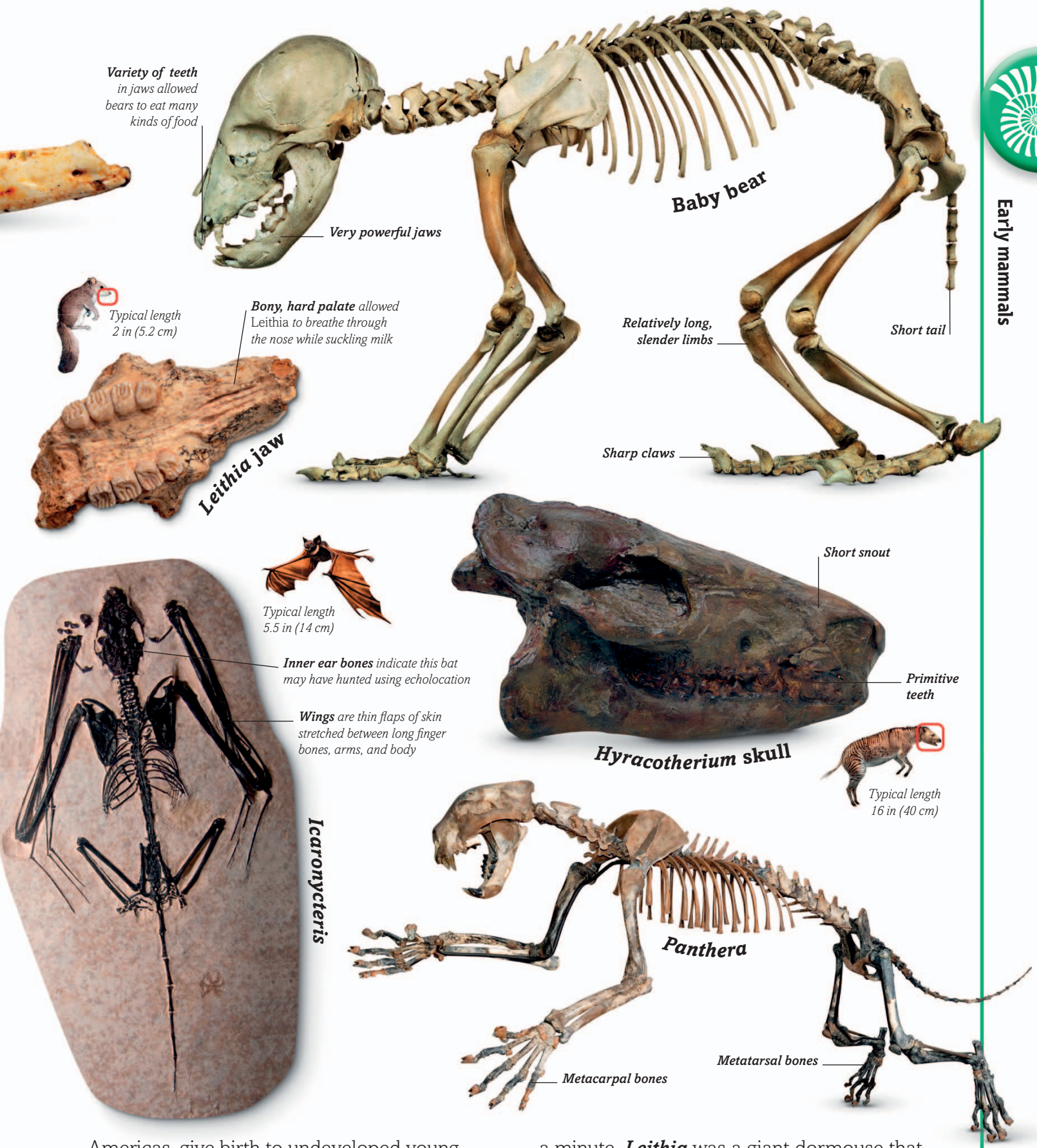


MASS EXTINCTION

Mass extinction
The mass extinction about 66 million years ago killed off 70 per cent of all species. Dinosaurs, pterosaurs, mosasaurs, and plesiosaurs were completely wiped out.

The first mammals—warm-blooded, hairy animals that feed their babies with milk—did not evolve until around 245 million years ago. They only became successful as a group after the dinosaurs went extinct 66 million years ago.

Most mammals give birth to live young, but not all of them do. ***Morganucodon***, a mammal ancestor from 200 million years ago, may have produced small, leathery eggs. Some mammals—the platypus, for example—still do. Marsupial mammals, which live in Australasia and the



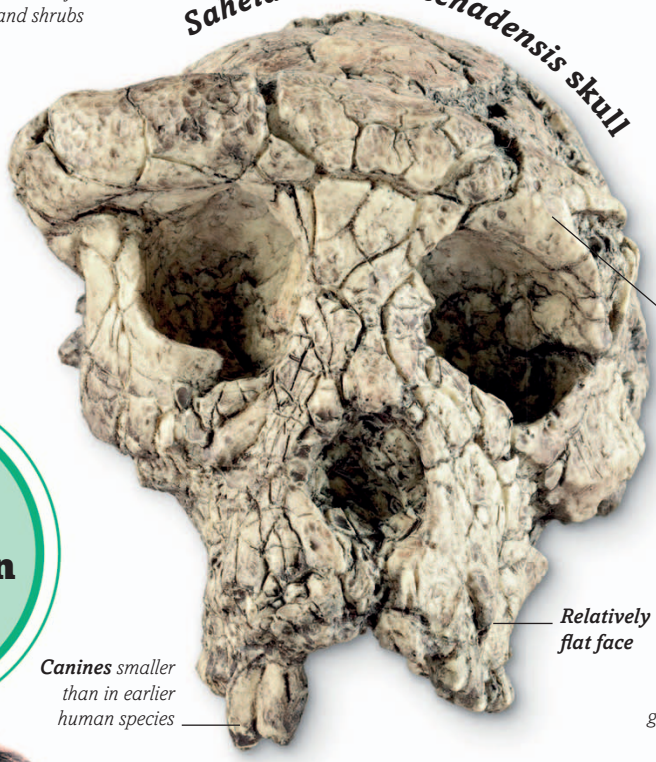
Americas, give birth to undeveloped young, which then develop in the mother's pouch. ***Thylacoleo*** was a marsupial lion that lived in Australia from 2 million to about 40,000 years ago. Thanks to specialized teeth, it could tear through even the toughest prey in less than a minute. ***Leithia*** was a giant dormouse that grew as big as a rat. Bats, such as ***Icaronycteris***, rose to prominence around 50 million years ago. Carnivores, which include lions and tigers (***Panthera***), dogs, hyenas, **bears**, and marine seals, were another important group.

Mega animals and humans

Teeth *indicate a diet of leaves, soft plants, and shrubs*

***Paraceratherium* teeth**

Shoulder height 18 ft (5.5 m)



***Sahelanthropus tchadensis* skull**

Brain size*, similar to that of chimpanzee, suggests it may be an ancestor of both humans and apes*

Relatively flat face

Canines *smaller than in earlier human species*

Blunt teeth *ground vegetation*

Mammoths have been found **preserved in ice** in Siberia, Russia.

Woolly mammoth

Skin *of frozen baby mammoth*

Skull of *Homo habilis* ("skillful man")

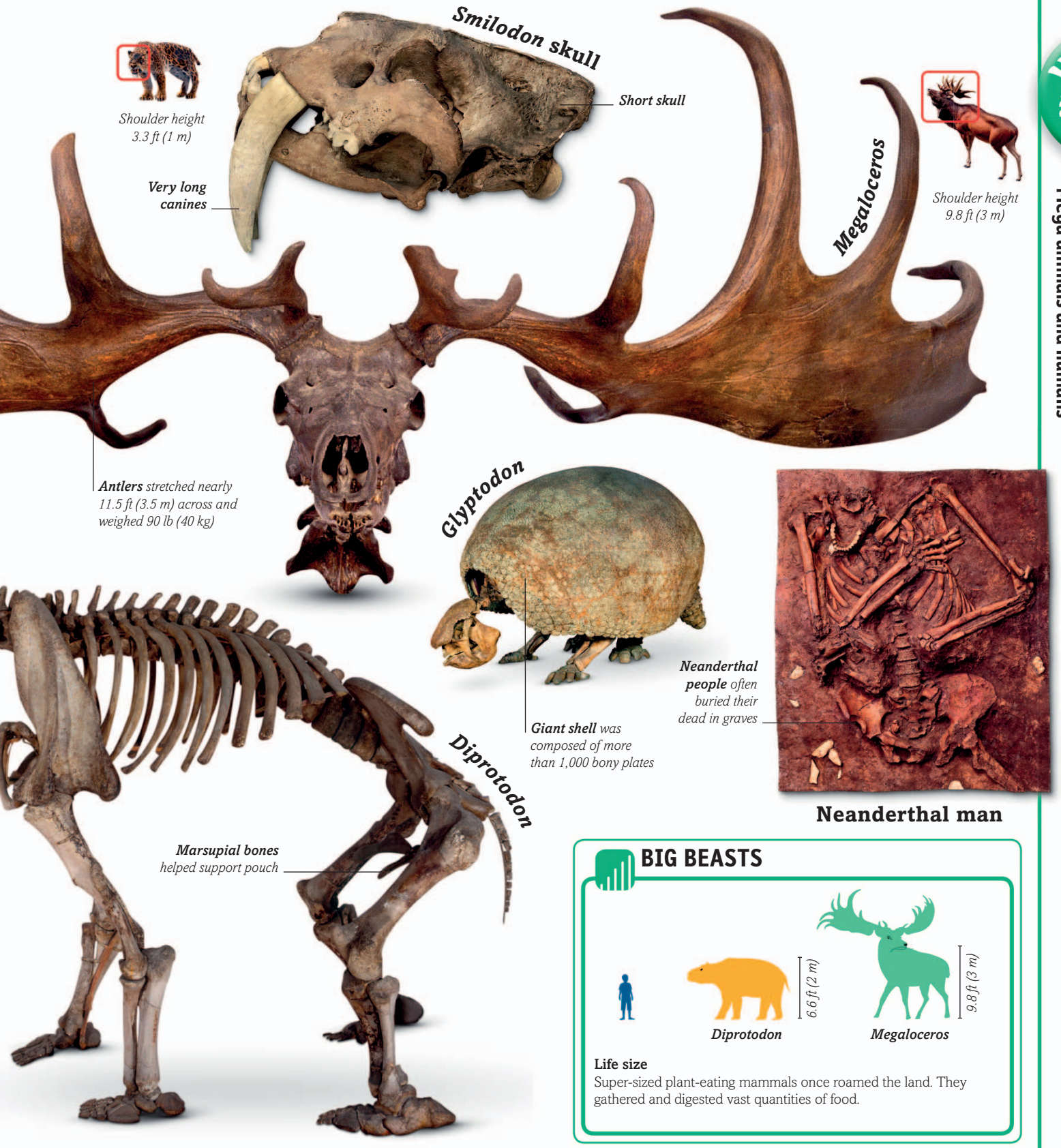
Brain much bigger *than previous humans*

Skull of *Homo ergaster* ("working man")

Skull narrows *behind eye sockets, limiting brain size*

After the extinction of the dinosaurs, mammals began to dominate life on Earth. As the climate began to cool, modern types of mammals and birds appeared, and the first human ancestors evolved in Africa.

The largest land mammal that has ever existed was ***Paraceratherium***—a 20-ton, giant, hornless rhinoceros that lived more than 30 million years ago. During the last ice age, which lasted from 110,000 to 12,000 years ago, some of the most famous prehistoric animals



Neanderthal man

BIG BEASTS

Life size
Super-sized plant-eating mammals once roamed the land. They gathered and digested vast quantities of food.

appeared. The shaggy-haired **woolly mammoth** roamed the frozen tundra. Many human ancestors and other humanoids, such as ***Homo habilis***, ***Homo ergaster***, and **Neanderthal man** lived during the same period. Mammoths were often hunted by the saber-tooth cat, ***Smilodon***, with its curved dagger teeth. The fancy antlers of the male Irish elk, ***Megaloceros***, designed to impress females of its species, would have made walking in the woods tricky. Australia also had mega animals. ***Diprotodon*** was an Australian wombat as big as a hippopotamus.

ICE AGE HERDS

On September 12, 1940, four friends were exploring the Lascaux caves in southwestern France when they discovered a new entrance. What they found inside was breathtaking. Nearly 2,000 painted animals were galloping, charging, and running riot over the walls of the caves. This incredible prehistoric art was the work of the early people who lived there nearly 17,300 years ago.

Some 900 animals are recognizable on the walls of the caves at Lascaux, including giant stags, horses, wild bulls, and bison. Some of the paintings are huge. One part of the cave, called the Hall of the Bulls, features a giant bull more than 16.5 ft (5 m) long. The pictures were created using colored minerals that were crushed to a powder and mixed with animal fat to make natural paints. We can only guess what these haunting images meant to early people. Perhaps they painted them to give thanks for successful hunting. Or perhaps they believed the beasts had magical powers that would bring them luck in future hunts. We will never know.

SHELLS

Shells

A shell is a hard, protective outer layer that has evolved in a wide variety of invertebrates—animals without backbones. Seashells are the most common examples—and most belong to mollusks, such as bivalves and gastropods. The shells of these animals are made from tough protein (called conchiolin) that is hardened by crystals of calcium carbonate, extracted from the sea.

Whorl › A whorl is a single, complete, 360-degree revolution, or turn, in the spiral growth. The shell grows as the animal inside it gets bigger. On hatching, the conch has a transparent shell with one-and-a-half whorls. The shell reaches its full size after three years, by which time it is heavy, solid, and consists of 9 to 11 whorls.

Aperture › The aperture is the opening through which the animal comes out of the shell and is the most recent part of the shell to be formed. The shell's lip only starts to form after the shell has reached its full size, typically when the animal has reached about three years of age.

Conch shell

Flared lip of shell

Types of shells

Bivalves
- Have two, hinged shells, known as valves. They feed by siphoning water through the shell.

Gastropods
- Live inside a single shell. Most scrape up their food with a tough tongue, called a radula.

Cephalopods
- Typically fast-moving. Only a few live in a single coiled shell; most lack an external shell.

Tusk shells
- Live inside a curved, tubelike shell that is open at both ends. They probe for food in the sea mud.

Chitons
- Have flat shells made up of eight plates. They feed on algae living on rocks.

LIVING MOLLUSKS

Gastropods. Include snails and slugs of all kinds and all sizes, from microscopic to large. They can be found in the sea (right), in freshwater, and also on land.

Bivalves. Include clams, oysters, cockles, mussels, scallops (right), and numerous other families. They live mostly in saltwater, but a number can be found in freshwater.

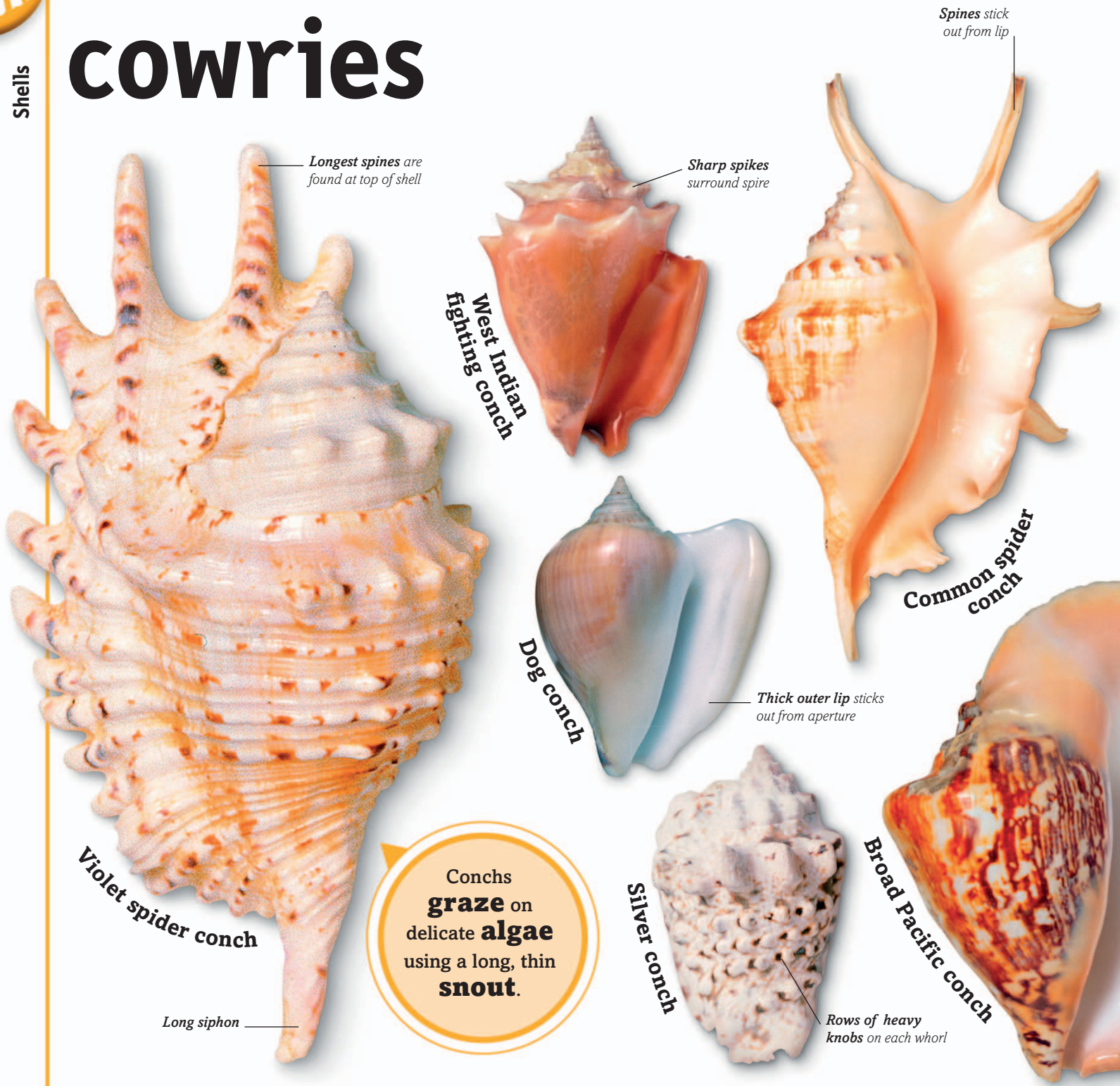
Tuns, winkles, and relatives

Tuns are carnivorous sea snails, found at all depths. Their name comes from an old term for wine casks. Many have barrel-shaped shells. Winkles—also called periwinkles—are smaller creatures that live along the coastline.

Tuns live in tropical seas and spend the day buried in sandy sea beds, coming out at night to feed, mainly on sea cucumbers. Their shells have a typically rounded shape, like the **channeled tun**, which has a body that is wider than it is tall and a very small spire. Tritons, such

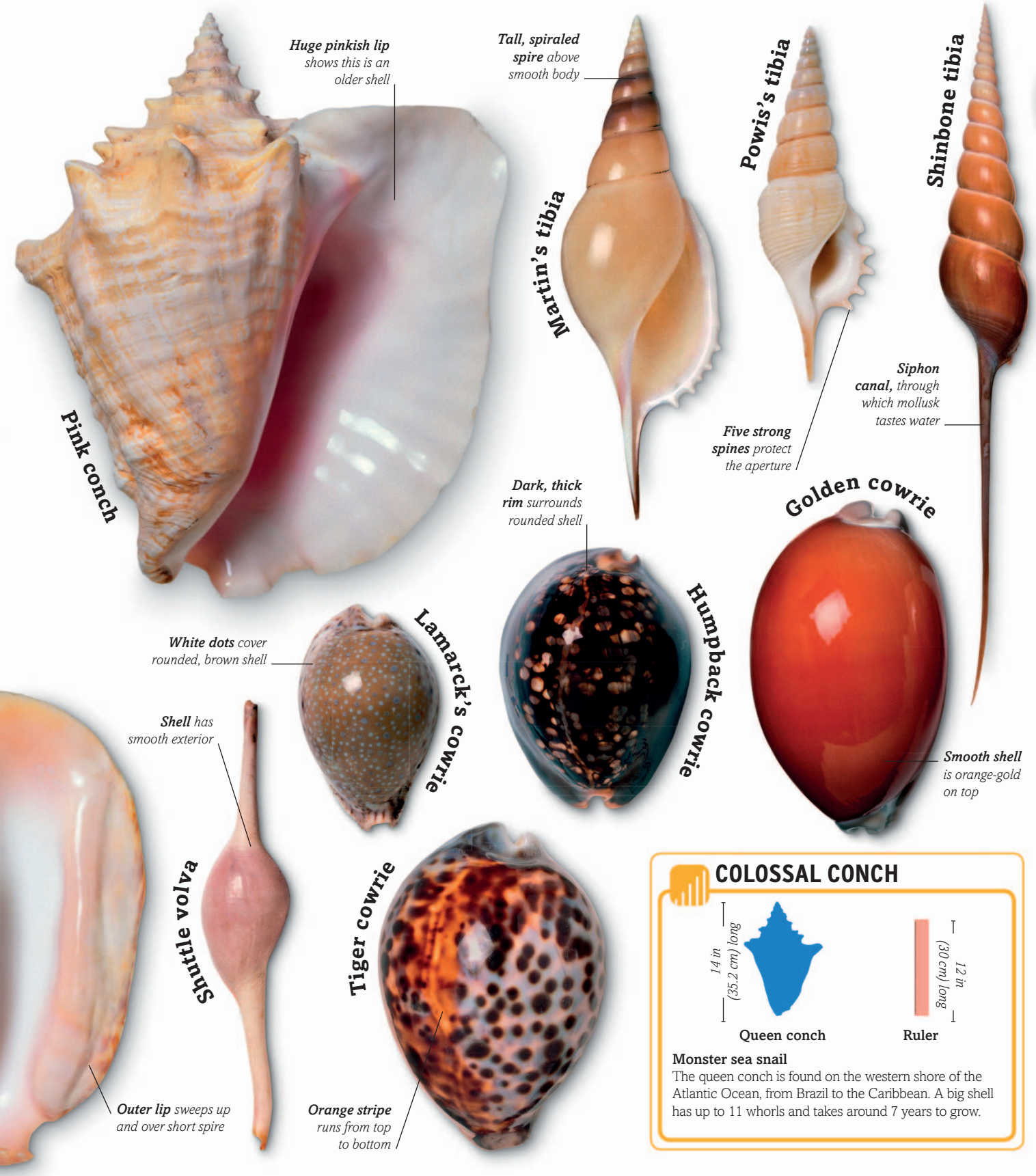
as the **lesser girdled triton**, which lives in the same warm seas, have a taller spire than tuns. The **tower screw shell** has an even taller spire. These tropical snails filter food from the water, an unusual habit for a sea snail. Others have different feeding methods, such as the **common periwinkle**, which grazes on algae growing on rocks. It is one of the most common snail shells found on the coasts of the north-eastern Atlantic. Tuns' shells also have large openings, or apertures, such as on the **spotted tun**, where the snail's foot pokes out.

Conchs and cowries



Conchs and cowries are highly prized shells that are collected to make jewelry and ornaments. Conchs are important in both Hinduism and Buddhism. Like most snail shells, conchs with left-handed (counterclockwise) shells are the rarest.

Conchs are big sea snails that have a sturdy spiral above a large body section. The shape of the **pink conch** is typical of the main group of conchs, known as the strombs. Strombs have a wide, flaring lip that sticks out to the side of the shell aperture. Spider conchs, like the **common**



COLOSSAL CONCH

Monster sea snail
The queen conch is found on the western shore of the Atlantic Ocean, from Brazil to the Caribbean. A big shell has up to 11 whorls and takes around 7 years to grow.

spider conch and **violet spider conch**, do not have this feature. Instead, the lip is divided into extensions that look like a spider's legs. The **shinbone tibia** belongs to a group of smaller, narrower conchs. The lower part of the shell has a fluted tube into which the snail's siphon (water tube) fits. Cowrie shells are smooth, easy to polish, and have a wide range of patterns, from the spots of the **tiger cowrie** to the rich colors of the **golden cowrie**. The cowrie's whirling spire disappears into the shell as it grows. All cowries have toothed ridges along the opening.

UNUSUAL MOVER The queen conch is one of the largest marine snails. It lives in the shallow, tropical waters of the western Atlantic coasts of North and Central America and throughout the Caribbean Sea. It has been highly prized by humans for centuries, both as a source of food and for its highly distinctive shell, which typically reaches 6–12 in (15–30 cm) in length.

After hatching, a queen conch starts its life as a tiny larva, floating in the open ocean and feeding on minute phytoplankton. After 18 to 40 days, it settles into the sand, where it remains buried for the first year of its life, slowly changing into the adult form. Queen conchs reach sexual maturity at three to four years of age, and will typically live for around seven years. They are unusual among sea snails for the way in which they move. They dig the flap that covers the opening of their shell (called the operculum) into the sand, and extend their foot to throw themselves forward—a little like a pole-vaulter. This shell-thrusting motion is called "leaping," and helps the conch escape danger more quickly.

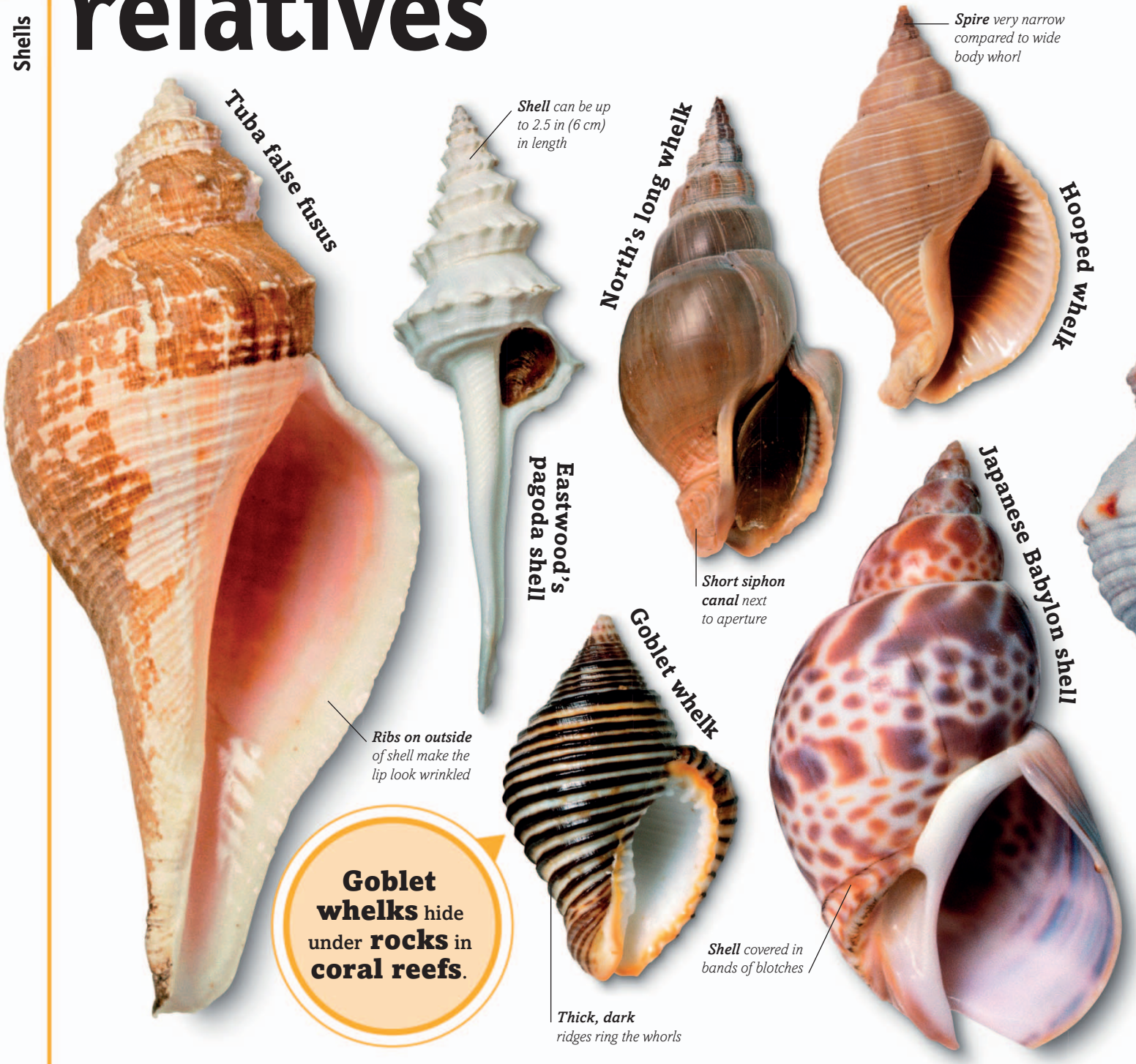
Augers, cones, and turrids

This group of shells are all pointed and cone-shaped, but they all share another, much more deadly, characteristic. They are carnivorous sea snails that have specialized mouthparts for pumping venom into prey.

An "auger" is used to describe a small hand drill that is used to bore holes in wood or the ground. Auger shells look like drill bits, and, traditionally, the sharp **marlinspike** shell is used in Asia for that very purpose, for gouging out holes. The **subulate auger** is even sharper, but it lives in

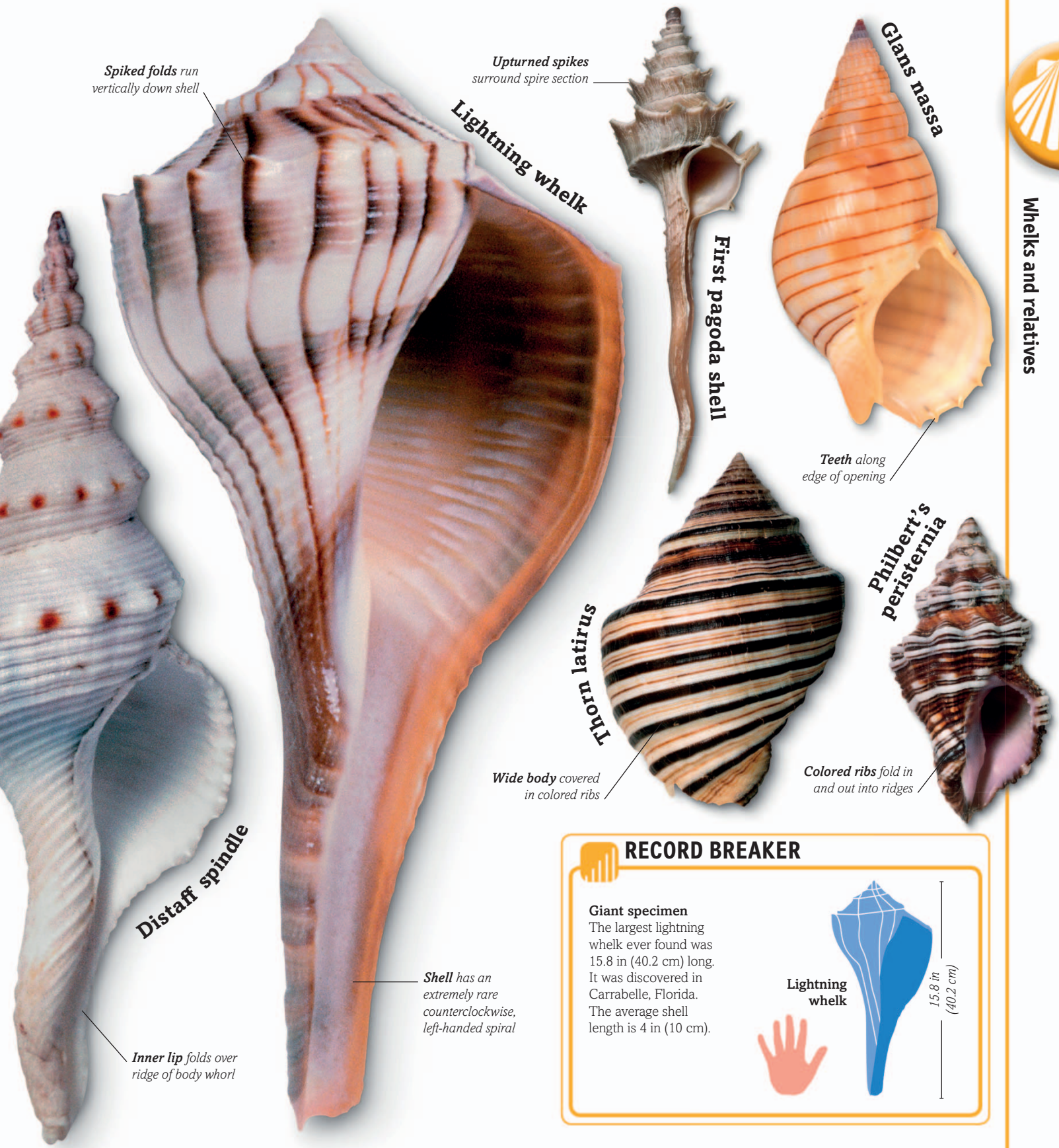
deep water and so is harder to collect. Pointed turrid shells, such as the **Babylon turrid**, are much more common. They make up the largest family of deep-sea snails, with 4,000 varieties, and most, like the **Indian turrid**, are covered in bumps and nodules. Cone shells are highly varied and are often named after their pattern. For example, the rich, creamy colors of the **pontifical cone** look like the robes worn by the Pope. Cone shells live in shallow, tropical seas and harpoon their prey with fast-acting venom that is powerful enough to kill a human.

Whelks and relatives



Whelks and whelk-allies are common in cold, rough, coastal seas, but some are tropical or live at greater depths. They are carnivores or scavengers and have excellent sensors for "tasting" the presence of food.

The name "whelk" is applied to many kinds of sea snail—it comes from the words "whirl" and "whorl." The **hooped whelk** belongs to a large group of snails called the neptunes, which can be found all around the world's coasts. The **Eastwood's pagoda shell** comes from

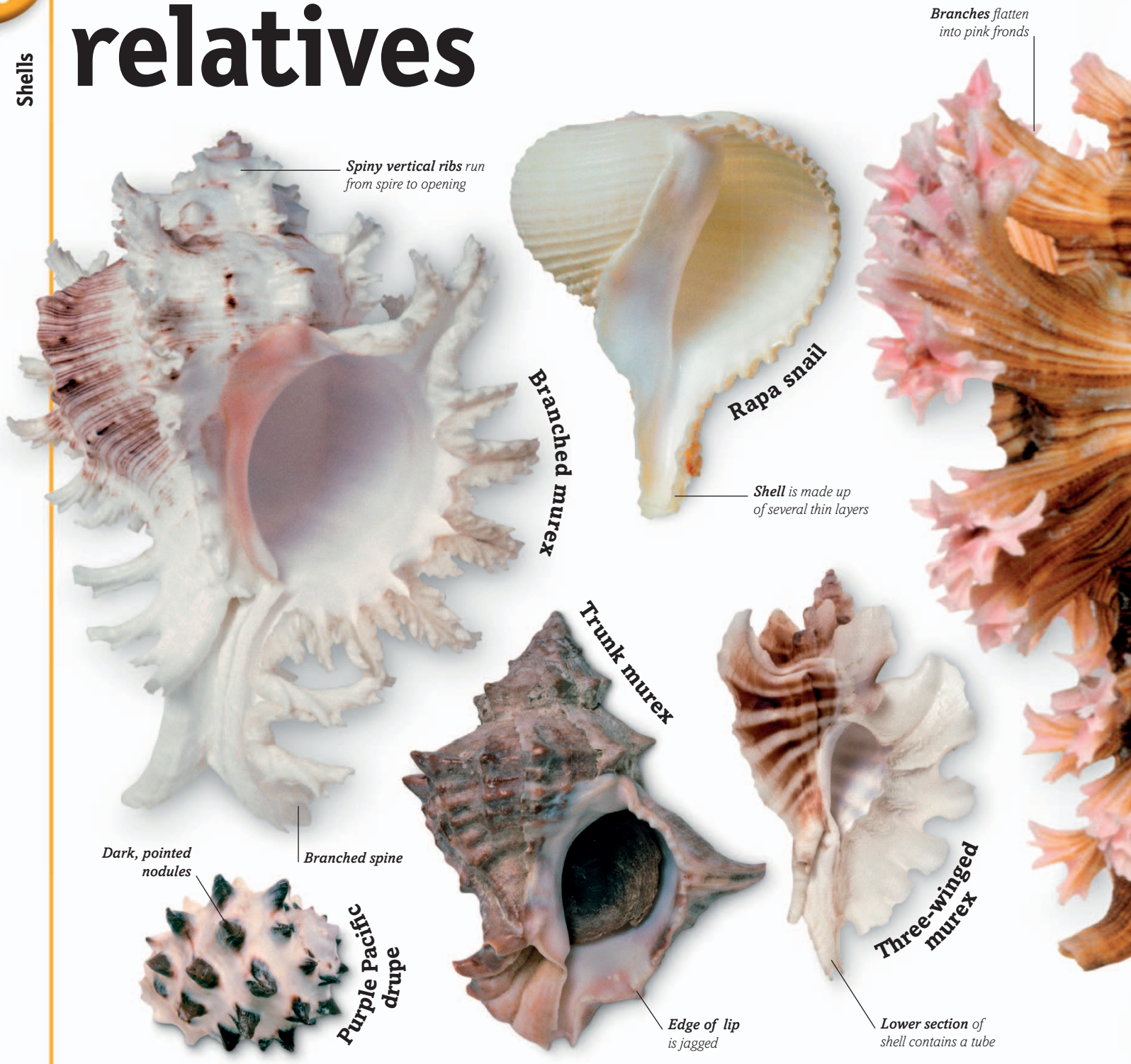


RECORD BREAKER

Giant specimen
The largest lightning whelk ever found was 15.8 in (40.2 cm) long. It was discovered in Carrabelle, Florida. The average shell length is 4 in (10 cm).

southern Africa, where it lives on the muddy sea bed. The **distaff spindle** has a similar shape to the pagoda shells and is characterized by the brown-orange striped markings on its spindle. The **lightning whelk** is found along the coast of Florida and eastern North America, and its relatives are spread along the western coast of the Atlantic. The **glans nassa** is one of the nassa mud snails from Southeast Asia. The **thorn latirus** and **Philbert's peristernia** are both members of a large group of small, carnivorous snails that live worldwide.

Murexes and relatives



The murexes are a highly varied group of snails with amazingly complex shells. The spirals of the shells are hard to see among all the frills, spines, and plates that stick out in all directions. Murexes are predators that live in warm, shallow seas.

Murex snails were highly prized in the ancient world, because their shells were ground to make a purple dye that the wealthiest Romans used to color their clothes. The **trunk murex** was collected for the same reason. The beautiful pink color of the **rose branch murex** makes

The most **ornate** rose branch murexes are found in waters off **Sri Lanka**.

it highly valued by shell collectors. However, many are given extra colors by unscrupulous traders. The **purple Pacific drupe** shares its name with a group of fruits that have a stone in the middle—the shell looks like a colorful fruit stone. Rock shells, like the **corded rock shell**, have shells similar in shape to those of murexes. However, the **dog whelk** is only frilled when it lives in sheltered waters; in rough conditions it is smooth. The **veined rapa whelk** grinds through the shells of other mollusks and can inflict huge damage on oyster beds.

Other snails

Turban shells and limpets are among the most primitive of the sea snails. Like almost all other sea snails, they use gills to breathe in water. Land snails and most freshwater snails have lungs to breathe air.

Limpets cling firmly to rocks, and the shell of the **long ribbed limpet** is shaped to fit a particular space. When the tide goes out and the shell is exposed to the air, the limpet pulls its shell down to seal water underneath—this prevents the animal from drying out and means

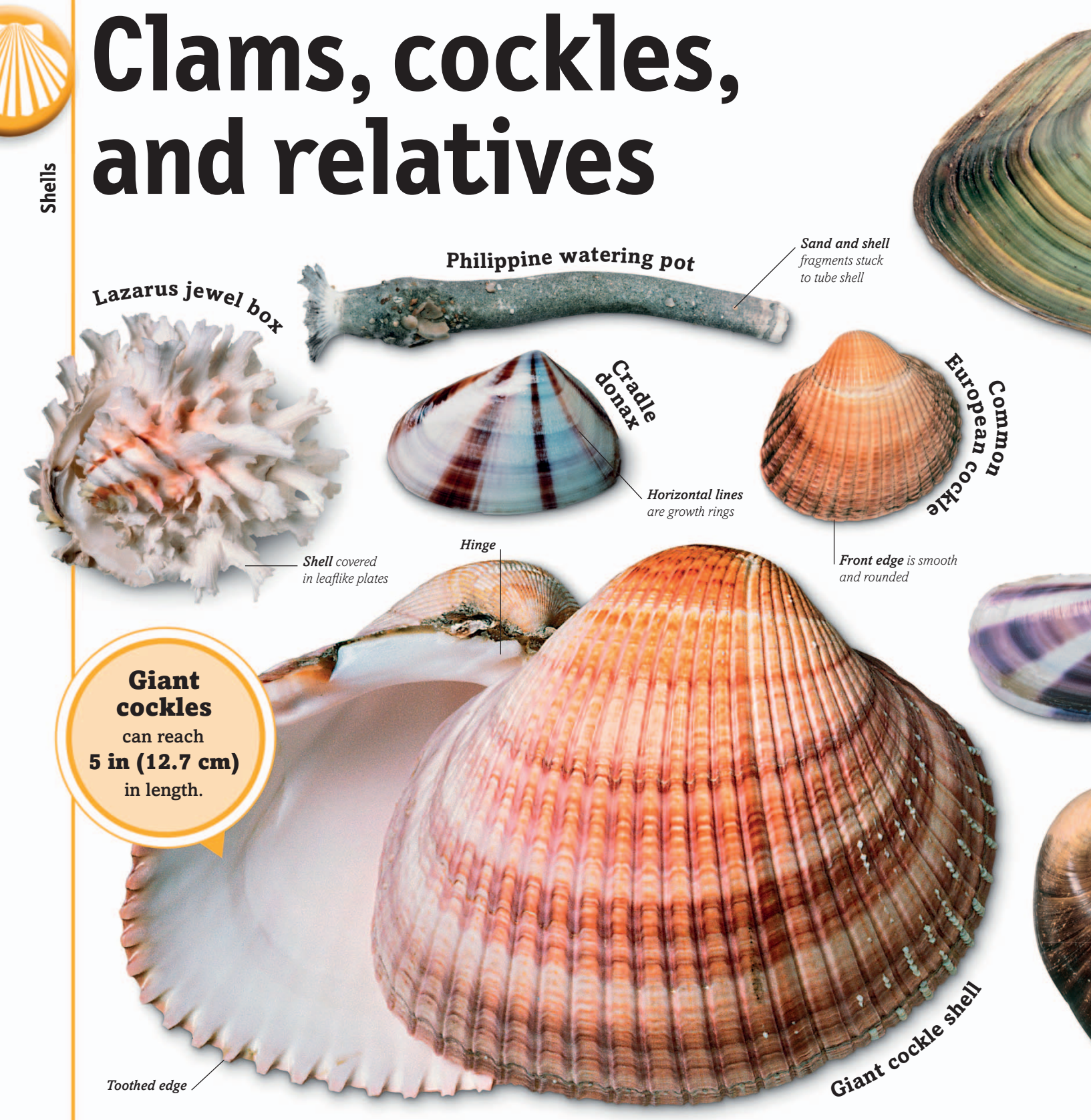
it can keep breathing. When underwater, **Lister's keyhole limpet** pumps a flow of water into its shell and squirts it out the top through an opening called a keyhole. **Rumphius' slit shell** does something similar, by pumping out water through the slit in the side of its shell. The **checkered top** looks similar to the slit shell, but lacks the slit. It is named after the way it resembles an upside-down spinning top. The **triumphant star turban** has several spikes sticking out of the side.

FLOATING THE WAVES

While most snails slither around on their single, flexible foot, the bubble raft snail takes a ride on the ocean's currents, floating under a raft of bubbles. The snail is a predator that attacks other floating creatures, most often the Portuguese man o' war, which is a relative of the jellyfish. It is a hit-or-miss lifestyle, however; the snail cannot swim and can only go where the ocean takes it.

To make its raft, the bubble raft snail traps bubbles of air in mucus, which hardens to keep it secure. The resulting air-filled float sticks to the snail's foot and its thin, lightweight shell ensures that it stays afloat. The snail lives its life upside-down, with the spire of its shell pointing toward the ocean floor. It protects itself through camouflage on its shell, using a trick known as countershading. The spire and whorls of the shell are pale in color, while the region around the opening is a deep blue-purple. This means that, seen from above, the blue shell is difficult to spot in the dark ocean water; from below, the shell's pale colors blend in with the sunbeams shining down.

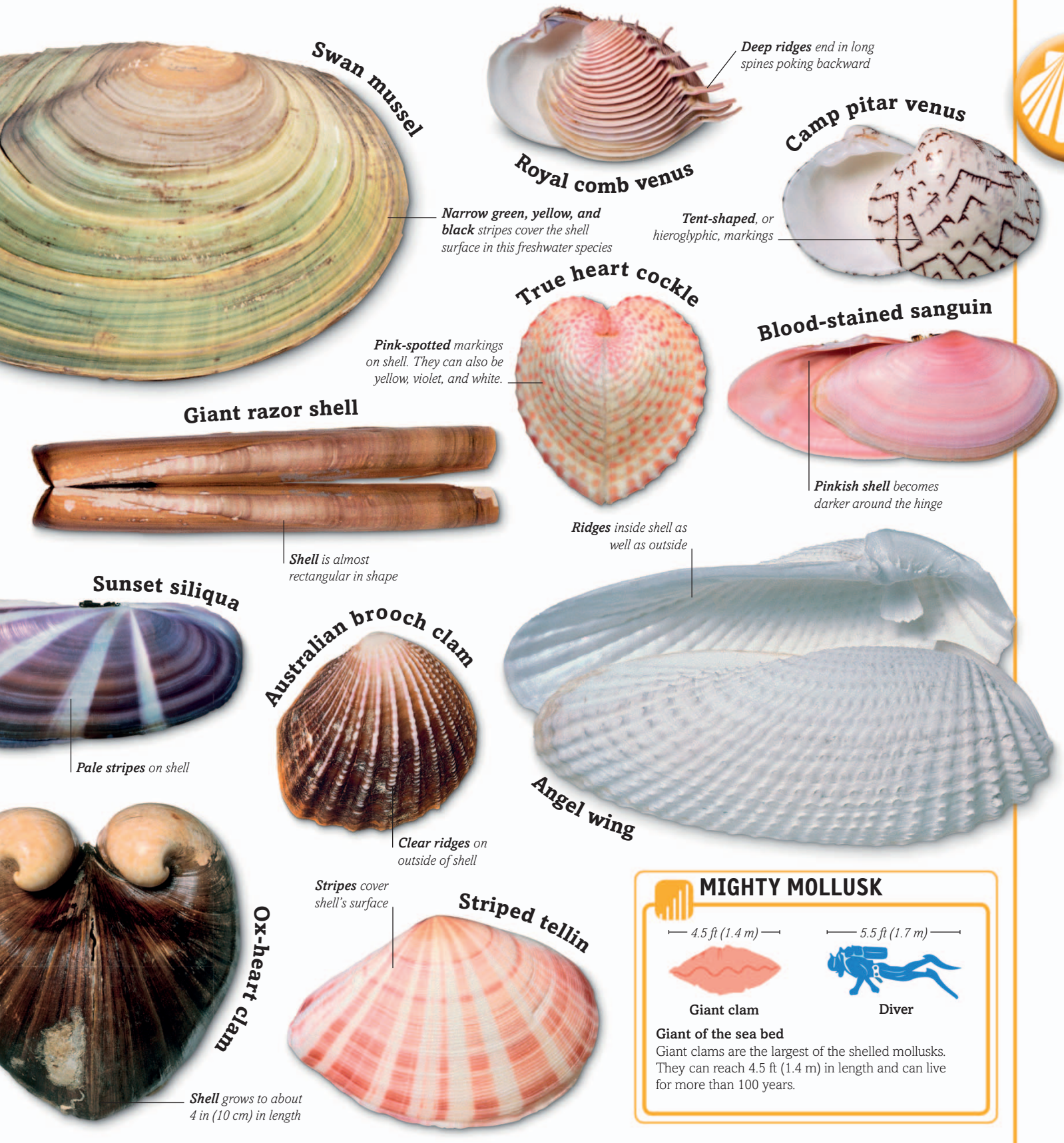
Clams, cockles, and relatives



Giant cockles can reach **5 in (12.7 cm)** in length.

Clams and cockles are bivalves, mollusks that have two shells connected by a hinge. Similar seashells include tellins and surf shells. These animals are mostly filter feeders; they draw water into the shell and filter out any particles of food.

Clams and cockles tend to have more symmetrical shells than other bivalves. An excellent example is the **ox-heart clam**, which displays almost complete symmetry, as does the **true heart cockle**. The **angel wing**, so named because its white shell is shaped like the



MIGHTY MOLLUSK

Giant of the sea bed

Giant clams are the largest of the shelled mollusks. They can reach 4.5 ft (1.4 m) in length and can live for more than 100 years.

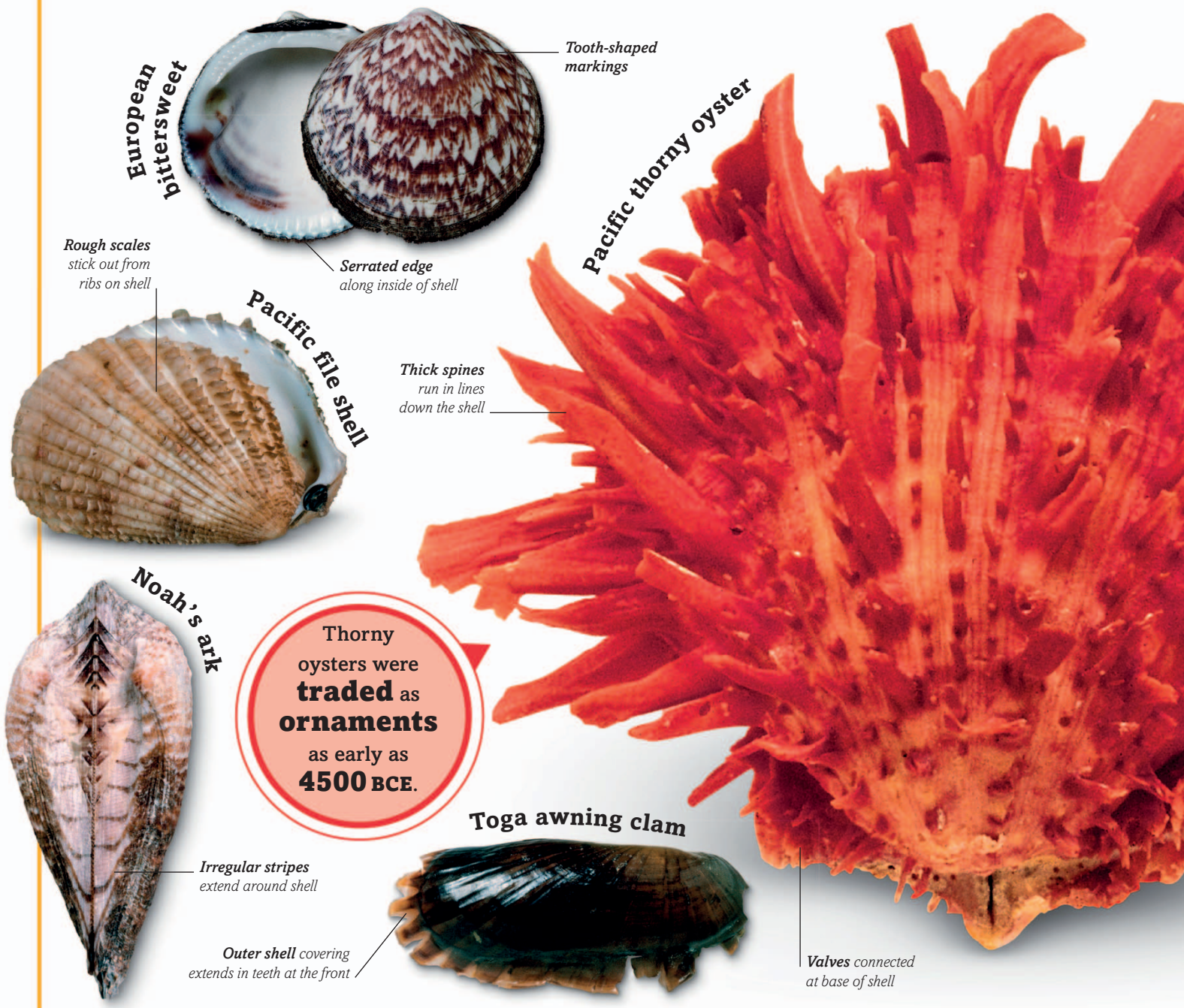
feathered wings of an angel, is an exception, being much longer on one side than the other. **The giant razor shell** is named after the sharp, straight edge of its valves. It is mostly found buried in the sand near the low-water line. The **giant cockle** also prefers sandy habitats, although it lives at greater depths. The **striped tellin** lives in the sea bed, using siphons several times longer than its shell to connect to the water above. The venus clams, such as the **royal comb venus** and **camp pitar venus**, are named after the Roman goddess of love.

SUPER-SIZED SHELL

The largest shellfish of all, the giant clam lives a quiet life among the corals, sponges, and seaweeds of a tropical reef. It can outlive most of its neighbors, and, on average, lives for 100 years. During that time, the outside of the clam's shell becomes encrusted with barnacles and many other hangers-on; other life forms make a home inside this ocean giant's shell.

The giant clam's mighty valves close tightly enough to grip anything trapped between them, including a human arm. However, the mollusk only clams up when threatened, and it closes so slowly that no diver would be caught unaware. During the day, the clam has its shell fully open, filtering food from the water. But the clam gets most of its food from microscopic algae that live inside its body tissues. In return for a safe place to live, the algae share the sugars they produce naturally with their host. This sharing arrangement, known as mutualistic symbiosis, means the clam is nourished by extra food and can grow into a giant.

Oysters, scallops, and relatives



Oysters come in many different types, but all are famed for their ability to produce pearls. Scallop shells have rounded valves, earlike projections at the hinge, and are probably the most familiar seashell shape of all.

The shape of the shell is not the only difference between oysters and scallops; they tend to live in different habitats, too. The **Pacific thorny oyster** and **cock's comb oyster**, for example, become fastened to a rocky surface at an early stage in their development and do not move.

In contrast, the **austral scallop**, **lion's paw**, and **queen scallop** keep on the move for most of their lives. They open and close their valves rapidly to create a jet of water that propels them along in spurts or even enables them to swim in open water. The **great scallop** is too large to move that much and spends most of its life lying on the sandy sea bed. The **Pacific file shell** is also able to swim by clapping its valves together. It gets its name from the sawlike edge of its valves and the rough surface of its shell.

Strange shells

Spikes *protect the sea floor animal*

Sea urchin

Bony plates *under skin add protection*

Rock minerals *have replaced the hard body parts*

Heart urchin fossil

Hermit crab in a shell

Shell *left by dead whelk*

Rear end

Marbled chiton

Girdle *surrounds eight shells*

Blue-green *underside*

Coarse spines *surround plates*

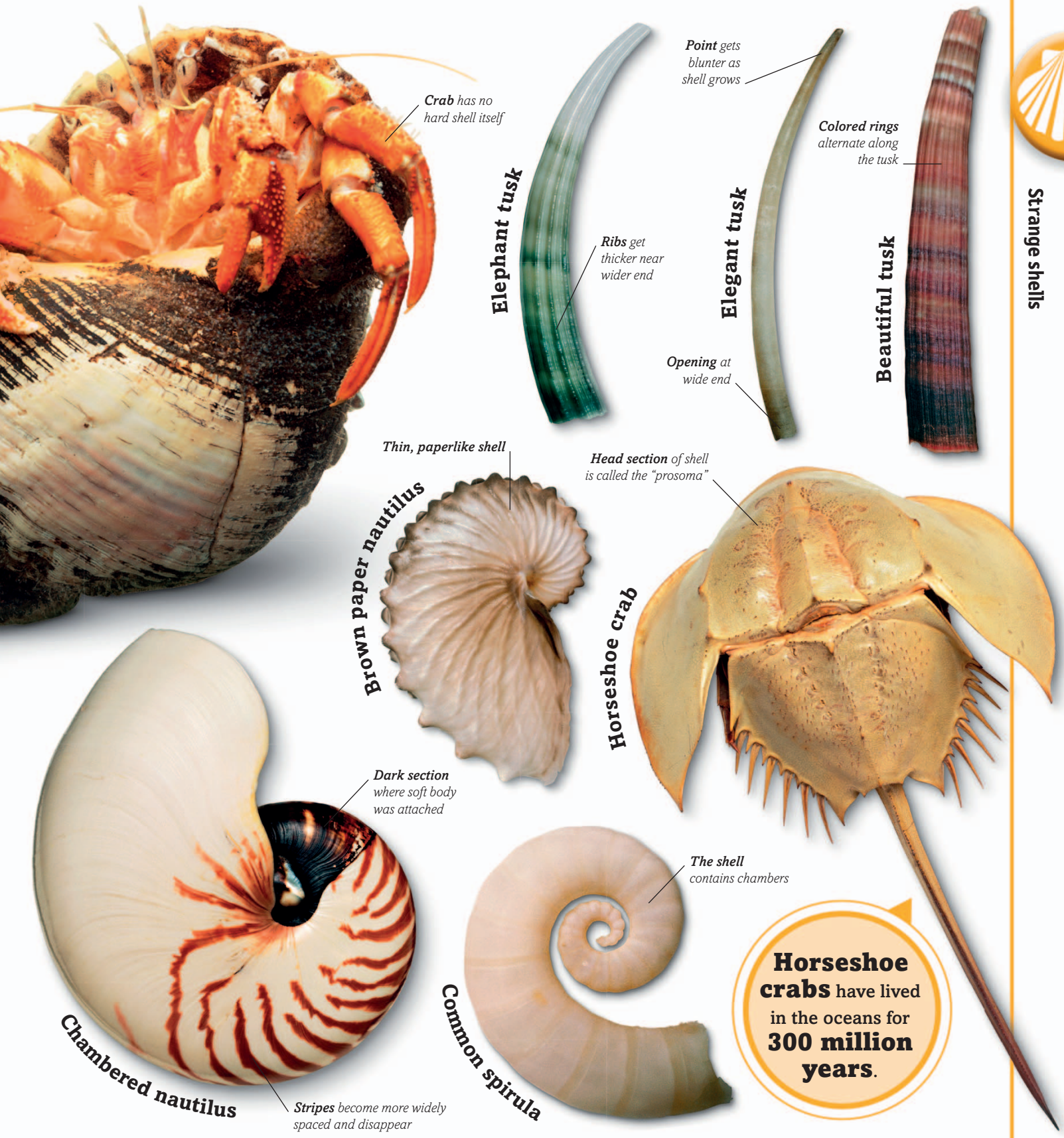
Fuzzy chiton

LARGEST CHITON

Giant of the family
The northern Pacific gumboot chiton is the largest chiton in the world. It is 13 in (33 cm) long and weighs 4.4 lb (2 kg).

Most mollusks are gastropods (such as snails and slugs) or bivalves (including clams and oysters). However, there are other kinds of mollusks that make different types of shells, and other kinds of shellfish that are not mollusks at all.

The **marbled chiton** is an example of a small group of mollusks. Instead of having one shell like the gastropods, or two like the bivalves, these animals have eight valves that overlap each other to make a flexible coat of armor. Chitons are grazers that eat the microbes that grow on rocks.



Cephalopods are active mollusks with tentacles. They include soft, shell-less octopuses, as well as squids and cuttlefish with internal shells. Only a few cephalopods—**nautilus** and **spirula**—have external shells. **Elephant tusk** and other sand-burrowing **tusk shells** are also mollusks. Bony-plated **sea urchins** are echinoderms—a group that includes starfish. **Horseshoe crabs** are joint-legged arthropods, more closely related to spiders and scorpions. True crabs are arthropods too—including **hermit crabs** that commandeer discarded shells of dead snails for protection.

NATURE'S SUBMARINE

The chambered nautilus is a relative of squids and octopuses. Together, they make up a group of mollusks called cephalopods. Like other cephalopods, the nautilus swims freely, and has tentacles for grabbing prey and a horny beak for biting through shells. However, unlike its relatives, the chambered nautilus lives inside a shell.

The chambered nautilus is the closest thing the natural world has to a submarine. The spiral shell is made up of many chambers, and the nautilus lives in the largest one. When it outgrows that chamber, it adds on a bigger one, sealing off the unwanted smaller chamber behind it. A tube runs through all the chambers and allows the nautilus to control how much water is in each sealed chamber. Adding water makes it sink; taking it out makes the animal float up. Like all cephalopods, the nautilus moves using jet power, squirting a jet of water out of the shell. This means the nautilus moves shell-first. It has about 90 tentacles that grip and hold prey thanks to ridges on their surface.

FAMOUS TREASURES

The gold mask of a pharaoh

Gold throne
Panel on the back of a gold throne showing Tutankhamen and his wife.

When Tutankhamen, the young pharaoh of Egypt, died suddenly at the age of 19 around 1327 BCE, his body was placed within three gold-lined coffins, nestling inside each other like Russian dolls. Then his tomb was sealed up. It lay undisturbed for approximately 3,000 years, until a group of archaeologists digging in Egypt's Valley of the Kings, led by British Egyptologist Howard Carter, discovered it in November 1922.

Breaking into the tomb, they found an amazing collection of treasures. Two gilded statues of soldiers guarded the entrance to Tutankhamen's burial chamber, which glinted with fabulous objects—chariots and gold-covered furniture, including a throne to be used by the god-king in the afterlife. All around lay weapons, jars of precious oils, chests of jewelry, beautifully painted caskets, and a fleet of miniature ships to help him on his trip to the underworld. The king's mummified body, protected by amulets (charms), lay inside the innermost coffin of the golden shrine, his head and shoulders covered by the most magnificent gold mask.

The ancient Egyptians loved gold and jewelry. They assigned magical qualities to the gemstones—amethysts, carnelians, and jaspers—that they used in their amulets and necklaces. They believed that gold was sacred to the sun-god Ra because it does not tarnish, and always shines brightly. Much of their gold came from Nubia (modern-day Sudan) on the Nile River.

Breastplate
Found in Tutankhamen's tomb, this breastplate features a sacred scarab beetle.

Mask of gold
Tutankhamen's death mask is a portrait of the young pharaoh. Made of solid gold, it weighs 22.5 lb (10.2 kg) and is 21 in (54 cm) high. The lifelike eyes are made of obsidian and quartz. Blue glass was used for the stripes of the royal headdress, called the *nemes*. Precious lapis lazuli was used to outline the sweeping eyelids and eyebrows.

The jade princess

In ancient China, jade was thought to have magical powers to preserve dead bodies and to keep wicked demons away. When a prince or princess died, they were sometimes buried in suits made entirely of jade in the hope that they might live forever.

Prince Liu Shen and his wife Princess Tou Wan died nearly 2,000 years ago during the Han Dynasty (206 BCE–220 CE). They were buried side by side in a lavish tomb hollowed out of a hillside, surrounded by more than 10,000 precious objects. Both were dressed in burial suits made up of over two thousand small jade squares, or plaques. To make the plaques, craftsmen had to saw thin slices of jade from a jade rock. It was time-consuming work because

Skilled work
A lifelike deer decorates this jade buckle, made by a craftsman of the Han Dynasty.

jade is a hard material to cut, and experts think it would have taken more than ten years to complete a single suit.

Small holes were drilled into the corners of each plaque and they were then sewed together. Liu Shen and Tou Wan's suits were sewed together with gold thread, indicating their royal status. Silver thread was used for nobles' suits, and bronze for those of lower rank. In 223 CE, Emperor Wei ordered an end to the making of jade suits to stop looters from breaking into tombs to steal the valuable threads.

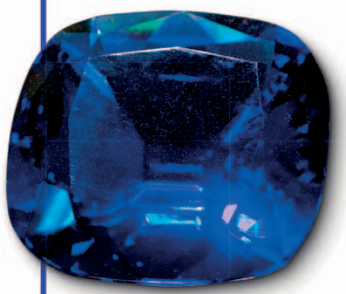
Looters did not disturb Princess Tou Wan's tomb, but when her coffin was opened in 1968, her suit was found in thousands of pieces and all that was left of her body was a little dust. Her restored suit is now on display in Hebei Provincial Museum in China. Experts used 25 oz (700 g) of gold thread to join together the 2,156 individual jade plaques.

Total protection
The jade suit covered the entire body from head to toe.

Princess Tou Wan's burial suit
The princess's restored burial suit is on display in Hebei Provincial Museum, China. Her head rests on a bronze headrest inlaid with jade.

The Hope Diamond

The Hope Diamond—one of the most famous diamonds in the world—is a large, deep-blue stone weighing 45.52 carats (9.1 g/0.32 oz). This rare gemstone, once owned by the kings of France, has a fascinating and eventful history.



Deep-blue stone
The Hope Diamond, like the example shown here, owes its deep-blue color to traces of the element boron in its crystal structure. It glows red when exposed to ultraviolet light.

In the 1660s, a French merchant named Jean-Baptiste Tavernier returned from his travels in India with a large, uncut blue diamond. He had it cut in the Indian style and then sold it to King Louis XIV of France in 1668. After having it recut to a more brilliant shape, the king had the gem mounted on a gold stick to be held and displayed. An observer reported that the jewel was the size of a pigeon egg. It took the breath away when it caught the light. Known as the "Blue Diamond," the stone became part of the Crown Jewels of France. However, during the French Revolution in 1792, it was stolen along with the rest of the Crown Jewels.

The diamond was probably smuggled to Britain, but no one knew its precise fate until it turned up in the gem collection of a wealthy British banker, Henry Philip Hope, in 1839. The Hope family sold the Hope Diamond, as it was now known, in 1901, and it passed through several hands before being bought by a wealthy New York socialite, Evalyn Walsh McLean, in 1912. Although the diamond was said to bring bad luck, she wore it to parties until her death in 1947. In 1958 it was donated to the Smithsonian Institution, in Washington, DC.

Generous donation
Edna Winston, wife of donor Harry Winston, presented the Hope Diamond to the Smithsonian Instution in 1958.

Mounted Hope Diamond
The French jeweler Pierre Cartier designed the Hope Diamond's modern setting for Evalyn Walsh McLean in 1920. It is set in platinum, surrounded by 16 white diamonds, suspended in a chain made of 45 diamonds.

Aztec turquoise

The ancient Mexicans treasured turquoise. They decorated all kinds of objects—knife handles, helmets, collars, and masks—with tiny pieces of the hard, blue-green gemstone, which came from sources in modern-day Arizona and New Mexico, about 1,243 miles (2,000 km) away.

Common currency
Ancient Mexicans traded beautiful jewelry and artifacts, such as this gold and turquoise necklace.

The Aztecs, the last people to rule ancient Mexico, thought that turquoise was sacred. The Aztec fire god was called Xiuhtecuhtli, which means "Turquoise Lord." Stunning turquoise-covered sculptures and ornaments featured in their rituals and sacrifices to the gods.

Like all the people of ancient America, the Aztecs did not have metal tools. Craftsmen ground and polished the hard turquoise rock with a paste made of grit mixed with water. They created thousands of flat, thin pieces, which were then fitted tightly together in a mosaic design, and used glues made of pine resin and other plant materials to fix the pieces in place.

When Spanish soldiers invaded Mexico in 1519, the last Aztec king, Moctezuma II, sent valuable gifts to the Spanish commander Hernán Cortés. It is possible that the fearsome double-headed turquoise serpent (below) was among them. Moctezuma welcomed Cortés into his capital city of Tenochtitlan, now buried under Mexico City, but the Spanish took him prisoner and soon went on to conquer Mexico.

Double-headed serpent
This double-headed serpent may once have been the chest ornament of an Aztec high priest, perhaps King Moctezuma himself. Its body is covered with 2,000 pieces of turquoise.

Mosaic mask
Ancient Mexicans used these masks with inlaid eyes and teeth to worship the gods.

Viking silver

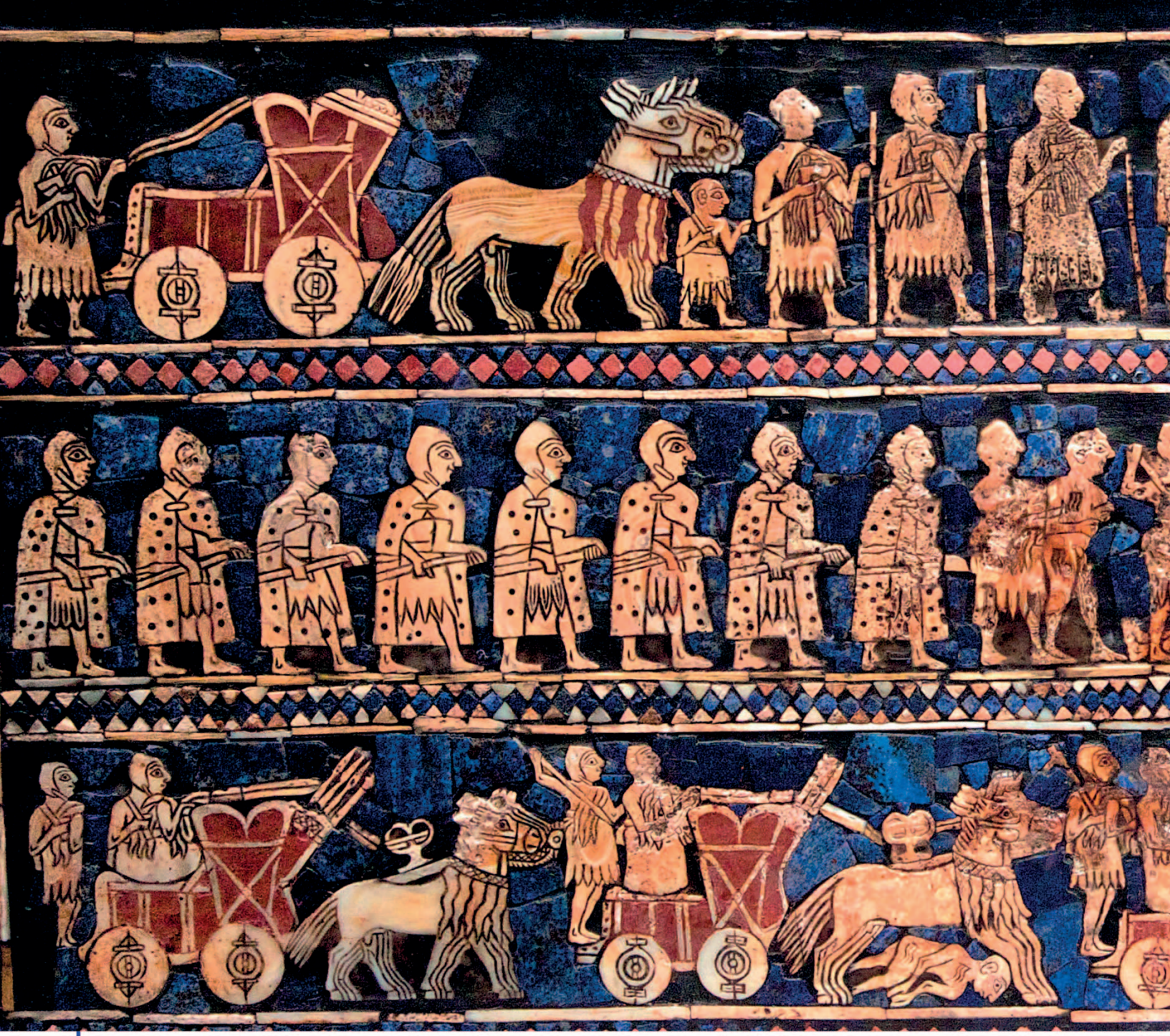
On May 15, 1840, workmen repairing a riverbank in Cuerdale, in northwestern England, stumbled upon heaps of silver and coins inside the remains of a lead box. The buried treasure, known as a hoard, most likely belonged to a Viking chieftain who never returned to retrieve it.

The Cuerdale Hoard is one of the biggest Viking hoards ever found. It was buried in about 905 CE, a time when the Vikings—seafaring warriors originally from Norway, Denmark, and Sweden—controlled much of northern and eastern England. No one knows why the treasure was hidden. A local chief may have buried all his wealth for safety during a time of turmoil and upheaval, intending to return for it when things calmed down. Perhaps it was the war chest of a Viking king who was on the eve of fighting a large battle. He had gathered the silver together to reward his warriors, but the battle was lost, and he never came back.

Amazing discovery
Twisted bracelets, broken brooches, and ingots (solid lumps) of silver were among the items found in the Cuerdale Hoard.

The silver hoard weighed 88 lb (40 kg). The bulk of it was made up of "hack-silver"—hundreds of rings, brooches, bracelets, and other ornaments that had been broken up into small pieces to be used as currency, or to be melted down and used again. There were also around 7,500 silver coins. Some of the coins have Kufic (the oldest Arabic script) writing on them. As well as fighting and raiding, the Vikings were active traders, with links that stretched all the way from the far north of Europe to southern Russia, Constantinople (modern-day Istanbul), and the Middle East.

Traders' coins
Many of the coins were minted in the Viking kingdom of York (northern England), but others came from more distant lands where the Vikings raided and traded.



Royal treasure

This ancient treasure is known as the Standard of Ur. It was found in the grave of a king of Ur, an early city that arose in Sumer (now in southern Iraq) more than 5,500 years ago. Made of wood, the Standard is decorated with mosaics (small tiles) of lapis lazuli, shell, and red limestone.

The Standard is quite small, about the size of a large computer screen. One side shows a battle scene with four-wheeled war chariots, spearmen, and foot soldiers. On the other, a procession of men and animals is bringing food for a royal banquet, shown at the top. When first discovered, the object was thought to be a war standard, but experts now believe it was part of a musical instrument like a lyre. A musician in the banquet scene on the Standard is playing such an instrument.

Into battle
The war side of the Standard shows a conquering Sumerian army. On the bottom row, war chariots pulled by donkeys trample the enemy. In the middle, armed soldiers guard a group of captives. At the top, bound prisoners are being led in front of the king, who is shown larger than the rest.

When the king of Ur died, he was buried with members of his family and with his court officials and servants so that they could continue to look after him in the next world. Many fabulous things were found in the royal cemetery of Ur, including intricate gold headdresses and necklaces, statues made of gold and lapis lazuli, combs and makeup kits, drinking cups, many weapons, and an ornate helmet. Although the limestone and shell used on the Standard was probably sourced nearby, the lapis lazuli came from a remote valley in northeast Afghanistan more than 1,400 miles (2,250 km) away, one of the few places on Earth where it is found. Lapis lazuli has always been highly prized for its rarity and intense deep-blue color.

Celebration and music
The peace side of the Standard depicts celebration. In this detail from the top row, a musician is seen playing a lyre decorated with the head of a bull. Experts believe that the Standard may have formed the sounding box for an instrument like this. Next to him, a seated guest is drinking from a cup.

Treasures of Troy

Legendary jewels
Schliemann published a famous photograph of his wife Sofia wearing the "jewels of Helen."

Heinrich Schliemann, a German businessman, loved the story of the Trojan War as told by the ancient Greek poet Homer in his epic poem, the *Iliad*. He dreamed of finding the long lost city of Troy and in the 1870s, he began looking for it at a site in northwest Turkey.

Digging into a hillside, Schliemann quickly came across ruins. He identified one of them as the palace of King Priam, ruler of ancient Troy, where he found objects made of copper, silver, and gold. A silver vase contained two gold diadems (headdresses), six gold bracelets, two gold goblets, and 8,750 gold rings. He believed they were the jewels of the beautiful Helen of Troy of legend. Schliemann smuggled the jewels out of Turkey, then part of the Ottoman Empire. The government was furious and refused to allow him to dig there again. The official who had been responsible for overlooking the excavation was even sent to jail. Schliemann went on to Mycenae in Greece, where he discovered a gold death mask that he mistakenly claimed belonged to Agamemnon, king of the Greek army in the Trojan War.

The hill Schliemann excavated at Troy contains the remains of several ancient cities. The events on which Homer's epic is based probably took place about 1,200 BCE. Modern research shows that the treasures of Troy came from a city that is about 1,000 years older. Today Troy is a UNESCO World Heritage Site.

Golden diadem
This is the larger of the two gold diadems, or ornamental headdresses, that Schliemann found at Troy. It is made of 16,000 pieces of gold threaded onto gold wires.

Mask of Agamemnon
The gold death mask was made from one sheet of hammered gold. When he discovered it at Mycenae, Schliemann said, "I have gazed on the face of Agamemnon." We now know that it belonged to a king who ruled about 1550 BCE, long before the Trojan War is supposed to have taken place.

The tale of a pearl

What links a queen of England, an emperor of France, and a famous Hollywood star? The answer is an enormous, pear-shaped pearl, nicknamed La Peregrina, meaning "the Wanderer," which was found in the Gulf of Panama more than 550 years ago.

Portrait of a queen
Queen Mary I of England is sewen here wearing the La Peregrina pearl. It later became a favorite of Spanish queens.

The pearl was given to the Spanish royal family during the rule of either King Ferdinand V or his successor, King Charles V. In 1554, Charles' son, the future King Philip II, gave it to his new wife, Queen Mary I of England. When she died, in 1558, the pearl returned to Spain and formed part of the Spanish crown jewels.

In 1808, the French Emperor Napoleon I made his brother Joseph king of Spain. Joseph was forced to flee the country, and he took La Peregrina with him. He left the pearl to his nephew, Emperor Napoleon III of France, who, in 1870, also lost his throne, and later sold the pearl to a Scottish duke.

In 1969, La Peregrina came up for sale at Sotheby's in London. There was huge excitement when actor Richard Burton bought it as a Valentine's Day gift for his wife, the beautiful Hollywood star Elizabeth Taylor. In 2011, Taylor sold the pearl, reset in a necklace with diamonds and rubies, for $11 million.

Diamonds, rubies, and pearls
On acquiring the pearl, filmstar Elizabeth Taylor commissioned Cartier to redesign the necklace, setting La Peregrina with pearls, diamonds, and rubies.

Glossary

Accessory mineral
A minor mineral that is present in small amounts in a rock.

Achondrite
A stony meteorite that does not contain chondrules (round crystalline balls).

Asteroid
A chunk of rock, smaller than a planet, that orbits the Sun.

Batholith
A very large igneous intrusion of molten magma underground.

Bedrock
The solid rock that lies under soil and sediments.

Botryoidal
A mineral habit that resembles a bunch of grapes.

Breccia
A sedimentary rock made up of angular fragments.

Cabochon
A gemstone that is polished but not faceted (flat faces cut in it).

Calcareous
A rock that contains a significant amount of calcium carbonate mineral, or is chalky.

Canyon
A deep, steep-sided valley, typically cut by a river.

Carat
The standard measure of weight for precious stones and metals. A carat is equal to 0.007 oz (0.2 g).

Chalcedony
A microcrystalline type of quartz. The most common is agate, but it can occur in different forms, including onyx.

Chondrite
A stony meteorite containing tiny spherical chondrules.

Cleavage
The characteristic way a mineral or rock breaks along a certain plane, or in a certain direction.

Coccolith
A microscopic rounded platelet made of the mineral calcium carbonate, which once formed a part of the spherical shells of a tiny planktonic animal.

Concretion
A hard and compact rocky lump formed when mineral cement is deposited in the spaces between sedimentary particles. Often rounded or oval, they are found in shale and clay beds, as well as soils.

Crystal
A naturally occurring solid substance whose atoms are arranged in a regular 3-D pattern.

Crystal system
The systems into which crystals are grouped based on their symmetry. There are six crystal systems: cubic, monoclinic, triclinic, trigonal/hexagonal, orthorhombic, and tetragonal.

Dendritic
A crystal habit that looks like branching fingers.

Dodecahedral
A crystal or mineral with a dodecahedron shape—a 3-D form with 12 faces.

Element
A chemical substance that cannot be broken down further.

Erosion
Gradual wear and transportation of the solid surface of Earth by wind, water, and ice. It grinds down rocks and shapes the land.

Evaporite
A natural salt mineral formed from residues left behind when briny water has evaporated.

Extinct
A group of organisms (animals, plants, fungi, or microorganisms) that has no living members and is no longer in existence. Many fossils, such as dinosaurs and trilobites, belong to extinct groups.

Extrusive rock
An igneous rock that formed from magma that solidified above ground.

Face
An external flat surface on a rough crystal.

Facet
A flat face cut into a gemstone. A cut stone is called faceted.

Fault
An extended fracture or weakness in rock—often a flat plane—along which rock masses move. A fault line is where a fault appears.

Fibrous
A mineral habit composed of thin fibers.

Fluorescence
The optical effect whereby a mineral appears to glow in ultraviolet (UV) light. It often glows a different color under UV light than it does in ordinary light.

Fossil
A trace of past life that has been preserved in a rock or mineral such as amber. Fossils include bones, shells, skin impressions, footprints, dung, wood, leaves, and pollen.

Fossiliferous
A rock containing fossils.

Fracture
The distinctive way in which a mineral breaks.

Gemstone
A beautiful, high-quality, hard mineral that is valued for its color and rarity. Gems usually have a near-perfect, or unique, crystal shape.

Geode
A cavity in a rock that has been filled, or partially filled, with crystals. It is sometimes called a "thunder egg."

Identifying minerals

There are many ways to identify a mineral, including observing its color and shape, and how it looks when it reflects light. The hardness of a mineral can be measured by how easily it scratches.

COLOR

Many minerals have characteristic colors that make them instantly recognizable. Others, such as fluorite, come in a range of tones, which are due to different impurities in the crystals.

Purple fluorite

Green fluorite

LUSTER

Luster is the way a mineral reflects light. There are a number of terms to describe this, from waxy to metallic, earthy, and vitreous (glassy).

Galena: metallic luster

Quartz: vitreous luster

SPECIFIC GRAVITY

A mineral's specific gravity is a measure of its density. This is calculated by weighing a crystal and comparing it to the mass of an equal volume of water. This requires specialist equipment.

Jasper: 2.7

STREAK

A mineral may not always appear the same color. It may have been altered by weathering, for example. So geologists carry a hard ceramic scratch plate and test a mineral's "streak", which does not vary.

Orpiment

Cinnabar

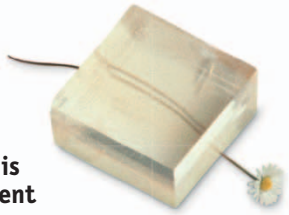
FRACTURE

Minerals also crack and splinter in other directions to their cleavage. The way they do this is often typical of a mineral.

Obsidian: shell-like fracture

TRANSPARENCY

If light can pass through a mineral, it is called translucent. If a mineral is opaque, no light can pass through it. Transparent minerals are clear and see-through.



Calcite is transparent

CLEAVAGE

Most crystals have planes of weakness along which they will break, known as their cleavage. Because crystal structures are regular and repeating, they break again and again along characteristic angles.

Topaz cleaves, or breaks, into a prism-shaped crystal

HARDNESS

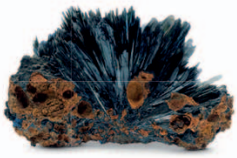
One of the easiest tests is to find a mineral's hardness. This is measured on the Mohs scale—a relative scale, from 1–10, tested by scratching the mineral—or by using it to scratch something else.

Talc: 1 – can be cut with fingernail

Diamond: 10 – can cut glass

HABIT

The outward appearance of a crystal is called its habit. A mineral's habit depends on the pattern that its crystals form as they grow. If there is no clear shape, it is called "massive".



Vivianite: needlelike

Gypsum: bladed

Groundmass
The compact, fine-grained mineral material in which larger crystals or grains are embedded.

Habit
The general appearance and shape of a mineral. A mineral's habit can be affected by its crystal system and the conditions under which it grew.

Ice cap
A thick covering of ice over an area of land. Larger ice caps more than 19,305 sq miles (50,000 sq km) are usually called ice sheets.

Igneous rock
A rock formed when molten lava or magma solidifies on or below Earth's surface.

Impurity
An atom or chemical compound incorporated into a mineral's crystal structure that is not an essential part of its makeup. It often affects the color of minerals and gems.

Inclusion
Any material that gets trapped inside a crystal during its formation.

Ingot
A solid block of metal, typically rectangular in shape.

Intrusive rock
An igneous rock that forms when magma solidifies below the surface.

Invertebrate
An animal with no backbone, such as worms and arthropods.

Lava
Magma that has flowed onto Earth's surface through a volcanic opening.

Luster
The way in which light reflects off the surface of a mineral.

Magma
Molten rock found deep inside Earth. Magma collects in a magma chamber to feed a volcano.

Mantle
The layer of the planet that lies between the core and the crust. It contains over 80 percent of Earth's total volume, and consists of hot, dense rocks.

Matrix
Also known as groundmass, the matrix of a rock is the fine-grained mass in which larger grains or crystals are embedded.

Metamorphic rock
A rock that has been transformed within Earth by heat or pressure, or both.

Meteor
A meteoroid (rock and dust debris in space) that burns up as it travels through Earth's atmosphere, appearing as a bright streak, or "shooting star," in the night sky.

Meteorite
A rock or dusty debris from outer space that reaches the surface of Earth.

Microcrystalline
A mineral habit that is made up of microscopic crystals.

Mineral
A naturally occurring solid that has specific characteristics, such as a particular chemical composition and crystal shape.

Native element
A chemical element found in nature in its pure form.

Nodule
A hard, rounded, stony lump found in sedimentary rock. It is typically made from calcite, silica, pyrite, or gypsum.

Nugget
A small lump of a precious metal found in its native state.

Octahedral
A crystal or mineral that has an octagon shape—a solid 3-D form with eight faces.

Opaque
A substance that does not let light pass through it.

Ore
A rock or mineral from which a metal can be extracted.

Organic
Relating to living things.

Pearly
A mineral luster with a soft sheen, like a pearl.

Petrification
The process by which a living thing turns to stone fossil in a rock.

Pigment
A colored substance that is powdered and mixed to make paint.

Pisolitic
A rock texture formed of pea-sized balls.

Placer deposit
A deposit of sand or gravel on a river bed or lake bed, with particles of valuable minerals.

Plateau
An area of high-level ground.

Polymorph
A mineral with an identical chemical composition but a different structure.

Porphyritic
A rock texture made of larger crystals embedded in a fine-grained groundmass. Typical of volcanic rocks.

Prism
A solid 3-D form whose two end faces are the same shape, equal size, and parallel to one another.

Prismatic
Crystals with a uniform cross-section, having parallel long sides.

Recrystallization
The process by which secondary minerals grow; changes in a rock when heat or pressure cause minerals to regrow.

Rock
A solid mixture of minerals. There are three types: igneous, metamorphic, and sedimentary.

Secondary mineral
A mineral that replaces another as a result of weathering or other alteration process.

Sediment
Particles of rock, mineral, or organic matter that are carried by wind, water, and ice.

Sedimentary rock
A rock formed from sediments that have been cemented together by weathering or burial.

Shield volcano
A broad volcano with gently sloping sides that produces swift-flowing basalt lavas.

Smelting
The chemical process of extracting metal from its mineral ores.

Striation
A prominent groove in a rock or mineral, usually all in the same direction.

Tectonic plate
One of the huge, rocky slabs into which the outer layer of our planet is broken. Heat within Earth drives tectonic plates across the surface. Volcanoes and earthquakes happen where these plates bump and crash into each other.

Translucent
A substance that allows light to pass though it.

Twinning
Crystals that share a common face or edge.

Volcanic bomb
A large lump of lava that is ejected into the air from a volcano.

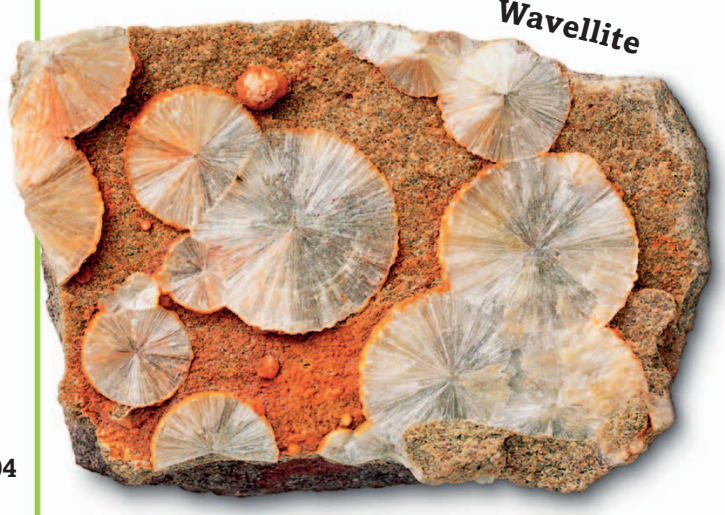
Volcano
The site of an eruption of lava and hot gases from within the Earth. Magma follows a central passage to reach the surface and erupts as lava.

Weathering
The slow breakdown of rock by long exposure to the weather, including moisture, frost, and chemical rainwater.

Wingspan
The distance from wingtip to wingtip, when the wings are fully outstretched.

Index

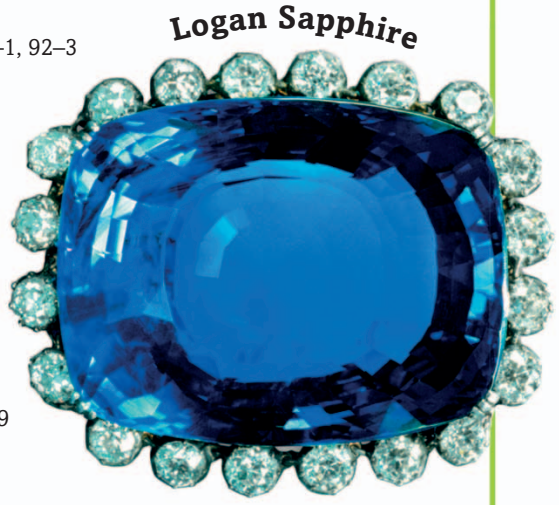
A-C



Wavellite

D-G

H-L



M-O


Precious opal

P-T

U-Z

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(cb/jaw). **Science Photo Library:** THE NATURAL HISTORY MUSEUM, LONDON (cb). **138 Corbis:** Jonathan Blair (tl). **Dorling Kindersley:** The Senckenberg Nature Museum (tr); The Natural History Museum, London (c). **139 123RF.com:** Michael Rosskothen (cla). **Alamy Images:** Thomas Cockrem (cb). **Corbis:** Ken Lucas (tl). **Dorling Kindersley:** The Natural History Museum, London (tr). **Getty Images:** Eric Van Den Brulle (cr); ANTONIO SCORZA (ca). **SuperStock:** Clive Glen (clb). **140 Dorling Kindersley:** Oxford Museum of Natural History (ca). **Dreamstime.com:** Seanyu (cla). **Science Photo Library:** DIRK WIERSMA (tr). **140-141 Dorling Kindersley:** Senckenberg Gesellshaft Fuer Naturforschugn (c). **141 Dorling Kindersley:** The American Museum of Natural History (crb); The Natural History Museum, London (tl); State Museum of Nature, Stuttgart (cb). **Dreamstime.com:** Seanyu (cra). **142 Alamy Images:** Corbin17 (clb). **Dorling Kindersley:** The Royal Tyrrell Museum of Palaeontology, Alberta, Canada (ca); The Natural History Museum, London (tr); The Senckenberg Gesellshaft Fuer Naturforschugn Museum (cl). **142-143 Dorling Kindersley:** The Natural History Museum, London (c). **143 Dorling Kindersley:** Oxford Museum of Natural History (cla); The Royal Tyrrell Museum of Palaeontology, Alberta, Canada (tc); The Senckenberg Gesellshaft Fuer Naturforschugn Museum (crb). **144 Corbis:** Louie Psihoyos (cla); Bernard Weil (cr). **Dorling Kindersley:** The Royal Tyrrell Museum of Palaeontology, Alberta, Canada (clb); The Senckenberg Nature Museum, Frankfurt (crb). **145 Alamy Images:** John Cancalosi (tl); WaterFrame (cra); The Natural History Museum (cb). **Dorling Kindersley:** Jon Hughes (ftr); The Natural History Museum, London (tr). **Science Photo Library:** MATTEIS (cl). **146-147 Getty Images:** Spencer Platt (c). **148 Alamy Images:** Encyclopaedia Britannica / Universal Images Group Limited (cb); Amy Toensing / National Geographic Image Collection (c). **Dorling Kindersley:** The Natural History Museum, London (tr, crb). **Science Photo Library:** JAIME CHIRINOS (cla). **149 Alamy Images:** Pat Canova (crb); WaterFrame_sta (clb). **Dorling Kindersley:** The Natural History Museum, London (cla). **Science Photo Library:** UCL, GRANT MUSEUM OF ZOOLOGY (t); The Natural History Museum, London (fcla, cr). **Roman Uchytel:** Roman Uchytel (crb/Hyracotherium). **150 Dorling Kindersley:** The Natural History Museum, London (cla); National Museum of Wales (clb); The Natural History Museum, London (cb); The Oxford Museum of Natural History (crb). **150-151 Dorling Kindersley:** The Natural History Museum, London (ca, cb). **151 Alamy Images:** The Natural History Museum (tr). **Dorling Kindersley:** The Natural History Museum, London (tc, cr). **Science Photo Library:** The Natural History Museum, London (c). **152-153 Photoshot:** World Pictures. **154-155 Alamy Images:** Frans Lanting. **156-157 Dreamstime.com:** Milanmarkovic. **157 naturepl.com:** Wild Wonders of Europe / Lundgren (br); Nature Production (crb). **162-163 naturepl.com:** Alex Mustard. **164 Science Photo Library:** GILLES MERMET (ca). **165 Alamy Images:** The Natural History Museum, London (r). **Science Photo Library:** GILLES MERMET (crb). **172-173 naturepl.com:** GEORGETTE DOUWMA. **176-177 Photoshot:** Imagebroker. **181 Dorling Kindersley:** The Natural History Museum, London (cr). **182-183 Getty Images:** Ullstein bild. **184-185 Alamy Images:** Scott Camazine. **186 Alamy Images:** Kenneth Garrett / Danita Delimon (cla). **Getty Images:** De Agostini / A. 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