

SCIENCE COURSE

Geology & Plate Tectonics Fundamentals

8 Chapters

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GEOLOGY & PLATE TECTONICS FUNDAMENTALS

Contents

Chapter 1	Reading the Rocks	2
Chapter 2	Minerals and Rocks	8
Chapter 3	Moving Plates	12
Chapter 4	Quakes and Volcanoes	17
Chapter 5	Mountains and Faults	22
Chapter 6	Shaping the Surface	27
Chapter 7	Deep Time	32
Chapter 8	Rocks and People	37

Geology & Plate Tectonics Fundamentals

Course 1 · Chapter 1 · Reading the Rocks: Scope & Sources

In 1788 the Edinburgh naturalist James Hutton took two friends by boat to a headland on the Berwickshire coast, Siccar Point, where grey layers of rock stand on end beneath a cap of red sandstone laid down almost flat. One of the friends later wrote that the mind seemed to grow giddy looking so far back into the abyss of time. The scene is often called the birth of modern geology, and it is a good place to begin: ordinary rock, patiently read, can tell you things that no written record can. This course covers what the Earth is made of, how it moves, and how we know. This first chapter sets out what geology studies, the scale of time it works on, the layers of the planet, the three families of rock, and the kinds of evidence behind the claims. Dates, depths and ages are from general knowledge and flagged "check" where they matter.

What Geology Studies

Materials

Minerals and rocks: what they are made of, how they form and how to tell them apart. A mineral is a naturally occurring solid with a definite chemical make-up and crystal structure; a rock is usually a mixture of minerals (check the definitions against a textbook).

Processes

The forces that build and wear down the surface: volcanoes, earthquakes, mountain building, erosion, rivers and ice. Some are fast and dangerous, and most are slow beyond easy imagination.

History

The record of the planet and its life, read from layers of rock and the fossils in them. This is where geology meets biology and climate science.

The key idea

> Hutton's principle, often summed up as "the present is the key to the past", says that the slow processes we can watch today, such as rivers carrying sediment or lava cooling, also explain the rocks we find. It is a method as much as a fact: you test an explanation of an old rock by asking whether a process we can observe could have made it.

Deep Time

Geologists measure the Earth's age in billions of years, with the commonly given figure of about 4.5 billion years (check). The mind cannot picture it, so a scale helps. Imagine the whole history of the Earth squeezed into a single 24-hour day.

Event (check each)	Rough age	On the 24-hour clock
Formation of the Earth	4.5 billion years ago	00:00
Oldest known life (microbes)	Over 3.5 billion years ago	About 05:00
First animals with hard shells and the "Cambrian explosion"	About 540 million years ago	About 21:00
Dinosaurs go extinct	About 66 million years ago	About 23:35
Modern humans	A few hundred thousand years ago	Last few seconds

Hutton wrote of finding "no vestige of a beginning, no prospect of an end", a phrase still quoted. The estimate of 4.5 billion years comes from radiometric dating of meteorites and the oldest Earth rocks, a method the course covers later (check).

Layers of the Earth

Layer (check depths)	What it is	How we know
Crust	Thin, rocky outer skin; thinner under oceans and thicker under continents	Direct sampling, mines, boreholes
Mantle	Thick layer of hot rock that is solid but creeps very slowly over long periods; most of the planet's volume	Earthquake waves; samples brought up by volcanoes
Outer core	Liquid iron-rich metal; its movement helps produce the magnetic field	Earthquake waves that cannot pass through it in the same way (S-waves)
Inner core	Solid iron-rich ball under enormous pressure	Earthquake wave patterns

No one has drilled more than about 12 kilometres down (check), a tiny fraction of the distance to the centre, roughly 6,400 kilometres (check). Most of what we know about the interior comes from the way earthquake waves travel through it, a good example of indirect evidence.

The Three Families of Rock

Igneous

Formed from molten rock. If it cools slowly underground it forms coarse crystals, as in granite; if it cools quickly at the surface it forms fine grains or glass, as in basalt. Edinburgh's Arthur's Seat is the remains of an ancient volcano (check).

Sedimentary

Formed from fragments, shells or chemical deposits laid down in layers and then cemented, as in sandstone, limestone and shale. Fossils are found mainly here. The red sandstone at Siccar Point is one example.

Metamorphic

Existing rock changed by heat and pressure without melting completely, as in marble from limestone and slate from shale. Scotland's Lewisian gneiss in the north-west

is among the oldest rocks in Europe, close to three billion years old (check).

The families are linked by the **rock cycle**: any rock can be weathered into sediment, buried, heated, melted and cooled again. The cycle is slow, and parts of it are driven by plate movements (Chapter 3).

How Geologists Know

- **Field observation.** Mapping rocks where they appear, recording layers, angles and fossils. Geology is a field science first.
- **Layering and fossils.** Younger layers usually lie on top of older ones (the principle of superposition), and certain fossils mark particular periods (check).
- **Laboratory work.** Thin slices of rock under a microscope, chemical analysis and radiometric dating.
- **Geophysics.** Earthquake waves, gravity, magnetism and satellite measurements of ground movement.
- **Models.** Computer and laboratory models test whether a proposed process could produce what is observed.
- **Reasoned caution.** Rock records have gaps. A missing layer may mean erosion or no deposit at all, and geologists describe confidence, not certainty.

Map of the Course

Chapters	Theme
2	Minerals and rocks: identifying and classifying
3	Plate tectonics: the theory and the evidence
4	Earthquakes and volcanoes
5	Mountains, faults and folds
6	Surface processes: weathering, rivers and ice

Chapters	Theme
7	Deep time: fossils, dating and the geological timescale
8	Geology and people: resources, hazards and Scotland's rocks

A British comparison

Britain is unusually rich in geology for its size: rocks of almost every age are found within a few hundred miles, which is one reason the science developed here in the 18th and 19th centuries. Scotland has the ancient gneiss of the north-west, the Highland Boundary Fault that crosses the country from Arran to Stonehaven (check), the volcanic hills around Edinburgh and the coast at Siccar Point. On a clear day in Edinburgh you can look at several of these at once from Arthur's Seat.

Check the details

Ages, depths and dates change as methods improve, and popular sources often repeat rounded or outdated figures. Check numbers against the British Geological Survey, a university text or the International Commission on Stratigraphy before relying on them. Local rock descriptions should be checked against a geological map of the area.

Exercises

EXERCISE 1

Explain in about 80 words why Hutton's idea that "the present is the key to the past" is both a fact about rocks and a method, and give one example of using it.

→ Solution

EXERCISE 2

Make your own 24-hour clock for the Earth's history using two more events from a source you trust, and say which source you used.

→ Solution

EXERCISE 3

Choose one rock from each family (igneous, sedimentary, metamorphic) and describe how it forms and one way you could tell it apart from the others.

→ Solution

Quick Reference

- **Geology:** materials, processes and history of the Earth
- **Deep time:** about 4.5 billion years (check)
- **Layers:** crust, mantle, outer core, inner core
- **Rock families:** igneous, sedimentary, metamorphic, linked by the rock cycle
- **Method:** observe, compare with present processes, test with data and models

Geology & Plate Tectonics Fundamentals

Course 1 · Chapter 2 · Minerals and Rocks: Identifying and Classifying

Pick up a pebble from an Edinburgh beach and you are holding a record of how it was made. Reading it begins with two steps: say which minerals it contains, then say how they are arranged. This chapter covers how minerals are identified with simple tests, which few minerals make up most of the crust, and how the three rock families of Chapter 1 are sorted into named types. Hardness values, densities and names are from general knowledge and flagged "check" where they matter.

What Is a Mineral?

Five conditions

A mineral is naturally occurring, solid, has a definite chemical composition, has an orderly internal crystal structure, and is normally inorganic (check; textbooks differ slightly on the last point). Ice in a glacier counts, water in a river does not.

Crystal structure

The atoms are arranged in a repeating pattern. That pattern decides how a mineral breaks, how hard it is, and the shape of its crystals when they have room to grow.

Mineral or rock?

Quartz is a mineral. Granite is a rock made of quartz, feldspar and mica. Limestone is mostly the single mineral calcite, which shows that a rock can consist of one mineral (check).

Why so few minerals matter

More than five thousand minerals have been named (check), yet a handful of silicate minerals make up most of the crust: feldspars, quartz, micas, pyroxenes, amphiboles and olivine. Silicates are built from silicon and oxygen, the two most abundant elements in the crust. For most field geology, a short list is enough.

Identifying a Mineral

Property	How to test it	Example (check)
Hardness	What scratches what, using the Mohs scale of 1 to 10, with a fingernail (about 2.5), a coin and a steel knife as everyday tools	Talc is 1, quartz 7, diamond 10
Streak	Colour of the powder when rubbed on unglazed porcelain	Haematite looks grey or black but streaks red-brown
Lustre	How light reflects: metallic, glassy, pearly, dull	Pyrite is metallic, quartz is glassy
Cleavage and fracture	Whether it splits along flat planes or breaks unevenly	Mica peels in sheets; quartz breaks with curved fracture
Density	How heavy it feels for its size	Galena feels unusually heavy
Reaction to acid	Fizzing in weak acid (use with care)	Calcite fizzes; quartz does not

Colour alone is a poor guide, because the same mineral can come in many colours. Use several tests together, and say how confident the result is.

Classifying Rocks

Family	Main clue	Examples (check)
Igneous	Interlocking crystals; size shows cooling speed; no layers or fossils	Granite (slow, coarse), basalt (fast, fine), pumice (frothy glass)
Sedimentary: clastic	Grains of broken rock, sorted by size and cemented	Conglomerate, sandstone, shale
Sedimentary: chemical or organic	Mineral crystals or shells and plant remains	Limestone, rock salt, coal

Family	Main clue	Examples (check)
Metamorphic: foliated	Minerals lined up in bands or sheets by pressure	Slate, schist, gneiss
Metamorphic: non-foliated	Interlocking crystals without banding	Marble, quartzite

Two questions get you far in the field: are the grains or crystals interlocking, or separate and cemented? Are they in layers? Interlocking and unlayered usually means igneous or non-foliated metamorphic. Separate grains in layers usually means sedimentary.

Reading Texture

- **Crystal size.** Large crystals formed slowly, usually deep; fine grains formed fast, near the surface.
- **Grain size and sorting.** In sedimentary rock, large rounded grains suggest strong flow and short travel; well-sorted fine grains suggest gentle water or wind.
- **Fossils.** Shells and plant remains show a sedimentary origin and often the environment, such as a shallow sea.
- **Banding.** Alignment of minerals suggests directed pressure, as in schist and gneiss (check).

A British comparison

Edinburgh gives a ready field kit. Arthur's Seat is volcanic, with fine-grained basalt and coarser rocks from the same volcano (check); Salisbury Crags beside it is an intrusion of dolerite that cooled underground (check); and the sandstone of the Old and New Town buildings is sedimentary, quarried locally in the past (check). A walk from the Crags to a stone tenement wall covers two of the three rock families.

Check the details

Mohs hardness numbers and mineral lists differ a little between sources, and rock names depend on exact composition, which needs a lab to confirm. Do not collect from protected sites, and test with acid only with proper safety advice.

Exercises

EXERCISE 1

You find a glassy, grey mineral that scratches glass and does not fizz in acid. Say which tests you used, what the most likely mineral is, and how sure you are.

→ Solution

EXERCISE 2

Explain the difference between granite and gneiss in terms of minerals and texture, and why both can look similar at first sight.

→ Solution

EXERCISE 3

Describe a two-question field key (yes or no) that separates igneous, sedimentary and metamorphic rocks, and say one rock it would misclassify.

→ Solution

Quick Reference

- **Mineral:** natural, solid, definite composition, ordered crystal structure
- **Tests:** hardness, streak, lustre, cleavage, density, acid reaction
- **Common silicates:** feldspar, quartz, mica, pyroxene, amphibole, olivine
- **Igneous clue:** interlocking crystals, no layers
- **Sedimentary clue:** cemented grains, layers, fossils
- **Metamorphic clue:** banding or recrystallised texture

Geology & Plate Tectonics Fundamentals

Course 1 · Chapter 3 · Plate Tectonics: The Theory and the Evidence

Look at a map of the Atlantic and the coast of South America seems to fit against the coast of Africa. Many people noticed this long before it became science. In 1912 the German meteorologist Alfred Wegener argued that the continents had once been joined and had drifted apart, and most geologists of his day rejected the idea, partly because he could not explain what moved them. It took until the 1960s for the evidence to turn the argument, and the resulting theory, plate tectonics, is now the framework for almost everything else in geology. This chapter follows that change of mind: the early evidence, the discoveries on the ocean floor, the plates and their boundaries, and the causes of movement. Dates and names are from general knowledge and flagged "check" where they matter.

Wegener and the Case for Drift

The fit

The edges of the continents, especially when matched at the edge of the continental shelf and not at the coast, line up well (check). On its own, a good fit is suggestive, not proof.

Matching fossils

The same fossil plant *Glossopteris* and the freshwater reptile *Mesosaurus* are found on continents now separated by oceans (check). Wegener argued that they could not have crossed an ocean.

Matching rocks and climate

Mountain belts and rock types continue across the Atlantic, and glacial deposits of the same age appear in places that are now warm, such as India and southern Africa (check).

Why was he rejected?

The evidence was strong, but Wegener's proposed mechanism, continents ploughing through the ocean floor driven by tides and the Earth's rotation, was too weak, and

physicists showed it. A good theory needs a plausible cause as well as a pattern. The Edinburgh-trained geologist Arthur Holmes suggested in the late 1920s that slow convection in the mantle might move the surface (check), but the idea had to wait for supporting data.

The Ocean Floor Changes the Argument

Discovery (check each date)	What it showed
Mid-ocean ridges (surveys after the Second World War)	A continuous mountain chain winds through the world's oceans, with a rift valley along its crest
Young ocean floor (1950s and 60s)	Ocean-floor rocks are far younger than the continents, with the youngest at the ridges; no known ocean floor is older than about 180 million years
Seafloor spreading (Harry Hess, early 1960s)	New crust forms at the ridges and moves outward; old crust sinks back at trenches
Magnetic stripes (Vine, Matthews and Morley, 1963)	Rocks on either side of a ridge record the Earth's magnetic field, which has reversed many times, in a mirror-image pattern of stripes
Earthquake locations (1960s)	Quakes trace narrow belts, outlining plates and dipping zones where one plate descends beneath another

The magnetic stripes were the turning point. When lava cools, magnetic minerals in it lock in the direction of the field at that time. A symmetrical pattern on either side of a ridge is just what you would expect if crust is made at the centre and carried away in both directions (check). Satellite measurements now track plate movement directly, at a few centimetres a year, about the speed at which fingernails grow (check).

The Plates and Their Boundaries

The outer shell of the Earth, the **lithosphere**, is broken into about a dozen large plates and several smaller ones (check). Each plate is a rigid slab of crust and the uppermost mantle, riding on the softer, weaker layer beneath, the asthenosphere.

Boundary	Movement	Typical features (check examples)
Divergent	Plates move apart	Mid-ocean ridges, rift valleys; Iceland sits on the Mid-Atlantic Ridge; East African Rift
Convergent: ocean meets continent	Denser ocean plate sinks beneath (subduction)	Deep trenches, volcanic mountain chains such as the Andes
Convergent: continent meets continent	Neither sinks easily, so crust crumples	Himalaya, Alps
Transform	Plates slide past each other	San Andreas Fault in California

Most earthquakes and volcanoes occur at plate boundaries, which is why they cluster in belts such as the "Ring of Fire" around the Pacific (Chapter 4). Intraplate volcanoes such as Hawaii are explained by hot spots, plumes of hot rock rising from deep in the mantle (check).

What Drives the Plates?

- **Mantle convection.** Heat from the interior makes the mantle flow very slowly, as Holmes proposed. The exact pattern is still debated (check).
- **Slab pull.** The cold, dense edge of a plate sinking at a trench pulls the rest of the plate along. Many geologists regard this as the largest force (check).
- **Ridge push.** The elevated ridge slides down, nudging the plate away. This is generally considered smaller (check).
- **Why it matters.** The cause is understood in outline but not in every detail. That is normal in science: the theory rests on evidence of movement, which is firm, more than on a complete account of the engine, which is still being refined.

A British comparison

Scotland carries the marks of a vanished ocean. Several hundred million years ago the northern part of Britain lay on a separate continent from England and Wales, with an ocean called Iapetus between them. When it closed, the collision raised the Caledonian mountains, and the join runs roughly along the Solway Firth and the Southern Uplands (check). Scotland and England were once thousands of kilometres apart, and Scottish and

English rocks of the same age contain different fossils because of it (check). Hutton's city is thus a good place to see what plate tectonics explains.

Check the details

Plate numbers, speeds and dates depend on the source and the method, and the story of who discovered what is often simplified in popular accounts. Check figures against the British Geological Survey or the US Geological Survey. Treat "Wegener was simply right" as a simplification: he was right about drift and wrong about the mechanism.

Exercises

EXERCISE 1

Explain why most geologists rejected Wegener in the 1910s and 1920s, and what changed by the 1960s. Name two pieces of evidence that carried most weight.

→ Solution

EXERCISE 2

A plate moves 2.5 cm a year. How far does it travel in 100 million years, and what does your answer tell you about the width of the Atlantic?

→ Solution

EXERCISE 3

Choose one of the four boundary types and describe the landscape you would expect, the likely hazards, and one real example you could look up.

→ Solution

Quick Reference

- **Drift (1912):** Wegener's fit, fossil and rock evidence, without a good mechanism
- **Seafloor spreading:** new crust at ridges; magnetic stripes in mirror image
- **Plates:** about a dozen large lithosphere slabs moving a few cm a year
- **Boundaries:** divergent, convergent (ocean or continent), transform
- **Drivers:** mantle convection, slab pull and ridge push

Geology & Plate Tectonics Fundamentals

Course 1 · Chapter 4 · Earthquakes and Volcanoes

On 1 November 1755 an earthquake destroyed much of Lisbon, and the shock was felt as far away as Scotland, where the water in Loch Lomond is reported to have surged without any wind (check). Chapter 3 explained where such events happen: along the edges of plates. This chapter explains how. It covers why rock suddenly breaks, how seismic waves are used to measure and locate quakes, why some mountains erupt, what makes volcanoes dangerous, and the honest limits of prediction. Numbers and dates are from general knowledge and flagged "check" where they matter.

Why the Ground Shakes

Stress builds

Plates move steadily, but rock along a fault is rough and sticks. Stress builds for years or centuries as the rock bends slightly, like a plastic ruler held at both ends.

The rock breaks

When the stress exceeds the strength of the rock or friction on the fault, it slips. The stored energy is released as seismic waves in seconds. This is the elastic rebound idea, developed after the 1906 San Francisco earthquake (check).

Focus and epicentre

The **focus** (or hypocentre) is where the rock first slips, underground. The **epicentre** is the point on the surface directly above it. Shallower quakes tend to cause more surface damage for a given size.

Seismic Waves and Measurement

Wave (check)	Type	Notes
P-waves	Body wave, compressional	Fastest; arrive first; pass through solids and liquids
S-waves	Body wave, shearing	Slower; arrive second; cannot pass through liquid, which is how the liquid outer core was detected
Surface waves	Travel along the ground	Slowest, but usually cause the most damage

- **Locating a quake.** The gap between the arrival of P- and S-waves at a station shows the distance to the source. Three stations give a position by triangulation.
- **Magnitude.** A measure of the energy released, now usually given as moment magnitude. The scale is logarithmic: each whole number is about 32 times more energy (check). A magnitude 7 releases about a thousand times the energy of a magnitude 5.
- **Intensity.** A description of the shaking and damage at a place, such as the Mercalli scale. A single quake has one magnitude but many intensities, depending on distance, ground and buildings.
- **Why buildings matter.** Casualties depend heavily on construction and soil, so a smaller quake can kill more people than a larger one elsewhere (check).

Volcanoes

Setting	Why magma forms	Typical eruption (check examples)
Divergent boundary	Rock rises and partly melts as pressure drops	Runny basalt, mostly effusive; Iceland
Subduction zone	Water from the sinking slab lowers the melting point of the mantle above	Thicker, gas-rich magma; explosive; the Andes, Japan, Mount St Helens
Hot spot	A plume of hot mantle rises through a plate	Basalt shield volcanoes; Hawaii

Two features control how an eruption behaves: the **viscosity** of the magma and the amount of dissolved gas. Runny, gas-poor magma flows out; sticky, gas-rich magma traps gas until it blasts

apart, like shaking a bottle of fizzy drink.

Hazards

- **Earthquakes:** building collapse, landslides, liquefaction of soft ground and tsunamis when the sea floor moves (check).
- **Volcanoes:** lava flows, ash falls, pyroclastic flows (fast hot clouds of gas and ash), lahars (volcanic mudflows) and gas. Ash can disrupt air travel, as in Iceland's 2010 eruption (check).
- **Climate effects:** very large eruptions can cool the climate for a year or more by putting sulphur aerosols in the upper atmosphere (check).

Prediction and Preparedness

Forecast, not prophecy

Scientists cannot predict the time, place and size of an earthquake in advance, though they can map where earthquakes are likely and estimate probabilities over decades (check). Volcanoes are easier: signs such as swarms of small quakes, ground swelling and gas changes can give days or weeks of warning, though not always exactly when or how big (check). Useful responses are building codes, warning systems that give seconds of notice, hazard maps and drills, because they work without precise prediction.

A British comparison

Britain is far from plate boundaries, so serious earthquakes are rare, but not unknown: the Colchester quake of 1884 damaged hundreds of buildings, and small events are felt in Scotland, especially near Comrie in Perthshire, long known for tremors (check). Scotland's volcanoes are all extinct, from Arthur's Seat to the old centres of Mull and Skye, which belong to the time the Atlantic was opening (Chapter 3, check). Those rocks are a map of what a volcano's interior looks like once the top has worn away.

Check the details

Death tolls, magnitudes and dates differ between sources and are often revised. Treat predictions in the media with caution, and check hazard statements against national agencies such as the British Geological Survey or the US Geological Survey. Advice on what to do in an earthquake varies by country.

Exercises

EXERCISE 1

A seismic station records the S-wave 40 seconds after the P-wave. Explain how this gives the distance to the quake, and why three stations are needed to locate it.

→ Solution

EXERCISE 2

Explain why a magnitude 6 earthquake can kill more people than a magnitude 7, using the ideas of magnitude, intensity and construction.

→ Solution

EXERCISE 3

Compare an Icelandic basalt eruption with a subduction-zone eruption in terms of magma, eruption style, main hazards, and warning time.

→ Solution

Quick Reference

- **Earthquake cause:** stored stress released by sudden slip on a fault
- **Waves:** P first, S second, surface waves last and most damaging
- **Magnitude vs intensity:** energy of the quake vs shaking at a place

- **Volcano settings:** divergent, subduction, hot spot
- **Prediction:** hazard maps and probabilities for quakes; monitoring for volcanoes

Geology & Plate Tectonics Fundamentals

Course 1 · Chapter 5 · Mountains, Faults and Folds

In 1860s and 1880s geologists at the Geological Survey puzzled over the north-west Highlands, where older rocks seemed to lie on top of younger ones, which should not happen. Ben Peach and John Horne, working for the Survey, showed that a huge sheet of rock had been shoved for many kilometres over its neighbours along a low-angle fault, now known as the Moine Thrust (check). Their 1907 memoir became a classic of the science (check). This chapter looks at what bends and breaks rock, the kinds of folds and faults, how mountain belts rise and are worn down, and how to read the structures on a geological map. Dates and figures are from general knowledge and flagged "check".

Stress and Strain

Stress

A force acting on rock. There are three kinds: compression (squeezing), tension (pulling apart) and shear (sliding past). Plate boundaries produce each of them (Chapter 3).

Strain

The change in shape or volume that results. Rock can deform elastically (and spring back), by flowing like putty (ductile), or by breaking (brittle).

What decides the response

Temperature, pressure, rock type and the speed of stress. Rocks deep in the crust, hot and under pressure, tend to bend. Shallow, cold rocks tend to break. Given enough time, even hard rock folds (check).

Folds

Term	Meaning
Anticline	An arch-shaped fold, with the oldest rocks normally in the core
Syncline	A trough-shaped fold, with the youngest rocks normally in the core
Limb	The sloping side of a fold
Axial plane	The imaginary surface that divides a fold into two halves
Overturned or recumbent fold	A fold pushed so far that one limb is upside down or lies flat

Folds range from crinkles that fit in a hand to structures many kilometres across. A useful check is that the rocks in an anticline get older toward the centre, which helps a geologist read a landscape that has been cut across by erosion (check the exceptions with overturned folds).

Faults

Fault type	Stress	Movement (check)
Normal	Tension	The block above the fault surface moves down; the crust is stretched, as in rift valleys
Reverse (thrust, if low angle)	Compression	The block above moves up; the crust is shortened and thickened, as in mountain belts
Strike-slip	Shear	Blocks slide sideways past each other, as on the San Andreas Fault

- **Fault plane.** The surface along which movement occurs; it may be steep or nearly flat.
- **Evidence of faulting.** Offset layers, crushed rock (fault breccia), polished and grooved surfaces (slickensides) and abrupt changes of rock type along a line.
- **Activity.** A fault may be active, with movements still happening, or ancient and inactive. Only the first kind is an earthquake risk (Chapter 4).

Mountain Building

Up, then down

Mountains rise where plates collide, because crust is shortened and thickened by folding and thrusting, and because thick crust floats higher, like an iceberg. But they do not rise forever. Rain, rivers, ice and gravity wear them down, and as the weight is removed the roots rebound upward, which slows the loss (check). The result is a balance of uplift and erosion, and old mountain belts like the Appalachians and the Scottish Highlands are low and rounded because the uplift stopped long ago.

- **Young belts** such as the Himalaya and Alps are still rising, with sharp peaks, steep valleys and many earthquakes (check).
- **Old belts** such as the Caledonian mountains (Chapter 3) are worn to their roots, and their former heights are known mainly from the folded and metamorphosed rocks left behind (check).
- **Rift mountains and volcanic ranges** follow different routes: stretching in the first case, and volcanic building in the second.

Reading a Geological Map

- **Colours and letters** show the age and type of rock at the surface, according to a key (check the key for each map).
- **Lines** mark boundaries between rock units and faults, and usually show which side moved.
- **Dip and strike symbols** show the angle of the layers. A small T-shaped symbol and a number give the direction and steepness of the dip.
- **Cross-sections** are interpretations of what lies underground, built by connecting surface information. Good geologists show where the interpretation is uncertain.

A British comparison

The Highland Boundary Fault runs from Arran in the south-west across Loch Lomond to Stonehaven on the east coast, and divides the Highlands from the Lowlands (check). The Moine Thrust runs from Loch Eriboll in the north to Skye in the south-west (check). Siccar Point, where Hutton saw tilted layers capped by flatter ones, is also a structural lesson: it is an unconformity, a gap in time where older rocks were folded, worn down and covered by

new ones. The British Geological Survey publishes maps of all three on its website and in the Edinburgh office.

Check the details

Names of faults, lengths and dates vary across sources, and structures once thought simple have often been revised. Use the British Geological Survey maps and the key supplied with them. When visiting outcrops, stay safe, follow the Geological Conservation Review guidance and the Scottish Outdoor Access Code, and never hammer protected exposures.

Exercises

EXERCISE 1

Sketch (in words) an anticline and a syncline and explain how you could tell them apart on a map from the ages of the rocks.

→ Solution

EXERCISE 2

Match each fault type (normal, reverse, strike-slip) to a plate boundary type from Chapter 3, and say what happens to the width of the crust in each case.

→ Solution

EXERCISE 3

Older rocks lie on top of younger rocks along a low-angle fault. Explain what that suggests, and how Peach and Horne's explanation of the Moine Thrust solved a similar puzzle.

→ Solution

Quick Reference

- **Stress:** compression, tension, shear; strain is the response
- **Folds:** anticline (arch) and syncline (trough)
- **Faults:** normal (tension), reverse or thrust (compression), strike-slip (shear)
- **Mountains:** rise by collision and thickening, worn down by erosion
- **Scotland:** Highland Boundary Fault, Moine Thrust, Siccar Point unconformity (check)

Geology & Plate Tectonics Fundamentals

Course 1 · Chapter 6 · Surface Processes: Weathering, Rivers and Ice

Plate tectonics and volcanoes build the land; weather, water and ice take it apart and carry it away. Every pebble on a beach and every grain of sand is a small piece of a larger rock that has been broken down and moved. Hutton saw this as part of a great cycle: the land wears away, the sediment is laid down in the sea, and in time it is lifted again to become new land. This chapter covers the three stages (weathering, erosion and deposition), the landforms of rivers, glaciers and coasts, and the way ice shaped much of Scotland. Figures and dates are from general knowledge and flagged "check" where they matter.

Weathering, Erosion, Deposition

Weathering

The breaking down of rock in place, without much movement. **Physical** weathering splits rock, for instance when water freezes in cracks and expands (freeze-thaw). **Chemical** weathering changes the minerals, as when slightly acidic rain dissolves limestone (check).

Erosion

The removal and transport of broken material by water, ice, wind or gravity. Weathering and erosion work together: weathering prepares the material and erosion carries it away.

Deposition

The laying down of material when the carrying agent loses energy, for instance where a river slows as it enters the sea. Deposits that are buried and cemented become sedimentary rock (Chapter 2).

Rock type matters

Hard, resistant rocks such as granite and quartzite tend to form high ground, while softer rocks such as shale and mudstone are worn into valleys. This is why a map of rock types

often looks like a map of hills and lowlands. The relationship is not simple: climate, structure (Chapter 5) and the history of ice also play a part.

Rivers

Stage (check)	Typical features	Main process
Upper course	Steep, V-shaped valleys, rapids, waterfalls	Downward erosion
Middle course	Wider valley, meanders beginning	Erosion and transport, sideways cutting
Lower course	Broad floodplain, meanders, oxbow lakes, levees, delta	Deposition

- **Load.** Rivers carry material dissolved in the water, as suspended fine particles, and rolled or bounced along the bed. Faster water carries bigger pieces, which is why floods move boulders.
- **Meanders.** Water flows faster on the outside of a bend, which erodes it, and slower on the inside, where sediment builds up. Over time bends migrate and sometimes get cut off as oxbow lakes.
- **Floodplains.** Fertile flat land made by repeated floods, which is why many cities and farms are on them and why flood management matters (check).

Glaciers

Feature (check)	How it forms
U-shaped valley	A glacier widens and deepens a former river valley
Corrie (cirque)	An armchair-shaped hollow cut by ice at the head of a valley
Arête and pyramidal peak	Sharp ridges and horns left between corries

Feature (check)	How it forms
Hanging valley and waterfall	A small side valley left high above the main glacial valley
Moraine	Ridge or sheet of rock debris dropped by melting ice
Drumlin	Smooth, elongated hill of glacial deposit, shaped in the direction of ice flow
Erratic	A boulder carried far from its source and left stranded
Fjord or sea loch	A glacial valley flooded by the sea

Ice sheets covered much of northern Britain during the last glacial period, which ended about 11,700 years ago (check). The weight of ice also pressed the land down, and the crust is still rising slowly in Scotland as it recovers, while parts of southern England are sinking (check).

Coasts and Wind

- **Waves** erode cliffs by hydraulic action and abrasion, forming wave-cut platforms, caves, arches and stacks as headlands are cut back (check).
- **Longshore drift** moves sand and shingle along a coast in a zigzag path, building beaches, spits and bars.
- **Wind** moves sand in deserts and on dunes, and shapes the surface by abrasion and by sorting grains (check).
- **Sea-level change** drowned river valleys and left raised beaches where the land rose. Scotland has both (check).

> **A British comparison**
>
> Edinburgh's skyline is glacial. Castle Rock and the Royal Mile form a classic crag and tail: ice flowing from the west was blocked by the hard volcanic plug of the Castle Rock and left a ridge of softer rock and deposit trailing behind it (check). The Highlands are full of corries, U-shaped glens and sea lochs, and Loch Lomond lies along the Highland Boundary Fault (Chapter 5, check). The Firth of Forth is a drowned and glacially deepened valley. A walk from the Castle down the Royal Mile is a walk down the tail.

Check the details

Glacial dates and extents are revised as new dating methods arrive, and the details of how individual landforms formed are often debated. Check specific claims about a location against British Geological Survey or NatureScot (formerly Scottish Natural Heritage) resources. Coasts, rivers and cliffs can be dangerous: heed tide tables, local warnings and rockfall signs.

Exercises

EXERCISE 1

Explain the difference between weathering, erosion and deposition, using one example of each from a river's journey to the sea.

→ Solution

EXERCISE 2

Describe how you could tell, from a photograph, whether a valley was cut by a river or by a glacier. Name three clues.

→ Solution

EXERCISE 3

Explain what a raised beach tells you about the history of a coast, and why some parts of Britain are rising while others sink.

→ Solution

Quick Reference

- **Weathering:** breakdown in place (physical and chemical)

- **Erosion and deposition:** removal and laying down by water, ice, wind and gravity
- **Rivers:** V-shaped valleys, meanders, floodplains, deltas
- **Glaciers:** corries, U-shaped valleys, moraines, drumlins, fjords
- **Scotland:** glaciated landscape, crag and tail, rising land (check)

Geology & Plate Tectonics Fundamentals

Course 1 · Chapter 7 · Deep Time: Fossils, Dating and the Timescale

In the 17th century Archbishop James Ussher added up the generations in the Bible and concluded that the world began in 4004 BC. Within two centuries geologists had evidence that the Earth was many millions of years old, and within three, that it was billions. This is one of the most dramatic changes of scale in the history of science, and it was achieved by careful reading of rocks, not by a single discovery. This chapter covers the two kinds of dating (relative and absolute), fossils as clocks, the geological timescale and its main divisions, and the great extinctions. Ages and dates are from general knowledge and flagged "check" where they matter.

Relative Dating

Superposition

In an undisturbed series of sedimentary layers, the oldest is at the bottom and the youngest at the top. Niels Steno proposed this in the 17th century (check).

Cross-cutting

A fault or an igneous intrusion is younger than the rock it cuts across. If a dyke cuts a sandstone, the sandstone is older.

Unconformities

Surfaces that represent a gap in the record, where rock was tilted or eroded before new layers covered it. Hutton's Siccar Point (Chapter 1) is the classic example.

Relative dating says which of two things is older without saying by how much. It is enough to build a sequence, which is how the first geological timescale was assembled in the early 19th century, before anyone could measure ages in years (check).

Fossils as Clocks

- **What a fossil is.** The preserved remains or traces of ancient life: shells, bones, leaves, footprints, burrows. Fossilisation is rare and favours hard parts buried quickly (check).
- **Faunal succession.** William Smith, a canal surveyor, noticed around 1800 that layers in different places could be recognised by the fossils they contained, and that the sequence was always in the same order (check).
- **Index fossils.** Species that lived for a short time, were widespread and are easy to identify, such as many ammonites and trilobites, make good markers for a particular period (check).
- **Environment.** Fossils also show what a place was like: marine shells mean sea, coal plants mean swamp. This is the present-is-the-key idea again.
- **Limits.** Fossils are found only in some rocks, mainly sedimentary, and the record has large gaps.

Radiometric Dating

Idea (check)	Explanation
Radioactive decay	Some atoms (parent isotopes) change into others (daughter isotopes) at a steady, known rate that is not affected by heat, pressure or chemistry
Half-life	The time for half of the parent atoms in a sample to decay
The clock	Measure the ratio of parent to daughter atoms in a mineral that closed when the rock formed; the ratio gives the age
Different isotopes for different ages	Carbon-14 (half-life about 5,700 years) for organic material up to roughly 50,000 years; uranium-lead (half-life of hundreds of millions to billions of years) for the oldest rocks
Igneous rocks	Best for dating, because crystals lock in the isotopes when they cool; sedimentary layers are dated indirectly using volcanic ash layers above and below

Radiometric dating turned a relative sequence into numbers. The 4.5 billion year age of the Earth comes from lead isotopes in meteorites and the oldest Earth minerals (check). Scientists test the method by comparing different isotope systems on the same rock, which usually agree within small errors (check).

The Geological Timescale

Division (check dates)	Roughly	Notable events
Precambrian (about 88% of Earth's history)	4.5 billion to 540 million years ago	Formation of Earth, first life, oxygen in the atmosphere, first animals near the end
Palaeozoic	540 to 252 million years ago	Shelled animals, fish, land plants, forests, first four-legged land animals
Mesozoic	252 to 66 million years ago	Dinosaurs, first mammals and birds, flowering plants
Cenozoic	66 million years ago to now	Rise of mammals, ice ages, humans

Within these eras are periods such as the Cambrian, Devonian, Carboniferous, Jurassic and Cretaceous. Many period names come from places where the rocks were first described, and several from Britain: the Cambrian from Cambria (Wales), the Ordovician and Silurian from Welsh tribes, and the Devonian from Devon (check).

Mass Extinctions

Five big ones

Geologists recognise five major mass extinctions in the last 540 million years (check). The largest, about 252 million years ago at the end of the Permian, is estimated to have wiped out the majority of marine species, probably linked to massive volcanic eruptions and climate change (check). The most famous, about 66 million years ago, ended the non-bird dinosaurs and is linked to an asteroid impact and volcanic activity (check). The causes of each are still studied, and the evidence for a single cause is rarely complete.

A British comparison

Britain gave many names to the timescale because geology developed here early and the rocks are varied. Scotland also supplied people: Hutton, who saw deep time at Siccar Point, Charles Lyell, from Angus, whose *Principles of Geology* popularised the idea and

influenced Darwin, and Hugh Miller, the Cromarty stonemason who described Old Red Sandstone fish (check). Edinburgh's museums hold fossils that can be seen free of charge, a good way to check the order of life in the timescale.

Check the details

Boundary dates of periods are revised by the International Commission on Stratigraphy, so check the current chart. Popular statements such as "radiometric dating is just guesswork" or "the Earth is exactly 4.5 billion years" both oversimplify: ages come with uncertainties that scientists state, and different methods are cross-checked.

Exercises

EXERCISE 1

A sandstone is cut by a granite dyke, and a limestone layer lies flat on top of both. Put the three in order from oldest to youngest and name the principle behind each step.

→ Solution

EXERCISE 2

A sample contains one quarter of its original parent isotope, which has a half-life of 100 million years. How old is it? Show your working and state the assumption.

→ Solution

EXERCISE 3

Explain why the Precambrian is called the "missing" part of the fossil record even though it covers most of Earth's history, and what other evidence geologists use for it.

→ Solution

Quick Reference

- **Relative dating:** superposition, cross-cutting, unconformities
- **Fossils:** faunal succession; index fossils mark periods
- **Radiometric dating:** parent and daughter isotopes, half-lives, igneous minerals
- **Timescale:** Precambrian, Palaeozoic, Mesozoic, Cenozoic
- **Extinctions:** five major ones, causes still debated

Geology & Plate Tectonics Fundamentals

Course 1 · Chapter 8 · Geology and People: Resources, Hazards and Scotland's Rocks

Geology is not only a story of the past. Every building, road, battery and meal depends on materials taken from the ground, and every settlement lives with some risk from it. Edinburgh's tenements are built of sandstone, its streets were once laid with whinstone (dolerite) setts, and the coal, oil and shale of Scotland helped power the Industrial Revolution (check). This final chapter draws the course together by asking what geology is for: where resources come from, how hazards are judged, how rocks record climate, how landscapes are protected, and how you can now read a landscape for yourself. Figures and dates are from general knowledge and flagged "check" where they matter.

Resources from the Ground

Resource (check examples)	Where it comes from	Link to the course
Building stone, sand and gravel	Quarries in sandstone, granite, limestone and glacial deposits	Rock types (Chapter 2) and glacial deposits (Chapter 6)
Coal, oil and gas	Buried plant and marine remains in sedimentary basins	Sedimentary rocks and deep time (Chapters 2 and 7)
Metal ores	Minerals concentrated by hot fluids around igneous intrusions and plate boundaries	Minerals and plate tectonics (Chapters 2 and 3)
Groundwater	Water stored in porous rock layers (aquifers)	Rock structure (Chapter 5)
Geothermal heat	Hot rock near the surface in volcanic or deep sedimentary settings	Volcanoes and plate boundaries (Chapters 3 and 4)
Critical minerals for batteries and electronics	Particular ore bodies, often in a few countries	Minerals and plate tectonics (Chapters 2 and 3)

- **Finite and renewable.** Most mineral and fuel resources form over millions of years and are used up far faster, so they are effectively finite. Groundwater and geothermal heat can be renewable if managed carefully (check).
- **Costs.** Extraction changes landscapes and ecosystems, and burning fossil fuels adds carbon dioxide to the atmosphere. A fair account weighs the benefits against the costs and does not hide either.
- **North Sea oil and gas.** Offshore fields off Scotland came from organic-rich sedimentary rocks buried in a rift basin, which links back to Chapter 3 (check).

Hazards and Risk

> **Hazard is not risk**
>
> A **hazard** is a natural process that can cause harm, such as an earthquake, volcano, landslide or flood. **Risk** combines the hazard with how many people and buildings are exposed and how vulnerable they are. The same quake is a high risk in a crowded city with weak buildings and a low risk in empty country. This is why geologists work with planners and engineers, not just on their own (Chapter 4).

- **Landslides and rockfall.** Steep slopes, weak rock, water and shaking. Scotland has landslides in the Highlands after heavy rain, notably on the A83 at the Rest and Be Thankful (check).
- **Floods.** Rivers return to their floodplains (Chapter 6), so building there needs defences or restraint.
- **Subsidence.** Collapse over old mines, dissolving rock or soft ground. Parts of Scotland's Central Belt sit over old coal workings (check).
- **Radon.** A radioactive gas from certain rocks such as granite that can build up in buildings; mapped by the British Geological Survey (check).

Rocks and Climate

- **Records.** Ice cores, ocean sediments, fossils and coal measure past climates, showing warm periods, ice ages and abrupt changes (check).
- **Slow control.** Over millions of years, volcanoes add carbon dioxide to the atmosphere and weathering of rock removes it, a slow thermostat that helps explain long-term climate

(check).

- **The present.** Burning fossil fuels releases in decades carbon that was stored over millions of years, which is why the rock record is used to understand the scale of current change (check). Details of climate science are a course of their own; here the point is that geology supplies the long baseline.

Protecting the Record

Outcrops, fossil sites and landforms cannot be replaced. In the UK, key sites are protected as Sites of Special Scientific Interest, and many are listed by the Geological Conservation Review (check). Simple rules for visitors: look and photograph, take only what the site allows, never hammer protected rock faces, stay clear of cliffs and tides, and follow local signs.

Reading a Landscape

1. What are the rocks?

Hard or soft, layered or crystalline, igneous, sedimentary or metamorphic (Chapter 2). Hills are often hard rock, valleys soft.

2. How are they arranged?

Tilted, folded, faulted or flat (Chapter 5). Straight valleys and sudden changes of rock often follow faults.

3. What shaped the surface?

Rivers, ice, sea or wind (Chapter 6). U-shaped valleys, corries and drumlins say ice; meanders and floodplains say rivers.

4. How old, and what does it say?

Fossils and dates (Chapter 7) place it in the timescale, and the plate setting (Chapters 3 and 4) explains why it is there.

Scotland as a Case Study

Place (check each)	What to read there
North-west Highlands	Ancient Lewisian gneiss, the Moine Thrust and the ancient continent of Laurentia (Chapters 1, 3 and 5)

Place (check each)	What to read there
Highland Boundary Fault	The edge between Highland and Lowland, with a change of rock and landscape (Chapter 5)
Southern Uplands	Marks the closed Iapetus Ocean (Chapter 3)
Edinburgh	Volcano (Arthur's Seat), intrusion (Salisbury Crags), sandstone buildings, glacial crag and tail (Chapters 2 and 6)
Siccar Point	Unconformity and deep time (Chapters 1 and 7)
Coasts and islands	Volcanic centres of Skye and Mull, raised beaches, sea lochs (Chapters 4 and 6)

A British comparison

Few places in the world let you stand on so many chapters of this course within a day's travel. The British Geological Survey, which has an office at Lyell Centre near Edinburgh (check), and the free museums of the city hold maps, fossils and rock collections that continue the work of Hutton, Lyell and Miller. A good next step is to take a BGS map or an app of the area where you live, choose a hill or a stream, and apply the four questions above.

Check the details

Resource figures, hazard maps and conservation rules change, so use current sources: the British Geological Survey, NatureScot, the Scottish Environment Protection Agency for flood maps, and local councils. This chapter is an introduction and not safety or planning advice.

Exercises

EXERCISE 1

Explain the difference between hazard and risk using a flood or an earthquake example, and say two ways to reduce risk without changing the hazard.

→ Solution

EXERCISE 2

Pick a building stone or resource used near you. Say which rock family it belongs to, how it formed, and what a geological map would tell you about where it came from.

→ Solution

EXERCISE 3

Apply the four landscape questions to a hill or valley you know, writing one or two sentences for each, and say where you are least sure.

→ Solution

Quick Reference

- **Resources:** stone, fuels, ores, water, heat, critical minerals
- **Hazard vs risk:** the process vs the process plus exposure and vulnerability
- **Climate:** rocks give the long record and a baseline
- **Reading a landscape:** rocks, structure, surface processes, age and setting
- **Be safe:** look, record, do not hammer protected sites

Course complete

You have followed the Earth from its materials and plates to the shaping of the surface, deep time and the way people depend on the ground. Keep practising: pick a rock, a hill or a map and ask the four questions.