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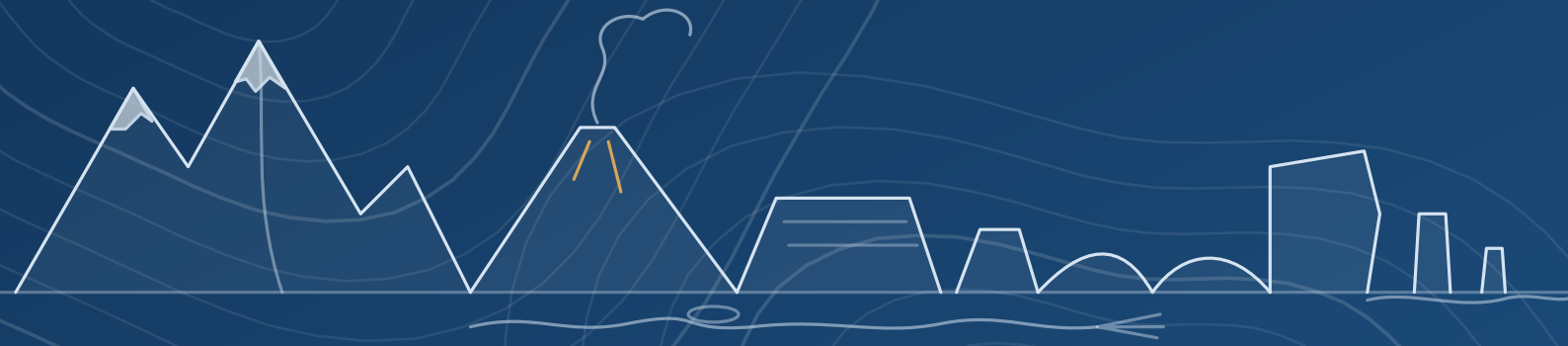
Geomorphology Notes

The complete Geomorphology section of Paper I — concepts, theories, landforms and applied geomorphology, with previous year questions.

Compiled by Arvind KrS

EARTH'S INTERIOR | PLATE TECTONICS | GEOMORPHIC CYCLES | LANDFORMS | APPLIED GEOMORPHOLOGY

50	8	156	271
Chapters	Units	Previous year questions	Diagrams and figures



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01 Foundations of Geomorphology

02 The Earth: Origin, Interior and Geomagnetism

03 Crustal Evolution and Mountain Building

04 Vulcanicity, Earthquakes and Tsunamis

05 Geomorphic Cycles and Landscape Development

06 Drainage, Channel Morphology and Slopes

07 Landforms of the Geomorphic Agents

08 Applied Geomorphology

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LOTUSARISE IAS

Geography Optional — Geomorphology

Paper I · Section A: Physical Geography — Geomorphology

Mains 2027 Edition · Compiled October 2026

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How to read these notes

Every chapter is marked against the questions UPSC has actually asked on it, so the points that matter most stand out on the first read and are quick to find at revision.

Uplift is rapid and short-lived, and erosion starts only after uplift ends.

Yellow marker: key point. A point that carries the ideas UPSC has asked about in this chapter. Read these first, and make sure each one is in your answer.

Isostasy is the state of balance between the crust and the denser mantle beneath.

Blue marker: definition. The cleanest definition of a term, ready to open an answer with.

The landscape is a function of **structure, process and stage**.

Saffron underline: PYQ term. A key term or phrase that appears in this chapter's previous year questions.

Davis's General Theory PYQ 2019 · 2014

PYQ tag on a heading. The years in which UPSC asked about this section. Sections without a tag are background or linking material.

PYQ RADAR **5** questions Last asked **2023**

PYQ radar. At the start of each chapter: how many times the topic has been asked, and how recently. The contents page shows the same count for every chapter.

Suggested method. First read: the whole chapter. Revision: the yellow and blue marks, the tagged headings and the PYQ list at the end of the chapter. Last week before Mains: the PYQ list alone, answering each question in your head from the marked points.

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UNIT 01 | 6 CHAPTERS

Foundations of Geomorphology

Factors controlling landform development; endogenetic and exogenetic forces.

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GEOGRAPHY OPTIONAL | PAPER I · GEOMORPHOLOGY

Nature, Scope and Fundamental Concepts of Geomorphology

PYQ RADAR **3** questions Last asked **2015** 2015 ×2 · 2012

CONTENTS

01 Nature and Scope of Geomorphology
02 Evolution of Geomorphic Thought
03 Systems Approach and Geomorphic Models
04 Fundamental Concepts of Geomorphology
05 Previous Year Questions

- **Geomorphology** is the science of **landforms**: their description, origin, development and the processes that shape them. It is the core branch of physical geography, alongside climatology, oceanography and biogeography.
  - The word joins three Greek roots: **ge** (earth), **morphe** (form) and **logos** (discourse).
- It rests on a few **fundamental concepts**, such as uniformitarianism, the control of structure and the complexity of landforms. These concepts grew out of more than two thousand years of geomorphic thought, and each era added a method: the cyclic view, quantitative measurement, process study and the systems approach.
- The Indian landscape shows these ideas at work. The Himalaya is a **young, still-rising range**, the Peninsula is an **old, polycyclic block**, and the Indo-Gangetic plain is a **Quaternary alluvial trough**.

01 Nature and Scope of Geomorphology

Meaning and Definitions

- **Interpretative description of relief** is the classical definition. It covers what a landform looks like and why it is there.
- **William David Thornbury (1954)** widened the field to include **submarine forms** as well as land surfaces.

- **Arthur L. Bloom** defined it as the **systematic description and analysis of landscapes and the processes that change them.**
  - This fuller definition joins form, process and time. It rests on the view that every landform can be related to a process or a set of processes, and that forms change in sequence as those processes keep working.
- **Geomorphology grew out of geology.** In North America it long sat inside geology departments, and some writers treated it as a branch of geology.
  - Structural and dynamic geology remain essential because rocks (geomaterials) and endogenetic forces set the stage on which the surface processes work.

Scope: Three Bases of Organisation

- **By dimension and scale of relief:** landforms are grouped into first, second and third orders.
- **By process:** endogenetic processes (diastrophism, volcanism, earthquakes) and exogenetic processes (weathering, mass movement, rivers, glaciers, wind, waves, groundwater), plus human activity, which now speeds up many natural rates.
- **By approach: historical** study of how landforms evolved over long spans, and **functional** study of how forms relate to present processes and conditions.

Orders of Relief

- **First-order relief** covers **continents and ocean basins**, the largest forms. Plate tectonics explains their origin.
- **Second-order relief** covers **structural or constructional forms** built mainly by endogenetic forces on a continent: mountains, plateaus, plains, rift valleys and large lakes.
- **Third-order relief** covers the **micro- to meso-scale sculpture** carved or built on second-order forms by exogenetic agents.
  - These forms may be erosional (gorges, cirques, sea cliffs, yardangs), depositional (flood plains, deltas, dunes, eskers, stalagmites) or residual (monadnocks, inselbergs).
  - Third-order forms are the **core subject matter** of geomorphology.

ORDER	EXAMPLES	CHIEF SHAPING FORCE	INDIAN EXAMPLE
First	Continents, ocean basins	Plate tectonics	Indian plate; Indian Ocean basin
Second	Mountains, plateaus, rift valleys	Endogenetic (diastrophic)	Himalaya, Deccan Plateau, Narmada rift
Third	Valleys, dunes, deltas, falls	Exogenetic (denudational)	Hundru falls, Thar dunes, Sundarbans delta

Historical and Functional Approaches

- **Historical (evolutionary) approach:** landforms are read as a **time-dependent sequence** of stages, as in the Davisian cycle and in denudation chronology.

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- **Functional (process-response) approach:** landforms are read as **time-independent** adjustments of form to present process and material, as in dynamic equilibrium.
- **Integration is the current view.** Long-term evolution and short-term equilibrium are two ends of one time scale, not rival truths.

BASIS	HISTORICAL APPROACH	FUNCTIONAL APPROACH
Time	Long, cyclic	Short, steady or graded
Key question	How did it evolve?	How does it work now?
Method	Qualitative, deductive from stages	Quantitative, field measurement
Typical model	Davis cycle, denudation chronology	Dynamic equilibrium, process-response

02 Evolution of Geomorphic Thought

Ancient and Medieval Ideas

- **Early thinkers made scattered observations** that later became formal concepts.
  - **Herodotus** (5th century BC) called Egypt the gift of the Nile, named the river-mouth deposit a **delta** after the Greek letter Δ, and inferred from marine shells far inland that **sea level had shifted**.
  - **Aristotle** (384–322 BC) noted that rivers disappear underground in limestone and that sea and land exchange places.
  - **Strabo** (c. 64 BC–c. AD 24) linked the size of a delta to the erodibility of the rocks upstream, an early hint of **differential erosion**.
  - **Seneca** (Lucius Annaeus Seneca) held that rivers deepen their valleys by abrasion.
- **A long lull followed** the fall of Rome. In the medieval period the Persian scholar **Avicenna (Ibn Sina, 980–1037)** separated mountains raised by uplift from those left by erosion of running water.

Catastrophism

- **Catastrophism** held that the earth was only a few thousand years old and that its features formed through **sudden, violent events** such as floods, earthquakes and eruptions.
  - It was tied to a literal reading of scripture. In the early 19th century **Georges Cuvier** gave it a scientific form through successive extinctions.

Renaissance and 18th-Century Foundations

- **Leonardo da Vinci** (1452–1519) held that rivers cut their own valleys and deposit the eroded material elsewhere.
- **Georges-Louis Leclerc, Comte de Buffon** (1707–1788) rejected the short age of the earth and saw rivers as able to wear uplands down to sea level.

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- **Giovanni Targioni Tozzetti** linked narrow valleys to hard rock and broad, winding ones to soft rock, another early form of differential erosion.
- **Jean-Étienne Guettard** noted that rivers leave part of their load on flood plains and stressed marine erosion.
- **Nicolas Desmarest** (1725–1815) argued that valleys are made by their rivers and that landforms pass through **successive stages**.

Uniformitarianism: Hutton, Playfair and Lyell

- **James Hutton (1785)** challenged the idea of a young, catastrophe-shaped earth with the view that **the same slow processes seen today** shaped the earth in the past, working in an endless cycle of decay and renewal.
  - He read his theory to the Royal Society of Edinburgh in **1785**, published it in **1788** and expanded it as *Theory of the Earth* in **1795**.
  - Two ideas became famous: **"no vestige of a beginning, no prospect of an end"** and the principle later summarised as **"the present is the key to the past"**. He also held that topography is **carved out, not built up**.
- **John Playfair (1802)** restated Hutton's ideas clearly in *Illustrations of the Huttonian Theory of the Earth*. He showed that valleys are proportioned to their streams (**law of accordant junctions**) and recognised the work of glaciers.
- **Charles Lyell (1830)** popularised the doctrine in the three volumes of *Principles of Geology* (1830–1833), which shaped the thinking of Charles Darwin.
  - **William Whewell (1832)** coined the terms **uniformitarianism** and **catastrophism** while reviewing Lyell's work.
- **George Greenwood (1857)** defended erosion by **rain and rivers** against Lyell's marine emphasis in *Rain and Rivers*. He is regarded as a father of **subaerialism** and anticipated base level.

Nineteenth Century: The European Schools

British School: Marine versus Subaerial Denudation

- **Andrew Crombie Ramsay (1846)** explained the plains of South Wales as **marine platforms**: waves plane the land during a slow rise of sea level.
  - Later he gave more weight to glacial and fluvial erosion and argued that glaciers could scoop out lake basins.
- **Joseph Beete Jukes (1862)** studied the rivers of southern Ireland. He separated **transverse** streams (across structure) from **longitudinal** streams (along the strike), showed that the transverse ones are older and described river capture.
- The debate over whether plains were cut by the sea or worn down by rain and rivers shaped British geomorphology into the 20th century.

Recognition of the Ice Age

- Ignaz Venetz, Jens Esmark and Jean de Charpentier argued in the 1820s–1830s that glaciers had once spread far beyond their present limits.

- **Louis Agassiz (1840)** gave the **Ice Age theory** wide currency, claiming a former ice sheet over northern Europe.
- **James Geikie (1874)** showed in *The Great Ice Age* that the ice age had several glacial phases separated by **warm interglacials**.
- **Albrecht Penck and Eduard Brückner** (1901–1909) set out four Alpine glacial stages: **Günz, Mindel, Riss and Würm**.

German School

- **Ferdinand von Richthofen** (1833–1905) worked in China on **loess** and on the genetic treatment of landforms.
  - He supported a marine origin for planation surfaces cut beneath a slowly advancing sea, and his regional studies seeded climatic geomorphology.
- **Albrecht Penck** (1858–1945) produced a systematic morphology of the earth's surface (1894), did pioneering glacial work and trained a generation of geomorphologists.
- **Desert (aeolian) geomorphology** began with German work in the dry lands.
  - **Johannes Walther (1900)**, in *Das Gesetz der Wüstenbildung*, and **Siegfried Passarge (1904)**, in *Die Kalahari*, described desert weathering and gave **wind deflation** a large role in shaping arid plains and basins.
  - Later work showed that **rare sheet floods and running water** do more of the work in deserts than wind, but their field studies founded the arid branch of the subject.

The American School of Subaerial Denudation PYQ 2015

- **The American school was the leading group of its time.** From about **1875 to 1920**, the **golden age** of geomorphology, four men working mostly in the arid, well-exposed Colorado Plateau and Great Basin showed that **rain, rivers and weathering on land**, not the sea, carve most landscapes.
  - The bare, flat-lying rocks and deep canyons made the relation between structure, stream work and time visible.

John Wesley Powell (1834–1902)

- **Base level (1875):** Powell named the lowest level to which a stream can cut, set by sea level, the key limit on vertical erosion.
  - Base levels were later classed as **ultimate** (sea level), **local** (a lake or a resistant rock bar) and **temporary**.
- **Genetic classification of valleys:** he classed valleys as **consequent**, **antecedent** and **superimposed**, drawing on the Green River cutting through the Uinta Mountains.
- **Wearing down to a plain:** if erosion worked long enough, an upland would be reduced to a surface near base level. Davis later named this the **peneplain**.

Clarence Edward Dutton (1841–1912)

- **Isostasy (1882):** Dutton coined the term for the gravitational balance of high and low crustal blocks, which explains why eroded regions keep rising.

- **The Great Denudation:** in the Grand Canyon district he recognised a vast Tertiary stripping of rock from the plateau country, which showed subaerial erosion at a regional scale.

Grove Karl Gilbert (1843–1918)

- **Grove Karl Gilbert (1877)**, in the *Report on the Geology of the Henry Mountains*, is often called **America's first true geomorphologist**, a process-based and quantitative thinker far ahead of his time.
  - He set out laws of **declivities** (gradient inversely related to discharge), **structure** (erosion fastest where resistance is least), **divides** and **equal action**, and the interdependence of all parts of a drainage system.
  - He related load, discharge, velocity and gradient, laying the base of the **graded stream**. His idea of **dynamic equilibrium** was revived after 1950.
- His later work and its revival are covered in **theories of landform development by Gilbert, Hack, Morisawa and Schumm**.

William Morris Davis (1850–1934)

- **William Morris Davis (1899)**, professor at Harvard, pulled scattered American ideas into the **first general theory of landscape development**, the **geographical cycle**.
  - Its building blocks were the complete cycle of river life (1889, in *The Rivers and Valleys of Pennsylvania*), the geographical cycle (1899) and slope evolution.
  - Landscape is a function of **structure, process and stage**, the **trio of Davis**. An uplifted block passes through youth, maturity and old age to a **peneplain**, and rejuvenation restarts the cycle.
  - He extended the cycle to arid and glacial landscapes; followers extended it to coastal (Douglas Johnson, 1919), karst (Jovan Cvijić, 1918) and periglacial (Louis Peltier, 1950) regions.
  - His essays were collected as *Geographical Essays* (1909). His clear prose made him the dominant voice in world geomorphology until about 1950.
- The stages and criticism are set out in the **Davis cycle of erosion**.

GEOMORPHOLOGIST	KEY FIELD AREA	MAIN CONTRIBUTION	LASTING CONCEPT
Powell	Colorado River, Uinta Mountains	Limit of downcutting; valley types	Base level
Dutton	Grand Canyon, High Plateaus	Crustal balance; regional stripping	Isostasy, Great Denudation
Gilbert	Henry Mountains, Lake Bonneville	Quantitative laws of stream work	Grade, dynamic equilibrium
Davis	Appalachians, New England	Cyclic synthesis	Geographical cycle, peneplain

Evaluation of the American School

- **Strengths:**
  - It settled the **subaerial versus marine** debate in favour of rivers and weathering.

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- It supplied lasting tools (base level, grade, isostasy, peneplain, antecedence) and a **genetic language** for landforms.

- **Limitations:**
  - Davis's **deductive, stage-based** framework buried Gilbert's process work for half a century.
  - It assumed rapid uplift followed by long stillstand, which plate tectonics rejects.
  - Its humid-temperate norm fits the tropics and deserts poorly.
- **Current view:** Gilbert's process and equilibrium ideas are central today. Davis survives in denudation chronology, in the language of rejuvenation, and as a model of long-term change.

First Half of the 20th Century

- **Davisian dominance:** the cycle (normal, erosion or humid cycle) guided work worldwide.
- **British denudation chronology: Sidney William Wooldridge and David Linton (1939)** read south-east England as a palimpsest of erosion surfaces from successive cycles.
- **German opposition: Walther Penck** (1888–1923), in *Die morphologische Analyse* (1924, posthumous), tied landform to the **ratio of uplift rate to erosion rate**.
  - He replaced stages with waxing, uniform and waning development and argued for **parallel retreat** of slopes.
  - His model is compared with Davis's in the **Penck model of landform development**.
- **Climatic geomorphology:** building on Richthofen and on travellers in Africa and the tropics, **Julius Büdel (1948)** and **Louis Peltier (1950)** held that each climate produces its own assemblage of landforms. Their morphogenetic regions are covered under **climatic geomorphology**.
- **C. H. Crickmay (1933)** proposed panplanation by lateral river erosion. **Lester Charles King** set out pediplanation in *Canons of Landscape Evolution* (1953).

The Post-1950 Revolution

- **Quantitative revolution:** after William C. Krumbein brought statistics into sedimentary geology in the 1930s, **Robert E. Horton (1945)** gave laws of stream numbers and lengths by order. **Arthur Newell Strahler (1952)** refined stream ordering and called for a dynamic, physics-based geomorphology.
  - This founded **drainage basin morphometry** and turned description into measurement.
- **Process geomorphology:** instrumented field plots, flumes and sediment traps measured rates over small areas and short times, so form geomorphology gave way to **process geomorphology**.
  - **M. Gordon Wolman and John P. Miller (1960)** showed that moderate, frequent events do most of the long-term work of transport.
- **Systems and equilibrium: Richard Chorley (1962)** recast landscapes as **open systems**. **John T. Hack (1960)** proposed **dynamic equilibrium**, in which forms are time-independent adjustments to rock and process.
- **Thresholds and episodic change: Stanley A. Schumm** introduced geomorphic thresholds and complex response (1973). **Marie Morisawa** stressed tectonic controls.
- Deductive, model-based reasoning replaced purely inductive description, and applied and environmental geomorphology grew.

- **Form versus process geomorphology:**
  - **Form geomorphology** is the systematic study of the **characteristics, origin and development** of relief features, largely by description and stage.
  - **Process geomorphology** is the study of the **nature, types and mode of operation** of geomorphic processes in erosion, transportation and deposition, and of the landforms that result.
  - The shift also replaced **evolutionary theory** (how forms developed through time) with **functional theory** (how forms are adjusted to present processes).

Recent Trends

- **Tectonic geomorphology:** landforms are read as records of active faulting and uplift. River profiles, terraces and fault scarps are used to measure deformation, for example along the **Himalayan Frontal Thrust**.
- **Dating revolution:** cosmogenic nuclide (such as ^{10}Be) and luminescence dating now give **absolute ages and rates** for surfaces, terraces and escarpments.
- **Remote sensing and GIS:** DEMs, LiDAR and InSAR allow mapping and monitoring from space.
  - In January 2023, satellite data from the National Remote Sensing Centre showed **Joshimath** subsiding by about 5.4 cm in 12 days.
  - A 2023 DEM-based study classified the landforms of the **Chota Nagpur Plateau** and mapped its planation surfaces and rejuvenation falls.
- **Hazards and cascades:** the **South Lhonak GLOF** in Sikkim (3–4 October 2023) began when a frozen moraine slope collapsed into the lake. The outburst destroyed the Teesta III dam at Chungthang and moved huge volumes of debris down the Teesta. Such events show landforms changing in hours.
- **Humans as geomorphic agents:** mining, dams, urban sprawl and sand extraction now move more sediment than many natural agents.
  - The proposal to formalise an **Anthropocene Epoch** was, however, rejected in March 2024 by the Subcommission on Quaternary Stratigraphy, a decision upheld by the International Union of Geological Sciences. The Anthropocene remains an informal but widely used term.
- **Planetary geomorphology** compares landforms on the Moon and Mars; India's Chandrayaan-3 (2023) landed near the lunar south pole.
- **Applied focus:** the field now serves hazard, river and coastal management, as seen in **applied geomorphology**.

Indian Contributions

- **Early phase:** geologists such as **Darashaw Nosherwan Wadia** and officers of the Geological Survey of India provided the first physiographic accounts. University teaching of geography then began in the 1930s–1940s.
- **Cyclic and denudation-chronology phase (1950s–1970s):** work followed the Davisian model, using topographic maps to identify erosion surfaces.
  - **S. P. Chatterjee** and **Kanangopal Bagchi** led at Calcutta, where Bagchi worked on the Ganga delta.
  - **R. L. Singh** at Banaras Hindu University pioneered morphometric analysis of terrain.

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  - **Enayat Ahmad** worked on gullies and the Ranchi plateau; **K. R. Dikshit** studied erosion surfaces of the Deccan Traps.
- **1968 turning point:** the 21st International Geographical Congress in New Delhi spurred regional studies of the Peninsula.
- **Process and field phase (1980s onward):**
  - The International Conference on Geomorphology and Environment at Allahabad (1987) led to the **Indian Institute of Geomorphologists** and its journal.
  - The **Pune school** (K. R. Dikshit, **Vishwas S. Kale**, S. R. Jog) developed fluvial, palaeoflood and coastal geomorphology of monsoon rivers and the Konkan coast.
  - The Central Arid Zone Research Institute (Jodhpur) led arid geomorphology of the Thar.
- **Current focus:** river dynamics of the Ganga and Kosi, Himalayan landslides and GLOFs, and remote-sensing-based mapping.

PERIOD	DOMINANT IDEA	KEY NAMES	METHOD
Ancient–medieval	Scattered observation	Herodotus, Strabo, Avicenna	Philosophical
17th–early 19th century	Catastrophism vs uniformitarianism	Cuvier; Hutton, Playfair	Field reasoning
19th century	Subaerial vs marine denudation; Ice Age	Lyell, Ramsay, Agassiz, Powell, Gilbert	Descriptive, genetic
1899–1950	Cyclic theory; climatic geomorphology	Davis, Walther Penck, Büdel	Deductive, historical
1945–1980	Quantitative, process, systems	Horton, Strahler, Chorley, Hack, Schumm	Measurement, models
1980–present	Tectonic, dating, remote sensing, Anthropocene	Global and Indian teams	Absolute dating, GIS, InSAR

03 Systems Approach and Geomorphic Models PYQ 2012

Meaning of a Geomorphic System

- **A system** is a set of objects studied together through their relationships and attributes.
- **A geomorphic system** is a structure of **interacting processes and landforms** that work individually and jointly to form a landscape complex.
  - It runs on inputs of energy and matter (insolation, rainfall, uplift) and releases outputs (water, sediment).

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- A large system nests subsystems, such as slopes, channels and flood plains, linked by input-output flows.

- **Origin:** the approach comes from **Ludwig von Bertalanffy's general system theory** (1950). **Arthur Strahler (1952)** and **Richard Chorley (1962)** brought it into geomorphology.

Closed and Open Systems

- **Closed system:** a boundary that energy and matter cannot cross. It runs down towards maximum entropy.
  - The **Davisian cycle** behaves as a closed system. The potential energy of the initial uplift is spent until the peneplain stage, and rejuvenation is only a temporary recharge.
- **Open system:** energy and matter cross the boundary continuously, so the system can hold a **steady state**.
  - A **drainage basin** is the standard example. It takes in rain and solar energy and exports water and sediment at its mouth.
  - The Ganga–Brahmaputra basin is such an open system: Himalayan uplift and monsoon rain feed it, and the Bengal delta and the Bay of Bengal fan receive its sediment.

BASIS	CLOSED SYSTEM	OPEN SYSTEM
Exchange across boundary	Neither energy nor matter	Both energy and matter
Trend over time	Runs down to maximum entropy	Holds a steady state
Dominant feedback	Positive, progressive change	Negative, self-regulating
Landform view	Time-dependent (cycle)	Time-independent (equilibrium)
Example	Davis's cycle ending in peneplain	Drainage basin, graded river

Types of Systems

- **Richard Chorley and Barbara Kennedy (1971)** grouped physical systems into four types of rising complexity.

SYSTEM TYPE	WHAT IT DESCRIBES	EXAMPLE
Morphological	Correlation among form properties	Slope angle vs soil depth; basin order vs area
Cascading	Flow of mass or energy through linked stores	Hillslope → channel → delta sediment cascade

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SYSTEM TYPE	WHAT IT DESCRIBES	EXAMPLE
Process-response	Morphological and cascading systems linked, so process changes form and form changes process	River adjusting width and depth to discharge
Control	Process-response system with human intervention at key valves	Dammed Teesta or Bhagirathi; embanked Kosi

Equilibrium States

- **Equilibrium** is a balance between **driving forces** (process energy) and **resisting forces** (strength of materials).
  - **Static:** no change at all, which is rare in nature.
  - **Stable:** the system returns to its former state after a small disturbance.
  - **Unstable:** a small disturbance pushes the system to a new state.
  - **Metastable:** the system is stable until a **threshold** is crossed, and then it shifts.
  - **Steady-state:** the system fluctuates about a **constant mean**, as in a graded channel.
  - **Dynamic:** the system fluctuates about a **mean that itself drifts**, as in a slowly lowering landscape.
  - **Dynamic metastable:** a drifting mean is broken by sudden jumps when thresholds are crossed. This is the most realistic picture of long-term landscape change.

Feedback Mechanisms

- **Negative feedback (self-regulation):** a change in input sets off adjustments that cancel it and restore balance. It keeps open systems near equilibrium.
  - When a **graded river** receives extra load after a storm, it deposits sediment, the gradient steepens, velocity rises and the extra load is carried. Grade is then restored.
- **Positive feedback (self-reinforcing):** a change amplifies itself and drives the system further from balance.
  - Heavier rain increases runoff, which strips the soil and exposes impermeable rock. Infiltration then falls, runoff rises further and gullies grow, as in the Chambal ravines.
  - In the Himalaya, permafrost thaw weakens moraines, and slope failure into a glacial lake can set off a GLOF cascade, as at South Lhonak in 2023.

Thresholds and Complex Response

- **Geomorphic threshold (Stanley A. Schumm):** a limit at which a landform or system changes abruptly.
  - **Extrinsic thresholds** are crossed by outside change, such as a climate shift or base-level fall.
  - **Intrinsic thresholds** are crossed by internal evolution, such as a valley floor steepening by deposition until it gullies, with no outside trigger.
- **Complex response:** a single disturbance, such as a base-level fall, produces several phases of cutting and filling that differ from place to place within a basin.
- **Relaxation time:** the lag before a system settles into a new equilibrium after disturbance.

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- **Indian illustration:** at **Joshimath**, a town built on old landslide debris, the added load of construction, blocked drainage and toe erosion by the Alaknanda pushed a metastable slope past its threshold in 2022–23.

Evaluation of the Systems Approach PYQ 2012

- **Strengths:**
  - It unites **form and process** and allows quantitative modelling and prediction.
  - It suits drainage basins and human intervention.
  - It explains both steady adjustment and sudden change through thresholds.
- **Limitations:**
  - It can become jargon that relabels old ideas.
  - Boundaries and inputs are hard to measure. Black-box treatment hides mechanisms, and short-term equilibrium says little about million-year evolution.
- **Current view:** systems thinking is now the **default framework**, combined with absolute dating so that long-term history and short-term process can be linked.

Geomorphic Models

- **A model** is a **simplified, structured approximation** of reality: an idea, hypothesis, theory, law, relation or equation.
- **Characteristics of models:**
  - They are selective (they keep the essentials), structured (the parts are linked) and suggestive (they open further enquiry).
  - They work as analogies and can be re-applied to the real world.
- **Functions (Peter Haggett and Richard Chorley, 1967):**
  - Psychological, making complex systems graspable.
  - Acquisitive, guiding data collection.
  - Logical, explaining data.
  - Normative, comparing the unknown with the known.
  - Constructional, leading to theories and laws.
- **Models can be classed in several ways:**
  - By reality, as descriptive or normative.
  - By material, as hardware (physical) or theoretical (symbolic, conceptual).
  - Chorley (1967) grouped geomorphic models into three families.

FAMILY	TYPES	GEOMORPHIC EXAMPLE
Natural analogue	Historical (time); spatial (place)	Hutton's "present is key to the past"; morphogenetic regions

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FAMILY	TYPES	GEOMORPHIC EXAMPLE
Physical	Hardware; mathematical (deterministic, stochastic); experimental design	Flume meanders; Horton's laws; Strahler's regression of slope on channel gradient
General system	Synthetic (process-response); partial; black box	Drainage basin models; Davis's cycle as a black box

- **Hardware models** in flumes and sand tables face scale problems, because nature is too complex to shrink faithfully.
- **Deterministic models** assume fixed cause and effect, such as Horton's laws or allometric growth. **Stochastic models** add probability to allow for random events.
- Human intervention must rest on tested models, because human changes can exceed a system's resilience.

Methods of Studying Landforms

- **Three tasks: description**, **classification** and **explanation**.
  - **Description** can be subjective (literary, of little scientific use), genetic (forms with their causes) or quantitative (morphometric).
  - **Classification** is either genetic (by origin) or quantitative (by measured attributes).
  - **Explanation** interprets how the processes produced the forms.
- **Approaches:**
  - Qualitative or quantitative.
  - Systematic (by process or landform type) or regional (by area).
  - Inductive (from field facts to generalisation) or deductive (from theory to test), with systems analysis cutting across both.
- **Data sources:** topographic maps, field instrumentation, laboratory analysis, air photos, satellite imagery, DEMs and dating.

04 Fundamental Concepts of Geomorphology

- **William David Thornbury** condensed the discipline into **ten fundamental concepts**. They remain the standard summary of how landforms are read. Many of the terms used here are explained in the **terminology of fundamental concepts in geomorphology**.

NO.	CONCEPT (SHORT FORM)	CORE IDEA	INDIAN ILLUSTRATION
1	Uniformitarianism	Same processes and laws, varying intensity	Kedarnath 2013 and Sikkim 2023 floods

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NO.	CONCEPT (SHORT FORM)	CORE IDEA	INDIAN ILLUSTRATION
2	Structure dominates	Rock and structure control and show in form	Vindhyan scarps; Deccan trap steps
3	Differential rates	Relief exists because processes work at unequal rates	Western Ghats escarpment vs Konkan lowland
4	Process imprint	Each process leaves its own landform set	Thar dunes; Himalayan cirques
5	Orderly sequence	Erosional agents produce a sequence of forms	Youthful Himalayan vs old-stage Peninsular rivers
6	Complexity over simplicity	Most landscapes are compound and polycyclic	Chota Nagpur Plateau
7	Mostly post-Tertiary	Little topography older than Tertiary	Tested by the ancient Peninsular surfaces
8	Pleistocene legacy	Ice-age changes must be understood	Himalayan moraines, terraces; relict Thar dunes
9	Climate and process	Climate sets the weight of each process	Laterite in the Western Ghats; aeolian forms in the Thar
10	Historical extension	Geomorphology is most useful when extended into history	Palaeochannels of the Sarasvati–Ghaggar

Concept 1: Uniformitarianism

- **Statement:** the same **physical processes and laws** that operate today operated throughout geological time, though not always with the same intensity.
- **Origin:** Hutton (1785) proposed it, Playfair (1802) clarified it and Lyell (1830) popularised it.
- **Correction of Hutton:** Hutton's belief that processes always worked at the same intensity is untenable.
  - Glaciers were far more active in the Permo-Carboniferous and Pleistocene glaciations than now, because climate change alters the rate and location of processes.
- **Modern refinement: Stephen Jay Gould (1965)** separated two kinds of uniformitarianism.
  - **Methodological uniformitarianism** (uniform laws and kinds of process) is accepted.
  - **Substantive uniformitarianism** (uniform rates and state of the earth) is rejected.
- **Role of rare events: neo-catastrophism** recognises that rare, high-magnitude events do a large share of geomorphic work.
  - Examples are the Kedarnath flood of June 2013, the Sikkim GLOF of 2023 and the Wayanad debris flows of July 2024.

- **Current view:** uniformitarianism is kept as **actualism**, meaning the same laws with variable rates, including sudden events.

Concept 2: Geological Structure as a Dominant Control

- **Statement: geological structure** is a dominant control on the evolution of landforms and is reflected in them.
- **Structure** in the broad sense includes lithology, the attitude of beds (folded, faulted, domed, dipping), joints, permeability and chemical and mechanical resistance.
- **Expressions:**
  - Hogbacks and cuestas form on dipping beds.
  - Trellis drainage develops on folded rocks, and rectangular drainage on jointed rocks.
  - Karst forms on limestone, and tors on jointed granite.
- **Indian examples:**
  - The Vindhyan sandstone scarps (Kaimur, Bhander and Rewa) stand out against softer shales.
  - The stepped trap topography of the Deccan is carved from successive basalt flows.
  - The Son and Narmada follow fault-guided courses, and trellis drainage marks the folded Siwaliks.
- **Evaluation:**
  - Structure is **passive**: it sets the resistance, but process and climate decide the outcome. The same granite forms tors in a humid climate and inselbergs in a semi-arid one.
  - Dynamic equilibrium theory, as in Hack's work, gives structure an even larger role by treating forms as adjusted to rock resistance.

Concept 3: Relief from Differential Rates of Process

- **Statement:** the surface has relief largely because **geomorphic processes operate at differential rates**.
- **Differential weathering and erosion** on rocks of unequal resistance leave the hard rocks standing high.
- **Differential uplift** matters as much: where uplift outpaces erosion, relief grows, as in the Himalaya; where erosion outpaces uplift, relief declines.
- **Indian example:** cosmogenic-nuclide estimates show the **Western Ghats escarpment** retreating inland at roughly 200 to 2,400 metres per million years since continental rifting, while the plateau top behind it wears down far more slowly. This difference in rates keeps a steep edge between the high Deccan and the Konkan–Malabar lowland.

Concept 4: Processes Leave Their Imprint

- **Statement:** each geomorphic process leaves a **distinctive imprint** and develops its own **characteristic assemblage** of landforms.
- **Examples of imprints:**
  - Running water leaves V-shaped valleys, flood plains and deltas.
  - Glaciers leave U-shaped valleys, cirques and moraines.
  - Wind leaves dunes, yardangs and deflation hollows.

  - Waves leave cliffs and platforms, and solution leaves karst.
- **Basis of genetic classification:** process is the basis for classifying landforms by origin. It links to concept 9 and to the morphogenetic regions of climatic geomorphology.
- **Indian examples:**
  - Barchans and longitudinal dunes mark the Thar.
  - Cirques and hanging valleys mark Gangotri and Zanskar.
  - Karst is seen in the Borra caves and the limestone of Meghalaya.
- **Limitation: equifinality** means different processes can produce similar forms. Pediments, for example, may be fluvial or weathering-controlled, so form alone can mislead.

Concept 5: Orderly Sequence of Landforms

- **Statement:** as erosional agents work, they produce an **orderly sequence** of landforms, so **stage** or time can be read from form.
- This is the base of the cyclic concept (Davis) and of stage terms such as youthful, mature and old valleys.
- **Indian example:**
  - Himalayan rivers have deep gorges, rapids and knickpoints, the features of youth and rejuvenation.
  - Peninsular rivers such as the Kaveri and the lower Mahanadi have broad, graded valleys of maturity to old age, broken where uplift has rejuvenated them, as at the Shivanasamudra falls.
- **Evaluation:**
  - The sequence assumes stillstand and uniform external conditions, which rarely hold.
  - Equilibrium theorists argue that forms can be time-independent.
  - **Current view:** sequences are real but interrupted, and absolute dating now replaces inferred “stage”.

Concept 6: Complexity of Geomorphic Evolution Is More Common than Simplicity

PYQ 2015

- **Statement:** most landscapes result from **several processes, several factors and several cycles**, not from one.
  - Landforms are polyfactor (lithology, tectonics, climate, vegetation, soil and human action together) and polyprocess.
  - At large scales many landscapes are a **palimpsest**: a surface written on many times, where earlier inscriptions are only partly erased.

Reasons for Complexity

- **Successive cycles of erosion** leave **polycyclic** forms. The peninsular plateaus are the example, with planation surfaces at different heights.
- **Several processes act within one cycle.**
  - Wind dominates hot deserts, but rare storms build pediments, bajadas and playas.
  - Glacial regions also carry fluvio-glacial kames, eskers and outwash.
- **Spatial variation** in rock, climate, vegetation and soils occurs within a single region.
- **Tectonic events** such as uplift, warping and faulting interrupt cycles and cause rejuvenation.

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- **Base-level change** comes from sea-level rise or fall, which may be tectonic or glacio-eustatic.
- **Climatic change** leaves relict forms from earlier climates beside present ones.

Horberg's Classification of Landscapes

- **Leland Horberg (1952)** classed landscapes into five types by their complexity.

TYPE	MEANING	EXAMPLE
Simple	One dominant process	Stepped scarps from differential stream erosion on sandstone–shale beds
Compound	Two or more processes	Glaciated highlands with fluvial lowlands; Himalaya with glacial, fluvial and mass-movement forms
Monocyclic	One cycle of erosion	Young volcanic cones, lava plains, freshly emerged coastal plains
Multicyclic (polycyclic)	Two or more cycles	Chota Nagpur Plateau; Appalachians (Schooley, Harrisburg, Somerville surfaces)
Exhumed (resurrected)	Buried, then re-exposed by erosion	Surfaces stripped of Deccan lava or sediment cover; Lewisian gneiss hills of north-west Scotland

- **Simple landscapes** are an idealisation. Even a "fluvial" landscape involves weathering, creep and slumping, and even "karst" involves surface runoff.
- **Compound landscapes** are the norm.
  - **Composite fault-line scarps** are one example: the upper part is the fault face and the lower part has been cut back by erosion.
  - Volcanic cones rising within river-cut valleys, as in the south-western USA, are another.
- **Monocyclic landscapes** are rare and short-lived, because any fresh surface is soon rejuvenated or reworked.
- **Multicyclic landscapes** are identified by **diagnostic forms**:
  - valley-in-valley (multi-storeyed) profiles and paired terraces
  - incised meanders and **knickpoints** (heads of rejuvenation)
  - uplifted peneplains and hanging valleys.
- **Indian examples of polycyclic relief:**
  - The **Ranchi plateau** carries a high **Pat surface**, a central Ranchi surface and a lower marginal surface. The Hundru falls (Subarnarekha), Dassam falls (Kanchi) and Jonha (Gautamdhara) falls mark heads of rejuvenation at its edge.
  - The **Damodar at Rajrappa** and the **Narmada at Bhedaghat** show rejuvenated valleys with terraces and gorges.
  - Falls on north-flowing rivers from the **Rewa and Rohtas plateaus**, such as Chachai, Keoti, Purwa and Telhar Kund, record the rejuvenation of the peninsular foreland after the Ganga trough subsided.

- **Exhumed landscapes** had a former surface buried under lava, sediment or ice and later **uncovered by erosion**.
  - In the Peninsula, erosion of the **Deccan Trap** cover along its margins re-exposes the pre-trap surface on older rocks.
  - In Scotland, Lewisian gneiss hills buried under Torridonian sandstone over a billion years ago are now re-exposed.
  - Former ice-covered surfaces of North America and northern Eurasia reappeared after deglaciation.
  - Exhumed forms are recognised by an **unconformity** at the surface and by relief that does not fit present processes.
- **Evaluation:** complexity forces **multi-factor** explanation rather than single-cause models, whether cyclic, climatic or structural. It also explains why denudation chronology needs absolute dating to avoid circular reasoning.

Concept 7: Little of the Earth's Topography Is Older than Tertiary

- **Statement:** little topography is **older than the Tertiary**, and most is **no older than the Pleistocene**.
- **Basis:**
  - The Alpine–Himalayan, Rocky and Andean orogenies and Tertiary uplift rejuvenated older cycles and started new ones.
  - Pleistocene ice sheets then scoured or buried much of North America and northern Eurasia, leaving moraines and lakes.
  - **George H. Ashley (1931)** went further and argued that most scenery is **post-Miocene**.
- **Indian support:**
  - The Himalaya is a Cenozoic range whose gorges, terraces and falls were mostly carved in the Quaternary.
  - Tertiary uplift phases on the Chota Nagpur Plateau and the Palamu uplands produced their scarps and falls.
  - The subsiding Ganga foredeep rejuvenated rivers on the peninsular foreland.
- **Criticism:**
  - The concept carries a **Pleistocene bias** from glaciated Europe and North America.
  - **Cliff D. Ollier** showed many **very old landscapes**, with preserved valleys, weathering profiles and duricrusts; wherever geomorphic histories are long, things were different in the past.
  - **Indian counter-evidence:** the peninsular plateaus carry erosion surfaces and laterites of great age, and cosmogenic dating shows the Western Ghats escarpment evolving steadily since Late Cretaceous rifting.
  - Time matters for preservation as well as formation: some forms appear instantly (fault scarps), some in weeks to months (cinder cones, gullies, dunes) and some take millions of years (planation surfaces).
- **Current view:** "Tertiary" is now an informal term (Paleogene plus Neogene). The concept holds for **young orogenic and glaciated regions** but fails for **stable cratons** such as Peninsular India, Australia and Africa.

Concept 8: Legacy of Pleistocene Geological and Climatic Changes

- **Statement:** present landscapes cannot be interpreted without appreciating the **geological and climatic changes of the Pleistocene**.
- **Pleistocene effects:**
  - Glaciation spread over high latitudes and mountains.
  - Sea level fell by roughly 120 m at glacial maxima, causing rejuvenation, and its later rise drowned valleys into rias.
  - Pluvial lakes formed, and periglacial belts shifted.
- **Update:** the Quaternary now begins at 2.58 million years (ratified in 2009), and the fourfold Alpine scheme (Günz, Mindel, Riss, Würm) has been **replaced by the marine oxygen-isotope record**, which shows dozens of glacial–interglacial cycles, not four.
- **Deeper climatic legacy:**
  - Laterite within the Tertiary basalts of Northern Ireland records a hot, humid past, and Triassic England was largely desert.
  - **Permo-Carboniferous glaciation** affected India, Africa, Australia and South America; the **Talchir tillites** of the Gondwana basins record it in India.
- **Indian examples:**
  - Moraines lie far below present snouts in Himachal, Sikkim and Ladakh.
  - Fluvial terraces formed in the Himalaya and the Ganga plain.
  - Relict dunes of the Thar were stabilised in wetter phases.
  - Submerged terraces and palaeochannels lie on the western continental shelf.

Concept 9: World Climates and the Weight of Processes

- **Statement:** an appreciation of **world climates** is needed to understand the **varying importance** of the different geomorphic processes.
- **Mechanism:**
  - Temperature and precipitation directly control weathering, frost action, runoff and wind work.
  - Climate works indirectly through vegetation and soils.
- **Climatic geomorphology**, building on Richthofen and advanced by Büdel, Peltier, **Jean Tricart and André Cailleux (1965)**, divides the world into **morphogenetic regions**.
  - It uses **diagnostic forms** such as duricrusts (laterite, silcrete, calcrete), inselbergs, pediments and tors.
- **Indian examples:**
  - Chemical weathering and laterite dominate the humid Western Ghats and Meghalaya.
  - Aeolian and sheet-flood forms dominate western Rajasthan.
  - Frost shattering and solifluction occur in Ladakh and Spiti.
  - Monsoon floods do most of the channel work on Peninsular rivers.

- **Evaluation:**
  - Most diagnostic forms are not unique to one climate, relict forms blur the link, and structure and tectonics often override climate.
  - **Current view:** climate is a **strong modifier** rather than a sole cause. Climate change is now shifting process zones, as retreating glaciers and new glacial lakes in the Himalaya show.

Concept 10: Geomorphology Gains by Historical Extension

- **Statement:** geomorphology deals mainly with present landscapes, but it is **most useful when extended into history**.
- **Applications of historical extension:**
  - It helps reconstruct past climates, sea levels and drainage.
  - It helps locate placer deposits, groundwater in buried channels and dam sites.
  - It helps assess **hazard recurrence**, since past landslides and floods predict future ones.
- **Indian examples:**
  - Palaeochannel mapping of the Sarasvati–Ghaggar system is used for groundwater.
  - Palaeoflood records on the Narmada and other monsoon rivers help estimate extreme floods.
  - Old landslide debris beneath **Joshimath** has been re-interpreted as a hazard.

Spatial and Temporal Scales

- **Spatial scale:**
  - **Micro-geomorphology** covers plots, gullies and single slopes, the meso scale covers basins and regions, and **mega-geomorphology** covers continents.
  - At each scale **different variables dominate**: a cloudburst transforms a small gully catchment but barely registers in a large basin.
- **Temporal scale:**
  - **Stanley A. Schumm and Robert W. Lichty (1965)** separated **cyclic time** (millions of years, when time, initial relief and geology are the causes), **graded time** (centuries to millennia, when equilibrium forms can be recognised) and **steady time** (days to years, when forms are effectively fixed and water and sediment flows respond).
  - **Cause and effect change with scale.** A variable that is independent over short spans, such as channel form, becomes dependent over long ones.
- Post-1950 instrumentation moved study to small areas and short times; present practice links scales through dating and modelling.
- The form–process–material–time equation and its levels of study are covered under **factors controlling landform development**.

Critical Evaluation of the Fundamental Concepts

- **Strengths:**
  - The concepts give a **compact, testable framework**, and uniformitarianism, structure, process imprint and complexity remain valid in refined form.

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- **Weaknesses:**
  - They reflect **mid-20th-century glaciated-region experience**, as the Tertiary and Pleistocene concepts show.
  - They pre-date **plate tectonics**, the **systems approach** and **absolute dating**, so continuous uplift, feedback, thresholds and rare extreme events are missing.
- **Current synthesis:**
  - Landforms are products of **structure, process, climate and tectonics** acting over multiple time scales.
  - Landscapes are polycyclic, compound and often palimpsests of old and new.
  - Change runs through both steady adjustment and **threshold-crossing events**, and humans are now a leading geomorphic agent.

Previous Year Questions

2012	Write short notes on: Systems approach to landform analysis.
2015	Discuss the contributions of the American School of Subaerial Denudation in geomorphology.
2015	"Present-day landforms bear more complexity than simplicity". Elucidate.

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UNIT 03 | 8 CHAPTERS

Crustal Evolution and Mountain Building

Geosynclines; Continental drift; Isostasy; Plate tectonics; Recent views on mountain building.

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Plate Tectonics theory

PYQ RADAR **11** questions Last asked **2025** 2025 · 2023 · 2021 · 2019 · 2014 · 2000 · 1999 · 1998 · 1995 · 1990 · 1988

CONTENTS

01 Concept and Development of Plate Tectonics
02 Plate Margins
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- **Plate tectonics** is the unifying theory of the solid Earth: the **rigid outer shell (lithosphere) is broken into plates** that move over a weak, ductile **asthenosphere**, and nearly all large-scale **earthquakes, volcanoes, mountain belts, trenches and ocean basins** arise where these plates interact.
- It grew in the **1960s** out of Alfred Wegener's **continental drift theory** and Harry Hess's **seafloor spreading**, and replaced the older idea of permanent continents and ocean basins.
- Unlike drift, which moved only continents, plate tectonics moves **whole lithospheric slabs** of continent and ocean floor together, and explains the creation of crust at ridges and its destruction at trenches.

01 Concept and Development of Plate Tectonics

PYQ 2021 · 2019 · 2014 +6

Meaning of Plate Tectonics

PYQ 2021 · 2014 · 2000 +5

- **Plates** are rigid slabs of lithosphere, from a few hundred to many millions of square kilometres, that **move as single units** and deform mainly **along their margins**.
- **Plate tectonics** is the study of the **origin, nature and motion of plates**, the deformation within them and the interaction of their margins.
  - A classical image: plates glide over the asthenosphere much as **pack ice drifts on the Arctic Ocean** under the drag of currents and winds.
- The theory is not the work of one scientist; **geophysicists, seismologists and marine geologists** built it together between 1960 and 1968.

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Foundations and Development of the Theory

- The theory rests on **two earlier concepts**:
  - **Continental drift**: the horizontal mobility of continents (**Alfred Wegener, 1912–15**).
  - **Seafloor spreading**: creation of new ocean floor at mid-ocean ridges and its consumption at trenches (**Harry Hammond Hess, 1960–62**; term coined by **Robert S. Dietz, 1961**).
- **Isostasy** supplied the idea of a rigid layer floating on a yielding one, which became the lithosphere–asthenosphere pair.
- **Arthur Holmes (1928–31)** proposed **mantle convection currents** as a force able to move continents, answering the chief objection to Wegener.

YEAR	SCIENTIST(S)	CONTRIBUTION
1928–31	Arthur Holmes	Mantle convection as the driving mechanism
1960–62	Harry Hess; Robert Dietz (1961)	Seafloor spreading; ridges as upwelling zones, trenches as sinks
1963	Frederick Vine & Drummond Matthews (also Lawrence Morley)	Magnetic stripes over the Carlsberg Ridge explained by spreading plus field reversals
1963; 1965	J. Tuzo Wilson	Hotspots (1963); transform faults and the word “plate” for lithospheric slabs (1965)
1966	J. Tuzo Wilson	Oceans open and close in cycles (Wilson cycle)
1967	Dan McKenzie & Robert Parker	Plate motion on a sphere by Euler’s theorem (“paving-stone” model of the North Pacific)
1968	W. Jason Morgan	Rigid blocks bounded by rises, trenches and transform faults; Euler poles for the Atlantic
1968	Xavier Le Pichon	Global model of six large plates
1968	Bryan Isacks, Jack Oliver & Lynn Sykes	Seismology confirmed the model: earthquakes trace plate boundaries and descending slabs

Layers by Mechanical Strength

- Plate tectonics divides the upper Earth by **rigidity**, not by chemistry, and so sets aside the old **SIAL–SIMA** scheme.
  - **Lithosphere**: the **crust plus the uppermost mantle**, rigid and brittle; about 5–100 km thick under oceans (thickening with age of the sea floor) and 100–200 km or more under continents, thickest beneath old cratons.
  - **Asthenosphere**: a **weak, ductile layer** of the upper mantle below the lithosphere (roughly 100–350 km depth), close to its melting point, over which plates move.

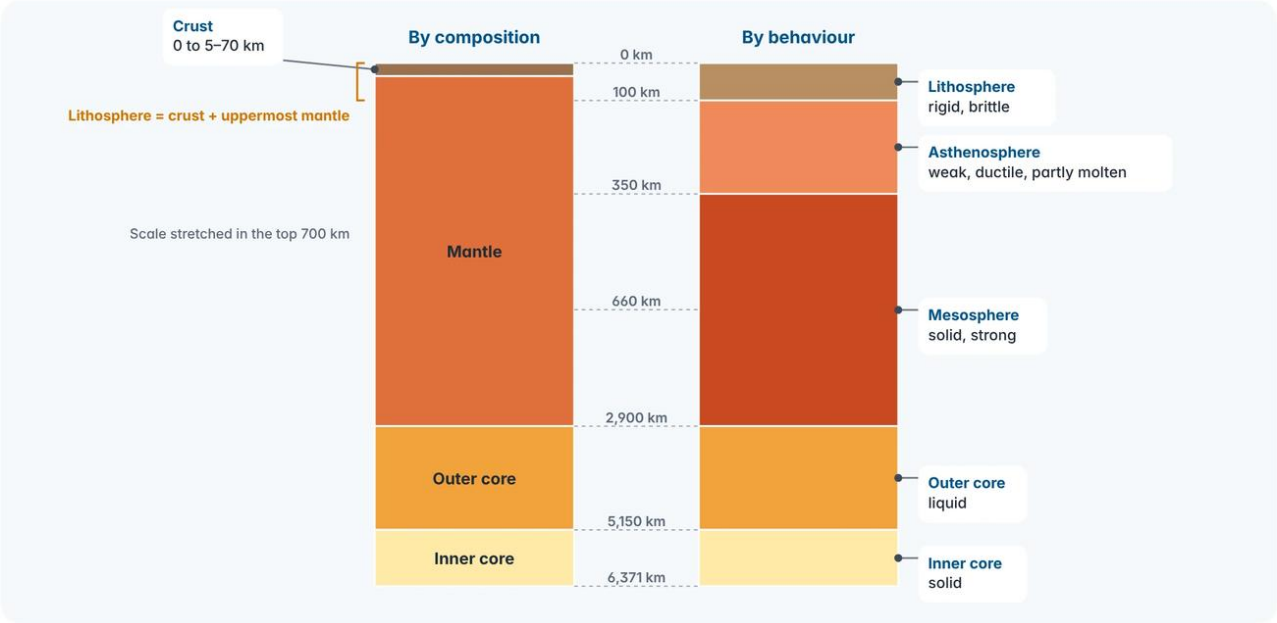
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  - **Mesosphere**: the stronger lower mantle beneath.
- Oceanic plates carry **thin, dense basaltic (sima-like) crust**; continental plates carry **thick, lighter granitic (sial-like) crust**.

GEOMORPHOLOGY · INTERIOR OF THE EARTH

Lithosphere, Asthenosphere and Mesosphere

The Earth can be layered by composition (crust, mantle, core) or by how rock behaves (rigid lithosphere, weak asthenosphere, strong mesosphere).



Lithosphere
- Crust plus the rigid uppermost mantle
- About 100 km thick; broken into plates
- Plates ride on the asthenosphere

Asthenosphere
- About 100–350 km; weak and ductile
- Partly molten: source of magma
- Allows isostatic adjustment

Mesosphere
- Rest of the mantle to 2,900 km
- Solid and strong under high pressure
- Core layers are the same in both schemes

Boundary depths approximate; the asthenosphere's base varies.

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Basic Postulates

- The lithosphere is broken into **rigid plates** that **move horizontally** over the asthenosphere.
- Plates are **created** at divergent margins, **consumed** at convergent margins and **conserved** at transform margins.
- The **surface area of the Earth stays constant**: crust added at ridges is balanced by crust lost at subduction zones, so the Earth is not expanding.
- **Plate interiors are relatively stable**; seafloor spreading, volcanism, faulting, folding and mountain building are concentrated **along the margins**.
- Plate motion is **relative**: a change in speed or direction of one plate alters the motion of its neighbours.

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Lithospheric Plates

Types of Plates

- Oceanic plates: carry oceanic crust only, e.g. the Pacific, Nazca and Cocos plates.
- Continental plates: mostly continental crust, e.g. the Arabian plate and much of the Eurasian plate.
- Continental–oceanic plates: carry both, e.g. the Indo-Australian, North American and African plates.

Major Plates

- Most maps show **seven major plates**; the count becomes **eight** when the Indian and Australian plates are treated separately, as modern GPS data support.
- A widely used global model by **Peter Bird (2003)** recognises **52 plates**: 14 large and 38 small.

PLATE	NATURE	PRESENT MOTION (APPROX.)	NOTES
Pacific	Almost wholly oceanic	North-west, ~7–10 cm/yr	Largest and fastest large plate; ringed by trenches
North American	Continental + western Atlantic floor	West-south-west, ~2–3 cm/yr	Pushed away from the Mid-Atlantic Ridge
South American	Continental + South Atlantic floor	Westward, slow	Overrides the Nazca plate at the Peru–Chile trench
Eurasian	Mostly continental	Very slow, roughly eastward	Among the slowest plates
African	Continental + ocean floor	North-east, ~2 cm/yr	Splitting into Nubian and Somali plates
Antarctic	Continental + ocean floor	Nearly stationary	Surrounded almost wholly by spreading ridges
Indo-Australian	Continental + oceanic	Indian part ~4–5 cm/yr NNE; Australian part ~6–7 cm/yr north	Now largely two plates with a diffuse boundary

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GEOMORPHOLOGY · PLATE TECTONICS

The Major Lithospheric Plates

Seven major plates, eight when the Indian and Australian plates are counted separately, with smaller plates filling the gaps between them.

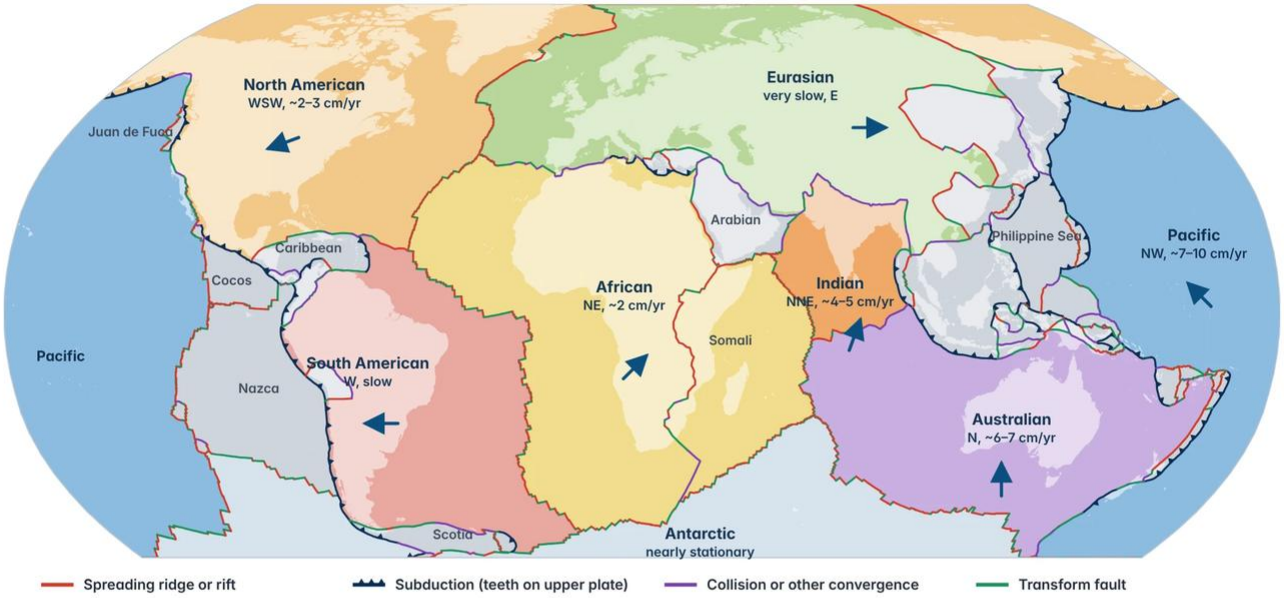


Plate	Nature	Motion	Note
Pacific	Almost wholly oceanic	NW, ~7–10 cm/yr	Largest and fastest; ringed by trenches
North American	Continent + western Atlantic floor	WSW, ~2–3 cm/yr	Pushed away from the Mid-Atlantic Ridge
South American	Continent + South Atlantic floor	W, slow	Overrides Nazca at the Peru–Chile trench
Eurasian	Mostly continental	Very slow, E	Among the slowest plates
African	Continent + ocean floor	NE, ~2 cm/yr	Splitting into Nubian and Somali
Antarctic	Continent + ocean floor	Nearly stationary	Almost ringed by spreading ridges
Indo-Australian	Continental + oceanic	Indian NNE 4–5; Australian N 6–7 cm/yr	Now largely two plates, diffuse boundary

Boundaries from a global plate model (52 plates); motions approximate. Robinson projection. Boundary of India: official outline.

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Minor Plates and Microplates

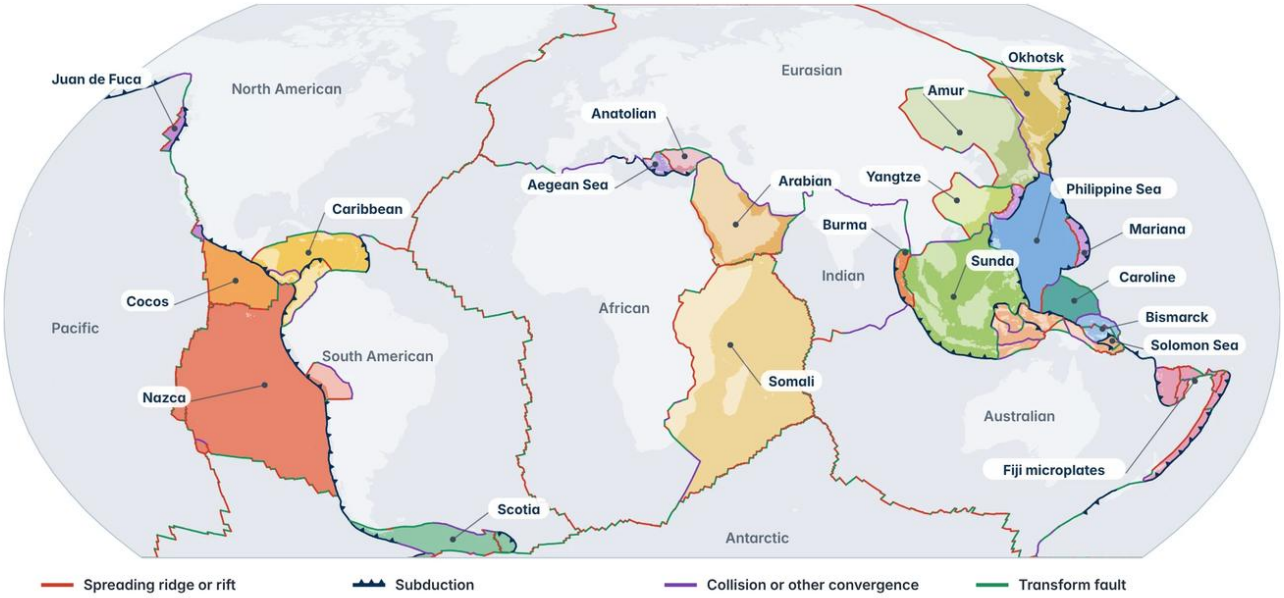
- Americas: Cocos and Nazca (subducting beneath Central and South America), Caribbean, Juan de Fuca (between the Pacific and North American plates), Scotia.
- Asia–Pacific: Philippine Sea plate (between the Eurasian and Pacific plates), Caroline plate (north of New Guinea, astride the Equator), North and South Bismarck, Sunda and Burma plates, and the Amur and Yangtze (South China) blocks.
- Middle East–Mediterranean: Arabian plate (mostly the Arabian Peninsula), Anatolian (Turkish) plate (most of Asia Minor), the Iranian (Persian) block and the Aegean Sea plate.
- South-west Pacific: a mosaic of microplates around Fiji between the Pacific and Indo-Australian plates.

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GEOMORPHOLOGY · PLATE TECTONICS

Minor Plates and Microplates

Between the large plates lie dozens of smaller ones, crowded into the most active collision and subduction zones of the Americas, the Middle East and the western Pacific.



Americas

- Cocos and Nazca sink beneath Central and South America
- Caribbean; Juan de Fuca off the Pacific Northwest
- Scotia between South America and Antarctica

Asia–Pacific

- Philippine Sea between Eurasia and the Pacific
- Caroline astride the Equator, north of New Guinea
- Sunda, Burma, Amur and Yangtze blocks

Middle East and South-west Pacific

- Arabian, Anatolian and Aegean Sea plates
- Iranian (Persian) block within the Alpine belt
- A mosaic of microplates around Fiji

Plate outlines from a global model of 52 plates; major plates shown pale. Robinson projection. Boundary of India: official outline.

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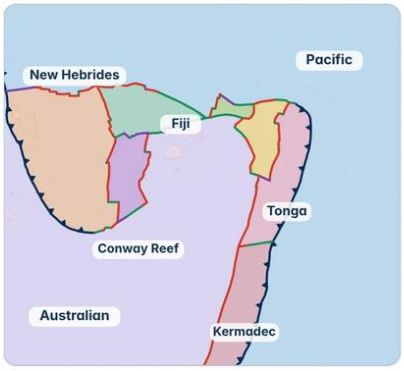
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GEOMORPHOLOGY · PLATE TECTONICS

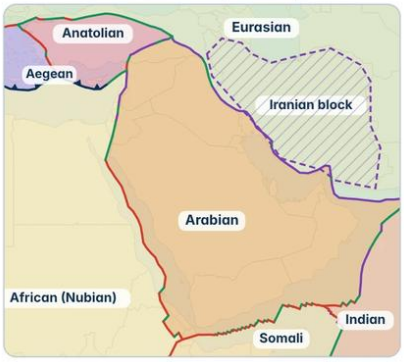
Where Microplates Crowd Together

Three regions where converging and spreading boundaries break the lithosphere into small plates: the Fiji area, the Middle East and the western Pacific.

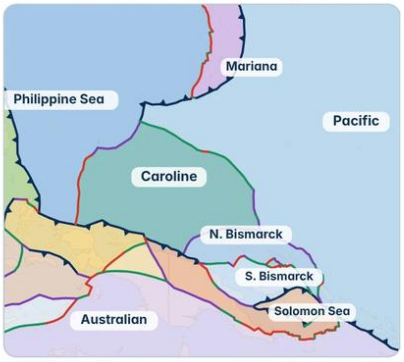
South-west Pacific: microplates around Fiji



Middle East: Arabia, Anatolia, Iran



Western Pacific: the Caroline plate



Spreading ridge · Subduction · Convergence · Transform

Fiji region

- Pacific plate sinks at the Tonga–Kermadec trench
- Back-arc spreading opens the Lau and North Fiji basins
- Splits the area into many small plates

Middle East

- Arabia pushes north into Eurasia: Zagros and Makran
- Anatolia escapes west between two faults
- Iran is a deforming block, not a rigid plate

Caroline plate

- Small oceanic plate north of New Guinea
- Between the Pacific and Philippine Sea plates
- Hemmed in by trenches and the Bismarck plates

Regional maps; plate outlines from a global model; the Iranian block is shown inside the Eurasian plate.

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02 Plate Margins

PYQ 2021 · 2019 · 2014 +6

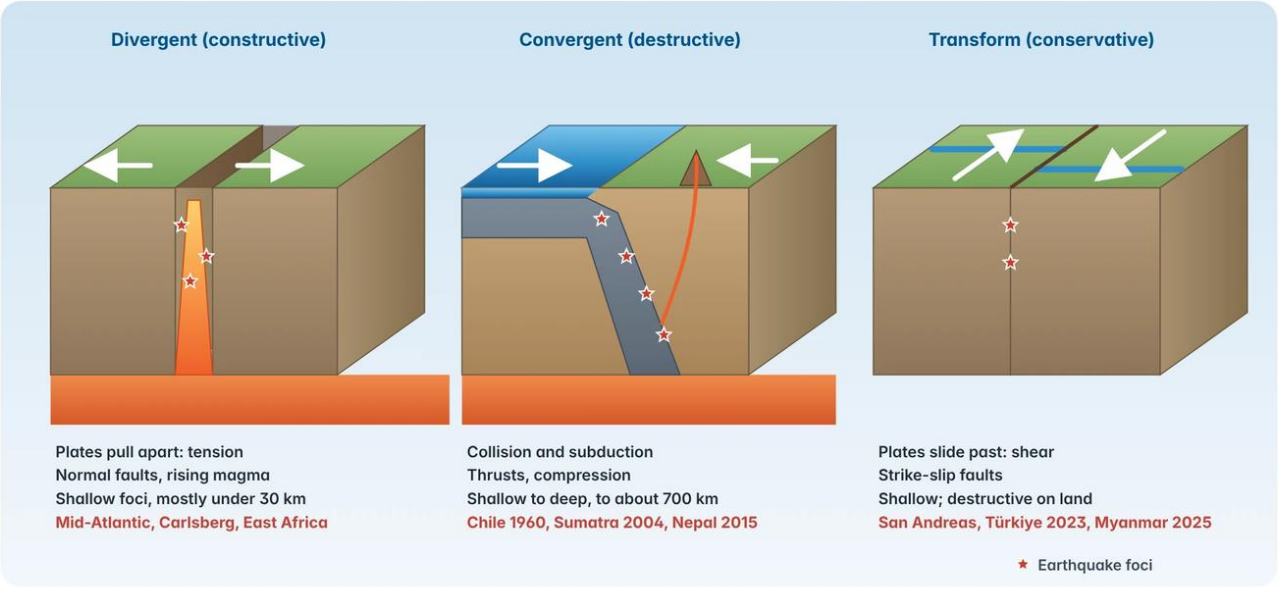
- **Plate margins are the most active zones** of the Earth; seismicity, vulcanicity, faulting and mountain building are concentrated there.
- A **plate margin** is the marginal part of a plate, while a **plate boundary** is the surface trace of the zone of motion between two plates.
- By the **relative motion** of the plates, margins are of **three types**:
  - **Divergent (constructive, accreting)**: plates move apart.
  - **Convergent (destructive, consuming)**: plates move together.
  - **Transform (conservative, shear)**: plates slide past each other.

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GEOMORPHOLOGY · EARTHQUAKES

Earthquakes at the Three Kinds of Plate Boundary

Plates pulling apart, colliding or sliding past one another each produce a typical pattern of faulting, focal depth and earthquake size.



Why boundaries shake

- Most epicentres lie on plate boundaries
- Stress builds where plates meet
- Release comes as fault slip

Largest shocks

- Megathrusts at subduction zones
- All Mw 9 and above occur there
- Foci deepen along the sinking slab

Himalaya

- India thrust beneath Eurasia
- Main Himalayan Thrust
- About 4–5 cm a year of convergence

Block diagrams; not to scale.

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FEATURE	DIVERGENT	CONVERGENT	TRANSFORM
Motion	Apart	Together	Side by side
Crust	Created	Destroyed (subducted)	Neither created nor destroyed
Landforms	Mid-ocean ridges, rift valleys	Trenches, island arcs, fold mountains	Fault valleys, offset ridges, fracture zones
Volcanism	Quiet fissure eruptions of basalt	Explosive, andesitic	Absent
Earthquakes	Shallow, moderate	Shallow to deep (up to ~700 km), strongest	Shallow, can be severe
Examples	Mid-Atlantic Ridge, East African Rift, Carlsberg Ridge	Andes, Japan, Himalaya	San Andreas, North Anatolian, Sagaing

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Divergent (Constructive) Margins

Oceanic Divergence: Mid-Ocean Ridges

- At a **divergent boundary** two plates **move away from each other**, usually along the crest of a **mid-ocean ridge**.
- Mechanism:
  - As plates separate, pressure on the hot upper mantle falls, causing **decompression (partial) melting**.
  - The magma rises into the rift and solidifies as **basalt**, adding **new oceanic crust** to the trailing edges of both plates.
  - Each new strip is magnetised in the field of its time, giving **symmetrical magnetic stripes** on either side of the ridge.
- Outcomes:
  - **Fissure eruptions** of low-silica **tholeiitic basalt**; submarine ridges and rises.
  - A central **rift valley** on slow ridges; **transform faults** that offset the ridge axis.
  - **Shallow-focus earthquakes** of moderate size; **hydrothermal vents** (black smokers).
- Examples: Mid-Atlantic Ridge, East Pacific Rise and, next to India, the Carlsberg Ridge and Central Indian Ridge, which separate the Indian plate from the Somali (African) plate.
- Iceland sits astride the Mid-Atlantic Ridge and is being pulled apart and built up by basalt; the 1973 eruption on Heimaey and the recurring Reykjanes Peninsula eruptions since 2021 show the ridge at work on land.

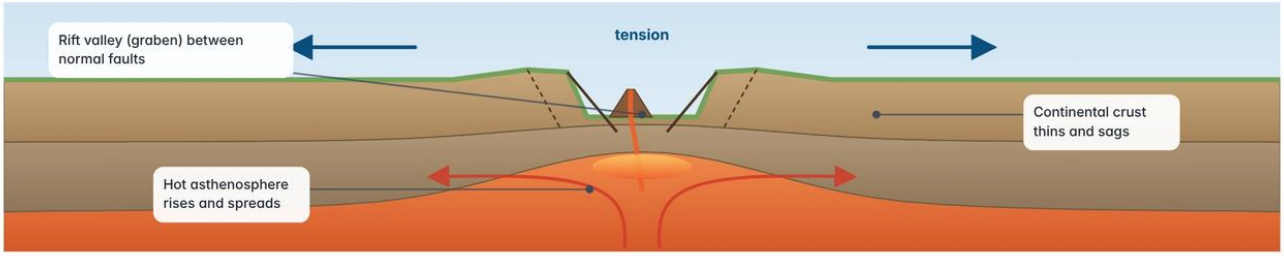
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GEOMORPHOLOGY · PLATE TECTONICS

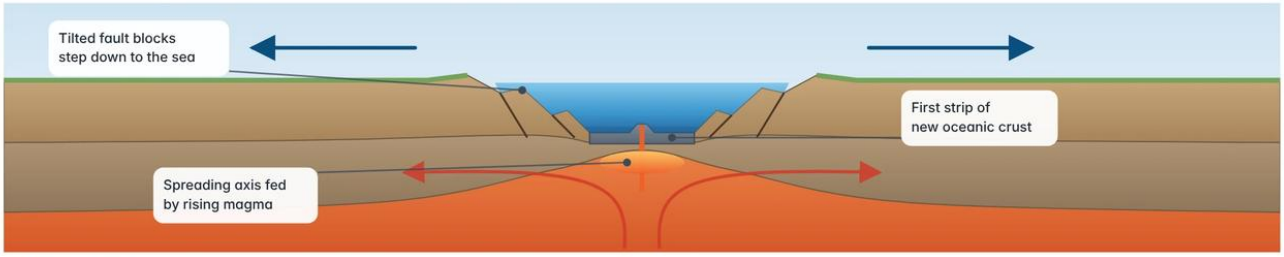
From Continental Rift to Ocean Basin

A divergent boundary grows in stages: a continent stretches into a rift valley, splits into a narrow sea and widens into an ocean with a mid-ocean ridge.

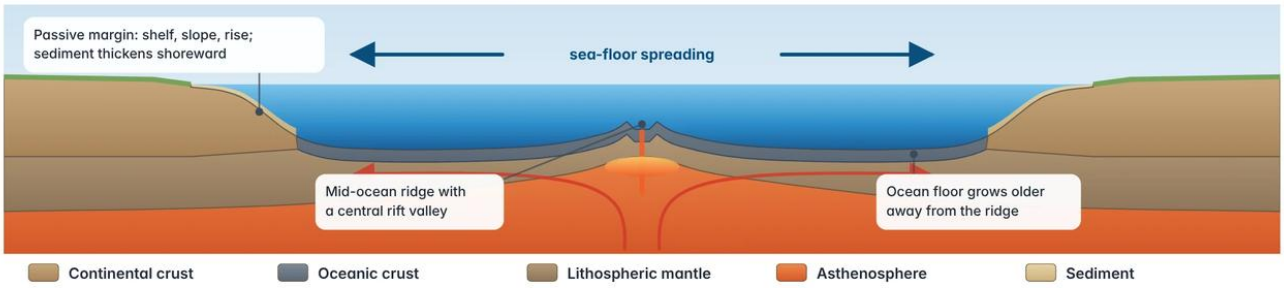
A Continental rift a long trough as the continent is stretched (East African Rift)



B Narrow sea the continent splits and the first ocean floor forms (Red Sea, Gulf of Aden)



C Ocean basin a wide ocean with a mid-ocean ridge and passive margins (Atlantic Ocean)



1 Rifting

- Upwelling stretches and thins the crust
- Normal faults drop a graben
- Volcanoes, shallow earthquakes

2 Narrow sea

- Continent splits; sea floods in
- Basalt makes the first ocean floor
- Red Sea and Gulf of Aden today

3 Ocean basin

- Ridge keeps adding ocean floor
- Old rift edges become passive margins
- Atlantic: stage after the Red Sea

Schematic cross-sections; not to scale.

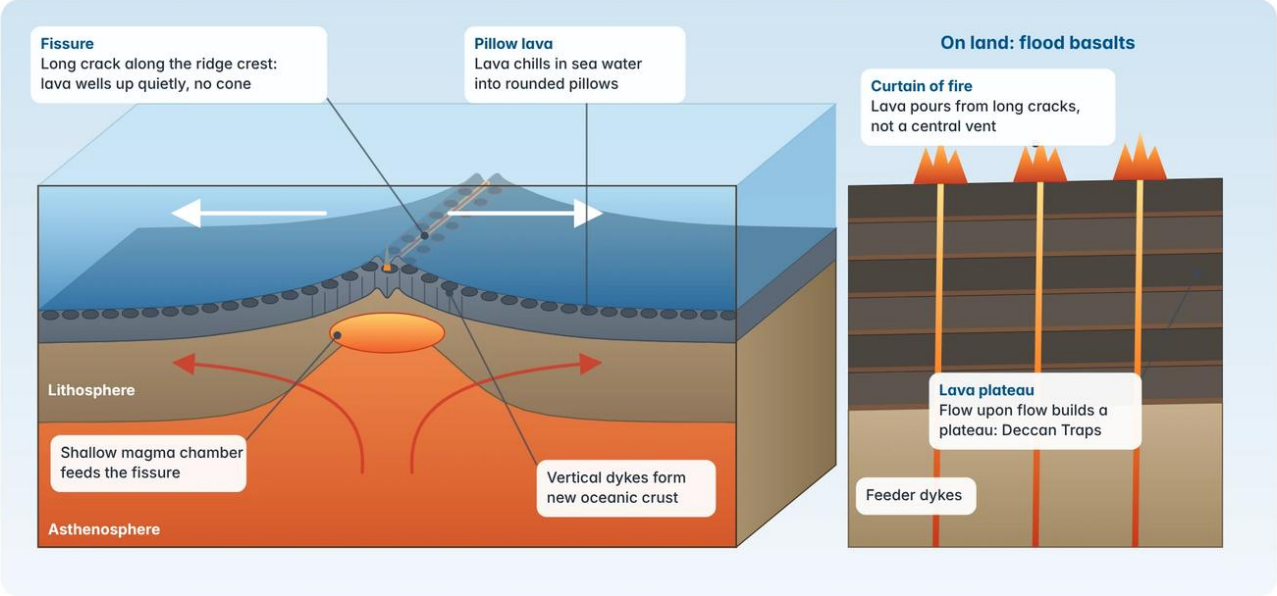
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GEOMORPHOLOGY · PLATE TECTONICS

Fissure Eruptions at Divergent Boundaries

Where plates pull apart, basaltic magma rises through long cracks rather than a single vent, building new ocean floor and, on land, vast lava plateaus.



At mid-ocean ridges

- Most of Earth's lava erupts here, under the sea
- Basalt: runny, low in silica, few explosions
- Builds new ocean floor at divergent boundaries

On land

- Iceland sits astride the Mid-Atlantic Ridge
- Laki, 1783: a 27 km long fissure
- East African Rift volcanic fields

Flood basalts

- Deccan Traps of peninsular India
- Columbia River Plateau, Siberian Traps
- Gentle slopes, flat-topped plateaus

Schematic block diagram; not to scale.

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Continental Rifts

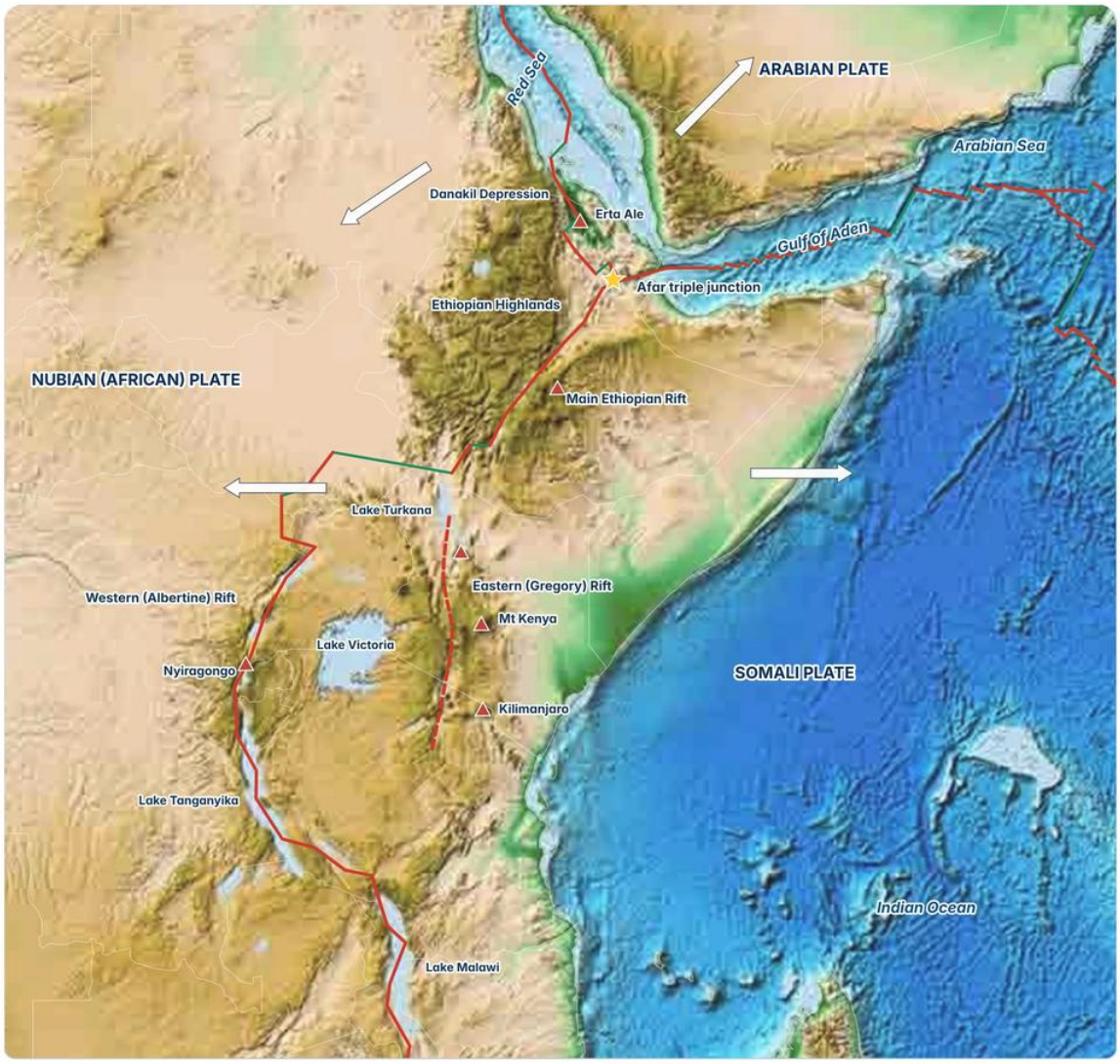
- Divergence can begin **inside a continent**, forming a **continental rift valley** bounded by normal faults.
  - East African Rift, Baikal Rift, West Antarctic Rift and Rio Grande Rift are the major active continental rifts.
- A rift that keeps widening floods to form a **proto-ocean** (the Red Sea) and finally a **mature ocean** (the Atlantic).
- Some rifts fail; India's Narmada–Son, Cambay and Kutch grabens are old rifts that still host **intraplate earthquakes** (Kutch 1819, Bhuj 2001).

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GEOMORPHOLOGY · PLATE TECTONICS

East African Rift, Red Sea and the Afar Triangle

Africa is splitting along the East African Rift, while the Red Sea and Gulf of Aden have already opened into narrow oceans; the three meet in the Afar triple junction.



A rift in the making

- Somali plate pulls away east from Nubia
- Two branches: Eastern and Western Rifts
- Long lakes, steep fault scarps, volcanoes

Afar triple junction

- Red Sea, Gulf of Aden and the Ethiopian Rift meet
- Danakil Depression lies below sea level
- Stage between rift and ocean

Red Sea and Gulf of Aden

- Arabia moves north-east from Africa
- New ocean floor along the axis
- A young ocean, about 1–2 cm a year

Shaded relief; boundaries from a global plate model, rift branches simplified. Equirectangular projection. lotusarise.com

Convergent (Destructive) Margins

- At a **convergent boundary** two plates **move towards each other**; the denser plate usually **sinks (subducts)** into the mantle and part of the lithosphere is **consumed**.
- The inclined zone of earthquakes marking the sinking slab is the **Wadati–Benioff zone**, after **Kiyoo Wadati** and **Hugo Benioff**; it reaches depths of about **700 km**.

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- General outcomes:
  - Deep oceanic trenches, island arcs and festoons, fold mountains.
  - **Explosive volcanism** of andesite, dacite and rhyolite; **metamorphism**.
  - The world's largest and deepest earthquakes.
- Convergence is of **three types**:

TYPE	WHICH PLATE SINKS	MAIN LANDFORMS	EXAMPLES
Oceanic–continental	Denser oceanic plate	Trench + continental volcanic arc + fold mountains	Andes (Nazca under South America); Cascades
Oceanic–oceanic	Older, colder, denser oceanic plate	Trench + volcanic island arc	Mariana, Aleutian, Japan, Indonesia
Continental–continental	Neither sinks deeply (buoyant)	Huge fold-thrust mountains, plateaus	Himalaya–Tibet, Alps

Oceanic–Continental Convergence

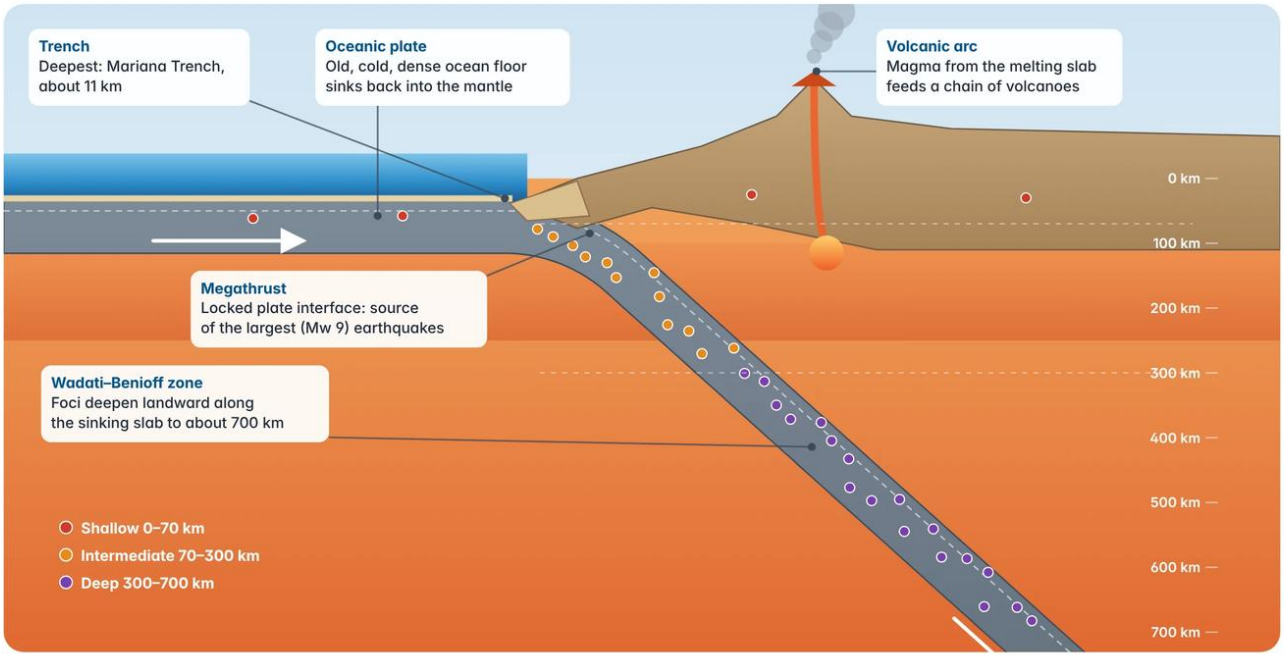
- The **denser oceanic plate subducts** beneath the lighter continental plate, forming a **trench** offshore.
- **Water released from the sinking slab** lowers the melting point of the overlying mantle wedge (**flux melting**); the magma rises to build a **continental volcanic arc**.
- Sediments and crust scraped off the slab are squeezed into **fold mountains** along the continental edge: the Andes and the western Cordillera of North America.
- The weight of the dense, sinking slab **pulls the rest of the plate behind it**; this **slab pull** is now regarded as the main driver of plate motion.

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GEOMORPHOLOGY · PLATE TECTONICS

Subduction Zones and the Wadati–Benioff Zone

Old ocean floor sinks beneath a trench into the mantle; earthquake foci deepen along the sinking slab, and melting feeds a volcanic arc.



Subduction

- Ocean floor bends down at a trench
- Balances crust made at mid-ocean ridges
- Slab pull: the main force driving plates

Earthquakes

- Deep foci occur only at subduction zones
- Inclined Wadati–Benioff zone traces the slab
- Megathrusts: Chile 1960, Sumatra 2004

Landforms

- Deep-ocean trenches
- Volcanic arcs: Andes, Japan, Indonesia
- Accretionary wedge of scraped sediment

Cross-section; vertical scale exaggerated near the surface.

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Oceanic–Oceanic Convergence

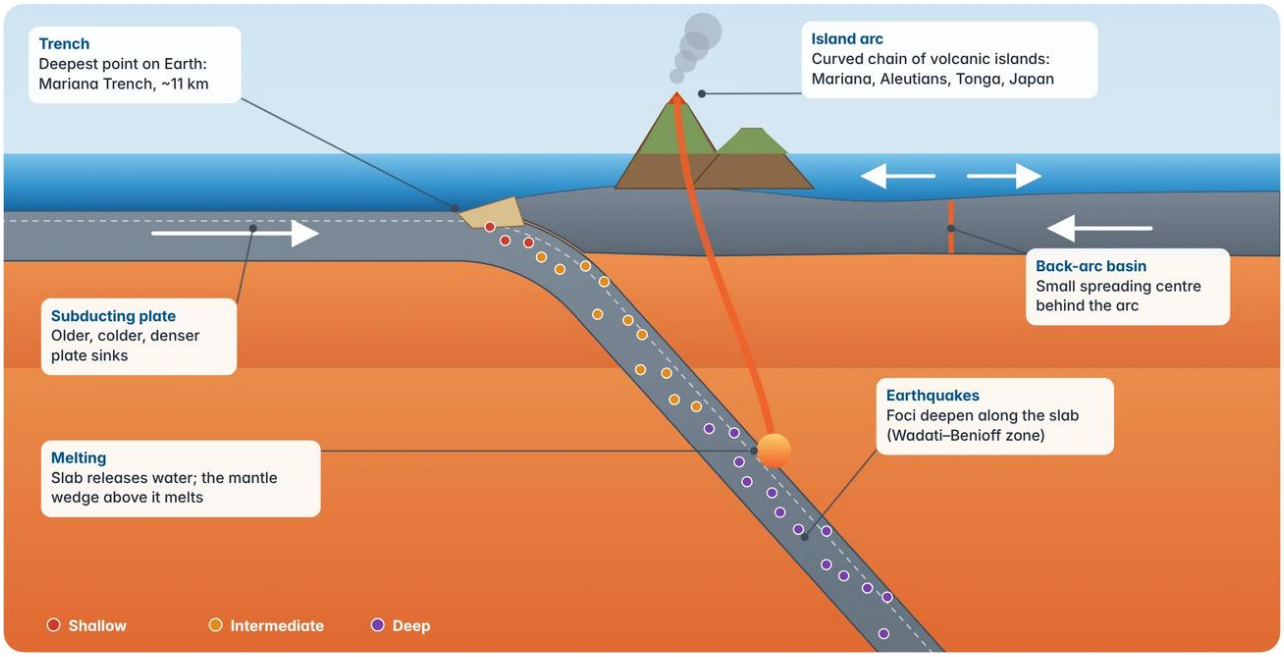
- Where two oceanic plates meet, the **older, colder and denser** one sinks beneath the other.
- The result is an **oceanic trench** paired with a curved **volcanic island arc**, plus shallow to deep-focus earthquakes.
  - Young arcs: Aleutian and Mariana Islands (the Mariana Trench holds the deepest point of the oceans).
  - Mature arc systems with thicker crust: Japan, Sumatra–Java and the Philippines.
- Indian example: the **Indian plate subducts beneath the Burma microplate** along the Andaman–Sumatra trench; the Andaman–Nicobar arc and Barren Island, India's only active volcano, belong to this system.

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GEOMORPHOLOGY · PLATE TECTONICS

Ocean–Ocean Convergence and Island Arcs

When two oceanic plates meet, the older and denser one sinks beneath the other, cutting a deep trench and raising a curved arc of volcanic islands.



Process

- Two oceanic plates converge
- The older, denser plate subducts
- Water from the slab lowers melting point

Landforms

- Deep trench on the ocean side
- Arc of volcanic islands parallel to it
- Back-arc basin behind the arc

Examples

- Mariana Islands and Trench
- Aleutian Islands, Alaska
- Tonga–Kermadec, Lesser Antilles

Schematic cross-section; vertical scale exaggerated.

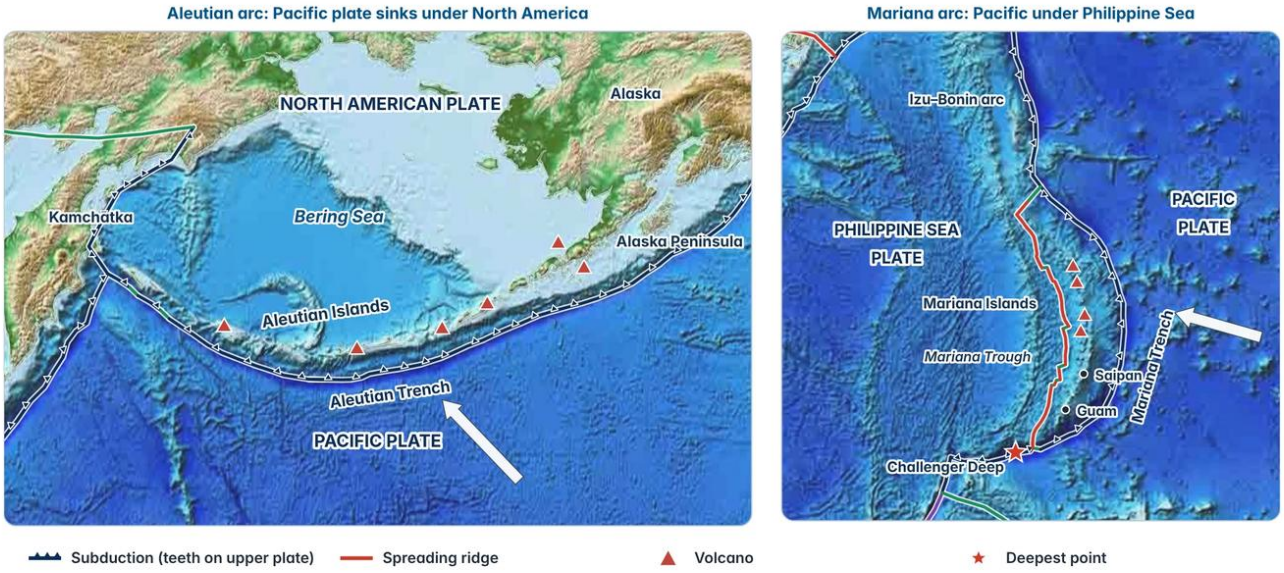
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Island Arcs: the Aleutians and the Marianas

Two classic ocean–ocean convergent boundaries in the Pacific, each with a deep trench on the ocean side and a curved arc of volcanic islands behind it.



Aleutian Islands

- Arc of about 2,500 km from Alaska to Kamchatka
- Aleutian Trench to the south, Bering Sea behind
- Strong earthquakes: Alaska 1964 (Mw 9.2)

Mariana Islands

- Old, dense Pacific floor sinks steeply
- Challenger Deep, about 10.9 km below sea level
- Mariana Trough: back-arc spreading

Common pattern

- Trench on the ocean side, arc behind it
- Arc convex towards the sinking plate
- Explosive andesitic volcanoes

Shaded relief; boundaries from a global plate model. Equirectangular projections, different scales.

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Continental–Continental Convergence

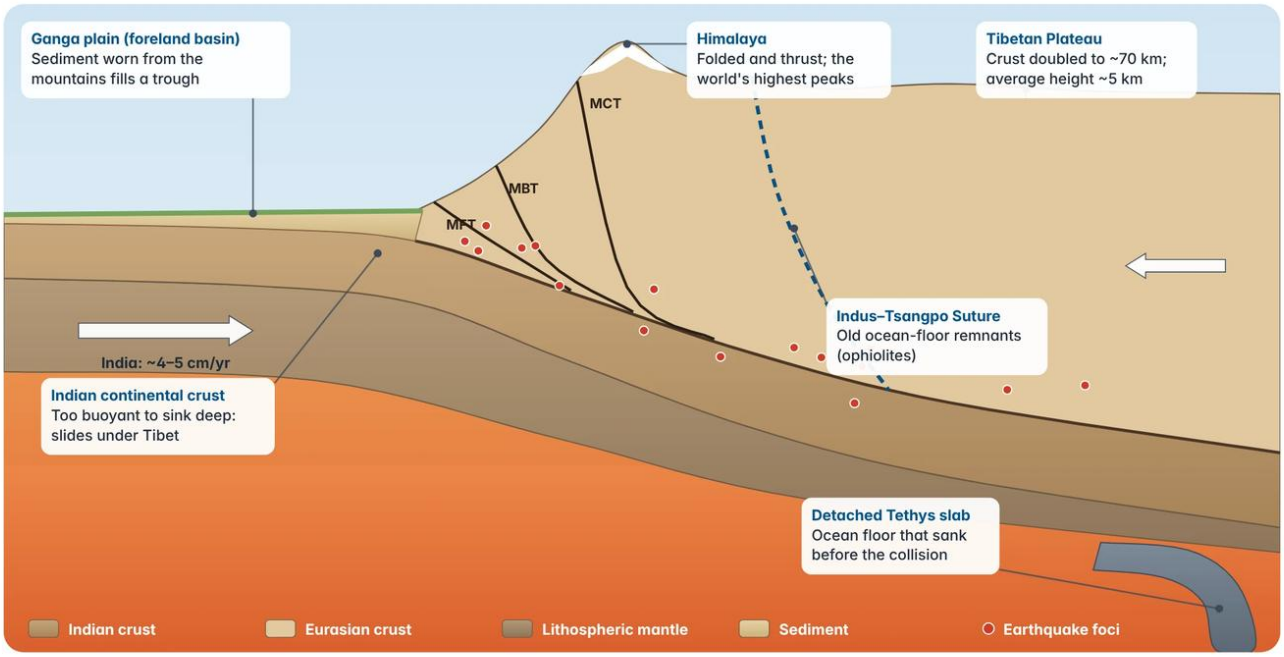
- When an ocean between two continents is **fully consumed**, the continents **collide**; continental crust is **too buoyant to subduct deeply**.
- The ocean-floor sediments and continental margins are **crumpled, thrust and stacked** into great **fold-thrust mountains**, and the crust thickens to form plateaus.
  - Himalaya and Tibetan Plateau: the Indian plate against the Eurasian plate after the closing of the Tethys.
  - Alps: the African (Adriatic) plate against the Eurasian plate.
- The line where the two continents are welded is a **suture zone**, e.g. the Indus–Tsangpo Suture in Ladakh and southern Tibet.
- **Obduction**, the opposite of subduction, **thrusts slices of ocean floor up onto the continent** as **ophiolites**, e.g. Spontang (Ladakh), the Naga–Manipur hills and the Andaman islands.

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GEOMORPHOLOGY · PLATE TECTONICS

Continent–Continent Collision: the Himalaya

After the Tethys Ocean closed, India drove into Eurasia; light continental crust resisted subduction and piled up into the Himalaya and the Tibetan Plateau.



Process

- Ocean between two continents closes
- Neither continent subducts deeply
- Crust thickens by folding and thrusting

Features

- Fold mountains, suture zone, ophiolites
- High plateau behind the range
- Shallow earthquakes; little volcanism

Examples

- Himalaya and Tibet: India meets Eurasia
- Alps: Africa (Adria) meets Europe
- Zagros: Arabia meets Iran

Schematic south–north cross-section; not to scale.

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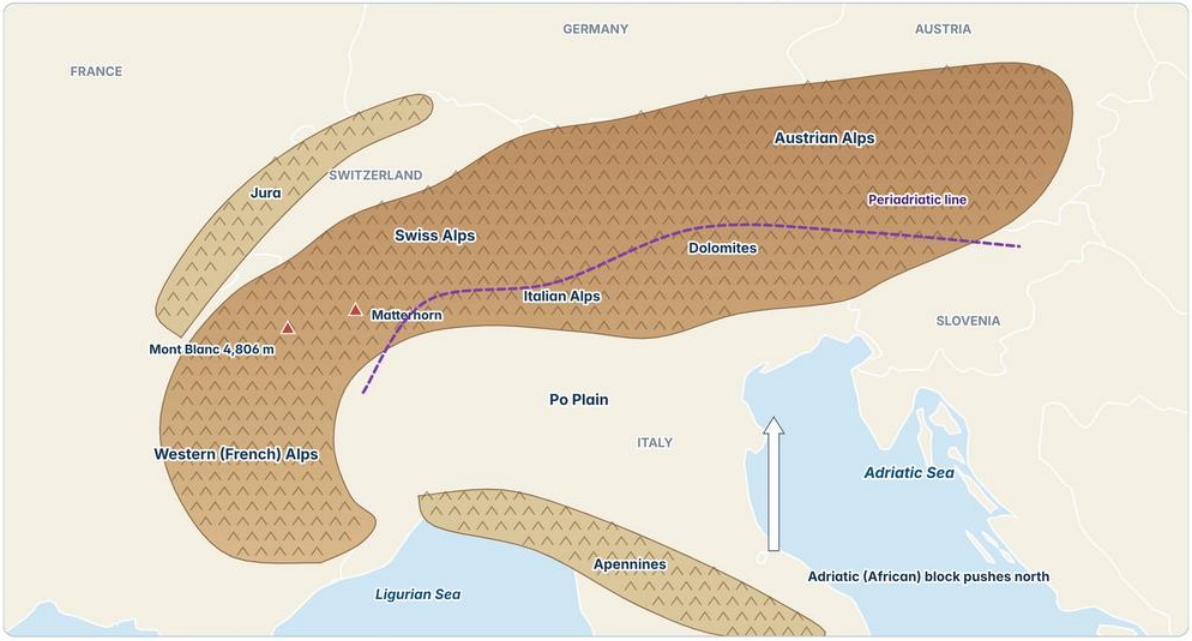
The Alpine–Himalayan Collision Belt

Continental collision along the line of the vanished Tethys Ocean has raised a chain of young fold mountains from the Atlas and Alps to the Himalaya.

The Alpine–Himalayan belt: where Africa, Arabia and India meet Eurasia



The Alps: the Adriatic block driven north into Europe



One long belt

- Atlas and Alps to the Himalaya and Myanmar
- Closure of the Tethys Ocean
- Young fold mountains, still rising

Alps

- Africa's Adriatic block pushes into Europe
- Rock sheets (nappes) thrust far north
- Mont Blanc, Matterhorn

Himalaya and Tibet

- India drives into Eurasia at ~4–5 cm a year
- Crust thickened to about 70 km
- Earthquakes along the whole belt

Belt map in shaded relief, boundaries from a global plate model; Alps sketch map simplified. Equirectangular projections, different scales. Boundary of India: official outline.

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Transform (Conservative) Margins

- Along a **transform fault** (strike-slip boundary) two plates **slide horizontally past each other**; lithosphere is neither created nor destroyed, only deformed.
  - The term and concept are due to **J. Tuzo Wilson (1965)**.

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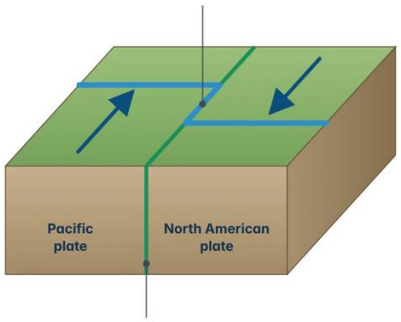
- **Oceanic transforms** run roughly at right angles to mid-ocean ridges and **offset the ridge axis**; their inactive extensions are **fracture zones**.
- Transform faults lie **parallel to the direction of relative plate motion**, which is why they trace small circles about the pole of rotation.
- Features: **no volcanism**, **shallow but often destructive earthquakes**, fault troughs, shutter ridges and offset streams.
- Continental examples:
  - San Andreas Fault (California): Pacific plate against the North American plate, close to San Francisco and Silicon Valley.
  - North Anatolian Fault (Turkey) and East Anatolian Fault, whose rupture caused the Turkey–Syria earthquake of February 2023 (M7.8).
  - Alpine Fault of New Zealand.
- Around India: the Owen Fracture Zone (India–Arabia), the Chaman Fault on the western margin and the Sagaing Fault on the eastern margin; the Sagaing Fault produced the Myanmar earthquake of 28 March 2025 (M7.7), which ruptured several hundred kilometres of the fault.

GEOMORPHOLOGY · PLATE TECTONICS

The San Andreas Transform Fault

Along the San Andreas Fault the Pacific plate slides north-west past the North American plate, offsetting streams and roads and producing frequent earthquakes.





Transform fault · Subduction · Spreading ridge · ★ Triple junction

San Andreas Fault

- About 1,200 km through California
- Pacific plate moves north-west past North America
- Joins ridge segments in the Gulf of California

Earthquakes

- Shallow but damaging shocks
- San Francisco 1906 (about Mw 7.9)
- Stress builds on locked segments

Transform boundaries

- Conservative: no crust made or destroyed
- Strike-slip movement; offset streams
- Also: North Anatolian, Alpine Fault (New Zealand)

Boundaries from a global plate model. Equirectangular projection. Block diagram schematic.

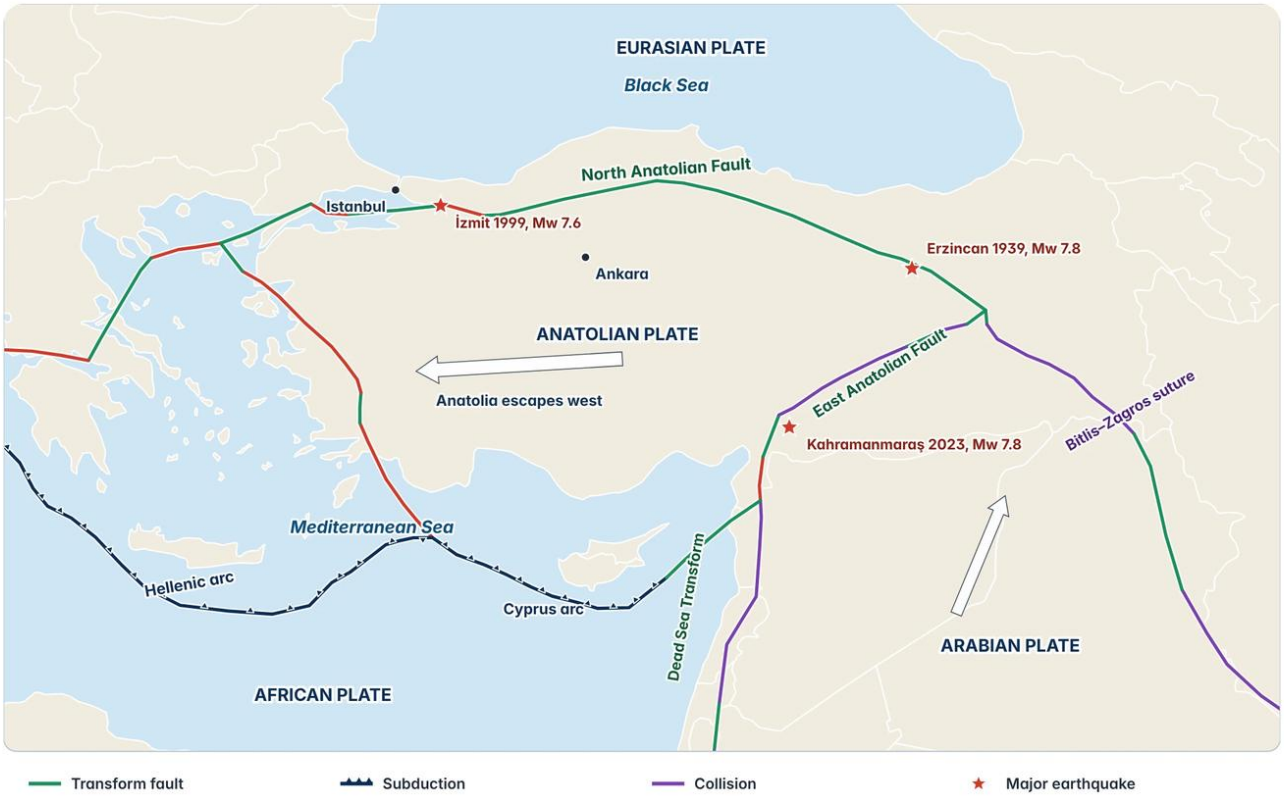
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GEOMORPHOLOGY · PLATE TECTONICS

The North Anatolian Fault and the Anatolian Plate

Squeezed between Arabia and Eurasia, the Anatolian plate slides westward along two great transform faults, the North and East Anatolian Faults.



North Anatolian Fault

- Right-lateral strike-slip, about 1,200 km
- Moves 2–3 cm a year
- Quakes have marched westward since 1939

Why Anatolia moves

- Arabia pushes north into Eurasia
- Anatolia is squeezed out to the west
- Pulled towards the Hellenic subduction zone

Hazard

- İzmit 1999 near Istanbul
- East Anatolian Fault: Kahramanmaraş 2023
- Istanbul faces a large future shock

Boundaries from a global plate model. Equirectangular projection.

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Plate Boundary Zones and Triple Junctions PYQ 2019

- Not all boundaries are sharp lines; **plate boundary zones** are **broad belts of deformation** where the effects of plate interaction are spread out.
  - Examples: the Mediterranean–Alpine region and the Tibet–Himalaya belt.
  - The **Indian and Australian plates** are separating across a diffuse zone in the central Indian Ocean; the April 2012 Indian Ocean earthquakes (M8.6 and M8.2) occurred inside this zone.
- A **triple junction** is a point where **three plates meet**, e.g. the Afar junction of the Nubian, Somali and Arabian plates, and the Mendocino junction off northern California.

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03 Plate Motion and Its Causes

Geometry of Plate Motion: Euler's Theorem

- **Leonhard Euler's theorem** states that any displacement of a rigid cap on a sphere is a **rotation about an axis through the Earth's centre**. The point where this axis cuts the surface is the **Euler pole (pole of rotation)**.
- Applied to plates by **McKenzie and Parker (1967)** and **Morgan (1968)**:
  - Every point on a plate moves along a **small circle** about the Euler pole.
  - **Transform faults must lie along these small circles**; margins not parallel to them become constructive or destructive.
  - **Relative velocity is zero at the pole and greatest 90° away** from it, so spreading and convergence rates vary along a single boundary.
- Proof: Morgan drew **great circles perpendicular to the transform faults** of the equatorial Mid-Atlantic Ridge; they met at a **common pole in the North Atlantic**, as the rigid-plate model predicted.

Rates of Plate Motion

- Measurement: from the **ages of magnetic stripes and isochrons** (lines joining sea floor of equal age), and today directly by **GPS, satellite laser ranging and VLBI**.
- A spreading rate may be quoted as the **half rate** (one side of the ridge) or the **full rate** (both sides together); a half rate of 1 cm/yr means a full rate of 2 cm/yr.

RIDGE	FULL SPREADING RATE (APPROX.)	CLASS
Gakkel (Arctic) Ridge	Below 2 cm/yr	Ultra-slow
Mid-Atlantic Ridge	~2–5 cm/yr	Slow; deep axial rift
Carlsberg and other Indian Ocean ridges	~3–6 cm/yr	Slow to intermediate
East Pacific Rise	~12–15 cm/yr or more	Fast; no axial rift
Red Sea	~1–2 cm/yr	Embryonic ocean

Driving Forces

Classical View: Mantle Convection

- **Arthur Holmes** proposed that **thermal convection currents** in the mantle carry plates like a conveyor belt.
  - **Rising limbs** lie below **mid-ocean ridges** and diverge beneath the lithosphere, dragging plates apart.
  - **Descending limbs** converge beneath trenches and pull plate margins down.
- **Lord Rayleigh**'s physics of convection in fluids, and later work on temperature-dependent mantle viscosity, made this plausible.

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- Two other classical ideas: **gravity sliding** of plates off the elevated ridge, and **wedging** of plates apart by magma intruded at the ridge.
- The lack of an agreed driving force was long considered the **weakest point** of the theory.

Current View: Slab Pull Dominates

- Plates are now seen as the cold upper boundary layer of mantle convection itself, driven mainly by **gravity acting on density differences**.
- **Donald Forsyth and Seiya Uyeda (1975)** compared plate speeds with plate-boundary types and found **slab pull to be the strongest force**:
  - Plates attached to long **subducting slabs** (Pacific, Nazca, Cocos, Indian, Australian) move **fastest**; plates without them (Eurasian, African, Antarctic) move **slowly**.

FORCE	SOURCE	ROLE
Slab pull	Weight of cold, dense lithosphere sinking at trenches	Dominant driver
Ridge push	Elevated, hot ridge slides downhill onto cooler flanks	Secondary driver
Mantle (basal) drag	Friction between plate base and mantle flow	Can drive or resist
Slab suction	Sinking slab draws the overriding plate towards the trench	Local
Mantle plumes	Hot upwellings (Réunion, Hawaii)	Local push; rifting and flood basalts

- Energy source: **Earth's internal heat** from radioactive decay and primordial heat; the forces that move plates are gravitational.

04 Plate Tectonics and Geological Phenomena

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Plate Tectonics and Continental Drift

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- Palaeomagnetism and seafloor spreading prove that **continents and ocean basins have never been stationary**; plate tectonics turned continental drift into an **established fact**, while rejecting Wegener's mechanism.
- Oceans open and close:
  - The Atlantic has been widening for about **180–200 million years**; the Pacific is shrinking as the Americas move west over it.
  - The Mediterranean is a remnant of the vast **Tethys Ocean**.
  - The Red Sea has recently begun to open.

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- The sea floor is **nowhere older than about 180–200 million years**, because older ocean floor has been recycled at subduction zones.

The Wilson Cycle

- **J. Tuzo Wilson (1966)** noticed that the Atlantic had closed and then reopened, and proposed a **cycle of ocean opening and closing**.

STAGE	PROCESS	EXAMPLE
Embryonic	Continental rifting	East African Rift
Young	Narrow sea floored by new oceanic crust	Red Sea, Gulf of Aden
Mature	Wide ocean with passive margins	Atlantic
Declining	Subduction around the margins	Pacific
Terminal	Ocean almost closed	Mediterranean
Suturing	Continent–continent collision	Himalaya, Alps

- The Appalachians of North America and the Caledonian–Hercynian belts of Europe record the **closure of an older Atlantic (Iapetus Ocean)** in the Palaeozoic; the present Atlantic reopened about **180 million years ago**.

Supercontinents

- Continents repeatedly assemble into supercontinents and break apart, the **supercontinent cycle**.
  - Rodinia: assembled about 1.1 billion years ago, broke up about 750 million years ago.
  - Pangaea: assembled about 335 million years ago, broke up from the **early Jurassic (about 200–175 million years ago)**.
- **Break-up of Pangaea**:
  - North-west Africa separated from North America first, opening the central Atlantic.
  - South America and Africa separated in the **Cretaceous**, opening the South Atlantic.
  - Greenland and Europe split from North America later, opening the **Labrador Sea** and North Atlantic in the late Cretaceous and early Tertiary.
- Projections suggest East Africa will split off, Australia will move towards Southeast Asia and the Mediterranean will close over the next tens of millions of years.
- **Pangaea I and II: James Valentine and Eldridge Moores (1970)**, probably the first to recognise a Precambrian supercontinent, called it **Pangaea I** and Wegener's supercontinent **Pangaea II**; Pangaea I was renamed **Rodinia** by **Mark and Dianna McMenamin (1990)**.

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- **Opening of the Indian Ocean:** the Indian Ocean began to open only with the break-up of Gondwana in the **Jurassic** and widened mainly in the **Cretaceous**; from its magnetic anomalies **Dan McKenzie and John Sclater (1971)** reconstructed its growth.
  - Rapid northward spreading behind India in the early Tertiary gave way to a **lull in the Eocene**, while **Australia pulled away from Antarctica**; the present spreading pattern dates from about **36 million years ago**.
  - Deep water through the **Tasmanian gateway** opened about **34 million years ago**, isolating Antarctica.

Red Sea, Gulf of Aden and Gulf of California

- Red Sea and Gulf of Aden:
  - An **axial trough between Africa and Arabia** with magnetic stripes like those of the oceans, spreading at about 1–2 cm/yr.
  - They meet at the **Afar triple junction** of the Nubian, Somali and Arabian plates; Arabia is rotating away from Africa about its own Euler pole.
- Gulf of California:
  - The East Pacific Rise enters the gulf; stripes show spreading for about the last **4–6 million years**.
  - The spreading has **torn Baja California** from mainland Mexico and carried it north-west with the Pacific plate.

Movement of the Indian Plate

- Break-up: India separated from Gondwana (Africa–Madagascar–Antarctica–Australia) in the **Cretaceous**, and the **Indian Ocean** opened behind it.
- Rapid drift: the Indian plate raced north across the Tethys at about **15–18 cm/yr** in the late Cretaceous–early Tertiary, among the fastest plate speeds known.
  - Passing over the Réunion hotspot about **66 million years ago**, it received the Deccan Traps; the hotspot's track is the Chagos–Laccadive Ridge (Lakshadweep, Maldives).
  - The older Rajmahal Traps are linked to the Kerguelen hotspot.
- Collision: India met Eurasia about **50 million years ago**; its speed dropped sharply, and the Himalaya and Tibetan Plateau began to rise.
- Present motion:
  - GPS shows India moving **north-north-east at about 4–5 cm/yr**; convergence across the Himalayan arc is about 3.5 cm/yr in the west to 5 cm/yr in the east.
  - Roughly **2 cm/yr is absorbed across the Himalaya** on the Main Himalayan Thrust; the rest is taken up in Tibet and beyond, with **east–west extension** of Tibet along north–south rifts. The Dingri (Tingri) earthquake of January 2025 (M7.1) in southern Tibet was on such a normal fault.
  - This continuing push keeps the **Himalaya rising** and makes the arc one of the most seismic belts on land.
- Recent research:
  - Seismic imaging and **helium-isotope** data suggest the Indian plate beneath Tibet is **tearing and partly delaminating** (a 2025 study).
  - The Indian and Australian plates are now resolved as largely **separate plates**.

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Plate Tectonics and Mountain Building PYQ 2021 · 2014 · 2000 +5

- Earlier hypotheses failed to give a convincing mechanism for **fold mountains**:
  - Harold Jeffreys: thermal contraction of the Earth.
  - Frank Bursley Taylor and **Alfred Wegener**: continental drift.
  - **Arthur Holmes**: convection currents.
  - Reginald Aldworth Daly: sliding continents.
  - John Joly: radioactive heat cycles.
- Plate tectonics links each **mountain type** to a **type of convergence**:
  - **Cordilleran (Andean) type** at ocean–continent margins.
  - **Island arcs** at ocean–ocean margins.
  - **Collision (Himalayan–Alpine) type** at continent–continent margins.
- Old fold belts (Appalachians, Caledonides, Aravallis) are **eroded roots of earlier collisions**.
- The **geosynclines** of classical theory are reinterpreted as **sediment wedges on continental margins and in trenches**.
- **Granite batholiths** form when continental rocks are carried to depth in collision belts and melt; the light, silica-rich magma rises and further uplifts the range.
  - The **granite-gneiss batholiths around Ranchi** on the Chotanagpur plateau are read as roots of **Precambrian mountain belts**.

Plate Tectonics and Vulcanicity PYQ 2021 · 2014 · 2000 +5

- **Most active volcanoes lie on plate boundaries**:
  - Roughly **four-fifths** at **convergent** boundaries.
  - About **15%** at **divergent** boundaries.
  - The **remainder within plates**, over hotspots.
- Belts: the Circum-Pacific belt (Ring of Fire), the Mid-Atlantic belt and the Mid-continental (Alpine–Himalayan) belt.

SETTING	MELTING PROCESS	MAGMA / LAVA	ERUPTION STYLE	EXAMPLE
Mid-ocean ridge	Decompression melting	Tholeiitic basalt	Quiet fissure flows	Iceland, Mid-Atlantic Ridge
Continental rift	Decompression, small-degree melting	Alkaline basalt	Fissure and central	East African Rift
Subduction zone	Flux melting by water from the slab	Andesite, dacite, rhyolite	Explosive	Andes, Japan, Barren Island

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SETTING	MELTING PROCESS	MAGMA / LAVA	ERUPTION STYLE	EXAMPLE
Hotspot (intraplate)	Mantle plume	Basalt	Shield and flood eruptions	Hawaii, Réunion, Deccan Traps

- Ridge volcanism:
  - Lava is **youngest at the ridge and older away from it**, both on the sea floor and on islands such as Iceland.
  - Volcanic islands formed at a ridge are carried away from their magma source, **go extinct and subside** into **seamounts and flat-topped guyots**.
- Subduction magmas:
  - Classically, the andesite–dacite–rhyolite suite was traced to partial melting of the subducted amphibolite and eclogite (**Alfred Edward Ringwood, 1974**) or to melting of oceanic basalt mixed with ocean-floor sediments (**James Gilluly**).
  - The current view stresses **water released from the slab** triggering melting of the mantle wedge above it.
- Hotspots:
  - A stationary **mantle plume** beneath a moving plate leaves an **age-progressive chain**. The Hawaiian–Emperor chain ages north-westward, with a bend about **47 million years** old, as the Pacific plate moves north-west over the plume.
  - The hotspot idea was proposed by **J. Tuzo Wilson (1963)** and the plume model by **W. Jason Morgan (1971)**.
- **Flood basalt plateaus** mark plumes that coincided with **continental break-up**:
  - Deccan (India over Réunion).
  - Paraná of Brazil (opening of the South Atlantic).
  - Columbia River plateau of the USA (Yellowstone hotspot).

Plate Tectonics and Earthquakes

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- **Earthquake belts coincide with plate boundaries**; about **81% of the largest earthquakes** occur in the Circum-Pacific belt and about **17%** in the Alpine–Himalayan belt.
- Divergent margins: **shallow-focus, moderate** earthquakes from rifting and magma movement, mostly shallower than about 30 km (Mid-Atlantic Ridge, Carlsberg Ridge, East Pacific Rise).
- Convergent margins: **the strongest and deepest** earthquakes, with foci down to about **700 km** along the Wadati–Benioff zone.
  - Megathrust earthquakes: Chile 1960 (M9.5), Sumatra–Andaman 2004 (M9.1), Japan 2011 (M9.0–9.1) and Kamchatka, July 2025 (M8.8).
  - Collision earthquakes: Nepal (Gorkha) 2015 (M7.8) in the Himalaya.
- Transform margins: **shallow but severe** earthquakes (San Andreas, Turkey 2023, Myanmar 2025).
- Intraplate earthquakes occur on old faults inside plates under stress transmitted from the margins: Kutch 1819 (which raised the Allah Bund), Latur 1993, Bhuj 2001.

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- Megathrust earthquakes that lift the sea floor generate **tsunamis**; the **2004** tsunami followed the slip of the Indian plate beneath the Burma microplate.

Evidences for Plate Tectonics

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- **Palaeomagnetism and magnetic reversals**:
  - Rocks lock in the Earth's field as they cool below the **Curie point** (about 580 °C for magnetite).
  - **Symmetrical, reversed stripes** on either side of ridges record spreading; **apparent polar wander** paths differ between continents but match once the continents are refitted.
- **Age of the ocean floor**: deep-sea drilling from the Glomar Challenger (from 1968) under JOIDES and its successor programmes found sediments youngest and thinnest at ridges, older and thicker towards the margins, and no ocean floor older than about 200 million years.
- **Distribution of earthquakes and volcanoes** along narrow belts, and inclined Wadati–Benioff zones under trenches.
- **Hotspot chains** that age in the direction of plate motion.
- **Heat flow** that is high at ridges and low at trenches; **gravity anomalies** over trenches.
- **Direct measurement**: GPS and other space geodesy now **measure plate motion in real time**, matching rates derived from magnetic stripes.

Significance of Plate Tectonics

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- Landforms: almost all first-order relief (ocean basins, ridges, trenches, fold mountains, rift valleys, island arcs) owes its origin to plate movement.
- Hazards: explains the location of **earthquakes, volcanoes and tsunamis**, guiding seismic zoning and early-warning systems.
- Minerals and energy:
  - Magma from the mantle and hydrothermal circulation concentrate ores. Porphyry copper deposits cluster along subduction belts (Andes of Chile and Peru); massive sulphides form at ridges.
  - Geothermal energy is concentrated at boundaries (Iceland, New Zealand), and petroleum basins lie on rifted margins and in foreland basins.
- Other sciences: explains the distribution of fossils, past climates and biogeography, and the long-term carbon cycle.
- Future geography: from present plate motions, the shape of continents can be projected.

Continental Drift, Seafloor Spreading and Plate Tectonics Compared

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BASIS	CONTINENTAL DRIFT	SEAFLOOR SPREADING	PLATE TECTONICS
Proponents	Alfred Wegener (1912–15)	Arthur Holmes (convection, 1928–31); Harry Hess (1960–62); Robert Dietz (1961)	McKenzie & Parker (1967), Morgan (1968), Le Pichon (1968), Isacks, Oliver & Sykes (1968)

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BASIS	CONTINENTAL DRIFT	SEAFLOOR SPREADING	PLATE TECTONICS
What moves	Continents only (sial through sima)	Ocean floor	Whole lithospheric plates, continent and ocean together
Driving force	Pole-fleeing force, tidal force	Mantle convection	Slab pull, ridge push, mantle convection
Evidence	Jigsaw fit, fossils, tillites, matching rocks	Ridge relief, magnetic stripes, age of sea floor	All of these plus seismicity, hotspots, GPS
Weakness	Forces far too weak; sial could not plough through sima	Ocean floor only; continents left out	Driving-force balance and onset still debated
Status	Mechanism rejected; idea of mobility retained	Absorbed into plate tectonics	Accepted unifying theory
Contribution	Started mobilist thinking	Supplied the mechanism of crust creation	Explains most endogenetic landforms

Critical Evaluation

- Strengths:
  - The theory **unifies** drift, spreading, seismicity, vulcanicity and mountain building in one framework.
  - It **predicts** measurable motions that GPS confirms, and it is the accepted paradigm of the Earth sciences.
- Limitations and live debates:
  - **Driving forces**: the relative weight of slab pull, ridge push and mantle flow is still debated, though slab pull is widely held dominant.
  - **Rigid-plate assumption**: continents deform over **wide zones** (Tibet, the Basin and Range), and India and Australia are separating along a diffuse boundary.
  - **Intraplate activity**: hotspots and interior earthquakes (Latur, Bhuj) need **additional explanations** (plumes, reactivated old faults).
  - **Subduction initiation**, how a new trench forms, is poorly understood.
  - Onset: whether modern-style plate tectonics began over **3 billion years ago** or much later in the Proterozoic is an open question.
- **Current view**: plate tectonics is the **surface expression of mantle convection** in which the plates themselves, through slab pull, are the most active part.

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Previous Year Questions

2025	"The Himalaya is still rising." Expand this statement and describe the processes involved in it with suitable sketches and diagrams.
2023	"Evidences from palaeomagnetism and sea floor spreading have validated that continents and ocean basins have never been stationary." Elucidate with suitable diagrams.
2021	The concept of Plate Tectonics has been derived from the Isostasy and Continental Drift Theory. Elaborate citing suitable examples.
2019	Compare and contrast different types of plate boundaries.
2014	State the concept of plate tectonics. How does it help in explaining the formation of the Himalayas and Appalachian Mountains?
2000	With reference to the theory of Plate tectonics, explain the origin and growth of the Young Fold Mountain systems of the World.
1999	Bring out the distinctions between the continental drift theory and the plate tectonics theory.
1998	Discuss the concept of volcanicity and show how the theory of Plate Tectonics explains the mechanism of volcanism and volcanic eruptions.
1995	Discuss the limitations of the theory of Continental Drift and show how the theory of plate Tectonics is an improvement over it.
1990	Write short note on Plate tectonics in about 200 words.
1988	Critically analyse the concept of plate tectonics and bring out the evidences to support it.

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9 chapters · from page 105

03 **Crustal Evolution and Mountain Building**
8 chapters · from page 227

04 **Vulcanicity, Earthquakes and Tsunamis**
3 chapters · from page 364

05 **Geomorphic Cycles and Landscape Development**
8 chapters · from page 419

06 **Drainage, Channel Morphology and Slopes**
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07 **Landforms of the Geomorphic Agents**
8 chapters · from page 615

08 **Applied Geomorphology**
2 chapters · from page 784

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