PLATE TECTONICS

Comprehensive Study Material

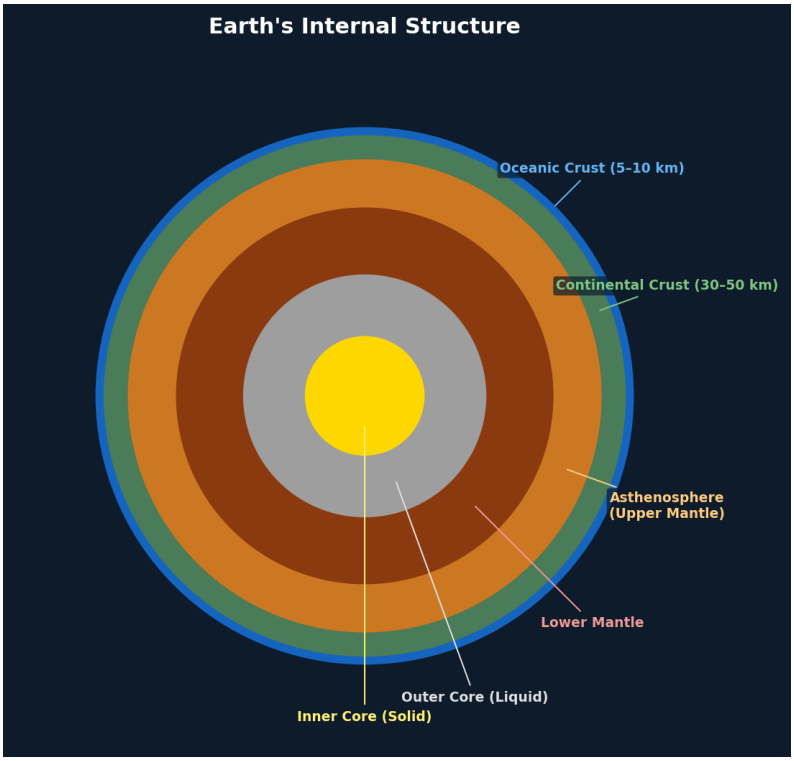

Fig. 1 — Earth's Internal Structure

SECTION 1 — CONCEPT & DEFINITION

What is Plate Tectonics?

- **Definition:** Scientific theory explaining the large-scale motion of Earth's lithosphere.
- **Lithosphere:** Rigid outer shell = Crust + uppermost Mantle (~100 km thick).
- **Plates:** Broken into ~15–20 major/minor rigid slabs (tectonic plates).
- **Motion:** Plates move at **1–15 cm/year** (rate of fingernail growth).
- **Driving force:** Heat from Earth's interior → Mantle convection.

■ *Key Terminology*

Term	Definition	Example/Fact
Lithosphere	Rigid crust + upper mantle	~100 km thick
Asthenosphere	Weak, partially molten layer below lithosphere	Allows plate movement
Tectonic Plate	Rigid slab of lithosphere	7 major + 8 minor plates
Plate Margin	Edge where two plates meet	Site of geologic activity
Isostasy	Gravitational equilibrium of lithosphere	Explains mountain roots
Subduction	Denser plate sinks below another	Pacific under North America
Accretion	Addition of material to continent edge	Terrane accretion

■ *Earth's Internal Zones — Quick Reference*

Layer	Depth	Composition	State	Temp (°C)
Continental Crust	0–50 km	Granite (SiAl)	Solid	0–300
Oceanic Crust	0–10 km	Basalt (SiMa)	Solid	0–200
Upper Mantle	10–410 km	Peridotite	Solid/Plastic	300–1600
Asthenosphere	100–350 km	Peridotite	Partially molten	1300–1600
Lower Mantle	410–2900 km	Mg-Silicates	Solid (high P)	1600–3700
Outer Core	2900–5100 km	Fe-Ni alloy	Liquid	3700–5000
Inner Core	5100–6371 km	Fe-Ni alloy	Solid	~5200

SECTION 2 — ORIGIN & HISTORICAL DEVELOPMENT

Continental Drift Theory — Alfred Wegener (1912)

- **Proposed:** All continents were once joined as **Pangaea** (~335 Ma).
- **Evidence 1 — Fit of Coastlines:** S. America & Africa fit together (jigsaw).
- **Evidence 2 — Fossil Record:** *Mesosaurus*, *Glossopteris* on separated continents.
- **Evidence 3 — Geological Continuity:** Mountain ranges match across oceans.
- **Evidence 4 — Palaeoclimatology:** Tropical coal in Antarctica; glacial deposits in Africa.
- **Weakness:** Could not explain the *mechanism* of plate movement → rejected initially.

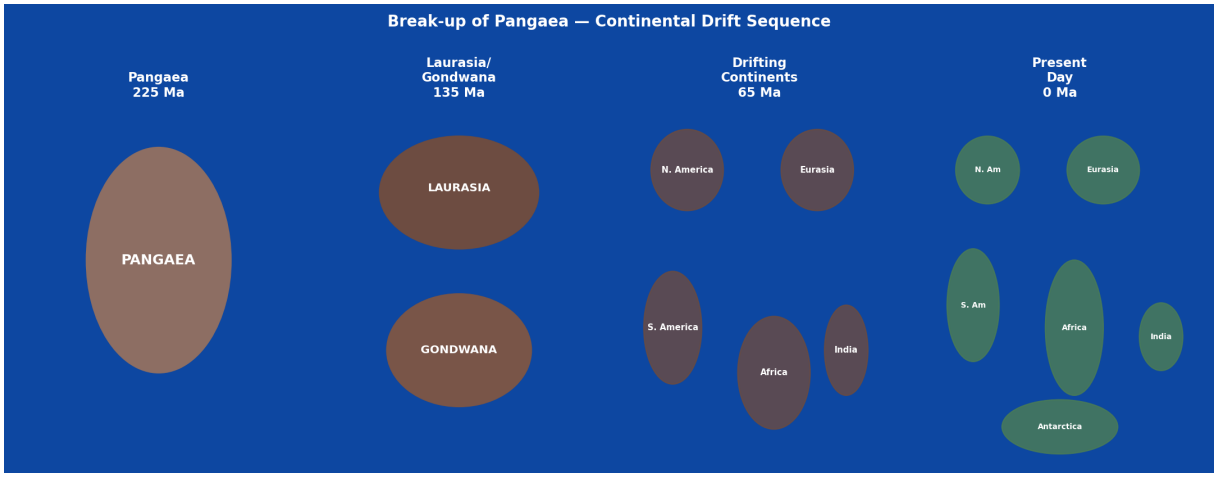

Fig. 2 — Break-up of Pangaea: 225 Ma → Present Day

Timeline of Discovery

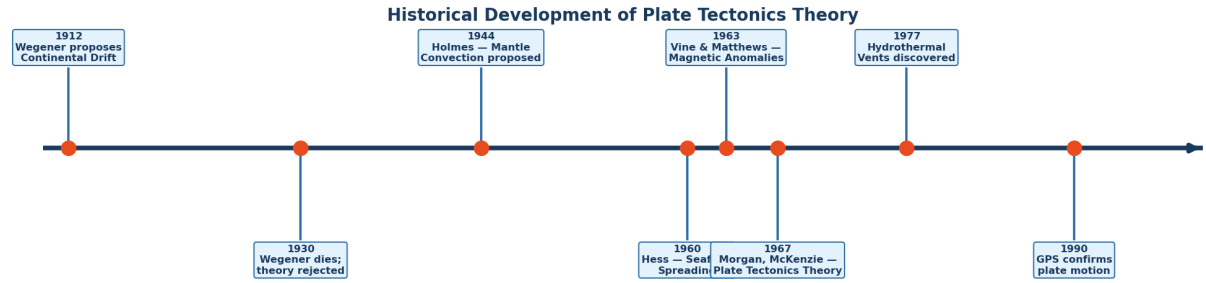

Fig. 3 — Key Milestones in Plate Tectonics Theory

■ *Seafloor Spreading — Hess (1960)*

- **New oceanic crust** formed at mid-ocean ridges; older crust destroyed at trenches.
- **Evidence:** Age of ocean floor increases away from ridge.
- **Vine & Matthews (1963):** Magnetic anomalies — symmetric striping confirms spreading.

- **Rate:** 2–18 cm/year at different ridges.

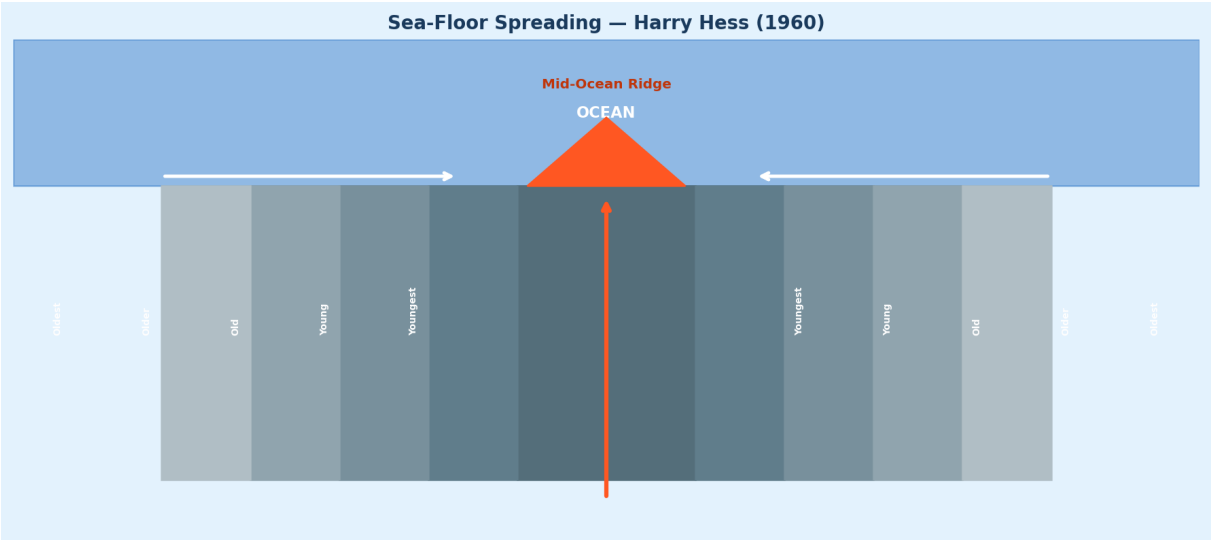

Fig. 4 — Sea-Floor Spreading: New Crust at Mid-Ocean Ridges

SECTION 3 — MECHANISM: DRIVING FORCES

Primary Driving Forces

Force	Description	Contribution
Mantle Convection	Thermal convection cells in mantle; hot material rises, cools, sinks	PRIMARY driver
Ridge Push	Gravity slides new crust away from elevated mid-ocean ridges	Moderate
Slab Pull	Dense, cold oceanic slab sinks into mantle pulling plate behind	DOMINANT force
Basal Drag	Viscous drag of convecting mantle on base of plate	Secondary
Trench Suction	Descending slab draws overlying plate toward trench	Minor

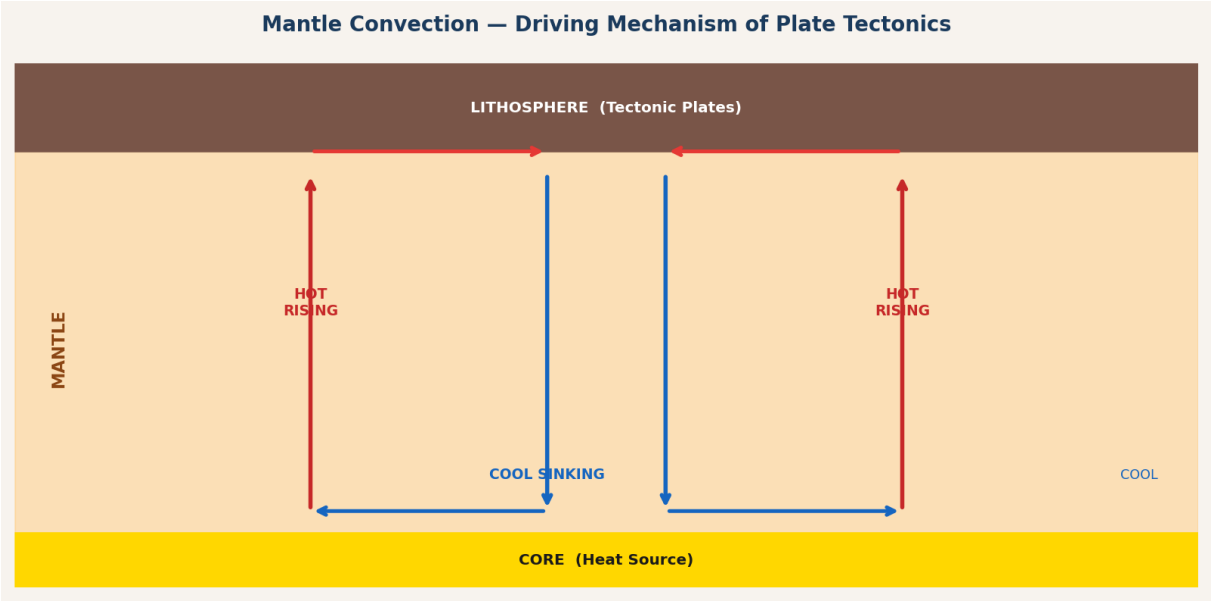

Fig. 5 — Mantle Convection Cells: The Engine of Plate Tectonics

■ *Heat Sources*

- **Primordial Heat:** Residual heat from Earth's formation (gravitational accretion).
- **Radioactive Decay:** U-238, Th-232, K-40 → continuous heat generation.
- **Latent Heat:** Crystallization of inner core releases heat to outer core.
- **Total Heat Flow:** ~44 terawatts escaping Earth's surface.

■ *Plate Velocity Measurements (GPS)*

Plate	Velocity (cm/yr)	Direction
Pacific Plate	~7–10	NW
North American	~2–3	W
Eurasian	~2–3	NE
Indian	~5–6	NE

Antarctic	~1–2	Varies
Nazca	~7–8	E

SECTION 4 — TYPES OF TECTONIC PLATES

Major vs Minor Plates

Plate Name	Type	Area (×10■ km²)	Key Features
Pacific	Oceanic	103.3	Largest plate; Ring of Fire boundary
North American	Continental/Mixed	75.9	San Andreas Fault; Mid-Atlantic Ridge
Eurasian	Continental	67.8	Alps, Himalayas; Icelandic volcanoes
African	Continental	61.3	East African Rift; stable craton core
Antarctic	Continental	60.9	Surrounds Antarctica; slow movement
Indo-Australian	Continental	58.9	Collides with Eurasia → Himalayas
South American	Continental	43.6	Andes; Nazca subduction
Nazca (minor)	Oceanic	15.6	Fastest sinking plate; Atacama Trench
Caribbean (minor)	Oceanic/Mixed	3.3	Island arcs; seismically active
Arabian (minor)	Continental	5.0	Red Sea Rift; NE motion
Philippine (minor)	Oceanic	5.5	Complex subduction; trenches
Cocos (minor)	Oceanic	2.9	Subducts under Caribbean/N. America

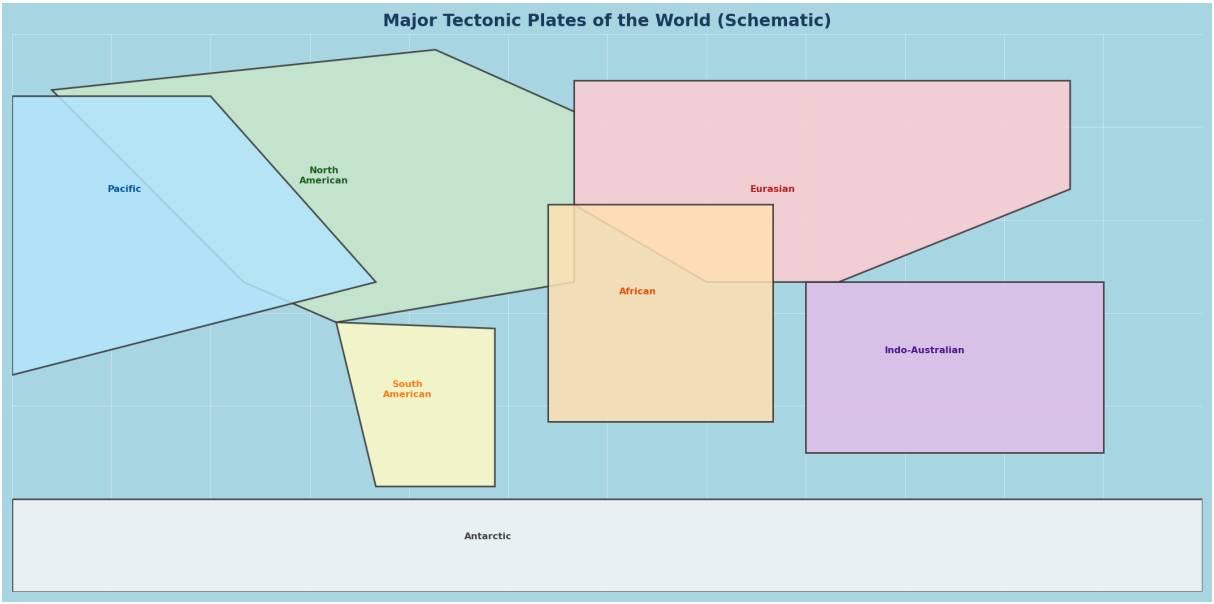

Fig. 6 — Major Tectonic Plates of the World (Schematic Map)

■ *Oceanic vs Continental Crust — Comparison*

Property	Oceanic Crust	Continental Crust
Composition	Basalt (SiMa)	Granite (SiAl)
Thickness	5–10 km	30–70 km

Density	3.0 g/cm³	2.7 g/cm³
Age	Younger (<200 Ma)	Up to 4,000 Ma
Behaviour	Subducted → recycled	Too buoyant to subduct
Examples	Pacific, Nazca	Shields, Cratons

SECTION 5 — PLATE BOUNDARIES

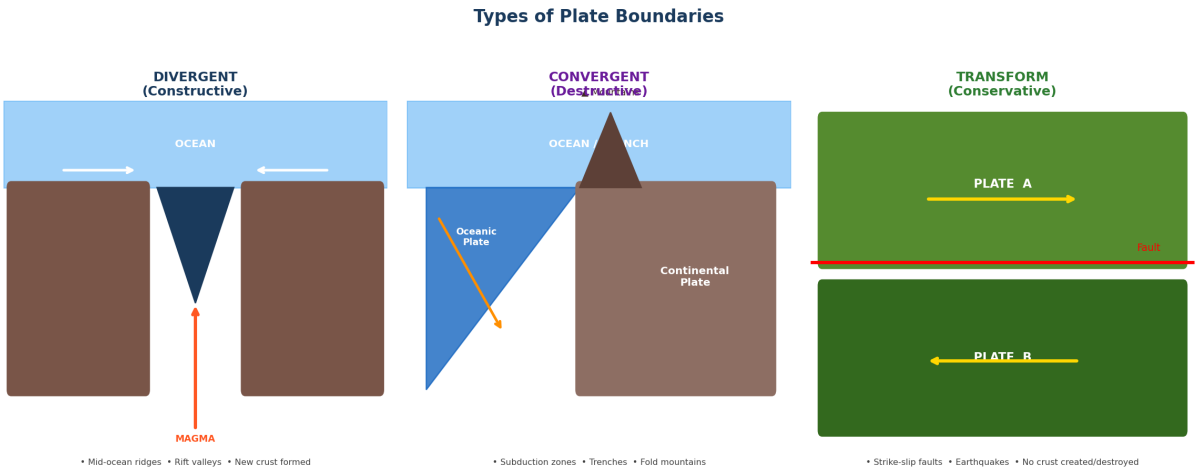

Fig. 7 — Three Types of Plate Boundaries: Divergent | Convergent | Transform

1. Divergent Boundaries (Constructive Margins)

- **Definition:** Plates move apart; new lithosphere created.
- **Location:** Mid-ocean ridges; continental rift zones.

➤ **Process: Magma upwells → cools → new basaltic crust.**

- **Landforms:** Mid-ocean ridges, rift valleys, submarine volcanoes.
- **Seismicity:** Shallow, low-magnitude earthquakes.
- **Examples:** Mid-Atlantic Ridge; East African Rift; Red Sea Rift.
- **Rate:** 2–15 cm/yr spreading.

2. Convergent Boundaries (Destructive Margins)

Sub-Type	Plates Involved	Result	Example
Oceanic–Oceanic	Two oceanic plates	Volcanic island arcs + trenches	Japan, Philippines
Oceanic–Continental	Oceanic + continental	Fold mountains + trenches	Andes, Cascades
Continental–Continental	Two continental plates	High fold mountains (no subduction)	Himalayas, Alps

- **Key Feature:** Benioff Zone — inclined plane of seismicity along subducting slab.
- **Accretionary Prism:** Scraped sediments piled at collision zone.
- **Back-arc basins:** Extensional basins behind volcanic arc.

3. Transform Boundaries (Conservative Margins)

- **Definition:** Plates slide horizontally past each other; crust neither created nor destroyed.
- **Fault Type:** Strike-slip (lateral) faults.

➤ **No volcanism — only powerful earthquakes.**

- **Examples:** San Andreas Fault (CA); North Anatolian Fault (Turkey); Alpine Fault (NZ).
- **Seismicity:** Shallow, but very powerful — up to M 8.0+.

■ *Boundary Comparison Chart*

Feature	Divergent	Convergent	Transform
Motion	← →	→ ←	↑ ↓
Crust Change	Created	Destroyed	Neither
Volcanism	High	High	None
Earthquakes	Shallow, weak	Deep/Shallow, strong	Shallow, strong
Landforms	Ridges, Rifts	Mountains, Trenches	Fault zones
Example	Mid-Atlantic Ridge	Himalayas, Andes	San Andreas
Heat Flow	Very high	Moderate	Low

SECTION 6 — EFFECTS ON EARTH'S DYNAMICS

Fig. 8 — Effects of Plate Tectonics on Earth's Systems

A. Earthquakes & Seismicity

- **Cause:** Stress accumulation along plate boundaries → sudden slip.
- **Focus:** Point inside Earth where rupture starts.
- **Epicentre:** Point on surface directly above focus.

➤ **90% of all earthquakes occur along plate boundaries.**

- **Depth:** Shallow (0–70 km) at transform/divergent; Deep (up to 700 km) at subduction.
- **Measurement:** Richter Scale (magnitude); Mercalli Scale (intensity).
- **Tsunamis:** Triggered by submarine earthquakes at convergent zones.

B. Volcanism

- **Hot Spot Volcanoes:** Mantle plumes penetrate lithosphere (Hawaii, Yellowstone).
- **Shield Volcanoes:** Low viscosity basaltic lava; at divergent margins.

- **Stratovolcanoes:** Explosive; silica-rich magma; at convergent subduction zones.

➤ **Ring of Fire: 75% of world's active volcanoes.**

- **Pyroclastic flows:** Fast-moving hot gas + ash (Pompeii, Mt. Pinatubo).
- **Caldera Formation:** Collapse of magma chamber roof after eruption.

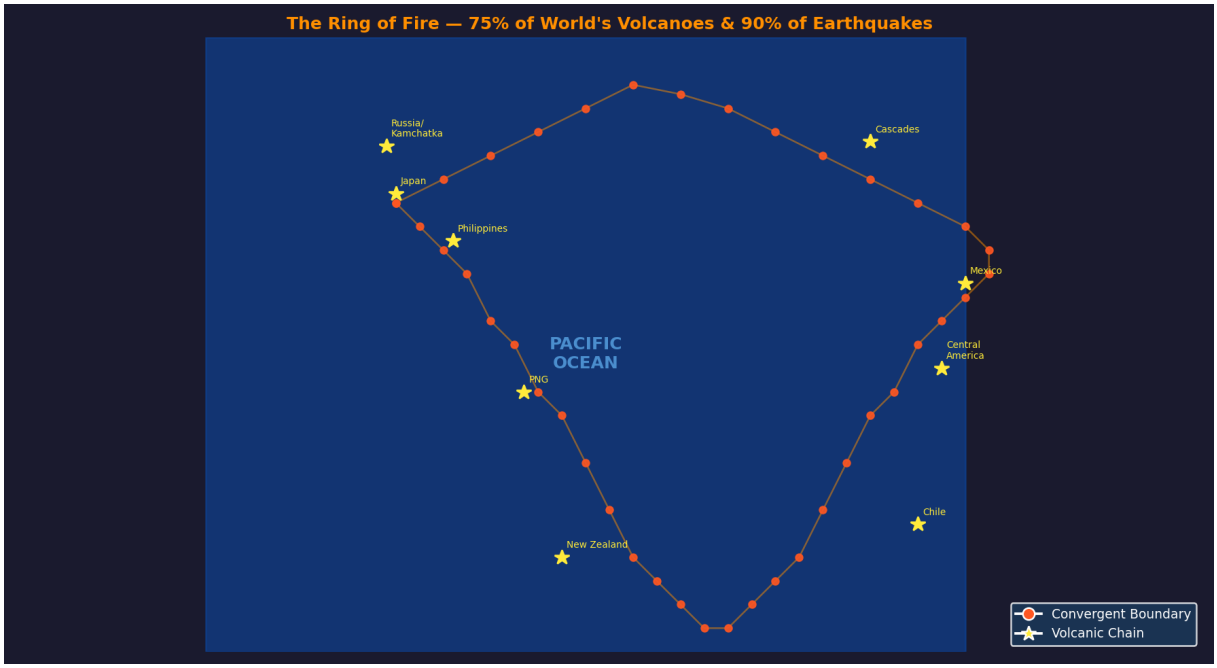

Fig. 9 — The Ring of Fire: Earthquake & Volcano Distribution

C. Mountain Building (Orogenesis)

- **Fold Mountains:** Sediment layers crumpled at convergent boundaries.
- **Block Mountains:** Fault-bounded uplifted blocks at rift zones.

➤ **Himalayas: India–Eurasia collision (50 Ma); still rising ~5 mm/yr.**

- **Andes:** Nazca plate subduction under South America.
- **Alps:** Africa–Eurasia convergence.
- **Isostatic Rebound:** Continental crust rises as erosion removes mass.

D. Ocean Basin Formation

- **Stage 1 — Embryonic:** Continental rift forms (East Africa today).
- **Stage 2 — Young:** Narrow sea develops (Red Sea).
- **Stage 3 — Mature:** Wide ocean with spreading ridge (Atlantic).
- **Stage 4 — Old:** Subduction begins; ocean shrinks (Pacific).
- **Stage 5 — Terminal:** Ocean closed; continents collide (Tethys → Himalayas).

E. Climate & Atmosphere

- **Volcanic CO2:** Outgassing influences greenhouse effect & long-term climate.
- **Weathering:** Mountain building → silicate weathering → CO2 drawdown → cooling.

- **Ocean Circulation:** Plate positions control thermohaline circulation.
- **Rain Shadow Effect:** Mountains force precipitation on windward side.

➤ **Himalayan uplift linked to monsoon strengthening (~8 Ma).**

F. Mineral & Resource Distribution

- **Metallic Ores:** Porphyry copper, gold at subduction zones (Andes, Pacific Rim).
- **Oil & Gas:** Found in sedimentary basins at passive continental margins.
- **Geothermal Energy:** Exploited at divergent boundaries (Iceland, NZ).
- **Coal:** Ancient swamp forests preserved at suture zones.
- **Diamonds:** Kimberlite pipes — ancient cratons far from active boundaries.

G. Biodiversity & Evolution

- **Vicariance:** Plate separation isolates populations → speciation.

➤ **Marsupials in Australia isolated 45 Ma after separation from Antarctica.**

- **Mass Extinctions:** Plate assembly (Pangaea) → ocean anoxia → Permian extinction.
- **Island Biogeography:** Volcanic island chains host endemic species.

SECTION 7 — SUMMARY CHARTS & QUICK REFERENCE

Master Summary Table

Topic	Key Points	Examples/Facts
Concept	Lithosphere divided into moving plates; driven by mantle heat	15–20 plates; 1–15 cm/yr
Origin	Wegener (1912) Continental Drift → Hess (1960) Seafloor Spreading → Plate Tectonics (1967)	Pangaea broke up ~225 Ma
Mechanism	Mantle convection + Slab pull (dominant) + Ridge push	44 TW heat flow
Types	7 major plates: Pacific (largest), Eurasian, N. American, African, Antarctic, Indo-Australian, S. American	~8 minor plates
Divergent	Plates apart; new crust; ridges & rifts; shallow EQs	Mid-Atlantic Ridge; E. African Rift
Convergent	Plates collide; subduction or collision; mountains, trenches, volcanoes	Himalayas; Andes; Japan Trench
Transform	Plates slide; no crust change; strong shallow EQs; no volcanism	San Andreas; N. Anatolian
Earthquakes	90% at plate boundaries; Benioff Zone; tsunamis	Ring of Fire: 90% of seismicity
Volcanoes	At divergent + convergent margins; hot spots	75% in Ring of Fire
Mountains	Fold mountains at convergent; block mountains at rifts	Himalayas rising 5 mm/yr
Oceans	5-stage Wilson Cycle from rift to collision	Atlantic growing; Pacific shrinking
Climate	CO2 outgassing; silicate weathering feedback; ocean circulation	Monsoon linked to Himalayan uplift
Resources	Ores at subduction zones; oil at passive margins; geothermal at ridges	Porphyry Cu; Geothermal Iceland

Wilson Cycle — Ocean Life Cycle

Stage	Phase	Example Today	Key Process
1	Embryonic	East African Rift	Continental rifting begins
2	Juvenile	Red Sea	Narrow ocean forms
3	Mature	Atlantic Ocean	Full spreading ridge active
4	Declining	Pacific Ocean	Subduction > spreading
5	Terminal	Mediterranean Sea	Ocean nearly closed
6	Suturing	Himalayas/Alps	Continent–continent collision

Important Geographical Locations

Location	Type of Boundary	Significance
Mid-Atlantic Ridge	Divergent	Longest mountain chain on Earth (~65,000 km)
Mariana Trench	Convergent (O-O)	Deepest point: ~11,034 m (Challenger Deep)
Himalayas	Convergent (C-C)	Highest peaks; still rising; 50 Ma collision
San Andreas Fault	Transform	CA; moves ~6 cm/yr; major EQ risk

East African Rift	Divergent	Africa splitting; future ocean forming
Iceland	Divergent	On Mid-Atlantic Ridge; volcanic island
Ring of Fire	Convergent/Transform	40,000 km arc; 75% volcanoes; 90% EQs
Hawaii	Hot Spot	Mantle plume; not at plate boundary
Andes Mountains	Convergent (O-C)	Nazca under S. America; 7,000 km range
Red Sea	Divergent (Young)	Arabia separating from Africa; new ocean

late Tectonics unifies all Earth Sciences —■Geology, Oceanography, Seismology, Volcanology &

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