Unit 15 · Earth and the Universe

STUDY NOTES

Key terms

Geochronology: finding the ages of rocks, fossils and events of the Earth's history, and their order.

Relative dating: the order of events, without numbers. **Absolute dating**: ages in years.

Half-life ($T_{1/2}$): time for half of a radioactive parent to decay. **Parent** → **daughter**.

Index fossil: common, widespread, short-lived; dates and matches layers (ammonites).

Fossil: remains or trace of a living thing of the distant past, preserved in rock (by custom, older than about 10,000 years). **Paleontology**: their study.

Lithification: sediment pressed and cemented into rock. **Mineralization**: minerals fill or replace hard parts.

Carbon (radiocarbon) dating: how long ago a living thing died, from the carbon-14 left.

Planetarium: domed theater whose projector shows the sky and its motions.

Space exploration: studying space by going there (telescopes above the air, probes, people); space begins about 100 km up.

Formulas

$\left(\frac{1}{2}\right)^n, n = \frac{t}{T_{1/2}}$	t time passed; n half-lives **Use:** fraction of the parent left
$N = N_0 \left(\frac{1}{2}\right)^n$	N_0 at death; N now (or counts a minute) **Use:** carbon-14 left
$t = n \times 5{,}730$ years	n from N/N_0 **Use:** age by carbon-14

Geochronology

Relative dating rules

1. **superposition**: lower layer older
2. **original horizontality**: laid flat; tilted or folded later
3. **cross-cutting**: a fault or igneous vein is younger than what it cuts
4. **faunal succession**: each layer its own fossils, same order everywhere

Radioactive clocks (nothing changes a half-life: decay is inside the nucleus)

Parent → daughter	Half-life	Dates
uranium-238 → lead-206	4,470 million yr	oldest rocks, the Earth
potassium-40 → argon-40	1,250 million yr	volcanic rocks, 100,000 yr up
carbon-14 → nitrogen-14	5,730 yr	once-living things, to about 50,000 yr

- other clocks:
  - tree rings (over 12,000 yr)
  - varves
  - ice layers
- Earth 4.54 billion yr (Patterson, 1956, meteorites' lead); oldest grain about 4.4 billion yr

Time scale: eons → eras → periods → epochs; boundaries where fossils change sharply (mass extinctions); dated by volcanic ash

- **Cenozoic**:
  - Quaternary 2.6–now (valley clays, Terai)
  - Neogene 23–2.6 (Siwalik)
  - Paleogene 66–23 (India meets Asia about 50)
- **Mesozoic**:
  - Cretaceous 145–66
  - Jurassic 201–145 (shaligrams, Mustang)
  - Triassic 252–201
- **Paleozoic**: Permian 299–252 … Ordovician (Sagarmatha's top) … Cambrian 539–485
- **Precambrian**: 4,540–539 (oldest Lesser Himalaya rocks)
- older books: Cryptozoic eon; Cambrian at 570 or 540

Importance:

- Earth's story and its speed
- history of life
- resources (coal: Carboniferous, Permian)
- earthquakes (1934 and 1255, 679 yr apart, trenches on the Main Frontal Thrust)
- past climate
- archaeology

Fossils

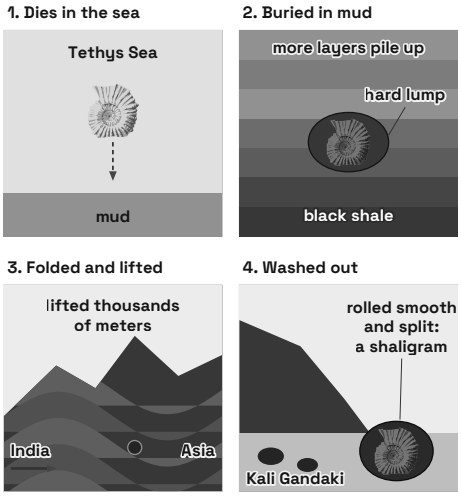
Needs:

- hard parts

- **quick burial** (mud, sand, ash: no scavengers, no oxygen)
- rock left undisturbed

Steps:

1. death and burial
2. soft parts decay
3. lithification
4. mineralization
5. uplift and exposure



Kinds

- **petrified**: minerals fill or replace (petrified wood, Siwalik teeth)
- **mold**: hollow print, shape in reverse; **cast**: mold filled, a copy
- **carbon film**: pressed flat, thin black carbon (ferns)
- **trace**: footprints, burrows, nests, coprolites
- **unaltered**: amber, frozen mammoths, tar pits

Importance:

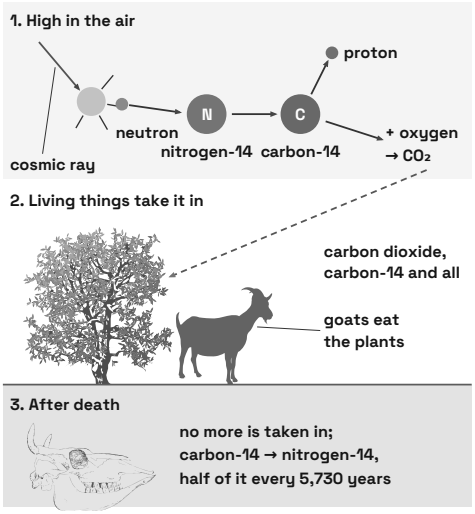
- history of life and evolution (*Archaeopteryx*)
- dating and matching rocks
- past environments (sea fossils on mountains)
- moving continents (*Glossopteris*)
- resources (coal, oil, limestone)
- extinctions

In Nepal (Higher Himalaya: fossils destroyed by heat)

Belt	Fossils	Age	Tells
Tethys (Mustang, Manang, Dolpa)	ammonites (shaligrams), brachiopods, corals, sea lilies, trilobites	450–66 million yr; shaligrams about 150	the Tethys Sea; lifted thousands of m
Siwalik (Dang, Deukhuri, Tinau Khola, Rato Khola)	crocodiles, gharials, giant tortoise, hippo, three-toed horse, *Stegodon*, *Deinotherium*, *Sivapithecus*	13–1 million yr	rivers, forests; drying climate; dates the mountains' rise
Kathmandu Valley (Lukundol, Nakhu Khola)	*Stegodon ganesa*, elephants, hippo, crocodile	a few million yr	old lake; much warmer climate
Lesser Himalaya (Tansen)	stromatolites; Gondwana plants; crocodile's tooth	over 500; 300; 45 million yr	early life; Gondwana

- Ramapithecus = *Sivapithecus*, an ape (orangutan's relative), **not** a human ancestor
- no dinosaurs: Tethys rocks are sea floor; land rocks of their age rare

Carbon dating



1. **made in the air**: cosmic-ray neutron + nitrogen-14 → carbon-14 + proton; about 1 in 10^{12} carbon atoms
2. **taken in**: photosynthesis, food; living things keep the air's share

3. **at death** intake stops; beta decay to nitrogen-14, half-life 5,730 yr (Libby's 5,568; now 5,700 ± 30)

- measured by **counts a minute** (activity ∝ carbon-14 left) or atom counting (accelerator mass spectrometer, a few mg)
- 1, 2, 3, 4, 5, 9 half-lives: 50, 25, 12.5, 6.25, 3.1, 0.2%
- **uses**:
  - archaeology (Lumbini's wooden shrine, 6th century BC; Mustang's caves)
  - earthquakes, landslides
  - ice ages
  - genuine or fake
  - bomb carbon
- **limits**:
  - once-living only
  - to about 50,000 yr
  - air's share varied (**calibration curve**)
  - contamination

Planetarium

- **star ball**:
  - lamp inside, a hole (and lens) per star
  - turning it turns the sky
  - small projectors for Sun, Moon, planets
  - **digital** since the 1980s
  - domes 3 m (inflatable) to 37 m
- first: Zeiss Model I (Bauersfeld), Jena 1923; public show at the Deutsches Museum, 21 October 1923
- **uses**:
  - any time and weather
  - time sped up
  - any place or date
  - teaching
  - training (sailors, pilots, astronauts)
  - exploring space
  - wonder
- **observatory** = telescopes on the real sky (Nagarkot)
- Nepal: B.P. Koirala Memorial board, Kirtipur (museum 2019; theater planned); portable domes; the site's Night Sky

Space exploration

- rocket pushes on its exhaust (Newton's third law); orbit about 7.7 km/s; escape 11.2 km/s
- before:
  - Mysore rockets 1780s
  - Tsiolkovsky 1903
  - Goddard 1926 (liquid fuel)
  - V-2 reached space 1944
- **race**:
  - 1957 Sputnik 1, Laika
  - 1958 Explorer 1 (Van Allen belts), NASA
  - 1959 Luna 2, Luna 3 (far side)
  - 1961 Gagarin
  - 1963 Tereshkova
  - 1965 Leonov's spacewalk
  - 1966 Luna 9 lands
  - 1968 Apollo 8
  - **1969 Apollo 11** (Armstrong, Aldrin)
  - 1970 Venera 7 on Venus
  - 1971 Salyut 1
  - 1975 Apollo–Soyuz
- **robots**:
  - 1972–73 Pioneer 10 (Jupiter)
  - 1976 Viking 1 on Mars
  - 1977 Voyagers
  - 1997 Sojourner
  - 2015 New Horizons (Pluto)
- **stations, telescopes**:
  - 1981 Space Shuttle
  - 1986 Mir
  - 1990 Hubble
  - 2000 first ISS crew
- **many nations**:
  - 2003 Yang Liwei
  - 2008 Chandrayaan-1
  - 2014 Mangalyaan
  - 2015 rocket lands back
  - 2019 Chang'e 4, **NepaliSat-1** (Maskey, Shrestha)
  - 2021 *Ingenuity*, Webb
  - 2022 DART
  - 2023 Chandrayaan-3
  - 2024 Chang'e 6
  - 2026 Artemis II

Why:

- knowledge
- weather, phones, GPS, maps
- protecting the Earth
- new technology
- cooperation and inspiration

COMMON MISTAKES

✗ all gone after two half-lives
✓ half of **what is left** each time.

✗ carbon dating for dinosaurs or rocks
✓ only to about **50,000 yr**; rocks by U–Pb, K–Ar.

✗ mold = cast
✓ mold the **hollow**, cast the **filled copy**.

✗ Ramapithecus a human ancestor
✓ *Sivapithecus*, an **ape**.