Unit 15

Answers: Earth and the Universe

Quick checks

1 c By superposition the sandstone is oldest and the limestone youngest of the layers. But the igneous rock cuts through all three, so by the rule of cross-cutting it came after all of them: molten rock forced its way into a crack in layers that were already there.

2 b The periods were first recognized from their fossils: each has its own set of living things, and the change from one set to the next, often at a mass extinction such as the one at the end of the Permian or the Cretaceous, marks a boundary. Radioactive dating of volcanic ash near each boundary then gives its age. The periods are of very different lengths, from under 3 million years (the Quaternary, so far) to about 79 million (the Cretaceous).

3 b A hollow with the shell's shape, and no shell, is a **mold**: the shell was buried, then dissolved away. Had the hollow been filled with minerals, it would be a cast. A trace fossil is something the snail did (a trail), not the shape of its body.

4 b Elephants, hippos and crocodiles live in warm places. Their bones buried in the valley's lake clays, where they lived and died beside the lake, show a warmer climate then. Sea fossils, not elephants, would show a sea; and the Lukundol beds are a few million years old.

5 c Rice straw was alive and holds its own carbon, and an old house is a few hundred or thousand years old, well inside the method's range. Granite and copper were never alive. The crocodile tooth was alive once, but 9 million years is far beyond 50,000 years: no carbon-14 is left.

6 b A planetarium's projector can be set to any date, so it can show the sky of the past or the future. But its stars are only spots of light on a dome: discovering a comet or measuring a star's real light needs a telescope on the real sky, in an observatory.

7 b Sputnik 1, the first artificial satellite, was launched on 4 October 1957. Gagarin flew in 1961, Apollo 11 landed on the Moon in 1969, and Hubble was launched in 1990.

1 a. **b** *Geo* (the Earth) + *chronos* (time) + *logos* (study): geochronology. Paleontology studies fossils, seismology earthquakes, and geomorphology the shapes of the land.

1 b. **c** By the principle of superposition, each layer was laid down on top of those already there, so the bottom layer is the oldest and the top one the youngest.

1 c. **c** A footprint is something the animal did, not part of its body: a trace fossil. The others are the remains, or copies of the remains, of the living things themselves.

1 d. **b** The coils inside shaligrams are ammonites, mollusks of the Jurassic sea, about 150 million years old, from the black shales of the Tethys Himalaya in Mustang.

1 e. **c** A neutron hitting a nitrogen-14 nucleus turns it into carbon-14 and a proton: $^{14}N + n \rightarrow {}^{14}C + p$. Nitrogen is the commonest gas in the air.

1 f. **b** About 5,730 years (measured more recently as 5,700 ± 30). 4,470 million years is the half-life of uranium-238.

1 g. **b** The Soviet Union launched Sputnik 1 on 4 October 1957, starting the space age. 1961 was Gagarin's flight and 1969 the first landing on the Moon.

1 h. **c** Neil Armstrong stepped onto the Moon first, on 20 July 1969, followed by Buzz Aldrin; Michael Collins stayed in orbit. Yuri Gagarin was the first person in space, in 1961.

2 a. Sedimentary rocks form from layers of mud, sand and lime laid down gently, often in water, which can bury dead plants and animals quickly and keep them whole while the sediment hardens. Igneous rocks form from molten rock at hundreds of degrees, which would burn or melt any living remains. (Metamorphic rocks, changed by great heat and pressure, have usually lost any fossils they had.)

2 b. The rocks of Mustang, in the Tethys Himalaya, formed as mud and lime on the floor of the Tethys Sea, which lay between India and Asia, and the shells of sea animals such as ammonites were buried in them. When India collided with Asia, these layers were squeezed, folded and lifted thousands of meters, so the sea animals' fossils now lie high in the mountains.

2 c. An index fossil must be easy to recognize, common, found over a wide area, and must have lived for only a short time. Ammonites had distinctive shells, were very common, swam in seas all over the world, and changed so fast that each species lasted only a short time, often less than a million years. So finding a given ammonite tells you fairly closely when its rock formed, anywhere in the world.

2 d. 50,000 years is nearly nine half-lives of carbon-14 ($9 \times 5{,}730 = 51{,}570$ years). After nine half-lives only $(\frac{1}{2})^9 = 1/512$, about 0.2%, of the carbon-14 is left: too little to measure reliably, and so little that the smallest trace of modern carbon getting into the sample would change the result greatly.

2 e. In cities, streetlights and buildings light up the night sky so that only the brightest stars can be seen; for months in the monsoon the sky is cloudy; and school is in the daytime. A planetarium shows the full starry sky indoors at any time and in any weather, can speed up its motions and show it from any place or date, so a whole class can learn the constellations and the movements of the sky together.

3 i.

Relative dating	Absolute dating
Tells the order of events: which rock or event is older.	Tells the age in years.
Uses superposition, cross-cutting and index fossils.	Uses radioactive clocks (uranium–lead, potassium–argon, carbon-14), tree rings, yearly layers.
Gives no numbers.	Gives numbers, with a margin of error.
Example: the limestone is younger than the shale below it.	Example: the charcoal is 2,600 years old.

3 ii.

Mold	Cast
A hollow print in rock, left when a buried shell or bone dissolves away.	A stone copy formed when minerals or sediment fill a mold.
Shows the shape in reverse: hollow where the shell bulged.	Shows the shape of the original itself.
Forms first.	Forms after the mold.

3 iii.

Body fossil	Trace fossil
The remains of the living thing itself, or their copy: shell, bone, tooth, leaf, wood.	A sign of its activity: footprint, trail, burrow, nest, droppings.
Tells what the living thing looked like.	Tells how it moved and behaved.
Example: an ammonite in a shaligram.	Example: a dinosaur's footprint.

3 iv.

Planetarium	Observatory
A domed theater where a projector shows a copy of the sky.	A place with telescopes for observing the real sky.
Works at any time, in any weather, indoors, even in a city.	Needs clear, dark nights; usually on a high, remote site.
Can show the sky of any place, past or future, at any speed.	Shows the sky as it is now, from where it stands.
Mainly for teaching and public shows.	Mainly for research and observation.
Example: a portable inflatable planetarium.	Example: the observatory at Nagarkot.

4 a. Geochronology is the science of finding the ages of rocks, fossils, sediments and the events of the Earth's history, and the order in which they happened. Its importance:

- It turns rocks into a history with dates: when seas opened and closed, when the Himalaya rose and how fast.
- It dates fossils, showing when groups of living things appeared and died out, and so the history of life and evolution; it made the geological time scale.
- It helps find resources such as coal, oil, gas and ores, which formed in rocks of particular ages.
- It shows how often faults move and landslides or floods happen, as with the earthquakes of 1255 and 1934 in Nepal, so that buildings can be made safer.
- It dates past climate changes and human history (archaeology).

4 b. A fossil is the remains or trace of a living thing of the distant past, preserved in rock. Formation: a living thing, best one with hard parts such as shells, bones or wood, dies and is buried quickly by mud, sand or ash, which protects it from scavengers and from the oxygen that decay needs. Its soft parts rot; the hard parts remain. More layers pile on, pressing and cementing the sediment into rock (lithification). Water seeping through the rock carries minerals into the spaces of the bone or shell, or replaces it grain by grain, so it turns to stone in its own shape (mineralization); sometimes the shell dissolves and leaves a mold, which may be filled to make a cast. Millions of years later, movements of the Earth lift the rock and erosion wears it away, exposing the fossil. Example: the Kali Gandaki ammonites, buried in the mud of the Tethys Sea, lifted into the Himalaya and washed out by the river.

4 c.

- **Petrified (mineralized)**: spaces filled or substance replaced by minerals, keeping the shape: petrified wood, Siwalik bones and teeth.
- **Mold**: a hollow print left when a buried shell dissolves: the hollow of a shell in rock.
- **Cast**: a mold filled with minerals, a stone copy: the raised copy of a clam shell filling its mold.
- **Carbon film**: a thin black layer of carbon left when a leaf or soft body is pressed flat: fossil fern leaves.
- **Trace fossil**: a sign of activity: footprints, burrows, droppings (coprolites).
- **Unaltered remains**: the living thing almost unchanged: insects in amber, mammoths frozen in the ice of Siberia.

4 d.

- **Tethys Himalaya** (Mustang, Manang, Dolpa; the summit of Sagarmatha): sea fossils, ammonites (shaligrams, about 150 million years old), brachiopods, corals, sea lilies, trilobites. Significance: the Himalaya's rocks were once the floor of the Tethys Sea, lifted thousands of meters when India met Asia; they date the rocks; the shaligrams are sacred.
- **Siwalik (Chure)** (Dang, Deukhuri, Butwal's Tinau Khola, Mahottari's Rato Khola): fish, crocodiles, gharials, giant tortoises, hippos, three-toed horses, elephants such as *Stegodon*, *Deinotherium*, and the ape *Sivapithecus*, about 13 to 1 million years old. Significance: warm rivers, swamps and forests at the foot of the rising Himalaya, a climate becoming drier with grasslands spreading; they date the Siwalik layers and the mountains' rise; *Sivapithecus* is part of the apes' story.
- **Kathmandu Valley** (Lukundol, Nakhu Khola, Chapagaun; Phaidhoka near Bhaktapur): *Stegodon*, elephants, hippo, crocodile, fish, wild cattle, a few million years old. Significance: the valley was a lake, and its climate was much warmer than now.
- (Also stromatolites in the Lesser Himalaya, early life, and fossils in the Gondwana rocks of Tansen.)

4 e. Carbon dating finds how long ago a living thing died from the carbon-14 left in its remains. Neutrons from cosmic rays turn nitrogen-14 in the air into carbon-14 ($^{14}N + n \rightarrow {}^{14}C + p$), which becomes carbon dioxide. Plants take it in for photosynthesis and animals eat plants, so every living thing keeps the same share of carbon-14 as the air. At death it takes in no more, and its carbon-14 decays into nitrogen-14 by beta decay with a half-life of 5,730 years. The share left, measured by counting beta particles or carbon-14 atoms and compared with a living sample, gives the number of half-lives: $t = n \times 5{,}730$ years.
Limits: only things that were once alive; only up to about 50,000 years (too little carbon-14 left after that); the air's carbon-14 has varied, so results need calibration with tree rings; contamination with younger carbon must be removed.

4 f. A planetarium is a theater with a dome-shaped ceiling on which a projector shows the night sky, the stars, Moon and planets, and their motions; a star ball with a lamp inside and a hole for each star makes the stars, and digital ones draw the sky by computer.
Uses: shows the sky at any time and in any weather, even in a city; speeds up time to show the sky turning through a night or a year; shows the sky from any place on the Earth and at any date, past or future; teaches constellations, Moon phases, eclipses, the planets' movements and finding directions by the stars; trains navigators and astronauts; takes audiences on journeys through space; and brings astronomy to the public.

4 g.

- 1957: Sputnik 1 (USSR), the first artificial satellite; Sputnik 2 carries the dog Laika.
- 1958: Explorer 1 (USA) finds the Van Allen belts; NASA is set up.
- 1959: Luna 2 reaches the Moon; Luna 3 photographs its far side.
- 1961: Yuri Gagarin, the first person in space. 1963: Valentina Tereshkova, the first woman.
- 1965: Alexei Leonov, the first spacewalk.
- 1969: Apollo 11; Neil Armstrong and Buzz Aldrin walk on the Moon.
- 1970: Venera 7 lands on Venus. 1971: Salyut 1, the first space station.
- 1976: Viking 1 lands on Mars. 1977: Voyager 1 and 2 launched.
- 1981: the first Space Shuttle flight. 1990: Hubble Space Telescope.
- 2000: the first crew on the International Space Station.
- 2003: China's first astronaut. 2014: India's Mangalyaan at Mars.
- 2019: Chang'e 4 on the Moon's far side; NepaliSat-1, Nepal's first satellite.
- 2021: Webb Space Telescope launched. 2023: Chandrayaan-3 near the Moon's south pole. 2026: Artemis II flies around the Moon.

4 h. The Siwalik rocks are about 13 to 1 million years old. Even 1 million years is about 175 half-lives of carbon-14, so none would be left; and the tooth's carbon has been replaced by minerals. Instead:

- the volcanic ash contains minerals with potassium-40 (or uranium), which can be dated by their radioactive clocks; by superposition, the tooth lies below the ash, so it is older than the ash's age, which sets a minimum age; dating an ash or lava layer below the tooth as well would bracket its age between the two;
- the kinds of animals in the layer can be matched with the same fossils in dated Siwalik layers elsewhere (index fossils);
- the direction of the rock's magnetism, matched with the known record of the Earth's field reversals (magnetic dating, as was done in the Surai Khola), can date the layer too.

5 a. $n = \dfrac{40}{10} = 4$. Fraction left $= \left(\frac{1}{2}\right)^4 = \frac{1}{16}$.
One-sixteenth.

5 b. $\frac{1}{16} = \left(\frac{1}{2}\right)^4$: 4 half-lives.

$$t = 4 \times 5{,}730 = 22{,}920$$

About 22,900 years.

5 c. $\dfrac{2}{16} = \dfrac{1}{8} = \left(\frac{1}{2}\right)^3$: 3 half-lives.

$$t = 3 \times 5{,}730 = 17{,}190$$

About 17,200 years.

5 d. $n = \dfrac{28{,}650}{5{,}730} = 5$: $\left(\frac{1}{2}\right)^5 = \frac{1}{32} = \mathbf{3.125\%}$.
$0.2\% \approx \frac{1}{512} = \left(\frac{1}{2}\right)^9$: after 9 half-lives, $9 \times 5{,}730 =$ **51,570 years**, which is why the method stops at about 50,000 years.

5 e. One half-life: **½ is left**, and **½ has become lead-206**. So there is **1 atom of lead-206 for each atom of uranium-238** (assuming the rock had no lead when it formed).

5 f.

$$\frac{539}{4{,}540} \times 100 = 11.9\%$$

$$0.119 \times 1{,}440 \ = 171$$

About 12% of the Earth's history; it would begin about 171 minutes, nearly 3 hours, before midnight: all the animals with shells and bones, the dinosaurs, the forests and ourselves fit into the last three hours of the day.

5 g. 3.6 m = 3,600 mm. $\dfrac{3{,}600}{1.2} = 3{,}000$ pairs, one a year:
about 3,000 years.

5 h.

$$\frac{24 \times 60}{92} = \frac{1{,}440}{92} = 15.7$$

About 15 to 16 times a day.