

PART ONE - SKIMMING (15%)

Duration: 20 minutes

- This part of the exam aims to test your ability to locate main ideas in a text.
- The text you are going to read is about geological research and what it can tell us about the Earth's development since the beginnings of the universe.
- Which paragraphs match with the following headings? Write the paragraph number beside the correct heading.
- The headings are not in the same order as the information in the text. One of the answers is given as an example.
- Before you begin answering the questions, it may be useful to spend a few minutes previewing the text.

**Paragraph
Number**

Heading

4	<i>e.g. Natural changes in the Earth over a long time.</i>
	a) The likely cause of the K/T extinction.
	b) The frequency of severe weather and natural disasters on Earth.
	c) The creation of the Earth and its neighbouring planets.
	d) The estimated age of the Earth according to religious sources.
	e) The beginnings of life out of the Earth's natural chemistry.
	f) Evidence about the Earth from rocks before the Cambrian period.
	g) The first influential theory to explain the Earth's slow change.
	h) The first attempt to show how different rock sections relate to each other.

Geology and 'Deep Time'

1. The world is not only large in its spatial dimensions. It also extends almost unimaginably far back in time. It is impossible to get a full grasp of the concepts and processes at work in geology without an understanding of what writers John McPhee, Stephen Jay Gould, and Henry Gee have referred to as 'deep time'.
2. Most of us know our parents, many remember our grandparents. Only a few have met great grandparents. Their youth lies more than a century in our past, a time which seems alien to us with our vastly different scientific understanding and social structure. Just a dozen generations back, England was ruled by Queen Elizabeth I, motorized transport and electronic communication was undreamt of, and Europeans were exploring the Americas for the first time. Fifty generations ago, the Roman Empire was in full swing. And 150 generations back, the Great Pyramid of Ancient Egypt had not been constructed. About 300 generations takes us back to the Neolithic in Europe at a time when the last Ice Age had only just ended and simple agriculture was the latest technological revolution. It is unlikely that archaeology can reveal where our ancestors were living at that time, though comparisons of our maternally inherited mitochondrial DNA may indicate the broad region. Add another zero to the year and we have gone back 3,000 generations to 100,000 years ago. At this time, we cannot trace separate ancestry of any living racial group. Mitochondrial DNA suggests that there was a single maternal ancestor of all modern humans in Africa not long before. But, in geological time, this is still recent.
3. Ten times older at a million years and we start to lose track of the modern human species. Another factor of ten and we are looking at the fossil remains of early ape ancestors. This far back it's impossible to point even to a single species and say with certainty that amongst these individuals was our ancestor. Multiply by ten again and, 100 million years ago, we are in the age of the dinosaurs. The ancestor of humans must be some insignificant shrew-like creature. A thousand million years ago and we are back amongst the first fossils, maybe before even the first recognizable animals. Ten billion years ago and we are before the birth of the Sun and solar system, at a time when the atoms that today make up our planet and ourselves were being cooked in the nuclear furnaces of other stars. Time is indeed deep.
4. Historical time is trivial compared to the age of the Earth, yet a few centuries have seen many volcanic eruptions, cataclysmic earthquakes, and devastating landslides. And think of the relentless progress of less devastating changes. In 30 generations, parts of the Himalayas have risen by maybe a metre or more. But at the same time they have eroded, probably by more than this. Islands have been born, others washed away. Some coasts have eroded back hundreds of metres, others have been left high and dry. The Atlantic has widened by about 30 metres. Now multiply all these comparatively recent changes by factors of ten or a hundred or a thousand, and you are beginning to see what can happen over geological 'deep time'.

Birth of Geology

5. Humans have noticed fossil remains since prehistoric times. There are ancient stone tools that appear to have been chipped so as to show off a fossil shell. The fossilized stem of a giant cycad was placed in an ancient Etruscan burial chamber. But attempts to understand the nature of fossils are comparatively recent. The science of geology arose primarily in Christian Europe where beliefs based on biblical stories made it unsurprising to discover the shells and bones of extinct creatures high up in mountainous regions: they were the remains of animals that perished in the biblical flood. Even granite, it was suggested by so-called neptunists, was precipitated from an ancient ocean. The idea of extreme acts of God such as the flood helped people to imagine that the Earth had been shaped by catastrophes, and this was the generally accepted theory until the end of the 18th century.
6. In 1795 the Scottish geologist James Hutton published his now famous Theory of the Earth. The much quoted though paraphrased summary of its message is that 'the present is the key to the past'. This is the theory of gradualism or uniformitarianism, which says that if you want to understand geological

processes you must look at the almost imperceptibly slow changes occurring today and then simply trace them out through history. It was a theory developed and championed by Charles Lyell, who was born in 1797, the year Hutton died. Both Hutton and Lyell tried to put religious beliefs in events such as the creation and the flood to one side and proposed that the gradual processes at work on the Earth were without beginning or end.

Dating Creation

7. Attempts to calculate the age of the Earth came originally out of Christian theology. It is only comparatively recently that so-called creationists have interpreted the Bible literally and therefore believe that Creation took just seven 24-hour days. St Augustine had argued in his commentary on Genesis that God's vision is outside time and therefore that each of the days of Creation referred to in the Bible could have lasted a bit longer than 24 hours. Even the much quoted estimate in the 17th century by Irish Archbishop Ussher that the Earth was created in 4004 BC was only intended as a minimum age and was based on carefully researched historical records, notably of the generations of patriarchs and prophets referred to in the Bible.
8. The first serious attempt to estimate the age of the Earth on geological grounds was made in 1860 by John Phillips. He estimated current rates of sedimentation and the cumulative thickness of all known strata and came up with an age of nearly 96 million years. William Thompson, later Lord Kelvin, followed this with an estimate based on the time it would have taken the Earth to cool from an originally hot molten sphere. Remarkably, the first age he came up with was also very similar at 98 million years, though he later refined it downwards to 40. But such dates were considered too recent by uniformitarianists and by Charles Darwin, whose theory of evolution by natural selection required more time for the origin of species.
9. By the dawn of the 20th century, it had been realized that additional heat might come from radioactivity inside the Earth and so geological history, based on Kelvin's idea, could be extended. In the end, however, it was an understanding of radioactivity that led to the increasingly accurate estimates of the age of the Earth that we have today. Many elements exist in different forms, or isotopes, some of which are radioactive. Each radioactive isotope has a characteristic half-life, a time over which half of any given sample of the isotope will have decayed. By itself, that is not much use unless you know the precise number of atoms you start with. But, by measuring the ratios of different isotopes and their products it is possible to get surprisingly accurate dates. Early in the 20th century, Ernest Rutherford caused a sensation by announcing that a particular sample of a radioactive mineral called pitchblende was 700 million years old, far older than many people thought the Earth to be at that time. Later, Cambridge physicist R. J. Strutt showed, from the accumulation of helium gas from the decay of thorium, that a mineral sample from Ceylon (now Sri Lanka) was more than 2,400 million years old.
10. Uranium is a useful element for radio dating. It occurs naturally as two isotopes — forms of the same element that differ only in their number of neutrons and hence atomic weight. Uranium-238 decays via various intermediaries into lead-206 with a half-life of 4,510 million years, whilst uranium-235 decays to lead-207 with a 713-million-year lifetime. Analysis of the ratios of all four in rocks, together with the accumulation of helium from the decay process, can give quite accurate ages and was used in 1913 by Arthur Holmes to produce the first good estimate of the ages of the geological periods of the past 600 million years.

The Geological Column

11. Look at a section of sedimentary rocks in, for example, a cliff face and you will see that it is made up of layers. Sometimes annual layers corresponding to floods and droughts are visible. More often, the layers represent occasional catastrophic events or slow but steady sedimentation across hundreds of thousands or even millions of years, followed by a change of environment leading to a layer of slightly different rock. In the case of a really deep section of ancient rock, such as that seen in the Grand Canyon in Arizona,

hundreds of millions of years of deposits are represented. It is a natural human instinct to divide up and classify things, and sedimentary rock with its many layers is an obvious candidate. But, when viewing a spatially narrow cliff face of flat layers, it is easy to forget that the layers are not continuous around the world. The entire globe was never covered by a single shallow ocean depositing similar sediments! Just as today, there are rivers, lakes, and seas, deserts, forests, and grasslands, so in ancient times there was a panoply of sedimentary environments.

12. In the early 19th century, William Smith, an English civil engineer, began to make sense of the sections of rock layers and produced diagrams to show the associations between them. He was surveying for Britain's new canal network and started to realize that rocks in different parts of the country sometimes contained similar fossils. In some cases the rock types too were the same, sometimes only the fossils were similar. This enabled him to correlate the rocks in different places and work out an overall sequence. As a result, he published the first geological map. Once the dates were added in the 20th century, and the rocks correlated between different continents, it was possible to publish a single sequence of layers representing periods of geological time for the whole world. The geological column we know today is the product of many techniques, refined over the years and agreed by international collaboration.

Extinctions, Unconformities and Catastrophes

13. It became clear that some of the changes in the geological column were bigger than others, and these provided convenient places to divide the geological past into separate eras, periods, and epochs. Sometimes there was a sudden and significant change in the nature of the rocks across such a boundary, indicating a major environmental change. Sometimes there was what is known as an unconformity, a break in deposition, caused, for example, by a change in sea level so that either deposition stopped or the layers were eroded away before the column continued. They are often also marked by major changes in fauna, represented by fossils, with many species becoming extinct and new ones beginning to arise.
14. A few intervals in the geological record stand out for the severity of the extinctions across them. The end of the Cambrian period and the end of the Permian period were both marked by the extinctions of around 50% of families and up to 95% of individual species of marine invertebrates. The extinctions that marked the late Triassic and late Devonian saw the loss of about 30% of families and, slightly smaller at 26%, but the most recent and the most famous, is the mass extinction at the end of the Cretaceous period 65 million years ago. That so-called K/T boundary is famous not only because it saw the extinction of the last of the dinosaurs but also because there is good evidence for the cause.
15. The first suggestion, by Walter and Louis Alvarez, that the extinction might be due to an astronomical impact at first received little scientific support. However, they soon discovered that sediments in a narrow band at that point in the geological column were enriched in iridium, an element abundant in some types of meteorite. But there was no sign of an impact crater of that age. Then evidence began to emerge, not from the land but from the sea just off the Yucatan Peninsula of Mexico, of a buried crater 200 kilometres across. There is evidence of debris from a much wider area. If, as is calculated, it marks the point where an asteroid or comet, maybe 16 kilometres across, hit the Earth, the results would indeed have been devastating. Apart from the effects of the impact itself and the tsunami that resulted, so much rock would have been vaporized that it would have spread round the Earth in the atmosphere. At first it would have been so hot that its radiant heat would have triggered forest fires on the ground. The dust would have stayed in the atmosphere for several years, blocking out sunlight, creating a global winter, and causing food plants and plankton to die. The sea bed at the impact site included rocks rich in sulphate minerals and these would have vaporized, leading to a deadly acid rain when it washed out of the atmosphere again. It is almost surprising that any living creatures survived.
16. It was once hard to understand how any mass extinctions could have occurred. Now, there are so many competing theories that it is difficult to choose between them. They mostly involve severe climate change, whether triggered by a cosmic impact, changing sea levels, ocean currents and greenhouse gases, or a cause from within the planet such as rifting or major vulcanism. It does seem that most of the mass

extinctions we know coincided at least approximately with major eruptions of flood basalts. In the case of the late Cretaceous, it was the eruptions that produced the Deccan Traps in western India. There has even been a suggestion that a major asteroid impact caused shock waves to focus on the other side of the Earth, triggering eruptions. But the times and positions do not seem to line up well enough to prove that explanation. Whatever the reason, the history of life and of the planet has been punctuated by some catastrophic events.

Nature's Chaos

17. We can all remember climatic events that stand out, say over the last decade, as the worst winter, flood, storm, or drought. Take the record back for a century and the likelihood is that an even bigger one will stand out. Authorities often use the concept of a '100-year flood in planning coastal or river flood defences; they are designed to withstand the sort of flood that only happens once a century. It is likely to be more severe than the sort which happens only once a decade. But, if you extend the same idea to a thousand years or a million years, there is likely to be one that will be bigger still. According to some theorists, that is likely to be true of anything from floods, storms, and droughts to earthquakes, volcanic eruptions, and asteroid impacts. Over geological time we had better watch out!

Deeper Time

18. The list of geological periods that is often shown in books goes back only about 600 million years to the start of the Cambrian period. But that ignores 4 billion years of our planet's history. The trouble with most Pre-Cambrian rocks is that they provide poor records. The constant tectonic reprocessing of the Earth from within, and the relentless pounding of weather and erosion from above, mean that most of the Pre-Cambrian rocks that survive at all are deeply folded and metamorphosed. But on most clear nights you can see rocks that are more than 4 billion years old — by looking up at the Moon rather than down at the Earth. The Moon is a cold, dead world with no volcanoes and earthquakes, water or weather to resurface it. Its surface is covered with impact craters, but most of those happened early in its history when the solar system was still full of flying debris.
19. The Pre-Cambrian rocks that do survive on Earth tell a long and fascinating story. They are not, as Darwin had supposed, devoid of the traces of life. Indeed, the end of the Pre-Cambrian, from about 650 to 544 million years ago, has yielded a rich array of strange fossils, particularly from localities in southern Australia, Namibia, and Russia. Prior to that there seems to have been a particularly severe period of glaciation. The phrase 'snowball Earth' has been used, conveying the possibility that all the world's oceans froze over. Inevitably, that would have been a major setback for life, and there is scant evidence for multicellular life forms before this. But there is abundant evidence for microorganisms — bacteria, cyanobacteria, and filamentous algae. There are filamentous microfossils from Australia and South Africa that are around 3,500 million years old, and there is what looks like the chemical signature of life in carbon isotopes in rocks from Greenland that are 3,800 million years old.
20. During the first 700 million years of its history, the Earth must have been particularly inhospitable. There were numerous major impacts far bigger than that which may have killed the dinosaurs. The scars of this late heavy bombardment can still be seen in the great Maria basins on the Moon, which are themselves giant impact craters filled with basalt lava melted by the impacts. Such impacts would have melted much of the Earth's surface and certainly vaporized any primitive oceans. It is possible that the water on our planet today came from a subsequent rain of comets as well as from volcanic gases.

Origin of Life

21. The early atmosphere of Earth was once thought to have been a mixture of gases such as methane, ammonia, water, and hydrogen, a potential source of carbon to primitive life forms. But it is now believed that strong ultraviolet radiation from the young Sun would have broken that down quickly to give an atmosphere of carbon dioxide and nitrogen. No one yet knows for certain how life began. There are even

claims that it may have had an extra-terrestrial origin, arriving on Earth in meteorites from Mars or beyond. But laboratory studies are beginning to show how some chemical systems can begin to self-organize and catalyse their own reproduction. Analysis of present-day life forms suggests that the most primitive are not the sort of bacteria that scavenge organic carbon or that use sunlight to help them photosynthesize but those that use chemical energy of the sort that is found today in deep-sea hydrothermal vents.

22. By 3,500 million years ago, early life forms such as microscopic cyanobacteria and primitive algae already existed. These began to have a dramatic effect. Using sunlight to power photosynthesis, they took in carbon dioxide from the atmosphere, effectively eating the blanket that, by the greenhouse effect, kept the Earth warm when the power of the Sun was weak. This may be what led ultimately to the late Pre-Cambrian glaciation. But long before that, it resulted in the worst pollution incident the world has known. Photosynthesis released a gas that had not existed on Earth before and which was probably toxic to many life forms and may have killed off some of them: oxygen. At first, it did not last long in the atmosphere but quickly reacted with dissolved iron in sea water, resulting in thick deposits of banded iron oxide. Almost literally, the world went rusty. But photosynthesis continued, and free oxygen began to build up in the atmosphere from about 2,400 million years ago, paving the way for more complex animal life that could breathe the oxygen and eat the plants.

Birth of Earth

23. The origins of the Sun and its surrounding solar system date from about 4,500 million years ago. There was a great cloud of gas and dust, the product of several previous generations of stars. It began to contract under gravity, perhaps boosted by the shock waves from a nearby exploding star or supernova. A slight rotation in the cloud accelerated as it contracted and spread the dust out into a flattened disc around the proto-star. Eventually, the central mass, mostly of hydrogen and helium, contracted sufficiently to trigger nuclear fusion reactions at its core and the Sun began to shine. A wind of charged particles began to blow outwards, clearing some of the surrounding dust. In the inner part of the nebula, or disc, only refractory silicates remained. Further out, the hydrogen and helium accumulated to form the giant gas planets Saturn and Jupiter. Volatile ices such as water, methane, and nitrogen were driven still further out and formed the outer planets, Kuiper belt objects, and comets.
24. The inner planets — Mercury, Venus, the Earth, and Mars — formed by a process known as accretion which began as particles bumped into one another, sometimes splitting, occasionally joining together. Eventually, the larger lumps developed sufficient gravitational attraction to pull others to them. As the mass increased, so did the energy of the impacts, melting the rocks so that they began to separate out, with the densest, iron-rich minerals sinking to form a core. The new Earth was hot, probably at least partially molten, from the impacts, from the energy released by its gravitational contraction, and from the decay of radioactive isotopes. It is likely that many radioactive elements in the pre-solar nebula had been created not long before in supernovae explosions and would still have been radioactively hot. So it is hard to see how there could have been liquid water on the surface initially, and it is possible that the first atmosphere was mostly stripped away by the force of the solar wind.
25. The formation of the Moon had long been a mystery to science. Its composition, orbit, and rotation did not fit with the idea that it had split off from the young Earth, formed alongside it, or been captured whilst passing it. But one theory does now make sense and has been convincingly simulated in computer models. It involves a proto-planet about the size of Mars crashing into the Earth about 50 million years after the formation of the solar system. The core of this projectile would have merged with that of the Earth, the force of the impact melting most of the Earth's interior. Much of the outer layers of the impactor, together with some terrestrial material, would have vaporized and been flung into space. A bit of that collected in orbit and accreted to form the Moon. This cataclysmic event gave us a companion which seems to have a stabilizing effect on the Earth, preventing its rotation axis swinging chaotically and thus making our planet a more amenable home to life.