1. **Understand the concept of a biosphere and Earth System Science and that the biosphere has evolved over time**

**Biosphere**: a thin layer of life that exists on the surface of the planet and that interacts with the hydrosphere (oceans, lakes and rivers), the atmosphere, and the lithosphere (the Earth's crust).

1. **Distinguish between the oldest and youngest portion of a geological section using the Principles of Superposition, Original Horizontality, Lateral Continuity, and Cross-cutting Relationships**
   * 1. **The Principle of Superposition**. In a succession of layered rocks, the rock layer at the bottom of the pile will be the oldest and the layer at the top the youngest.
     2. **The Principle of Original Horizontality**. This principle states that, because of gravity, layers of sediment (which eventually become rock layers) are originally deposited in the horizontal position. This means that "If it's tilted or folded, then it was originally flat".
     3. **The Principle of Lateral Continuity**. This principle states that sediments are originally extend out laterally in space in a continuous formation. This means that when present formations separated by a valley or a missing portion but contain similar rocks, then they must have been originally continuous. Simplistically, "If it's here, it's probably there too."
     4. **The Principle of Cross-Cutting Relationships**. This principle states that a rock feature that cuts through (or intrudes into) another rock feature is the younger of the two features. Simplistically, "If it cuts through, it's probably younger."
2. **Describe the Principle of Faunal Succession and the use of fossils in correlation and in the subdivision of Earth history**

**Principle of Faunal Succession**. Strata of like age can be recognized by the fossils they contain even if the outcrops of strata are separated by large distances geographically. This only works because **species have evolved through time**. Using the appearance and disappearance of fossils to subdivide geological time is the science of **biostratigraphy**. Each fossil species is said to have a **range** through geological time. In other words, it exists in the geological record from the point that it evolves to the point that it becomes extinct.

1. **Recognize the qualities that make fossils useful in biostratigraphy**

Using the appearance and disappearance of fossils to subdivide geological time is the science of **biostratigraphy.**

It was here that most of the creatures with hard parts like shells, teeth, and internal skeletons evolved. Fossils with **hard parts fossilize** much **more readily** than soft-bodied creatures. So, in addition to an increasing biodiversity as new species evolved, many of the new "hard part creatures" would more readily form fossils.

1. **Identify important historical figures in the development of stratigraphy and biostratigraphy**

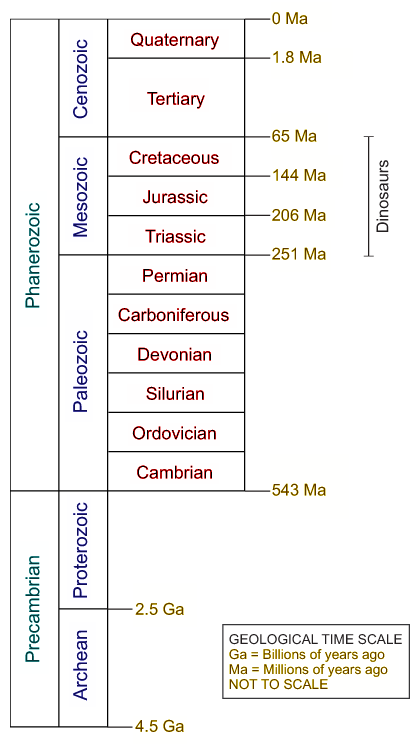
Previously the Archbishop of Armagh, **James Ussher** (1581 - 1665, pictured on left) had calculated the Earth to be 6000 years old by **adding up** all the dates mentioned in the **Bible**. He arrived at a date of October 22, 4004 BC as the date of the creation of planet Earth.

**George Cuvier** (1769 - 1832) examined the remains of **mammoths** in Europe concluding they were a **once living** species that had become **extinct**

1. **Appreciate the scale of changes that can occur over geological time scales**

I appreciate the scale of changes that can occur over geological time scales. Appreciate very much. Thank you EOSC 114.

1. **List some of the major subdivisions / ages of the geological time scale and appreciate the relative scale between the Phanerozoic and the Precambrian**



1. **Understand how extinction events are linked to the structure of the geological time scale**

**Eras** are broad subdivisions that are particularly significant. They represent a grouping of geological periods. These major groupings are not placed arbitrarily but represent times when there has been a **major change in the Earth's biosphere**.

The base of all periods is defined on the emergence or **radiation** of new species.

1. **List some of the major developments in the history of life on Earth**

As mentioned above, the base of the **Phanerozoic** is defined by the **emergence** of **creatures with hard parts**. The base of the Mesozoic and the Cenozoic, however, are based on the **emergence of new species following a mass extinction** at the top of the Paleozoic and Mesozoic respectively.

1. **Define the characteristics of a mass extinction**
2. **At least 30%** of Earth's species must be lost
3. It must be across a **broad range of ecologies**, not restricted to any one niche.
4. It must have a **short/sudden duration** (around 1 million years maximum).
5. **List the "Big Five" mass extinction events and their order through time**

From most recent to least, the "Big Five" in the Phanerozoic:

1. Cretaceous / Paleogene (Tertiary) (K/Pg), 65 Ma
2. Late Triassic, 205 Ma
3. Permo / Triassic, 251 Ma
4. Late Devonian, 360-375 Ma
5. Late Ordovician, 440-450 Ma
6. **Distinguish between broad extinction-producing phenomena**
   * 1. **Biological causes**.  
        1. **Competition** between creatures occupying the same ecological niche
        2. (excessive) **Predation**: Predators do not have to do the whole job, just drive a population to a low enough level then "random extinction" can complete the extinction. The idea behind a random extinction is that, although the number of individuals in a species may grow and the species may spread over a wide area, nothing ensures the permanent survival of a species.
        3. **Pathogens**: disease being introduced to an area by incoming plants or animals
     2. **Earth-based causes**.  
        1. **Changes in continental configuration.**
           1. **Changes in climate, ocean cyclicity, sea level**. Weather patterns and the movement of the oceans are directly linked to the distribution of continents
           2. **The greater the landmass the lower the diversity**. If plate tectonics causes the formation of a large interconnected land mass there will be more competition between species and lower biodiversity.
        2. **Changes in the atmosphere.** In addition to the climatic effects due to continental configuration, volcanic activity can also have severe effects. Gases such as carbon dioxide can cause greenhouse warming and aerosols may cause climatic cooling. These can significantly affect the health of the biota.
     3. **Extraterrestrial impacts.**
     4. **Combination of many factors**. It is very unlikely that any one factor would be responsible for a global crisis in the biosphere. A combination of events and circumstances are generally recognized as being the cause of mass extinction events.
7. **Describe the late Ordovician and Permo-Triassic extinction**

**The Late Ordovician extinction**. Gondwana (a continent consisting of South America, Africa, Antarctica, India, and Australia; see figure below) moves towards the South Pole during the late Ordovician causing a severe ice age. As water was locked up in the form of glaciers at the Southern Pole, sea level fell. This may have had a severe effect on creatures that lived in the shallow water close to the continental margins. As the sea retreated off the continental shelf and into the ocean basins, shallow marine ecosystems would have been devastated.

**The Permo-Triassic Extinction: The WORST "day" for the Biosphere, 251 million years ago**. During this extinction event, between **95 - 98%** of all species would go into extinction. It hit both ocean- and land-based ecosystems and was less than 1 million years in duration.

1. **Continental configuration: drop in biodiversity.** At the end of the Permian, the supercontinent of Pangaea or "all lands" would have brought many species into direct competition.
2. **Sea level fall: less ocean ridge activity.** Sea floor spreading slowed its pace during the Permian. As a result, the oceanic ridges were smaller in size and displaced less water. Consequently oceans retreated from shallow areas into the deeper basin causing problems for creatures that lived in any remaining shallow marine environments.
3. **Oceanic stagnation.** The close of the formation of Pangaea saw the end of an ice age. Cold polar waters probably disappeared and ocean circulation slowed or stopped. This would have reduced ventilation of deep ocean waters killing off many deeper marine species. In addition occasional overturn of stagnant water could have brought oxygen poor waters to shallower marine communities as well.
4. **Climate change.** Due to the formation of a large landmass, climate would have been much drier and subject to drought.
5. **Siberian Traps: massive volcanic activity in Russia.** Around 2 - 3 million km3 basaltic lava were produced within a million years. Carbon dioxide from the volcanic activity and methane caused by melting of gas hydrates would have resulted in greenhouse warming of the planet. In addition, gas emission from volcanoes would have also produced acid rain effects.
6. **Possible impacts.** Although still very controversial, it is possible that the Earth suffered impacts from space during this time as well.
7. **Describe the character of the extinction at the K/Pg boundary**

Over 50% of all species on the planet would go into extinction during the K/Pg extinction event. On land, few creatures over 25 kg in weight would survive. In general the extinction was even more severe in the oceans with around 80 - 90% of marine species including the ammonites and marine reptiles going into extinction.

1. **Discuss the evidence used to support the K/Pg impact**
   * 1. The **1-cm clay layer** lies directly on top of the latest Cretaceous rocks and was found to be **enriched** in the element **iridium**. Iridium is known to exist in **higher concentrations** in **extra-terrestrial objects such as asteroids**. Alvarez suggested that the clay layer enriched in iridium has been produced by a meteor or comet over 10 km in diameter impacting the Earth.
     2. **Fern spores vs. pollen**. Ferns are often the first plants to colonize a landscape that has been devastated by fire. In the earliest **Paleogene** (part of what was formerly called the Tertiary), many areas show an increase in fern spores relative to pollen (see figure below). This suggests that global forest fires may have raged at the end of the Cretaceous leaving a landscape open for ferns to spread. This is further supported by high concentrations of soot found around the K/Pg boundary.
     3. **Tektites** are thought to be produced during an impact event. They are composed of natural glass. During impact, rock is melted and ejected from the crater. As it travels through the air and cools, it forms characteristic aerodynamic shapes. Many tektites are found at the K/Pg boundary in many different locations, again suggesting a massive impact event.
     4. **Shocked quartz**. In many sections around the K/Pg boundary, fragments of the mineral **quartz** show evidence of multiple fractures. These fractures are thought to be produced when rock is shattered during a high-energy impact. The fragments are called **shocked quartz**.
     5. **Tsunami deposits**. Tsunami waves leave characteristic sedimentary deposits on inundated shores and as far inland as the waves reach. This feature was found in Mexico, Texas, New Jersey, and the Carolinas suggesting the passage of an enormous wave, far larger than could have been produced by standard tectonic processes. Such a wave could have been generated if an impact had occurred in the ocean.
2. **Describe the location and probable nature of the K/Pg impactor**

**Yucatan Peninsula of Mexico**. An oil company had drilled wells in the area and encountered unusual fractured and even melted rock suggesting the area had been subjected to some form of extreme stress. The presence of a crater was finally confirmed when geophysical data revealed a large circular disturbance over 180 km in diameter, the **Chicxulub Impact Crater**.

1. **Describe the initial and long-term effects of the impact and their environmental consequences**

**Initial effects** (seconds to days) of the impact in the area of the **Yucatan Peninsula** were significant.

* + - 1. Everything **close** by would have been **vaporized**.
      2. The **intense heat** from the blast and the **hot debris** (including tektites) would have started **massive forest fires** as suggested by the fern and pollen data.
      3. As the impact occurred partly in the ocean, a **massive tsunami** would have been generated.

**Longer-term effects** (months to decades) of the impact were numerous.

* + - 1. **Global temperature changes**
         1. **Dust** thrown into the **atmosphere** would have **shut off sunlight** for weeks or perhaps months generating a period of cold (a "Cold House"), lasting weeks to months. The lack of sunlight would also have had severe consequences for plants and photosynthetic algae.
         2. After the dust had settled, **water vapour** would have remained in the atmosphere acting as a blanket, **preventing heat** from **escaping** the Earth. This would have created a greenhouse effect and caused a **rise in global temperature**.
         3. Eventually the excess water vapour would be removed by rainfall. However, the temperature of the Earth would continue to rise due to the **release of greenhouse gases during impact** (a "Hot House"), lasting years to decades. In particular, **carbon dioxide** would have been **liberated** when large quantities of **limestone** (calcium carbonate, CaCO3) would have **vaporized** during the impact.
      2. **Acid rain**
         1. High-energy blasts can cause oxygen to combine with nitrogen to form **oxides of nitrogen**. When these are dissolved in water (i.e., rainfall), it becomes **nitric acid**.
         2. In addition to the vaporization of limestone as described in (a) above, rocks called **evaporites** were also vaporized in the blast.

Evaporites form when salts precipitate out of solution as the sun evaporates a body of water. This can occur on a vast scale, for example in the Mediterranean Sea, which is closed off at the Strait of Gibraltar. With virtually no input of water from the Atlantic Ocean, high rates of evaporation resulted in the Sea being converted into a vast saltpan. This process had also occurred in the Yucatan area.

The effect of high-energy blasts on sulfate-rich evaporites is the release of large amounts of sulfur gases. These gases, when dissolved in rainwater, fall to Earth as **sulfuric acid**.

Although the acidity of the nitric- and sulfuric-containing rain was weak and could probably not affect any large animals directly, they would have affected the acidity of soil and the surface ocean. This would have had a devastating effect on plant life and plankton. Thus, the effects from acid rain on the organisms that form the **base of the food chain or food web** had serious repercussions for all the creatures at higher trophic levels.

1. **Consider other potential causes of the K/Pg environmental collapse**
2. During the late Cretaceous, the supercontinent of **Pangaea** was starting to **fragment**. This would have caused **changes** in **oceanic circulation** and **climate**.
3. Even more significantly, **global climate** would have been affected by an **increase** in **volcanic activity**, in particular, during the formation of the Deccan Traps in India, which were highly active at this time. Like the Siberian Traps that occurred at the end of the Permian, this activity would have **produced** vast quantities of **gases** that could have seriously **affected** the **Earth's climate**.
4. **Describe the type and location of potential impactors and rate of meteor influx**
5. **Comets** are essentially **material left over** from the **formation** of the **Solar System** and are composed of icy material and other debris - effectively "dirty snowballs" in space. As comets travel towards the Sun, the ices vaporize producing the comet's tail. Found in **the Kuiper belt** exists in an area from about the orbit of Neptune to about 50 au's out (1 au = 150 million kilometres). The **Oort cloud** is a cloud of comets that exists way beyond the Kuiper belt and is only weakly associated with our Sun.
6. **Asteroids** are mostly found in a belt between the orbit of Mars and Jupiter. It is speculated that they may represent the material that might have formed another planet early in the history of the Solar System if it were not for the gravitational effects of Jupiter.

**Around 100 billion (100 000 000 000 = 1 x 1011) objects enter our atmosphere every 24 hours!** Most of these are **burned** out at a distance of **60 km** above the **Earth's surface**. These objects are commonly **traveling** around **11 - 30 km / second**. At such speeds, the atmosphere acts like a brick wall. If an object enters at a shallow angle, it may skip like a stone being skipped across a pond and fly back out to space.

1. **List some of the major impact features preserved on the Earth’s surface and explain why impact craters appear to be rare on Earth**

The evidence of this early bombardment is missing on Earth due to processes of erosion and active plate tectonics.

Gene Shoemaker was to change this view by studying features such as the **material thrown out of a crater (ejecta)**, **shocked quartz**, and **chemical anomalies**, which demonstrated **extraterrestrial origins for these features**. With the aid of satellite imagery, we are now beginning to identify more craters on the surface of our planet. A significant impact crater can be found in Northern Quebec, the **Manicouagan impact crater**. This formed about 214 million years ago in the Late Triassic. It is 70 km in diameter but was probably as wide as 100 km before glacial erosion stripped away the upper levels.

1. **Describe the hypothesis proposed by Raup and Sepkoski**

They analyzed the number of mass extinctions during the Phanerozoic and concluded that every 25 million years there was severe stress on the biosphere, sometimes associated with a mass extinction event.

There is no known terrestrial geological process that could cause this frequency of problems for the biosphere. So it was suggested that an extraterrestrial source may be to blame. In particular, comets in the Oort cloud were cited as being the most likely culprit. **Raup and Sepkoski's hypothesis suggests that every 25 - 26 million years, something shifts the Oort cloud, which causes some comets to fall in towards the Sun and a possible impact with the Earth.**

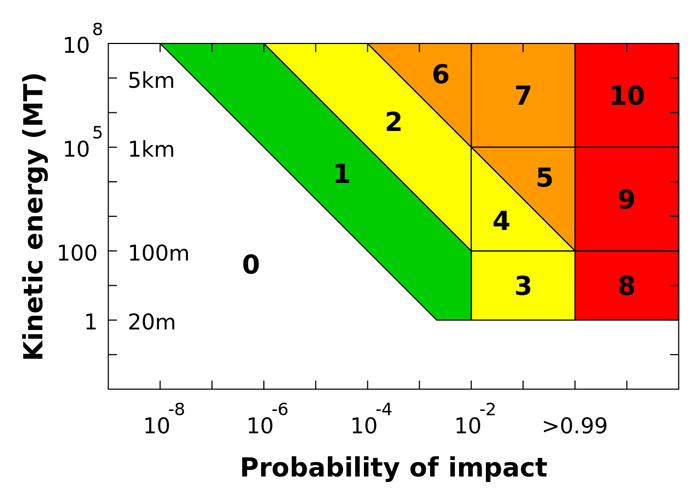
1. **Nemesis - Companion Star**. This hypothesis proposes that our Sun has a companion star way beyond the outer limits of our Solar System whose orbit brings it close to the Oort cloud every 25 million years. The gravitational effects of this close pass could cause comets to fall into the inner Solar System. If this body was a red dwarf star or even a black hole, it might be difficult to detect. However, even though powerful telescopes such as Hubble have the ability to see such faint objects, none have been found (yet).
2. **Planet X**. Like the Nemesis hypothesis, this has an astronomical body (Planet X) that causes shifts in the Oort cloud as it orbits around the Sun. In this case, the body is a planet lying within the bounds of the Oort cloud but outside the Kuiper belt. Again, no evidence of such a planet has been found.
3. **Movement Through the Galactic Plane**. In the same way that our planet orbits the Sun, so our Solar System orbits around the centre of the Milky Way Galaxy. The figure below shows the position of our Solar System in one of the spiral arms of the galaxy. However, galaxies are not just flat pancakes of stars, they also have "thickness".
   1. In addition to traveling around our galaxy, our Solar System is also moving up and down through it. Every 25 - 26 million years we pass through the densest part of the galaxy, which contains a higher number of stars and also the most gravitational effects. It is proposed that it is this movement through the dense part of the galactic plane that is responsible for the shifts in the Oort cloud and thereby a potential impact related biosphere crisis every 25 million years or so.
4. **List and describe some recent impacts and "near misses"**
5. **Tunguska, Siberia: June 30, 1908**. A large explosion about 8 km above the surface attributed to an extraterrestrial object breaking up in the atmosphere (which is why no crater was found). Fortunately, the area was not populated but people and horses 480 km away were knocked off their feet. The shock wave from the blast traveled around the Earth twice. In Scotland and Sweden, a light appeared in the sky so bright that you could read books at 2 AM without the aid of artificial light. It has been suggested that this might have been a fragment of comet Encke which was passing close by the Earth at the time.
6. **Asteroid near misses: 1989, 1996, 2009, 2011**.  
     
   **March 22, 1989**: A 500-m asteroid misses Earth by 6 hours. The impact crater would have been 7 km across.  
     
   **May 19, 1996**: A 150-m diameter asteroid misses Earth by 430 000 km, a hair's breadth away in astronomical terms. The Crater would have been around 1 km in diameter (similar to Meteor Crater in the USA) and released twice the energy produced by Mount St. Helens in 1980.  
     
   **March 2, 2009, 5:44 AM Pacific Time** (were you asleep?): Asteroid 2009 DD45, 40 m in diameter, buzzed about 70 000 km from Earth, about 1/5 of the distance between the Earth and the moon. The asteroid's size is comparable to that of the Tunguska impactor of 1908.  
     
   **November 7, 2011, 3:28 PM Pacific Time** (point of closest approach): Asteroid 2005 YU55, a 70-metre wide asteroid was as close as 324,900 km (from the centre of the Earth). Scientists used this flyby as an opportunity to make observations of the asteroid's surface.
7. **Understand the risk associated with an impact hazard**

The risk of being killed in an impact event by a body around 1 km or greater in the next 50 years is about 1:20,000.

|  |
| --- |
| **THE TORINO IMPACT HAZARD SCALE** |

**Assessing Asteroid And Comet Impact Hazard Predictions In The 21st Century**

|  |  |  |
| --- | --- | --- |
| No Hazard (White Zone) | 0 | The likelihood of a collision is zero, or is so low as to be effectively zero. Also applies to small objects such as meteors and bodies that burn up in the atmosphere as well as infrequent meteorite falls that rarely cause damage. |
| Normal (Green Zone) | 1 | A routine discovery in which a pass near Earth is predicted that poses no unusual level of danger. Current calculations show the chance of collision is extremely unlikely with no cause for public attention or public concern. New telescopic observations very likely will lead to re-assignment to Level 0. |
| Meriting Attention by Astronomers (Yellow Zone) | 2 | A discovery, which may become routine with expanded searches, of an object making a somewhat close but not highly unusual pass near Earth. While meriting attention by astronomers, there is no cause for public attention or public concern as an actual collision is very unlikely. New telescopic observations very likely will lead to re-assignment to Level 0. |
| 3 | A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of localized destruction. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by public and by public officials is merited if the encounter is less than a decade away. |
| 4 | A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of regional devastation. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by public and by public officials is merited if the encounter is less than a decade away. |
| Threatening (Orange Zone) | 5 | A close encounter posing a serious, but still uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted. |
| 6 | A close encounter by a large object posing a serious but still uncertain threat of a global catastrophe. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than three decades away, governmental contingency planning may be warranted. |
| 7 | A very close encounter by a large object, which if occurring this century, poses an unprecedented but still uncertain threat of a global catastrophe. For such a threat in this century, international contingency planning is warranted, especially to determine urgently and conclusively whether or not a collision will occur. |
| Certain Collisions (Red Zone) | 8 | A collision is certain, capable of causing localized destruction for an impact over land or possibly a tsunami if close offshore. Such events occur on average between once per 50 years and once per several 1000 years. |
| 9 | A collision is certain, capable of causing unprecedented regional devastation for a land impact or the threat of a major tsunami for an ocean impact. Such events occur on average between once per 10,000 years and once per 100,000 years. |
| 10 | A collision is certain, capable of causing global climatic catastrophe that may threaten the future of civilization as we know it, wheth |



1. **List possible mitigation strategies and appraise their relative effectiveness**

The impact hazard is unique. It is **potentially the most devastating** but the **only** disaster that can be **completely avoided**. The most important factor in all the following strategies is **TIME**. We need to have a long warning period of potential impact, which makes projects like Spaceguard vital. Below are selected impact mitigation strategies that have been proposed.

1. **Fragmentation.** Destroy an approaching impactor with nuclear weapons. This might not work for metallic bodies, as we may have to drill into an object to deploy the weapon, which would be difficult. Even if fragmentation was achieved there is no guarantee that the fragments produced during the explosion would not still impact our planet.
2. **Sudden Orbit Adjustment.** This would involve exploding a nuclear warhead in front or on the surface of an approaching body to adjust its trajectory so it is no longer an impact threat. Such a solution is still rather unpredictable.
3. **Steady State Orbit Adjustment.** These strategies would require more warning time but would permit adjustment of the orbit of the approaching object in a more predictable manner.
   1. Attach chemical or nuclear rocks to the object to gently nudge it out of the way.
   2. Deploy robot "mass drivers" to land on the surface of the object. These would excavate material and launch it off the surface. This action would act as a form of propulsion and slowly change the approaching object's trajectory.
   3. Ablation systems: irradiate the surface with lasers or focus sunlight with large mirrors. The gases produced by vapourizing the surface would act as a propellant to adjust the object's trajectory.
   4. Attach large solar sails. These are large reflective mirrors that "catch" charged particles from the Sun (solar wind) and act like giant sails in space.