GEOG 442 – The Great Extinctions

Evolution has spawned an incredible diversity of lineages from nearly the beginning of the planet itself to the present.

Speciation often results from the isolation of a population of organisms, which then evolve along their own trajectories, depending on such factors as founder effect, genetic drift, and natural selection in environments that are different to some extent from the range of environments from which they've been isolated.

Speciation can be allopatric or sympatric.

Once a new species forms, it is endemic to its source region. It may then be later able to escape its source region, migrating into new regions and even becoming cosmopolitan.

Even a cosmopolitan species is subject to environmental change out of its environmental envelope and to competition from other species. This can then set off a process of decline and local extirpations across its range, resulting in disjunct distribution, eventually recreating an endemic distribution in its last redoubt before its final extinction.

Extinction, then, is the normal fate of species. If a species is lucky, it may go extinct by dint of having evolved into one or more daughter lineages that are so divergent from the parent that we consider the parent extinct.

Many species are not lucky: Their last lineage fades out.

Extinction is normal. We can talk about the background extinction rate, the normal loss of species and lineages through time.

The average duration of species is somewhere between 1 and 13 million years, depending on the kind of critter we're talking about. Mammal species tend to last about 1-2 million years; unicellular dinoflagellate algae are on the other end at 13 million years.

Over deep time, the extinction rate has actually been declining overall, but the pattern is highly variable. This may mean that lineages overall are better adapting. It could also just mean that younger fossils are easier to find, making a random pattern look like one that's declining.

Since the Cambrian about 540 million years ago, when there was an absolute explosion of diversification of life, including multi-cellular eukaryotic plants, fungi, and animals, there have been all kinds of extinction events at various scales and durations. A few are really standouts, way beyond the normal background extinction variability. These are the Great Extinctions. Five are generally recognized:

- End-Ordovician or Ordovician-Silurian event about 440-450 mya
- Late Devonian event around 370 mya
- End-Permian or Permian-Triassic event around 245 mya
- End-Triassic event around 205-210 mya
- End Cretaceous, Cretaceous-Tertiary, Cretaceous-Palaeogene event (K-T or K-P) ~65.5 mya

There may have been two other, comparable events in the Pre-Cambrian

- Snowball Earth extinction event ~600 mya that wiped out a lot of stromatolites and acritarchs
- End-Vendian event that wiped out the bizarre Ediacaran fauna during the last period of the Pre-Cambrian Eon ~544-540 mya

Why do mass extinctions occur?

Global cooling due to variations in solar radiation, increased cloudiness, volcanic activity, increased snow, and positive feedback loops leading to runaway glaciation (e.g., Snowball Earth). Sun was 25% cooler in the early history of the solar system, making runaway glaciation more likely.

Sea-level change: seas draw down during cold times because glaciation locks up water as ice on the continents; seas rise during warm times as continental glaciers melt and as sea surface waters expand, flooding coasts, drowning many habitats, and sometimes bringing anoxic water to estuarine environments. Sea levels can also rise and fall, with attendant implications for life, as a result of plate tectonic forces changing the shape and volume of ocean basins (cup spilleth over). Changes in sea level are often accompanied by changes in the composition of the atmosphere, due to burial or exposure of carbon-rich dead organic materials. Changes in sea level affect the distribution of marine-influenced and continental climate effects, too.

Marine anoxia – less dense, well-oxygenated surface waters often separated from deep, dense, cold, anoxic waters by a pretty steep pycnocline. Anoxia is increased by the respiration of surface marine organisms. If something then causes the disruption of the pycnocline and allows anoxic waters to the surface or to estuarine environments, it can then suffocate life there.

Changes in the distribution of climates because of changes in the distribution of land masses and ocean-current blocking **obstacles in the sea** due to **plate tectonics**. Think of how life in Northern Europe is cool as opposed to glacial cold because of the **thermohaline** circulation and what disruption in it would mean.

Large igneous provinces and flood basalts. These cover thousands of square kilometers and are usually hundreds of meters thick. All are connected to a mantle hotspot (like Hawai'i's). The hotspots can bring up material from the mantle-core boundary, from superswells of molten magma in the mantle, and sometimes from persistent depressurization melts forming at the top of the mantle. They can also be formed or enhanced by bolide impact antipodal to them as seismic waves converge and interact there, resulting in faulting and melting, which lets melts get to the surface through faulting. This scale of volcanism drastically impacts climate, oceans, and the biosphere.

LIPs release **greenhouse chemicals**, such as carbon dioxide and methane, which can substantially raise global atmospheric temperatures AND trigger release of methane clathrates in permafrost, which amplifies the greenhouse effect. Carbon dioxide can interact with water to form carbonic acid, which acidifies atmospheric water and surface water.

LIPs also release huge amounts of **sulfur species**, such as sulfates (SO_4), sulfur dioxide (SO_2), sulfur trioxide (SO_3), hydrogen sulfide (H_2S), and these can interact with the atmosphere to produce sulfuric acid (S_2SO_4), which strongly acidifies rain and surface waters exposed to it.

LIPs can also create cooling as well as heating of the atmosphere. Sulfuric acid triggers water condensation and freezing, which increases **cloudiness**, which creates shading below and high albedo above. Explosive eruptions can also put out a lot of **particulates**, which also promote cloud formation. As if that weren't bad enough, all the basalt spewed out by these eruptions weathers very rapidly and the process tends to react mafic minerals with carbon dioxide, which then draws down the greenhouse gas, to the extent of triggering runaway cooling and glaciation. This would have been very effective at threatening global life on Earth early in its history, as the sun then was much feebler.

LIPs also put out all kinds of **toxic gasses** that can directly kill living things and rapidly oxidize metals in hydrothermal fluids, which leads to **anoxic ocean water**.

Bolide impact. Earth was hammered as badly as Mars, the Moon, and Mercury back before 3.7-4.0 billion years ago (the Hadean Eon). Plate tectonics and rapid gradation got rid of most of the evidence but a lot of craters are known (if mainly around hotspots of geology and geography departments). But there is an interesting antipodal pairing of seven LIPs with oceanic hotspots, which might have something to do with bolide impacts.

There have been **five truly huge extinction events** in the Earth's history over the last half billion years, and a sixth is currently underway. I'll discuss these and then maybe circle back to talk about the Snowball Earth and End-Vendian events.

First major extinction (or Ordovician-Silurian) took place about **440-450 mya**). This would have been at the end of the Ordovician Period.

Life by then would have included many multicellular forms, including plants, animals, and fungi.

All of them would have been marine/aquatic, as life had not yet invaded the land surfaces.

This extinction destroyed **25%** of all families then existing (each family would consist of anywhere between a few and a few thousand individual species).

This event is **generally attributed to climate change**: a relatively severe and sudden global cooling, which was associated with **massive glaciation in Gondwana**, the supercontinent holding the landmasses of what would much, much later become South America, Africa, Antarctica, Madagascar, India, Australia, and New Zealand. Gondwana was in the south polar regions at that time and subject to low sun angle effects that can promote glaciation.

Remember how continental glaciation ties up so much of the earth's water in land-ice? That **lowers sea levels**, and this may have had something to do with this extinction event, and the cooling of sea water would no doubt have contributed. The lower sea levels meant less ecospace for these marine/aquatic ecosystems, as productive continental shelf and tideland ecosystems were stranded above sea level.

Life rebounded when the glaciation ended, and all kinds of new clades evolved, including sharks, bony fish, ammonoids, and corals in the Silurian and Devonian periods that followed the Ordovician. This was a major fish diversification.

During the Devonian, life invaded the land surfaces, plants, animals (invertebrates and amphibians), and fungi. The plant life gave rise to great forests.

Second major extinction (or Late Devonian) took place about **370 mya**, between the middle and the late Devonian.

This event killed off nearly **20%** of the families then existing. Life by then was both terrestrial and marine/aquatic. The extinction event disproportionately hit the marine life forms, particularly those living in warm tropical waters.

It may have been triggered by **another glaciation event**, as there are glacial deposits in Brazil, then part of Gondwana, at that time.

There is some discussion and debate that this global cooling and glaciation may have had something to do with the **invasion by land plants of the land surface**. This invasion opened up a lot more habitable space for plants – and their photosynthesis. **Photosynthesis draws down carbon dioxide**, and, so, the atmosphere would have seen a strong drop in carbon dioxide, a greenhouse gas, and increase in oxygen, not a greenhouse gas.

Remember that **the sun was cooler then** at that point in its fuel cycle (there's been ~25-30% increase in its brightness over Earth history), so carbon dioxide from volcanoes was probably crucial to maintaining life-friendly temperatures.

There is also some speculation that there may have been a major extraterrestrial impact event then, though that remains pretty inconclusive.

Third major Extinction or (Permian-Triassic) happened roughly **245 mya** at the end of the Permian and, indeed, the end of the Palæozoic. This one was a doozy: **Over 50%** of all families were lost then. The slaughter was again disproportionate between land and sea: Over 90% of all marine families died at this time, including the last of the famous trilobites.

Indeed, the ecological clearing that happened then created ecological space for the great diversification of the dinosaurs, which had been held in check by the synapsids that pre-empted ecological space in the Permian.

What happened to cause this, the greatest extinction event of all, is still controversial. Geologically, Pangæa had formed, creating large **desert**-like continental areas.

Glaciation was also found, both to north and south, since Panæa reached from the South Pole to near the North Pole. Again, these conditions would drastically reduce continental shelf and tide water ecosystems, with their great productivity, causing ecological collapse.

The Late Permian also seems to have experienced **intense global warming** episodes, too. As if that weren't bad enough, there was a massive volcanic flood basalt eruption in Siberia, the **Siberian Traps**. These eruptions included explosive events, silica rich magmas, as well as basaltic, so the volcanic sulfates could have created cloud nuclei and the ash could have created shading and cooling and had something to do with the glacial episodes.

There may even have been an extraterrestrial impactor, which itself may have had something to do with the Siberian Traps, though that remains controversial.

So, this, the worst extinction in Earth history, is probably the most contentious.

Fourth major extinction (or Triassic-Jurassic) happened around **205-210 mya**, marking the the end of the Triassic Period (the first of the three great periods of the Mesozoic or age of the dinosaurs).

The dinosaurs were beginning their radiation into dominance over ecological space, forcing the synapsids into minor player status, where certain of them evolved into mammals. There weren't too many large dinosaurs at this time, though.

During this extinction, nearly **25%** of families and nearly 50% of all genera were lost. This extinction was more even-handed between land and sea, with about 20% of marine families going extinct.

On the land, the last of the big amphibians went extinct, clearing space for the evolution of big dinosaurs.

No-one is too clear on what happened here. It may have something to do with geology, as this is the time that **Laurasia and Gondwana began to split apar**t and the **Atlantic started to diverge,** and there would have been a lot of **volcanic activity** as a result.

Fifth major extinction (or Cretaceous-Tertiary or K-T Boundary) -- this is the famous one about **65.5 mya** that took out the large terrestrial dinosaurs, pterosaurs, marine reptiles, and the marine ammonites, as well as a huge chunk of representatives of all kinds of other lineages. Not quite **20%** of all families were lost then, but this included about 85% of all species.

This is the time of the great **Chicxulub** extraterrestrial impact in the Yucantán.

It was also roughly the same time as the great **Deccan Traps** flood basalt antipodal to the great crater.

They may have been connected events. The Deccan Traps themselves could have triggered massive extinction even without ET.

This is the one that created ecological space for the synapsid lineage, or the mammals. We owe our existence to the dinosaurs' tragedy!

Sixth major extinction (or Pleistocene-Holocene) is the one underway for the last 100,000 years (when modern humans had evolved and begun to disperse out of Africa) and picking up speed over the last 10,000-12,000 years (as humans began to practice agriculture).

We transform the landscape with fire and agriculture, pollution, overexploitation of species, and moving species around, creating invasions.

Megafaunal extinctions follow our arrival in the New World about 12,000 bp, the Caribbean about 8,000 bp, Australia about 40,000 bp, and Madagascar about 2,000 bp.

African megafauna had long been aware of our pesky presence and had co-evolved with us: Critters elsewhere were cognitively and immunologically naïve.

Agriculture allowed us to divert more primary productivity (and land and habitats) into our dietary compass, and increases in its efficiency have raised carrying capacity to the point that we climbed from about 1-10 million individuals at the beginning of the Neolithic to over 6 billion today.

We create islands of habitats, reducing the number of individuals in each island often below viable minimum breeding population levels and rarity picks them off. We actively attack other animals that compete with us in any way.

We are changing the climate and may have been for 10,000 + years.

We create invasives.

The normal background rate of extinction is around 1-2 spp/year or 2-5 families every million years or so. We are currently losing spp at a rate somewhere between 100 and 10,000 spp/year or about 100 – 1,000 times the background rate.

It has taken the earth about 10 million years to rebound from the last five big extinctions, so this is an impoverishment that will affect us effectively permanently.