Student questions: Dr. Kim Lau colloquium on "Mass Extinction and Ocean Anoxia: A New Tool and a New Paradigm"

10/20/21

What are the evidences for what could cause the sixth mass extinction, how likely are massive volcanism, glaciation and other extraterrestrial contributions to earth be responsible again for the next mass extinction as against the human-caused mass extinction?

- Some scientists argue that the "Anthropocene" will be marked by the sixth mass extinction, caused by anthropogenic climate change (check out https://www.amazon.com/Sixth-Extinction-Unnatural-History/dp/0805092994).

During the Permian extinction phase, do we have any hard evidences of climate change or any bio or geochemical markers?

- There is a lot of evidence for climate change. In addition to extinction on land and in the sea recorded in the fossil record, there are many geochemical markers (beyond the C, O, and U isotope data that I showed) that the Earth's environments were extremely perturbed. Biological markers include bacterial biomarkers. In terms of direct evidence for climate warming, some of the evidence comes from geochemical/isotopic proxies (such as the O isotopes that I showed) and from looking at the physiology of the taxa that saw the greatest extinction rates.

Do you think the geochemical methods you outlined could be used to find mass extinctions that are not apparent in the fossil record, such as from creatures that don't leave fossil evidence?

- A great question. It's possible. I would say that since the evolution of organisms with hard body parts is tied closely with the evolution of multicellular life and animals/plants, the question becomes really how we can identify mass extinctions before complex creatures (with skeletons) evolved. Thinking about what a mass extinction in a microbial world looks like is very interesting! But I would guess that, because many microbes do not need oxygen (and many actually cannot tolerate oxygen), the questions about anoxia that I showed in my talk are probably not the "trigger" I would look for.

Is there any reason the same chemical traces of extinction wouldn't be preserved in Martian rocks, if there was once life there?

- No reason, but it might be difficult to assume that the chemical cycles on Mars were similar enough to those on Earth for us to interpret them within the same Earth-based framework.

With all of the study on how higher temperatures impact ocean anoxia, are there plans to study the ocean redox record from the Arctic or Antarctic ocean floor? If I understood correctly, the near-freezing temperatures should keep oxygenation greater compared to other locations during the mass extinction events.

- Unfortunately no marine sediments from the Permian/Triassic are preserved on the seafloor, and we can only use what has been lithified and uplifted onto continents! In fact, the paleogeographic position of Antarctica was not as extreme as it is today (https://www.nationalgeographic.com/science/article/antarctica-fossil-forest-discovery-permian-spd). There are some paleo-high-latitude sites (namely, New Zealand) but these are far and few between. But those sites are incredibly important as you mention.

As you mentioned at the end, it is not wise as a scientist to claim to be able to predict something as bold as the next mass extinction event. With that being said, are there any trends, good or bad, that you have noticed with your research that might come into fruition in the near future?

- There's no question from the end-Permian extinction, as well as the many other documented examples of rapid climate warming throughout the fossil record, that the Earth's surface will see environmental deterioration (acidification, anoxia) and severe impact to its ecosystems. However, these same examples show that the Earth has built-in feedbacks such that the climate eventually recovers. The question is how long will it take.

Can carbonate records make predictions for the future of marine life?

- Absolutely! They are among some of the best records we have for what marine conditions used to be.

You said that mass extinction events led to an increase in biodiversity but also killed out many before. Do you think the earth would be more diverse if there were more mass extinction events in its history, or more diverse if they didn't happen at all?

- A great question. A common example is the proliferation of mammals in the Cenozoic, which has been proposed to have resulted from the emptying of ecological niches because of the extinction of reptiles and dinosaurs on land. Because mass extinctions can lead to the diversification of new groups, it's very possible that there is a close relationship! Although there is probably a balance; having too-frequent perturbations that lead to extinctions also would make it challenging.

Are there elemental isotopes other than Uranium 238 that could have been used to determine how warming temperatures are linked to the deterioration of the marine environment?

- There are many! Some have been used for many decades (C, O, Sr, S) and some are still being developed (such as U).

Does global cooling result in hyperoxic conditions in bottom water?

- Global cooling can definitely impact O2 concentrations. However, there is an idea that there is actually a maximum ceiling to O2 concentrations in the atmosphere (which would also limit the max O2 in the oceans). The idea is called the "fire" or "charcoal window" and it is that if O2 is too high (the max varies, with the "canonical," older estimate of ~35% of the atmosphere), then organic carbon (e.g., plants and other terrestrial organic matter) would spontaneously combust, drawing down O2.

Is oxygen distribution in the ocean mostly a factor of paleogeography, temperature, or microbial concentration?

- All, plus where there is nutrients (that controls the distribution of photosynthesis and respiration). The paleogeography can be really important for dictating oceanographic currents that can also change nutrient delivery through upwelling processes.

When the microbes transform organic matter into inorganic matter during demineralization does the inorganic product leave any clues of being correlated to microbes and this process?

- Yes, they can on isotope systems such as C and N!

How would analyzing the geochemical trajectory of carbonate under different diagenetic scenarios be explained/linked by a change in seawater?

- If we can identify the diagenetic scenario, it can help to evaluate whether those conditions favor or don't favor the preservation of seawater signal, or provide some constraints on how you could try to "correct" or account for the diagenetic change.

How are the various isotopes of carbon and uranium measured?

- Mass spectrometry: C isotopes are measured using isotope ratio mass spectrometers that measure C and O in CO2 gases that are released when you dissolve carbonates. U isotopes are measured using relatively much larger instruments called multi-collector inductively coupled mass spectrometers that can measure isotope ratios at very high precision.

In one of the maps shown in the slides, why are the ocean anoxia and hypoxia areas mainly concentrated near the coasts?

- Nutrients accumulate along the coasts, either from runoff/rivers from land or from upwelling of nutrient waters from the intermediate-deep waters of the ooceans.

Are there any long-lasting effects of mass extinction events that could be remotely sensed (such as on exoplanets)?

- A great question. I think it's possible but without the ability to follow a planet over a long period of time, it would be challenging to interpret definitively as an extinction versus not an extinction.

If data were available for the other Big 5s, do you think it would be similar to what you're seeing with the Permian event?

- Some have been analyzed, though not to this degree. There is good evidence that the end-Triassic extinction, 50 million years later, had probably a similar cause (large volcanic event) and also experienced ocean acidification and anoxia, though it did not last as long.

You mentioned exoplanets, do we think oxygen as a tracer of life can be as useful on other planets given we don't know about the univerality of processes like photosynthesis?

- It is unlikely that the presence of oxygen alone will be sufficient evidence for life. It can be produced through abiotic processes.

How do we know the Permian/Triassic mass extinction was caused by the Siberian Traps?

- The rocks from the Siberian Traps have been dated to coincide with dates of the extinction.

I thought I saw carbonates were sampled from all over North America, but were there samples collected from elsewhere included in your data?

- Yes, samples were from China, Turkey, N America, Japan, Iran.

How can a proxy be both local and global?

- A good question! A proxy can be local if its residence time in the ocean is short and its signature (concentration or isotope value) varies spatially. However, some researchers have considered this to be global if they compile this record from multiple locations/time intervals and assume that a lot of shifts in local environments can only indicate a global change.

How often do you work with vulcanism to help date mass extinctions?

- I don't do geochronology myself, but volcanic remnants such as ash beds are really important for dating mass extinctions! This can help to test hypotheses of what processes are temporally connected to the extinction (such as if the volcanic event can be dated to the extinction) as well as to understand the rates of change.

Are we currently experiencing high levels of ocean anoxia?

- There is lots of evidence to suggest this! https://www.science.org/doi/10.1126/science.aam7240

Are gaps in the rock record a significant limitation in determining where anoxia has occurred in the oceans at different places and times?

- Missing time can certainly make it challenging to compare environmental records across records especially if the length of those gaps is unknown. It is a limitation if the research question requires knowledge at that temporal scale.

When black shales are deposited are the anoxic conditions constant or can they be seasonal?

- Both! There's evidence for high organic carbon burial in the modern ocean in stably anoxic and variably reducing environments. Sometimes you can find little burrows on the laminations of black shales which also indicate that there was temporal variability (although being certain it is seasonal is more challenging).

Were there signs in the data that any of the mass extinction events were coming?

- In some locations that had high sedimentation rates, there are some proposals that there were multiple phases to the extinction, with the most dramatic extinction preceded by a less severe pulse of extinction.

Do your models and conclusions regarding temperature as a foundational factor for oceanic anoxia apply only to mass extinctions, or also to smaller extinction events?

- I think it would apply very broadly. The relationship between temperature and microbial rates does not require extinction, only that the extinction likely is related to a large enough temperature change that this became globally significant.

How do global ocean currents impact anoxic conditions with different configurations of the continents?

- Because oxygen and nutrient supply from deep waters reflects continental configuration, it's very possible that certain configurations and their circulation patterns are an important control on phanerozoic redox conditions. For example,

Why is oxygen (past and present) difficult to measure in the ocean?

- Because oxygen (O2) is not incorporated into minerals, it is not recorded directly into any components of the sedimentary record.

Why does the ocean west of Mexico have low oxygen levels?

- The currents off the western coast of Mexico upwell (meaning deep waters come to the surface) mostly because of the wind patterns there that pull surface waters away from the coast.The deeper waters have a lot of oxygen and nutrients, which can fuel photosynthesis. Areas of high photosynthesis produce lots of dead sinking organic matter, which is aerobically respired, consuming oxygen. Here is a cartoon that might be useful: https://oceanservice.noaa.gov/education/tutorial_currents/03coastal4.html

If the composition of the ocean changes over time, do the proxies used to determine various redox conditions maintain the same reactions?

- Great question; that is a major assumption that geochemists make in order to interpret these signals. At the least, it's important to consider how other processes could be impacting these proxies.

Are all the processes which effect the ocean redox state become triggered at the same time?

- If they are caused by the same driver (such as temperature), then yes, they can be initiated at the same time. However, the different processes do act of different timescales. For example, weathering is slow compared to the response of circulation patterns or the change in oxygen solubility in waters.

Why are the Bahamas so susceptible to the change in diagenesis?

- The late Neogene sediments of the Bahamas were deposited during a period in which the Earth experienced really dramatic sea-level changes, which can induce the advection of waters through the carbonates. These waters often have different geochemistry than the seawater, which means that there's more disequilibrium and potential for the geochemistry of the carbonates to be altered.

In the AAPIG graph at the end, is there anything that happened in 1995 that caused a huge spike in AAPII representation in awarded STEM related PhD degrees?

- Yes, good eye! This spike is related to a temporary change in U.S. immigration laws following the Tiananmen Square protests (the Chinese Student Protection Act of 1992: https://en.wikipedia.org/wiki/Chinese_Student_Protection_Act_of_1992)

With the changing of today's climate in terms of carbon dioxide in the atmosphere and increasing temperatures, do you think that we're experience (or could be experiencing) a mass extinction event now without a specific geologic source?

- Definitely! See one of my earlier answers and the link to the book, "The Sixth Mass Extincton."

What is/are the primary source/s of naturally occurring hydrogen sulfide?

- H2S comes naturally from magmatism and volcanic activity, and you can smell it (like rotten eggs) sometimes in hot springs. It can also form naturally from the reduction of sulfate, which can occur in organic-rich, really oxygen-poor environments. You may have smelled H2S before in wetlands or very water-logged areas.

Doesnt the multi-proxies approach have more scope for error?

- Good point, there are certainly more assumptions that need to be considered for each proxy, so using multiple proxies can mean more assumptions. However, the power of multi-proxies is that you can compare expected patterns between proxies to rule out or test different processes.

Other than temperature, what are other factors that can be strongly correlated to anoxia ?

- Nutrients is a key factor in the modern ocean. For example, in areas where there is high runoff of agricultural fertilizers, the coastal areas or lakes experience eutrophication and experience O2 depletion.

When the team measures the abundance of the delta U238, do they also have to measure the abundance of the daughter isotopes of U238?

- You can measure 234U as well. For rocks of this age, the 234U/238U has reached secular equilibrium (meaning the production rate of 234U has reached the decay of 238U and the ratio of these two does not change). If the sample 234U/238U deviates from secular equilibrium, it is a sign that there has been U added to the system relatively recently and would give me caution to interpret as a seawater signature. It is also possible to try to use U-Pb geochronology to date carbonates, but there are a lot of complicating factors (U loss/addition, common Pb) that make it unlikely that the age of deposition is preserved.

Did the astroidal-caused extinctions result in a greater anoxia than basalt flows that occured in the Tr-J extinction?

- The Earth system consequences of a bolide impact versus a large basaltic eruption are very different. It is possible that a bolide impact could lead to anoxia; however, the mechanisms are less defined.

Was the total biodiversity loss calculated using fossils preserved in the geologic timescale?

- Yes, that's exactly how this data is gathered!

What is the relationship between oxugent fugacity and Uranium?

- The solubility of U(VI) is much higher than the solubility of U(IV). If oxygen is present, U(VI) will be present. If oxygen is not present, U(IV) is the dominant redox state and U(IV) will be removed into minerals rather than being present as a solute. Similarly, 238U is found at greater proportions, relative to 235U, in U(IV) than in U(VI). So, the proportion of U(VI) vs. U(IV) can result in different U concentrations in solution and in different 238U/235U ratios.

Do you think the slowing of the great ocean conveyor to effect the levels of oxygen in the ocean?

- Yes, there are a lot of hypotheses about how changes in ocean circulation can impact the distribution of oxygen. Some hypotheses propose that a more sluggish circulation that is less efficient at delivering oxygen throughout the ocean.

Are there any paleoredox proxies found in carbonates which are not affected by diagenesis?

- It would be difficult to say that any carbonate did not see any diagenetic change, because diagenesis encompasses all the processes that occur during lithification. I think it's possible to define certain scenarios where diagenesis is unlikely to change a proxy significantly. Inorganic geochemical proxies are particularly challenging because of the recrystallization (dissolution and precipitation) that occurs as carbonate minerals transform to more stable phases. Conversely, non-inorganic geochemical proxies (such as microbial biomarkers) would be better preserved.

Are differences in the global deep water circulation rate and ocean conveyor belt accounted for in these models of the end-Permian extinction?

- Yes, they are! The model can stimulate ocean circulation patterns depending on the energy balance of the Earth (how warm the sun is, essentially) and the paleogeographic configuration. The model actually predicts slower circulation immediately after the temperature rise, but this does not last for more than several hundred years.

Is there a significant variation on the isotope record depending on location?

- There are certainly differences in the absolute values between locations, although they all show a large negative shift at the extinction horizon. It's difficult to pinpoint exactly what's causing the variability at each site with current knowledge, unfortunately. However, if you were to "bin" the data by time bins (such as the late Permian, earliest part of the Triassic, etc), I think you'd find that the data between sites are statistically more similar than different, although I haven't done these tests myself for all the data.

Can we ever take a core sample from the ocean floor?

- Absolutely! This is done by scientists on research cruises to sample sediment across the seafloor (https://joidesresolution.org/). However, as you go deeper in the Earth's past, there is less and less sediment available that can be drilled because old oceanic crust is subducted and no longer accessible.

Besides uranium isotopes, are there any other indicators that you can use to determine temperature-induced changes?

- There are some "paleo-thermometers" in addition to the oxygen isotope data that I showed. A lot of recent research has promoted clumped isotopes, or looking at multiple isotope systems within the same compound, as a way to determine past temperatures. For example, you can look at the O and C isotopes in carbonate minerals (e.g., $CaCO_3$) because temperature controls the distribution of C and O isotopes in the mineral lattice.

Where would you get the funding for the proposed mechanism?

- Good question. NASA and NSF both support the study of environment change in Earth's past and of mass extinctions.

Is the asteroid impact one of the causes that killed off the non-avian dinosaurs?

- That is still the prevailing hypothesis, although there is active debate about the role of the Deccan Traps, a large igneous province (similar to the Siberian Traps), in this extinction.

What factors affected the climate that caused extreme temperature changes resulting in variation of O isotopes?

- Most likely the high amounts of greenhouse gases related to the Siberian Traps. The magmatism directly related to the Siberian Traps would release the potent greenhouse gases CO_2 and CH_4, and the basalt itself formed sills and dikes in coal and carbonate rocks that could have also released a lot of CO_2 and CH_4 (as well as S gases).

How old are the oldest limestones (or other ocean rock) located that you have used for stable isotope and ocean oxygen research?

- For other research I have done, I have worked with carbonates more than 650 million years old! Those were from Mongolia and were deposited in between two Snowball Earth periods.

Is there a record of very recent anoxia in the oceans showing a similar path to extinction events you have studied?

- There are lots of evidence for more expansive anoxia in recent times using different proxies and lines of evidence. Check out the journal article "Declining oxygen in the global ocean and coastal waters" by Denise Breitburg and co-authors (http://www.sciencemag.org/lookup/doi/10.1126/science.aam7240) and another compilation here: http://dx.plos.org/10.1371/journal.pone.0115246.