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Introduction:

<u>Anthropocene</u>

There is a well-known and often discussed fact among professionals and politicians alike that few people acknowledge as being exceptionally significant to the past. This known-yet-unknown fact is that humans have had an impact on the Earth since they evolved. While many people are concerned about these effects it is unknown whether the impacts that humans have on the Earth will be represented in the geologic record as anything more than a thin line in a stratigraphic section.

The term "Anthropocene" was coined by a Dutch, Nobel-Prize winning chemist named Paul Crutzen in 2002 (Kolbert, 2011). The term was meant to indicate the beginning of a time in which humans have had a significant impact on the geologic record. Already the term has been used informally in the geologic literature to discuss the modern environment that is dominated by human activity (Zalasiewicz at al., 2010). While there is some debate as to when the term for the new Epoch should be formally applied if adopted, some believe this term should be applied to 8,000 years ago when it is believed that "…increased CO_2 levels [due to the introduction of widespread agriculture] in the atmosphere prevented the Earth's entry into another glacial period" (Kolbert, 2011). Others believe that the term ought to be applied to the beginning of the Industrial Revolution. The planet has been subjected to such distinct changes in biota, chemical introductions and sedimentary changes since the Industrial Revolution that some believe there is sufficient evidence to create a Holocene-Anthropocene boundary at this time (Zalasiewicz et al., 2008). Whether or not the term will be formally adopted is going to be determined by its usefulness. The applicability of the term will most likely be decided by the scientists that study late Holocene successions (Zalasiewicz et al., 2008).

Due to the fact that the term is already being used un-ironically in scientific literature it is obvious to some that it is in fact a useful term. However, in order for it to be useful to everyone geologists need to decide on a specific time period in the geologic time scale for this epoch to officially begin. One of the main issues surrounding the adoption of the term is that the Anthropocene would be the shortest epoch on the geologic time scale (Kolbert, 2011). Due to the controversial nature of the usefulness of the term its formal application to a time period could take years, perhaps even decades, to come to a close if it is eventually accepted as a formal time period.

The term "Anthropocene" is a vivid one for both scientists and the public and it is now suggested that some of our impacts on the Earth are similar in magnitude and influence to meteor impacts and large historic volcanic eruptions. "Some of these changes are now seen as permanent, even on a geologic time scale" (Zalasiewicz et al., 2010). While there are still many debates and specifications to be made in the adoption of the Anthropocene, formalization of the term may represent "official" acknowledgment that the world has changed, substantially and irreversibly, through human activities (Zalasiewicz et al., 2010). By acknowledging that humans have had a significant impact on the earth we will be able to gain a greater understanding of the extent of our impacts and perhaps even into the path that our influence has sent the Earth on. The Anthropocene represents a new phase in which natural forces and human forces "…have become intertwined, so that the fate of one determines the fate of the other" (Zalasiewicz et al., 2010). Due to the fact that our fate is so entwined with that of our home it is important that we understand exactly what our impact is and how it is affecting feedback mechanisms and affecting the geologic record itself.

Humans have been influencing the fossil record since we first appeared and entered the fossil record ourselves, not to mention all of the animals that we have contributed to the fossil record over the years. Humans are suspected to have aided in the megafaunal extinctions at the end of the Pleistocene as well as playing a role in the various extinctions occurring today, so we are by no means an insignificant player in the fate of this planet's biota. Humans have also managed to impact the geologic record in more subtle ways than mass extinctions; we may be even further biasing the fossil record in small, but significant ways.

<u>Acid Rain</u>

Acid rain is a broad term referring to a mixture of both wet and dry deposition from the atmosphere containing higher than normal amounts of nitric and sulfuric acids (US EPA, 2007). It occurs when polluted gases become trapped in clouds that drift for hundreds—even thousands—of miles and are finally released as acidic precipitation (US EPA, 2007). Nitric acid and sulfuric acid may be produced by natural sources (volcanoes and decaying fauna) as well as human practices (fossil fuel burning). This acid can be detrimental to the environments in which it is found by acidifying water sources thereby damaging various aquatic ecosystems. Many plants and animals have a limited range of environments in which they can survive and these environments can be defined by acid level parameters.

When lakes, streams and wetlands become acidified it often results in the loss of several species native to the area. Most living organisms are adapted to a specific set of environmental parameters and when those parameters are changed the organisms cannot always migrate out of the area and so they die. Acid rain can also impact future fossil records by more rapidly decaying newly dead organisms that might otherwise have been preserved. Acid rain can also penetrate the substrate and degrade previously buried organisms by altering the chemical processes in the sediment. The acids can cause pitting on the hard parts of organisms while simultaneously more rapidly decomposing an organism's soft parts.

Acid rain in the north-eastern United States and south-eastern Canada typically has a pH of 4.2 – 4.6 with the lowest pH in the United States (4.2) centered on/around Lake Erie and Lake Ontario (Figure 1) (Nettesheim, et al., 2009). While the effects of acid rain can be mitigated by the introduction of lime to the ecosystem it is not enough to just treat the symptoms. Although we already do try to mitigate the impacts of the acid rain it does not fix the problem, it merely lessens it. Other measures have been taken, including new air pollution constraints (Nettesheim, et al., 2009), but we have already affected Lake Erie's ecosystem and the recovery will take time. Even our minor changes to the drainage basin affect the lake and even though we try to mitigate and minimize our effects they are still present and observable today, so how will they appear in the future? Will our "acid rain layer" leave a noticeable impact on the fossil record?

<u>Ostracods</u>

Ostracods belong to the kingdom Animalia, the phylum Arthropoda and the class Crustacea (Olney, 2002). Ostracods are one of the most diverse groups of living crustaceans as well as one of the most abundant fossil arthropods. They are represented by some 50,000 living and fossil species (Park & Ricketts, 2003). Ostracods are bivalved organisms that range in size between 65µm and 125µm (very fine to fine grained sand size) and can be found in marine and freshwater environments.

Ostracods have been a recognized member of the fossil record in rocks dating back to the beginning of the Cambrian as Archeaocopida – the primitive ostracod (Bignot, 1985). Ostracods first occupied marine environments. The first freshwater ostracods were discovered in Carboniferous rocks and by the Jurassic ostracods were common in all freshwater environments (Olney, 2002) much as they are today. Some ostracods are even adapted to terrestrial environments such as damp soils and leaf litters (Armstrong & Brasier, 2005).

Freshwater Biology/Ecology:

Due to the diversity of habitats occupied by ostracods significant morphological changes have been observed between marine and non-marine species. These changes include, but are not limited to, "…less robust shells in nonmarine species as well as a lack of ornamentation, or the presence of a slightly punctate shell surface, in non-marine fauna" (Bignot, 1985). Some ostracod species are restricted to freshwater environments (Darwinulina and most Cypridacea). Other species are restricted to marine environments, and can live in a range of salinities in brackish, marginal marine and estuarine environments (Bignot, 1985).

Many ostracods consume detritus, ooze or living organisms and have even been known to hunt diatoms, foraminifera and small polychaete worms (Armstrong & Brasier, 2005). The majority of ostracod species can be found at the bottom of deep bodies of water as well as on root systems/stems of aquatic plants and also in shallow, sometimes ephemeral, bodies of water. While most ostracods subsist on their own endeavors there are some species that are parasitic and commensal (Bignot, 1985). Whether swimming, crawling or burrowing, the benthic species prefer still waters where the muds and fine sands are rich in organic material. Some species, such as the myodocopids, are planktonic (Bignot, 1985).

Ostracods are sensitive to the salinity of the water in which they live, the substrate on which they reside and the dissolved oxygen levels in the area can limit both assemblage diversity and life span. Ostracods in colder climates tend to have larger, heavier carapaces and so take longer to mature (Armstrong & Brasier, 2005). Temperature is also a large factor in ostracod life-cycles including impacts on metabolic rate, maturation and controls on the breeding season and, in some freshwater species, the incidence of parthenogenesis (Armstrong & Brasier, 2005).

Freshwater Morphology/Fossilization:

The general organization of the ostracod carapace includes an apparently unsegmented body with a head, thorax and appendages contained within a calcitic ovate, kidney-shaped or bean-shaped, carapace (Bignot, 1985) (Figure 2). The carapace itself is composed of two valves that are held together on the dorsal side of the shell by an elastic ligament and a hinge, similar to other bivalved organisms (Boomer et al., 2003). The body of the ostracod is fixed laterally to the valves by muscles and hangs within the carapace like a sack. "The sack contains a digestive system, complex genital organs, a central nervous system, a median eye behind a transparent furrow (tubercule) and, in some cases, a brood pouch" (Bignot, 1985). There are also seven, up to eight, appendages attached to the ostracod's body including, in most species, three pre-oral and at least four post-oral. Appendages are used as sense organs as well as for capturing and aiding in the mastication of food, locomotion and cleaning the internal cavity (Bignot, 1985). As in other arthropods the soft parts are covered by a rigid, jointed exoskeleton of chitin (Armstrong & Brasier, 2005) which is also shed during times of molting.

Sexual dimorphism is common among ostracods and is generally represented by elongation in the males and a larger posterior in females (Armstrong & Brasier, 2005). Males also tend to be approximately 3-10 times less numerous than females or entirely absent when parthenogenesis is the rule; due to this variability reproduction can occur in both fertilized and unfertilized eggs (Bignot, 1985).

Ostracods are hatched with a carapace and three pairs of appendages already present (Bignot, 1985). The larvae then undergo eight or nine molting stages called instars. The first instar possesses a thin bivalve carapace but the body lacks maxillulae (developed at instar two) and thoracic legs (developed between instars four and six); muscle scars do not usually appear until instar six, genital impressions at instar seven, and sexual dimorphism before instar eight – by instar eight/nine (depending on the species) all of the appendages have developed (Armstrong & Brasier, 2005). Freshwater ostracods typically grow to adulthood in about 30 days and live no more than a few months (Bignot, 1985).

When an ostracod dies, the body and appendages disappear quickly, leaving only the carapace to be fossilized. The carapace can be fossilized with the valves either joined or separated. Most fossils are benthic (Bignot, 1985) due to the degraded nature of planktonic species as they pass through the water column during deposition. There have been instances in which individual ostracods have been preserved with their appendages intact as a result of phosphate (or silica) incrustation or the formation of pyritic internal moulds which have confirmed, through observation, that most ancient ostracods had an anatomy comparable to that of present day individuals (Bignot, 1985).

Lacustrine ostracod species are very resistant to desiccation and cold and so can exist in such places as ephemeral streams and sabkhas as well as seasonal wetlands as well as allowing for the transport of the ostracods on the feet and feathers of birds (Armstrong & Brasier, 2005).

Importance in the Fossil Record:

Ostracods are abundant and diverse in freshwater, marginal-marine and marine environments as well as being spread worldwide. Due to their dense calcite carapace and tiny size, ostracods are essentially guaranteed a decent fossil record. Because ostracods have such a complex morphology and a highly effective means of dispersal (Kaesler, 1983) they are frequently observed in the fossil record. Analyses of an ostracod assemblage, species and valves can all yield important information regarding the environment of deposition, taphonomic processes, paleoclimates, paleoceanography and paleobiogeography (Boomer et al., 2003). Freshwater ostracods can help a paleoenvironmentalist reconstruct an entire ecosystem's history based on the species discovered and the amount of shell degradation. Both the amount and type of degradation can indicate post-mortem conditions in the environment.

Changes in hydrology can be monitored by ostracod assemblage species in both shallow and deep water lakes and wetlands due to the specialization of some ostracods to specific environments. Ostracods can also be used to indicate changes in groundwater composition (Reeves et al., 2007). Essentially, ostracods are the most sensitive, terrestrial climate indicators that paleontologists have at their disposal in some locations and they are used extensively in reconstruction, as well as current evaluation of terrestrial ecosystem health.

Actualistic Taphonomy

Taphonomy refers to the study of the processes (such as death, decay, burial and preservation) that affect animal and plant remains as they become fossilized. Experimental taphonomy is then the simulated reconstruction of the processes that allow for fossilization.

Actualistic taphonomy takes experimental taphonomy one step further by recreating, as accurately as possible, as many factors of an organism's death, decay and burial (Kowalewski & LaBarbera, 2004).

Previous Work

Much work has been done in both actualistic taphonomy and ostracod studies.

Davies et al. published a damage-scale for crustacean shells in 1990 determining the amount of damage done based on the percentage of the carapace that had been altered.

Kontrovitz et al. published created an arbitrary ornamentation scale to measure the amount of ornamentation on ostracod shells in 1998.

Kowalewski and LaBarbera (2004) published a review of data collection methods including direct field observations, field experiments (specimen-deployment/specimen-marking) and laboratory experiments. The researchers suggest that one may create a study using one or more of the aforementioned strategies and thereby compile a single analysis of both the experimental and field data.

Bailey et al. published a paper in 2005 detailing the effects of sulfuric acid on Lake Tanganyika ostracod shells. The researchers used "…experimental tanks to simulate pH, depth, duration of acidification, and buffering conditions…of a hypothetical acidified lake" (Bailey et al., 2005). They discovered that the buffering abilities of the bedrock played a primary role in the preservation of calcareous fossils after burial.

In 2009 Thomas Evans came to the conclusion that taphonomic experiments should be repeatable. He also concluded that all experiments should be capable of being utilized across fields. Evans is suggesting that all scientists should be able to utilize each other's work and collect data that is relevant to multiple studies.

Research Objectives:

The primary object of my research is to provide a set of data that indicates whether or not humans are having a significant impact on the potential future fossil record of freshwater ostracods due to acid rain. As I am unable to travel to the future and observe the fossil record that we have left behind, I hope to be able to accurately construct a model fossil record for the ostracod assemblages in an area of Lake Erie. In this model I want to explore the differences before and after human involvement/contamination/degradation of the surrounding environment and acidification/ contamination of Lake Erie. I hope to do this through several taphonomic experiments taking into account factors such as nitric acid levels and organic acid contribution as well as the buffering capacity of the sediment. I hope to discover how such factors have been amplified/diluted by human industrial involvement in the area.

Methods:

Data Already Collected

I have already compiled general acid rain data for Lake Erie and the surrounding watershed from 1990 until 2009.

Data to Be Collected

A current sample population of ostracods from Lake Erie is necessary to know exactly which species are being affected in the area and to determine how they will be affected in the fossil record as well due to deterioration caused by acidification of lake water and distributary channels. It is also necessary to find a place in Lake Erie that is sufficiently rich in dissolved oxygen [preferably year round (not stratified in various seasons), though I am not sure that any such area exists] and nutrients for a diverse population of ostracods to be present. I will also need to gather sedimentation rate data for the areas that I will be studying in order to accurately represent the effects of the acid rain at various times after the death of the ostracods. Varying sedimentation rates can cause more rapid burial and therefore impact the effects of the acid rain on the buried ostracod shells. I will also need to find out how far into the lake the area affected by the acid rain reaches and how far along the shore it spans in order to get a more accurate picture of the total acidification of the area and be able to sample from areas of the section that are more or less acidic than others and test the shells at these various recorded acidities (or past acidities and amounts of wet/dry acidic precipitation as recorded by the EPA). Following that, it will be necessary to learn how acidic Lake Erie is now compared to older acid levels in the region of the lake that I will be studying.

I will also take samples of the substrate from my pre-determined sampling sites to determine the buffering ability of the substrate and to be able to better reconstruct the actual substrate and sediments in which the shells would be residing, in the lab.

Sampling Locations

While I do not currently have an exact sampling location in mind I will look for an area of Lake Erie that is shallow enough to be affected by acid rain in the water (where dilution is minimal) with a muddy bottom and abundant plant life. It is also necessary that the area have a sufficient dissolved oxygen percentage so that a large number and diversity of ostracods may be present in the area.

Sampling Techniques

I will use a shovel to scrape bottom sediments (~2.5cm deep) into a Ziploc sandwich bag underwater in the areas in which I am sampling. Rather than disturbing the environment further by uprooting entire plants (and also because it is unnecessary) I will make note of the plants in the areas and the density of the populations through photographs, leaf and stem samples (in case of misidentification and for use in the sediment reconstruction in the experiments), and field book entries.

Lab Techniques

I expect that all of the samples I acquire will consist mainly of loose, unconsolidated clays and silt-sized sediments. These sediments will need to be dried which will be done in a drying oven. Once dried, the sample will be weighed and then the ostracods will be removed. Once all of the ostracods have been removed the sample will be weighed again in order to determine the weight % of ostracods in the sediment. After the ostracods have been removed the remaining sediment will be burned to remove any organic matter and re-weighed to determine the weight % of organic matter in the sediment.

In order to identify the ostracods I will sieve them for ten minutes using a standard 8" diameter sieve set consisting of a base pan, a 63µm, a 125µm, and a 250µm sieve due to the fact that ostracods are very rarely larger than 125µm and I do not think that I am likely to find any of that size in a freshwater environment like Lake Erie.

Ostracods are very small crustaceans and as such cannot be properly identified in the field so I will be using a Scanning Electron Microscope (SEM) to gather characteristic data from the species sampled including, but not limited to, shell width/depth, ornamentation and shape and size of the shell. I will be using the information compiled and detailed on Dr. John Havel and Elissa Dey's (both of Missouri State University) website containing data on 420 freshwater species.

After the experiments have been run I will again use the SEM to gather the same type of data from each species sampled. I will then use the information gathered to determine how each species is affected by the acid and analyze variations within each group to determine the net impact of the acid on the shells.

<u>Lab Experiments</u>

Once I have acquired some ostracod samples I will keep them alive in a tank provided with pondweed and a little manure, as is suggested by Armstrong and Brasier, until I am ready to run my experiments in order to better observe the degradation of soft-body parts as well as shells immediately after death and deposition.

The amount of organics and their acid contribution to the substrate during decay may also affect preservation and I think it is important to distinguish the organic acid effects from the nitric acid effects on the shells as well as determine how humans have changed the substrate since industrializing the waterfront/southern coastline of Lake Erie. I think that I can do this by running two similar experiments at once:

- The first experiment will be run with fresh water (non-acidic), in a tank with ostracods in a substrate/sediment that is equal in percentage weight to the organics in the sampling area in Lake Erie to determine the organic acid effect on the ostracods buried at various depths (to simulate sedimentation rates).
- The second experiment will be run in several similar tanks with ostracods in a substrate/sediment with organics equal to those in the freshwater, non-acidic tank, but the water will have been acidified with nitric acid at various levels that might be observed in the sampling area of Lake Erie, thereby determining the combined effects of the nitric acid and the organic acid on the shells after deposition and burial at various depths (the same as in the freshwater, non-acidic tank). Once both sets of data have been compiled, the percent damage done by the organic acids will be subtracted from the percent damage observed in the series of varying acidity levels to determine the overall effect of the nitric acid on the shells and therefore determine a proxy for the effect of general lake acidification and human biasing of potential ostracod fossil records.

I will run the experiments for at least one month and take cores at the end of the month to analyze the acid effects on the shells. I will use the scale created by Davies et al. in 1990 to determine the intensity of shell degradation. After careful analysis I will hopefully be able to determine exactly how much of an impact humans have had on the preservation quality of ostracods.

<u>Drawbacks/Problems</u>

I will not be introducing live plants, and the bacteria that comes with them, into the experimental tanks, so any chemical reactions that may be induced by the presence of those organisms will not be taken into account in this experiment and therefore some effects of the environment will not be accounted for in the comparison between pre- and post-industrialized waterfront sediments.

Timeline/Budget:

Acid Rain Effects on Lake Erie Ostracod Preservation			
Year: Season/Month	Work to be completed	Equipment Needed	Cost
2012: Spring	Identify ideal sample area and range of acid rain deposition in Lake Erie and most probable location for adequately large, diverse ostracod species		
2012: Summer	Gather sediment samples from Lake Erie, identify assemblages, identify pH ranges in sample area	Sandwich baggies Car/gas pH strips (500)	$4.85 $75.00 $21.25
2012: Fall	Process ostracods Calculate weight % organic matter in the sediment	Petri dishes (40)	$44.30 +shipping
2012/2013: Winter, Spring	Reconstruct Lake Erie sediments before/after industrialization of the waterfront		
2013: Summer, Fall	Run “2” experiments Analyze data Write final paper	3 gallon glass tanks	$13.00 each +shipping

Expected Results:

I expect that, because the ostracods I will be studying are freshwater ostracods, their shells will not hold up very well against nitric acid depending on the depth to which they are buried and the buffering capacity of the substrate. I expect that more shallowly buried ostracod shells will not ever fossilize because they will be almost immediately degraded by the acidification of the water and substrate. I expect that more deeply buried ostracods will stand a better chance of fossilization, though I suspect that they may be slightly damaged before they could formally enter the fossil record. I expect to find that humans have had and/are having a significant negative impact on my modeled fossil record compared to a pre-industrialized waterfront ecosystem.

Conclusion:

The Anthropocene is a time period referencing the beginning of significant human impacts on the Earth that will mark a distinct change in the stratigraphic rock record of future years. Through the use of actualistic taphonomy scientists can model the effects of human impacts on future fossil records and indicate how humans have affected, are affecting, and will affect, processes such as the death, decay and burial of organisms. This information is important in considering the long term effects of human activities, such as the industrialization of waterfronts and the subsequent environmental impacts, like acid rain, they will have on the environment.

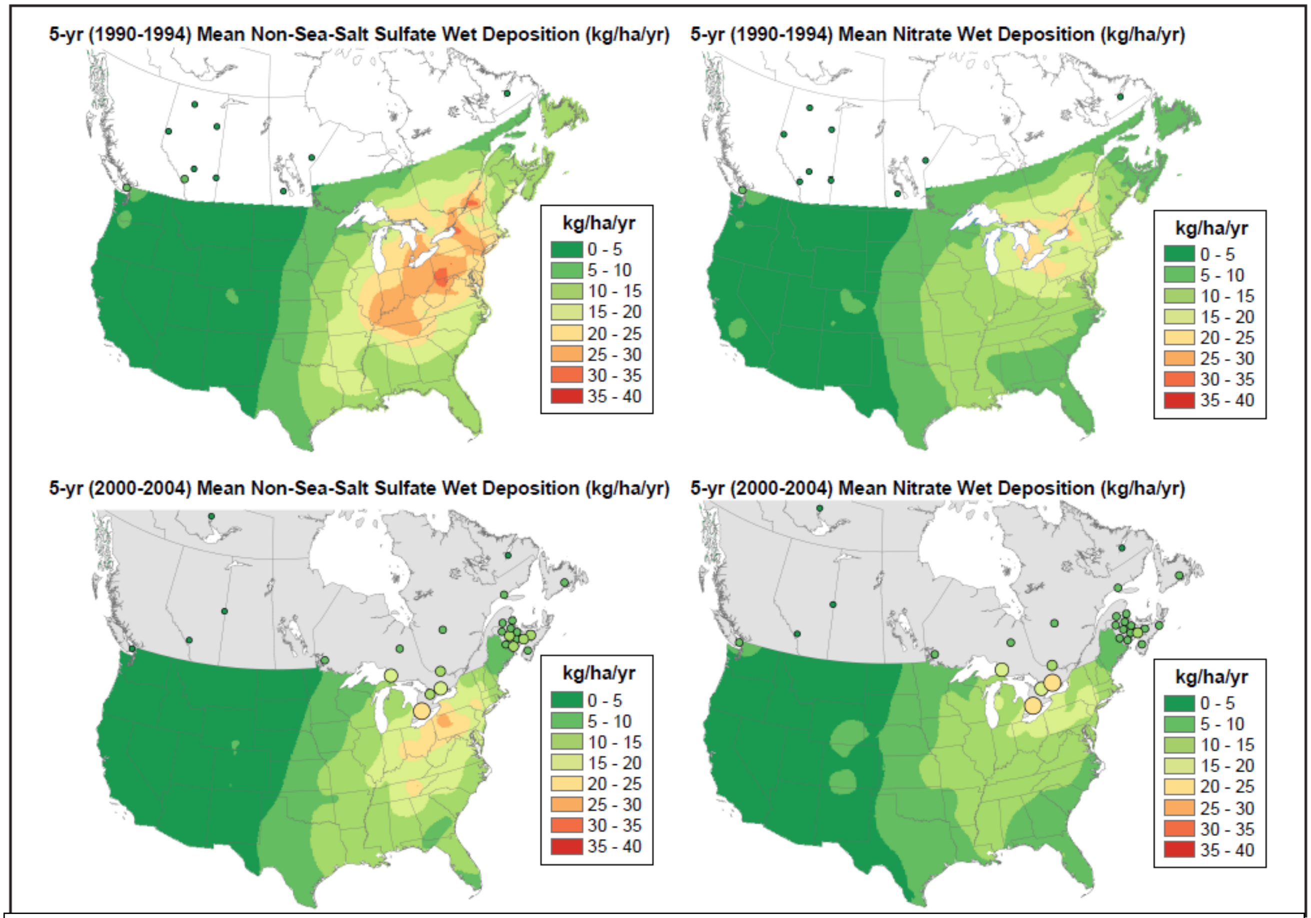

Figure 1. Five-year patterns of mean non-sea-salt-sulphate wet deposition (kg/ha/yr) and mean nitrate wet deposition for the periods 1990-19944 and 2000-2004.
Source: Figure 3 of the EPA 2009 Great Lakes Acid Rain report

Figure 2. Podocopid: freshwater ostracod; body about 485 µm long
Source: microlife.pavarium.com

Annotated Bibliography

Armstrong, H. A., & Brasier, M. D. (2005). *Microfossils*. (2nd ed.). Malden, MA: Blackwell Publishing.

A book discussing various microfossils, their evolution and current lifeways.

Bailey, J. V., Cohen, A. S., & Kring, D. A. (2005). Lacustrine fossil preservation in acidic environments: implications of experimental and field studies for the Cretaceous-Paleogene boundary acid rain trauma. *PALAIOS*, *20*(4), 376-389. doi: 10.2110/palo.2003.p03-88

A research project using sulfuric acid to test the resilience of Lake Tanganyika ostracods in order to better understand the effect of acid rain trauma due in a hypothetical lake to an impact with effects similar to those of the K-T boundary.

Bignot, G. (1985). *Elements of micropaleontology*. (2 ed.). Boston: IHRDC.

A book detailing the current lifeways and evolution of several microfossils.

Boomer, I., Horne, D., & Slipper, I. (2003). The use of ostracodes in paleoenvironmental studies, or what can you do with an ostracode shell?. In L. Park & A. Smith (Eds.), *Bridging the gap, trends in ostracode biological and geological sciences* (pp. 153-179). New Haven, CT: Paleontological Society.

An article detailing potential uses of ostracods in reconstructing paleoenvironments.

Chivas, A. R., De Deckker, P., & Shelley, J. M. G. (1983). Magnesium, strontium, and barium partitioning in nonmarine ostracode shells and their use in paleoenvironmental reconstructions - a preliminary study. In R. Maddocks (Ed.), *Applications of ostracoda* (pp. 238 - 249). Houston, TX: University of Houston-University Park.

An article discussing the ability to use chemical ratios in ostracod shells to aid in paleoenvironment reconstructions.

Evans, Thomas. 2009. Experiment design for actualistic taphonomic research; improving design, data acquisition, and collaboration. Abstracts with Programs - Geological Society of America 41(7): 30-31.

A review of taphonomic techniques and insights into future uses and considerations when designing experiments.

Green, O. R. (2001). *A manual of practical laboratory and field techniques in palaeobiology*. (1 ed.). Boston, MA: Kluwer Academic Publishers.

A book detailing laboratory and field techniques for paleobiologists.

Grosse, J. Josh's Microlife. Retrieved from http://microlife.parvarium.com/

A personal collection of photographs of living and fossilized organisms detailing where/when each was collected.

Havel, J., & Dey, E. (2005, September). *Ostracode diversity*. Retrieved from http://biology.missouristate.edu/ostracods/Default.htm

A website detailing characteristics of ostracod species with images present to aid in identification.

Horne, D. (2003). Key events in the ecological radiation of the ostracoda. In L. Park & A. Smith (Eds.), *Bridging the gap, trends in ostracode biological and geological sciences* (pp. 181-196). New Haven, CT: Paleontological Society.

An article detailing the evolutionary migration of ostracods from the oceans into freshwater and terrestrial environments.

Kaesler, R. L. (1983). Usefulness of ostracoda: questioning a rule of thumb. In R. Maddocks (Ed.), *Applications of ostracoda* (pp. 8 -18). Houston, TX: University of Houston-University Park.
An article describing the usefulness of ostracods and how they are used in paleo-reconstructions.

Kolbert, E. (2011, March). Age of man. *National Geographic*, Retrieved from http://ngm.nationalgeographic.com/2011/03/age-of-man/kolbert-text
An article discussing the Anthropocene and its relevance to geological and environmental studies.

Kontrovitz, M., Pani, E. A., & Bray, H. (1998). Experimental crushing of some podocopid ostracode valves: an aspect of taphonomy. *PALAIOS*, *13*, 500-507.
An article detailing the pressures at which ostracod shells will fracture and break in comparison to shell ornamentation.

Kowalewski, M., & LaBarbera, M. (2004). Actualistic taphonomy: death, decay, and disintegration in contemporary settings. *PALAIOS*, *19*, 423-427.
An article detailing the usefulness of actualistic taphonomy and the importance of taphonomic experiments.

Nettesheim, T., Jeffries, D. S., Vet, R., Carou, S., Atkin, A., & Timoffee, K. U.S. Environmental Protection Agency, (2009). *State of the great lakes 2009*. Retrieved from website: www.epa.gov/solec/sogl2009/9000acidrain.pdf
An article detailing the environmental stability of the Great Lakes ecosystems.

Olney, M. (2002). *Ostracods*. Informally published manuscript, UCL, London, United Kingdom. , Available from Microfossil image recovery and circulation for learning and education. (MIRACLE). Retrieved from http://www.ucl.ac.uk/GeolSci/micropal/ostracod.html
A website reviewing current information on basic ostracodology.

Park, L., & Ricketts, R. (2003). Evolutionary history of ostracoda and the origin of nonmarine faunas. In L. Park & A. Smith (Eds.), *Bridging the gap, trends in ostracode biological and geological sciences* (pp. 11-36). New Haven, CT: Paleontological Society.
An article detailing the movement of ostracods into freshwater environments and terrestrial environments.

Reeves, J., De Deckker, P., & Halse, S. (2007). Groundwater ostracods from the arid Pilbara region of northwestern Australia: Distribution and water chemistry. *Hydrobiologia*, *585*(1), 99-118. doi: 10.1007/s10750-007-0632-7
An article discussing the effects of water chemistry changes on the ostracod assemblages present.

United States Environmental Protection Agency, (2007). *What is acid rain?*. Retrieved from website: http://www.epa.gov/acidrain/what/index.html
A webpage detailing the origins and effects of acid rain.

Zalasiewicz, J., Williams, M., Smith, A., Barry, T., Coe, A., Brown, P., Cantrill, D., Gale, A., Gibbard, P., Gregory, F., Hounslow, M., Kerr, A., Pearson, P., Knox, R., Powell, J., Waters, C., Marshall, J., Oates, M., Rawson, P. & Stone. P. (2008). Are we now living in the anthropocene?. *GSA Today*, *18*(2), 4.
A paper detailing the argument for the adoption of the Anthropocene as a new geologic epoch.

Zalasiewicz, J., Williams, M., Steffen, W., & Crutzen, P. (2010). The new world of the anthropocene. *Environmental Science and Technology*, (44), 228-2231.
An article defending and encouraging the adoption of the Anthropocene as a new epoch on the geologic time scale.