Spring 4-14-2023

Glass: the Material that Defines Us

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Submitted to the BGSU Honors College

Spring 2023

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Thanks to Joel O'Dorisio, Dr. John Farver, Christine Shaal, Tiffany Menard, Clayton Scott Lilly, Colby Lilly, Alyssa Desotell, Kaitlyn Balkcom, Dr. Jeffery Snyder, Roya Franseth, Allen Kripal, Karlyn Rex, Mom and Dad, and anyone who has had to listen to me talk about this project for the past three months.

This project is dedicated to everyone who believed in me, even when I didn’t.

INTRODUCTION

What is glass? Glass is a term that defines more than just the cups in your sink or the windows in your house. When scientists refer to a substance as a “glass”, they are referring to a specific way the molecules of the substance are arranged. Let’s back up a bit to second grade science. You learned that there are three states of matter: solid, liquid, and gas. This is only partially correct. The three (main) states of matter should be renamed as crystalline lattice (solid, held together by extremely strong intermolecular attractions), liquid (disordered arrangement of molecules with some intermolecular interactions), and gas (no interactions between molecules outside of collisions). Glass exists somewhere between crystalline lattice state, as it is “solid”, but also contains the disordered molecular arrangement characteristic of liquids. Glass is, basically, its own state of matter that occurs when a liquid is cooled far too fast to form a crystal lattice. For the layman, this means that the molecules, ions, or atoms are not arranged in an ordered and structured pattern in the material, but instead are arranged willy-nilly, as if someone spilled marbles on the ground (Figure 1.0).

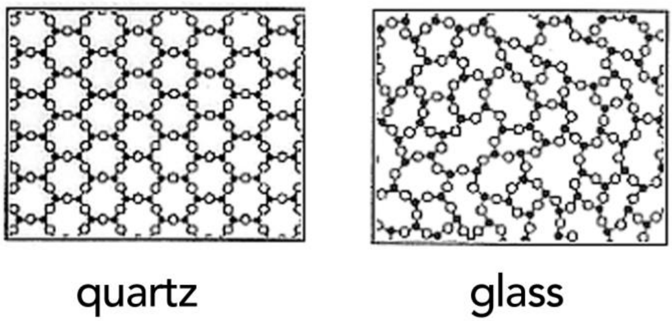

Figure 1.0: The Structural Difference Between Quartz and Glass Atoms (*Corning Museum of Glass,* 2011)

There are different types of glass, but we will get into that later. In this collection of essays, I hope to impart a sense of wonder for the natural world, a sense of awe for the masters of glass working, and a sense of appreciation for the scientists who helped master the properties of glass to give us the modern world we know today.

This project is not merely an honors project that seeks to fulfill requirements set in place by the faculty of BGSU, but a deep exploration of my interests and passions as an artist and a scientist. This is a culmination of what I have learned and what I hope to learn in the future. I selected this project after intense consideration. I have been conducting research since my freshman year, so I am familiar with lab work, creating a research question and methodology, and statistical analysis. I am able to run many geological machines from electron scanning microscopes to an ICP-OES. I did not want to do that for this project. Instead, I am choosing to delve deeper into a topic that is intensely interesting and personal to me using library research as well as experimental research in the glass studio. I am a geology major with a minor in glass. I frequently get the question “why?”. Using this project, I want to demonstrate and explore how geology, materials science and art can be interconnected through glass, as well as explore my own curiosity for glass.

The medium of this project is important as well. These topics can also be explores in artistic and scientific mediums. For example, I could have created a gallery show with objects about geology and glass intersections. However, I decided to write a small book because I was inspired into geology by a book, Dr. David Montgomery’s *The Rocks Don’t Lie.* I hope this project is equally as captivating to readers.

According to the Honors Project guidelines, this project should fulfill the criteria of being interdisciplinary and based in inquiry based learning. This project fulfills the interdisciplinary criteria because it seeks to connect science, art, and history in one cohesive narrative that should capture the attention and imagination of the reader. This project is based in inquiry based learning because it is driven entirely by my own interests and experience. I am investigating questions and attempting to find answers about a variety of topics that I am interested in. This project seeks to synthesize creative thinking, critical thinking, written and oral communication, as well as put to use skills gained from past courses in science, history, and literature.

This introduction serves as both an introduction to glass, my passion for science, art, and writing, and my honors project. However, it also serves as a pre-project reflection. I will be honest, this is a massive undertaking, even for me. The most I have ever written in a single semester was five essays, totaling around 80 pages all together, double spaced. I intend to complete at least fifteen substantial essays for this project over the course of one semester. I think I can do it. I know I can do it. So, let us get into the story of glass, I hope you enjoy.

“Glass continues to inspire us with its beauty, surprise us with its versatility, and transform our lives with its technical capabilities."
— Dr. Jeffrey Evenson, Senior Vice President and Chief Strategy Officer, Corning Incorporated

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Natural Glass

An understanding of the natural world is a source of not only great curiosity, but great fulfillment." — Sir David Attenborough

NATURAL GLASS INTRODUCTION

Glass is found in the natural environment in a variety of forms. This part of my book will contain essays about glass in a geological context, from fulgurites to diatoms. During my exploration of these topics, I found so many beautiful examples of the magic of glass formed from natural materials and natural (and unnatural) processes. In this section, I hope to leave you with a better understanding of glass formation processes, as well as the power of nature.

From Alamogordo to El’gygytgyn, this section will take you on a journey of discovery that has enticed generations. Welcome to part 1: Natural Glass.

DIATOMS: Jewels of the Micro World

It is common knowledge that biological organisms sometimes sequester inorganic minerals and compounds for various purposes. The most obvious example is ocean organisms sequestering $CaCO_3$, or calcium carbonate in order to make hard outer shells. However, this occurs with other materials, too. Sometimes called the jewels of the microorganism world, diatoms are tiny single celled organisms that form ornate outer shells made of silica through a process called silica morphogenesis[1]. This complex method of biological nanofabrication is increasingly understood by biochemists worldwide, but never fear; I will not be throwing too many complex organic chemistry terms your way (I am a geologist, not a biochemical engineer, after all).

Diatoms are not the only organisms that do biomineralization, however, they are the most beautiful in my opinion. In addition, I have spent two years researching diatom morphologies and how they change with environmental or climatological shifts. While diatoms are not truly “glass” organisms, they utilize the base of glass to form

[1] Sumper, Manfred, and Nils Kröger. "Silica formation in diatoms: the function of long-chain polyamines and silaffins." *Journal of Materials Chemistry* 14, no. 14 (2004): 2059-2065.

their frustules: the silica tetrahedron, so I decided to share these beautiful creatures regardless.

What are Diatoms?

Diatoms are, simply put, belonging to kingdom Protista, meaning that they are eukaryotic unicellular organisms. Diatoms are phytoplankton, meaning that they produce energy via photosynthesis. In the Cretaceous, around 100 million years ago, diatoms began to become widespread and developed great diversity. They are indeed one of the most diverse groups of eukaryotes. and estimates suggest that there are

Eon	Era	Period	Epoch	Age Ma
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01
			Pleistocene	1.64
		Neogene	Pliocene	5.2
			Miocene	23.3
		Palaeogene	Oligocene	35.4
			Eocene	56.5
			Palaeocene	65.0
	Mesozoic	Cretaceous		145.6
		Jurassic		208.0
		Triassic		245.0
	Palaeozoic	Permian		290.0
		Carboniferous		362.5
		Devonian		408.5
		Silurian		439.0
		Ordovician		510.0
		Cambrian		570.0
Proterozoic				2500
Archean				4000

Figure 2.1: Geologic Time Scale (*Harland et al* 1989)

well over 250 genera and about 100,000 marine and freshwater species[2].

Because they photosynthesize, diatoms produce oxygen. Fun fact: every fourth breath you take was produced entirely by diatoms. Diatoms produce 20-25% of the global oxygen content, making them super valuable and influential on our global and local ecosystems[3]. They also fix 20-25% of atmospheric carbon within these photosynthetic processes[4]. In addition, diatoms are one of the major food sources for secondary aquatic and marine consumers, usually zooplankton because they produce long chain fatty acids essential to the diets of many organisms[5].

Diatom Morphology: What Do Diatoms Look Like?

Diatoms essentially resemble hat boxes, where one part of the "shell", or **frustule**, as it is called, fits partially into the other half. The diatom's cell lives inside this boxlike form. Diatoms have two

[2] De Tommasi, Edoardo, Johan Gielis, and Alessandra Rogato. "Diatom frustule morphogenesis and function: a multidisciplinary survey." *Marine genomics* 35 (2017): 1-18.

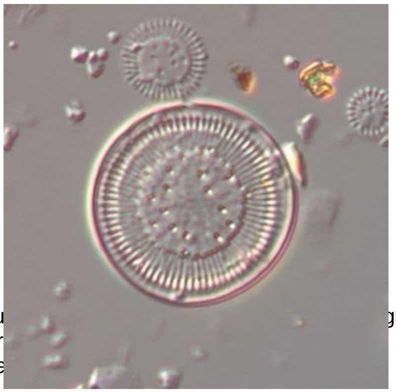
[3] Kale, Aditi, and Balasubramanian Karthick. "The diatoms." *Resonance* 20, no. 10 (2015): 919-930.

[4] Vyverman, Wim. "Experimental studies on sexual reproduction in diatoms." *Int. Rev. Cytol* 237 (2004): 91.

[5] Harvey, Ben P., Sylvain Agostini, Koetsu Kon, Shigeki Wada, and Jason M. Hall-Spencer. "Diatoms dominate and alter marine food-webs when CO2 rises." *Diversity* 11, no. 12 (2019): 242.

main divisions for morphology: centric and pennate[6]. Centric diatoms largely look like cylinders, while pennate diatoms take an elongate, oval like form. However, the distribution of sizes and shapes of diatoms is massive.

Centric diatoms are not always round. They are characterized by valve striae arranged basically in relation to a point, an annulus or a central areola and tend to appear radially symmetrical[7]. In addition to these basic qualifications, there are several subclasses of centric diatoms. These are the Coscinodiscineae, with a marginal ring of processes and no polarity to the symmetry. The Rhizosoleniineae have no marginal ring of processes and unipolar symmetry. The



Figu ght
micr
(*Lue*

[6] De Tommasi, Edoardo, Johan Gielis, and Alessandra Rogato (2017)

[7] "Diatoms." UCL. Accessed January 10, 2023. https://www.ucl.ac.uk/GeolSci/micropal/diatom.html.

Biddulphiineae have no marginal ring of processes and bipolar symmetry (see Figure 2.4 for a visual).[8]

The pennate diatoms are also diverse. Within the pennate category, there are two more morphological "types" or categories in which the diatoms are sorted. These are Fragilariineae and Bacillarineae. Fragilariineae pennate diatoms have no center line, called a "raphe". These are also called araphid diatoms. On the other hand, Bacillarineae have the raphe, and are subdivided into eunotioid, symmetric biraphid, monoraphid, asymmetric biraphid, epithemioid, nitzschioid, and surirelloid (see image below, Figure 2.3). Notice the raphe in the center of the diatom. (Side note: isn't she beautiful? She gleams like the North Star.)

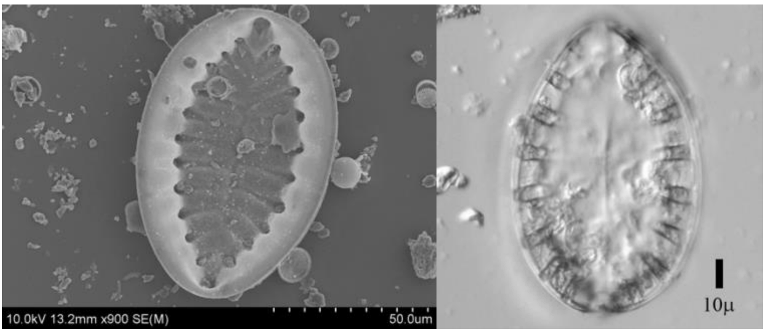


Figure 2.3: *Suriella* diatoms in SEM (left), and light microscopy (right) (*Me,* 2022)

[8] "Diatoms"

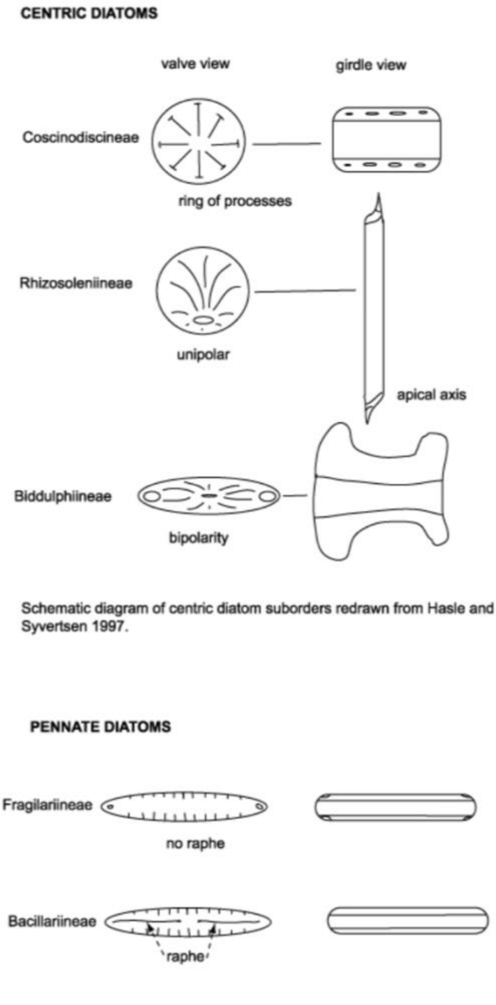


Figure 2.4: Diagram description of diatom subclasses (UCL, n.d.)

On another topic of morphology, diatom morphologies can change rather easily (well… at least compared to other species). They are impacted greatly by even small environmental events, meaning that they are awesome markers for climate events, if we are looking at paleoenvironments, and they even have their applications in modern climatology[9].

What determines how diatoms look? Genetics of course! Don't forget, diatoms are living glass organisms, so they reproduce. How do diatoms reproduce? Because they are eukaryotes, diatoms are largely asexual reproducers with limited capacity to sustain species without sexual reproduction over a long period of time[10]. Prolonged asexual reproduction in diatoms often results in smaller cell and frustule sizes. Sometimes, the diatoms get so small that they cannot function or reproduce. Eventually, the diatom must produce an auxospore and have it fertilized to have the species survive.

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9 Feitl, Melina G. "Investigation of diatom endemism and species response to climate events using examples from the genera Cyclotella (Lindavia) and Surirella in the Lake El'gygytgyn sediment record." MS Thesis., Bowling Green State University, 2016.

10 Vyverman, Wim. "Experimental studies on sexual reproduction in diatoms." *Int. Rev. Cytol* 237 (2004): 91.

Victorian Diatom Art

While diatoms are studied for their scientific value in modern times, they used to be of great interest to artists. Back in the days when art and science were more closely aligned, Victorian artists carefully arranged the phytoplankton in patterns on a microscope slide. One such artist was JD Moeller, a German artist and microscopist. His art has been carefully preserved so that we, using the power of the World Wide Web, may see it today (Figure 2.5).

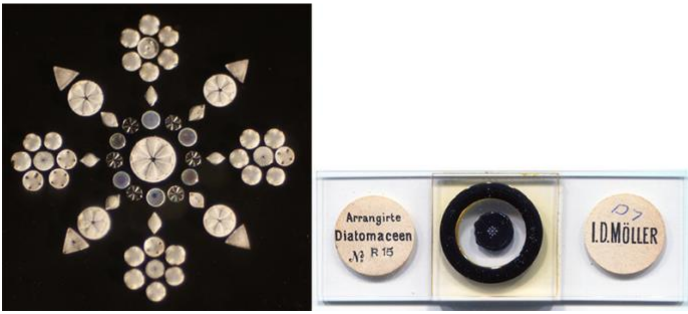

Figure 2.5: Johann Diedrich Moeller's Diatom Art (Johann Diedrich Möller, 1844-1907*)*

This art is now lost, but was not until recently. Klaus Kemp (1937-2022) is the last known practitioner of this antique and unique art form. Born in 1937 Berlin, Kemp evacuated Berlin at the onset of the war to Poland, but was captured during the Russian offense and relocated to and imprisoned in a concentration camp in East Berlin.

With the bribery of a guard with cigarettes from his mother, despite being heavily malnourished, he managed to escape the Russian controlled territory using a paid guide. This was a highly risky mission, as escapees were often shot on sight, as the Berlin Wall had not been constructed yet. After arriving in West Germany, the British Red Cross arranged transport to Manchester, UK, where Kemp attended school. He took a keen interest in science, and soon discovered the beauty of diatom art, his life's passion. He rose to fame and even inspired a film, *The Diatomist.* He is survived by his daughter, Deborah, and her family[11].

[11] Jüttner, Ingrid. "In Memory of Our Friend and Colleague Klaus Kemp." International Society for Diatom Research, November 7, 2022. https://isdr.org/in-memory-of-our-friend-and-colleague-klaus-kemp/.

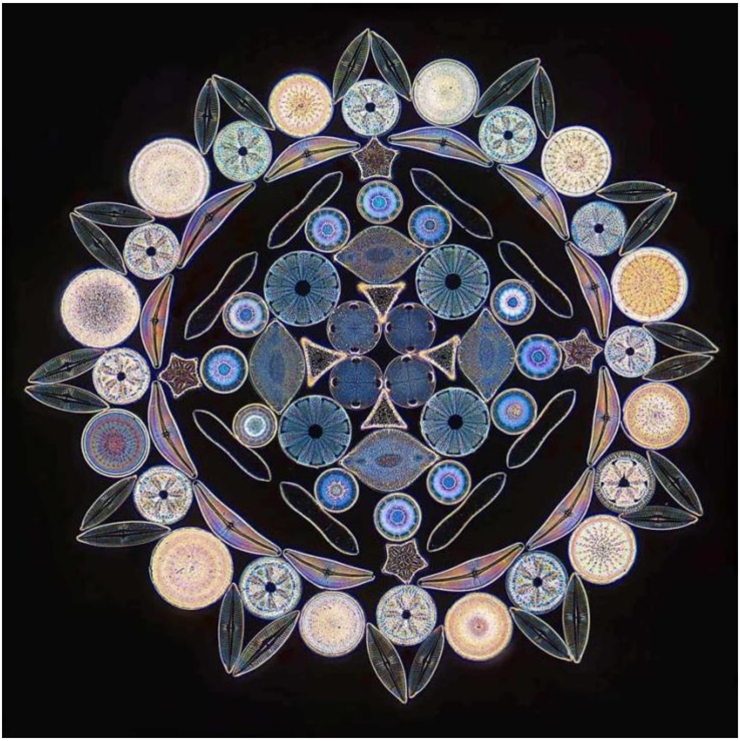

Figure 2.6: Diatom Arrangement (Klaus Kemp, 2014)

Diatom Inspired Art

In addition to Kemp’s work, diatoms have inspired works from other artists, who did not use the diatoms themselves as a medium.

Jiyong Lee

Lee’s work is particularly poetic, because he is a glass artist making diatoms out of glass. In the words of the artist himself:

“The segmentation series is inspired by my fascination with science of cell, its division and the journey of growth that starts from a single cell and goes through a million divisions to become a life. I work with glass that has a variety of transparency, translucency, and opacity, the qualities that serve as perfect metaphors for what is known and unknown about life science. The segmented, geometrical forms of my work represent cells, embryos, biological and molecular structures—each symbolizing the building blocks of life as well as the starting point of life. The uniquely refined translucent glass surfaces suggest the mysterious qualities of cells and, on a larger scale, the cloudiness of their futures. The Segmentation series is subtle and quiet yet structurally complex. In each work the clear solid glass is transformed through cutting, lamination, carving, and surface refining processes to make art that is both beautiful and deeply invested with meaning."[12]

These pieces are made by grinding the solid glass pieces to fit perfectly together, which is an impressive feat and requires intense attention to detail.

Figure 2.7: Jiyong Lee, Green yellow diatom segmentation, 8.5 x 12 inch, 2020

[12] Lee, Jiyong. "Segmentation Series." jiyongleeglass.com, 2022. http://www.jiyongleeglass.com/segmentation-series.html.

Figure 2.8: Jiyong Lee, Diatom Segmentation, 5.75 x 12.25 inch, 2018

Me

For my final project in Glass 1, I made a diatom micromosaic necklace.

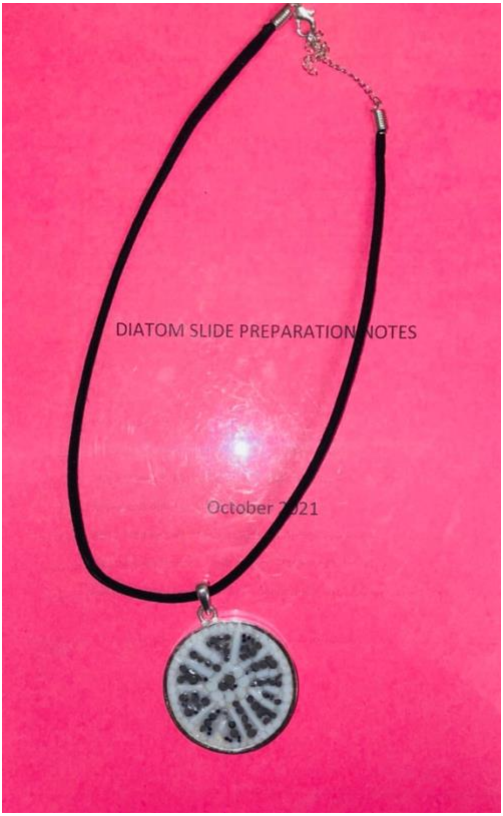

Figure 2.9: Madisyn Rex, Diatom Micromosaic, 2021

My Diatom Research

Now that you know a bit about diatoms, here is an abstract from my own research on diatoms, centered around climactic events from Lake El'Gygytgyn, in Russia. I presented this research at the Ohio Academy of Science Annual Meeting in April 2022. This research is called "COMPARISON BETWEEN BENTHIC AND PLANKTONIC DIATOM RESPONSE TO A 225 KA COLD EVENT FROM LAKE EL'GYGYTGYN, NORTHEAST RUSSIA"

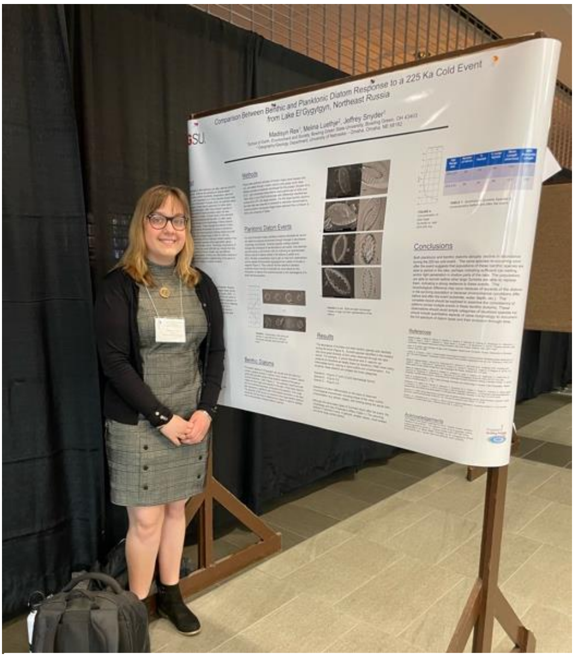

Figure 2.10.1: Me presenting my research at the Ohio Academy of Science Annual Meeting, April 2022

Abstract

Diatom assemblages are often used as a proxy for ancient climactic records due to their sensitivity to changing climates. Lake El'gygytgyn is a 13-km diameter impact-crater lake located in northeastern Siberia which has a virtually unbroken sediment record that reflects the regional climate and environmental history. There is no evidence of desiccation or basin glaciation since the lake formed soon after the 3.6 Ma impact. As such, the diatom record is also unbroken from ~3.5 Ma. Ancient lakes like El'gygytgyn often have endemic species of diatom, and the unbroken sediment record provides insight into the evolution and sensitivity to climates of these different species. A recent publication demonstrated the correlation between planktonic diatoms and climate using a systematic analysis[13] of the sediment record for the planktonic genus *Cyclotella (Lindavia),* and the benthic genus *Surirella.* Observations were conducted using a light microscope and a scanning electron microscope. The study concluded that climate had little impact on benthic diatoms. However, expanding on a specific time interval from 242 Ka to 209 Ka, preliminary data suggest that benthic diatoms (genus *Surirella*) also respond to climactic events. Over a small interval of time, where there was in this region a climactic

[13] Feitl 2016

event, the genus *Surirella* disappeared from sediment records, and reappeared in decreased numbers and with a smaller average diameter, indicating a previously unknown sensitivity to lake conditions.

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De Tommasi, Edoardo, Johan Gielis, and Alessandra Rogato. "Diatom frustule morphogenesis and function: a multidisciplinary survey." *Marine genomics* 35 (2017): 1-18.

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TRINITITE: MANMADE MINERAL FROM THE NUCLEAR AGE

Morality as it is known today was revised, and in some cases, utterly abandoned in the face of the horrors of the Second World War. The exact number of people killed in the war remains unknown, but is estimated to be around 75 million. Perhaps no incident in the war is more hotly debated than the decision to use the atomic bombs on civilian cities Hiroshima and Nagasaki. However, before the use of these bombs on civilian population, a bomb was detonated in the lonely desert 230 miles south of Los Alamos at 5:30am July 16th, 1945[14]. This action ushered in the nuclear age, and changed the face of politics and science forever.

The Gadget, as it was called, was fairly unassuming. It looked like a large steel globe, crisscrossed with wires like some sinister spider web. It did not look like the culmination of years of scientific research and engineering in a secret government operation known as the Manhattan

[14] "Trinity: World's First Nuclear Test." Air Force Nuclear Weapons Center. Accessed January 11, 2023. https://www.afnwc.af.mil/About-Us/History/Trinity-Nuclear-Test/.

Project. However, this was the greatest military advancement since the airplane. The Gadget contained Plutonium, like Fat Man, which was detonated over Nagasaki later that year.

Plutonium and Nuclear Fission

Uranium is the often the radioactive element brandished by works of fiction such as comic books or movies that is used in nuclear bombs. However, before uranium was used in nuclear weapons, they were made of plutonium[15].

Plutonium is a complex element. Discovered in 1940 by Dr. Glenn T. Seaborg, Joseph W. Kennedy, Edwin M. McMillan, and Arthur C. Wahl, element 94 was immediately recognized to be an unusual substance. It was discovered when these scientists were trying to find ways to perform controlled nuclear fission on uranium. Instead, they created plutonium, a discovery that was immediately suppressed by the US government upon realizing Plutonium's potential for use in the then theoretical nuclear bomb. Plutonium-239 is

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[15] "Plutonium." Atomic Heritage Foundation Nuclear Museum. Accessed January 11, 2023. https://ahf.nuclearmuseum.org/ahf/history/plutonium/.

fissile, meaning when it is bombarded with neutrons, the atoms can decay and release energy.

For those of us with an elementary (ha!) understanding of nuclear chemistry, this means that a neutron from an “unstable” source is slammed into an atom of a fissile isotope. The atom then undergoes deformation. Imagine throwing a bowling ball at a watermelon. Under normal circumstances, the watermelon remains whole. However, when you launch a bowling ball at it, it deforms. Sometimes, the watermelon deforms into two halves with a scattering of juices and guts. Similarly, the atom splits into two “daughter” atoms, and releases 2 to 3 neutrons. These daughter atoms are most commonly uranium or neptunium[16]. These neutrons continue splitting atoms until there is no more fissile material left. The breaking of the atom releases energy. A lot of it. This is because of the aptly named “strong nuclear force”. This force holds the protons and neutrons together in the nucleus of the atom. Have you ever stretched a rubber band so long it snapped? That is kind of what happens here. The deformation of the atom “stretches” the limits of

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[16] “Backgrounder on Plutonium.” NRC Web, 2021. https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/plutonium.html.

the strong nuclear force. Eventually, the rubber band snaps and recoils; the atom splits and a blast of energy is released. Plutonium bombs in 1945 were detonated using traditional explosives, which triggered the subsequent chain reaction resulting in the classic mushroom cloud we associate with nuclear weapons today.

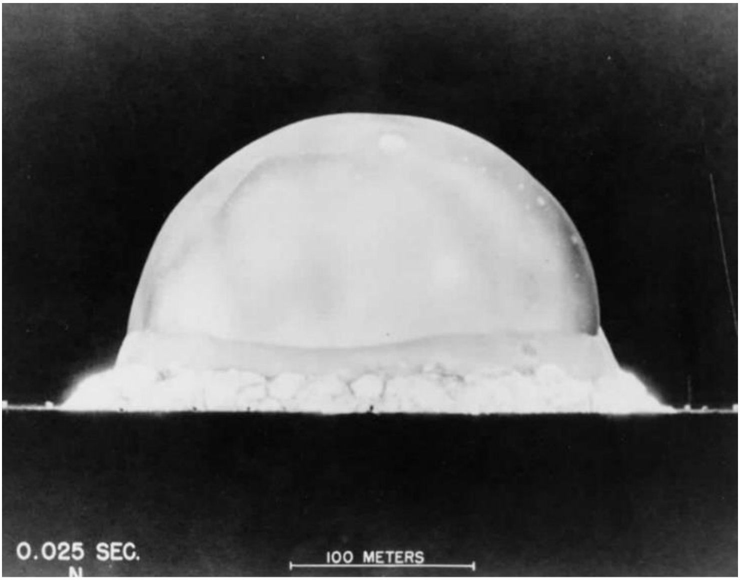

Figure 3.0: .025 Seconds into the Trinity test (US Department of Energy, 1945)

The Detonation

The day the sun rose twice over Alamogordo was perhaps the day that the local critters wondered what sins they could have possibly committed to incur the wrath of 15 – 20 kilotons of force. The blast lit up the sky for miles around, leaving behind a massive crater… and our subject of interest for this chapter: Trinitite.

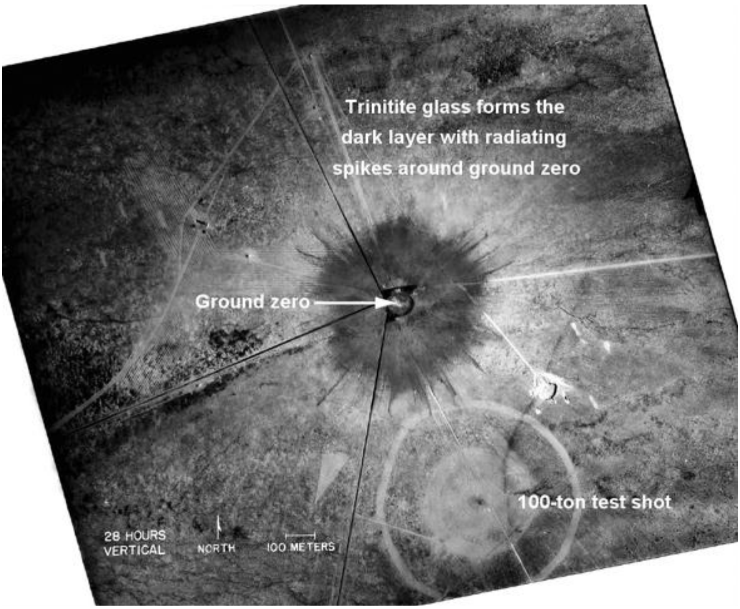

Figure 3.1: Trinity Test Site Aerial Image, 28 hours post-detonation (Eby et al, 2010)

Trinitite

Born of scorching temperatures exceeding 1470 degrees Celsius (2678 degrees Fahrenheit), a a new material lay under where the bomb had detonated. Unlike it's violent conception, the substance was beautiful, and immediately popular among collectors (once the site was declassified). The Trinitite often contains bits of the metal tower from which the bomb was detonated, as well as the bomb casing and fissile elements. Pale olive green (and sometimes red), and vesicular (that means it has a bunch of small holes), the glass was formed when the sands of the desert, primarily composed of quartz and feldspar were superheated until liquid state, then rapidly quenched to cool and solidify the substance[17].We will get into more detail about this sand in a minute. There are a few different forms of the Trinitite, each formed in different ways[18].

1. Pancake Trinitite
2. Red Trinitite
3. Scoriaceous Trinitite fragments
4. Dumbbell and bead shaped Trinitite

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[17] Giuli, Gabriele, Giovanni Pratesi, Sigrid Griet Eeckhout, Christian Koeberl, and Eleonora Paris. "Iron reduction in silicate glass produced during the 1945 nuclear test at the Trinity site (Alamogordo, New Mexico, USA)." *Geological Society of America Special Papers* 465 (2010): 653-660.

[18] Eby, Nelson, Robert Hermes, Norman Charnley, and John A. Smoliga. "Trinitite—the atomic rock." *Geology Today* 26, no. 5 (2010): 180-185.

The Sand: Building Blocks of Trinitite

The sand at the Alamogordo Bombing Site is what is known as arkosic sand. This means that the grains are rich in feldspar, a silicate mineral that forms in igneous rocks. The specific minerals found in this sand are **quartz**, **microcline** (a potassium rich alkali feldspar formed in felsic igneous rocks including granite), **albite** (a plagioclase feldspar formed mostly in felsic type igneous rocks… it gets more complicated but I won't try to explain igneous petrology to you), **muscovite** (a type of mica), **actinolite,** and **calcite**[19]. We can somewhat safely conclude that the sand that made up the Alamogordo Site originated from a felsic igneous source. This means that the progenitor rock formed as an intrusive rock, meaning it formed underground and cooled slowly. This is not necessary relevant to the level of understanding of Trinitite I am trying to impart on you, dear reader, but I thought it was interesting.

Unsurprisingly, the sand is very rich in silicate minerals. This means that the minerals contain the element silicon. The only non silicate primary mineral found in the sand is calcite. You can see the sand grains both microscopically and

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[19] Eby, Nelson, Robert Hermes, Norman Charnley, and John A. Smoliga. (2010)

microscopically in cross polarized light under a microscope in Figure 3.2.

When we look at minerals under a petrographic microscope, we tend to use two main types of light: plane polarized (not really important right now) and cross polarized light. When the cross polarized light goes through a mineral, it interferes with the atoms in the mineral, and changes the appearance of color of the mineral under the microscope. This phenomenon is known as **birefringence**, and is very useful for figuring out the spaces in between atoms in a crystalline substance. However, birefringence only occurs when a material's atoms are arranged in a crystal lattice structure. This will be important, because when we look at Trinitite under cross polarized light, we can see that it does not show up on the image/slide. This is because glass, once again, does not have a crystal lattice. It is amorphous. The cross polarized light simply passes through the substance with no interference with the atoms. We would not be able to use glass as a microscope slide material if it did have interference.

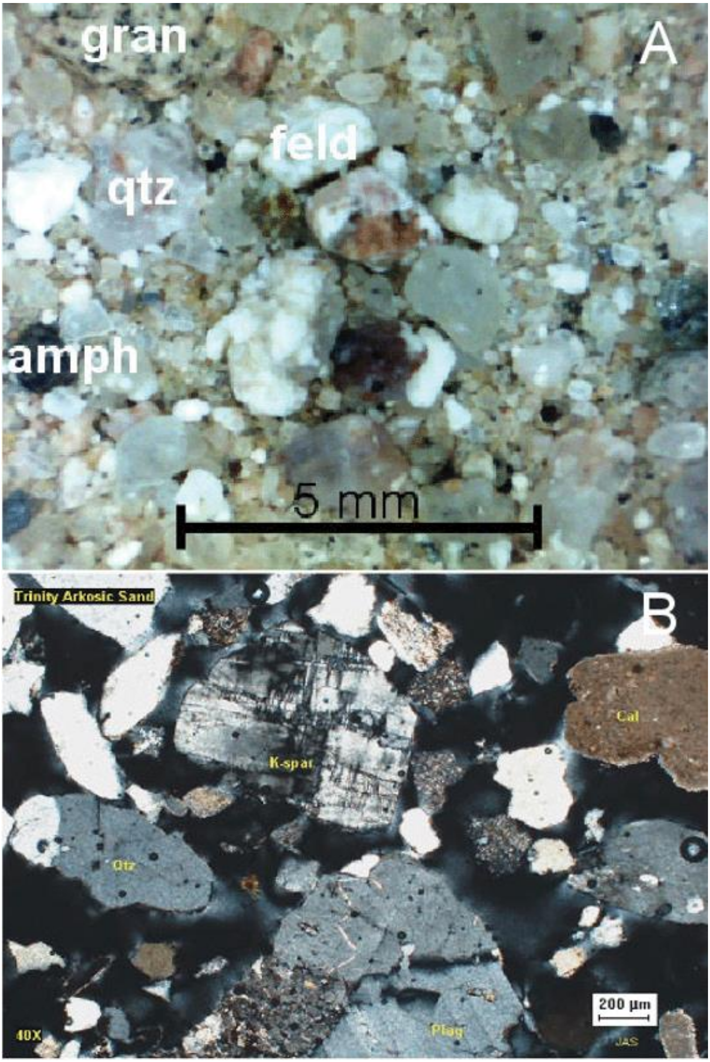

Figure 3.2: Macroscopic view (top) and microscopic view (bottom) of the arkosic sand that was melted by the blast. Top view: gran # granite fragment, qtz # quartz, feld # feldspar, and amph # amphibole. Bottom view: Qtz # quartz, K-feld # K-feldspar, Plag # plagioclase, and Cal # calcite. (Eby et al, 2010)

Pancake Trinitite

Pancake Trinitite is the layer of Trinitite formed on the surface of the blast site, 1-5 cm thick, and bottle green in color. It is glassy and smooth on the top, vesicular in the middle, with globules and spheres of Trinitite fused to the underside alone with unmelted sand particles[20].

Red Trinitite

Red Trinitite gets its color from the presence of copper in the glass. It is only found to the north of the detonation site, or ground zero. Fused into the glass are metal chondrules composed of iron (Fe), lead (Pb), and copper (Cu). The formation of these metal beads are unique. The Pb is only found mixed into the Cu beads, while Fe mostly exists alone. This is most likely due to the immiscibility of liquid Fe and Cu[21] [22].

Scoriaceous Trinitite Fragments

This type of Trinitite was named for its characteristic Trinitite color, but is unique because it

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[20] Eby, G. Nelson, Norman Charnley, Duncan Pirrie, Robert Hermes, John Smoliga, and Gavyn Rollinson. "Trinitite redux: Mineralogy and petrology." *American Mineralogist* 100, no. 2-3 (2015): 427-441.
[21] Eby, Nelson, Robert Hermes, Norman Charnley, and John A. Smoliga. "Trinitite—the atomic rock." *Geology Today* 26, no. 5 (2010): 180-185.
[22] Liu, Shichao, Jinchuan Jie, Bowen Dong, Zhongkai Guo, Tongmin Wang, and Tingju Li. "Novel insight into evolution mechanism of second liquid-liquid phase separation in metastable immiscible Cu-Fe alloy." *Materials & Design* 156 (2018): 71-81.

closely resemble scoria, which is a type of volcanic rock filled with holes called vesicles. This type is found immediately within the vicinity of “ground zero”[23].

Dumbbell and Ball Shaped Beads

These are thought to have formed when the original sand was entrained (picked up or captured) by the atomic dust cloud, melted, and rained back down on the ground as molten droplets. Fun Fact: these are often found around the openings of ant hills as ants move them out of the way in order to construct their nests[24].

[23] Eby, Nelson, Robert Hermes, Norman Charnley, and John A. Smoliga. "Trinitite—the atomic rock." *Geology Today* 26, no. 5 (2010): 180-185.

[24] Eby, Nelson, Robert Hermes, Norman Charnley, and John A. Smoliga. "Trinitite—the atomic rock." *Geology Today* 26, no. 5 (2010): 180-185.

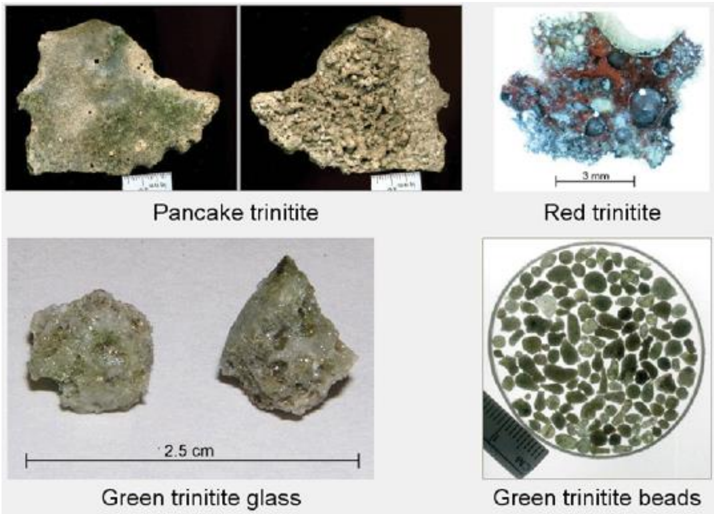

Figure 3.3: Types of Trinitite (Eby et al, 2010)

Chemically Speaking

Each of these types of glasses has different chemical compositions, even though they were created from the same explosion and sand. For example, the Trinitite fragments, including the red Trinitite and pancake Trinitite have lower levels of SiO2 than the beads and dumbbells, and the red Trinitite gets its color from the copper trapped within the glass.

Another way they differ, is that while the chemical compositions of the beads and dumbbells are relatively homogenous, with the exception of some granules of sand, the scoriaceous and pancake Trinitites are not homogenous, displaying portions of the total glass structure that are calcium or iron rich (lighter colored), and iron and calcium depleted (dark colored) glass.

Another interesting subject within the scoriaceous glass is the the occurrence of partially melted and recrystallized quartz. A bit of geology knowledge must be known here to explain why this is so interesting. Quartz exists in several different phases, or structures, based on temperature and pressure. For example, quartz under high temperature but low pressure will likely melt, while quartz under low temperature and high pressure will change structures into a higher density, but still solid and crystalline, form of quartz[25]. Most quartz that is found on Earth's surface is alpha-quartz, which is the low temperature and low pressure form of quartz. Why is this important? Well, the form of quartz that was found in the Trinitite… was alpha quartz. Why is this interesting? Well, it is interesting because even the temperatures and pressures of a nuclear bomb were not enough to force a new polymorph (same chemical compound/components, but a different molecular structure) in the quartz, other than partial melting. This gives us a bit of insight into the type of energy needed to force a phase change within quartz in the Earth. This tidbit of information is not really vital to the understanding and story of glass, but I thought it was an interesting little geology insight from the Trinity Test.

Radioactivity

The glasses are still slightly radioactive even today. This radioactivity comes from the residual plutonium and uranium from the bomb, radioactive Sr-90 and Cs-137 produced as fission products, and slightly unstable products produced by the free neutrons left over from the explosion (this occurs

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[25] Swamy, V., Surendra K. Saxena, Bo Sundman, and J. Zhang. "A thermodynamic assessment of silica phase diagram." *Journal of Geophysical Research: Solid Earth* 99, no. B6 (1994): 11787-11794.

when free neutrons interact with non-radioactive atoms to produce radioactive isotopes. For example, if a neutron interacts with Fe-58 to make it become Fe-59, It makes the atom unstable and it will decay, mostly by beta decay and gamma ray emission). Over 40 elements can be activated by this process[26]. As such, radioactivity can somewhat "spread" as surface contamination from an environmental geology perspective[27].

Legality of Owning Trinitite

While it is legal to own Trinitite, it is extremely illegal to mine/dig/search for Trinitite due to its mild radioactivity. In addition, this glass is rare to find as a collector, due to the fact that the vast majority of the Trinitite was buried in 1952[28].

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[26] Eby et al, 2010

[27] Grigaliūnienė, Dalia, Robertas Poškas, Raimondas Kilda, Hussam Jouhara, and Povilas Poškas. "Modeling radionuclide migration from activated metallic waste disposal in a generic geological repository in Lithuania." *Nuclear Engineering and Design* 370 (2020): 110885.

[28] Rhodes, Richard. "A Chunk of Trinitite Reminds Us of the Sheer, Devastating Power of the Atomic Bomb." Smithsonian.com. Smithsonian Institution, September 1, 2019. https://www.smithsonianmag.com/smithsonian-institution/chunk-trinitite-reminds-sheer-devastating-power-atomic-bomb-180972848/.

Art From Nuclear Waste

I am almost shocked at the amount of artists in the years after the declassification of the Trinity test that did not take advantage of or use the radioactive glass in their art. It seems to me that bomb-generated glass would be an obvious choice for anti-war artists and activists alike. Still, there were a couple that took an interest in the material.

Tom Jennings (1955-Present)

Tom Jennings is a contemporary American artist and creator of FidoNet, as well as an artist and author. He is the creator of Model 23 Trinitite Box.

According to his website:

"This is was first WPS product. The heart of the device is a small diorama, water colors on lead, with a reactor-shielding lead glass window, revealing a view, north and east, from the stolen McDonald Ranch, towards the Oscura Mountains, not quite north enough to encompass the Trinity Site; the soil and rock in the foreground is a recently-native form of man-made rock called trinitite. It is mildly radioactive (only four times average background radiation at sea level; quite safe within or without its little box). In the sky is the window of a Geiger-Mueller tube; with each disintegration of Cesium-137 within the trinitite a beta particle is emitted; those that reach the G-M tube cause a small spark within the tube, made audible with electronics inside the Model 23. Each same spark, processed by other electronics within, triggers one view of each of the frames on the film strip, projected badly on a tiny viewing screen visible in the viewing hood, after the red start switch is pressed. Some of the front-panel controls affect operation of the device.

The housing is a found box, once hosting a dew-point measuring instrument, which coincidentally required a tiny amount of Radium for its operation. The front panel is a quarter-inch slab of brass, reverse-etched in an eight-hour process to leave raised lettering, the varied colors due to copper and zinc dissolving in the etchant at different rates. The images are on a continuous loop film strip, a fractional-horsepower motor and a dog clutch advance the film strip one image or so at a time, triggered by trinitite disintegration. An 18-inch long optical path is folded within the machine. The knobs are half-century old bakelite, the controls themselves of the utmost quality, chosen for tactile feel. The G-M tube and it's high-voltage supply were scavenged from a Canadian military radiation survey meter; the rest of the electronics are of modern design."[29]

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[29] Jennings, Tom. "Model 23." sr-ix.com, 1997. https://www.sr-ix.com/Objects/Model-23/index.html.

Figure 3.4: Mixed media (wood, brass, lead, watercolor, electronic components), 16"h x 12"w x 9.25"d
main unit (viewing hood removed),
approx. 30 lbs. (Tom Jennings, 1997)

I adore this piece. Not only the artistic creativity, but the engineering and scientific prowess displayed by the functionality of the piece is amazing and inspiring. Reviewing Jenning's work is interesting, both from an artistic and technological perspective, and it is recommended to the reader that they look up Mr. Jennings too see more of his creations.

Trevor Paglen (1974-Present)

Also a highly accomplished contemporary artist, author, and geographer, Trevor Paglen takes an interest in topics such as mass surveillance, data collection, and technology. He is a photographer and a notable scientist, having won the MacArthur Fellowship in 2017. He created a sculpture in 2015 from two different types of glass; Trinitite from the Trinity Test Site, and the other, broken glass from windows surrounding the Fukushima Exclusion Zone. In the author's own words:

"Irradiated broken glass collected from inside the Fukushima Exclusion Zone forms the outer layer of this sculpture. The work's inner core is made out of Trinitite, the mineral created on July 16, 1945 when the United States exploded the world's first atomic bomb near Alamogordo, New

Mexico, heating the desert's surface to the point where it turned surface sand into a greenish glass.

Trinity Cube was created by melting these two forms of glass together into a cube, then installing the cube back into the Fukushima Exclusion Zone as part of the *Don't Follow the Wind* project. The artwork will be viewable by the public when the Exclusion Zone opens again, anytime between 3 and 30,000 years from the present"[30].

This piece speaks to me because it emphasizes the potential for harm to people and the environment from radiation exposure, both accidental and intentional. It actually mixes the two incidents, suggesting that any nuclear actions are harmful. While I do not necessarily agree, I find this piece compelling. It is also hopeful, assuming that people will still be around in 3,000-30,000 years.

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[30] Paglen, Trevor. "Trinity Cube." Trevor Paglen, July 14, 2020. https://paglen.studio/2020/01/21/trinity-cube/.

Figure 3.5: *Trinity Cube*, 2015
Irritated glass from Fukushima Exclusion Zone, Trinitite
7 ⅞ × 7 ⅞ × 7 ⅞ in.
Installation view, Fukushima, Japan, 2015 – ongoing. (Trevor Paglen, 2015)

Conclusion

Trinitite was created during a time of political and international turmoil, when the world lit up with bombs almost every night and day. The day the sun rose twice in New Mexico, the world was forced into a new age, full of danger beyond human comprehension. To this day, headlines about hostile countries' nuclear capabilities make the rounds almost weekly. Let us not forget the blue green glass that was the first indicator of the changed world that sunny morning in Alamogordo.

Figure 3.6: Trinity Test Site (Google Maps, n.d.)

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Grigaliūnienė, Dalia, Robertas Poškas, Raimondas Kilda, Hussam Jouhara, and Povilas Poškas. "Modeling radionuclide migration from activated metallic waste disposal in a generic geological repository in Lithuania." *Nuclear Engineering and Design* 370 (2020): 110885.

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Swamy, V., Surendra K. Saxena, Bo Sundman, and J. Zhang. "A thermodynamic assessment of silica phase diagram." *Journal of Geophysical Research: Solid Earth* 99, no. B6 (1994): 11787-11794.

"Trinity Site - World's First Nuclear Explosion." Energy.gov, 2022. https://www.energy.gov/lm/doe-history/manhattan-project-background-information-and-preservation-work/manhattan-project-1.

"Trinity Test Site." Google maps. Google. Accessed January 19, 2023.

"Trinity: World's First Nuclear Test." Air Force Nuclear Weapons Center. Accessed January 11, 2023. https://www.afnwc.af.mil/About-Us/History/Trinity-Nuclear-Test/.

Of Impacts and Infernos

Volcanic glasses and impact glasses are two examples of naturally occurring glass. There are a few types of volcanic glasses and impact glasses, which we will cover in this section. As a geology major, I feel that it is important to cover instances of naturally occurring glasses, because it demonstrates that the properties of this state of matter are not simply a human creation.

All glass is born from heat. Natural glass is born from violence. After all, what else can you call volcanic eruptions, lightning strikes, grinding and moving tectonic plates, and impacts from space? Since we already went over how glass forms, we can skip most of the boring stuff and get right to the exciting things: fire and brimstone. Well, maybe not brimstone, but you know what I am getting at.

Volcanic Glasses

"*The power of a volcano when it erupts is so evident, so visible, so palpable*." — Werner Herzog

Volcanic glass is rapidly cooled, uncrystallized magma. These rocks are primarily composed of quartz and alkali feldspar, similar in composition to a granite, meaning it has a high silica content and low magnesium and iron contents. Basaltic (deep mantle) magmas can, on occasion, form glass, but since they tend to crystallize very quickly, they do not tend to form glasses more than a few centimeters thick[31]. We will go over the main types of volcanic glass, both rhyolitic and basaltic, in short descriptions of the most interesting facts for these materials. No one wants to read a dissertation about the industrial applications of Pumice, so I will spare you (and me) from that. Now, on to the good stuff!

Obsidian

When you think of volcanic glasses, you probably picture obsidian. Obsidian is a felsic (high silica) glass that forms when lava extrudes from a volcano, then cools rapidly. It is usually black, shiny, and has conchoidal fracture.

Obsidian forms much the same way that manmade glass forms. It starts off as melted material, in this case, a felsic lava that is high in sodium, silica, potassium, oxygen, and aluminum. Then, it encounters a cooling agent, such as air or water, that cools the material before the atoms can orient themselves in a crystal lattice. However, this is not the most interesting part of obsidian.

Obsidian played a major role in ancient times and even prehistory. Around two million years ago, obsidian began to be used as a tool for hunting, cutting, etc, due to its sharpness. It was also used as a mirror like substance. Analysis of the edges of the tools can provide some insight into how they

[31] Friedman, Irving, and William Long. "Volcanic glasses, their origins and alteration processes." *Journal of Non-Crystalline Solids* 67, no. 1-3 (1984): 127-133.

have been used[32]. Evidence of these tools has been found almost everywhere around the world.

In particular, the material was highly valued in prehistoric Greece. It was used starting in the Upper Paleolithic until its decline in the Bronze Age, as metal usage took over. However, obsidian does not naturally occur in Greece, meaning that it was obtained via trade with other cultures who had access to the material[33]. Artistic usages of obsidian were extensive in both the Greek and Roman periods. From mirrors to mosaics, the Romans utilized the dense blackness of the obsidian as a decorative semi precious stone[34]. According to Pliny the Elder, a Roman historian, black tesserae (the stones used in a mosaic) were created from obsidian and black glass, and this method was used at least through medieval times to make mosaic[35].

Outside of a Eurocentric view of obsidian, evidence of Neolithic trade among Indigenous Americans has emerged from caches of obsidian found in Lake Huron, dated to around 9,000 years ago. A bit on the geology of the Great Lakes region: there are no sources of obsidian anywhere near

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[32] Tykot, Robert H. "Obsidian in prehistory." *Encyclopedia of Glass Science, Technology, History, and Culture* 2 (2021): 1237-1248.
[33] Tsampiri, Mailinta. "Obsidian in the prehistoric Aegean: Trade and uses." *Bulletin of the Geological Society of Greece* 53, no. 1 (2018): 28-49.
[34] Cagno, Simone, Peter Cosyns, Andrea Ceglia, Karin Nys, and Koen Janssens. "The use of vitrum obsianum in the Roman Empire: some new insights and future prospects." *Periodico di Mineralogia* 84 (2015): 465-482.
[35] Cantone, Valentina, Rita Deiana, Alberta Silvestri, and Ivana Angelini. "Obsidian and Obsidian-like Glass Tesserae: A Multidisciplinary Approach to Study the Dedication Wall Mosaic in the Church of St. Mary of the Admiral in Palermo (12th Century)." *Open Archaeology* 6, no. 1 (2020): 403-416.

here. In fact, this obsidian was matched in provenance to obsidian from Oregon… 4,000 miles from the discovery point. It is unlikely that the tribes that lived there trekked all the way to Oregon, so that leaves us to conclude that there was inter community trade from the west coast to the east coast, even as early as 9,000 years ago[36]. In fact, obsidian is everywhere in archeological locations around North America.

Today, obsidian is used as a semi precious gemstone, and is used to make scalpels that are ultra-sharp[37].

Figure 4.1: Obsidian Spearhead from the Hopewell Culture (NPS, 2022)

Pumice

You might be aware of pumice's existence because it is a popular method of removing dead skin, and it is used in grinding and polishing metal

[36] O'Shea, John M., Ashley K. Lemke, Brendan S. Nash, Elisabeth P. Sonnenburg, Jeffery R. Ferguson, Alex J. Nyers, and Danielle J. Riebe. "Central Oregon obsidian from a submerged early Holocene archaeological site beneath Lake Huron." *PloS one* 16, no. 5 (2021): e0250840.

[37] Disa, Joseph J., Jafar Vossoughi, and Nelson H. Goldberg. "A comparison of obsidian and surgical steel scalpel wound healing in rats." *Plastic and reconstructive surgery* 92, no. 5 (1993): 884-887.

and glass, due to its abrasive properties. Pumice also floats on water! This is due to the large amount of vesicles (holes).

Pumice is produced by explosive volcanic eruptions. Gasses, molten material, and dust are poured into the atmosphere during these volcanic events. This material is known as pyroclastic material, from the Latin *pyro,* or fire, and clast, meaning piece or part. As this material is quenched, the gasses in the material expand as a result of pressure change and form these vesicles[38]. The pumice rains down on earth, and can float on water, due to the lower density of the rock (since it has so much air). Eventually, the pumice takes on water and sinks to the ocean floor.

Figure 4.2: Pumice (Encyclopedia Brittanica, 2022)

[38] Thomas, Nathalie, Claude Jaupart, and Sylvie Vergniolle. "On the vesicularity of pumice." *Journal of Geophysical Research: Solid Earth* 99, no. B8 (1994): 15633-15644.

Apache Tears

Apache tears are obsidian nodules found primarily in the Mogollon Mountains in New Mexico, but can be found all over the southwest United States and Mexico. Small, tear-drop shaped, translucent, black, and shiny, they are plentiful, so much that even amateur rock hounds can find them[39]. Much like Prince Rupert's drops, which we will discuss in the Materials Sciences section of this book, Apache Tears can disintegrate when the tail is broken, due to the intense compressional and tensile forces within the drop. This will be explained in detail in a later chapter.

Apache tears form when molten lava is rapidly quenched as a volcano erupts. They are usually found in ash deposits, and are mostly rhyolitic (silica rich) in composition, just like obsidian. Apache tears are similar in formation to Pele's Tears, which will be discussed later in this chapter.

There are myths and legends surrounding these peculiar stones. According to legend, in the 1870s, 75 Apache men were chased by the United States Cavalry up a mountain in the Mogollon Mountains. 50 of those men were killed by the military, and the rest chose to leap to their deaths rather than die at the hands of the cavalry unit. The tears formed as a result of the Apache wives, mothers, daughters, and sisters who mourned the

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[39] Alfredo, Don. "Apache Tears and other Mineral Oddities from the Mogollon Mountains, New Mexico." *Rocks & Minerals* 26, no. 3-4 (1951): 138-143.

loss of the men[40]. Note: the name “Apache” refers to a group of culturally related, but distinctly different, Indigenous American tribes in the southwestern United States.

There are some people who believe that natural materials contain specific properties that can aid in emotional, physical, and spiritual healing. According to legend, Apache tears, and obsidian in general can help with healing from grief or other emotional traumas, and protection against evil and bad luck[41].

Apache tears are considered a sort of semi precious stone, and are frequently made into jewelry. These stones are made into jewelry as both raw stone and cut cabochons.

Apache tears are beautiful and interesting reminders of America’s brutal past, as well as a symbol of healing and a bright and hopeful future.

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[40] “Apache Tear Drop.” First People. Accessed January 26, 2023. https://www.firstpeople.us/FP-Html-Legends/Apache_Tear_Drop-Apache.html.

[41] “Apache Tears Meaning & Use Heal Grief, Gives Protection & Grounding.” HealingCrystalsForYou.com. Accessed January 26, 2023. https://www.healing-crystals-for-you.com/apache-tears.html.

Figure 4.3: An Apache Tear (Eugster, 2006)

Tachylite

Most basaltic lava comes from the ocean floor, because that is the thinnest part of the Earth's crust. Basaltic, or mafic, magma is the closest magma to the composition of the mantle. Not all sources of basaltic lava are underwater, though. Tachylite is a form of basaltic (low silica) glass. It is created by rapid cooling of molten basaltic magma. Like obsidian, tachylite has a dark brown or black appearance, but is greasy in luster, and can be either vesicular or spherulitic[42].

Tachylite is much more rare than obsidian is, because mafic magmas nucleate and grow crystals more easily than felsic magmas. This means that the rapid cooling that is required to form vitreous (glassy) substances is unattainable much of the time. This glass is very brittle, unlike obsidian, and can form from basaltic "bombs" that are violently thrown from basaltic volcanoes (in Iceland for example), in intrusive dikes and sills, and from lava flows[43].

Sideromelane

This glass is yellow or brown and somewhat translucent. It is another basaltic glass, formed from a submarine eruption or from magma/water

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[42] "Tachylite: Mineral Information, Data and Localities. - Mindat.org." Accessed January 26, 2023. https://www.mindat.org/min-51699.html.

[43] Winter, John DuNann. Principles of Igneous and Metamorphic Petrology. United Kingdom: Prentice Hall, 2010.

interactions[44]. It is commonly found in Palagonite tuff. Tuff is a consolidated rock formed of volcanic ash. Palagonite tuff is composed of this ash and coarse pieces of basaltic rock. These rocks are often dark brown and yellow[45]!

Palagonite

As mentioned above, Palagonite is usually found with sideromelane. It is what is known as an alteration product. When water (H2O) interacts with volcanic glass, it can change it chemically, especially since volcanic glasses are characteristically unstable, and will eventually crystallize, also known as devitrification. Palagonite is a poorly defined term for volcanic glass alterations, because it is kind of a catch all for any basaltic glass that is altered. Palagonite typically has an orange-yellow crystalline crust that is a result of chemical alteration of the glass[46].

Hyaloclastite

This is not really a type of glass. Like palagonite, it is formed from obsidian or tachylite. This is more like an accumulation of bits of natural glass. It is typically brecciated, meaning that all of

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[44] "Sideromelane: Mineral Information, Data and Localities. - Mindat.org." Monday.org. Accessed January 26, 2023. https://www.mindat.org/min-48508.html.
[45] Strekeisen, Alex. "Palagonite." alexstrekeisen.it. Accessed January 26, 2023. https://www.alexstrekeisen.it/english/vulc/palagonite.php.
[46] Schiffman, Peter, Randal J. Southard, Dennis D. Eberl and James Bishop. "Distinguishing palagonitized from pedogenically-altered basaltic Hawaiian tephra: mineralogical and geochemical criteria." *Geological Society, London, Special Publications* 202 (2002): 393 - 405.

the pieces, or clasts, are angular and sharp. Typically this is made of sideromelane, and has an alteration crust of palagonite. These are typically formed in subglacial volcanoes, in underwater volcanoes, or when lava flows meet water[47].

Pele's Hair

Relevant to the next few glasses, Pele, also known as Pelehonuamea, is a goddess in the Native Hawaiian religion. She is known as the goddess of fire and volcanoes, and "she who shapes the land", as lava both wipes out settlements and builds new land[48]. Many of the beautiful natural products of the Hawaiian volcanoes are attributed to the Goddess. For example, near Mount Kilauea in Hawaii, there are piles of straw-like golden fibers. These are glass, formed when gasses bubble to the surface of lava burst, and stretch the molten lava very thin, cooling it into fibers[49]. These fibers can be dangerous for humans, as they can be several feet long, but the 2mm thick. The fibers can puncture skin, and more seriously, eyes. Birds on occasion build nests out of the glass. Pele's hair does not form only in Hawaii,

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[47] White, James D. L., Jocelyn McPhie and S. Adam Soule. "Submarine lavas and hyaloclastite." (2015).

[48] Yamanaka, Katie. "Pele, Hawaiian Goddess of Fire and Volcanoes." Hawaii.com, January 25, 2022. https://www.hawaii.com/culture-historic-info/pele-goddess-of-fire/.

[49] "Pele's Hair." National Parks Service. U.S. Department of the Interior. Accessed January 27, 2023. https://www.nps.gov/havo/learn/nature/peles-hair.htm.

but those are the best known examples of this naturally occurring fibrous glass.

Pele’s Tears

Also named for the Hawaiian goddess, and best known for occurring on Mount Kilauea, Pele’s tears are tear shaped, black globs of solidifies lava that form when lava is flung through the air. They are commonly found on the ends of Pele’s hair, or by themselves. While the drop of lava is flying through the air, the drop deforms into a tear drop shapes, and it rapidly cools. This deformation and subsequent solidification cause tension and stress areas within the drop. If the “tail” is broken, the tensile stress within the “head” of the drop can cause the drop to shatter. This occurs with manmade Prince Rupert’s drops as well. Within the drops, gas from the volcano is trapped, which can be of interest to scientists who want to know about the gasses and chemical composition of the magma[50].

Like the Apache Tears, Pele’s tears are steeped in legend. According to Hawaiian stories, Pele came to Kīlauea as she was fleeing the wrath of her older sister, who she had offended somehow. She came to the first island in the chain, and dug a hole looking for fire, but her sister caught up and chased her off the island. This repeated all through

[50] Cogliati, Simone, Sarah Sherlock, Alison Halton, Kerry Reid, Hazel Rymer, and Simon Kelley. "Tracking the behaviour of persistently degassing volcanoes using noble gas analysis of Pele's hairs and tears: A case study of the Masaya volcano (Nicaragua)." *Journal of Volcanology and Geothermal Research* 414 (2021): 107212.

the island chain, until she took up refuge in Halemaumau, the main crater on Kīlauea. These legends most likely stemmed from the observations from the ancient Native Hawaiians that volcanism only really occurs on the last island in the chain, Hawaii, and some on Maui[51].

Limu o Pele

Also known as Pele's Seaweed, Limu o Pele is formed when underwater volcanoes release bubbles, where the seawater acts as a superheated fluid, and is entrained (trapped) in the magma, then rapidly expands, and the magma freezes into glassy shards[52].

[51] Vitaliano, Dorothy B. "Geomythology: geological origins of myths and legends." *Geological Society, London, Special Publications* 273, no. 1 (2007): 1-7.
[52] Schipper, C. Ian, and James DL White. "No depth limit to hydrovolcanic limu o Pele: analysis of limu from Lōihi Seamount, Hawaii." *Bulletin of volcanology* 72 (2010): 149-164.

Fulgurites

What happens when lightning meets rock, sand, or clay? Glass happens. Fulgurites form when cloud to ground lighting strikes rapidly heat ground material, liquifying it, then it is cooled and frozen in a glassy state. Fulgurites are the natural glass with the most variation in terms of chemistry, because they can form from almost any rock, clay, or sand[53]. The formation of fulgurites has limited research, but many agree that fulgurite formation resembles glasses formed from pyrometamorphic processes[54] [55].

Fulgurites were mentioned in the film *Sweet Home Alabama*, but do not at all resemble the beautiful crystal clear structures in the film. Real fulgurites look more like hollow, tubular plant roots, and are not clear.

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[53] Pasek, Matthew A., Kristin Block, and Virginia Pasek. "Fulgurite morphology: a classification scheme and clues to formation." *Contributions to Mineralogy and Petrology* 164 (2012): 477-492.
[54] Pasek, Matthew A., and Virginia D. Pasek. "The forensics of fulgurite formation." *Mineralogy and Petrology* 112, no. 2 (2018): 185-198.
[55] Grapes, Rodney. *Pyrometamorphism*. Springer Science & Business Media, 2010.

Tektites

I love being dramatic, and what is more dramatic than massive (and sometimes not ☹) celestial bodies smashing into Earth? Tektites are a type of natural glass formed via impact, much like the Trinitite, but natural. Globular, beadlike, or dumbbell-shaped, and fairly small, tektites are beautiful and interesting side effects of major geological events. They are also kind of rare. There are only four (known) tektite-strewn sites in the world: the Australasian field, Ivory Coast field, Czechoslovakian, and North American[56]. Tektites are commonly black, but can be brown or even green too, as is the case for the recently popular semi precious gem, moldavite[57].

[56] Glass, B. P. "Tektites." *Journal of non-crystalline solids* 67, no. 1-3 (1984): 333-344.
[57] Glass, B. P. "Tektites and microtektites: key facts and inferences." *Tectonophysics* 171, no. 1-4 (1990): 393-404.

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Handmade Glass

Handmade Glass Introduction

Whew! We finally made it through all that science stuff. Now we can get to some of the more exciting glass facts. In this section we will learn an abridged history of glassblowing, take a tour of some of the health hazards that are involved with glassforming, and learn a little bit about how to properly smoke marijuana (just kidding, we are looking at a cool form of glassblowing centered on smoking herbs). I hope you find this section interesting and informative!

A (very) Abridged History of Handmade Blown Glass

There are many different methods of glass forming, from fusing glass plates in a kiln, to bead working over a 3,000 degree torch. Because the processes and full history of glass could fill up several textbooks, I will need to abridge this section to make it manageable for my project's timeline. As such, this section will describe the major history and major processes utilized in furnace glass, aka traditional blown glass.

1st century BC. The Roman Empire conquered much of the Mediterranean. Jesus of Nazareth lived and died, accidentally creating Christianity in the process, and in ancient Syria, craftsmen melted sand and soda (sodium bicarbonate) to create the first step of blown glass. Now, Glass working had been around since the ancient Egyptians; people made beads and solid figurines, but the Syrians did something unique: they used hollow tubes to inflate the glass into hollow vessels. Before this, there were some glass vessels being made via core forming. Core forming is a technique in which glass is gathered over the end of an iron rod, around a core made of clay and horse dung[58]. The glass is built up into a shape, but you can see that this would be time consuming and had its limitations in terms of what could be placed in the vessels. Therefore, glass pre-blowpipe was very expensive[59].

Once the blowpipe was invented, glass could be inflated evenly, allowing the vessels to cool and heat uniformly. The first blowpipes were made of clay. The Romans caught wind of this invention and subsequently stole the idea. Glass shops began popping up all over the Roman Empire, from modern day France to Italy. Roman glassblowers knew how to color glass using metal oxides, making beautiful and ornate glass perfume bottles, bowls, plates, cups, amphoras, and more. Roman glassworking lasted from the 1st century BC all the way through the 5th century AD. Not much is known of this time period in glassworking, but what is known is that the new technology of glassblowing spread quickly along trade routes[60] [61].

There are two main methodologies to forming a glass bubble into a desired shape. Free

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[58] Warmus, William. “AACG - Art Alliance for Contemporary Glass.” A Brief History of Glass | AACG, 2012. https://contempglass.org/2012-celebration/info/a-brief-history-of-glass.

[59] McCray, Patrick. "A History of Glassforming." *Technology and Culture* 44, no. 2 (2003): 383-384.

[60] “The History of Glass Blowing.” Glass Blowing History - GlassBlowing Art, 2023. http://www.historyofglass.com/glass-history/glass-blowing-history/.

[61] Show, Glass Roots Art. "Glass Blowing."

blowing was developed first, and is still used today. This process involves using tools to manipulate the bubbles into desired shapes. Modern day examples of these tools include tweezers, jacks, straight and diamond shears, and crimps. Mold blown glass is also used today, and involves placing the glass bubble in a mold, then inflating it so that it takes on the desired shape of the mold. Mold blowing allows extremely fast production to take place[62].

After the Romans, glassblowing remained basically the same for hundreds of years. Venice, Italy became a major hub for glassworking, where techniques were developed and refined to make complex and intricate pieces, such as goblets, one of the most notoriously complex and difficult things to make in blown glass. Glass spread all over the globe, from Japan to the New World, and became ubiquitous. Each culture had a different style of glassblowing, and glass secrets were closely guarded and passed from father to son or master to apprentice.

In the 1820s, mechanically hot pressed glass was invented. Rather than inflation using air, the glass is poured into a mold, then pressed into a shape. Glassworking became progressively more automated, especially as demand for glass

[62] Stern, E. Marianne. "Roman glassblowing in a cultural context." *American Journal of Archaeology* 103, no. 3 (1999): 441-484.

products boomed (lightbulbs, Coca Cola bottles, etc)[63].

In the 1960s, glass transformed. Women became involved in the glass industry as glassblowers, and artists like Dale Chihuly and Lino Tagliapietra redefined glass from a craft into an art. Schools dedicated to glassblowing such as Pilchuck Glass School opened, and universities adopted programs dedicated to glass, one such example being Bowling Green State University. Art glass has become very popular around the world, and classes are available to the public nowadays.

[63]"The History of Glass Blowing." Glass Blowing History - GlassBlowing Art, 2023. http://www.historyofglass.com/glass-history/glass-blowing-history/.

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Health Hazards in the Modern Day Glass Studio

As I have written this narrative, my interests have evolved and I have added or removed content based on current world events and my own experience. As I finished my Brief History of Glassblowing, a train derailed in southern Ohio, spilling toxic Vinyl Chloride and other carcinogens into the water, soil, and air. As a person heavily involved in hot and cold shops, as well as labs, I am well acquainted with the Safety Data Sheet and various lab protocols. I am invested in my personal health and safety, and feel that this research is potentially valuable to current and future glassblowers.

This section will be set up slightly differently than the others. I will be going through tools and other items in the hot and cold shops that can cause significant harm to a person’s health. As with most hazards, the dose makes the poison, so if you have been exposed to a toxic chemical or substance, do not stress and make an appointment with a primary care physician if you feel that you are in danger of negative health effects.

Disclaimer: I am not a medical professional or an expert in industrial hazards.

Hot Shop

The hot shop is where most of the magic happens, but it can be dangerous, too. Hot shop tools can expose artists to toxic gasses, dusts, smoke, explosions, and hazardous chemicals or materials.

Burns

Skin Burns

The most obvious risk for glassblowers who work with molten glass is burned skin. Workable glass can be between 1,200-2,200 degrees Fahrenheit, and will cool over time. From my experience, glass becomes touchable comfortably at around 120 degrees F. This leaves a large margin between molten temperature and touchable temperature where the glass can cause significant damage to skin. Not only can the glass cause burns, but careless placement of tools and torches can cause burns, too. The annealers are another location where burns happen often. In my first semester, I received a gnarly 2nd degree burn from the annealer, which ended up scarring quite nicely in a triangle shaped dark spot on my forearm.

Steps are taken in the hot shop to avoid serious burns. Clothing that is worn in the hot shop should cover the torso (preferably the arms), shorts or pants should be at least down to the knees.

Clothing should be well fitted and made of natural fibers like cotton, rayon, hemp, etc. Synthetic fibers can ignite or melt with heat and stick to skin, causing serious second or third degree burns, whereas the natural fibers will simply burn away, and somewhat protect the skin. According to a 2018 review of burn patients, 70% of female patients hospitalized with severe burns were wearing synthetic clothes at the time of injury, and the burns were caused by ignition of the clothing or the melting of the clothing into the skin[64].

Ultimately, burns are somewhat inevitable, but occurrences reduce as glassblowers get more attuned to the hot shop. Even so, they still happen but mostly remain minor. When burned, you should run the burn under cool water, for ten minutes to half an hour, which will reduce swelling, pain, and scarring. Efforts should be made to keep the skin and body hydrated, using lotion and fluids. Keeping the burn area clean and dressed will help with infections and scab itching. If the burn is severe (penetrates several layers of skin deep), it is important to contact a doctor immediately. Burns

[64] Honnegowda, Thittamaranahalli Muguregowda, Pramod Kumar, Padmanabha Udupa, and Pragna Rao. "Epidemiological study of burn patients hospitalised at a burns centre, Manipal." *International wound journal* 16, no. 1 (2019): 79-83.

can cause permanent nerve damage if handled improperly[65].

Eye Safety

The glory holes and furnaces have to heat glass, which has a high melting point. The fire produced by the glory holes, as well as the heating elements in the furnaces, and the glass itself, puts off ultraviolet and infrared radiation, which can damage eyes over many years. This can be different from hotshop to hotshop as glass types and heating elements differ, but all glassblowers are exposed to some level of IR and UV radiation[66].

The damage caused by repeated exposure gives rise to polymegathism of the eyes[67] (a larger than normal variation in the size of the corneal endothelial lens… aka the layer of cells that cover the cornea). It can also cause cataracts[68], which are cloudy areas in the lens of your eye. In addition, while it has not been correlated with glassblowing,

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[65] Kowalske, Karen J. "Burn wound care." *Physical Medicine and Rehabilitation Clinics* 22, no. 2 (2011): 213-227.

[66] Oriowo, Olanrewaju M., B. Ralph Chou, and Anthony P. Cullen. "Glassblowers' ocular health and safety: optical radiation hazards and eye protection assessment." *Ophthalmic and Physiological Optics* 17, no. 3 (1997): 216-224.

[67] Oriowo, Olanrewaju M., B. Ralph Chou, Anthony P. Cullen, and Barbara E. Robinson. "Occupational exposure to optical radiation and the ocular health status of glassblowers." *Ophthalmic and Physiological Optics* 17, no. 6 (1997): 483-491.

[68] Cashwell Jr, L. Frank, Ivan L. Holleman, Richard G. Weaver, and Gerard H. van Rens. "Idiopathic true exfoliation of the lens capsule." *Ophthalmology* 96, no. 3 (1989): 348-351.

ultraviolet radiation exposure can lead to ocular cancer, which can be eye sight or life threatening[69].

This all sounds very scary, but do not worry. There are special glasses or lenses that are made of tinted borosilicate glass or sodium flare polycarbonate, which can absorb the harmful wavelengths. Care must be taken to avoid the harmful long term effects of low level UV and IR exposure.

Cuts

Glass is one of the sharpest materials known to man. As we discussed previously, it is so sharp that natural glasses are being investigated for usage in medicine as scalpels. However, this property of glass can negatively impact glassblowers. Obviously.

Most cuts received in the hot shop are relatively minor. Per Mayo Clinic guidelines, the steps taken after a cut should be as follows:

“Wash your hands. This helps avoid infection.

Stop the bleeding. Minor cuts and scrapes usually stop bleeding on their own. If needed, apply gentle pressure with a clean bandage or cloth and elevate the wound until bleeding stops.

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[69] Yam, Jason CS, and Alvin KH Kwok. "Ultraviolet light and ocular diseases." *International ophthalmology* 34 (2014): 383-400.

Clean the wound. Rinse the wound with water. Keeping the wound under running tap water will reduce the risk of infection. Wash around the wound with soap. But don't get soap in the wound. And don't use hydrogen peroxide or iodine, which can be irritating. Remove any dirt or debris with a tweezers cleaned with alcohol. See a doctor if you can't remove all debris.

Apply an antibiotic or petroleum jelly. Apply a thin layer of an antibiotic ointment or petroleum jelly to keep the surface moist and help prevent scarring. Certain ingredients in some ointments can cause a mild rash in some people. If a rash appears, stop using the ointment.

Cover the wound. Apply a bandage, rolled gauze or gauze held in place with paper tape. Covering the wound keeps it clean. If the injury is just a minor scrape or scratch, leave it uncovered.

Change the dressing. Do this at least once a day or whenever the bandage becomes wet or dirty.

Get a tetanus shot. Get a tetanus shot if you haven't had one in the past five years and the wound is deep or dirty.

Watch for signs of infection. See a doctor if you see signs of infection on the skin or near the wound, such as redness, increasing pain, drainage, warmth or swelling"[70].

Even today, minor cuts can get infected and result in more serious conditions. Caring for these cuts when they happen is much easier than sepsis and possible death after infection.

Explosions

While rare and unlikely, explosions are a possible hazard in a hot shop. Many hot shops stock pressurized propane and oxygen for the hot torches (heats up to 3,000 degrees). As with all pressurized gas canisters, there is a risk of explosion. This is pretty rare though.

Smoke

Glassblowers use wet newspapers, cork paddles, and wooden paddles that produce smoke when applied to hot glass, because they burn. Obviously. Exposure to any kind of smoke is not good for the human lung, but could mild exposure in the hot shop really cause damage? The short answer is yes.

[70] "Cuts and Scrapes: First Aid." Mayo Clinic. Mayo Foundation for Medical Education and Research, November 17, 2021. https://www.mayoclinic.org/first-aid/first-aid-cuts/basics/art-20056711.

Wood smoke exposure in the short term can cause inflammation and oxidative stress in the throat and lungs. Oxidative stress is the imbalance of the body's ability to detoxify reactive oxygen species in the body. Redox imbalances in the cells can lead to the creation of peroxides and free radicals that have the ability to damage cells. These chemicals have been shown to play major roles in the development of cardiovascular and pulmonary diseases[71]. Smoke exposure over many years can also cause cardiovascular and pulmonary diseases to develop[72].

Hazardous Chemicals

Different glass studios will use different colors in their glassworks. Colors are created by using metal oxides. Many of these colors are made with lead, arsenic, cadmium, chromium, cobalt, uranium, nickel, and more. Exposure to these heavy metal can lead to accumulation in the body, which can have long term health effects[73].

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[71] Diaz, Janet V., Jonathan Koff, Michael B. Gotway, Stephen Nishimura, and John R. Balmes. "Case report: a case of wood-smoke–related pulmonary disease." *Environmental Health Perspectives* 114, no. 5 (2006): 759-762.

[72] Ghio, A.J., Soukup, J.M., Case, M., Dailey, L.A., Richards, J., Berntsen, J., Devlin, R.B., Stone, S. and Rappold, A., 2012. Exposure to wood smoke particles produces inflammation in healthy volunteers. *Occupational and environmental medicine*, *69*(3), pp.170-175.

[73] IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. "Exposures in the Glass Manufacturing Industry." In *Beryllium, Cadmium, Mercury, and Exposures in the Glass Manufacturing Industry*. International Agency for Research on Cancer, 1993.

In addition to metals, hydrocarbons are rampant in a hot shop. Often, a glassblower will catch a whiff of propane while lighting a torch, but this is not really an issue. What is an issue, however, is the exposure of skin to propane, which can cause frostbite[74]. This is, admittedly, rare in a hot shop setting.

Silica

Let us finish with the thing in the hot shop that should scare the living daylights out of anyone who cares about their lungs: silica. There are two kinds of silica relevant to this discussion. Crystalline silica is a mineral dust, and a well known occupational hazard for thousands of workers around the world. Classified as a carcinogen, crystalline silica is perhaps one of the most dangerous things that you can inhale. Crystalline silica particles are so sharp and stable, that they never leave the lungs, and continue burrowing deeper and deeper into the tissue. The damaged cells will try to heal, but will come back less effective. Over time, the scar tissue can lead to silicosis, COPD, pulmonary tuberculosis, rheumatoid arthritis, and lung cancer[75]. All of these

[74] Title 29 of the CFR

[75] Calvert, G. M., F. L. Rice, J. M. Boiano, J. W. Sheehy, and W. T. Sanderson. "Occupational silica exposure and risk of various diseases: an analysis

diseases can be fatal. In a glass studio, exposure to crystalline silica comes from two main sources. The batch used to charge (or refill) the furnace, and silica that is used to make plaster blow molds. The best way to avoid acute exposure from these sources is to wear a particulate respirator or mask. For example, KN95 or N95 masks are considered safe for this particle. Fiberglass in the studio can be another source of silica particles in the air. In our studio, this comes in the form of FiberFrax, a high temperature resistant cotton-like fibrous substance used in the glass studio.

Amorphous silica particles can also cause damage to lung tissue, but it is not considered a carcinogen like crystalline sources of silica. This is because the glass particles do not cause the body to produce scar tissue in the lungs (fibroids). Over time, large amounts of glass dust can cause asthma like symptoms and glass dust can be irritating to eyes, skin, and mucous membranes[76].

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using death certificates from 27 states of the United States." *Occupational and environmental medicine* 60, no. 2 (2003): 122-129.

[76] Merget, Rolf, T. Bauer, H. U. Küpper, S. Philippou, H. D. Bauer, R. Breitstadt, and T. Bruening. "Health hazards due to the inhalation of amorphous silica." *Archives of toxicology* 75, no. 11 (2002): 625-634.

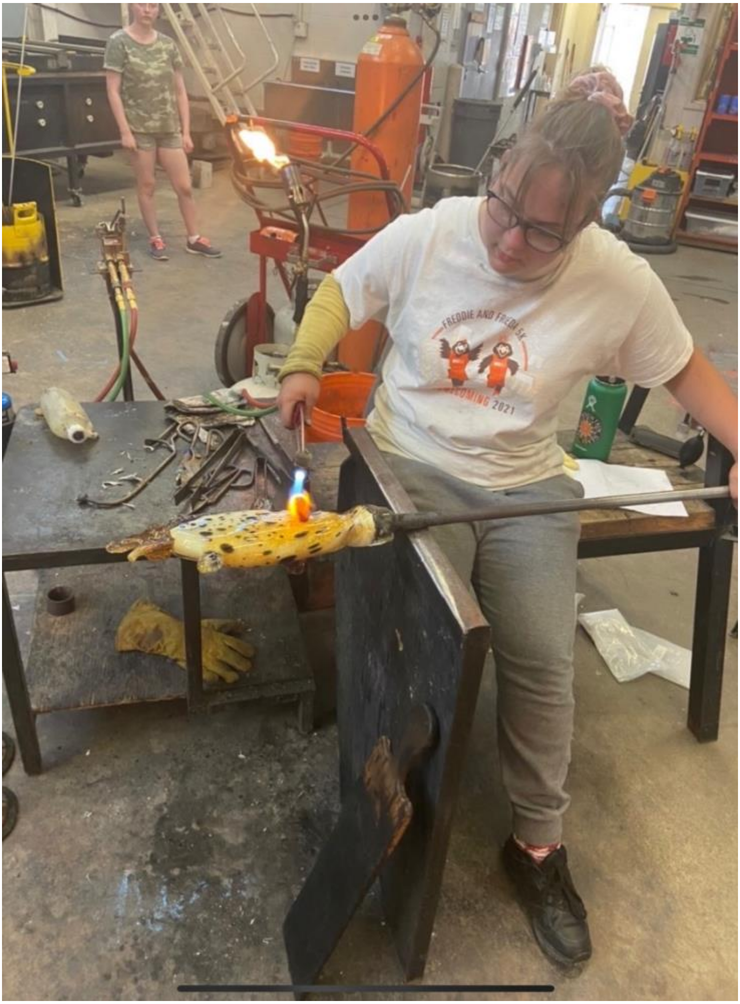

Figure 5.1: Practicing good safety in the hot shop. Wearing natural fiber clothes, closed toed shoes, and hair is pulled back

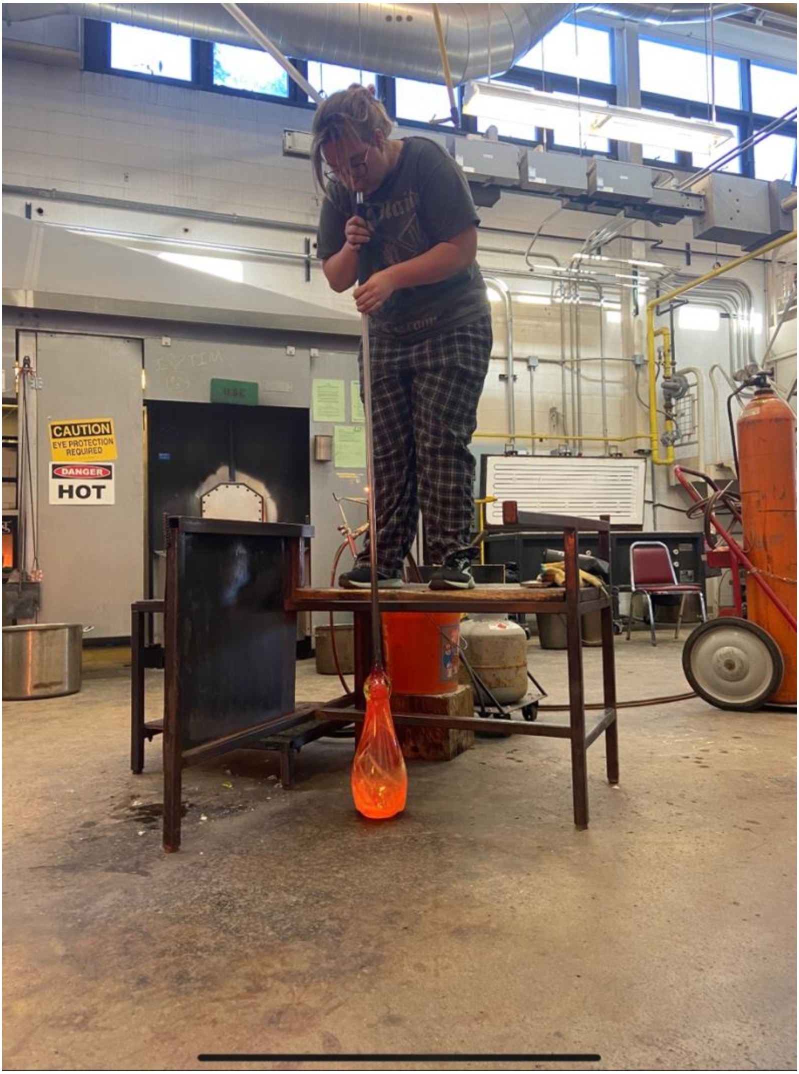

Figure 5.2: making a drop vase requires good situational and spatial awareness.

Cold Shop

Possibly more dangerous than the hot shop, the cold shop is where glassblowers cut, grind, and polish glass. It does contain many of the same hazards that befall the hot shop, so I will try to avoid redundancy. Cuts and silica exposure appear here too, so see above for that information. However, the cold shop exposes us to a few new dangers.

Rotational Tools

There are so many things that can go wrong in a cold shop. Most of these relate to rotational tools. Diamond saws, grinding wheels, dremels, belt sanders, lathes. These tools are rotational tools of various sizes and shapes in a cold shop. They present opportunities for glass to shatter in your hand or get caught in a snag on the wheel and fly across the shop. The lathe can catch loose articles like jewelry or hair, which can cause choking and suffocation, or trauma to the skin or head. The diamond wheel can easily cut off a limb. The belt sander and diamond wheel are so loud that repeated exposure can cause hearing damage.

For all of these machines, steps can be taken to avoid accidents. Clothing must be fitted, jewelry must be removed, hair must be pulled back, safety glasses must be worn at all times, masks are beneficial because of the glass dust produced, aprons should be worn to reduce dust on clothing, headphones should be worn to protect hearing, and most importantly: COMMON SENSE MUST BE APPLIED WHEN WORKING! Not working alone is important, using one machine at a time, focusing on the task at hand, not multitasking… and on and on. Very few accidents in the cold shop are unavoidable.

Figure 5.3: Practicing good safety in the cold shop. Loose articles tucked away, hair pulled up, glasses, and mask.

Conclusion

Other than rotational tools (and the silica), the cold shop is pretty safe. However, these things tend to cause more accidents than almost anything in the hot shop. On a personal note, the cold shop is my absolute nemesis. If I can avoid cold working, I will at all costs.

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Cashwell Jr, L. Frank, Ivan L. Holleman, Richard G. Weaver, and Gerard H. van Rens. "Idiopathic true exfoliation of the lens capsule." *Ophthalmology* 96, no. 3 (1989): 348-351.

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Bongs and Pipes: A Unique Glassblowing Subculture

As a preface to this essay, I do not do the marijuanas, but I do find the colorful and often complex pieces of glass paraphernalia used in the (now mostly legal) act fascinating. Within the already small community of glass workers, there exists a class of craftsmen who almost exclusively craft different methods of consuming marijuana and marijuana derived substances.

Only one kind of glass can be used to make these pieces (if they are to be functional), and that glass is borosilicate glass. Borosilicate glass was invented in the late 1800s by Otto Schott, and was first manufactured in the English speaking world by Pyrex. Borosilicate glass is an inert glass made from boric oxide, silica, soda ash, and alumina. It has a melting point of around 3,000 degrees Fahrenheit, and can generally withstand temperature changes of around 300 degrees F before cracking. Borosilicate glass has a much lower coefficient of expansion than soda lime glass, meaning that it can be exposed to large temperature fluctuations without cracking due to thermal shock. Obviously, when you are smoking things, you want your pipe or water pipe to be heat resistant. It is for these reasons that it is safe to cook, smoke, and perform lab work with borosilicate glass. As we will learn in a later essay, borosilicate glass is far safer for consuming food and drink than other materials.

Pipes

Tobacco and other substances can be smoked from glass pipes. These are fairly simple to understand. Leaves from a plant are packed into a bowl, then ignited. The smoke is ingested, and the smoker experiences the intended effects of the substance.

There are many kinds of pipes, but the most basic forms are as follows spoon pipes, bubblers, hammer pipes, Sherlocks/gandalfs, chillums/steamrollers, water rigs (not pipes)[77]. If you so desire, you can google each of these to find out exactly how they work, but that is not relevant to this essay.

As you can see, there are many types of pipes from which you can smoke all kinds of things. You can have boring, clear pipes, fun, colorful pipes, or even insanely ornate pipes (which, in reality, aren't going to be used for smoking). These pieces can cost anywhere from $15 for the simples ones, to thousands of dollars for the crazy ones. Particularly passionate smokers may amass a collection over time, but there are also collectors who have never touched tobacco or marijuana products, who are equally entranced by the bright colors and complex nature of these pieces.

[77] "Types of Glass Pipes." Tako Glass. Tako Glass, June 1, 2022. https://www.takoglass.com/blogs/news/types-of-glass-pipes.

Bongs

A “bong” or a “water pipe” is a unique piece of paraphernalia. A substance, which can be tobacco, marijuana, or another type of dried herb, is burned in the pipe. The smoke passes through the water in an attempt to clarify and remove some of the known toxins in the smoke. The effectiveness of this method of consuming a substance is challenged. Research has demonstrated that water filtration does have a reducing impact on the particulate matter and toxic substances that can be found in tobacco and marijuana smoke alike. However, water filtration can also impact the quantity of tetrahydrocannabinol (THC) (the main psychoactive chemical found in marijuana) that is consumed, as the THC can dissolve in water[78]. This is then, of course, not a very financially conservative method of consuming psychoactive drugs, but due to its somewhat harm reducing effects, it is a popular method. Even less fiscally conservative, water pipes are generally somewhat pricey.

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[78] Cozzi, Nicholas V. "Effects of water filtration on marijuana smoke: a literature review." *MAPS Bull* 4, no. 2 (1993): 4-6.

“Nice Glass”

For glass paraphernalia, there is a small but fascinating subculture surrounding pieces that are both functional and beautiful. While glass art has been made forever, glass pipes and bongs are relatively new. They used to be made from natural materials like metal or bone, but around the 70s, borosilicate glass began being used to make these items. One of the pioneers of this movement was Bob Snodgrass, a lampwork artist who started making pipes in 1971, and selling them at Grateful Dead concerts. He revolutionized the hard glass art in the United States (hard glass refers to borosilicate glass, which melts at a very high temperature)[79]. Over the past five decades, this art has spread. In almost any city in the United States, you can find head shops that employ glassblowers to create bongs and pipes, or that sell handmade bongs and pipes without employing in shop artists. Although, in some states where marijuana and paraphernalia are still illegal, it is customary to use the phrase “water pipe”, as some places will no longer sell their products if you use the word “bong”.

[79] “Bob Snodgrass, Snodgrass Family Glass.” Columbia River Glass, February 27, 2023. https://columbiariverglass.com/artist-bob-snodgrass/.

Before we get to some pictures of amazing lampworked paraphernalia, as an author’s note, I have limited experience with flameworking (lampworking and flameworking are the same thing). The experience that I do have, though, informs me that the art that these artists create is nothing short of awe inspiring.
Ok, let us look at some art.

Figure 1: Erik Anderson, Honu Disk Recycler, 4 lbs, 2023 ($639.00)

Image 2: Bob Snodgrass, Small Deadhead Hammer, 0.1 lbs, 2023 ($479.99)

Image 3: Jysn Lord and Ryan O’Keefe, Dozer Ducky Recycler, 2022

Image 4: Scott Deppe, Gold Encrusted Skull Bong, ($100,000)

As you can see, all of these pieces are super, super cool and even non smokers can collect and enjoy them. They range in price from the affordable to the ultra-luxury. As marijuana use becomes more accepted in mainstream society, I expect to see these pieces become more popular and complex. If you like flameworked art, but don’t want to look up paraphernalia, other incredible artists include Paul Stankard, Kimberly Thomas, and Kit Paulson. There are dozens more amazing flameworkers, but these are my personal favorites.

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Materials Science and Glass

Materials Science and Glass

This section will be limited to two essays, as the semester winds closer and closer to the end. In this section, you will get the pleasure of reading the research essay part of my application to the Goldwater Scholarship, known as the most prestigious undergraduate science scholarship in the United States. I'll update this if I win (I didn't). Secondly, you will get the pleasure of reading some riveting drama about Pyrex the material versus PYREX the brand, and why sometimes laboratory glassware blows up unexpectedly. *Bob appetit!*

Lead in Commercially Available Ceramic Glazes

I became curious about the lead content in commercial ceramics from a course I was taking in glassblowing where we used lead based enamel powder to paint patterns onto glass, which was then fired in a kiln to vitrify the enamel. I decided to conduct an investigation into the dishes we eat on that can be purchased cheaply from big box stores and online. I conducted the entire experiment by myself using a grant from the university, including finding and purchasing the dishes online and in person.

This experiment was a fantastic demonstration of how art can influence science. The enameling class I took with Chuchen Song gave me the inspiration to start and finish this project, revealing much about the nature of commercial goods and how we cannot, in fact, trust major corporations to take care of our health.

LEAD (Pb) IN COMMERCIALLY AVAILABLE CERAMICS

As someone who grew up in the Rust Belt in Ohio, I am very concerned with environmental ethics and justice, from the water we drink to the objects we use in our daily lives. My interest in lead poisoning comes from my concern for the future of the people in my community. Lead poisoning is permanent and tragic; informing the public about the dangers of lead and possible exposure is essential. Many people believe that lead poisoning only occurs via old paint and leaded gasoline, but the truth is much more insidious: lead is everywhere. Recently, the lead content of numerous sources has once again entered the news; everything from soil (Stewart et al., 2014) to children's toys (Shen et al., 2018) seems to be contaminated. As a future materials scientist, I take a particular interest in vitreous (glassy) materials like the glazes used on ceramics and believe that I have a responsibility to apply my skills and knowledge for the public good. However, the subject of this study is lead contamination in glazed ceramic dishes that are available for purchase from national retailers.

Background for my Research

Lead, Latin name, *plumbum* (Pb), is an industrially useful heavy metal with dire consequences if consumed. In children, lead poisoning can present as lower intelligence, smaller size, behavioral issues, learning difficulties, low appetite, and a lack of energy (CDC, 2022). In adults, symptoms can present as memory loss, headaches, mood swings, weakness and muscle problems, and sleep issues. Lead oxide, known as greta, is often added to ceramic glazes as a flux to reduce the firing temperature and to add a shiny glaze (Tunstall and Amarasiriwardena, 2002). Low-temperature-fired lead-glazed ceramic vessels are fired at lower temperature than is required to permanently fix the lead to the pottery, which allows lead to readily leach into food products, especially acidic foods (Lynch et al., 2008). There are no acceptable or safe levels of exposure for lead, as even at lower levels it has harmful effects (CDC, 2022; Wani et al., 2015). Even so, current United States standards do allow for some lead in consumer products. The Consumer Products Safety Commission established 90 ppm (0.009% by dry weight) as the acceptable concentration of lead in paint or other similar materials intended to adhere to a substrate (US National Archives, 2022). The primary concern of these regulations is the health of children, but any amount of lead has consequences for adults too.

The vast majority of glazed ceramic dinnerware produced before 1970 has high levels of lead (Gonzalez et al., 1996), but what about more modern stoneware or ceramics? Do acidic foods like tomatoes, lemons, or salad dressings containing vinegar leach significant amounts of lead out of modern ceramics and into food products? The objectives of this research project were to address these important societal environmental questions by: determining the amount of lead contained in commercially available ceramic products, and determining the amount of lead that can be leached from these ceramic products by common food items.

Materials and Methods

I obtained various modern glazed ceramic products from big box stores and online sources. The ceramic dishes were selected based on material, color, and country of production (e.g., US, Canada, Mexico, China, and India). Red, orange, and yellow dishes were selected first, as these glazes are more likely to have lead additives than other colors, such as blue, green, and white. A total of 114 ceramic dishes were purchased. The total lead content of the ceramics and glazes was determined using a Bruker S1 Titan field portable xray fluorescence (FP-XRF) instrument following the standard USEPA Method 6200A (USEPA, 2007). This is a non-destructive technique that allows an *in situ* analysis of the materials. The ceramics were placed on the sensor, then a 90 second analysis of the ceramic was conducted by the machine. The amount of lead that can be leached from the selected ceramic products was determined following the US Food and Drug Administration recommended method (USFDA, 1998) using 4% acetic acid solutions (the same concentration as food-grade vinegar). The ceramics were washed using mild dish soap, rinsed with copious amounts of Milli-Q water, then air dried upside down until dry. The dishes were then filled using 200 ml of acetic acid solution for bowls and mugs, 100 ml for plates, and 400 ml for casserole dishes and Dutch oven. The dishes were covered with plastic wrap and left alone in a dark room for 24 hours. The concentration of lead in the leachates was determined using a ThermoElement iCAP 6500 Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) following standard USEPA Method 6010 (USEPA, 2002).

Results

Of the 114 ceramic dishes tested, 91.2% contained greater than 1 ppm Pb, while 32.5% contained greater than the legal 90 ppm required by the FDA, according to XRF readings (Table 1). There were also high levels of arsenic, but only in 15.7% of the dishes; the same dishes with high Pb levels also had high As levels. However, just 4.4% of the

XRF Results	Number	Percent
Total illegal leaded dishes (>90 ppm Pb):	37	32.5%
Total leaded dishes (> 1 ppm Pb):	104	91.2%
Total dishes (total observed):	114	100%
Mugs above 90 ppm Pb	18	32.73%
Plates above 90 ppm Pb	6	42.86%
Bowls above 90 ppm Pb	4	28.57%
Casserole dishes above 90 ppm Pb	6	60.00%
Misc above 90 ppm Pb	3	25.00%

Table 1: percentages of dishes with lead (XRF machine) and breakdown of dishes above 90 ppm by use

dishes contained high Cd levels. The dishes with high levels of lead were then leached using a 4% acetic acid solution. Only 2 dishes out of 37 leached levels of lead above 1 ppm (Table 2). These were a handmade dish from Mexico purchased on Amazon and a casserole dish purchased from Goodwill.

Leached (ppm)	Dishes	% total
0.0000-0.0002	1	2.70%
0.0002-0.4402	33	89.20%
0.4402-0.8802	1	2.70%
0.8802-1.3202	1	2.70%
1.3202-1.7602	0	0%
1.7602-2.2002	1	2.70%

Table 2: Pb leached from the dishes into the acetic acid

Discussion

The large percentage of leaded dishware (91%) is not healthy, but more alarming is the large percentage of dishes that are above the FDA guideline of maximum 90 ppm Pb (32.5%). It is a small consolation that the majority of the dishes leached a very small amount (0.0002-0.4402 ppm Pb for 89.2% of the dishes). However, any amount of lead leached into food is harmful to children and adults alike. Often, the toxicity of the dish can be influenced by the intended usage of the dish. For example, mugs, which are used to consume hot beverages like acidic tea and coffee, are everyday use items, so even leaching tiny amounts of lead like 0.002 – 0.4402 ppm can be detrimental, as lead accumulates over time in the body and does not get removed. Even more concerning, casserole dishes, which are baked for hours at a time in an oven, often with tomato or other acidic foods, can leach large amounts of lead at a time.

Based on this research, it is advised to the reader that they avoid using vintage dishes, dishes that have been hand painted/glazed, dishes that are handmade, dishes purchased second hand, dishes with bright colors (e.g., red, orange, yellow), and dishes produced in Mexico. Good alternatives to ceramic dishes are mugs, plates, bowls, casserole dishes, and cups made of borosilicate glass due to its high heat capacity and inert nature. An interesting future avenue for this project is to experimentally determine how companies have managed to use lead in glazes but prevent leaching into foods and drinks.

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Pyrex vs PYREX

When I took Materials Science 1 with Dr. John Farver, we did a lab where we used the Becke Line Test to figure out if two samples of crushed glass from the Pyrex brand were soda lime or borosilicate glass. The basic principle of this test is that soda lime and borosilicate glass have different refractive indices. By comparing the refraction of each to an oil of known refractive index, we can figure out which glass is which. Why do we want to know this? Soda-lime glass is cheaper to produce, but cracks under rapid heating. To learn if the beakers are borosilicate or soda-lime, the refractive index of a broken Pyrex breaker can be evaluated against a known immersion oil. Borosilicate glass has a refractive index of 1.52, while soda lime glass has a refractive index of 1.46. An immersion oil with a refractive index of 1.49 was used to determine which type of glass the beaker was, because soda lime would have a negative refractive index to the oil, while borosilicate would have a positive refractive index to the oil.

What happened? How did we get to the point where trusted laboratory glassware can explode when it didn't before? Why is PYREX and Pyrex different?

Heat resistant glass, known as borosilicate glass, was invented in Germany in the 1880s by a man named Otto Schott. This first edition of a heat resistant glass was unique, and captivated the likes of chemists like W.C. Taylor, a Corning Glass employee who retrieved the formula then made improvements on it. In 1912, the company sold the strong glass under the name Nonex. Initially, this glass was mainly used in lanterns, because the cold shock of rain and snow would often cause soda lime lanterns to explode. With Nonex, these lanterns were significantly more durable. Nonex was also used to make cases for batteries, and other industrial uses.

This brings us to Bessie Littleton. In 1913, after multiple instances of new stoneware or ceramic dishes cracking in the oven after just one use, Bessie expressed frustration to her husband, Jessie Littleton, an engineer at Corning. She asked him if he could bring home some of that heat resistant glass for her to try to bake a cake in. He sawed off the bottom of a battery jar that would have been used on the railroad, and brought it home for her to try to bake it. It worked! She began experimenting with different foods, all of them successful. Finally, in 1915, Corning became convinced that this product was worth trying. With the basics down (shape, formula), all that was left was a name. Pyrex was settled on as it was similar to Nonex, its predecessor[80].

Pyrex exploded in popularity. Just four years after its birth, in 1919, Pyrex had sold its 4.5 millionth piece. In the 1950s, Corning began selling bakeware that was made of tempered soda lime glass, but up until the 1990s, all of the laboratory

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[80] Pyrex® Webshop EU. "Our History." Pyrex® Webshop EU. Accessed March 16, 2023. https://www.pyrex.eu/pages/our-history.

glassware sold was borosilicate glass. This was until PYREX was sold to World Kitchens, which started using cheaper soda lime glass for beakers, flasks, test tubes, and more. These soda lime glasses are susceptible to thermal shock, and are less drop resistant than the borosilicate glasses[81].

Therefore, there is a difference between PYREX the product, the heat resistant borosilicate glass, and Pyrex the brand, a company that makes bakeware and other products made of soda lime glass, though they started as one company. Today, vintage Pyrex containers are collected, traded, sold, and bought by a large community of collectors. The classic vintage designs like the 1960 Starburst Cinderella Casserole dish (which sells for hundreds to thousands of dollars on Ebay), or even the famous 1959 Lucky in Love casserole dish. One of the Lucky in Love dishes sold for $4,000 in 2015.

81 "A Brief History of Pyrex Kitchenware." Pyrex history - the pyrex collector: Information for the vintage glass kitchenware enthusiast. Accessed March 16, 2023. https://www.pyrexcollector.com/history.php.

Even today, these products are incredibly popular[82].

Image 1: Lucky in Love Dish, 1959

Unfortunately for vintage lovers, and tying into my own research, vintage Pyrex tends to test very high for lead concentrations in its decorative paint using XRF technology. This paint can be on the inside or outside of the dishes, and can leach into food. Many vintage collectors would suggest you don't use the dishes, however, to preserve the value of the dishes if they are in good or great condition.

In conclusion, we got to this position due to simple capitalism. Soda lime glass is cheaper to produce than borosilicate glass, and so when the product line was sold to World Kitchens, the company started to use mainly soda lime for the products. French Pyrex however, is still borosilicate glass.

82 Pyrex® Webshop EU. "Our History." Pyrex® Webshop EU. Accessed March 16, 2023. https://www.pyrex.eu/pages/our-history.

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Me and Glass

Life Lessons from the Hot Shop

What I like about glass is its power to convey truths to people about life, in a way that stands apart from sports, or poetry, or working that minimum wage job. When I decided to do this project, I knew I wanted to write a list of things that I have learned in the hot shop, either from other people or from glassblowing itself. This part is the true capstone of my project. The research was fun, but this reflection here is the most important part of this project for me, because it is me verbalizing how glass has helped me confront many of my personal issues and fears. Maybe it can help you too, in some way.

Lesson #1: You Have To Suck At Something First, In Order To Be Kinda OK At It.

One thing that I really like about glass is that everyone starts off on a pretty even playing field. Everyone struggles with the heat, with using the tools correctly, with gathering, keeping the glass hot, and everything else that comes with a glass studio. But, with time and practice, you slowly get better. I am someone for whom many things come easy. I like to knit, I can write fairly well, I can play the flute and piccolo, and hike long distances. I am not amazing at any of this, but moderate success can get boring quickly. Glass was different because I wasn’t immediately successful with it. I spend about 15-20 hours a week in the hot shop every week between my partners' times and my own sessions, and I am still just mediocre after fours semesters. However, I get better everyday on my journey from "I Suck" to "I'm Kind of OK"!

One recent example of this is my axolotl journey! My axolotls went from an abnormally shaped stick with feathers to a huge axolotl sculpture that I am very, very proud of (images later in the chapter).

Lesson #2: Stuff Happens, Try Again or Give Up.

In glassblowing, glass breaks all the time, especially while it is still being worked in the hot shop. With time, glass students become better at preventing these losses, but it is a long journey of trial and error before this is perfected. And sometimes, things happen, and you drop or lose your piece even when you did everything right. An errant touch of a tool, or a few seconds too long at the bench can be the difference between having a piece make it to the annealer or getting tossed out with the rest of the broken glass. When this happens, a glass artist has three possible choices. They can try again, use a different method, or give up. There are benefits to all three, but usually, I try to do the first or second a few times before going with the third option.

Lesson #3: Communication is Key

Blowing glass is not just cultivating a relationship with the glass itself, but your partners who you are working with. If you don’t communicate well with your partner, you probably will not have a successful glassblowing experience. Being a good partner/assistant means being attentive, receptive, and somewhat anticipatory of needs, whether it be heating the piece to give the gaffer (lead artist) a break, or getting tools or doors, et cetera. Being a good gaffer is also important. Being clear with requests or instructions, on time, and respectful are essential parts of being a gaffer. Special shoutout to Kaitlyn Balkcom for being my partner for the past three semesters!

Lesson #4: Burned Beeswax and Burning Wood are the Best Smells

Lesson #5: People Will Never See The Hours That Went Into Developing A Skill

Most people will never learn to blow glass, or write really well, or perform doctoral level research, or bake macarons, or play the piano. Most people have no idea of the endless hours spend even practicing skills that allow you to do your art. Just because they don’t understand, they may undervalue your work, but don’t sell yourself short or undermine your own efforts. And remember, things that look easy, may have taken someone a very long time to achieve. Be supportive of each other! Create a positive creation environment.

Lesson #6: Not Everyone Will Like Your Work, And That's Ok

No matter how hard you work on something, or how perfect it is, not everyone will like or even give it a second thought. Don't let it get you down! Everyone has their own likes and dislikes.

Lesson #7: All Things Come To An End

Possibly the most existential of the things I have learned from glass, I must confront the possibility that after I graduate, I may never be able to do this kind of art again. The thought breaks my heart, but I am learning to act more in the present and not worry about whether or not I can do this in the future. I am learning to appreciate every hour in the studio, even the ones where I am helping someone or working on something tedious. I am applying this philosophy to every aspect of my life. After all, any of us could die at any moment, so we should try to appreciate the present and past as much as possible.

In Conclusion

Ok, on that somewhat depressing note, I have finished the lessons I have learned from glass. I am sure there are more, but these are the most important ones to me, and I hope you can learn from them too.

My Glassblowing Journey (In Pictures)

My very first cup that I made in glass.

My first project in glass: 25 similar objects. I chose to make many little figurines and arrange them in different family units.

A marble that I made in my first month of glass, I liked the optical illusion it created.

My first attempt at a vase went a little haywire!

Three successful vases: they held flowers.

A hot air balloon made in my second semester.

A fish with a hook attached to a repurposed chain.

Enameled fish paperweight.

Fish with enamel, googly eyes, and paint.

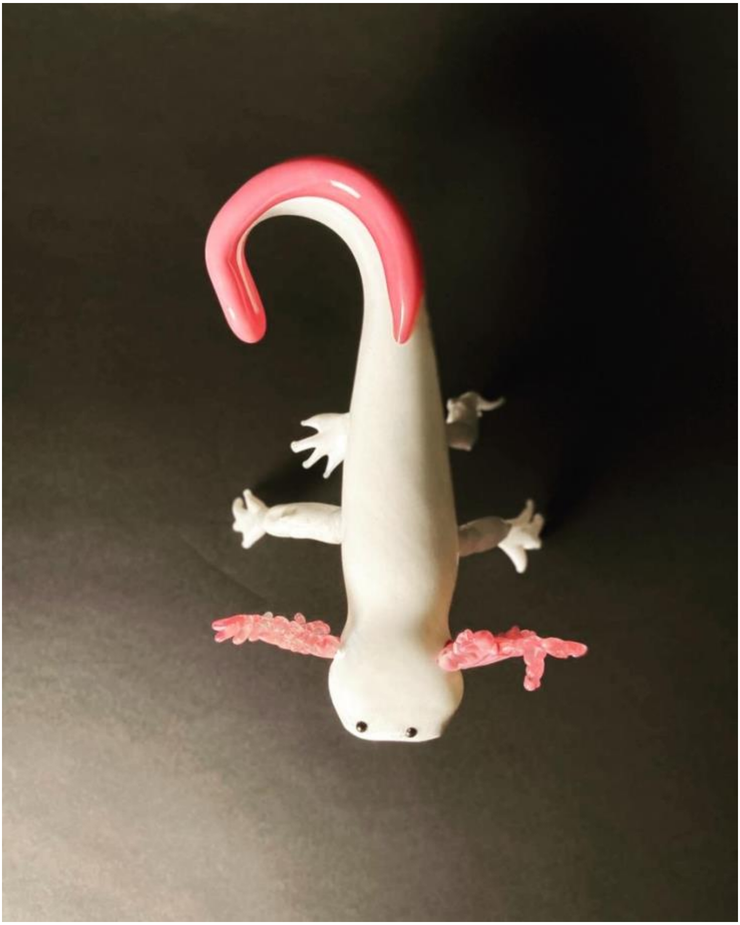
Fish in a fish bowl.

First project of my third semester: a white catfish.

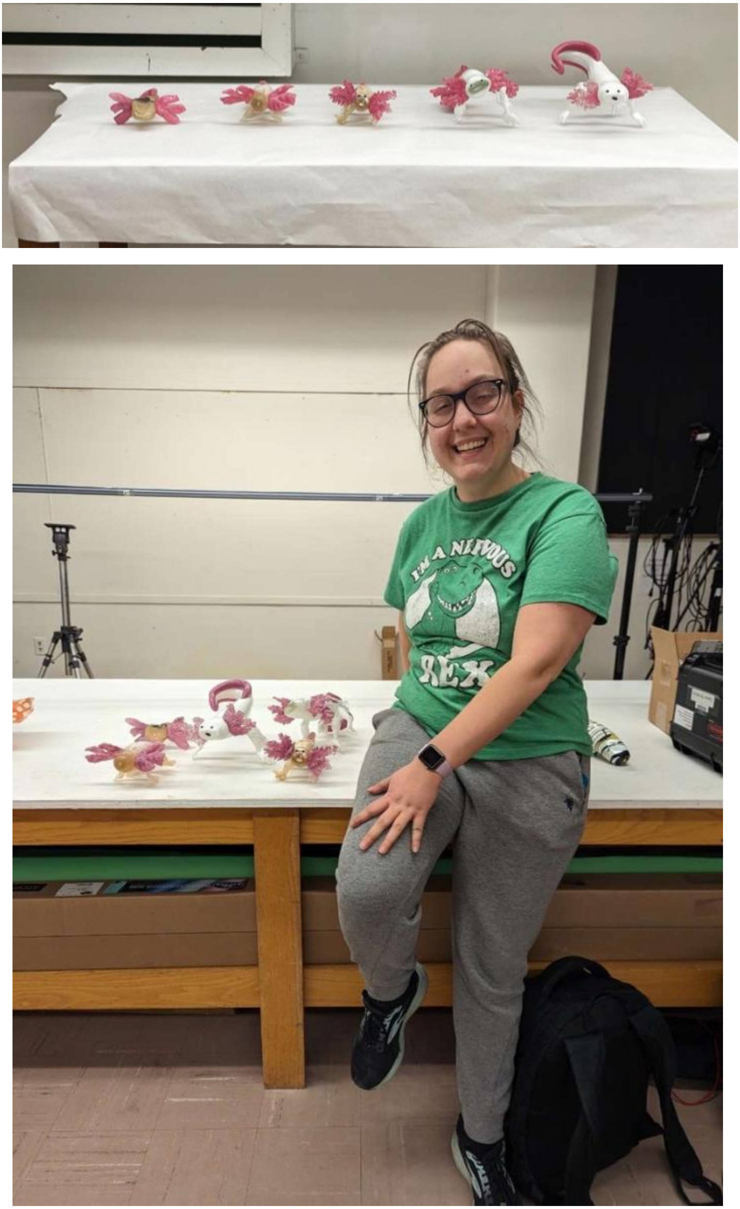
Making vases to experiment with colors!

A foray into sculpting with bonsai trees.

My first assignment in semester four: socks!



My first large project in fourth semester: axolotls!



Axolotl progression and me with my axolotls!

My most recent interest: attaching flowers to vases.

Am I an amazing glassblower? No. Am I a good glassblower? Also no. Am I able to pretty much make whatever strikes my fancy? Yeah, after a few tries usually. I am very pleased with my progress over the past two years. I love this art, and I love how it has influenced my future education decisions and past research. I love the friends that I have made in glass and I am very much looking forward to enjoying and savoring every last moment of the next year, my last year here at BGSU.

Blowing glass has given me so much happiness and joy. I am hoping to go to graduate school at Alfred University in Alfred, New York, for a Masters of Science in Materials Science. I would like to specialize in glasses, and continue blowing glass at the studios on Alfred's campus.

Reflection on this Project

Typing this now is very emotional for me.

Looking back on this project, I had no idea if I would be able to pull it off. However, 18,437 words later, I am here. What you are reading is the exhausting culmination of hours and hours and weeks and months of work. I said in my initial proposal that I wasn't sure if I could achieve everything I set out to do. In the end, I did have to manage expectations a bit, but I am proud of what I managed to create, and that was my most important goal for this honors project.

As far as future avenues for this work go, I would love to explore my themes of STEAM (Science, Technology, Engineering, Art, and Mathematics) in sculptural or scientific settings. I am sure that there are many interesting ways that I could implement these themes into sculpture.

I am highly satisfied with my effort and progress on this project. I had fun writing about weird and interesting topics related to glass. While I could not write about everything, I did write about what I wanted to delve deeper into. I found connections that I did not expect to find. If you made it to this part of my project, I want to thank you, and say I hope you had a fantastic time reading my work.