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Analysis and Description of the Iridescent Film on Calcites in Eastern Iowa

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Analysis and Description of the Iridescent Film on Calcites in Eastern Iowa

A Senior Thesis

By:

Cavit Schempp

In Partial Fulfillment
of the Graduation Requirements
for the degree of Bachelor of Arts in
Geology

Augustana College
Rock Island, IL 61201

1/7/2025

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Abstract

During the Devonian Period, eastern to central Iowa experienced multiple transgressive and regressive intervals. This study focuses on the Cou Falls and Gizzard Creek Members of the Coralville Formation, deposited during the Eifelian Stage. Sometime after the formation of the limestone, the interiors of various brachiopods, gastropods, and other fauna began to weather out, creating vugs within the limestone, which gave rise to the first of three growth phases of calcite in the form of rhombohedrons and scalenohedrons. After these primary calcites were formed, new fluids flowed through these vugs, depositing a previously misidentified iridescent film on the calcite crystals, observed in multiple locations in the region. Prior to this study, this iridescent film was being classified as stilpnosiderite, a pseudomorph of limonite. After the thin-film formed, two more phases of calcites grew: a secondary growth of large, white rhombohedrons and a tertiary growth of large scalenohedrons. These differences in morphologies are probably related to progressive changes in elemental concentrations of the groundwater. The focus of this research is to determine the thin-film composition and identify geochemical conditions of precipitation on the primary crystals. Based on SEM analysis, the film's composition is a mix of aluminum, calcium, nitrogen, silicon, and sulfur. When vugs are exposed to the natural elements (sunlight, rain, and groundwater), the film begins to disappear. Through experiments to simulate the natural environments of sunlight, rain, and groundwater for 100 days, it is evident that the film does not deteriorate within that time frame.

1. Background

Introduction

Thin-film iridescence is an intriguing optical phenomenon caused by the interaction of light with materials bearing a thin film. I will dive into the geological and crystallographic relationships to the thin-film iridescence found on the calcite crystals, reigning from the Gizzard Creek and Cou Falls Members of the Coralville Formation. With each crystal vug, a mineral-lined cavity, typically exhibiting only a single color of iridescence, challenges the typical rainbow effect. The highest quality iridescence is found in specimens from: Peske Quarry (the primary quarry used for this study), Jaben Quarry, Moscow Quarry, Conklin Quarry, and Klein Quarry (Figure 1). Investigating the interplay of geological history, stratigraphy, and

crystallography will shed light on the unique iridescence within the context of Devonian Period transgressive and regressive cycles.

The original idea of what this material was, based on the local mineralogy and iridescence, was that this film was a form of siderite (FeCO_3). This hypothesis was based on the fact that other minerals containing iron have been found in these quarries such as pyrite. However, pyrite in these formations tends to form on top of the film, meaning that it most likely formed after the deposition of the film. Through methods of quarry collection, experimentation, and analytical techniques like Scanning Electron Microscopy/Energy-Dispersive X-ray Spectroscopy (SEM/EDS), a general story of the formation of the film can be derived.

Stratigraphy

During the Devonian Period, the Laurentian shallow epicontinental seaway that covered the eastern portion of Iowa experienced a series of transgressive and regressive (T-R) cycles. Transgressions occur during periods of global warming, as land-based ice sheets melt and that melt water flows to oceans, raising sea levels; higher sea levels cause sea water to creep (transgress) inland, flooding continental interiors. Conversely, as global climate conditions cooled during ice ages, sea water was removed from the oceans to the land-based ice sheets, thereby lowering sea levels and causing the oceans to retreat (regress) from the land. The environment during these T-R cycles would vary depending on how much water had flooded or retreated from the continental interior, leading to a variety of environments ranging from shallow-marine to evaporite-forming depositional environments. This study looks into the Coralville Formation, but even more specifically the Gizzard Creek and Cou Falls Members (Fig. 3). These two titles of the members refer to the same stratigraphic unit, but the titling changes from Cou Falls, in the south-eastern region of Iowa, and Gizzard Creek in the north-western region, separated by a transitional line where the Gizzard Creek's dolomite changes to the Cou Falls packstone. These members are categorized by overlying the disconformity above the Rapid Member of the Little Cedar Formation. In the regions where the members are considered, the Cou Falls Member is a packstone with thin shaly carbonaceous partings in the lower portions. Crossing the transitional belt to the northwest, the Gizzard Creek is a dolomite containing calcite within its vugs (Day et. al., 1992). Primarily samples will be from the Cou Falls packstone, rather than the Gizzard Creek dolomite.

Thin-Film Iridescence

Thin-film iridescence is caused by the reflecting and refracting of incidental light. As light strikes a material with a thin film on it, the light will reflect a portion of it off the top of the film, while the remainder gets refracted (bent) and then continues through the film. Once the light that passes through the film reaches the crystal underneath, it is then both reflected and refracted again at the thin-film-crystal interface. With each refraction, the incident white light splits a bit into its separate prismatic color components, resulting in iridescence. The color of iridescence depends on layer thicknesses relative to the wavelengths of the different colors of light (Figure 2) (Dirks). The oddity of the specimens showcasing the iridescence in my study shows that only one color of iridescence is typically in each crystal vug, however, it is not uncommon to see a shift of color within the vug. The color of this iridescence is based on the thickness of the film, the colors that can be found are gold, green, blue, and purple (listed in increasing thicknesses) (Dirks).

Bacteria/Biofilms

Bacterias are capable of moving through the aquifer systems and settles into open spaces in which to colonize and feed. When they find vugs, karstic openings, and caves; they will begin to colonize together. Some modern bacteria are able to produce a biofilm overtop of themselves in organic/inorganic layers that they use as protection. Similar to in a human's body, the bacteria will use a biofilm to protect themselves even against antibiotics. Living organisms have basic primary elemental constituents being C, H, N, S, O, and P. However, they can also have other elements in notable quantities, being Na, K, Ca, Mg, Si, F, Cl, Br, and transitional metals of Fe, Co, Cu, Mo, Mn, Zn, Cr, and V (Engel and Macko, 1993).

Crystallography

Within the Cou Falls unit, the calcite crystals formed in the vugs follow three growth phases, which have been denoted as primary, secondary, and tertiary. Each growth is denoted by their own most common growth habits as detailed in the results and whether or not they have iridescence present. The primary growth phase is the only phase that displays the iridescent film, while the secondary and tertiary lack iridescence.

2.Methods

Unless otherwise noted, samples used in experimentation come from Peske Quarry. Doing this allows for general consistency that vugs were exposed to the same environments and are as similar in crystal growth time and variables exposed to during formation. Proper personal protection equipment (PPE) was worn to ensure safety during experimentation as some solutions can pose a risk to human health when exposed for prolonged periods.

2.1 100-Day Experiments

I chose a set of samples for each experiment to be used for 0, 1, 10, and 100 days and marked each one accordingly. Using the day 0 samples as bench markers for what the samples looked like beforehand by wrapping them in paper and placing them in a container allowed for the original condition to be preserved. On the scheduled days (1, 10, and 100), I removed the samples from the experiment and wrapped them in paper to prevent any contamination once the experiment was completed. Throughout the experiments, I took progress photos at regular intervals and made note of any observable changes when the samples were removed. This documentation allowed visual tracking and demonstrating the alterations that have occurred in the physical samples over time.

2.1.1 Light-Based Experiment (sunlight)

I placed a general greenhouse light in a dark space shining onto the floor and positioned the samples 6 inches from the light source. This allowed for consistent exposure to all samples.

2.1.2 Neutral Water Experiment (groundwater)

I placed the selected samples into a container and filled it with deionized water until the water level covers the samples. Next, I used an HTH test strip to check the current pH level. Using deionized water should result in the other tests on the strip reading neutral, but the pH level should be around 7.5 (modern groundwater pH for Iowa). Finally, I sealed the container and covered it with a blanket to prevent light exposure to the samples.

2.1.3 Acidic Water Experiments (rainwater)

2.1.3.1 Using *pH Down*

For this experiment, I poured enough DI water (7.0 pH) into the sealable container to cover the top of the samples and added Clorox pool & spa *pH Down* to the water. I stirred the mixture until the *pH Down* was fully dissolved. The quantities of water and *pH Down* will vary based on the size of the chosen container, but the pH goal is around 5.5. Next, I placed the samples into the solution, and visible gas bubbles began to float to the surface. If no reaction occurs, add more *pH Down* and stir until the reaction begins. Once the samples were reacting, I sealed it, and covered it with a blanket.

2.1.3.2 Using Perrier Sparkling Water

After labeling the samples, I placed them into the container and carefully poured Perrier Sparkling Water into the container, adding enough to cover the tops of the samples. I then sealed the container securely. Finally, I covered the container with a blanket to block out light and maintain consistent conditions. The purpose for using Perrier Sparkling Water is because in the natural world, rain becomes acidic due to the combination of CO_2 with the H_2O forming carbonic acid, and the Sparkling Water works similarly by bubbling CO_2 into the water.

2.2 Strong Acid Film Extraction

I broke off individual crystals that possessed the iridescence, and placed them onto different glass dishes. Within each dish I either applied a few drops of HCl (5% dilute) or Nitric Acid (HNO_3) to weather out the calcites. HCl has a pH of ~4 and Nitric Acid has a pH of 3, thus it is harsher than rain would normally be; however this is merely to speed the reaction up. As the film began to float in suspension, I diluted the solution with DI water and pulled the crystals off the glass dish to try to stop the reaction. Using an SEM disk and carbon tape, I dabbed onto the suspended film to lift it off the fluid and applied it to the tape itself for later analysis.

2.3 Film Growth Experiment

To investigate how the film might grow, I used an experiment by arranging the bottle caps in six sets, with two caps per set. I then labeled each set for different environments. The labels I used for this experiment were as follows: “Acidic water with matrix,” “Neutral water with matrix,” “No water with matrix,” “Acidic water with no matrix,” “Neutral water with no matrix,” and “No water with no matrix.” In the six caps labeled as having a matrix, I placed a small piece of limestone from the sample matrix. This served as a nucleation point for the film to grow on. For the caps labeled as “acidic water,” I filled them halfway with water from the acidic experiment, and for those labeled as “neutral water,” I used water from the neutral experiment. I left the caps labeled as “no water” empty.

Next, I used a spoon to scoop out floating film pieces from the *pH Down* acidic experiment and placed a few pieces into each cap. I then took one cap from each experiment set and placed it into its own sealable bag and used a vacuum to remove as much air as possible. After labeling the bags to correspond with the caps inside, I positioned the bottle caps according to their designations. As water evaporated from the caps over time, it was crucial to maintain the water levels. I gradually added the appropriate water (either acidic or neutral) into the caps as needed, approximately every 1-2 days based on the rate of evaporation, and left the caps undisturbed for 100 days.

2.4 SEM/EDS Analysis

I used a NanoImages SEC SNE-3200M Scanning Electron Microscope (SEM) with Bruker XFLASH Energy-Dispersive X-ray Spectrometer (EDS). These machines allowed me to obtain chemical compositions of the film and get high quality BackScattered Electron (BSE) and Secondary Electron (SE) photomicrographs of samples. Using carbon coating on the samples and inserting them into the machine, I began to image the specimens. I chose to use carbon, instead of gold, to coat my samples because our machine is able to read concentrations of gold, but not carbon. This allowed me to have accurate weight percentages without the addition of gold peaks to each analysis. After adjusting the clarity of the image and pausing it at its clearest, I captured the image on the Bruker ESPRIT (EDS) program for elemental analysis. I selected point and area targets, which provided the elemental analysis. Importing the elemental data into a Google Sheets workbook, I started to organize the individual scans by the different elements. This step

allowed me to find averages and compare the elemental analysis of each scan and all the scans together. See appendices for how I organized the raw data.

2.5 Crystallography

I took the time to examine the various crystal habits found at the quarries that provided an additional layer of understanding regarding the timing of the film formation and other crystals. Using a microscope connected to a digital monitor, I was able to analyze these crystals more closely. Aligning each crystal along its c-axis, and using the image projected onto the digital monitor screen, I was able to measure the angles of the different crystal faces (based on a and b axes as well) using a protractor. Lastly, I marked a stereonet graph using those angle measurements to map out the locations of the crystal faces.

3.Results

3.1 100-Day Experiments

3.1.1 Light and Neutral pH Water Experiments

For both sets of samples, there were no changes that I observed either by the naked eye or under a microscope up to 40x magnification. SEM analysis also indicated that chemical compositions remained unchanged over the course of the 100 days. The lack of changes provides us with insight that sunlight is unable to bleach out the color from the iridescence, and the neutral water was unable to dull or remove the film either over the course of 100 days. For the evidence from light experiments, see Figures 6 through 9 for visual changes and Tables 1 through 4 for elemental quantities, and for the neutral water, see Figures 10 through 13 and Tables 5 through 9, respectively.

3.1.2 Acidic pH Water Experiment

When I conducted the experiment, the reaction that began to take place immediately started to lift the film off the calcite crystals. However, it did not remove all the film off the crystals, but rather just large sheets at a time, still leaving some behind. After one day of the experiment, I removed the Day 1 sample. Gypsum had begun to grow because of the addition of sodium bisulfate into the system from the *pH Down* and continued to grow on all the samples left in the solution. This gypsum was a result of the calcite and limestone releasing calcium during

the reaction and that calcium mixed with the sulfur, to form the gypsum. This growth was taking place on any calcite it could attach to, however, did not grow from the film that remained on select portions of the calcites. Overall, this experiment did not go as I had planned in that the addition of sulfur into the system caused the growth of gypsum. This experiment supported my hypothesis that an acidic solution is capable of removing the film off the crystals. However, with the gypsum growth, I needed to prove that it wasn't the result of the gypsum.

After the *pH Down* experiment failed to perform in the expected manner, I needed to retest the hypothesis that acidic pH water, like that of rainwater, may be able to remove the film. Utilizing the Perrier Sparkling Water, which is carbonated water that has a similar pH to that of rainwater (5.0-5.5), allowed me to replicate atmospheric rain as closely as possible. However, after 1, 10, and 100 hours in this solution, samples were removed at their respective times, and once again there was no change to the film.

3.2 Film Extraction

Following the instructions from the hard acid film extraction portion of the methods section, the calcite crystals are rapidly weathered away by the hydrochloric and nitric acids, leaving small pieces of film floating in suspension. During the first run of this experiment, I used a sewing needle to remove the film from the glass dishes and place them on the pre-prepared SEM stage disks. After I completed the analysis on those samples, I noticed an odd nickel peak as a new addition to the film that typically had not been previously noted. This peak told me something odd had to happen with this experiment that I didn't have with other experiments, which led me to look at the only new factor, being the sewing needles. This led me to find that sewing needles consist of a nickel coating to protect the needles from rusting the steel underneath it. When the needle came in contact with the acid small amounts of nickel were released and subsequently analyzed. Due to the contamination of the nickel in the samples, a second run of the experiment was required. On the second attempt instead of using a sewing needle, I used bamboo toothpicks, which won't react with the acid. The analysis of the film that resulted after placing in the SEM is in section 3.6. Using the strong acids caused the weathering of the calcite crystals to be more rapid than what would happen in nature. However, slow and continued exposure to the acidity of natural rain I believe could eventually weather away the

calcites releasing the iridescent film and washing it away; that is a result that we observed at quarries with samples that had been exposed to rain and usually lacked iridescence where we believed there should have been.

3.3 Film Growth Experiment

After extracting the film off of the crystals in the Acidic Water Experiment and placing them in bottle caps, I periodically checked if any changes had taken place. The only adjustments I made during the experiment was in the addition of water in the samples that required water to be a part of the environment, due to evaporation of that water. At the end of the experiment, there was no new film growth, with the only thing growing being gypsum in the bottle caps that contained acidic water. As a result, I did not determine whether “normal atmospheric conditions” (based on the environments I created) would promote the growth of the film.

3.4 Regional Elemental Difference (SEM/EDS)

Elemental data of the primary elements composing the thin film samples from Peske Quarry, Jaben Quarry, and Moscow Quarry, reveal no regional differentiation of the film; according to quarry location and the stoichiometric percentages of elements present. See tables 9 through 11 and figures 14 through 16 for the elemental data of the samples from their respective quarries.

3.5 Film Analysis (SEM/EDS)

After around 500 elemental scans, the primary elements that compose the film are found to be aluminum, calcium, magnesium, nitrogen, silicon, sodium, and sulfur. These elements are summarized in table 12 and figure 17, as well as isolated film in tables 13 and 14 and figures 18 and 19.

3.6 Crystallography

The primary growth phase consists mostly of three different kinds of rhombohedrons which are discussed below with the exception of a flattened rhombohedron crystal habit. I was unable to accurately gather angle measurements of two crystal samples that contained these flattened rhombohedrons as such they are not included in the drawn stereonet, but are worth mentioning. There are also the occasional scalenohedron growth that is categorized in the primary growth category. I measured the average sizes of the rhombohedral crystals range from 1 to 4 mm, with some occurrences being slightly larger; and the scalenohedral crystals range from 3 to 5 mm. The modifications of these crystals take place on the c-axis, appearing to have been cut flat, and may show new crystal growth on this flattened (0001) face, however that does not always occur. Occasional modification along the edges can also be observed leading up to the point of the c-axis. The iridescent film ranges in the full range of colors from gold to purple and does not show preferential growth on any of the faces or edges of the crystals.

Utilizing microscope projections, it was possible to measure the angle at which the crystals have grown. Using those angles, I drew up stereonet diagrams of the crystal growth habits. See Figures 19-21 for the primary growth information. The results show that the normal rhombohedrons consist of $35^{\circ} \pm 5^{\circ}$ angles and the modified rhombohedron has a horizontal 0° (0001) face. Whereas the scalenohedron is constructed using faces at $50^{\circ} \pm 5^{\circ}$ angles on all the faces.

Secondary growth phases were found to occur as large pale white rhombohedrons that can create large bridging structures. They match typical rhombohedrons; however, they can sometimes also occur slightly elongated. The size can range from 4 to 12 mm and usually does not have any iridescence present. The result being $35^{\circ} \pm 5^{\circ}$ (Figure 22).

The tertiary growth phase occurs as medium to large, modified nail-head scalenohedral prisms and normal scalenohedrons that are clear to a milky white color. These can be commonly found with primary crystals stuck on the inside from the tertiary growth growing over the primary growth. This phase also does not show any iridescence. I was unable to get measurements of angles or sizes of the normal scalenohedrons, however I was able to do so for

the scalenohedral prisms. These scalenohedral prisms range primarily around 0.5 to 15 mm, with greater variance in unique cases. Results show that the six exterior edges are made up of 90° angles, and the faces on top of the crystal are composed of 30° ±5° angles (Figure 23).

Present in some primary rhombohedrons and scalenohedrons is an added structure on the faces of the crystals. These structures either show up as a bulbous structure (Figure 25) or an angular structure (Figure 26). This added structure is either the result of the thin-film deposition showing the crystallization of the calcites underneath the film or it is the structure of the film itself. However, without being able to remove the film without also weathering out the calcite crystals, it is difficult to tell whether it is a surficial texture of the film or the underlying crystal itself.

Discussion

Based on the fact that, iron is a required element for the formation of siderite, this was the primary element I wanted to test for. This led to the choice of using the SEM/EDS to check the chemical composition, and with a supreme lack of iron I was able to rule out the hypothesis of siderite. This use of the SEM/EDS helped me to build a general basis of the elements, in the film, to build the story of the iridescence.

The story that we have derived from the collected evidence is as follows: Around 390 mya, sediments were being laid down to make the current limestone matrix that contain these calcite-filled vugs. After the matrix was formed, the fauna that comprise the limestone began to weather away forming the current vugs. Sometime after that, the primary calcites began to grow. Based on the organic elemental markers of the thin-film, I surmised that the thin-film is a result of bacteria depositing their corrosive biofilm to intake nutrients. Once the bacteria died, the biofilm began to dry out, cementing itself to the primary calcite crystals. The longer the bacteria were present, the thicker the biofilm they created, leading to the different colors present, with purple being the thickest and gold being the thinnest (Dirks).

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Figures and Tables

Introduction Figures

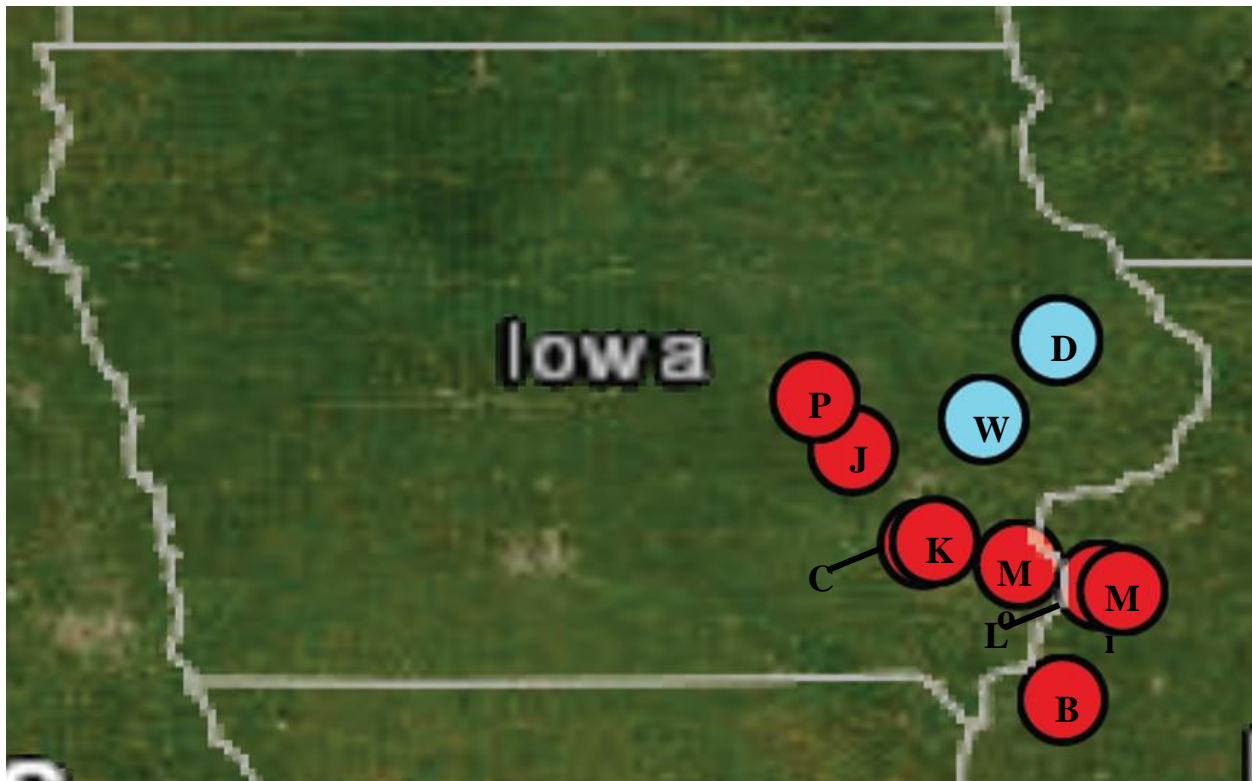


Figure 1: A map of the quarries that possess iridescence (red dots) and nearby quarries that do not possess iridescence (blue dots). Letters correspond to the following quarry names:

Red Dots

- P = Peske Quarry
- J = Jaben Quarry
- C = Conklin Quarry
- K = Klein Quarry
- Mo = Moscow Quarry
- L = Linwood Quarry
- Mi = Mill Creek Quarry
- B = Biggsville Quarry
- Fairfield
- St. Francisville,
- Canton, IA
- Knoxville
- Oskaloosa

Blue Dots

- D = Dyersville Diggings
- W = Weber Quarry

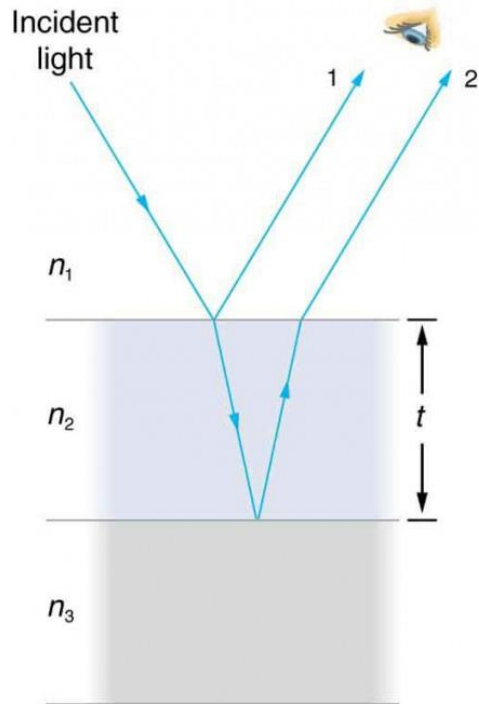


Figure 2: A diagram showing how light passes through and is both reflected and refracted by a thin film (n_2) iridescence (Dirks).

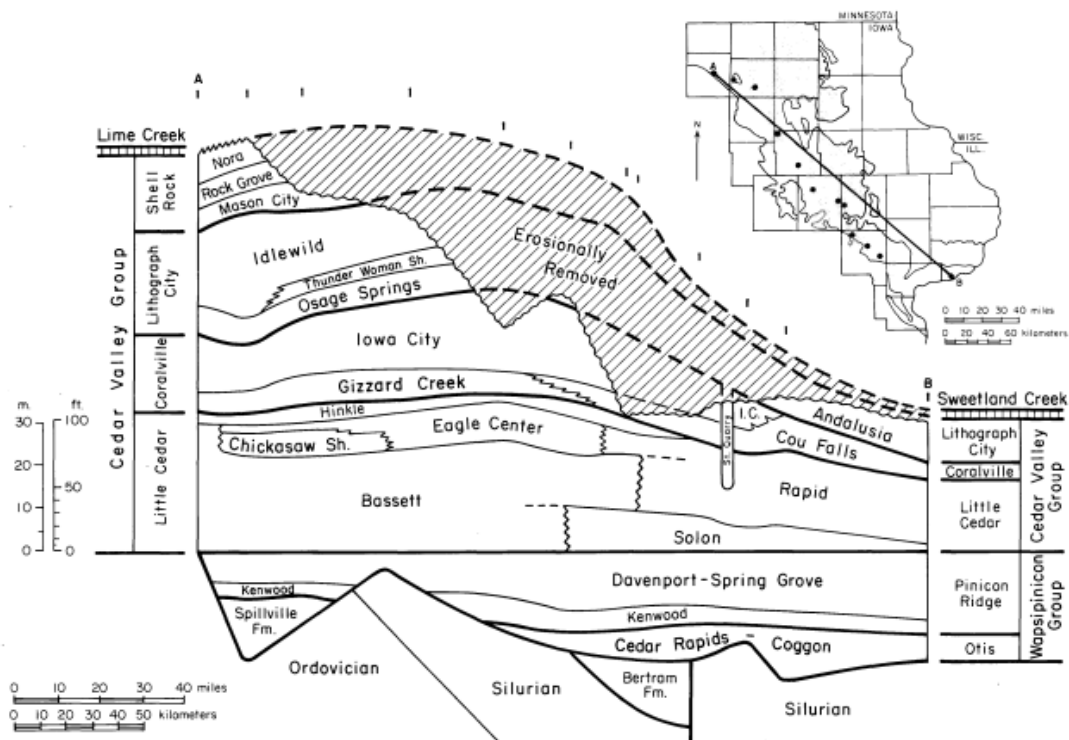


Figure 3: Generalized cross-section of the Cedar Valley and Wapsipinicon Groups from north-central to south-eastern Iowa (Day 1992, Witzke 1988).

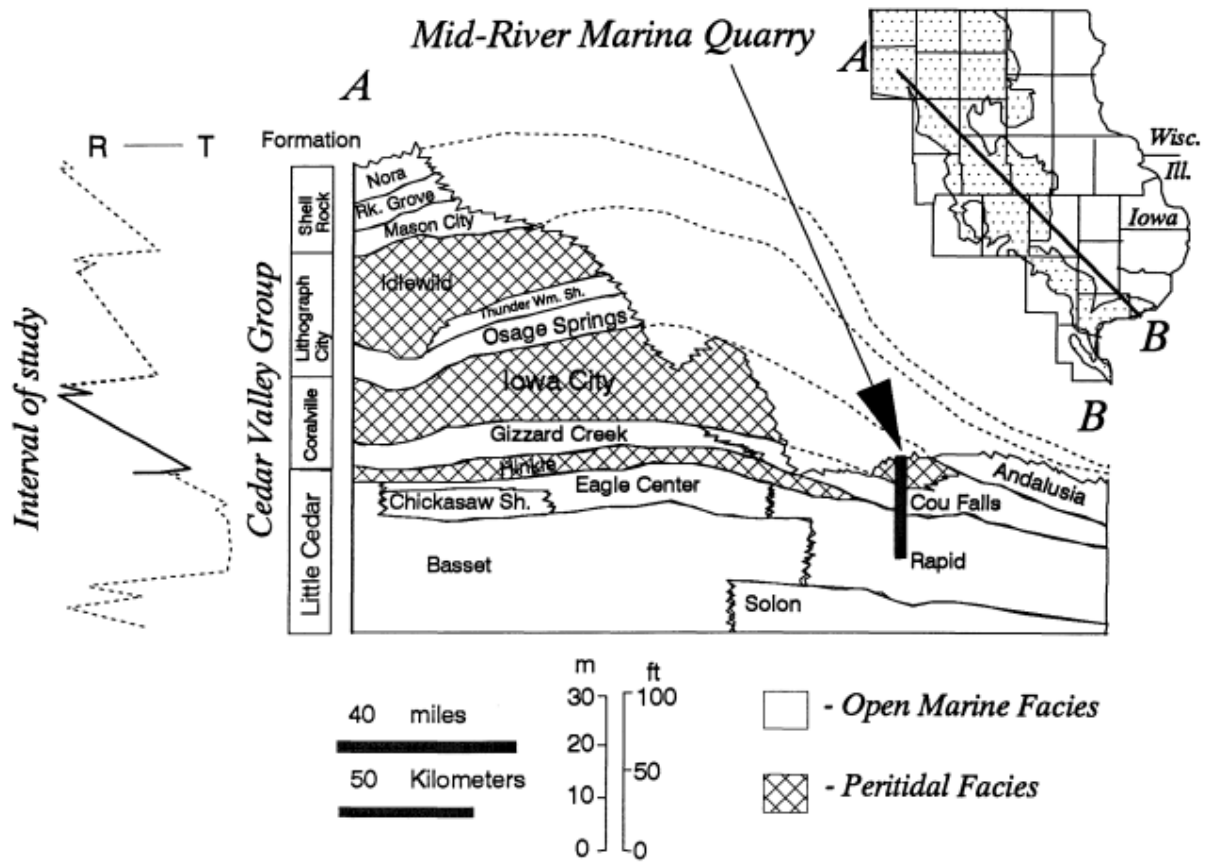


Figure 4: Cross section of the Cedar Valley Group with their associated T-R cycles (Day 1992, Witzke 1988).

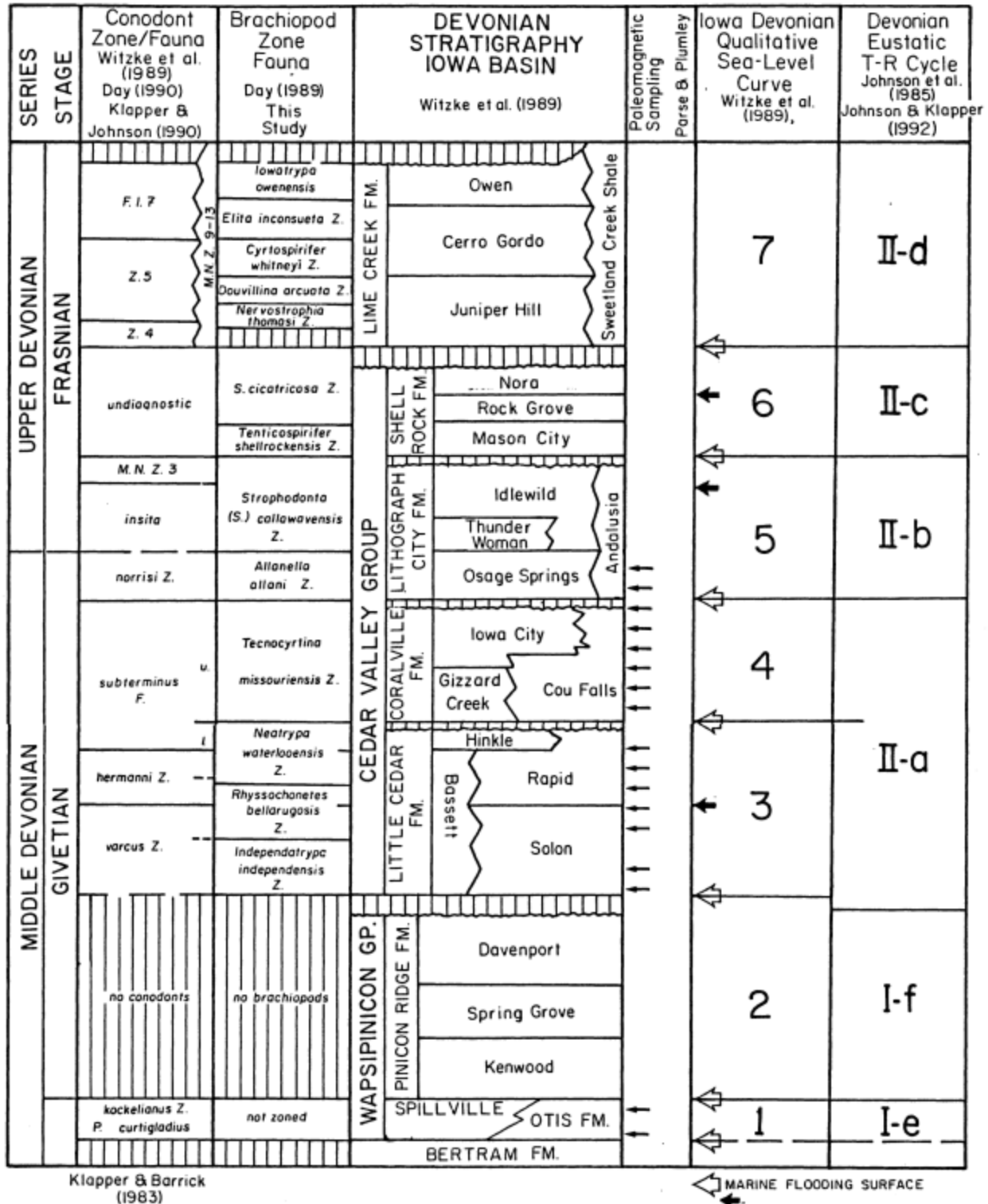


Figure 5: Stratigraphic unit with the corresponding T-R cycles as well as paleontology of units (Day 1992, Witzke 1988).

100-Day Experiment Tables and Figures

Light-Based Experiment

Table 1: Processed elemental data from Day 0 crystals collected from Peske Quarry presented in a pivot table, excluding calcium which comprises 97% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
Al	0.05	0.08
Mg	0.26	0.40
Na	0.01	0.02
S	0.53	0.84
Si	0.82	1.33
Grand Total	63.89	100

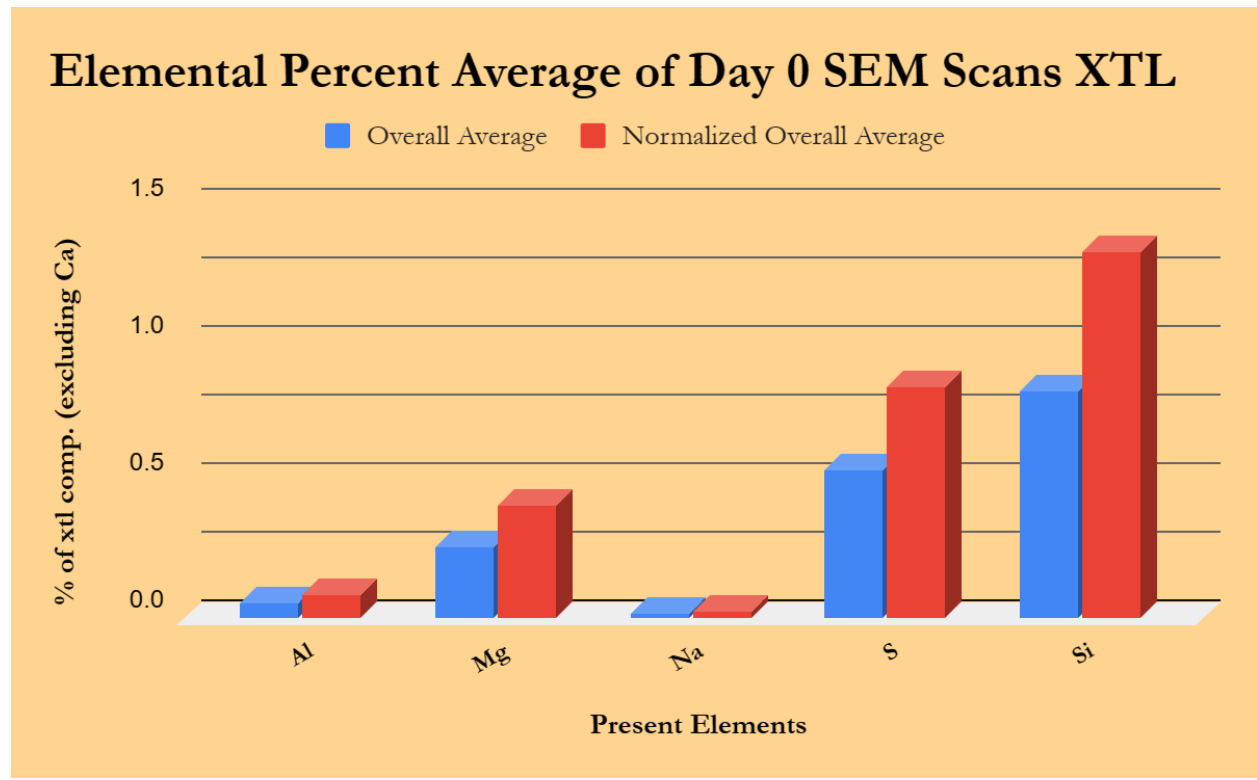


Figure 6: Graph of the elements from table 1.

Table 2: Processed elemental data from Day 1 crystals collected from Peske Quarry presented in a pivot table, excluding calcium which comprises 99% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
S	0.05	0.07
Si	0.07	0.10
Grand Total	83.82	100

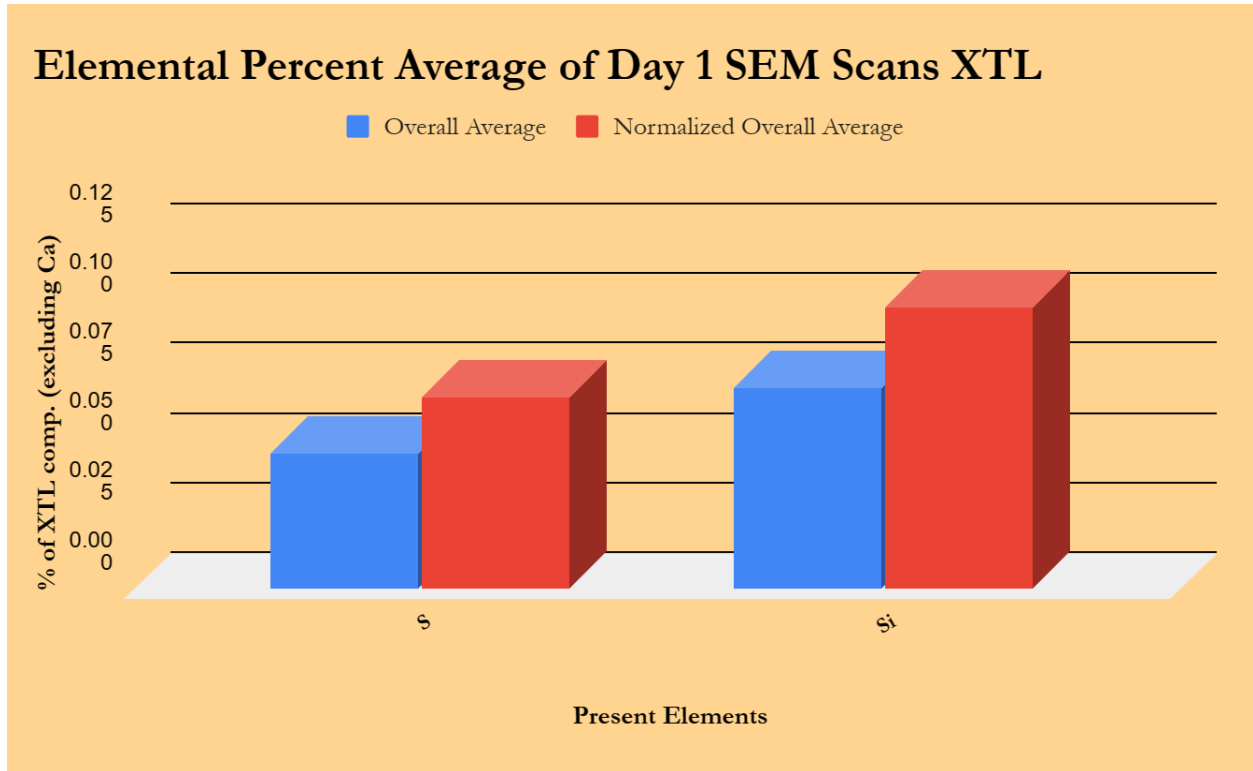


Figure 7: Graph of the elements from table 2.

Table 3: Processed elemental data from Day 10 crystals collected from Peske Quarry presented in a pivot table, excluding calcium which comprises 99% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
Al	0.05	0.07
Mg	0.03	0.06
N	0.17	0.22
Na	0.03	0.04
S	0.02	0.02
Si	0.04	0.09
Grand Total	89.48	100.00

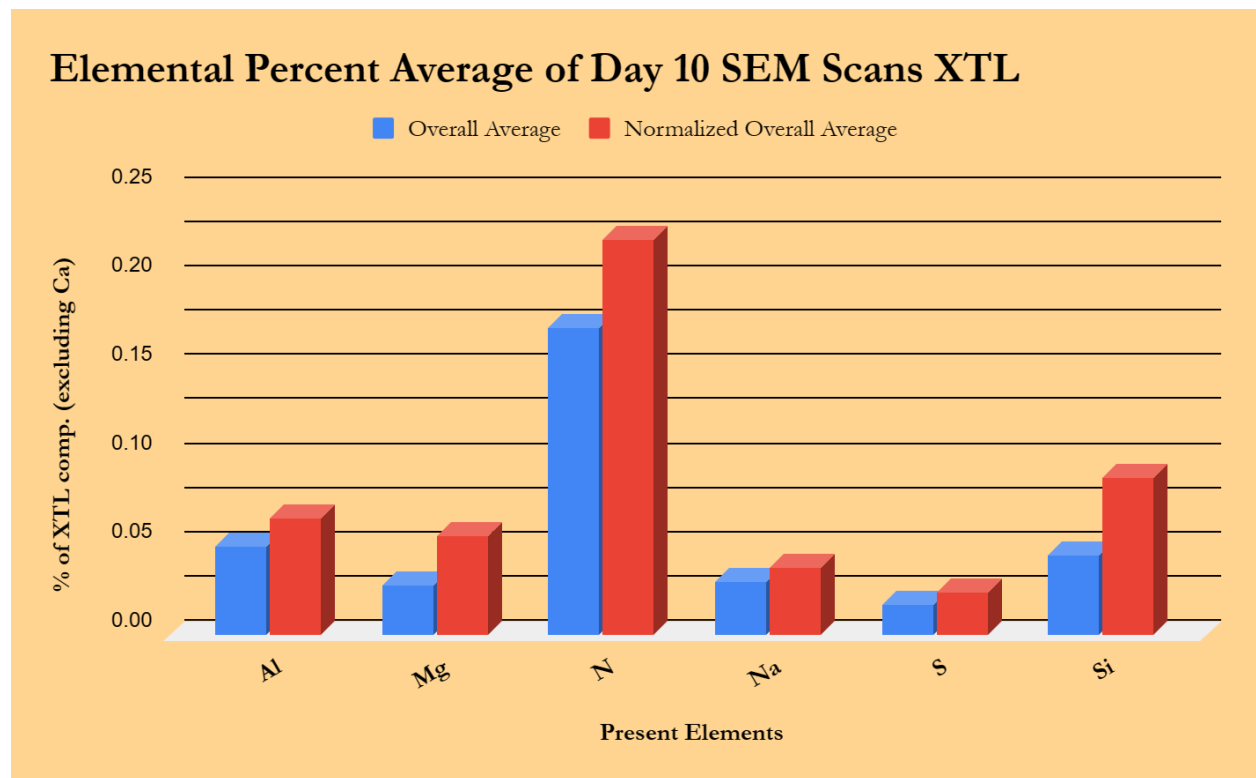


Figure 8: Graph of the elements from table 3.

Table 4: Processed elemental data from Day 100 crystals collected from Peske Quarry presented in a pivot table, excluding calcium which comprises 95% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
Al	0.11	1.19
Mg	0.02	0.02
N	0.13	0.17
Na	0.02	0.03
S	0.65	0.98
Si	0.98	1.37
Grand Total	79.21	100.00

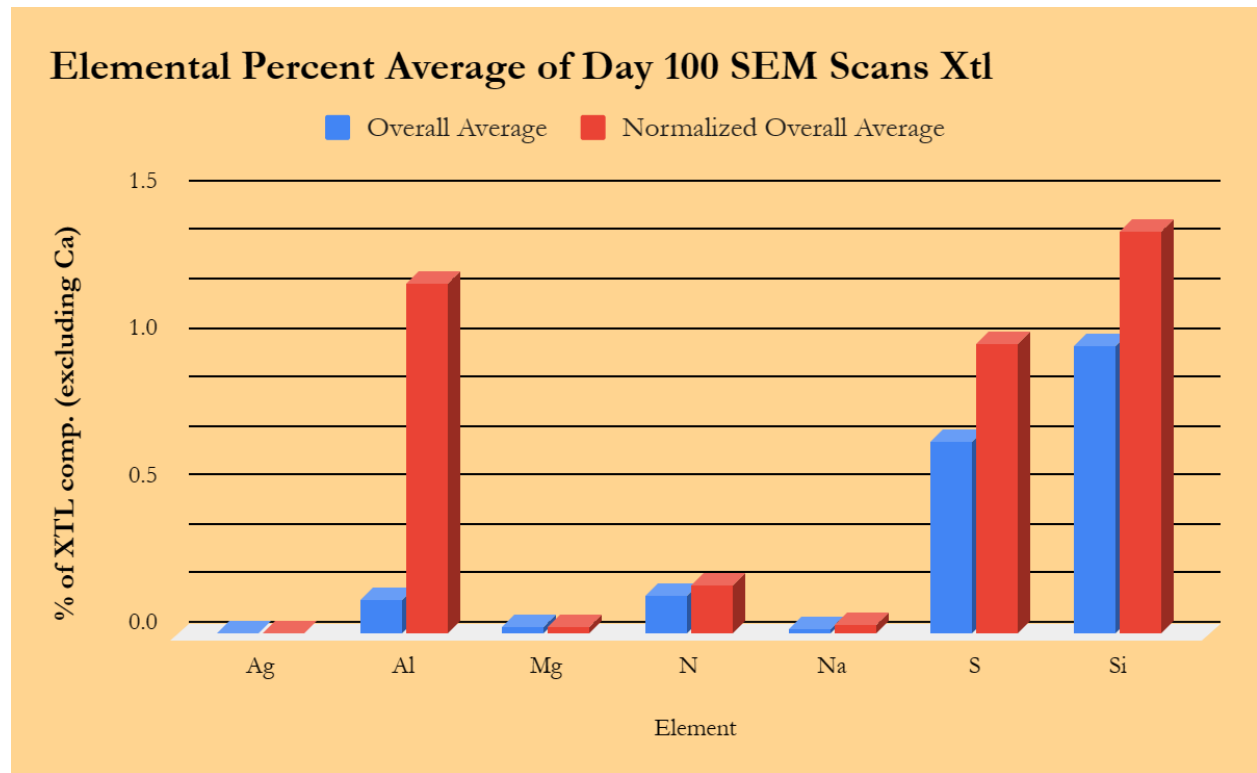


Figure 9: Graph of the elements from table 4.

Neutral pH Water Experiment

Table 5: Processed elemental data from Day 0 crystals collected from Peske Quarry presented in a pivot table, excluding calcium which comprises 96% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
Al	0.02	0.02
N	0.60	0.79
Na	0.04	0.06
S	0.68	0.92
Si	1.10	1.51
Grand Total	69.10	100.00

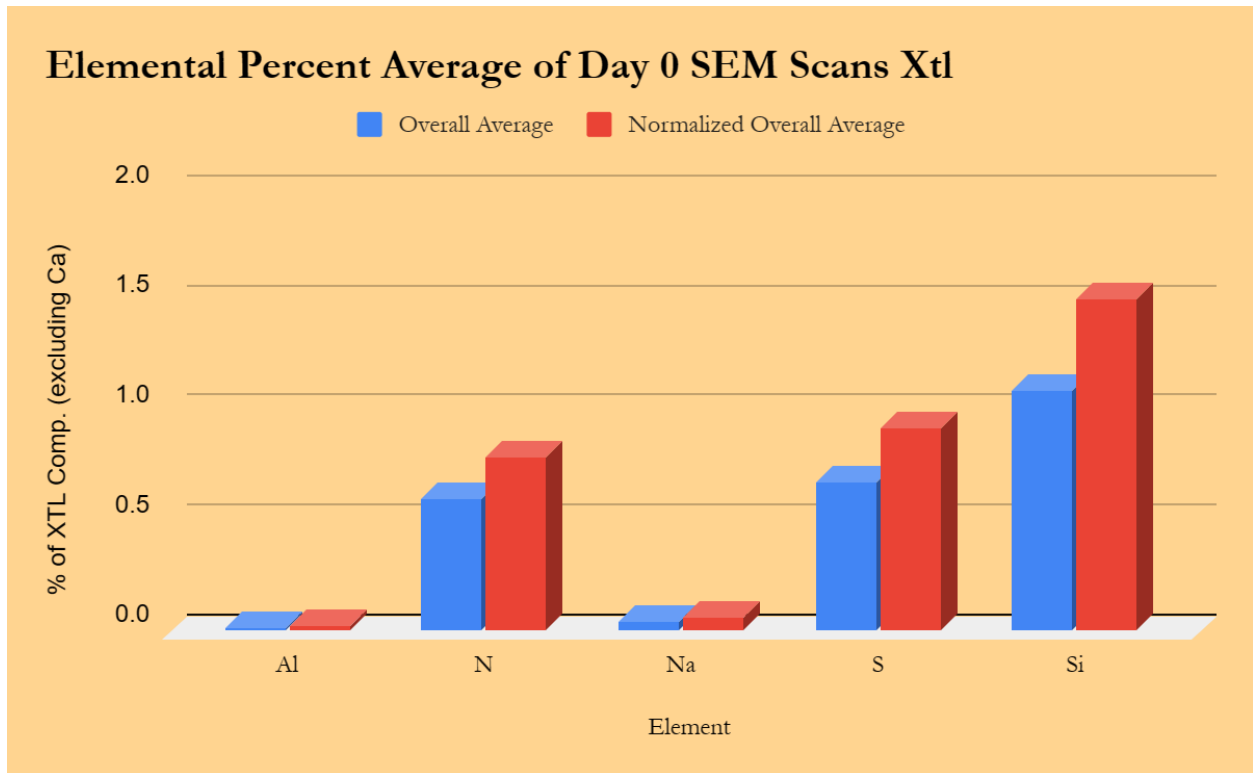


Figure 10: Graph of the elements from table 5.

Table 6: Processed elemental data from Day 1 crystals collected from Peske Quarry presented in a pivot table, excluding calcium which comprises 98% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
Al	0.03	0.03
Mg	0.02	0.02
N	0.48	0.60
Na	0.02	0.02
Si	0.02	0.03
Grand Total	88.41	100.00

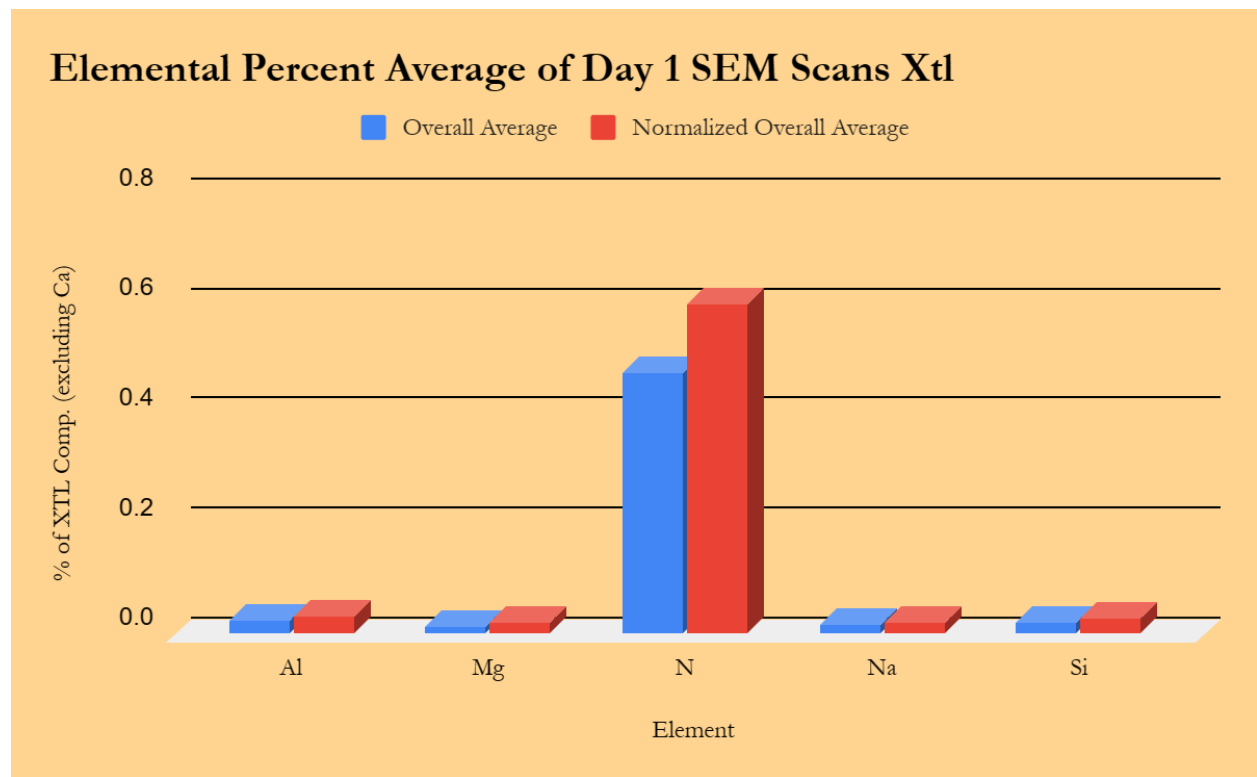


Figure 11: Graph of the elements from table 6.

Table 7: Processed elemental data from Day 10 crystals collected from Peske Quarry presented in a pivot table, excluding calcium which comprises 98% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
Al	0.03	0.04
Mg	0.27	0.34
N	0.03	0.04
Na	0.23	0.29
Si	0.13	0.18
Grand Total	76.95	100.00

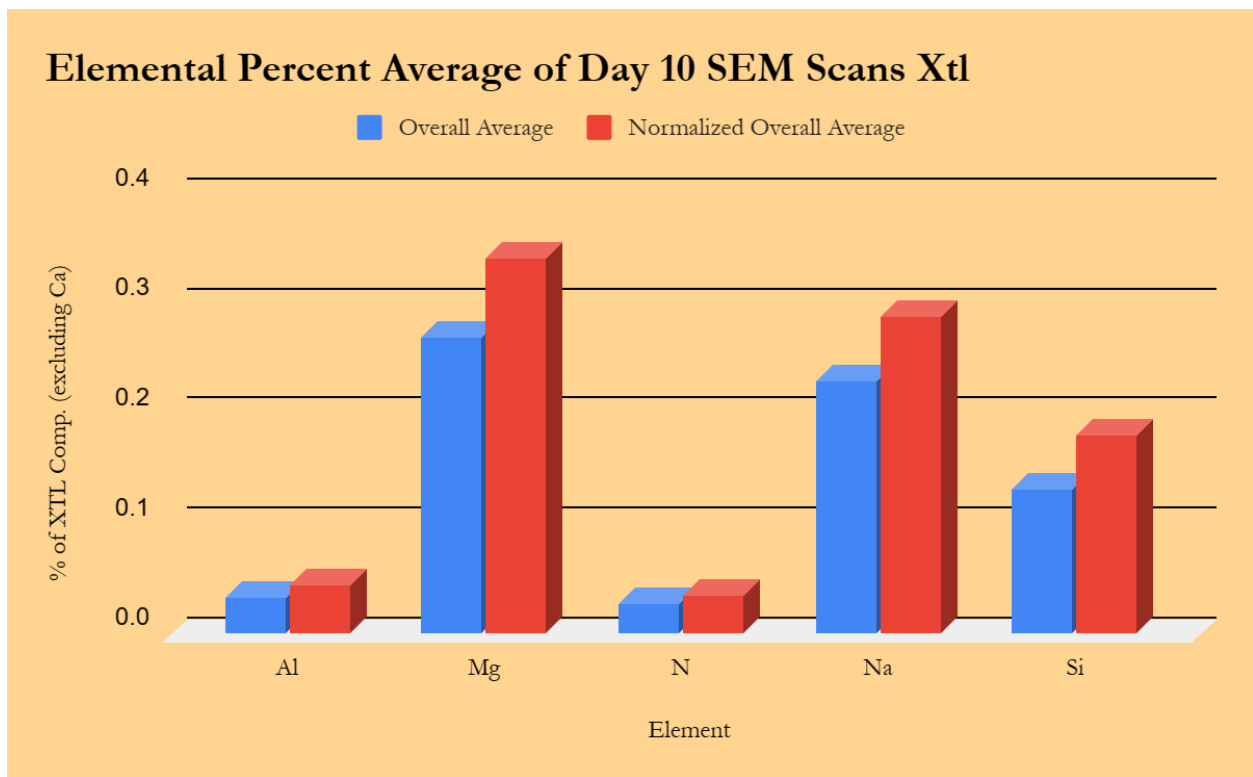


Figure 12: Graph of the elements from table 7.

Table 8: Processed elemental data from Day 100 crystals collected from Peske Quarry presented in a pivot table, excluding calcium which comprises 96% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
Al	0.06	0.07
Mg	0.01	0.01
N	0.05	0.07
Na	0.11	0.14
S	0.05	0.07
Si	0.16	0.23
Grand Total	80.18	97.73

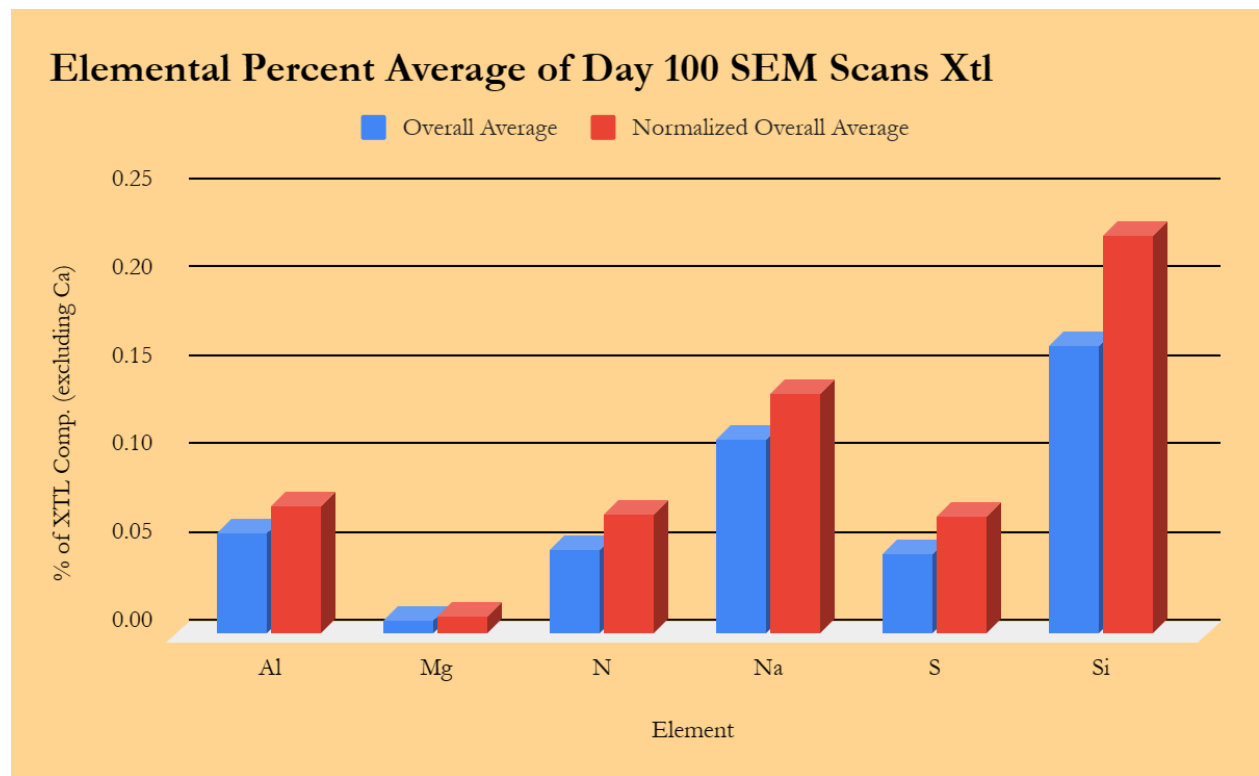


Figure 13: Graph of the elements from table 8.

Regional Differences Tables and Figures

Table 9: Processed elemental data from crystals collected from Peske Quarry presented in a pivot table, excluding calcium which comprises 95% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg (Stoichiometric %)	SUM of Norm. Overall Avg (Stoichiometric %)
Al	0.03	0.05
Cl	0.05	0.07
Mg	0.05	0.08
N	0.24	0.37
Na	0.21	0.30
S	0.57	0.88
Si	0.18	0.27
Grand Total	66.19	98.00

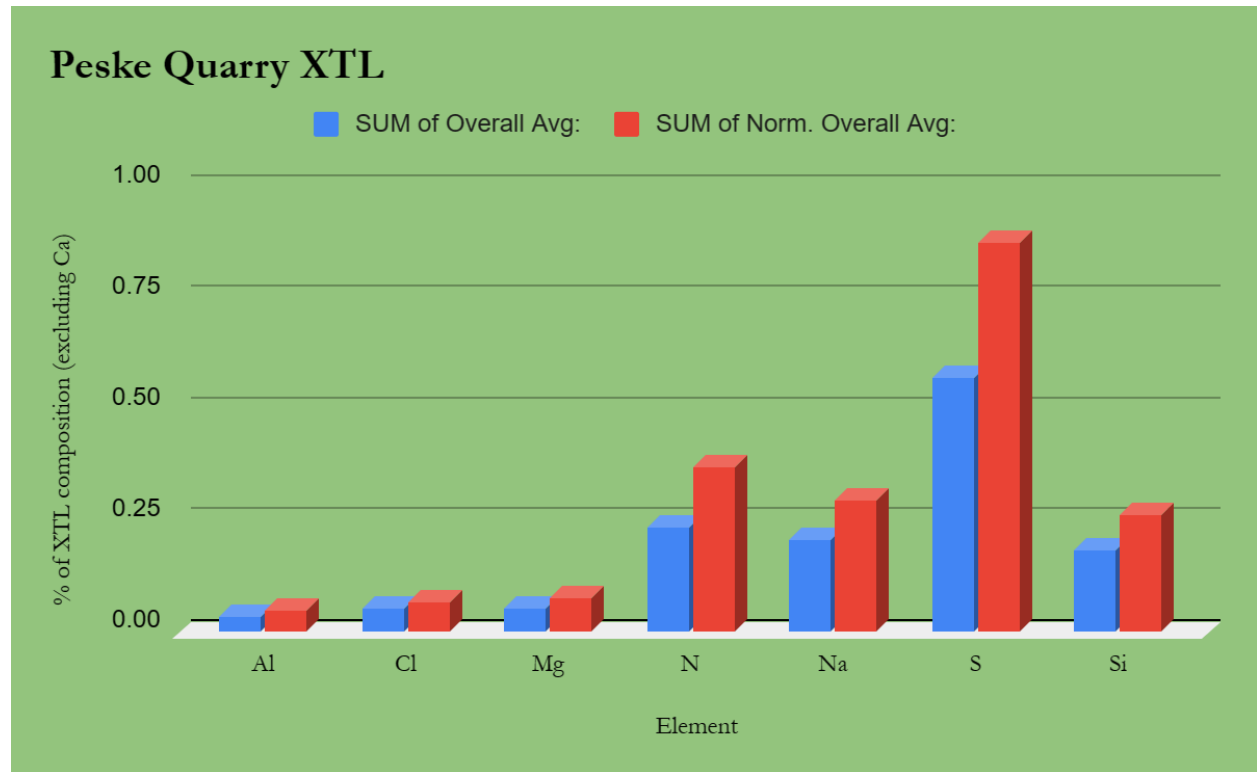


Figure 14: Graph of the elements from table 9.

Table 10: Processed elemental data from crystals collected from Moscow Quarry presented in a pivot table, excluding calcium which comprises 98% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
Al	0.39	0.46
Mg	0.03	0.13
N	0.49	0.5
Na	0.07	0.10
S	0.03	0.05
Si	0.19	0.27
Grand Total	79.20	99.97

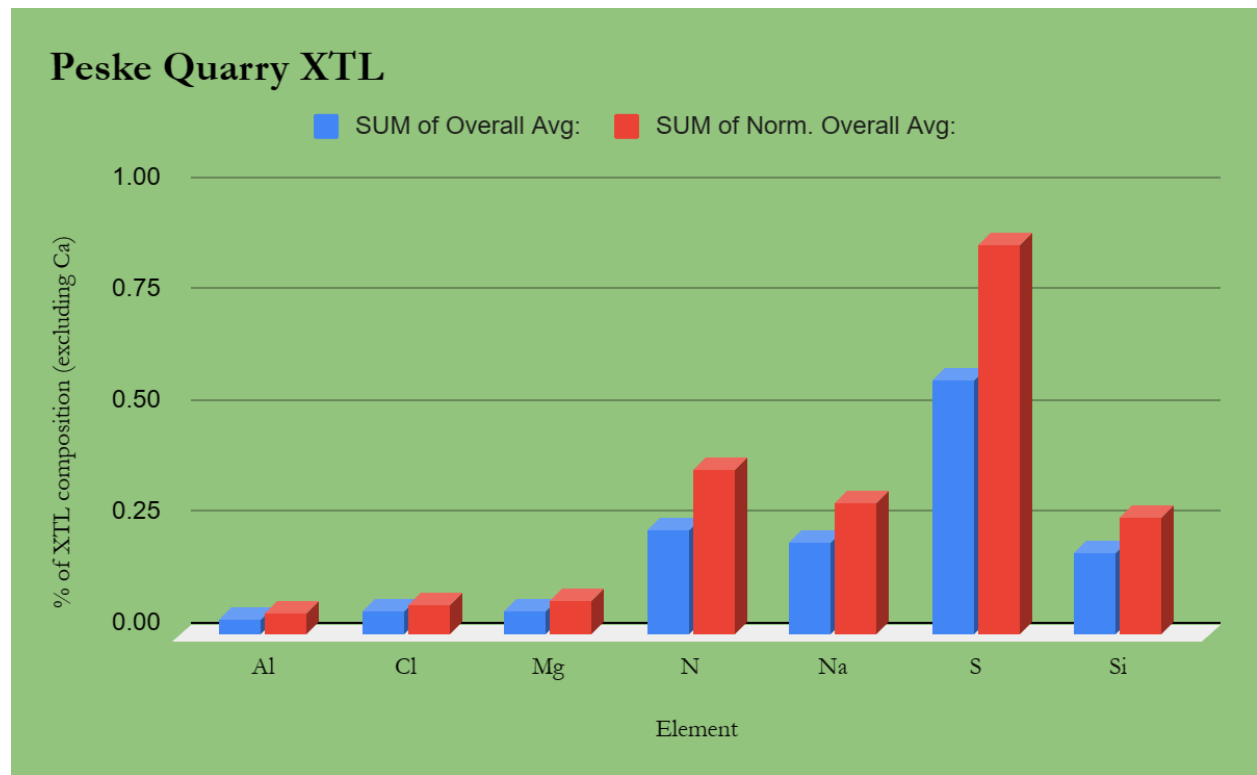


Figure 15: Graph of elements from table 10.

Table 11: Processed elemental data from crystals collected from Jaben Quarry presented in a pivot table, excluding calcium which comprises 98% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
Al	0.04	0.05
Mg	0.05	0.06
N	0.28	0.36
Na	0.01	0.01
S	0.02	0.03
Si	0.41	0.58
Grand Total	73.15	100.00

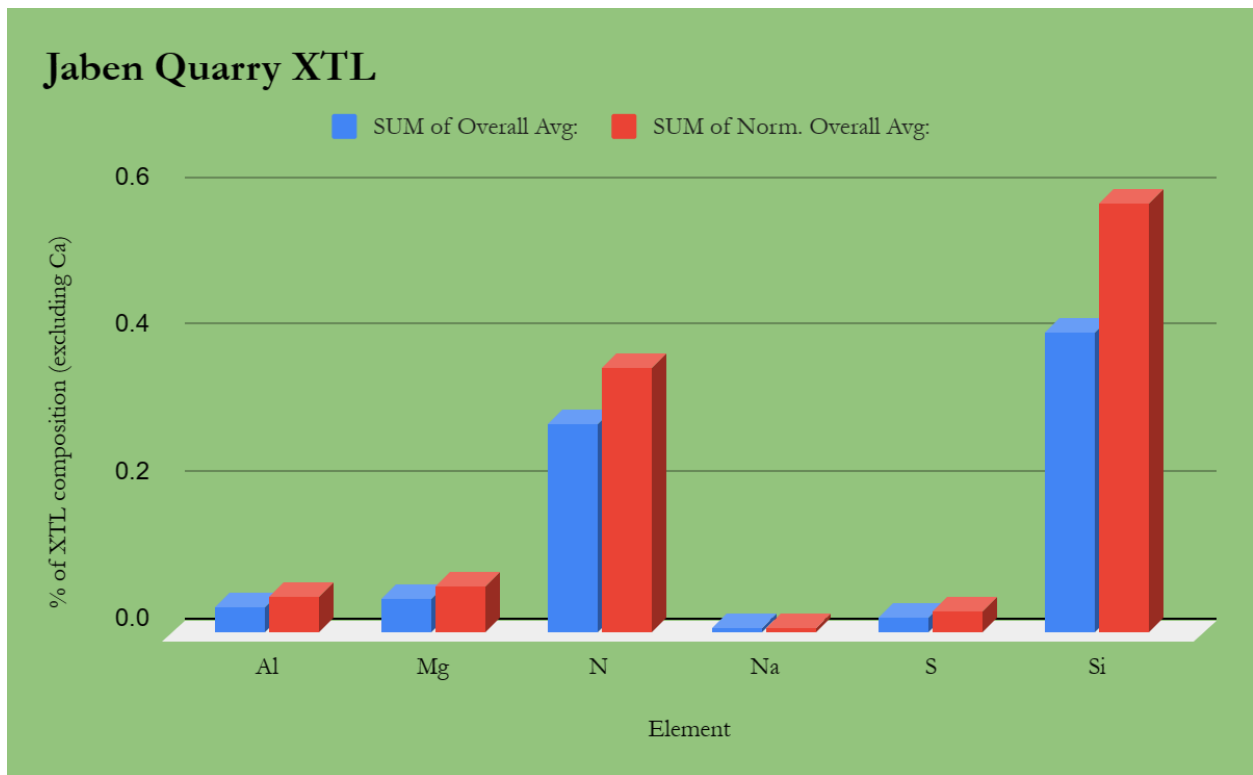


Figure 16: Graph of elements from table 11.

Film Analysis Tables and Figures

Table 12: Processed elemental data from crystals collected from Jaben Quarry presented in a pivot table, excluding calcium which comprises 53% and chlorine which comprises 40% of the total composition (normalized).

<i>Element</i>	SUM of Overall Avg:	SUM of Norm. Overall Avg:
Al	0.09	0.12
N	0.09	0.74
Na	0.04	0.05
S	0.07	0.18
Si	1.43	2.80
Grand Total	57.26	99.98

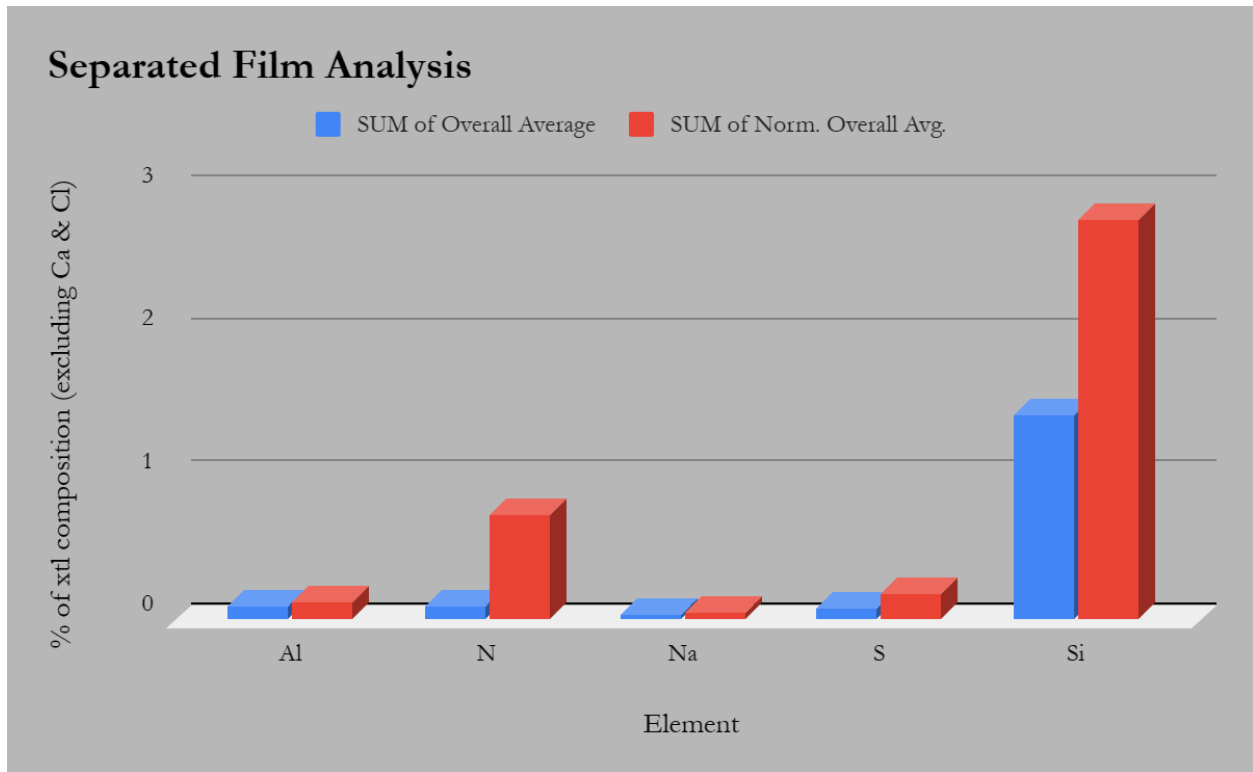
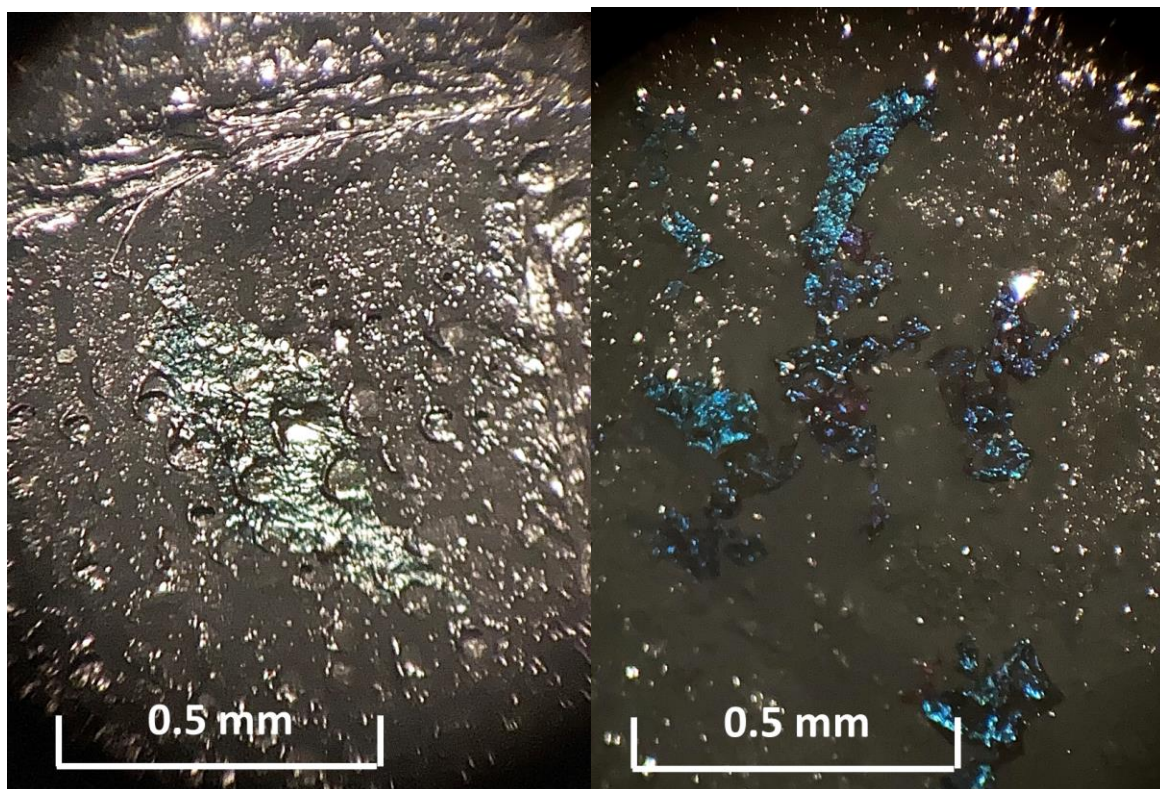


Figure 17: Graph of elements from table 12.

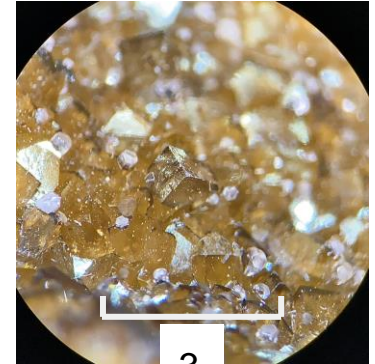
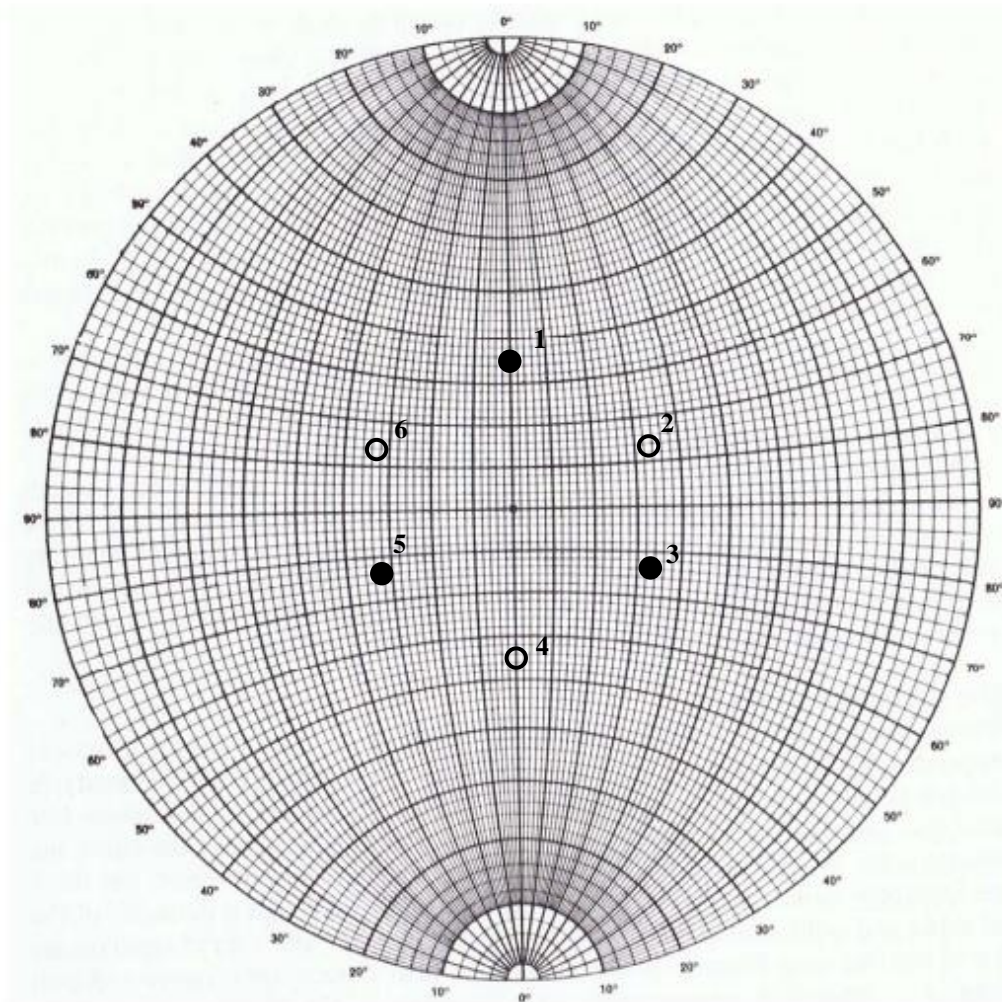
Tables 13 and 14: Elemental compositions of isolated blue iridescent thin film (Figure 18) and purple iridescent thin film (Figure 19).

Blue Iridescence			Purple Iridescence		
El.	Sto.	Norm. Sto. (%)	El.	Sto.	Norm. Sto. (%)
Si	0.24	0.95	Si	0.15	0.49
Al	0.13	0.47	Al	0.11	0.31
Mg	0.22	1.78	Mg	0.23	0.75
Ca	18.75	95.13	Ca	26.96	90.63
Na	0.04	0.31	Na	0.04	0.12
S	0.22	0.70	F	0.22	0.85
Total	19.6	99.34	Cl	0.02	0.04
			N	1.06	4.34
			S	0.04	0.12
			Total	28.83	97.65



Figures 18 and 19: Blue and purple iridescent thin film pieces used for tables 13 and 14.

Crystallography Figures



3
m
m

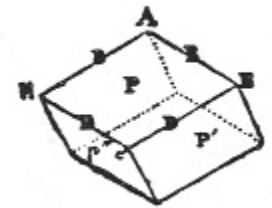
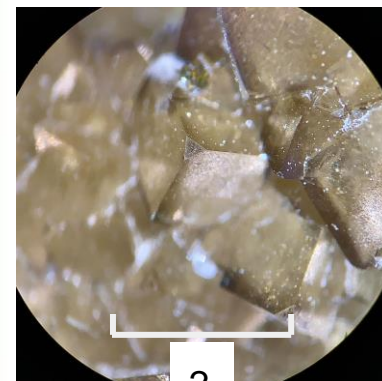
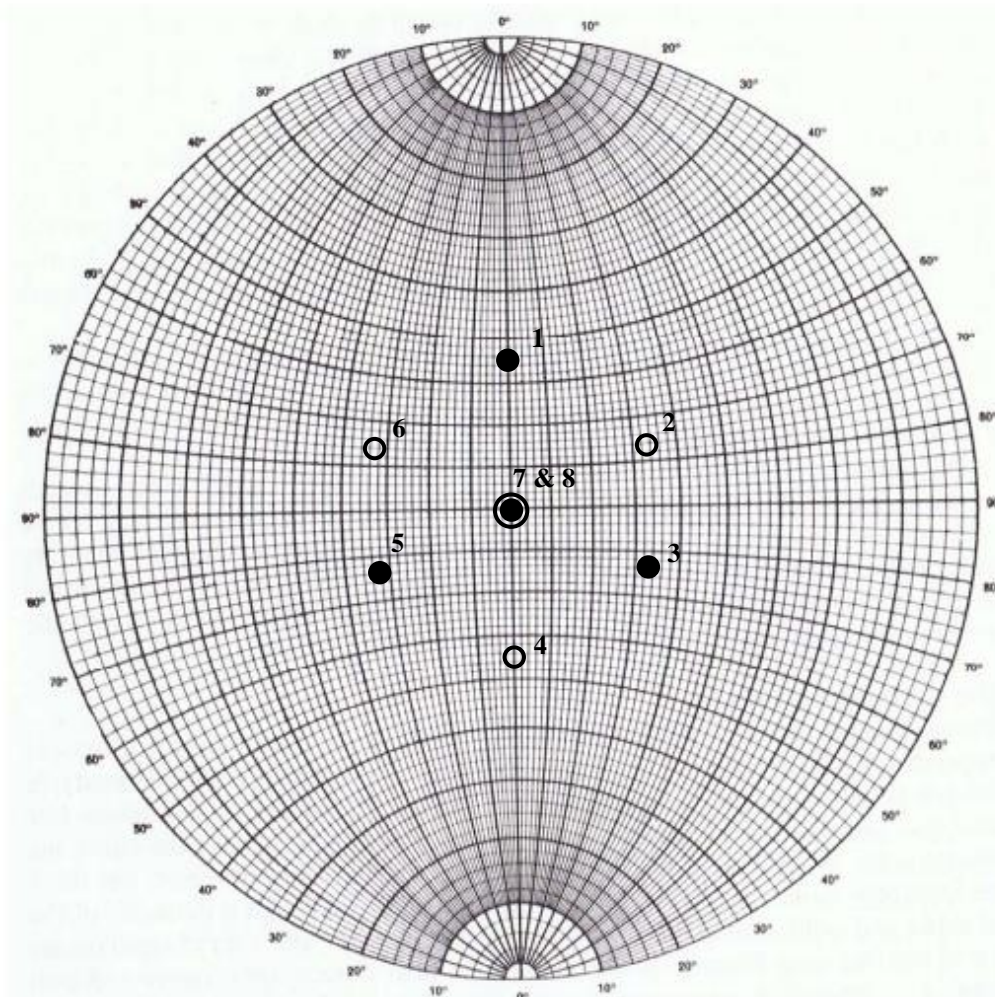


Figure 19: Stereonet of Primary Rhombohedron growth
Rhombohedron - Primary Growth

1. $\underline{1011}$
2. $\underline{1101}$
3. $\underline{0111}$
4. $\underline{10\bar{1}\bar{1}}$
5. $\underline{1\bar{1}01}$
6. $\underline{0\bar{1}\bar{1}\bar{1}}$

- 1-4 mm in size
- 35° ($\pm 5^\circ$) face angles
- Goldschmidt 1913 Figure 2



2
m
m

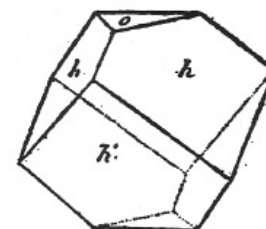
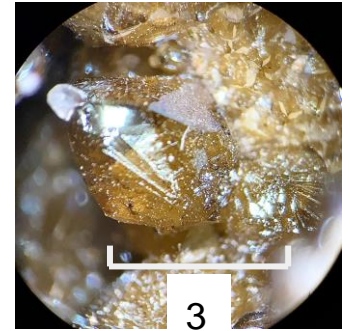
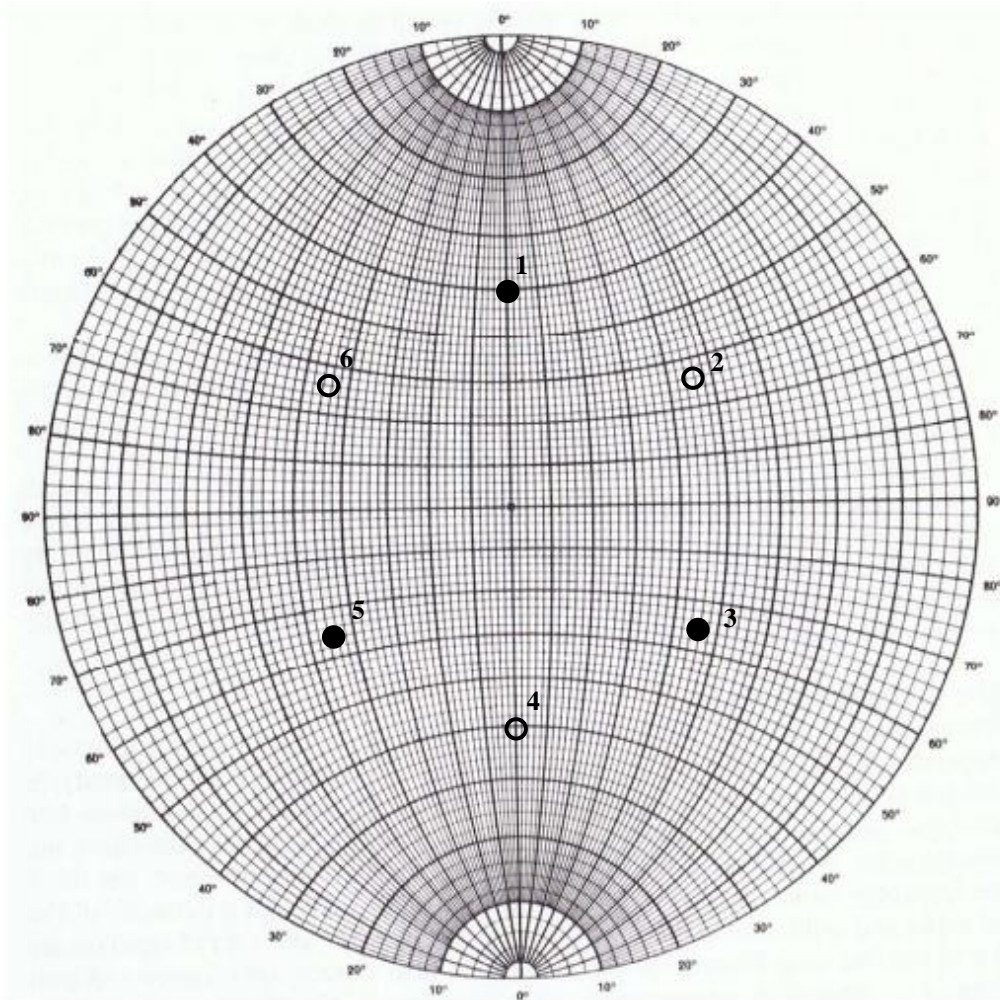


Figure 20: Stereonet of Primary Modified Rhombohedron growth

Modified Rhombohedron - Primary Growth

1. $\underline{1011}$
2. $\underline{1101}$
3. 0111
4. 1011
5. 1101
6. 0111
7. 0001
8. 0001

- 1-3 mm in size
- 0° angle for the c-axis flat face
- $35^\circ (\pm 5^\circ)$ face angles
- Goldschmidt 1913 Figure 16



3
m
m

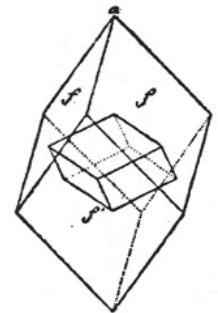


Figure 21: Stereonet of Primary Scalenohedron growth

Trigonal Scalenohedron - Primary Growth

1. $\underline{2021}$
2. $\underline{\underline{2201}}$
3. $\underline{0221}$
4. $\underline{2021}$
5. $\underline{\underline{2201}}$
6. $\underline{\underline{0221}}$

- 3-5 mm in size
- 50° angle on all faces
- Goldschmidt 1913 Figure 4

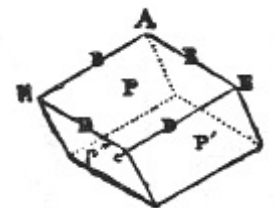
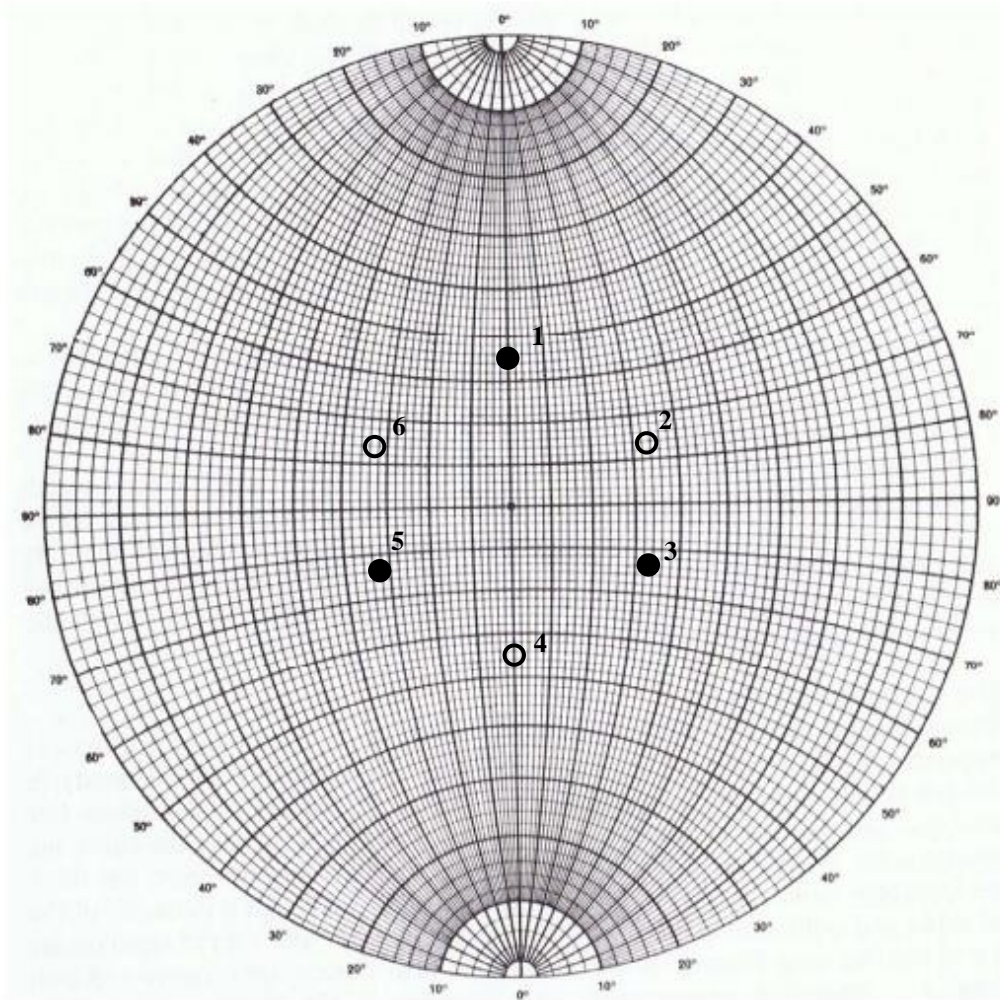
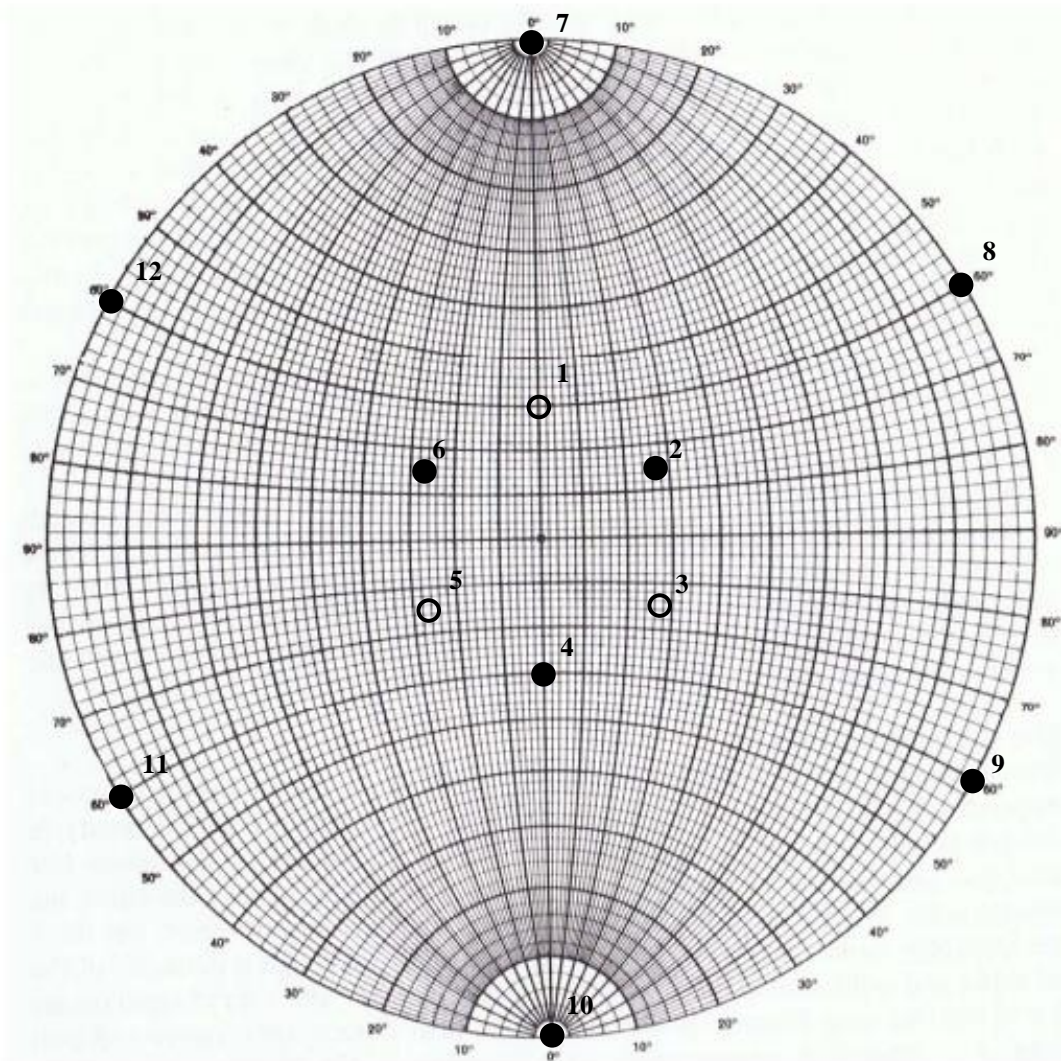


Figure 22: Stereonet of Secondary Rhombohedron growth

Rhombohedaon - Secondary Growth

1. $\underline{1011}$
2. $\underline{1101}$
3. 0111
4. 1011
5. 1101
6. 0111

- 4-12 mm in size
- $35^\circ (\pm 5^\circ)$ face angles
- Goldschmidt 1913 Figure 2



5
m
m

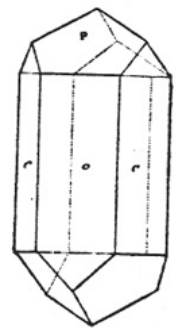


Figure 23: Stereonet of Tertiary Scalenohedral Hexagonal Prism growth

Scalenohedron and Hexagonal Prism - Tertiary
Rhombohedron - Secondary Growth

1. $\underline{1011}$
2. $\underline{1101}$
3. $\underline{0111}$
4. $\underline{1011}$
5. $\underline{1101}$
6. $\underline{0111}$
7. $\underline{2110}$
8. $\underline{1210}$
9. $\underline{1120}$
10. $\underline{2110}$
11. $\underline{1210}$

12. 1120

- .5-15 mm in size
- $30^\circ (\pm 5^\circ)$ angle on the top faces
- 90° angle on the outer faces
- Goldschmidt 1913 Figure 13

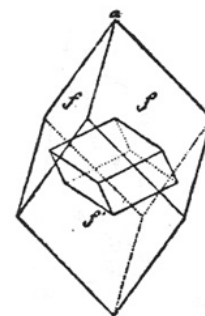
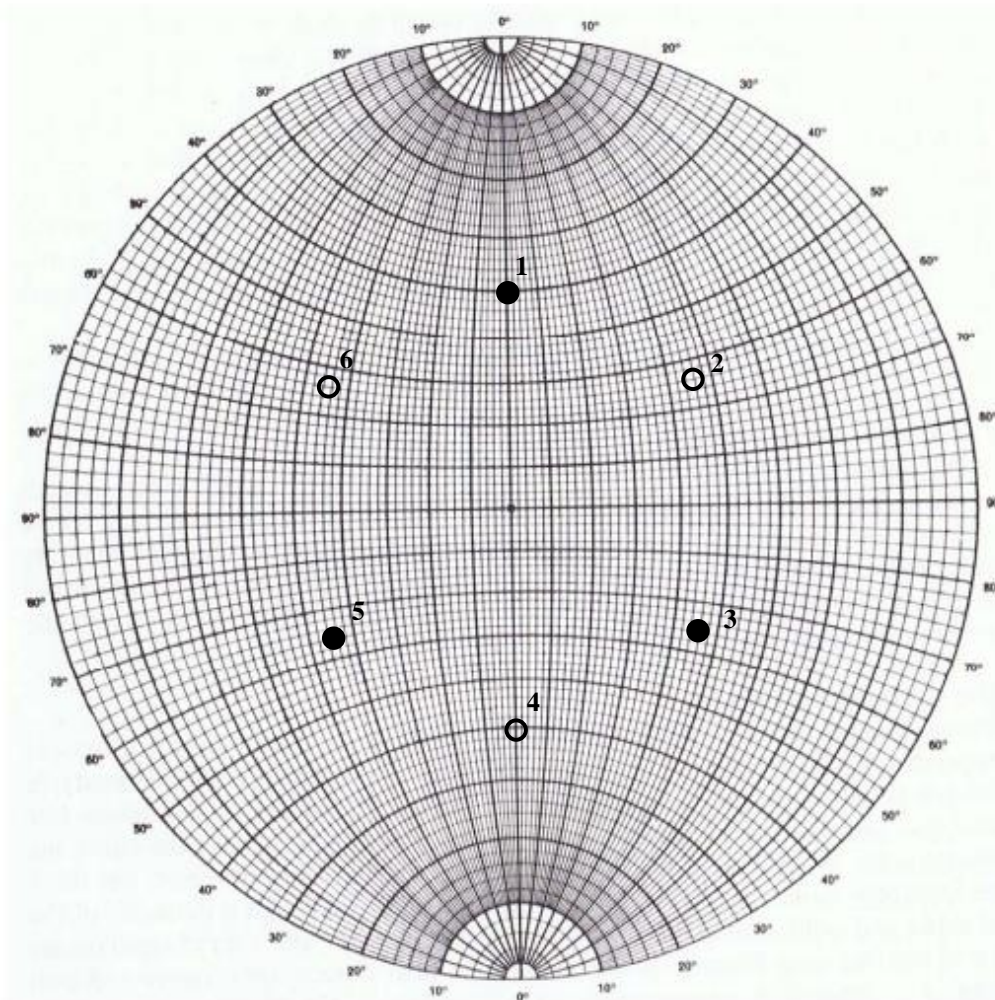


Figure 24: Stereonet of Tertiary Scalenohedron growth

Trigonal Scalenohedron - Tertiary Growth

1. $\underline{2021}$
2. $\underline{2201}$
3. $0\underline{221}$
4. $2\underline{021}$
5. $\underline{2201}$
6. $0\underline{221}$

- .5-15 mm in size
- 50° angle on all faces
- Goldschmidt 1913 Figure 4

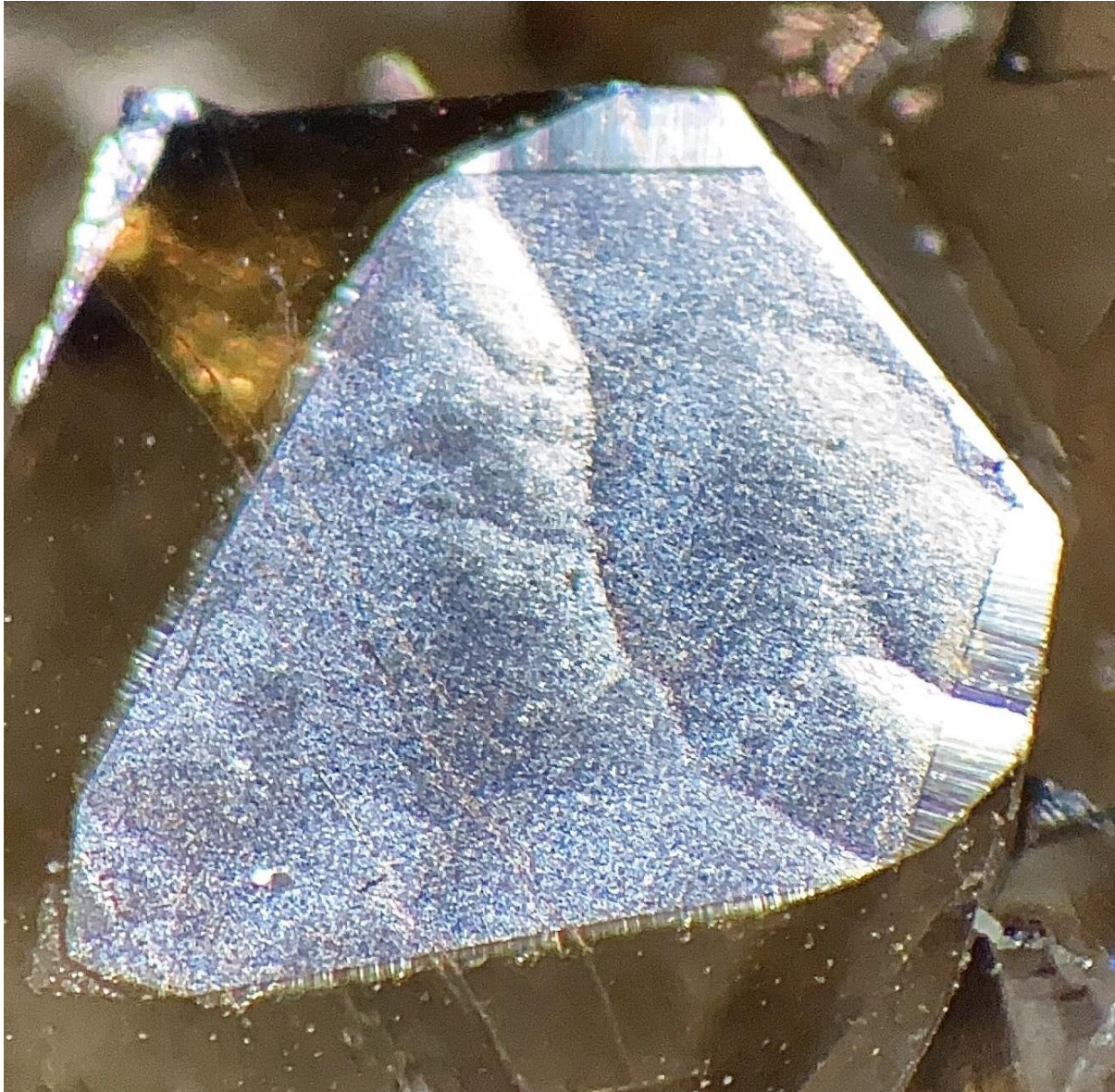


Figure 25: Bulbous texture on the surface of a primary scalenohedron.



Figure 26: Angular and straight-line texture on the surface of a primary rhombohedron.