Diatom Preservation in Lakes in the Jasper National Park Region, Alberta, Canada

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Abstract

Recent human activities (e.g., burning fossil fuels, synthesis of fertilizers) have led to a need to better understand how humans are changing the earth's systems. Paleolimnologists can add to our knowledge of the effects of human activities by determining past environmental conditions and how they have changed in response to human activities. Diatoms, unicellular algae characterized by a cell wall composed of hydrous silica, are one of the most frequently used proxies of environmental change. These include changes in water quality (e.g., nutrient concentrations) and water quantity (e.g., lake level), but our ability to use them is dependent on the quality of diatom preservation in lake sediments. The research outlined here focused on identifying the degree of diatom preservation and gaining insights into factors that control preservation in lakes located in Jasper National Park, Alberta. This research shows that in all lakes studied dissolution was occurring, but the degree of preservation varied markedly. This research will contribute to determining the accuracy of our estimates of nutrient concentrations from diatoms preserved in sediment cores.

1.0 Introduction

It has become clear that our planet is being altered by human activities (Smol 2008). Agriculture, fossil fuel burning, pollution and land clearance for infrastructure are just a few examples of anthropogenic influence. Some scientists have proposed that as a result of human-caused global change we are now in a new geologic period termed the Anthropocene (Stephan *et al.* 2011). One of the challenges to protecting and conserving earth systems is knowing baseline conditions (i.e., what was the system or ecosystem like

prior to disturbance), which is frequently unavailable from actual measurements (Smol 2008). Therefore, researchers often use records preserved in lake sediments (Paleolimnology) to determine past environmental conditions (Fritz 1996). Lakes are exceptional archives of environmental change as sediments accumulate and record aquatic, terrestrial and atmospheric changes over relatively long periods (100s to 1000s of years) of time (Batterbee 2000). Paleoindictaors preserved in lake sediment, including biological remains, geochemical signals and physical properties, provide archives of past environmental conditions. One of the most widely used paleoindictaors preserved in lake sediments are diatoms.

1.1 Diatoms

Diatoms are classified as protists. They are eukaryotic, unicellular algae that have cell walls composed of opaline silica and yellow brown pigmentation. The diatom cell is referred to as a frustule, and it is the siliceous cell wall that is preserved in lake sediment. As illustrated in Figure 1, a diatom is comprised of several components. The valves or thecae, two overlapping sections in each frustule, are comprised of two main sections (valve and cingulum). Taxonomic features ('ornamentation') used to identify diatoms are contained within the valves; whereas the cingulum consists of a series of bands called girdle bands that help hold the two valves together (Batterbee 2001)..

Diatoms are particularly useful paleoindicators for several reasons. First, they are generally well preserved due to their siliceous nature (Flower 1993). Therefore, diatoms valves are commonly found in stratigraphic deposits. Diatoms are found in large numbers (Moser 2013) and are taxonomically unique (Dixit *et al.* 1992). They are found worldwide and the number of species has been estimated at 200,000 (Mann and Droop 1996). The

high number of taxa is representative of the wide variety of environments that diatoms can survive. Diatoms can be found in almost any body of water no matter the size, as long as there is a sufficient light for photosynthesis (Moser 2004). Different diatoms have different ecological optimum and tolerance and there is a strong body of literature, which has defined the tolerances of many species of diatoms. Due to the large number of taxa, diatoms are good indicators of a variety of lake water conditions including salinity, pH, light availability, temperature and nutrient levels (Moser *et al*.1996). Changes in diatom species assemblages are typically used to determine past environmental conditions. However, for diatom assemblages to be accurate indicators, we need to know that what is preserved in the sediment is representative of the community living at the time of deposition (Moser *et al.* 1996)..

Despite diatoms being generally well preserved and resistant to degradation, some depositional environments can cause diatom dissolution or breakage (Ryves *et al.* 2009). Poor diatom preservation can potentially compromise the reliability of inferences of environmental conditions, therefore limiting the accuracy of historical reconstructions (Ryves *et al.* 2001). Previous experimental studies have shown that three main factors promote diatom dissolution – high pH, shortage of silica and high salinity (Hobbs *et al.* 2010). My proposed research project expands current scientific knowledge on diatom preservation in freshwater lakes. Previous research from the Canadian Rocky Mountains indicates poor preservation in many of these lakes, and has suggested it is related to reductions in pore water pH and dissolved oxygen (Hobbs *et al.* 2010). This research aimed to answer two specific questions surrounding diatom preservation in lakes in Jasper National Park: 1) Have well-preserved diatoms observed in surface sediment samples

(upper 0-5cm) collected in 2007 remained intact over time? and 2) Does the degree of dissolution differ between the lakes?

This study is part of a larger project funded by an NSERC-CRD grant that is focused on determining the causes of changes in nutrient inputs and lake production in the Jasper National Park region. Diatoms species composition will be used to infer past nutrient concentrations. Therefore, having knowledge about diatom preservation will help assess the accuracy of inferences of nutrient concentrations based on diatom community composition.

2.0 Methods

2.1 Study Site

Five small lakes in Jasper National Park, Alberta (Figure 2) were selected for this research project. Preliminary analyses revealed poor diatom preservation in some of the sediments retrieved for the project, which led to an interest in better understanding diatom preservation in these lakes. The selected lakes were all freshwater, and varied in size, depth and elevation (Table 1). The catchment of the lakes mostly contained coniferous trees and various shrub and forest plant species. Little Trefoil (Figure 3) and Dead Man's Hole (Figure 4) were in close proximity to a main road while a hiking trail was used to access the remaining three lakes – Hibernia (Figure 5), Upper Mina (Figure 6) and Katrine (Figure 7).

2.2 Field Methods

Temperature, pH and specific conductivity were measured at each site. In addition to sediment samples, two-liter water samples were collected in into Nalgene bottles in order to later examine the chemical properties of each lake. These water samples helped

to determine if water chemistry influences diatom preservation. Samples were kept in cool, dark environments until it was possible to subsample and filter samples, typically within 24 hours. Water samples of 500ml and 250ml were filtered through Cellulose acetate filters and placed into glass sample bottles. Tests for chlorophyll *a*, particulate organic carbon (POC) and particulate organic nitrogen (PON) were also conducted after removing particulates with filter papers.. All samples were sent to the Canadian Centre for Inland Waters (CCIW) in Burlington for analysis. The salinity of each lake was calculated by averaging the concentrations of several ions (Cl, SO_4, Ca, K, Mg, Na) and dissolved organic carbon (Bloom *et al*. 2003).

Sediment cores ranging from 43 to 53 cm in length were retrieved from the middle (estimated as the deepest part) of each lake using a gravity corer (Glew 1988) in the summer of 2007 and then again in 2014. The corer (with a plastic tube attached) was slowly lowered on a rope through the water until it penetrated the bottom sediment (Glew and Last 2001). A brass weight was used to trigger a plunger to seal the core tube. Samples were brought back to the surface using the rope. A plug was placed in the bottom of the tube to secure the sediment. To establish an intact sediment/water interface, only cores with a layer of water of at least three inches on the top of the sediment were accepted. An intact sediment water interface ensures that the most recent sediment remains undisturbed. Each core was subsampled at 0.5cm intervals (Glew and Last 2001) using an extruding device (Glew and Last, 2001) and placed into whirl packs while in the field. All samples were kept in a cool environment until analysis.

2.3 Lab Methods

^{210}Pb dating was used to establish the geochronology of the sediment cores. The method relies on the release of ^{210}Pb when radon gas decays in the atmosphere. Through precipitation, ^{210}Pb falls to the earth's surface in precipitation and is deposited into lake sediments (Appleby 1978). Using the half-life of ^{210}Pb (approximately 23 years) and how much isotope the sediment contains, the age of the sample can be determined (Olsson 1986).

A total of 15 samples from the top ~ 40cm of each core were ground, dried and placed through a mess screen. The top section of the core was selected because it represents a more recent time frame (approximately 1800-2007). The samples were then shipped to Mycore for analyses of Pb using beta counting. Dates were determined from the calculated concentration of ^{210}Pb using the constant rate of supply (CRS) model (Appleby 2001). Funds were only available to date three 2007 cores –Dead Man's Hole, Little Trefoil and Hibernia lakes. Using sedimentation rates from these (Table 2), and the slope of trend lines from the years 1998-2007, I was able to estimate depths for the year 2007 in all five 2014 cores.

2.3.1 Diatom Analysis

Standard processing techniques were used to observe the quality of diatom preservation (Battarbee *et al.* 2001). Slides were prepared after digesting 1-3 grams of sediment (depending on the water content in the samples) in a solution of 10% hydrochloric acid to remove excess calcium carbonate (Carr *et al.* 1986). Sample vials were then placed into a hot water bath for 1.5 hours. The sediment within the vials was rinsed with a solution of sulfuric and nitric acid and then neutralized by rinsing with e-pure water (approximately

10 times). This removed organic materials and isolated the diatom frustules. Once the samples were neutralized, a small aliquot of the slurry was evaporated onto a coverslip, and mounted on a microscope slide using Zrax® – a high refractive mounting medium. The preservation quality of diatoms present in each lake was quantified using differential interface contrast microscopy.

2.3.2 Scanning Electron Microscopy (SEM)

Sediment samples from 2007 cores were examined for dissolution using stubs created for a scanning electron microscope (SEM) located at the ZAPLAB, University of Western Ontario. The SEM uses electrons to produce a highly magnified image (Schweitzer 2014). The samples were prepared by evaporating a small amount of processed slurry directly on tinfoil using a hot plate. The sample was secured to the stub using double-sided tape. Carbon coating the surface of the stubs was done in order to ground the sample while inside the SEM. The scanning electron microscope produced an image by creating a beam of electrons that followed a vertical path down the microscope. The electrons passed through the lenses and electromagnetic fields that focus them to the sample while held within a vacuum,. X-rays and electrons were emitted from the sample as soon as the beam reaches the surface of the stub. Detectors located in the SEM collected the displaced electrons and x-rays and generated an image (Schweitzer 2014). Digital images revealed the state of the diatoms on the stub. ^{210}Pb dating showed which samples best represent the top 2007 sediment. SEM results paired with ^{210}Pb dates established how well diatoms were being preserved over the last seven years and helped to create a dissolution rating scale.

2.3.3 Quantifying Dissolution

A total of 200 diatom valves were analyzed per sediment sample to ensure results were maximized while avoiding redundant information. The number of 200 valves was determined by counting and analyzing a range of diatoms – 50 to 300 – in one sample and comparing the results for the different number of valves analyzed. It was found that the amount of well and poorly preserved diatoms leveled off after 200 (Fig 8) with any additional diatoms counted after this threshold presenting the same results. Each diatom was classified as either a centric (Figure 9) or pennate (Figure 10) diatom. A radial symmetrical circular shape can distinguish centric diatoms, whereas pennate diatoms are laterally symmetrical. Based on initial scans and observations of the microscope slides and SEM samples, the following classification scheme was determined to quantify dissolution. Diatom valves were identified and assigned a preservation rating – 1 being well preserved (Figure 11). A value of 2 was assigned when some dissolution was observed; that is, where external ornamentation and features showed some signs of dissolution (Figure 12); a value of 3 was assigned when some of the valve was eroded by dissolution (Figure 13).

To determine the degree of dissolution occurring over seven years, diatoms in 2007 sediment were compared to diatoms in the 2007 sediment collected in 2014 (identified using ^{210}Pb dating). The resulting values of the average dissolution determined whether or not the diatoms remained intact over the last seven years. Preservation patterns down core in each lake were observed by plotting the percentage of each classification of diatom dissolution (well preserved, some dissolution, significant dissolution) for sediment depths of 0-0.5, 4-4.5, 7-7.5 and 20-20.5. Amount of dissolution down core was determined first by dividing diatoms into two general categories of “well preserved” and “poorly persevered” for

each sediment depth. The “poorly persevered” category includes diatoms with any signs of dissolution (values of 2 and 3). The percent difference between the poorly persevered diatoms from the bottom of the core (20cm) and the top of the core (0cm) gave each lake a value that represented the increase in poorly persevered diatoms – or a dissolution rating (Table 2). Comparing water chemistry results between the different lakes to the dissolution value revealed if specific lake properties lead to a higher or lower amount of diatom dissolution. In addition, comparisons were made between the total size of centric and pennate diatoms populations present in each lake, at each depth, to see if there is preservation variation in overall assemblage.

3.0 Results

3.1 Sediment dating

Lab results from MyCoreScientific showed ^{210}Pb concentrations at selected sediment depths in three cores taken in 2007 (Figure 14,15,16). Sediment ages from three lakes – Deadman’s Hole (Figure 17), Little Trefoil (Figure 18) and Hybernia (Figure 19) – were also established. Sedimentation rate was calculated using the slope of a trend line from the years 1998-2007 of figures 17, 18 and 19. The sedimentation rate of the three lakes showed that the depth from 4 to 7cm of the cores collected in 2014 likely corresponds to the year 2007.

3.3 Dissolution Down-core

Down core examinations showed that in each lake the percentage of pennate diatoms is greater than centric diatoms (Figures 20 to 24). This is true at all sediment depths of all cores. Each lake showed dissolution of both pennates and centrics at all depths, and also showed gradual increasing diatom dissolution with depth (Figures 20 to

24). In the case of Katrine Lake (Fig 20), poorly preserved diatoms dramatically increased between 0-0.5 and 4-4.5 cm and at depth of 7-7.5 and 20-20.5 diatoms disappeared all together.

Deadman's Hole, Upper Mina, and Hybernia: The degree of diatom dissolution increased down core as indicated by the amount of poorly persevered diatoms in figures 21, 22, and 23. General trends show that the number of pennate diatoms with any degree of dissolution becomes more abundant with depth. Similar trends are seen in centric diatoms as the amount of well-preserved valves decreases down core.

Little Trefoil: Diatom dissolution is more evident in pennate than centric diatoms in this lake. The total number of well-preserved diatoms decreases and the quantity of diatoms with some dissolution increases with depth (Fig 24). It is also important to note that Little Trefoil contained low amounts of centric diatoms in all sediment depths.

3.4 Dissolution of 2007 diatoms by 2014

Four out of the five likes had similar trends when comparing 2007 sediment collected in 2014 (depths of 4 and 7 cm in the 2014 cores) to the 2007 sediment collected in 2007. The sediment collected in 2014 is referred to as "buried sediment" whereas the original 2007 sediment is referred to as "top 2007". Katrine (Figure 25), Deadman's Hole (Figure 26), Upper Mina (Figure 27) and Little Trefoil (Figure 28) all showed a greater number of poorly preserved diatoms in the buried 2007 sediment and a decrease in well-preserved centrics. In all four lakes, the overall presence of centric diatoms significantly decreased in the buried 2007 sediment and in the case of Katrine Lake centric diatoms disappeared all together. Upper Mina had the most change in preservation out of all the lakes. The total number of well-preserved centric diatoms significantly decreased and the amount of

pennate diatoms with some or significant dissolution increased in the buried 2007 sediment. Hibernia showed different results. Although buried 2007 data showed a slight decrease in well preserved pennate's, and an increase in poorly preserved pennates, preservation of centrics increased in the buried data (Figure 29).

3.2 Water Chemistry

Katrine Lake had relatively high chemical values – salinity (~100 mg/L) (Fig 30), DOC (~91 mg/L (Fig 31) and pH (10.1) (Fig 32) – compared to the other lakes. The remaining four lakes had similar ion (Fig 30) and dissolved organic carbon concentrations (Fig 31), less then 30mg/L and less than 16 mg/L, respectively, as well as pH values within the range of 8.3-8.9 (Fig 32). Chlorophyll a (chl a) values (Fig 33) were the highest in Katrine and Upper Mina, but were still relatively low (2.9 µg/L). Chlorophyll a was even lower in the other lakes; Little Trefoil and Hibernia had chl *a* concentrations of 1.5 µG/L and Deadman's Hole had concentrations of 0.7 µG/L. (Fig 33). Katrine Lake had the lowest amount of silica – 1.69 MG/L. Deadman's Hole, Little Trefoil, Upper Mina and Hibernia had silica concentrations of 3.93 mg/L, 5.54 mg/L, 10.5 mg/L and 13.5 mg/L, respectively (Fig 34).

3.5 Water Chemistry vs Dissolution

Preservation calculations showed that Katrine lake had the lowest diatom preservation with a dissolution rating of 95%, followed by Upper Mina at 20%, Hibernia and Dead Man's hole at 10% and lastly Little Trefoil at 8% (Table 3). The preservation values track some water chemistry variables. Although we only have five data points, plots (Figure 30 to 34) indicate potential trends in dissolution rating and lake chemistry. Salinity presents the most evident potential trend as the two lakes with the highest amount of dissolution

(Katrine and Upper Mina) also have the salinity values. Another potential trend can be seen with pH where Katrine has a higher pH value relative to the other 4 lakes.

4.0 Discussion

Diatom dissolution can differ between assemblages and in the results observed in this study dissolution could be a possible explanation for the percentage differences seen between pennate and centric diatoms. Preservation potential can depend on a diatom's life form. Planktonic taxa that are free living within the water are more susceptible to transport and dissolution whereas periphytic taxa that are attached to rocks or plants are less likely to show signs of dissolution (Sawai 2001).

Diatom dissolution rates can initially differ between assemblages due to variations in total surface area (Lawson *et al*. 1978). Moreover, diatom dissolution can be dependent on thickness and ornamentation (Hassen 2014). Robust diatom populations that have a larger average size (ie: pennates) are expected to dissolve more slowly compared to smaller fragile taxa such as centrics. This can be explained by the biogenic silica surface area: volume ratio that is lower in larger sized organisms (Barker *et al.* 1994). Inter-specific variations – or variations between species – should also be considered. Studies completed by Ryves 2001 found that certain species with raphid valves were less susceptible to dissolution then those with araphid valve structures, while the opposite was found when comparing species of other geneses. For the present research project, pennate diatoms are most likely appearing in higher percentages, as they are larger, more robust diatoms compared to the smaller fragile centrics. Therefore dissolution could have a greater effect

on the centric populations in these lakes. Future research should investigate diatoms to a species level to consider how species composition impacts dissolution in fresh water lakes.

4.1 Diatom Dissolution

Data displayed by the down core results as well as results comparing recently deposited material (surface of core collected in 2007) with material deposited seven years ago (2007 sediment in 2014 cores) shows that diatom preservation in all of the lakes studied in Jasper National Park, Alberta are being effected by dissolution. In most lakes ~10% of diatoms show signs of dissolution at 20 cm below the surface water interface. Little to no dissolution is occurring in the surface sediment samples indicating that dissolution is occurring in the sediments itself. This finding is similar to previous literature such as Hobbs *et al*. 2010 that discovered that in alpine lake cores, all first signs of dissolution occurred in the top sediment and then rapidly continued down-core. Hobbs *et al*. 2010 further discovered that in their sediment samples diatom frustules disappeared altogether after 3.5cm in depth. In the present study, the amount of dissolution was not the same between all lakes. Some lakes had less preservation than others (Table 3). Previous studies suggest that the process of dissolution within diatoms is complex and can be influenced by a number of variables including chemical properties of the lakes they live in (Ryves 2001).

The rate of dissolution in the water column and within the sediment can be related to variations in lake chemistry (Lent & Lyons 2001). Previous studies have shown strong relations between dissolution and salinity. After analyzing water chemistry data in this research project it was discovered that salinity is a chemical factor that could have caused diatoms to dissolve. Recent field studies, such as Ryves (2006) who looked at dissolution in sediment samples from saline and freshwater lakes in North America and West Greenland,

found that salinity was the most important factor affecting dissolution between data their sets. According to Flower and Ryves (2009) even when differences in salinity between the lakes that they used were small, they observed more dissolution in the lakes that had higher salinity. The majority of dissolution occurs within the water column but dissolution can continue after deposition (Hassen 2014). In the Jasper lakes, there is some evidence of dissolution in the most recent samples, which could suggest dissolution is occurring in the water column, but the increase in dissolution with depth suggests it is also occurring in the sediment. Dissolution in the sediment is dependent on the porosity – how much space is available for water to occupy the sediment. As sediments become compacted, porosity is reduced, so most studies suggest dissolution can mainly occur up to 20 cm in depth (Hassen 2014). Previous laboratory experiments have shown that the degree of dissolution can be promoted by the presence of alkali metals in carbonate waters (Hobbs *et al.* 2010) – specifically high concentrations of sodium (Na) and magnesium (Mg) (Flower 1993). In the case of Katrine and Upper Mina, which had the two highest levels of diatom dissolutions, the concentrations of Na and Mg were greater than the other lakes. The concentrations of these ions may have played a role on the effects that salinity had on the degrees of dissolution.

Results from previous laboratory studies have also indicated that dissolution is strongly influenced by water pH. Silica dissolution within diatoms increases exponentially above pH 9 (Ryves 2006). This is consistent with a study completed by Langmuir (1997) that found that the solubility of amorphous silica was largely insensitive to changes in pH below 9.5, above which it increased significantly. This could be a possible explanation for the 95% dissolution rating in Katrine Lake. As seen in Figure 22, the pH of Katrine Lake is

roughly 10.1, which is passed the threshold where diatom dissolution will occur rapidly. A combination of high salinity as well as high pH could be responsible for the high dissolution rating in Katrine Lake.

The sedimentation rates are also likely to play a role in dissolution according to Ryves 2006. In lakes where sediments are not re-suspended into the water column, and where the concentrations of biogenic silica are high enough to saturate pore waters; it is hypothesized that as sedimentation rate increases the amount of dissolution will decrease (Conley and Schelske 1989). This is due to diatom frustules being more quickly removed from the sediment water interface and the top layers of sediment where the majority of dissolution will occur (Ryves *et al.* 2003). Sedimentation rates have also been used to explain good preservation in highly corrosive, productive environments – particularity in areas where the decomposition of organic matter alters the pH of the pore water (Flower 1993). Future studies should examine the differences in sedimentation rates between the lakes and the possible effects it may have on diatom dissolution.

4.2 Implications for Environmental Inferences from Diatoms

Evidence of dissolution in diatom samples has implications for environmental inferences from diatoms. Diatom dissolution can potentially introduce a source of error into paleolimnological studies. In this study, only two out of five lakes showed dissolution of more than 10%, and if there is little difference in the amount of dissolution between samples, this would likely have little effect on environmental inferences that are based on entire diatom communities. This research supports previous research that indicates that paleolimnolgical studies should be avoided in lakes with high salinity and pH.

5.0 Conclusion

Diatom preservation in freshwater lakes from Jasper National Park, Alberta showed that dissolution is occurring in diatoms both down core and over time. For this study, salinity and pH is the most likely cause for dissolution but other factors such as sedimentation rates should also be looked at in future studies. Diatom preservation and the quality of diatom samples for analysis is a critical component of paleolimnological research. Although dissolution can present a source of error, dissolution in this study is relatively low in 3/5 lakes. Our results confirm previous research that dissolution is most likely to occur in lakes with high salinity, in particular with elevated sodium and magnesium, and lakes of high pH. These types of lakes should be avoided in environmental constructions.

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Appendix

Table 1: Summary of lake characteristics and core lengths

Lake Name	Latitude (°N)	Longitude (°W)	Elevation (masl)	Depth (m)	Average Diameter (m)	Secchi Depth 2007/2008 (m)	Secchi Depth 2014 (m)	Core 2007 (cm)	Core 2014 (cm)
Kettle Lakes									
Deadman's Hole (JP-01)	52.867167	118.07075	1000	11.6	100	6.1/7.2	6.1	54	52
Little Trefoil (JP-02)	52.892194	118.059278	1026	5.2	90	4.5/ 3.65	3.6	44	45
Bench Lakes									
Upper Mina (JP-03)	52.882139	118.1155	1212	12.0	250	4.5/ 5.05	3.2	47	44
Hybernia (JP-06)	52.870361	118.139444	1169	7.4	280	3.75/ 3.65	4.4	40	49
Katrine (JP-07)	52.919778	118.075111	1194	4.2	120	1.4/3.3	3.3	36	53

Note: Latitude, longitude, elevation, depth and diameter are as of 2007.

Table 2: Sediment Rate of Supply for Little Trefoil, Hybernia and Deadman's Hole

Little Trefoil		Hybernia		Deadman's Hole	
Depth (cm)	CRS (g/m2/yr)	Depth (cm)	CRS (g/m2/yr)	Depth (cm)	CRS (g/m2/yr)
0.5	143.4067967	0.25	34.60761985	0.75	186.4253348
1.25	142.5980906	1.5	37.76958847	1.75	171.6862526
1.75	151.8202827	2.75	40.71769678	2.75	154.2284324
2.5	162.3747554	3.75	41.06640181	3.75	130.3903449
3.25	135.6626947	4.75	45.13022437	4.75	116.806816
3.75	117.7622758	5.75	44.12051872	5.75	94.86068955
4.75	99.48647024	6.75	39.11418493	6.75	83.54047039
5.75	82.27078979	7.75	38.18890796	7.75	59.96717521
6.75	82.40068943	8.75	20.55540614	8.75	61.74809257
7.75	80.15034323	9.75	18.27660713	9.75	50.22053805
8.75	87.57029936	10.75	13.71816688	10.75	53.15788855
9.75	95.24709002	11.75	11.56235024	11.75	36.12095026
11.25	79.2699274	12.75	11.28249357	12.75	44.82986145
12.75	59.61421245	13.75	9.445409988	13.75	51.5093556
14.25	63.52600317	14.75	7.505754918	14.75	64.20094426
15.75	60.74183794			15.75	56.10348689
17.25	64.9951585			16.75	59.29805676
18.75	54.77673441			17.75	56.87476585
20.25	62.14577976			18.75	56.76527369
21.75	55.74356715			19.75	29.27288255
23.5	64.34833339				
25.25	59.27190689				
27.75	74.5225277				
30.25	40.27253324				

Table 3: Dissolution ratings and water chemistry data for each of the five lakes

Lake	Dissolution Rating (%)	Salinity (mg/L)	chl *a* (µg/L)	SiO_2 (mg/L)	pH
Deadman's Hole	10	13.1	0.7	3.9	8.9
Little Trefoil	8	12.8	1.5	5.5	8.6
Upper Mina	20	28.1	2.9	10.5	8.4
Hybernia	10	11.6	1.5	13.5	8.9
Katrine	95	101.0	2.9	1.7	10.1

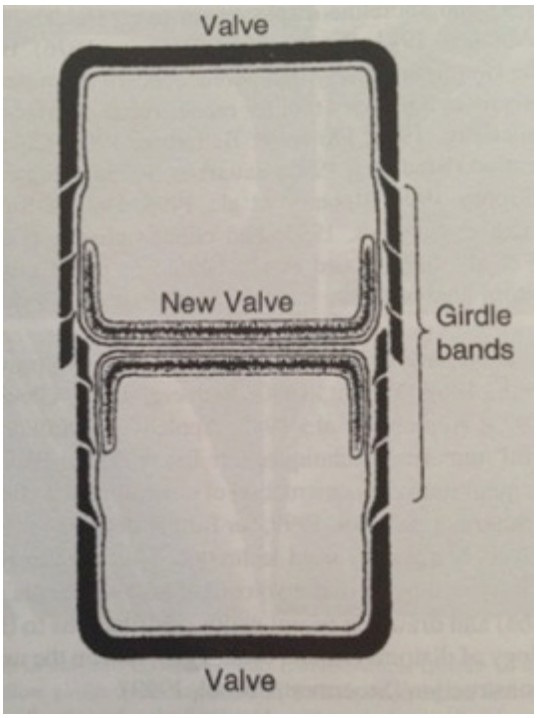

Figure 1: Cross-section of diatom cell (frustule) showing the two valves (theca) and girdle bands (cingulum) (Batterbee 2001).

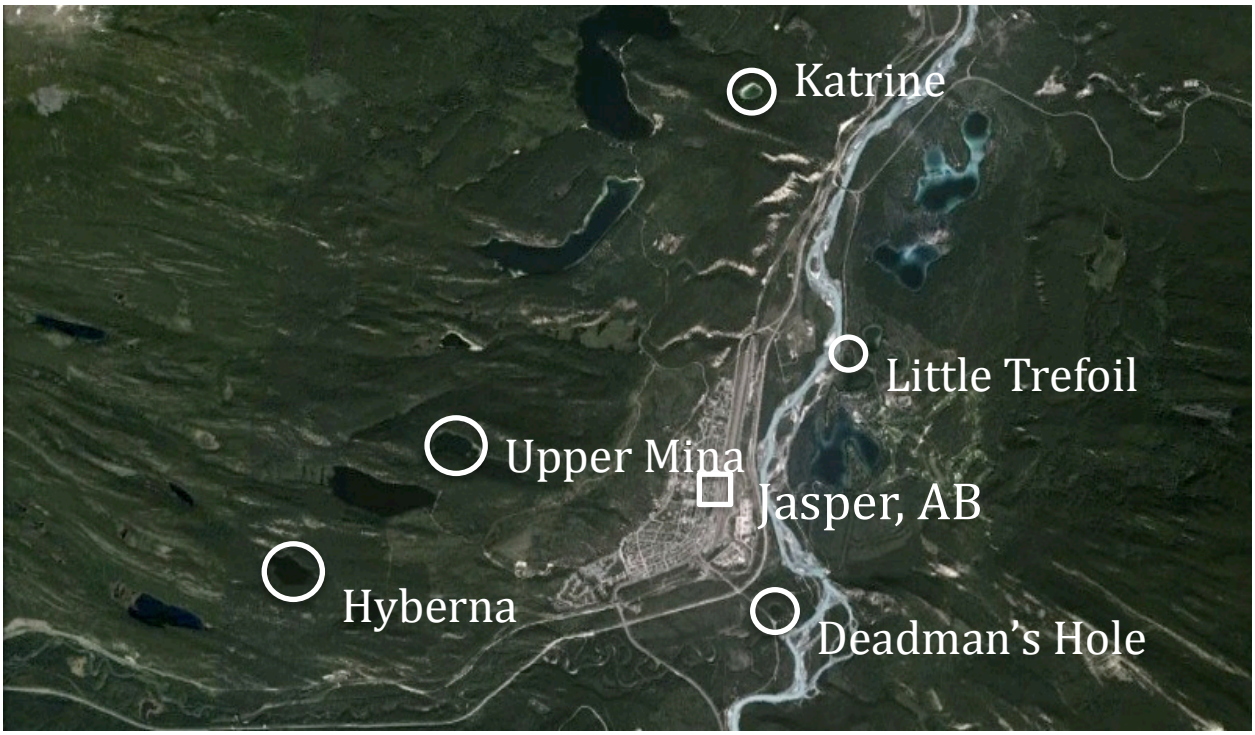

Figure 2: Location of sediment coring sites (Katrine, Little Trefoil, Upper Mina, Hybernia and Deadman's Hole) in Jasper National Park, Alberta.

Figure 3: Little Trefoil Lake – Jasper National Park, Alberta. Photo Credit: Mike Kenigsberg.

Figure 4: Dead Man's Hole Lake – Jasper National Park, Alberta. Photo Credit: Mike Kenigsberg.

Figure 5: Hibernia Lake – Jasper National Park, Alberta. Photo Credit: Mike Kenigsberg.

Figure 6: Upper Mina Lake – Jasper National Park, Alberta. Photo Credit: Mike Kenigsberg.

Figure 7: Katrine Lake – Jasper National Park, Alberta. Photo Credit: Mike Kenigsberg.

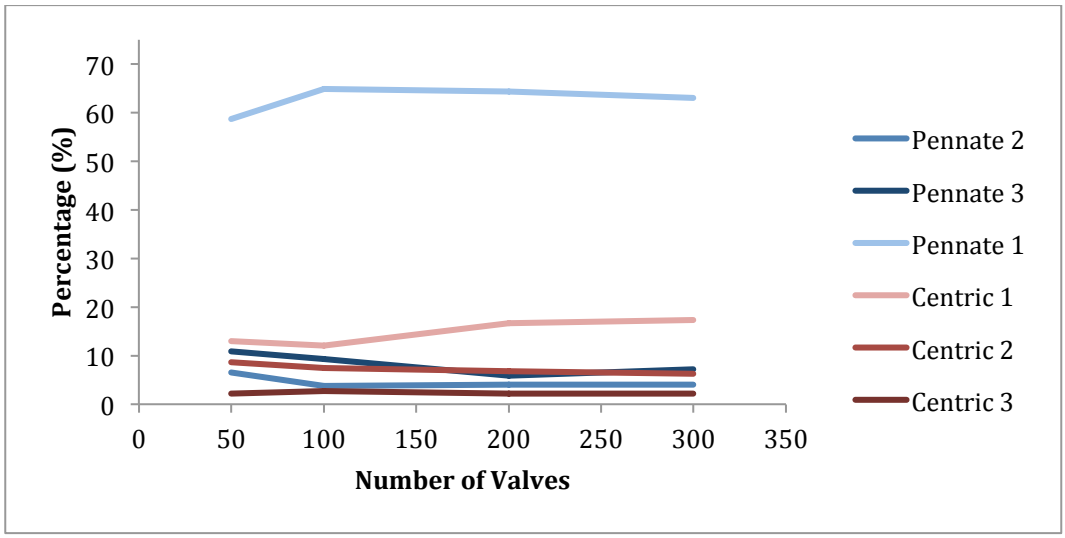

Figure 8: Graph depicting the representation of diatom quality for pennate and centric diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) when counting 50, 100, 200 and 300 diatoms.

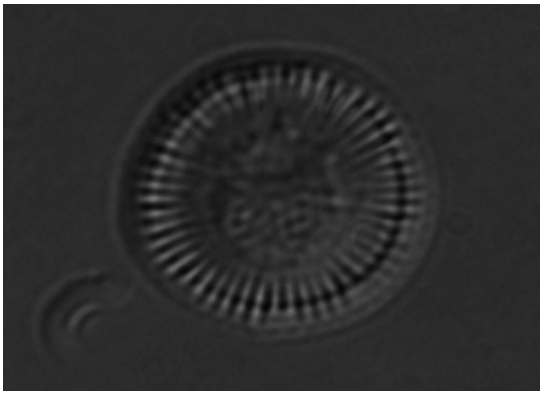

Figure 9: Example of a well-preserved centric diatom (*Cyclotella*)

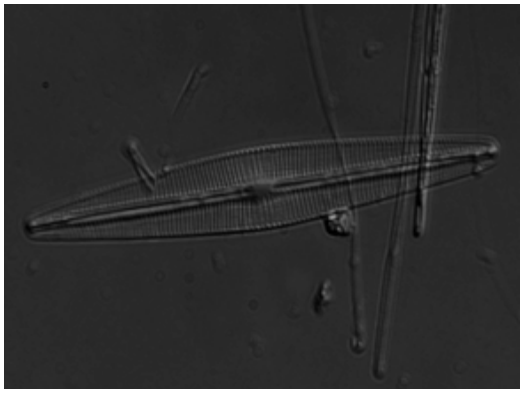

Figure 10: Example of a well-preserved pennate diatom (*Navicula*)

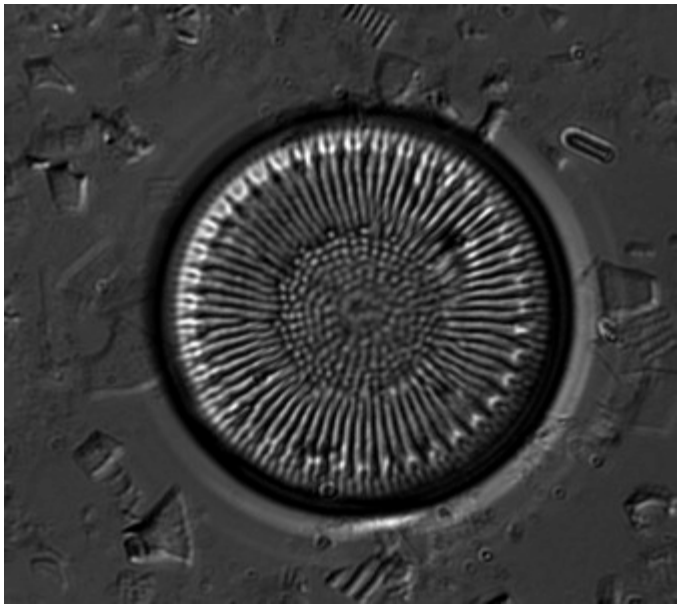

Figure 11: *Cyclotella bodanica* diatom, which has a preservation value of 1 indicating that the cell is well preserved

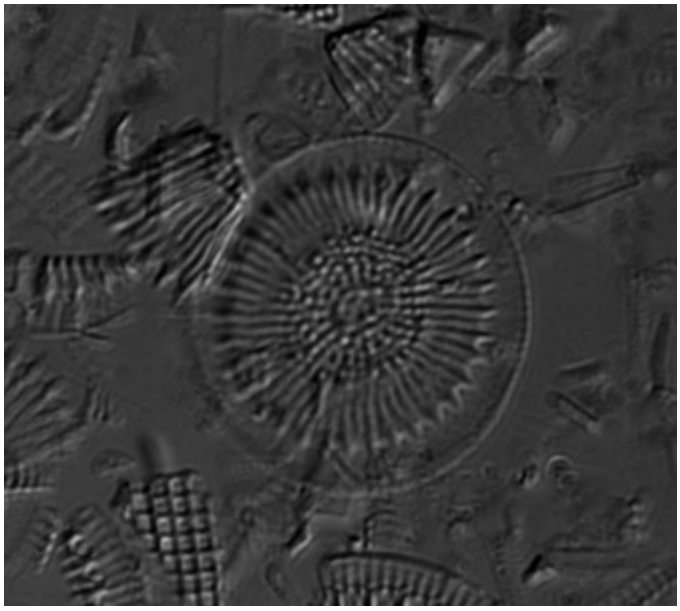

Figure 12: *Cyclotella bodanica* diatom, which has a preservation value of 2 indicating that the cell is showing some dissolution. Dissolution is occurring within the diatom.

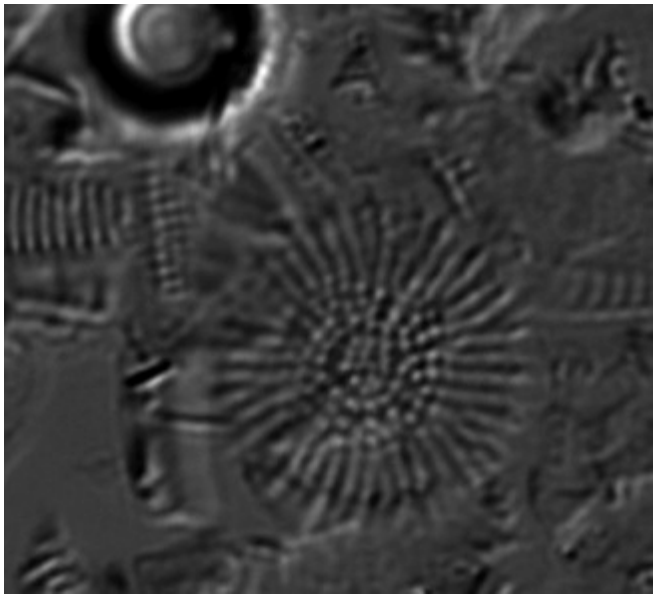

Figure 13: *Cyclotella bodanica* diatom, which has a preservation value of 3 indicating that the cell is showing significant dissolution. Dissolution is has dissolved the outside valves.

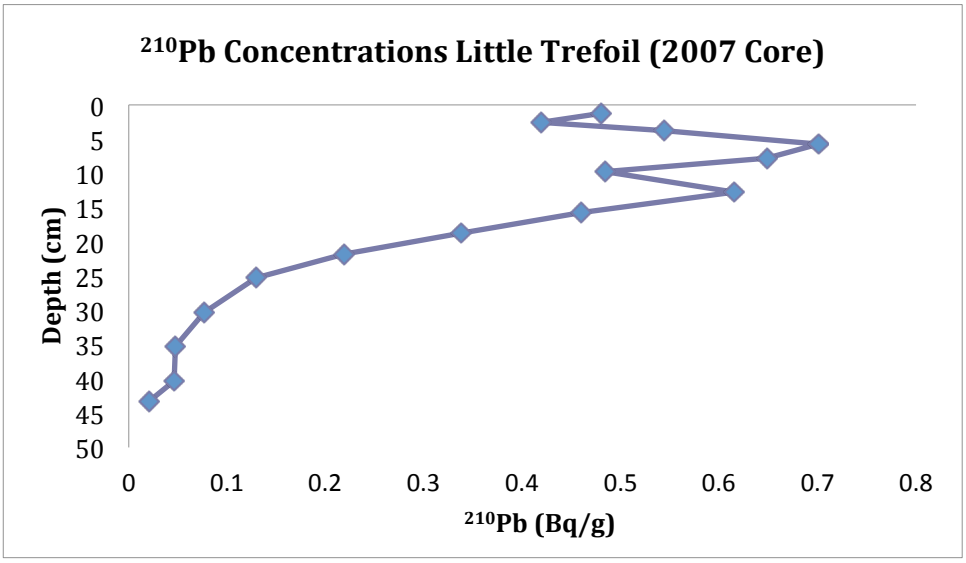

Figure 14: Lead 210 concentrations (Bq/g) in sediment from depths 0-43cm for a core taken in 2007 at Little Trefoil Lake, Jasper National Park, Alberta.

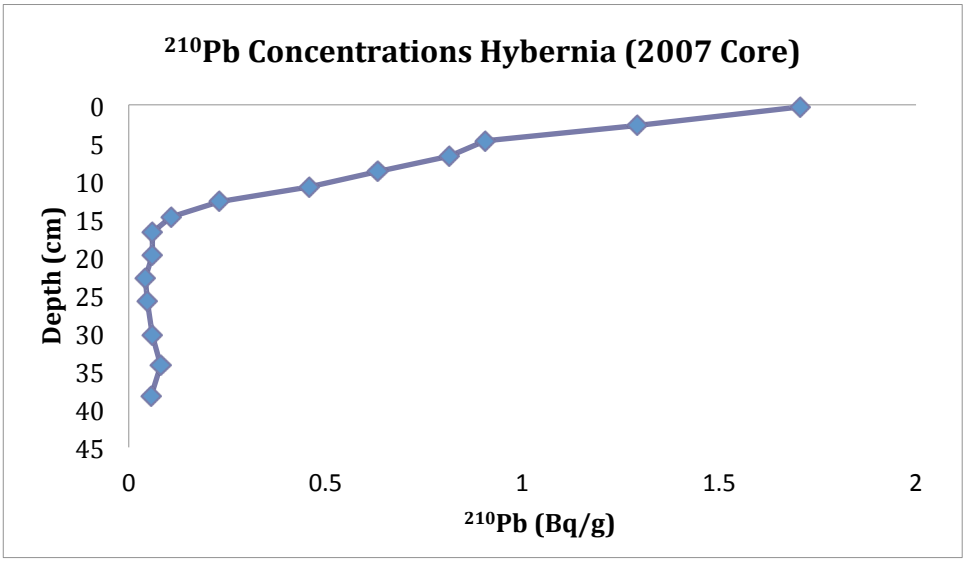

Figure 15: Lead 210 concentrations (Bq/g) in sediment from depths 0-38cm for a core taken in 2007 at Hybernia Lake, Jasper National Park, Alberta.

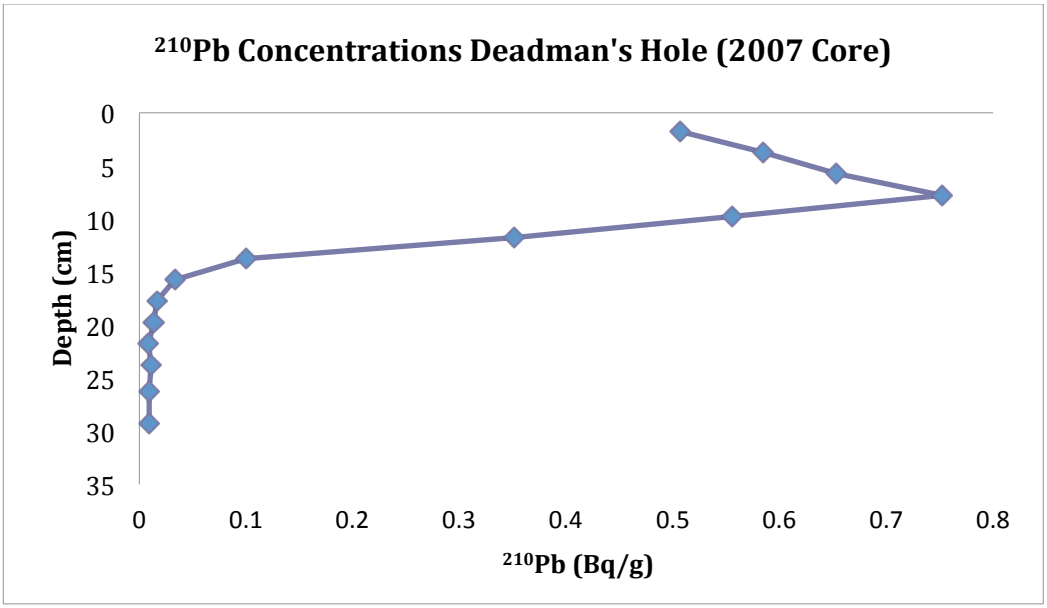

Figure 16: Lead 210 concentrations (Bq/g) in sediment from depths 0-29cm for a core taken in 2007 at Deadman's Hole Lake, Jasper National Park, Alberta.

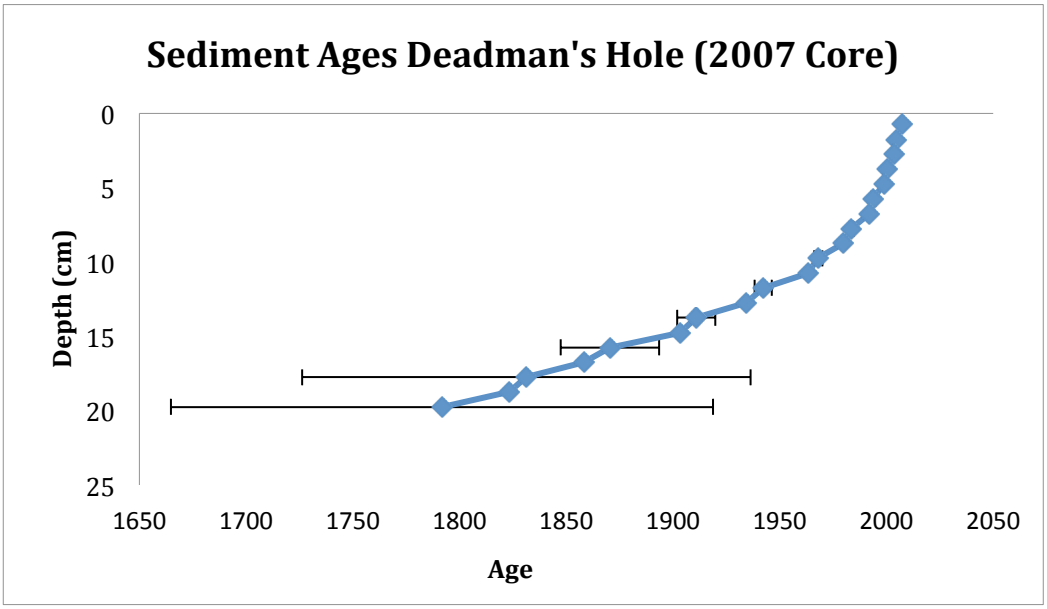

Figure 17: Age of sediment (year) located at midpoints 0.75-18.75cm for a core taken in 2007 at Deadman's Hole Lake, Jasper National Park, Alberta. Data points before 1950 without errors bar are years that have been interpolated.

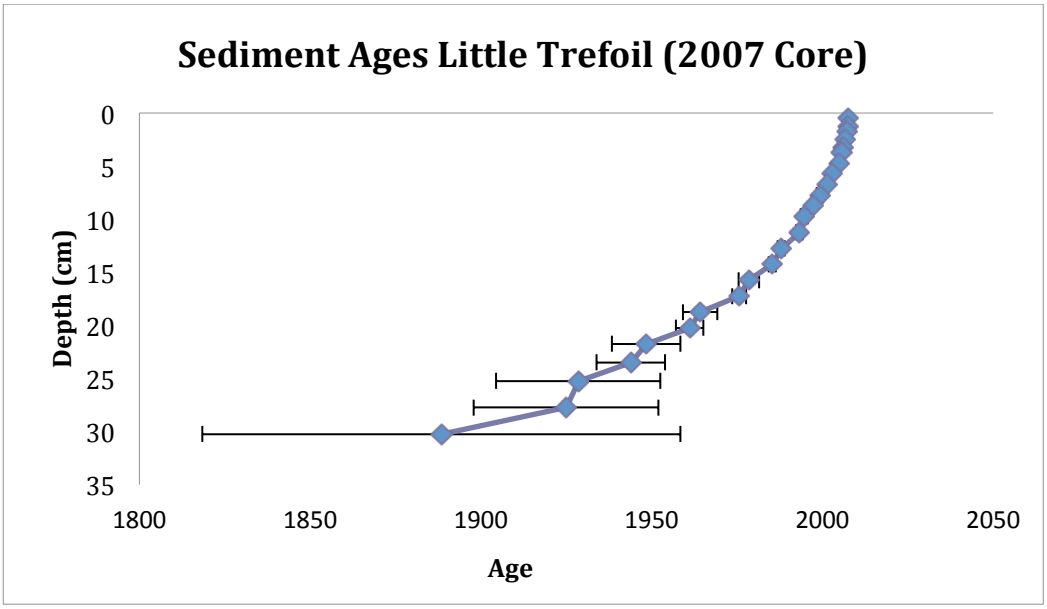

Figure 18: Age of sediment (year) located at midpoints 0.5-30.25cm for a core taken in 2007 at Little Trefoil Lake, Jasper National Park, Alberta.

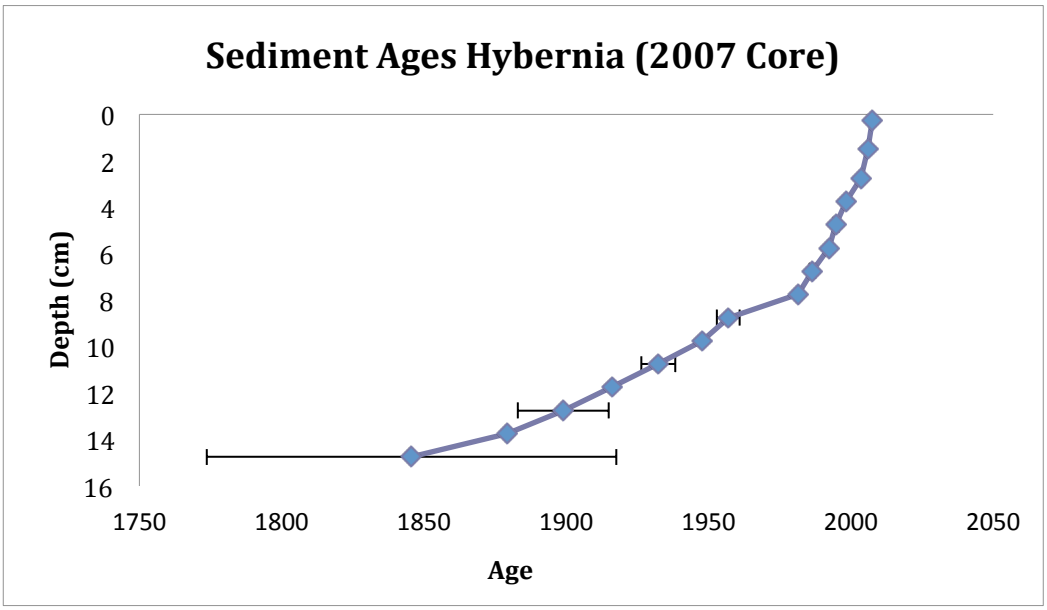

Figure 19: Age of sediment (year) located at midpoints 0.25-14.75cm for a core taken in 2007 at Hybernia Lake, Jasper National Park, Alberta. Data points before 1950 without errors bar are years that have been interpolated.

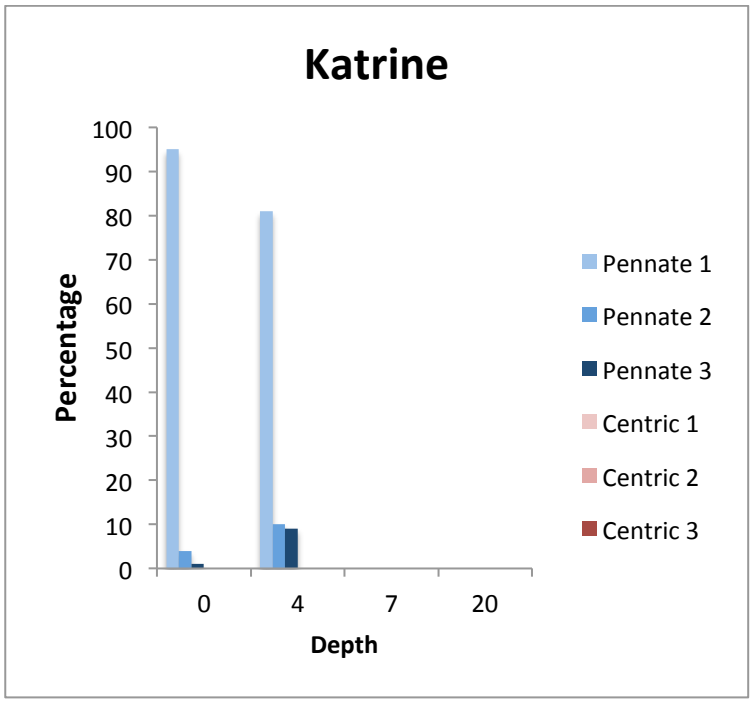

Figure 20: Percentage of pennate (blue) and centric (red) diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) at depths 0cm, 4cm, 7cm and 20cm for Katrine Lake located in Jasper National Park, Alberta.

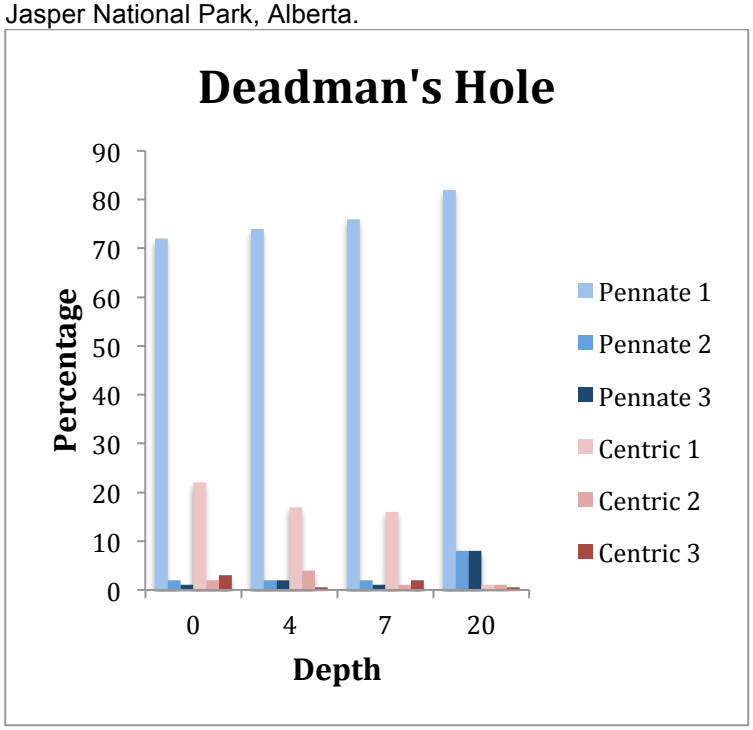

Figure 21: Percentage of pennate (blue) and centric (red) diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) at depths 0cm, 4cm, 7cm and 20cm for Deadman's Hole Lake located in Jasper National Park, Alberta.

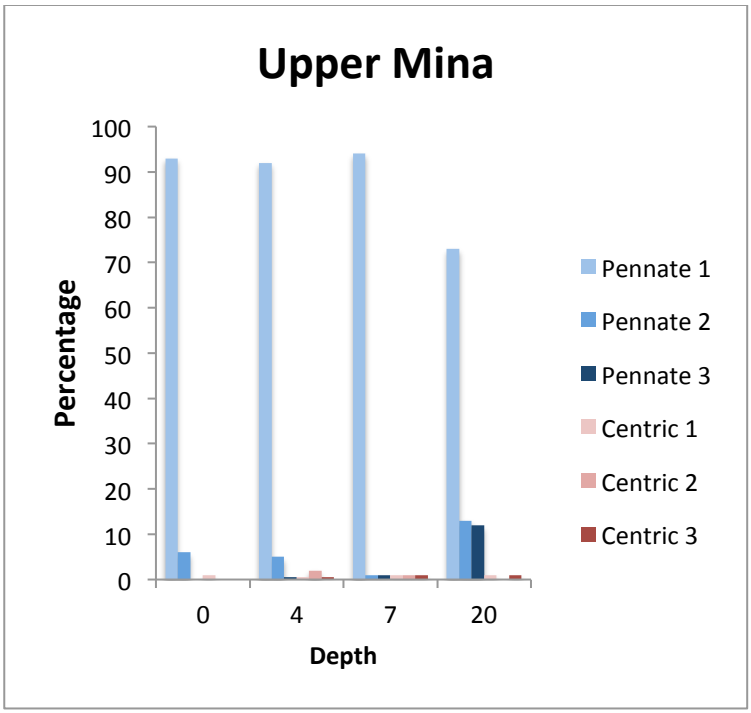

Figure 22: Percentage of pennate (blue) and centric (red) diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) at depths 0cm, 4cm, 7cm and 20cm for Upper Mina Lake Lake located in Jasper National Park, Alberta.

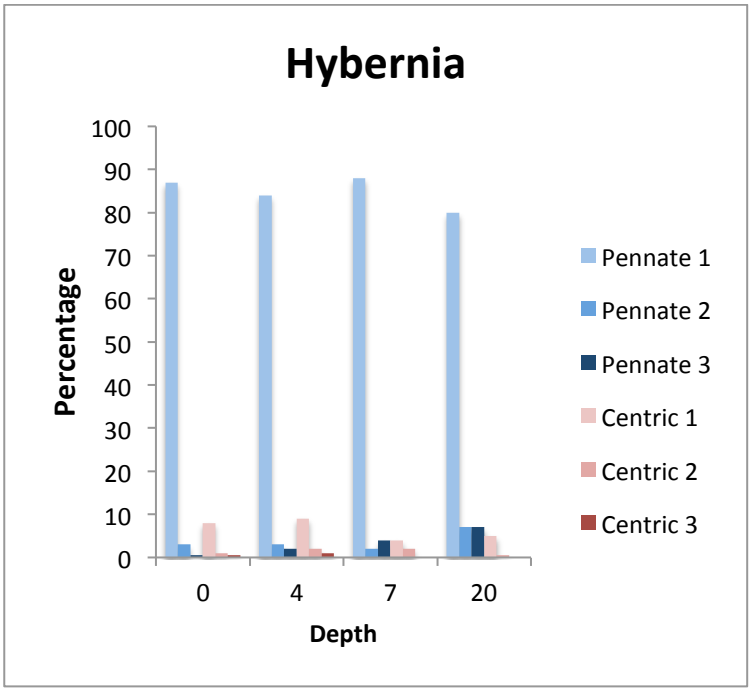

Figure 23: Percentage of pennate (blue) and centric (red) diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) at depths 0cm, 4cm, 7cm and 20cm for Hybernia Lake located in Jasper National Park, Alberta.

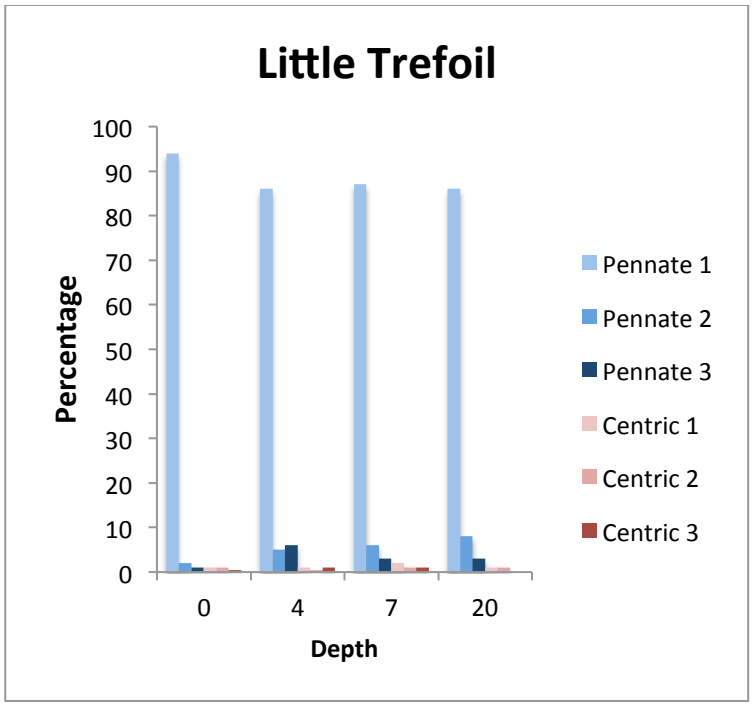

Figure 24: Percentage of pennate (blue) and centric (red) diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) at depths 0cm, 4cm, 7cm and 20cm for Little Trefoil Lake located in Jasper National Park, Alberta.

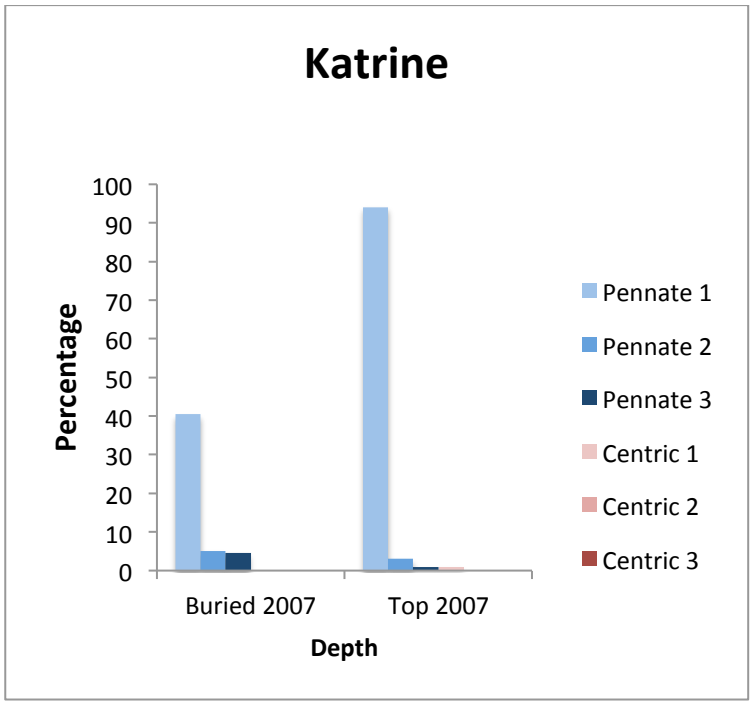

Figure 25: Percentage of pennate (blue) and centric (red) diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) at depths 4-7cm for the 2014 core (buried 2007) and 0cm for the 2007 core (top 2007) for Katrine Lake located in Jasper National Park, Alberta.

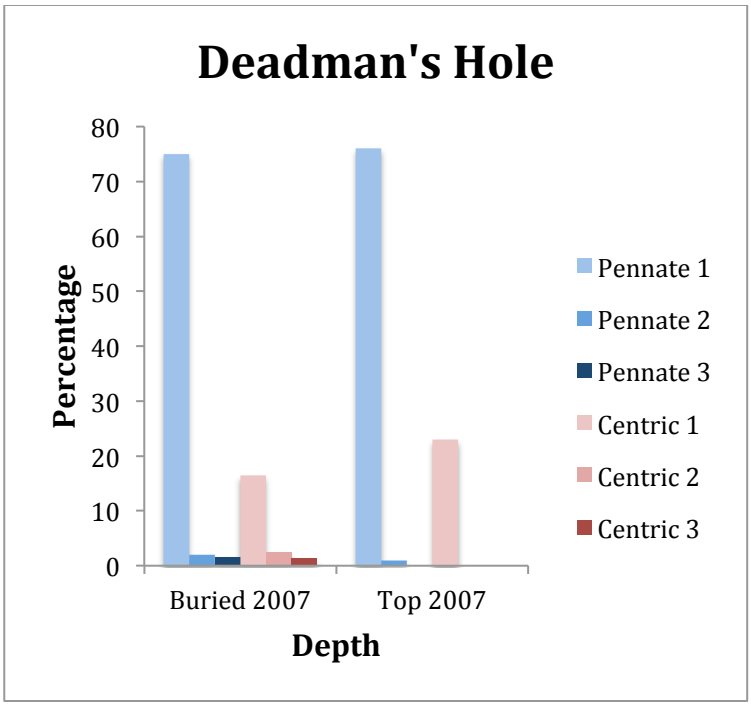

Figure 26: Percentage of pennate (blue) and centric (red) diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) at depths 4-7cm for the 2014 core (buried 2007) and 0cm for the 2007 core (top 2007) for Deadman's Hole Lake located in Jasper National Park, Alberta.

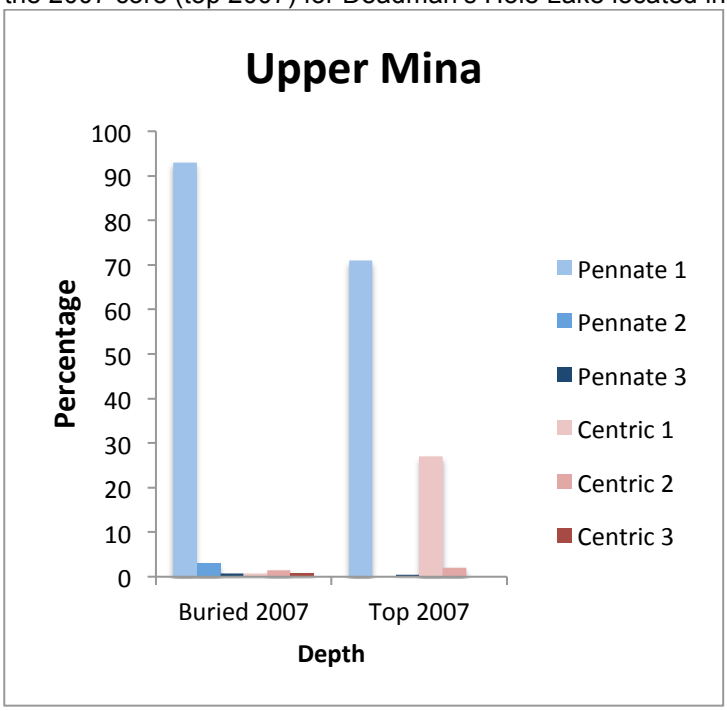

Figure 27: Percentage of pennate (blue) and centric (red) diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) at depths 4-7cm for the 2014 core (buried 2007) and 0cm for the 2007 core (top 2007) for Upper Mina Lake located in Jasper National Park, Alberta.

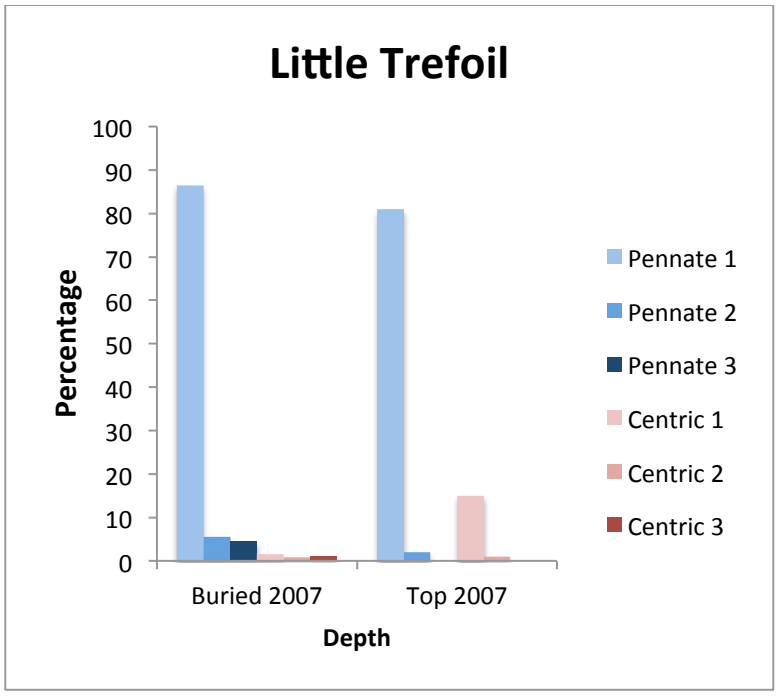

Figure 28: Percentage of pennate (blue) and centric (red) diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) at depths 4-7cm for the 2014 core (buried 2007) and 0cm for the 2007 core (top 2007) for Little Trefoil Lake located in Jasper National Park, Alberta.

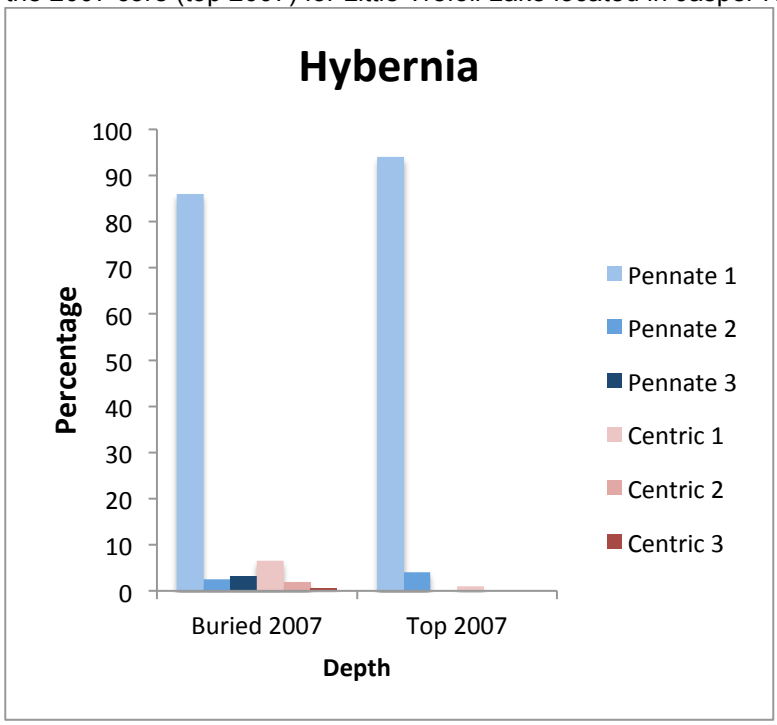

Figure 29: Percentage of pennate (blue) and centric (red) diatoms at each preservation rating (well preserved 1, some dissolution 2, significant dissolution 3) at depths 4-7cm for the 2014 core (buried 2007) and 0cm for the 2007 core (top 2007) for Little Trefoil Lake located in Jasper National Park, Alberta.

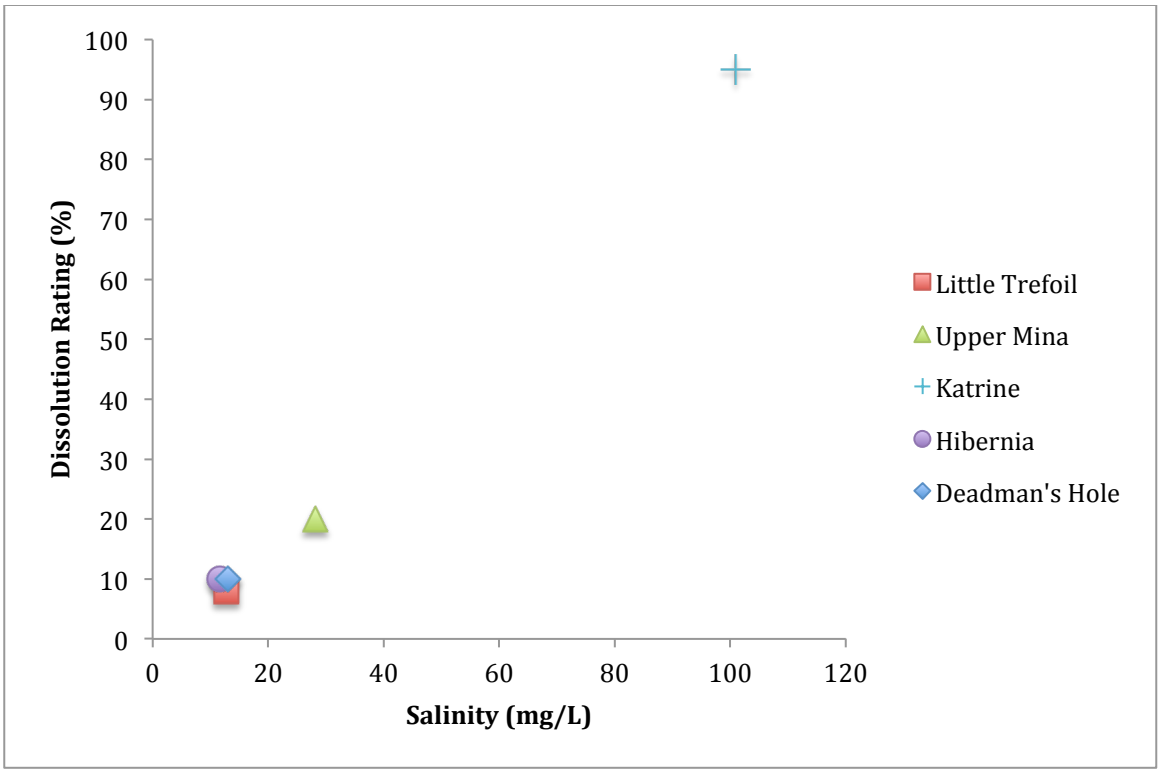

Figure 30: Graph depicting salinity (mg/L) versus dissolution rate (%) for lakes Little Trefoil, Upper Mina, Katrine, Hybernia and Deadman's Hole located in Jasper National Park, Alberta.

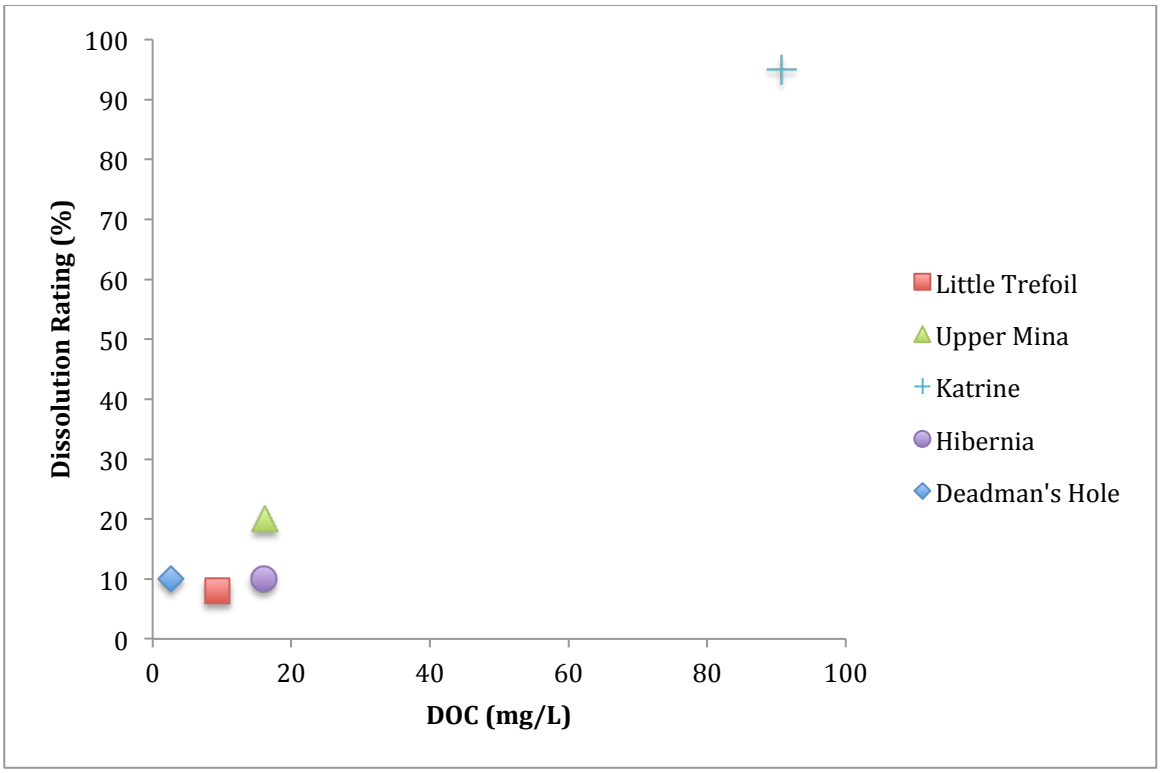

Figure 31: Graph depicting dissolved organic carbon (DOC) in mg/L versus dissolution rate (%) for lakes Little Trefoil, Upper Mina, Katrine, Hybernia and Deadman's Hole located in Jasper National Park, Alberta.

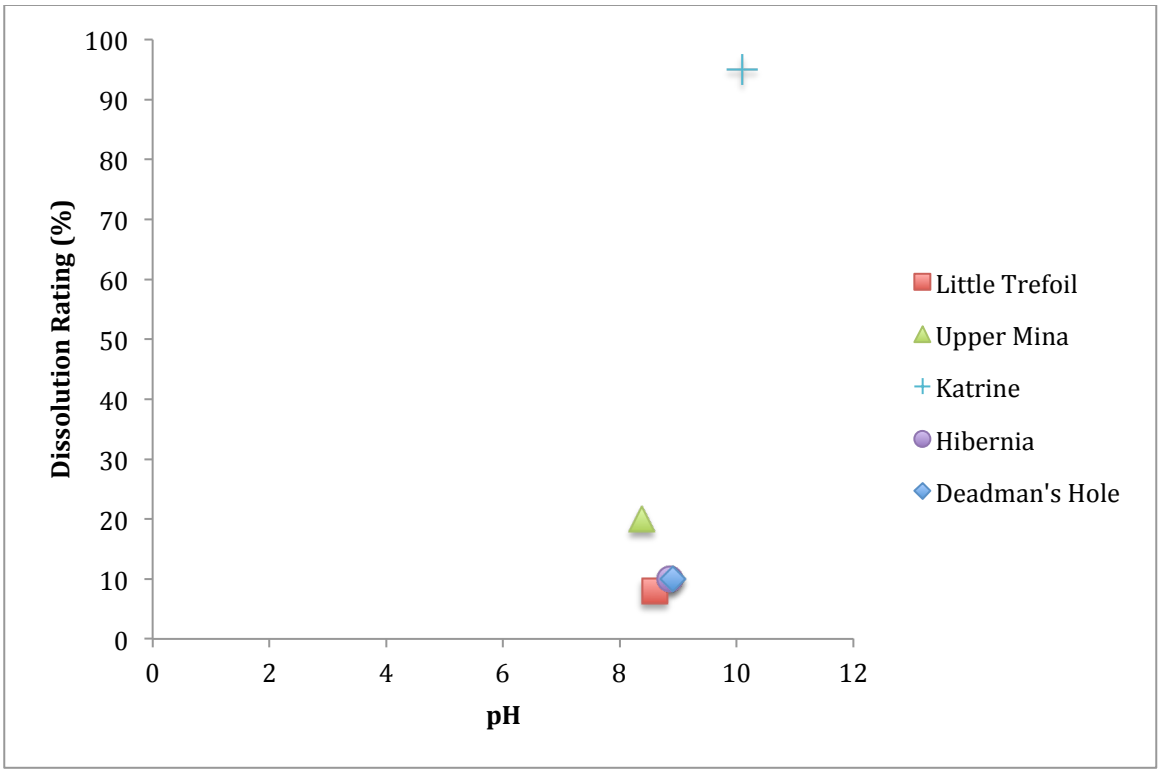

Figure 32: Graph depicting pH versus dissolution rate (%) for lakes Little Trefoil, Upper Mina, Katrine, Hybernia and Deadman's Hole located in Jasper National Park, Alberta.

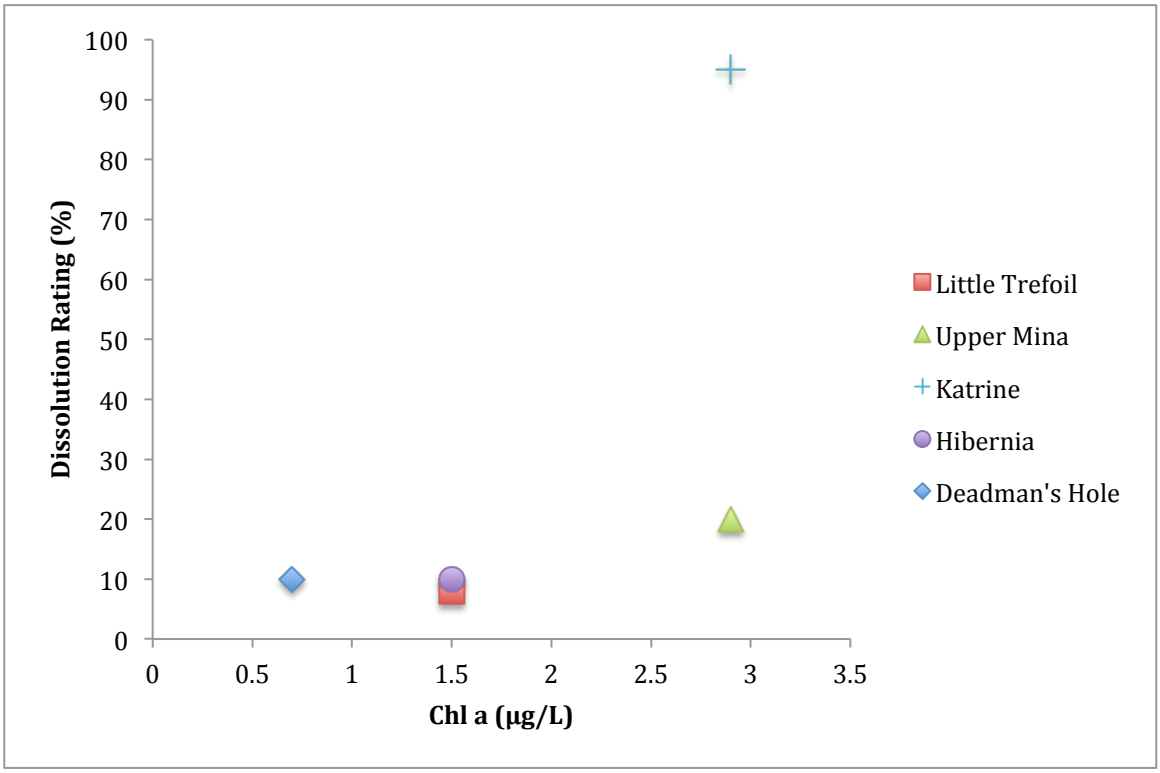

Figure 33: Graph depicting chlorophyll A (Chl a µg/L) concentration versus dissolution rate (%) for lakes Little Trefoil, Upper Mina, Katrine, Hybernia and Deadman's Hole located in Jasper National Park, Alberta.

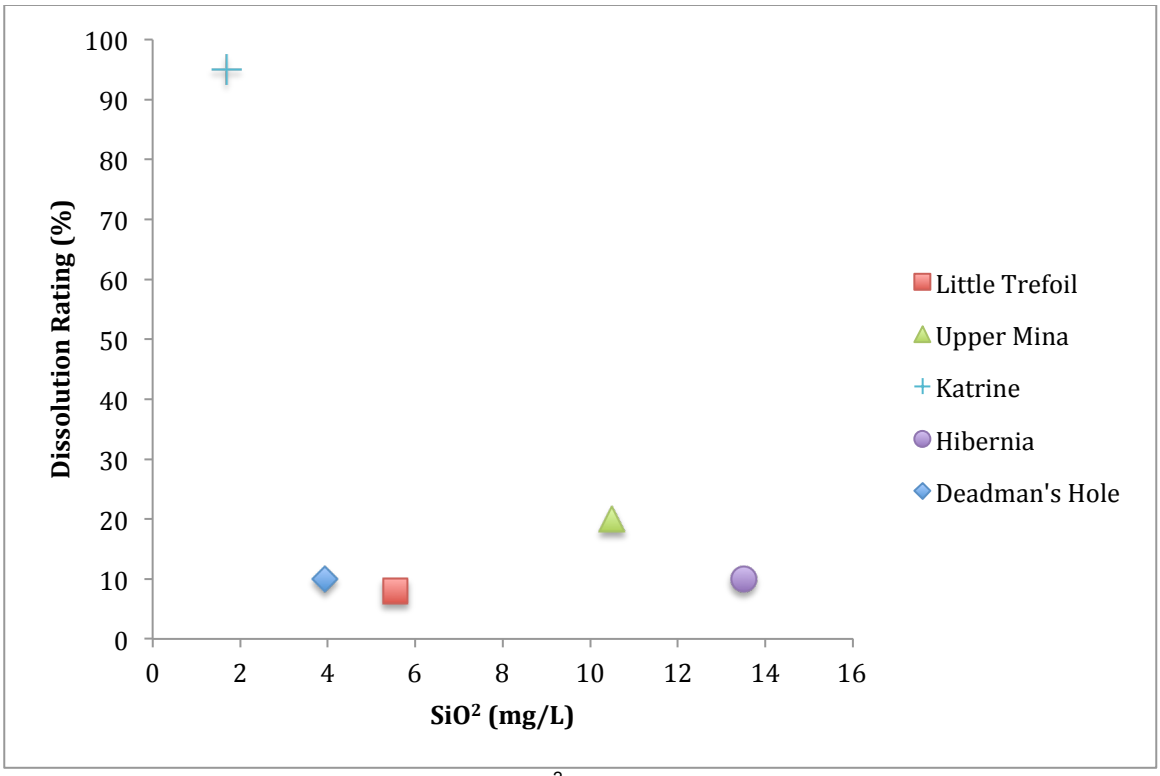

Figure 34: Graph depicting silica content (SiO^2 mg/L) versus dissolution rate (%) for lakes Little Trefoil, Upper Mina, Katrine, Hybernia and Deadman's Hole located in Jasper National Park, Alberta.