Using Condonts to Determine Depositional Variability within the Decorah Formation of Eastern Minnesota and Iowa

By

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ABSTRACT

The Decorah Formation is a well-known fossiliferous rock unit that crops out in the Midwest, such as Minnesota, Iowa, Wisconsin, Missouri and Illinois. Ordovician in age, it contains abundant shallow marine fossils. The purpose of this paper is to examine whether differences in depth and environment are preserved in the Decorah Formation, across three localities in Minnesota and Iowa. Does the Decorah show a time-transgressive succession, or was it deposited in the same environment throughout the study area? Samples were taken from the top and bottom of the Decorah Formation at Rochester, Decorah and Minneapolis outcrops. Conodonts were recovered and identified from each sample, and a similarity matrix was used to evaluate the level of taxonomic similarity across the study area. Overall, the distribution of taxa across the study area was similar; however, a strong similarity between the basal assemblage at Decorah and the assemblage from the top of the unit a Minneapolis suggests environmental change due to transgression. The unique nature of from distribution for the assemblage at the base of the unit in Minneapolis is consistent with this conclusion.

ACKNOWLEDGEMENTS

I would first like to thank Dr Julie Bartley for helping with revisions, understanding concepts and providing knowledge. I would also like to extend thanks to Dr. Jim Welsh and Dr. Laura Triplett for their help in revisions and answering any questions I might have had. Next, I would like to thank Dr. Carolyn Dobler for aid with the statistical side of my thesis. I would like to thank Jake Bruihler for assistance. I would like to thank Gustavus Adolphus College for the use of it facilities. Lastly, I would like to thank the Gustavus Geology majors for their help with little details and formatting issues.

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INTRODUCTION

The Decorah Formation is widespread throughout the Midwest, and is commonly found in outcrop therein. It is commonly known that this part of the world was covered by an intercontinental sea during the Ordovician, but that sea is gone and the only way to understand and study it is by understanding and studying the Decorah Formation it left behind. The Decorah is interesting because it is such a widespread rock unit, which is presumed to act synchronously across its entirety. Epeiric seas are rare today, and none exist of the size of the Ordovician seaway. It is interesting to understand how these seas work and the Decorah's widespread nature allows us to get a good look at how the sea was deposited and acted. Another reason to study the Decorah is the fossils found within it. The Decorah is well known for being fossiliferous and containing excellent samples of marine invertebrates from the Ordovician. Sloan and Kolata (1987) and George Marshall (1925) describe much of the fossil assemblage of the Decorah in the Upper Mississippi Valley. These specimens could help us to better understand the organisms which once lived here and maybe even the evolutionary path they took to get to today. The Decorah also contains a globally important time surface. Kolata et al. (1987) determined that the Decorah contained two bentonite layers, which can be correlated across the basin; their results showed that parts of the Decorah were deposited asynchronously (Kolata et al., 1987).

Epeiric seas tend to have very shallow depth gradients. Because of this, it is believed that most of these seas deposited simultaneously across the sea and that the lack of slope results in very little variability in depositional environment across broad areas of the seas. This flat deposition would result in rocks deposited at the bottom of a unit matching across the bottom of that unit, as well as the rocks at the top of a unit matching the rest of the top of that unit, in both time and environment. Since it is hypothesized that these seas deposited in one general environment, it should also be true that the fossils contained in these seas should be similar across the unit. This is because certain fauna live in certain environments. A deep sea creature would not be found in shallow water rocks because it would not live in shallow water. So if the Decorah indeed was deposited simultaneously, then the fossil assemblages should not change much. If this is not the case however, we could see a variety of fossils across the unit.

Conodonts are small sea worms that swam throughout the Paleozoic seas. They are considered to be some of the first vertebrates, as well as having one of the first jaw structures. Conodonts' soft body parts are hard to preserve; instead we commonly find the teeth elements. These tend to be clear or black in color and are microscopic.

Stauffer (1935) described the different species of conodont found in the Decorah. Later in 1987, Frederick placed conodont assemblages into regional groups. This study showed that certain conodonts were cosmopolitan, occurring throughout the whole of the Midwest. Stratigraphic work using conodonts established biostratigraphic zones for conodonts in the southern Midwest. George Marshall (1929) and later Sloan, R. (2003) had both done studies and displayed the stratigraphy and layout of the Decorah Formation. Sloan's study is particularly connected to this study as he did stratigraphy in the Minneapolis area, which is a part of this study. He used fossil algae to determine four biofacies and determined the Minneapolis area was as deep as 30m due to the need for algae to receive red light for photosynthesis. Also, sea level was thought to be rising during the Ordovician, and Simo et. al. (2003) have shown that the Decorah has seen some episodes of continental flooding and weathering. This could mean that the Decorah could show at least some form of transgression.

In this project, we use conodont form species to evaluate the differences in the Decorah. Conodonts were chosen for this study because of their relative abundance, relative ease of extraction from calcareous shale material, and because their morphological differences allow easy differentiation. The purpose of this study is to determine whether the Decorah shows variation in depositional environment, as preserved in the conodont assemblages across the area from Minneapolis, Minnesota to Decorah, Iowa. This study takes a new angle to what has been done and uses conodont species distribution to determine whether or not there are any noticeable differences in assemblages and there for the environment the rock was deposited in. I hypothesize that there will be no large scale differences across the localities, and that the null hypothesis will not be refuted, but it is possible that small scale changes have occurred.

GEOLOGIC SETTING

The Decorah Shale is Middle Ordovician in age, ~454 million years in age (Emerson, 2000), and is exposed throughout the Midwest. Laurentia (or proto- North America) at this time was very near the equator, it and was also rotated ~45º from its modern position. (Jin et al. 2013) During the Ordovician, sea level was much higher than today, resulting in much of the North American continent being covered by a shallow sea. The three locations studied are near the transcontinental arch, in the Hollandale Embayment and lie at the edges of the Iapetus Ocean (Figure 1). Here the depositional environment is described as intermediate depth with some shallowing events appearing during this time.

The Decorah Shale makes up the lower part of the Galena Group, which sits above the Platteville Limestone. The Decorah Formation is approximately 40m thick and is made up of three members: the Spects Ferry, Guttenburg, and Ion. Localities at Decorah, IA Minneapolis, MN and Rochester, MN have outcrops of the Decorah Formation that contain interbedded shales and limestones. (Emerson, 2000) The Decorah is very fossiliferous and the samples collected possessed a calcareous matrix. Gastropods, brachiopods and crinoids are commonly found within the Decorah, although no megascopic fossils were observed in these samples. The three sample localities were chosen because they are easily accessible and contain a large or complete section of the entire formation.

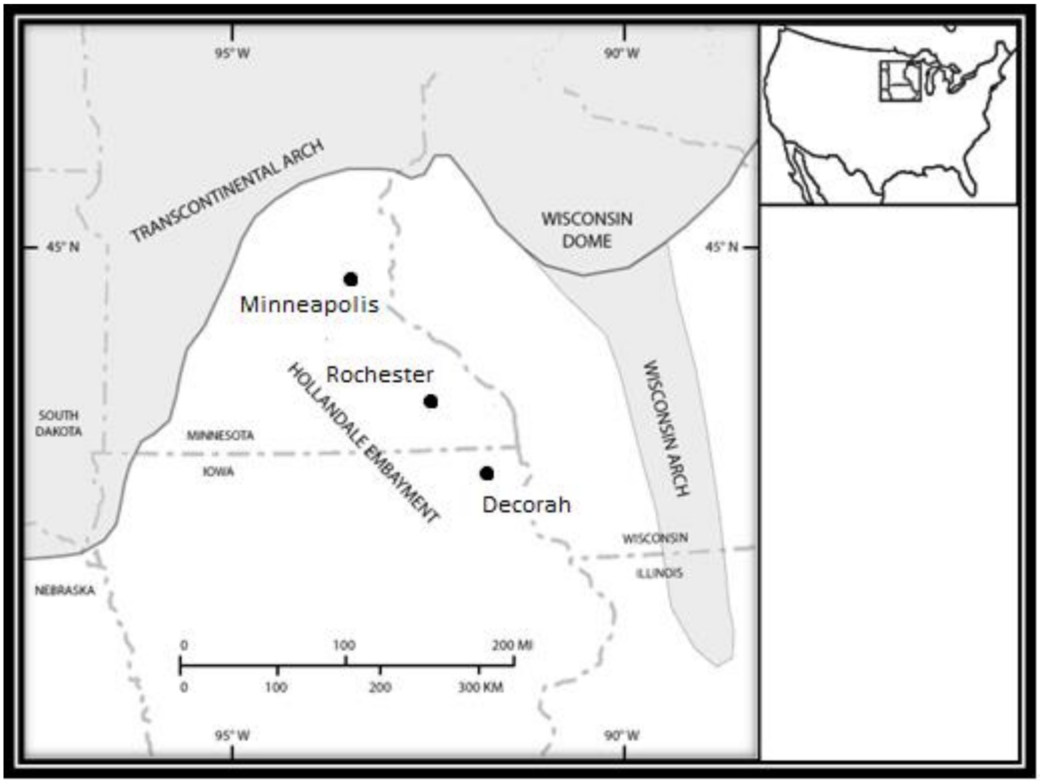


Figure 1. Regional map showing the Hollandale Embayment. Sample localities are indicated by black dots. Map from Johnson et al. (1989)

METHODS

Samples of calcareous shale were gathered from the three localities (Minneapolis, Decorah and Rochester) from as close to the top and as close to the bottom of the unit as possible. Approximately 2 kg of rock was collected for each sample. Samples were then transported to the lab where they we placed in plastic bins and labeled. Each sample was crushed to <1 cm in diameter. A colander was placed in the bins and the crushed rock was placed inside the colander. 5,000 mL of water was added to the bins as well as 500 mL of glacial acetic acid. The bins were then left in a fume hood overnight to allow the rock to dissolve and become sludge. Any samples that did not completely dissolve during this time were given 250 mL more of the acid and left for another night. The next day this sludge was wet sieved using .9 mm and 63 μm wet sieves. The material left in the 63μm sieve was then poured into 500 mL beakers and placed in an oven overnight at 80 C°. Once removed, the samples were placed in petri dishes and a microscope was used to find and separate conodonts from bulk samples. Each conodont extracted was sketched and tallied, then placed into a smaller petri dish for future observation. For this study, it was not necessary to identify fossil taxa by name; the analysis relies on knowing the number of distinct forms (as a proxy for diversity) rather than the taxonomy. The samples were counted and used to construct a rarefaction curve, which graphs the total number of fossils found to the number of species. A rarefaction curve is used to decide when enough fossils were found to have confidence that all unique taxa were recovered. Rarefaction curves are steep near the origin, when most fossils belong to previously unrecovered taxa. As the number of individuals increases, the number of new taxa declines, producing a plateau in the curve shape. Once the curve plateaued, the samples were considered to have reached a point where all if not most of the species were extracted Gotelli and Colwell (2001). Samples were gathered until they fulfilled to requirements of Gotelli and Colwell. The requirements are fulfilled when the curve reaches an asymptote found by using the function used by Hwey-Lian and Lung-An (1998) and bringing the total number of specimens to infinity. This will allow us to determine a simple y value (or number of different species) that will be the asymptote for the curve. A similarity matrix will be used to determine and similarities between each site by counting the number of presences and absences of each conodont element at each site. Lastly a Kruskal-Wallis One Way Analysis of Variance on Ranks test will be done on all of the locations using the percentages from Table 2, which shows the percentages of each specimen in a sample compared to the total population collected in each sample.

RESULTS

A total of 185 individual elements belonging to 12 distinct forms (Figure 2) were recovered. At the Decorah locality, 35 specimens were found in sample from the top of the unit and 30 were found in the bottom. At the Rochester, locality 42 conodont elements were found at the top, while 14 were found at the bottom. Finally, at the Minneapolis locality 36 conodont elements were found at the top, while 28 were found at the bottom. The number of conodont elements to be collected was predetermined using a rarefaction curve as stated above (Figure 3; Appendix 1). For this study, it was not necessary to identify the conodonts so they were assigned letters (A-L; Figure 2). I will present my results for each of the three localities, then the localities will be compared to each other. Data are summarized in Table 1. It is important to note that conodont elements are phosphatic, and that it is possible that some of the specimens are phosphatic worm parts. This does not jeopardize the integrity of the study as it is the differences between assemblages that matters.

Decorah:

The Decorah Top section sample was found to contain 6 types of conodont elements: A,B,C,E,F, and J. Conodont element A is the most common at 20 specimens found, this is followed by B which has 8 specimens. C, F, E and J were all rarer with one or two individuals recovered. The bottom sample from the Decorah locality contains 5 types of conodont elements:

A, B, C, G and K. Conodont element A was the most common, with 20 specimens recovered. C and K both had 3 specimens found. B and G were the rarest with only 2 specimens each. All the conodont elements in the Decorah locality were white in color.

Rochester:

The Rochester locality's top area recovered 6 types of conodont elements: A, B, C, D, E and F. The most common species, with 25 specimens found was conodont element A. Conodont element C was found 7 times. Conodont elements B, E D and F were rarer with 4 to 1 specimens found of each. The bottom section of Rochester was odd as only 14 conodont elements were found in total before the rarefaction plateaued (Figure 3). The site contained 5 types of conodont elements: A, B, F, I and J. In this area both conodont elements A and B were found 4 times. Conodont elements F, I and J were each found only twice. The conodont elements here were mostly clear in color with specimen I being black in color. This was the only black specimen found.

Minneapolis:

The Minneapolis top locality contained 5 types of conodont elements: A, B, C, G, and H. A was the most common species with 16 specimens found. B was the second most common with 8 specimens seen. Conodont elements C, G and H all had a total of 4 specimens found in this area. The bottom of the Minneapolis locality contained 6 types of conodont elements: A, C, F, H, K, L. Element A was the most common species with 14 specimens found. C was the second most common with 5 specimens found. Conodont element H was found a total of 4 times. Conodont elements K, F and L were found once or twice. The conodont elements at this locality were all clear in color.

Top:

The tops of the localities contained a total of 113 conodont elements. The species found were A, B, C, D, E, F, G, H and J. A is the most common of the species with 61 found followed by B with 20. C was common with 13 specimens found. Conodont element G, H and E were seen 4 times. F, J and D were all rarer.

Bottom:

The bottom of the areas contained 72 conodont elements. The species found were A, B, C, F, G, H, I, J, K and L. Species A was the most common species with 38 specimens found. B had 6 specimens found and C had been found 8 times. F was found 3 times, H was found 4 times and J, K, G and L were all found twice each.

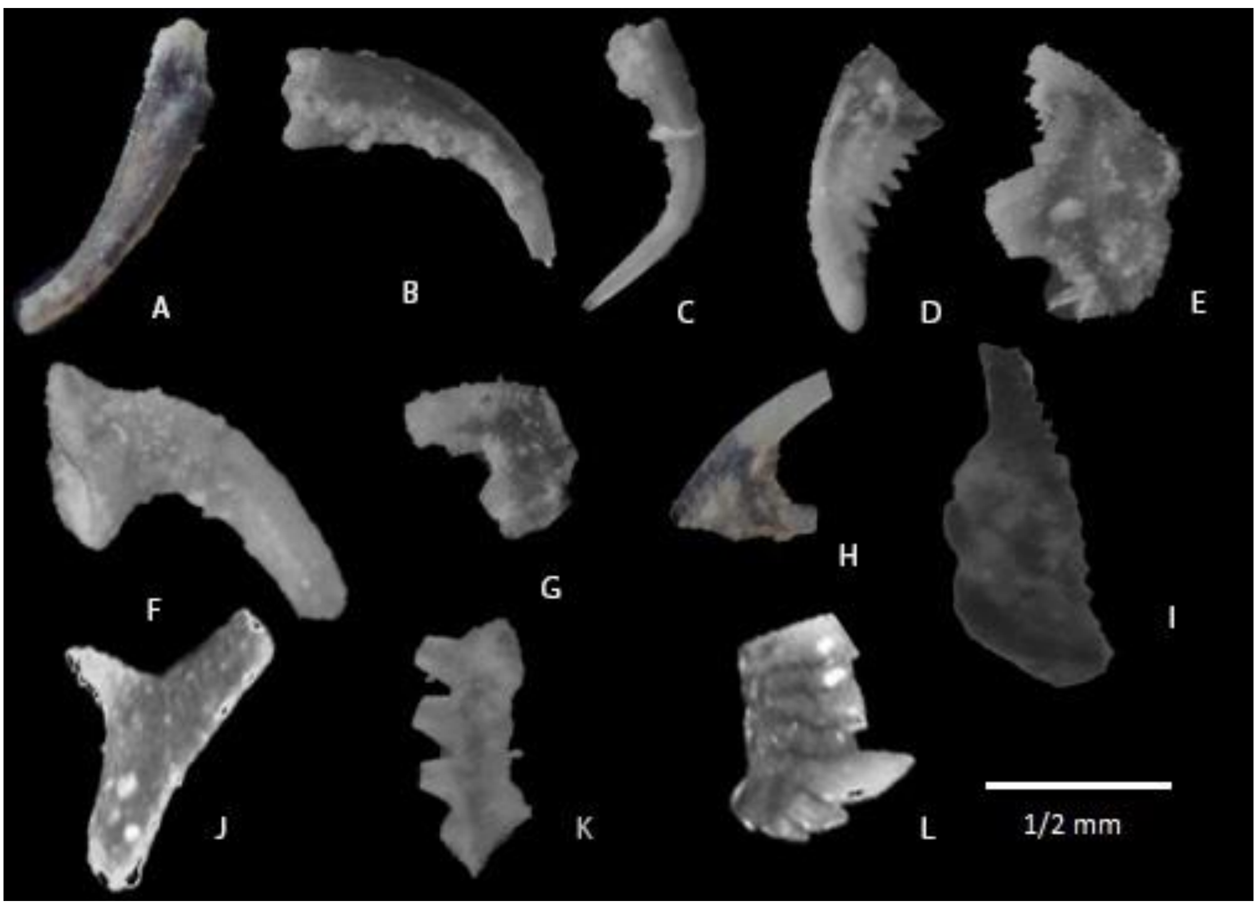


Figure 2. This photomicrograph displays the different conodont forms found. Each one was labeled with a letter for easy reference.

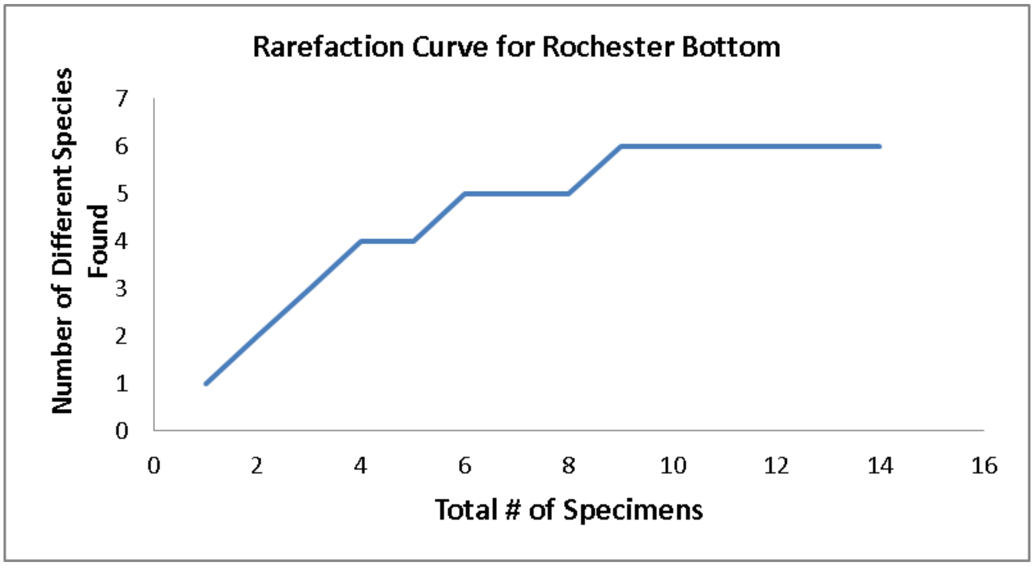


Figure 3. Rarefaction curve for the Rochester bottom site. Remaining rarefaction curves found in Appendix 1

Sample Number	A	B	C	D	E	F	G	H	I	J	K	L	Total
DEC-Top	20	8	2		1	2				1			33
DEC-Bot	20	2	3				2			3			30
ROCH-Top	25	4	7	2	3	1							42
ROCH-Bot	4	4				2			2	2			14
MIN-Top	16	8	4				4	4					36
MIN-Bot	14		5			1		4			2	2	28

Table 1. Distribution of taxa and number of individual elements recovered from each sample. Notice the low number of individuals recovered from the Rochester bottom sample.

Sample Number	A	B	C	D	E	F	G	H	I	J	K	L
DEC-Top	58%	24%	6%		3%					3%		
DEC-Bot	66%	7%	10%				7%			10%		
ROCH-Top	58%	10%	17%	5%	7%	3%						
ROCH-Bot	29%	29%				14%			14%	14%		
MIN-Top	44%	22%	11%			6%	11%	12%				
MIN-Bot	52%		18%			4%		14%			6%	6%

Table 2. Percentage represented by each conodont element form relative to the total population recovered in each sample.

	MIN-Top	MIN-Bot	ROCH-Top	ROCH-Bot	DEC-Top	DEC-Bot
MIN-Top		7	7	6	7	10
MIN-Bot	7		6	5	6	5
ROCH-Top	7	6		7	10	7
ROCH-Bot	6	5	7		9	8
DEC-Top	7	6	10	9		9
DEC-Bot	10	5	7	8	9	

Table 3. Similarity matrix comparing localities.; Each cell showing the total matches (absence + presence) of the 12 conodont forms between each pair of samples.

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
Col 2	12	0	0.000	0.000	11.750
Col 3	12	0	2.000	0.000	12.000
Col 4	12	0	1.500	0.000	9.250
Col 5	12	0	0.000	0.000	14.000
Col 6	12	0	1.500	0.000	6.000
Col 7	12	0	0.000	0.000	9.250

H = 0.185 with 5 degrees of freedom. (P = 0.999)

Table 4. Results of a Kruskal-Wallis One Way Analysis of Variance on Ranks.

A Mann-Whitney Rank Sum Test was also done comparing each of the localities to Minneapolis bottom, which seemed to have the lowest amount of similarities, to see if there were any differences between localities that the Kruskal-Wallis test could not determine. The P values for these tests ranged from .875-1.

DISCUSSION

Analysis was based on the notion that if the Decorah was deposited in a single biostratigraphic zone in relation to conodonts and within the same depositional environment, there would be little to no difference in species distribution at each location or from top to bottom. A significant difference in either time or depositional environment would result in the six samples differing in their assemblages of conodont elements, and would predict different proportions of each. If changes in the Decorah were driven by facies movement or environmental change, we would expect there to be noticeable patterns in the fossil assemblages.

The similarity matrix (Table 3) shows a few noticeable patterns. Notice the high amounts of similarity between the Rochester top and Decorah top sites, as well as the 10 points of similarity between the Decorah bottom site and the Minneapolis top site. Another important set of points to note is the fact that the Minneapolis bottom site has very little (5-6) similarity matches with four other sites. (DEC-Bot, DEC-Top, ROCH-Bot and ROCH-Top)

Generally, samples with a high degree of similarity in species distribution are interpreted to have been deposited under similar depositional conditions within the same biostratigraphic zones. Most of the sites analyzed in the study generally showed little difference in species distribution. This is expected as the sites are close in proximity and the shallow sea that occupied this area tended to have little slope in seafloor, resulting in little room for multiple environments. The conodont elements A, B and C were recovered from almost every sample, and in all but one sample element A was the most common by a large margin.

Some sites did indeed have little in common with other sites (Minneapolis bottom), while some sites many taxa in common, even when separated across the study area (Decorah bottom and Minneapolis top). When analyzing Table 4 the points that stick out are the cells that contain the numbers 10 and 5 since these are the extremes. The 10s exist between the bottom of Decorah and the top of Minneapolis. They also occur between the tops of both Decorah and Rochester. The 10 similarities that connect the Decorah and Rochester tops could be attributed to the fact that they are very near localities and are both on top. This would mean there was little change in environment from the Decorah to Rochester area in the top of the Decorah Formation and that they were deposited in the same environment. As sea level rose, the facies represented by the bottom of the Decorah at Decorah would have migrated towards shore in younger rocks, or in this case towards the Minneapolis location. This would result in the pattern seen in the similarity matrix. Another interesting group of points in the similarity matrix are the 5s. These are found exclusively while comparing the bottom of the Minneapolis outcrop the others.

A transgressive facies arrangement is the result of sea level rise, which means the facies move shoreward. Figure 4 shows what a transgression looks like in a shallow sea, like the one that existed in the Ordovician. As sea level rises, the shallow faces move landward, because each facies is generally associated with a certain water depth. Because this facies is found in shallow water, as the water deepens facies A moves to where the shallow water is, which is further up shore. Consequently facies B must now also move to the appropriate water depth which is where facies A was being deposited before. This results in facies B being found directly over facies A in that area. With the movement of these facies comes the movement of the rocks types and fossil assemblages found within. This is how we get shales with deep water animals found directly on top of sandstones. Note that in the Decorah, only limestone and shale lithologies are present, and they are intimately interbedded; Figure 4 is intended to show relationships only; not to express the lithologies observed in the Decorah Formation.

This pattern is probably explained by the transgression of the intercontinental sea. As sea level rose the facies that the bottom of the Minneapolis outcrop contained would have moved shoreward and out of the area studied. This could be why we do not see many connections to the Minneapolis bottom section. The Transcontinental Arch lay to the north of the Minneapolis locality, and was above sea level during most of the Ordovician. With the shore in this direction it makes sense that the Minneapolis locality would show the signs of the most shoreward location.

There are a few reasons why this pattern could occur. It could be possible that not enough specimens were found to get a good enough assemblage to make assumptions. This could be the case with the Rochester bottom site, as only 14 conodont elements were recovered. It’s also possible that this pattern is the result of a transgression.

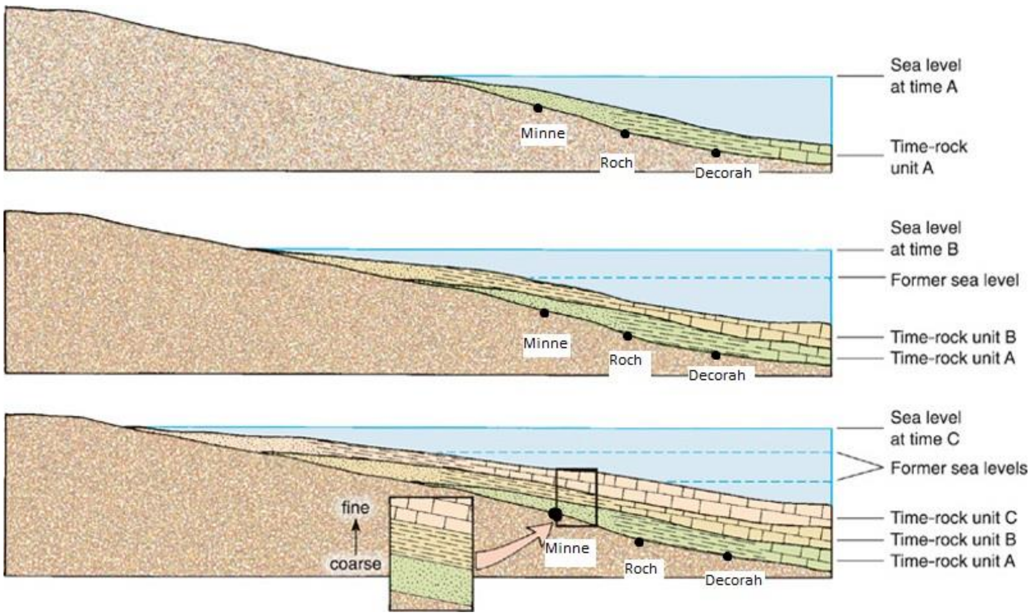
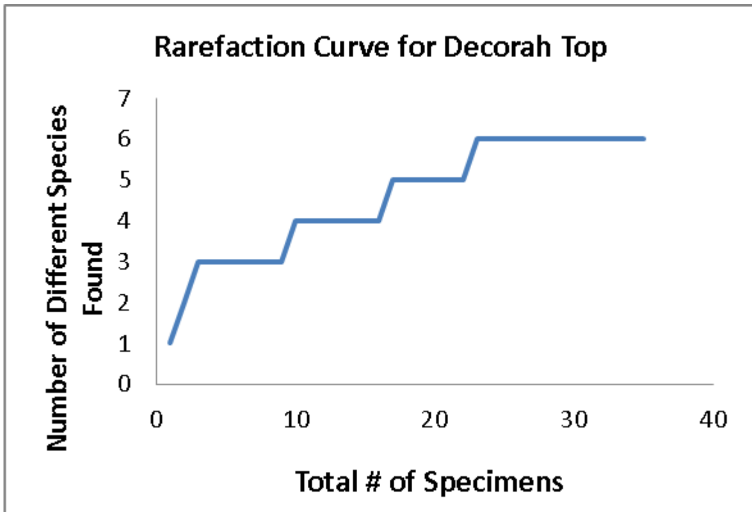


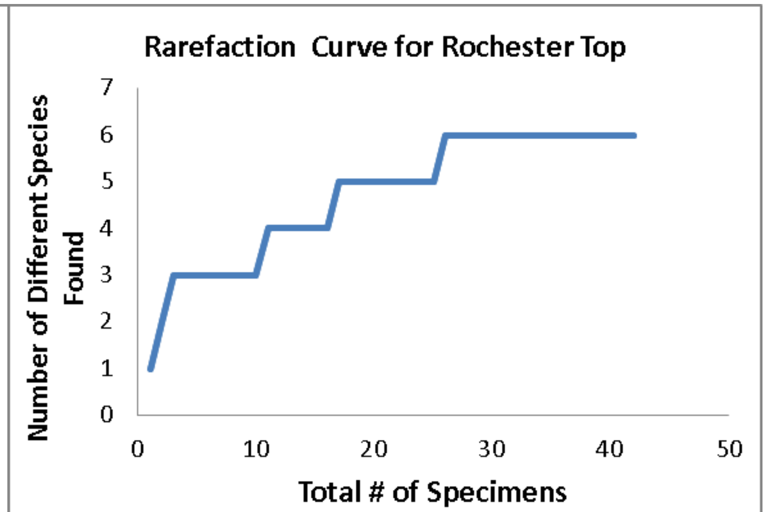
Figure 4. Diagram of a transgressive succession. Adapted from Levin (2005).

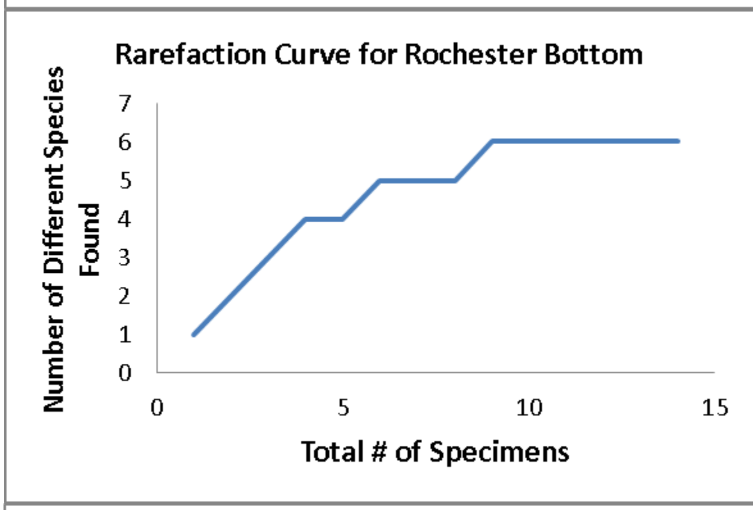
CONCLUSION

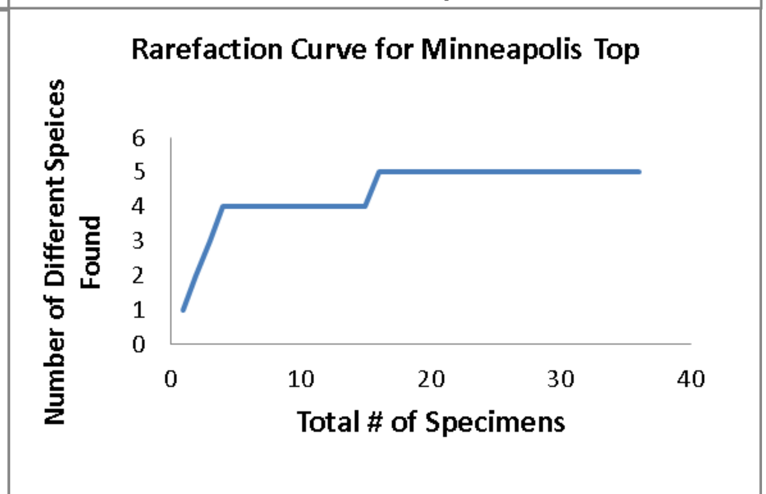
The Decorah Formation has been long studied due to its fossiliferous nature, and its use as a time marker. The conclusion provided by this study is that the Decorah in the Hollandale Embayment records a transgression, based on the pattern of conodont species distribution in the studied localities. This study could be improved if larger sample sizes were gathered as the statistical analysis does not allow us to refute the null hypothesis that the Decorah was deposited in one general environment.

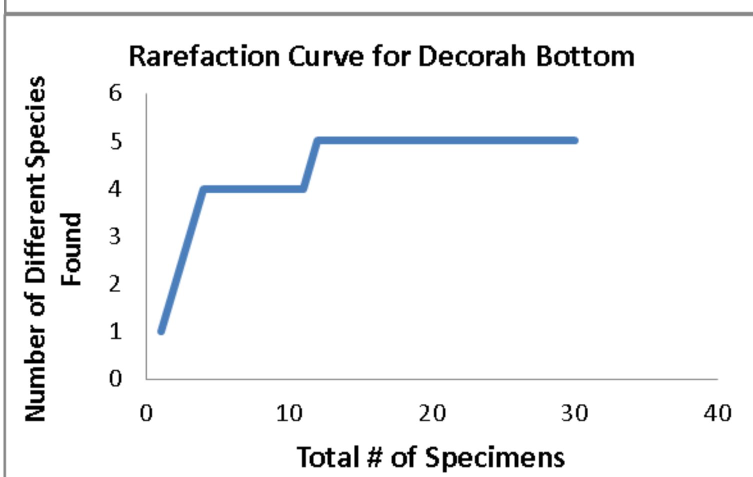
Appendix 1

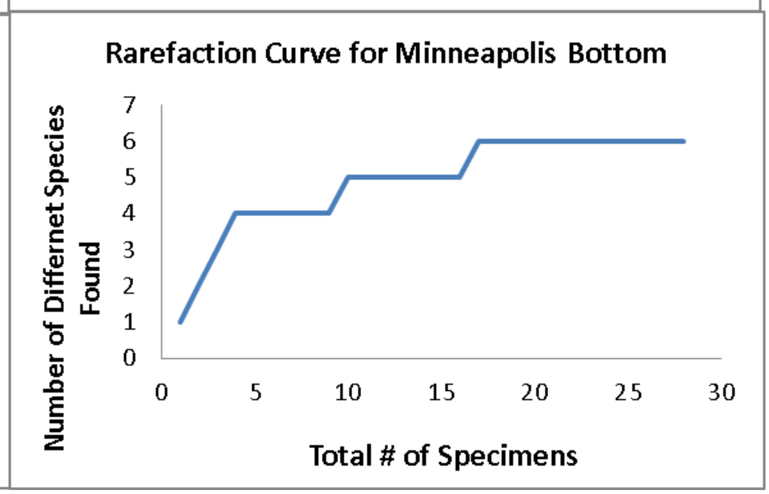












These are the rarefaction curves for the different localities and sections. Rarefaction was used to determine when enough specimens were gathered

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