A Study in 12th century stained glass techniques and re-creation of a stained glass panel dated between the 13th – 14th Century A.D.

Baron Artemius Andreas Magnus
Barony of Delftwood
Ariesdsn@aol.com

Catagories

1) In Glass:
   Sheet glass making:
   Index 2, Appendix A, B

2) Stained Glass
   Stained glass design, planning and construction
   Index 1,2,3,4,5,6, Appendix A, B, C, D, E

3) Metal working
   Construction of lead came and solder:
   Index 1, 6, Appendix A, B, C, D

4) Woodworking
   Construction of the wooden lead came molds
   Index 1, 6, Appendix A, B, C, D

5) Curiosa
   Construction of the glass stain and Black Walnut Ink
   Index 1, 5, 6, Appendix A, C, D

INTRODUCTION

The goal of this entry was to re-create a portion of a stained glass panel currently on display at the Corning Museum of Glass (see the photo below). My plan was to follow as, closely as I could, the description of stained glass making found in the writings of the twelfth century Monk Theophilus in reproducing this panel (De Diuersis Artibus, book 2) so it wont be a surprise to see many references to his writing.

What I wanted to accomplish was to make the panel almost entirely from scratch. This includes, making my own solder, lead came, stain, cutting glass with a hot iron and experiment in making sheets of glass. As I sought this goal I discovered a few limitations. They are described later in this paper.

NOTE: The documentation for this paper is broken up into several indexes representing a different phases of the project.

Overview of the Project

While I was at the Corning Museum of Glass, I noticed they had a few pieces on display. Since I was looking for an extant piece to re-create I decided to model my project based on one of these panels (Photo A). Since this project is not so much about the final outcome but went into making the panel, I wanted to do something simple that allowed me to try several skills. These panels were perfect.

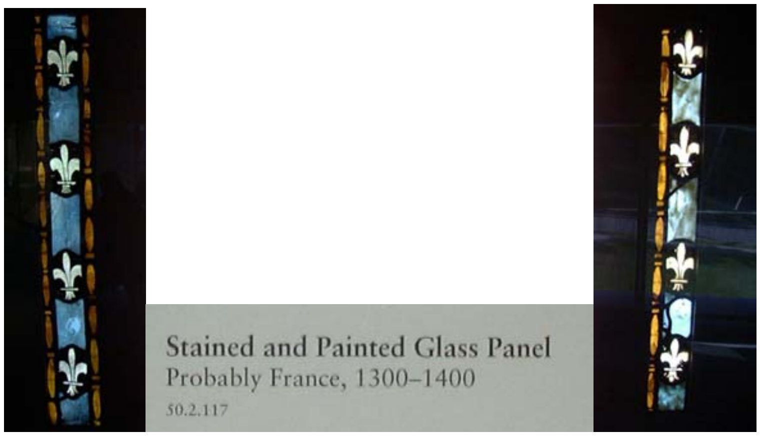


Photo A

The panels measures approximately 27 inches in length and about 3 inches wide. These panels, Accession 50.2.117, are described in the CMOG catalog as “bubbly glass, three panes leaded to form a long narrow panel; down center, alternate grey-blue panes and (painted) greenish white fleur de lis on dark back ground; narrow rectangles with long amber lozenges in dark ground and varying length, flanking central row of (B), at one side of (A) and (C).” I am assuming “B” refers to the center panels with the fleurs, and “A” and “C” are the sides with the lozenges (see catalog listing).

In an email from Dr. Dedo von Krosigk, the curator of European Glass at the CMOG, I found out that these panels are actually a set of three panels that came from the Bashford Dean collection. Dean was primarily a collector of arms and armor. From 1906-1927 Dean was the curator and major donor of Arms & Armor for the Metropolitan Museum of Art in New York, now known as the Bashford Dean Memorial Hall (see Armor & Fishman). Both panels in Photo “A” are thought to have come from Northern France or England. Dr. von Krosigk believes that the panel on the left may be 19th century but the panel on the right is original and is dated between the 13th and 14th century. I decided to build a portion of the panel on the right.

I also asked about the shading on the blue glass and the fleurs themselves. The shading on the blue glass, according to Dr. von Krosigk, is most probably dirt and corrosion. The fluers looked as if they were on white glass, but as I looked closer I noticed that there was an opaque material behind the display. In my own work, if I have a piece of stained glass on display indoors, I will place a layer of velum between the light source and the glass to act as a light diffuser. The museum staff used the same technique here to display the panels, and it turns out that the fleurs are painted on clear glass.

The Fleur de lis symbol is very common in history and it is no surprise they are found in stained glass as well. The Fleur de lis, or flower of the lily, was used by King Clovis 1 as his coat of arms to symbolize purity. The fleur has also been used by French Christian kings including King Charlemagne. The fleur is also found in Scottish and English heraldry. In religious term the fleur is often associated with the holy trinity(see Fleur-de-lis).

INDEX 1

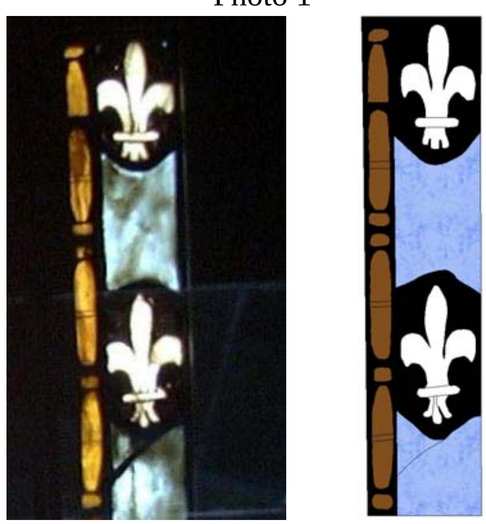
Construction of the stained glass panel
Choosing the glass

When I first started to re-create the glass panel from the 13-14th century, my plan was to use some of the glass created from my hands-on visit to the Corning Museum (see index 2). However, the glass I made is really too dark for this particular project. I chose to use antique glass for the fleurs and for the lozenges. The antique glass has air bubbles and striations that would be found in the imperfections of period glass. I chose a water glass for the blue glass between the fleurs. The wave pattern in the water glass represents the varying thickness of period glass. The colors were chosen to be the best possible match to the original as was available to me.

Creating the pattern

By using the photograph that I took from the museum and importing it into my computer I was able to create a pattern that will replicate the approximate size of piece of the panel I am making. One of the reasons I chose this particular piece is that the individual pieces are small and would fit in my kiln when it came time for staining. I measured the extant pieces on display while I was at the Corning Glass Museum. From these, I was able to set up ratios to approximate the individual pieces. Getting exact measurements while the panel was still in the case was difficult. Photo 1 shows the portion of the panel I am re-creating. Along side of it is the colorized version of the pattern I will be using.

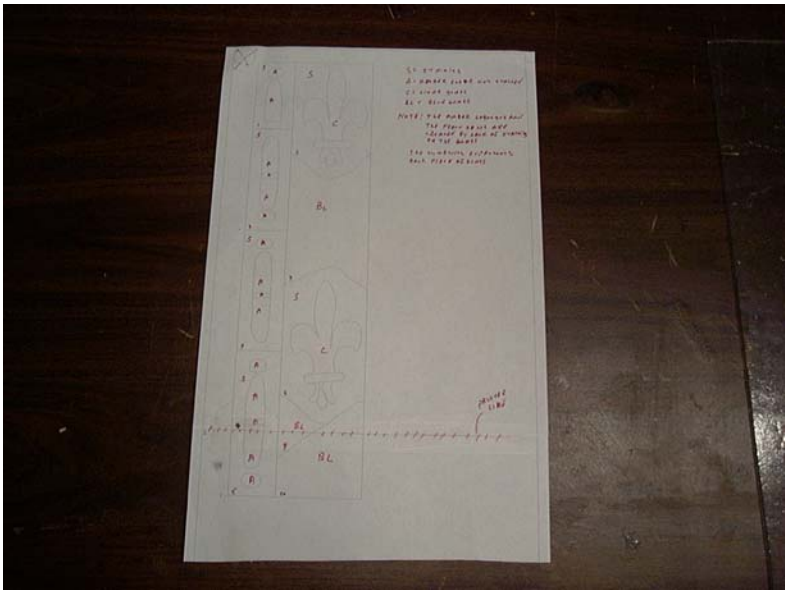
Photo 1



I can't stress enough that colors between the two pictures will not match due to the software options in my pattern maker, and the ink my printer uses. As you can see, in the panel near the bottom below the fleur de lis, there is an additional piece of came. This is part of a repair and I have decided to include it in the model I am building. Also please note that when comparing the photograph of the panel, the pattern and the final piece, there will be differences in the shapes of the fleur de lis, and the lozenges. These were hand drawn when they were created. I tried to match them up as close as I could, but no two hands draw the same.

Photo A shows a picture of the pattern that was created for this project. This becomes my cartoon that would have been on the whitewash board (see index 3- making the pattern). The pattern pictured below can be found in appendix E.

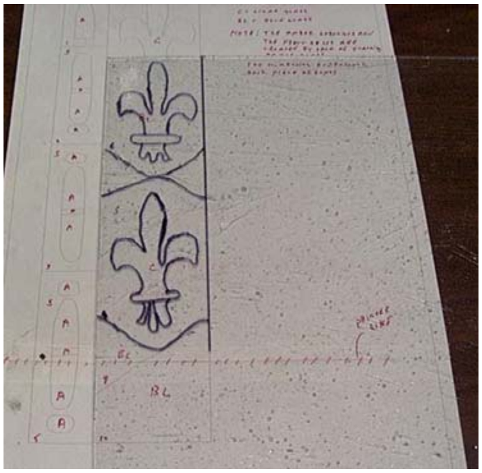
Photo A



Cutting the glass

1) The first step in cutting glass is transferring the pattern you wish to cut onto the surface of the glass (see index 4 – glass cutting). Conservation of the glass was important. The process to create sheets of glass is time consuming and involved, so planning how to cut the glass was important (see index 2). In Photo "B" I traced the first fleur, then moved the glass up the pattern so that I could trace the second fleur just below the first. Had I traced the fleurs exactly as the pattern indicated, I would be wasting the glass between the two tracings.

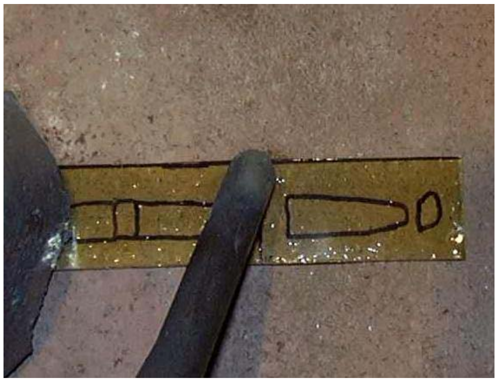
Photo B



It is especially important to plan your cuttings with a clear glass. Clear glass was very difficult to make. As described Appendix 1, the materials used to make the glass had many impurities. We know that it is these impurities that enabled Theophilus to get range of colors he was able to get without adding any extra additives (see appendix A-color). So to get colorless glass required very careful control of the kiln (Royce-Roll Journal of glass studies, pp74-75). I then traced the pattern of the other pieces onto their respective colors of glass.

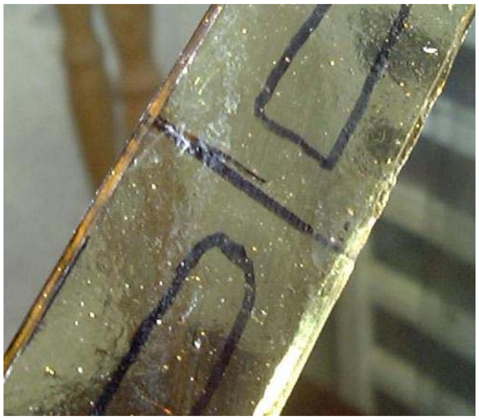
2) Now that the patterns have all been traced, the next step is to start cutting. The process starts by placing a drop of water on the edge of the glass where it is to be cut and then place a hot iron on that same spot (Theophilus, pp 48,49) (Photo C). I flipped the glass over so that the inked side of the glass was facing down. By working this way the heat of the iron would not burn off my tracing lines.

Photo C



3) The hot iron then caused a fissure to form in the glass. It is difficult to see where the fissure forms as it is a subtle crack (Photo D). I have learned from past experience the when a fissure forms from thermal contact, there is an almost bell like “tink” that can be heard.

Photo D



4) Next I dragged the hot iron along the line I wanted cut. The fissure will follow the hot iron. As can be seed in Photo D, it is not always exact. It is however close. As I learned

while experimenting with cutting glass (appendix 4), the glass doesn't always cut the way you want it to .I had two miss-haps where the fissure migrated into the glass that I did not want cut rendering those pieces useless. I ended up cutting additional glass. Photo E shows the cut piece of glass. I then used the same procedure on the remaining pieces of glass.

Photo E

5) If the glass did not cut the way it was intended but was still useable (i.e. the fissure went outside the line to be cut into spare glass), a grozing iron could be used to finish shaping the glass.

6) The glass can be smoothed down using another piece of glass or a stone (see Art History Final Project). Glass is predominantly quartz. According to the Mohs hardness scale quartz has a hardness of seven (see Cornelius p184). Also According to this scale the only material that can scratch or smooth quartz would be a material that has a hardness greater than seven. Seeing that the glass we are working with is not pure quartz, the impurities in the glass would make it either greater than seven or less. So it is possible to smooth glass with glass or a common rocks such as pumice (volcanic glass), granite (composite of quartz, mica, feldspar, hornblende), corundum (mineral hardness 9), or obsidian (volcanic glass). I smoothed down the edges with a piece of granite.

Staining

The glass is cut and it is now time to do the staining. I made the stain using the formula described in index 5 (see Theophilus pp 49). For this project there is no shading or details. The staining is used to create the fleur de lis, and the lozenges.

1) To make the fleurs and the lozenges, I simply painted the staining onto the surface of glass that I wanted covered using a wide paint brush (Photo F) For the fine details I used a smaller paint brush.

Photo F

2) I let the stain dry for bit and I used a toothpick to even out and fine tune the lines.

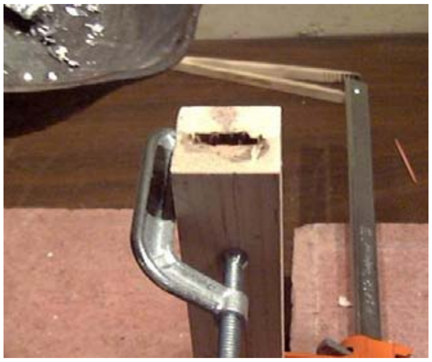
3) Due to the small size of my kiln, I could only fire one piece at a time. This turned out to be a very long process. The kiln has to be cold when starting. The piece is placed in the kiln painted side up. I found that firing the kiln to about 1300-1400 degrees Fahrenheit and holding the temperature there for five minutes, was enough to fuse the stain to the glass (Liban & Mitchel, pp 19).

4) At this high of temperature, if you take the glass out of the kiln it will break. Cool the kiln to 1000 degrees, then let the kiln cool on its own until it reads room temperature. I did make the mistake of taking one of the fluers out too early and it broke in half. This is what happens when you rush things. At this point I was also out of stain so I had to make more. From reading the sections on how to make stain (index 5-glass stain) and cutting the glass (index 4- glass cutting), replacing this piece was a long process.

Making the lead came and solder

At this point, the glass is cut and stained. We need to make our lead and solder. I used the mold that I made in index 6 (lead came and solder) to create my lead cames. Photo G shows a ***simulated*** pouring of the lead into the mold. **NOTE:** working with lead should always be done in a well ventilated environment.

Photo G



1) I used the mold as shown in Photo G to create the H shaped lead cames. To create the U shaped cames, I simply reversed one of the blocks of wood.

2) Once the lead cooled, I carefully separated the blocks of wood and pulled out the lead. As you can see in Photo H, the edges are rough when they come out of the mold.

Photo H

3) I used a knife to trim off the rough edges along the top of the lead. Photo I shows the same piece of lead now trimmed.

Photo I

4) I made the solder by melting 1 third lead to 2 thirds tin and cast it in the same mold that I used for the lead (see appendix A – solder).

The wood mold that I made in Index 6 survived long enough to allow me to cast enough lead and solder to complete the panel.

FINAL ASSEMBLY

We are at the point where we have all of the parts needed. The glass has been cut, shaped, smoothed and stained. The lead came and, solder have been made. Now it is time to put it all together.

1) I made a second pattern so that I could preserve my original with the notes on it. I placed the second pattern on the gypsum board and anchored it down. This would best represent the whitewash board. If you compare pictures, you will note that the pattern in Photo J is reversed from the patterns. I did this because past experience has shown that building in this manner usually has a better final result. This will vary from one person to another. It is a personal preference.

2) I placed a frame around the top and left edges of the pattern. This will hold the parts steady while I am building (Photo J). Theopilus said to start in the center and work outwards (see appendix A-assembling the glass pieces). Seeing that there really is no center to this piece I am starting in the upper left hand corner.

Photo J

3) I placed a piece of U lead across the top and down the left side along the frame. This held the first pieces of glass in place. I trimmed off a portion of the leaves off the top piece of lead where it intersected with the vertical piece. This allows for nice fit between the pieces of came without leaving a gap where they come together. This was done for all four corners of the panel.

4) The first piece of glass to get installed was the top fleur. At this point my camera died and the battery had to be recharged. I could either wait for it to recharge or continue

work. I chose to continue to work while the camera re-charged. So unfortunately there are no pictures of the construction process.

5) I placed the first fleur into the channels of the lead. I then took a piece of H lead and wrapped it around the bottom portion of the glass. I trimmed the lead to fit the glass and butt up against the lead came on the left. On the right side, I left enough glass exposed so that when I placed lead on that side, the glass could slide into the channel. I repeated the same process with the blue glass and the last fleur. By using a nail as a wedge, I was able to hold each piece in place so it would not move while working on adjacent pieces.

6) Once the pieces of glass were in place on the left side, I took a piece of H came slipped the exposed glass into the channel. Again, I used nails as a wedge to hold the lead in place.

7) I repeated the same process on the right hand side of the panel.

8) Once all of the glass was in place, I slipped the exposed edges of glass along the bottom and right side of the panel. Nails were used to wedge everything in place.

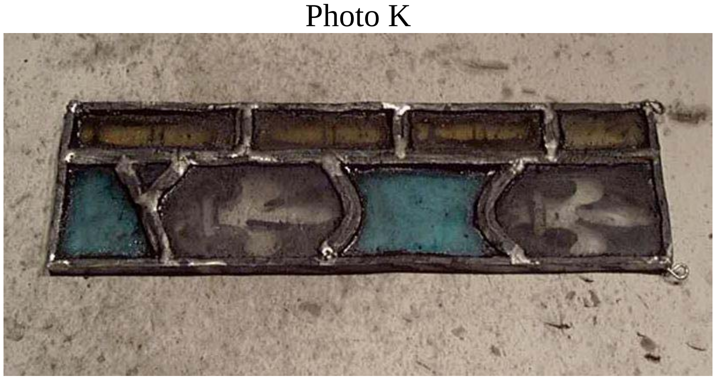
10) The next step is to solder. I took the solder that I made (see index 6 – lead came and solder), and my iron. I heated the iron up and touched the solder to the iron and soldered each joint where the lead came together.

11) I flipped the panel over and repeated the soldering process.

12) For this project I added two loops for hanging the piece on display. Had this panel been placed in an actual structure then these loops would not be present.

13) At this point the process is almost complete. The next step would be to use a whiting to fill in the gaps between the lead came and the glass (see appendix A – Whiting). For this step I used a commercial whiting. I carefully brushed the whiting into the gaps between the lead came leaves and glass. At this point my cameral was recharged so see photo K.

Photo K



14) Next was to clean off the excess whiting, and let it sit overnight.

15) The last step was to clean off any residue and put on display (Photo L).

Photo L

Had this been a larger piece that was going to be installed in a wall and that would have needed supporting structures, I would have followed the procedures outlined in appendix A, the sections on support and installation.

INDEX 2

MAKING THE GLASS:

Research

Theophilus described in his writings (I am summarizing in my own words here) that to make a sheet of glass: 1) you take a glob of molten glass and place it on the end of a blowpipe. 2) you blow and rotate the glass until a bladder is created. 3) remove the bladder from the blowpipe. 4) you remove both ends of the bladder to create a cylinder. 5) you then cut down the center of the cylinder lengthwise. 6) while still hot, you open up the cylinder until it lay as a flat sheet of glass (Theophilus pp 40,41).

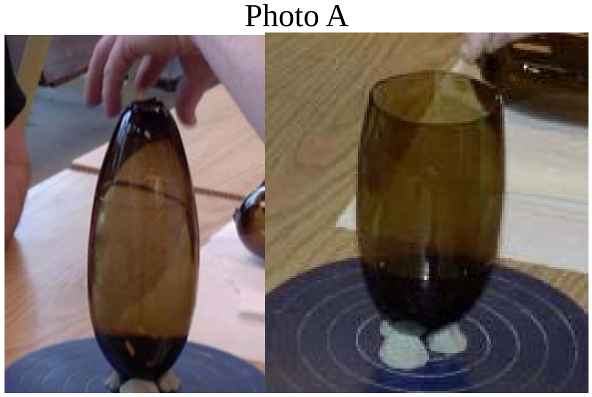
My first problem here was I don’t have a kiln, blowpipe, or the furnaces to make glass. To solve these limitations, I contacted Harry Seaman who is the director of instructors for the Corning Museum of Glass Walk in Studio. I described what I wanted to do and we set up a meeting time at the museum’s walk in studio.

By the time I arrived Harry had already blown two bladders of glass. As the annealing process requires an overnight wait, he wanted to have something to work with the day we arrived.

Because the studio only works with certain colors on certain days I really didn’t have a choice of colors to work with, so we used what was already in furnaces. The color of the day was brown. To make this color, small amounts of nickel oxide (seven tenths) was added to the molten glass. This is not one of the colors that were produced by Theophilus’s methods but still clearly illustrated the technique.

The first thing Harry did was to prop up one of the bladders that he had already made, and scored (scratch) it near the point where the curved top part meets the long portion of the glass. Then by heating and rotating the bladder we were able to create a crack running all the way around the top of the bladder. The left side of photo A shows where the top of the bladder had cracked and the right side shows the bladder with the top removed. We flipped over the bladder and repeated the process on the other side. When we were done we had a cylinder. We did this three times. Harry cut the first cylinder to instruct me in the technique, and then I cut the remainder.

Photo A



The next step was to create a crack going down the length of the cylinder without shattering the glass. We tried several methods. The first was to place a score down the entire length of the cylinder. Then heat the score until it cracked. This worked. Then we tried it by placing a score on each end of the cylinder. We applied heat again and still the crack traversed down the length of the cylinder. We noticed though that the crack did not match up with the scores on both ends of the cylinder. So we tried it again using one score. It worked just fine. Thinking back to the techniques described by Theophilus on cutting glass (see De Diuersis Artibus pp 48,49). We could have just as easily taken a hot iron, placed it on the lip of the cylinder, waited for a crack to form and dragged the iron down the length of the cylinder. I believe this would have accomplished the same thing and I would like to try this on another visit. Two of the conditions that could cause the crack not to form in a straight line would be defects in the glass such as air bubbles or impurities, or the varying thickness of the glass.

The next thing we did was go into the studio. Here we actually created a few more glass bladders (Photo B). Because of safety issues (I do not have any training in glass blowing), Harry did the actual forming of the bladder.

Photo B

For one of the bladders I was allowed to blow on the blow pipe to get an idea of how much (or little) pressure was needed to blow air into the glass. The bladders we made went into the annealing chamber and, once again, they had to stay there overnight.

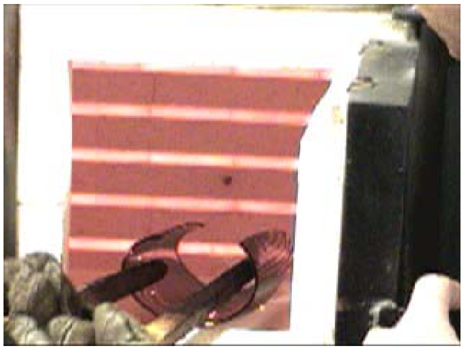
After lunch we met back at the studio to complete making the sheets of glass. We tried the following varying techniques.

1) The first attempt was to find the correct temperature needed to work with the glass and to figure out the best way to spread the glass. We discovered that the glass first starts to slump or soften between 1250 and 1260 degrees Fahrenheit. If we held the temperature at 1300 degrees Fahrenheit the glass would begin to slump or flatten on its own. When we spread the glass on this attempt we applied pressure near the top of the cylinder closet to the seam. The idea was to pry it apart using a spreading motion and a downward motion. This worked but with a lot of effort. We used two wooden sticks to pry the glass apart.

2) By the time we were ready for the second attempt, we had the temperature down but not the technique. Again we tried spreading the glass from the top of the cylinder thinking that we didn't have the temperature right causing the spreading to be difficult. We found that it was still difficult.

3) For the third attempt we tried spreading from the middle of the cylinder outward hoping that equal pressure on both sides of the glass would unfurl it (Photo C). This did in fact work better than trying from the top. For all the attempts we knew that once we got the edge of the cylinder spread back far enough, the glass would slump flat to table and not back on it self.

Photo C



Some of the things we learned:

1) Wood burns nicely at this temperate. In order to reduce the time before the wood sticks burst into flame (which were seconds), and set off fire alarms, we got them damp.
2) If we apply too much pressure on the glass it will crack even though it is in a semi molten state.
3) If we let the glass fold in on itself then it is not possible to separate the two pieces.
4) If we were to get a good sample, we needed to work the glass in small increments at the proper temperature. Work the glass a bit, let heat up again, work it some more, heat it up again, and keep this cycle going until the glass lay flat.
5) We had to keep a close eye on the glass while it was in the kiln else it would slump too quickly and fold in on it self.

In Photo D you can see the bladder, the ends cut off and sliced down the center, and then the resulting sheet of glass.

Photo D

INDEX 3

THE STAINED GLASS PATTERN

Research

The creation of the pattern itself is not well described in the literature of the Middle Ages. Theophilus says to draw your pattern or cartoon, along with any painting that has to be done, a whitewash board – a smooth board that was covered with chalk and wetted down (Theophilus, pp 47). The whitewash board could be repainted and used several times over. My research has shown that this process has not really changed much. Even in my own work I will start with drawing. Instead of using a whitewash board, create my pattern on a computer (I can't draw a straight line with a ruler) or use a commercial printed pattern.

INDEX 4

GLASS CUTTING

Research

Theophilus tell us that to cut glass, all one needs to do is take your glass, place some spittle or water where you wish to start cutting. Then get a hot iron and hold it on that spot until a fissure in the glass begins to form. Then simply drag the iron along the line you wish to cut. When done, finish shaping it with a grozing or groseing iron (Theophilus pp 48, 49).

I don’t mind telling you I was a bit apprehensive of this part. My experience has shown that when two temperature extremes meet, nasty things happen. So out came the safety glasses and the apron. As I don’t have a forge I used my acetylene torch to heat the iron. I placed the iron to the glass and nothing happened. I tried it again several times and still nothing or so I thought. I picked up my test piece and lo and behold there was a crack. Because of the lighting, the type of glass, and the work surface I had the glass on, I did not see the crack form nor did I hear one. There is a distinctive almost bell like “tink” when glass gets a thermal crack. I got my iron hot again and drew the iron down the length of the test piece occasionally stopping to see the progress of the crack. The crack was in fact following the iron.

Thinking that this was dumb luck, I tried another test piece. For this attempt I tried cutting a curved line. I paid closer attention to the sounds when I placed the iron on the glass. This time I heard the “tink” of the glass cracking. I dragged the iron across the glass in an S pattern and watched as the crack followed the iron.

It took a few attempts to figure out how fast to drag the iron. If I went too fast the fissure just stopped. If I went too slowly the defects in the glass would heat up and cause the crack to go in an unwanted direction. Lastly if I didn’t follow my drawn line, neither did the crack.

INDEX 5

GLASS STAIN

Research

To start this section of the project off I picked up an old cast iron pan, and a granite mortar and pestle. Theophilus used one third copper oxide, one third blue glass, and one third green glass, ground them to together to make a fine powder and added urine or wine as a binder (Theophilus pp 49). The first step is to make copper oxide, which is a black powder. The basic theory is to heat the copper and the oxide forms, and then just brush it off into a container. I tried several ways to make the copper oxide. My first attempt was to take copper shavings or filings and heat them up grind, re-heat, grind, until all the copper filings were reduced to copper oxide. It took me and hour to get enough filings to work with. I had to use a steel file because any other method (that I could think of) would introduce other materials into the collected filings. Steel is harder than copper. I had a very tired arm by the time I had enough filings to do anything with. I then put the filings in the pan and placed the pan on the stove on high heat. The reaction went quickly (more surface area the faster the reaction). Unfortunately it took a long time to reduce the filings to oxide (or what I thought was oxide). I then ground down blue and green glass to a fine powder.

I combined all the oxide I had with equal amounts of the blue and green glass. I ground them together and added some wine for a bonding agent (really couldn't bring myself to use urine which Theophilus suggested as an alternative to wine). On my first attempt I added too much wine because it painted on too watery, although I did have a dark enough "paint" to try the fusing. I painted a letter onto yellow glass noticing lumps in the paint, and placed it in the kiln. While I was mixing everything in the mortar, the grinding cleaned off the filings revealing that there was still a lot of copper that did not reduce to copper oxide. This explained the lumps in the paint. I fired it anyway. The temperature was not listed in Theophilus's manuscript so I went to two of my jewelry books that touched on enamel and decided to use the temperature outlined in the books. I set the temp for between 1300 and 1400 degrees Fahrenheit. My kiln does not have a reliable way to control the temperature accurately. The kiln relies on a rheostat that turns the kiln on and off to maintain temperature levels or to control the rate of heating. I let kept the temperature steady for 5 minutes then turned the kiln off. I let it cool slowly. When the kiln was cool I took the sample glass out. Per Theophilus, I did a scratch test on the stain and it did not come off.

I had a temperature to fire at, but I still did not have a good way to make the copper oxide. The next method was to put an entire sheet of copper in the pan and heat it instead of filings. I lightly sanded the sheet to reveal a bright copper. I then put the sheet in the same pan as before and heated it on my stove on high for 20 minutes. What resulted was a layer of copper oxide coating each sheet that I could then brush off into a container. This was a better method, as I knew that all I was getting pure copper oxide. I then cleaned off the sheet, sanded to reveal clean copper and heat it again.

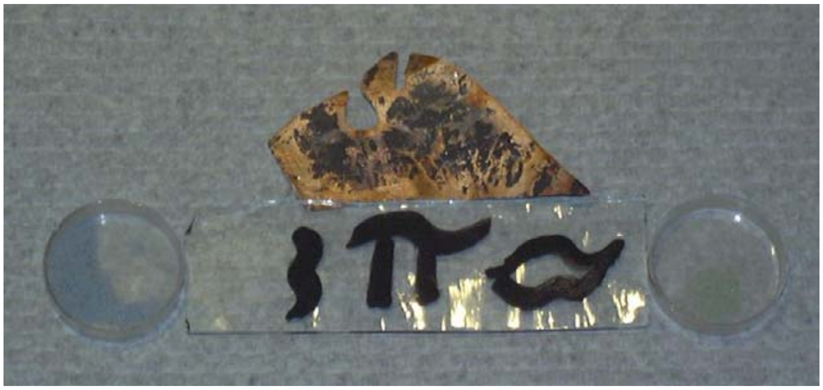
The yield was not that great but for the same amount of time I spent on the first method I found I was getting about the same amount of copper oxide without working as hard and knowing that I was getting pure copper oxide.

While the copper was cooking for my second method, I decided to play with the stain I had made with the previous batch of copper oxide. A few days had lapsed since I made this stain and the wine I had used evaporated. Instead of wasting what I had. I tried adding various amounts of wine to try and figure out a good consistency. I found that a thicker mixture worked better than a thinner. The stain held to the glass better and did not spread out.

I really wasn't satisfied with the way my copper oxide production was going. The next attempt was to use a propane torch instead of the stove. The torch had a higher heat and the reaction went quicker but it wasn't much better than the stove. Now Theophilus described how he made his copper oxide. Remembering Theophilus put thin sheets of copper in a fire and burned it, my third attempt at making copper oxide would be closer to his method. A fire was not feasible in my basement so I used the next best thing. I placed a thin sheet of copper in my kiln and fired it to about 1200 degrees and let it sit for about ten minutes. When the kiln cooled down some, I placed the copper sheet into a pan and covered it with a wire mesh screen. I learned and found that when the copper cools, the rate of contraction of the copper is faster than the rate of the copper oxide. What resulted was the copper oxide popping off the copper sheets sometimes making the copper sheet itself jump (see Chapter 3: Electrochemistry- make a solar cell in your kitchen). By placing the hot copper into the container and covering it, the copper won't jump all over the place and I can catch the copper oxide in my container instead of trying to clean it out of my kiln. This worked very nicely. What resulted were big thick flakes of copper oxide. I also found my copper oxide yield to be much higher than the other methods and didn't take anywhere as long.

I used the copper oxide that I made with kiln and once again grinding equal amounts of copper oxide, blue and green glass. I added a few drops of wine until I had the proper consistency and tried painting on piece of clear glass. This time the stain was smooth, covered the glass evenly, and there was no spreading. As last time, I fired the glass in the kiln at 1300-1400 degrees for about ten minutes. After the glass cooled in the kiln, I performed a scratch test on the paint and it held. Photo A shows some of the powdered blue and green glass, some copper oxide still on the copper (black residue), and my good stain sample.

Photo A



After this successful trial I attempted several other stains by varying the amount of blue and green glass. I found the one third method produced the best results.

INDEX 6

LEAD CAME AND SOLDER

Research

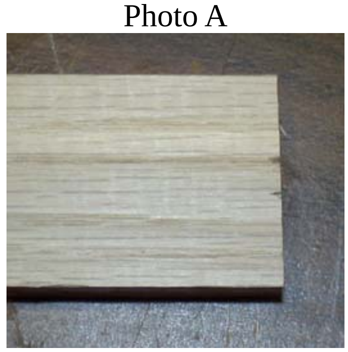
Lead came is used to hold the individual pieces of glass in place. There are two types. There is an “H” or “I” shape (channel) and a “U” channel. The “H” or “I” have two leaves and a heart forming two channels for glass to slide into. This used to keep the inside pieces of glass together. The “U” channel only has on channel for the glass to go into and is used for boarder pieces.

The Lead Came Mold:

To create a mold for the lead came and for the solder that I am using in this project, I am again, using the methods according to Theophilus’ writings. Theophilus gives to methods for making molds. The first is using iron (Theopilus pp 53,54), which is more durable or wood (Theophilus pp 55,56). Since I don’t have the means to make the iron version I chose wood.

1) I started off with two wooden blocks about 12 x 2 x 2 inches and sanded the surfaces smooth. This would end up being my mold. Theophilus does not state what kind of wood to use so I used a maple, which is proliferate in Europe. Maple is a hard wood and I believe, would survive multiple castings.
2) I marked the edge of one of the boards with two notches (Photo A). This represents the distance between the leaves of the came. I repeated the markings on the opposite end of the same board.

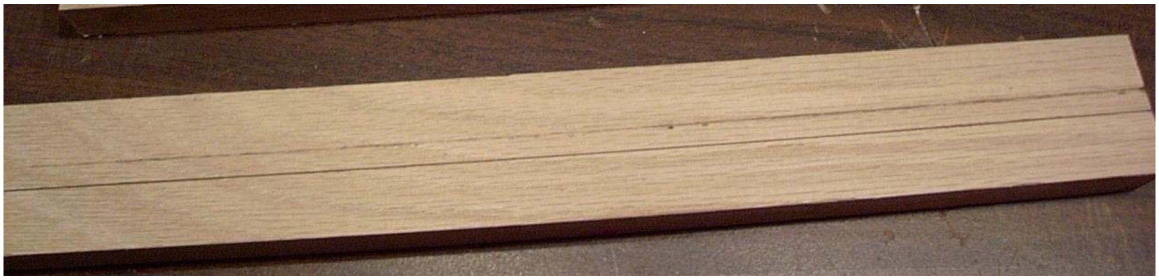
Photo A



3) I then soaked a string in some of my Lady’s Black Walnut ink (see Appendix C – Black walnut ink) made from some of seemingly thousands of black walnuts that rain on my house every year.
4) The string was slipped into the first set of notches at both ends of the board. I took the second board and placed it on top of the first and pressed. This created a line down the board representing where I needed to cut to create the first set of leaves. I then repeated this process with the other set of notches to make the line for the second set of leaves (Photo B). In retrospect, I probably could have used two threads and made both lines at the same time.

5) I also marked each board so that I knew how they went together when I actually got around to casting the lead.

Photo B



6) With the mold now marked, I used a series of knives and chisels, and files to cut the channels that would be leaves. Next I used a chisel to lower the middle section of both pieces of wood between the two channels to create the heart of the lead came.
7) In order to pour the lead into the mold I needed to cut a sprue. This is a funnel shaped cut so that the liquid lead can pour into the mold with out splashing around. I cut half a sprue on one end of both pieces of wood so when put together formed the full funnel (Photo C).
8) Once the wood was clean of dust and debris, I put both pieces together lining up the ends and clamped them together. The mold was ready to go.

Photo C

Casting the lead came itself in the handmade mold:

1) Theophilus is very clear on how to cast the lead (Theophilus pp 54,55). In a very well ventilated location, I placed raw lead into a cast iron pot. I melted the lead using a torch as I didn't have the means to make a fire, and poured it into the mold. After cooling I pried the two pieces of wood apart using a knife, and there I had my first piece of lead came (Photo D). Upon inspection I found gaps and holes in the lead in both the leaves and in the heart.

Photo D

NOTE: **Theophilus had left out on thing**! Obviously I had to modify the mold. I needed someplace for the air to go.

2) Adding more air vents: I built a second mold this time I added more sprues along the edges of the leaves to allow the air to escape (Photo E). This new mold worked much better and I used it to create the lead for this project.

Photo E

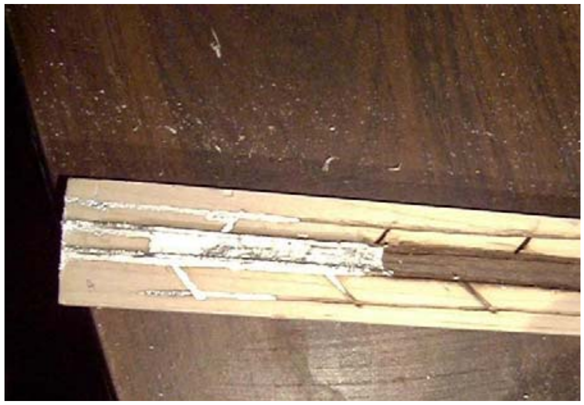
3) After I pulled the lead from the mold, I cut off all the lead from the sprues and cleaned up the edges.

4) Now as described in appendix A for lead, there are two shapes for the lead came. One is an H came (two leaves and a heart), of which we just finished making. Now we need to make the U came (one leaf and a heart). Theophilus does not describe how to make the U came or even mention the U came. To create the U came, I used intuition and simply turned one of the wood blocks around so that the uncut side faced the cut side of the other block. I then poured the lead following the above method (Photo F).

Photo F

For the solder, I took one part lead to five parts tin (Theophilus pp56). I melted them together and used the lead came mold to form the solder (Photo G). As Theophilus described there is no reason to make a mold when you already have one.

Photo G



APPENDIX A

STAINED GLASS CONSTRUCTION

In a book entitled *De Diuersis Artibus*, (De Diuersis Artibus , Theophilus, translated from the Latin by C.R.Dodwell) a 12th century Benedictine Monk by the name of Theophilus, penned what is considered to be the first “how to” book for the creation of stained glass.

How the glass was made

In northern Europe glass was made with two parts Beachwood ash and one part sand. This is known as potash glass due to its high concentration of potassium. This glass can produce stronger colors but is also more subject to deterioration as the potassium creates a softer more brittle glass and tends to discolor over time. This is why the works from this area now need heavy restoration. In southern Europe they used sand and a soda rich vegetable ash (marine or desert plants). Since these were rich in soda it is known as soda glass. Because the vegetable ash has fewer oxides than the Beachwood ash, the color ranges are not as good. However, the glass is more durable (Royce-Roll, Twelfth Century Stained Glass Technology, Avista Forum,p14). Theophilus used two parts wood ash to one part river sand (Theophilus p39). This combination came about by trial and error not by quantitative means.

There were two techniques to make a sheet of glass. The first is called the Muff Method. Here the glassmaker or glazier gathers a ball of molten glass called a parison, on the end of an iron rod called a pontil. He then molds the glass by rotating it. Then next step the glazier takes is to blow on the end the pontil, which is a hollow tube. What he creates is a hollow bottle shape known as a muff. He then cuts both ends of the bottle away to create a cylinder. While the muff is still hot, the glazier slices down the side of the muff length wise, and then flattens out the muff to create a flat sheet (Lee, Seddon, Stephens, pp 180,181).

The second method is called the sheet or crown method. Here the glazier gathers a parison onto a pontil and blows, shaping the glass as in the muff method. Once the desired shape is achieved, a second pipe is attached to the other end and the first pipe removed. The glass (crown) is rotated until it becomes flat and large. The crown is then removed from the second rod. The center of the crown forms an excrescence known as a bulls-eye. The resulting glass from both of these methods often had air bubbles and an uneven texture and thickness due to cooling and fabrication (Lee, Seddon, Stephens, pp 180,181).

Color of glass

The texts tell us that the color could be controlled by adding metal oxides to the glass. Red was made by adding iron oxide, green with copper, blue with cobalt, yellow with manganese (Brisac). Dr. Royce-Roll of the University of Alfred did research on this topic.

His research was based on the methods of Theophilus to see if he could re-create the colors used in Theophilus' time. He went so far as to make a scaled down version of kiln who's design was based on an early 14th century furnace. What he found is that the colors may not have all been created by adding different oxides as the history texts imply. He found that the impurities in the materials that were used in the creation of the frit in concert with heating the glass in either a reduced (oxygen poor) environment, oxidized (oxygen rich) environment, or a combination (alternating) of reduced and oxidized environments caused the color differences in the glass. Beachwood ash contains a high concentration of manganese. It is these oxides of the manganese that produce the wide varieties in color. The manganese found in the ash can produce purple (oxidation), yellow (reduction), and pink (combination of oxidation and reduction). It was difficult to reproduce the colors the same from batch to batch because the concentration of manganese varied from tree to tree. With the addition of copper oxide you can produce red, green and blue glass. If you look through Theophilus' manuscript, the only oxide that is mentioned is copper oxide. Also because of these impurities in the raw materials, clear glass was very difficult to make (Royce-Roll, The Colors of Romanesque stained glass).

One of the problems with colored glass or pot glass is that it was not transparent enough to let much light in such as the color red. This problem was overcome by a method called flashing. Here a very thin layer of colored glass is fused on top of a clear piece of glass. It was also discovered that if several pieces of colored glass were layered, the top piece could be etched away to allow the underlying color to come through increasing the amount of detail an image in a piece of glass could have (Stained Glass msn Encarta p1).

CREATING A PATTERN

Now lets describe how Theophilus outlined how he made stained glass windows. Once the design of the window was decided upon, a cartoon or sketch was created of the window. whitewash board – a smooth board that was covered with chalk and wetted down (Theophilus, pp 47). This included the glass shapes and whatever images were to be painted on the glass. When the glaziers were done with the project they were working on, the board could be painted over for the next project.

CUTTING THE GLASS

The glazier then chose the glass in the colors that were available to him. Each piece of glass to be cut was placed over the cartoon and the needed shape was traced onto the glass with wet chalk. In order to cut the glass, the glazier took a glowing hot dividing rod and placed it upon the glass where it needed to be cut. When a small fissure appeared in the glass, the rod was drawn along the line, lengthening the fissure or crack until the piece was fully cut. To refine the shape of the cut glass, the glazier used a grozing rod to break away small bits of glass. A grozing rod is a piece of metal with slots cut into it matching the thickness of the glass. To smooth the edges the glazier used another piece of glass or a grindstone (Lee, Seddon, Stephens, pp 181).

STAINING THE GLASS

At this point any painting that was to be done on the glass was done then fired in a kiln to fuse the paint to the glass. Theophilus used a combination of one third copper oxide, one third powdered green glass, and one third powdered blue glass (Theophilus, pp 49). The glass we already have. The copper oxide was made by taking copper and placing it into a furnace, and then burn it. This yielded a black powder. All three ingredients are mixed together and bound by either urine or wine. For each level of detail several firings must be done. First a darker wash was used to create the details. The glass is fired to adhere the enamel to the glass. Next, lighter wash is used to create shadows. Lastly, the highlight lines are added and again the glass is fired. Depending on the effect that needs to be achieved, highlights can be created by taking a stick and dragging it through the enameling while it is still wet or sopping it up with a rag to create a texture (Valldeperez, pp 90-94).

Around 1300 A.D., silver staining came into use. The staining (silver nitrate, gamboge gum and diluted with water) created hues of yellow and was used for haloes and crowns. It was discovered that by using silver staining on different colored glass, the glazier could make different colors from a single colored piece of glass (Lee, Seddon, Stepens, pp 184). An example would be silver staining on blue glass to create green colors used for trees and grass. Once the painting was done, the glazier then placed the pieces of glass into a kiln (clay vessels that set on top of iron rods) for firing. The kiln used beech wood for heat. The glass was placed onto iron sheets and covered with plaster. The kilns temperature was raised to about 1250 degrees. This fused the paint to the glass. The glass was then cooled slowly so that stress cracks did not form breaking the glass (Lee, Seddon, Stepens, pp 184).

CREATING THE LEAD CAMES

Once the glass was cut, the paint for the images fused, and the glass cooled, pieces could be assembled. Each piece of glass is fitted with lead strips called kames or cames. The cames are “I” or “H” channeled shaped strips that wrap around the edge of the glass providing the means of connecting each piece of glass together. To hold the inside glass we will use “H” channels, and for the outside pieces we will use “U” channels. The “H” channel cames are made of a heart (the center piece) and two leaves. The “U” channel is basically half of a “H” channel.

Theophilus proposed two methods in making his molds for the lead. The first method is to cast iron molds that are hinged at the end with an opening in the top. Molten lead is poured in the opening at the top. When full, the two halves are separated and you have lead came. The second method called for taking a flat piece of wood and marking it where the ends of the came should be. Then take a string soaked in ink and lay it across the length of the wood where you made your markings. Take a second flat piece of wood and press it down on the first. When separated a line will be drawn on both pieces of wood where you need to cut. Repeat this step with the second set of markings. The next thing to do is to take a knife and cut into the wood to the desired depth of the came along the lines you just created, on both pieces of wood. Next match the two sides up and bind them. Heat your lead and pour it into the mold. Let it cool and separate the two pieces of wood (Theophilus pp 53-56). You now have your H came. To create the U came, flip one of the boards around so that its flat side matches up with a cut side. Bind them together, melt your lead, and pour. Let it cool, separate the boards and now you have the U channel.

ASSEMBLING THE GLASS PIECES

Theophilus started with a center figure and worked his way outwards. A piece of glass was fitted into the lead came. Pins were placed around each piece to keep it from moving during assembly. The next piece of glass was fit into place next to the first. Again, the exposed lines were encased in lead and pinned into place. When all the pieces of glass were set in their proper spots, lead was placed around the entire outer edge of the piece (Theophilus pp 56). Not much has changed since then. Modern glazers assemble the glass in a similar manner (Valldeperez, pp 58-65).

SOLDER

The next step was to permanently connect all the pieces together using solder. Solder is a low melting metal alloy composed of lead and tin, cast into sticks. Theophilus used one part lead to five parts of tin (Theophilus pp 56) . But it has been shown that this may have been a personal preference. Some artisans used a 50 percent mixture of tin to lead. This mixture is by percent weight (Pizano May). Theophilus notes that you may cast the solder in the same molds that were used to create the lead came. After each junction of the lead cames is cleaned, a hot iron is used to melt the solder into the joints between the cames, locking the glass into place. Then the assembled piece is carefully flipped over and, the other side is soldered in the same fashion (Theophilus pp56-57).

WHITIING

Once the soldering was complete, the last step was to cement the piece. This was done by creating a mixture of powdered whiting (calcium carbonate), and linseed oil then rubbing this mixture under the edges of the lead. After the excess was removed and the glass dried, the window became waterproof and had a bit more stability to it (Art History Final Project).

SUPPORT

At this point the window itself was complete. In order to install the window a little bit more work had to be done. The next step was to install the banding wires. These are copper strips about 4 to 5 inches in length, soldered onto the leading and are used to secure the window. There are two types. One is called a division tie and is used to connect adjacent panels of windows. The division tie had one long strip of copper that twisted around a division bar along with the tie from an adjacent panel, holding the panels together. The second type has two strips of copper called a middle tie and is used to connect the panel to a supporting bar. The copper strips wrapped around the supporting bar, almost like a twist tie, adding extra support to the panels (Lee, Seddon, Stepens, pp.188-189).

INSTALLATION

The last step was the installation. The window aperture was cut so that the window will fit into a L shaped channel. The bottom piece gets set into first. The next piece gets set into place on top of it. To ensure a watertight fit, the lead on the top edge of the first panel was bent over and the bottom edge of the upper piece got placed over the top edge of the bottom panel. The two windows were loosely tied together. To give more support, bars were embedded into the cement in the window frame and stretched across the window aperture. The middle ties were used to attach the window to these bars. Once the full window was in place, the ties were tightened down securing the window. The very last step was to cement the window in place to ensure weatherproofing, and securing up the window (Lee, Seddon, Stepens, pp 188-189).

APPENDIX B

THE HISTORY OF STAINED GLASS UP TO THOPHILUS

There is a story that was told by Pliny the Elder (23-79 AD) of a ship carrying a cargo of natural soda that made shore for the night. Having nothing to hold their pots and pans on for cooking, the crew took several blocks of the soda and placed them over the fire. The blocks, mixed with sand began to heat up and the crew saw a strange liquid begin to flow. This was the discovery of glass (History of Glass Engraving, pp 1). Who knows if it is true or not, but it is an interesting tale. What we do know is that glass has been around for a very long time.

Colored glass has its roots as far back as ancient Egypt around 3000 years ago. The Egyptians pressed glass for perfume bottles, beads, and a wide variety of other uses. Glass was preferred over pottery. They discovered that by heating silica (sand, quartz) with potash, the silica could be fused. It wasn't until between 1554 BC and 1075 BC that the Egyptians discovered how to make clear glass. At this point in time they learned that they could cast this new glass into rods and while hot, mold them around sand cores to create vessels. The colors they created were more accidental than design due to the impurities in the materials they used. Color could be somewhat controlled by heating or cooling (Brisac).

The blowing iron came into use somewhere in the second century BC. This allowed the artisans to attach a blob of glass to the end of a tube and blow air into it. The glass could be easily shaped by heating, blowing, rotating, and then repeating the process again until the desired shape was achieved (Lee, Seddon, Stepens, pp 10).

By the first century AD, it was discovered how to make glass transparent and colorless. Color could be controlled by adding certain oxides.

The Romans had also been working with flat glass in the first century AD. They had inserted small pieces of colored glass into mounts for decoration. The Muslims used the flat glass to make mosaics in windows.

The earliest known pictorial glass is from records dating back to the 9th century. The oldest remnants were of a depiction of Christ's head from the Lorsch Abbey in the Rhineland (France) dated between the 9th and 11th century (Lee, Seddon, Stepens, pp 13). Medieval stained glass was not used to pass light but more to capture and reflect it and really did not take off until the Middle Ages in Paris. The Abbot Suger commissioned the windows for the Abbey Church of St. Denis between 1144 and 1151, starting the stained glass trend. Soon after that windows were commissioned for the Charters, Bouges, and Le Mans cathedrals. Stained glass reached its peak in the Middle Ages between 1130 and 1330 (History of Glass Engraving, pp 1). Popular scenes were iconic and religious. Another popular style is called a "rose" such as the one commissioned at St Denis. Most rose windows use one of two themes: either the glorification of Christ and the Virgin or Christ as the apocalyptic judge. Sources of inspiration of stained glass come largely from the Bible (Brisac).

APPENDIX C

I used the black walnut ink for making the mold for my lead came and solder, not on the glass itself. I have to give Dana Robertson, credit for providing the ink. Even though I did not make the Ink I took notes as she made it. NOTE WELL: When making black walnut ink wear gloves and old clothes as the ink stains everything.

The black walnut tree (Jeglans regia) is native to the Capathion Mountains in eastern Europe. It was introduced to the Americas via Spain through Chile and to California in 1867 (see Juglans regia L. pp 3of 6). Juglans nigra or Black Walnut is a hybrid of the European Walnut. (see Black Walnut – hybrid pp 10 of 14).

The ink recipe below is an amalgam of several recipes found in the Translation of Manuscript of Ibn Badis ca. A.D. 1025 (Levey pp18-21), and experimentation.

The Recipe is as follows.

1) Shuck green outer layer from nut or pick up walnuts from the ground with the husks already rotted off being wary of any territorial squirrels.
2) Fill a bucket with the walnuts & top of bucket with water (this batch had 35 walnuts).
3) Soaking the walnuts in water releases the tannins from the walnuts. The batched used for this project had been soaking for five months.
4) Place all the water now brown from soaking walnuts into a pot with some of the walnuts (this batch yielded about 19.5 cups).
5) Boil the walnut and water combination to release the last bits of tannin.
6) Strain walnuts from liquid and return liquid to pot.
7) Reduce ink by continuing to boil.
8) Every half hour test for darkness. This batch boiled for two hours.
9) When satisfied with color add 1 tsp gum Arabic, 1 tsp kosher salt, 1 tsp vinegar.
10) Let settle overnight.
11) Strain out silt and solids.
12) Put ink into bottles.

This batch yielded about 12 four ounce bottles.

APPENDIX D
Conclusions:

I started the research for this project about six months ago. Since then I have learned and experienced a lot. The goal of this project was to make a glass re-production of a glass panel using 12th century techniques.

1) I created sheets of glass (with help) from the basic glob of glass.
2) I learned how to and experience making my own lead cames and solder from scratch.
3) I learned how and experienced making my own staining for glass.
4) I learned how and experienced cutting glass with a hot iron.
5) I learned how to and experienced soldering with a hot iron.

I have a new appreciation for the old artists and what they went through to create the magnificent pieces of stained glass adorning Europe. I believe that I have approximately twenty hours logged into making the panel. That is just construction of the piece, not the research time. I cannot even begin to think how many man hours went into the construction of window like the Rose Window at St. Dennis in Paris, France.

For my first attempt at creating a stained glass panel pretty much from scratch, I am pleased with the results.

If I were to do this again (and I might):

1) I think I would develop better wood working skills to create better molds for the lead and solder.
2) I would refine my skills in cutting the glass with an iron. It is an art.
3) I would try to do a more complex piece this time using silver nitrate as a stain.
4) I would like to do a piece that has detailed staining. Not simple like this project.
5) I would like to try a piece that uses flashing.
6) Perhaps I can find a sample that uses flashing, silver nitrate and has detailed staining.

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Good history of glass but not really for stained glass.

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http://loonfoot.com/ian/stained%20glass/learningmodule/index.html
Great source for procedure and supports the information from Brisac and Lawrence.

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http://oak.atlantia.sca.org/19/glass.html
Good overview paper

http://www.metmuseum.org/toah/hd/glas/ho986.285.1,2.htm – examples of 13th century windows

http://www.ariadne.org/studio/michelli/sgtechniques.html - nice links to examples