Twisted Ribbon Geometry and Design

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Last Updated: May 2020

Preface: Ongoing Research

This paper is written for the Antioch Recovery Project (http://www.antiochrecoveryproject.org), part of the Classics Research Lab at Johns Hopkins University. The entire project focuses on researching and conserving the set of approximately thirty Antioch Mosaics currently located in the Baltimore Museum of Art. The research into the ancient works of art has been an ongoing process since they were excavated in the 1930s, and so this paper aims to join the growing conversation. While I arrive at certain claims through my work, there is no "conclusion" to this topic. This paper serves as a journal surrounding my research into the Twisted Ribbon border pattern. I encourage others to add on or disagree with certain aspects, and perform similar studies to other design elements of the Antioch Mosaics.

1: Introduction

Antioch Mosaics

Nearby modern day Antakya, Turkey lies ruins of the ancient cosmopolitan city of Antioch. Well known for its spice trade and location on the Silk Road, the Roman city played a critical role in the development of Christianity and was one of the most important cities in the Eastern Mediterranean at the time. However, the 250,000 person metropolis declined in the sixth century due to warfare and earthquakes.

In the 1930's, several museums from the United States and France sponsored expeditions to excavate the city's ruins. While they mostly found just walls, as pictured in *Figure 1a*[1] (right), many of the houses' floors remained intact, revealing over 300 intricate mosaics with valuable historical and cultural information about the city. Approximately half of the mosaics were left in Antakya, and the rest were spread throughout the world for museum visitors and researchers to admire and study.

The mosaics themselves are a combination of Ancient Greek and Roman influences, displaying both early Christian scenes and geometric designs. Colorful flora and fauna are depicted in high quality and craftsmanship in many of the mosaics. The artwork is constructed from marble and limestone, and are of magnificent size. As far as we know, the mosaics were primarily used as decoration and were a sign of wealth within the city.

[1] "Pinterest." *Pinterest*, https://www.pinterest.at/pin/443252788306540748/

Border Patterns

The following is an excerpt from the Baltimore Museum of Art's description of the Antioch Mosaics on display, noting the common geometric patterns found in the designs:

> *Border patterns are found in abundance on Antioch Mosaics. A border may frame the central image of a mosaic or connect one mosaic panel to another so that both become part of a single thematic scheme.*
>
> *Borders range from very simple two dimensional repetitions of the single shape to very complex patterns that create the illusion of three dimensions. Many Antioch mosaics combine two or three different borders on a single panel.*[2]

As displayed on the same placard from the Baltimore Museum of Art, common border patterns in the mosaics include:

Figure 1b: Crowstep

Figure 1c: Rope

Figure 1d: Meander Border

[2] *Antioch Mosaics Border Pattern Placard*. Baltimore Museum of Art.

Figure 1e: Wave

Figure 1f: Ribbon

Twisted Ribbon

The twisted ribbon border is a meandering pattern of what appears to be a flat ribbon waving along across the mosaic in a repeated manner. While there is thought to be no major significance to the pattern itself, it represents "the movement towards ornamental complexity" in the Antioch mosaics, "which was born in the late second century."[3] The ribbon itself is typically different colors on each side, which are shaded into gradients as it arcs. This paper will focus on the twisted ribbon that transverses sinusoidally, and it identifies some variations of the pattern.

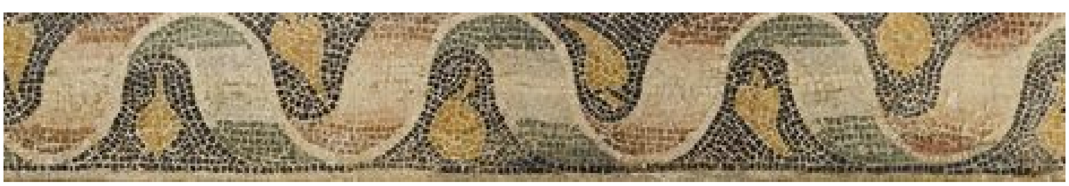

Figure 1g: Twisted Ribbon Pattern

[3] "Domestic and Divine: Roman Mosaics in the House of Dionysos." *Domestic and Divine: Roman Mosaics in the House of Dionysos*, by Christine Kondoleon, Cornell Univ. Press, 1994, p. 82.

2: Twisted Ribbon Corpus

Animal Friendship

Dating back to the 5th century, the large Animal Friendship mosaic depicts natural scenes of large animals confronting each other. The mosaic is currently at the Baltimore Museum of Art in four pieces, each displaying different scenes: Lion and Humped Ox; Lioness, Stag and Bear; Leopard and Goat; and Tigress and Boar.

Figure 2a: Lion and Humped Ox (89in. x 100in.)

Figure 2b: Lioness, Stag and Bear, from Daphne (82in. x 129.5in.)

Figure 2c: Leopard and Goat (49.5in. x 99in.)

Figure 2d: Tigress and Boar (55in. x 106.5in.)

Panel from the House of Ge and the Seasons

Originally from the 5th century, the mosaic from the House of Ge and the Seasons in the Yakto Complex is currently split in two. The larger half currently resides in the Princeton University Art Museum in New Jersey. It depicts a central figure surrounded by four opposing figures, each representing a different season.

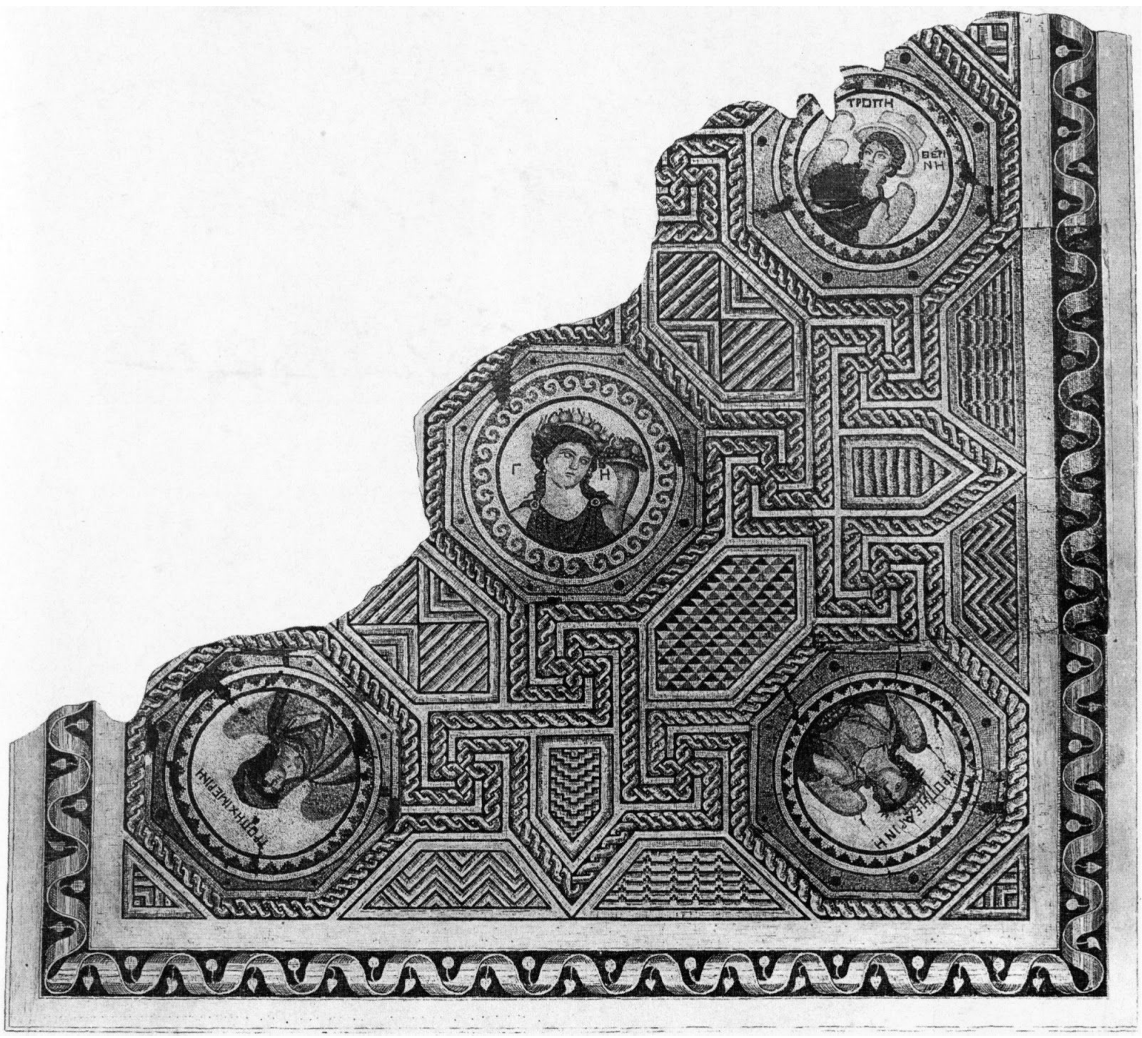

Figure 2k: Yakto Complex Mosaic

The smaller portion currently resides in the Museum of Fine Arts in St. Petersburg, Florida. It displays the twisted ribbon border around the outside of several other geometric designs, including the common meander pattern.

Figure 2e: Raised Panel E from Room 1[4]

Unknown Hatay Mosaic

Little information is known about the unnamed mosaic below, currently located at the Hatay Archaeological Museum in Turkey. The Twisted Ribbon pattern travels across the image leading in both directions.

Figure 2l: Unnamed Mosaic

[4] "Raised panel E from Room 1 portion of guilloche and meander border.," *Archaeological Archives*, accessed April 10, 2020, http://vrc.princeton.edu/archives/items/show/14448.

3. Ribbon Variations

Bird Rinceau

Originating from the House of the Bird Rinceau, the Bird Rinceau Mosaic was created between 526-540 CE. In the center of the 700 square foot mosaic are small rosebuds against a light background, surrounded by scenes of playful birds. Between the two main designs lies a ribbon border that steps up, over, and down around three dimensional boxes. Instead of sinusoidal, this ribbon appears to form three quarter circles winding through the mosaic in a repeated fashion. The mosaic could be purely decorative, or possibly hold roots in the early Christian Church.[5] Pieces are currently located in the Baltimore Museum of Art (Maryland), Worcester Art Museum (Massachusetts), Saint Louis Art Museum (Missouri), Princeton University Art Museum (New Jersey), and the Louvre Museum (Paris, France). The images below depict an overall reconstruction of the mosaic and a close up view of the twisted ribbon.

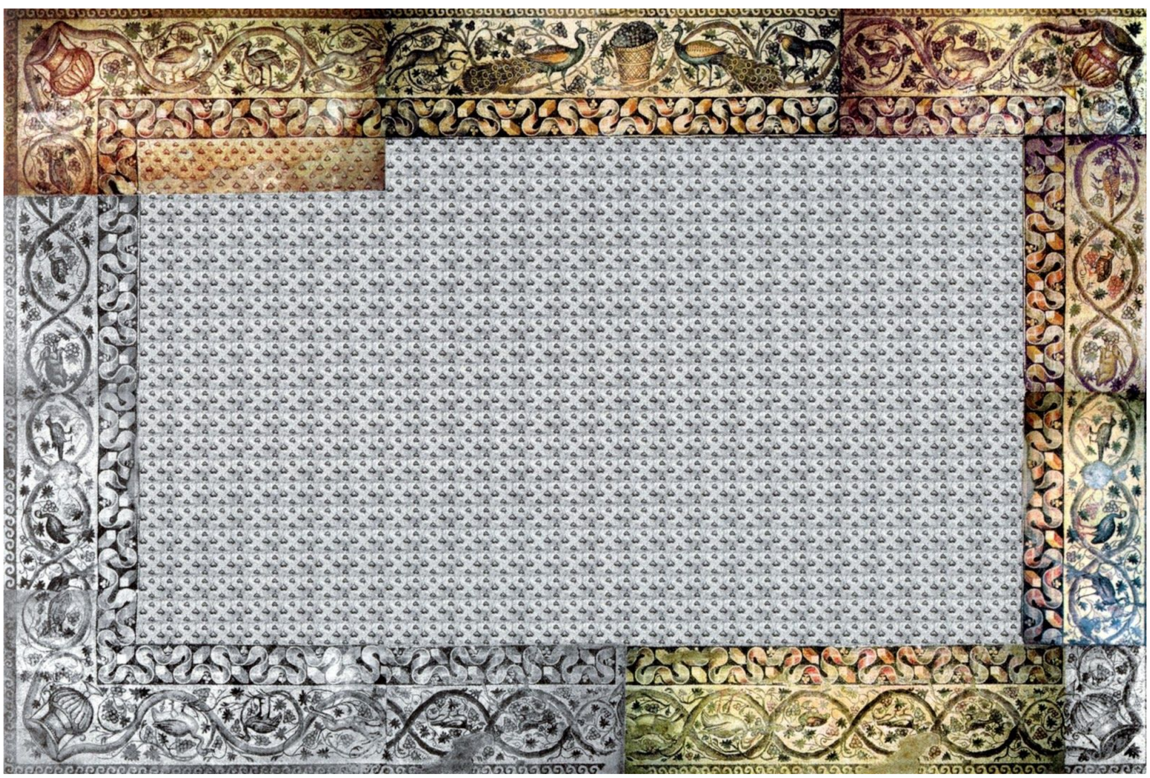

Figure 3a: Reconstructed Mosaic Based on the Surviving Fragments

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[5] *Antioch Mosaics Border Pattern Placard*. Baltimore Museum of Art.

Figure 3b: Top Right (63in. X 123in.)

Figure 3c: Right Side, Bottom

Figure 3d: Top Middle

Figure 3e: Top Left

Figure 3f: Right Side, Top

Meander Pattern Mosaic

This stone and lime mortar mosaic from the 5th century displays three interlocking patterns that weave throughout the frame. Each pattern, including a ribbon, enters the mosaic from one side and exits on the opposite. The piece is currently in the Baltimore Museum of Art.

Figure 3g: Meander Pattern Mosaic

Amerimnia ("Freedom from Care")

Currently resting in the Hatay Archaeological Museum in Antakya, Turkey, the *Amerimnia ("Freedom from Care") Mosaic* was created in the first quarter of the third century. It depicts a seated female figure that was facing the entrance of a tomb.

Figure 3h: Amerimnia ("Freedom from Care") Mosaic

Peddler of Erotes

The Peddler of Erotes mosaic is from the 3rd century and currently is located at the Baltimore Museum of Art. It was discovered in room 1 of the House of the Peddler of Erotes and depicts unrelated scenes of erotes in a variety of activities.

Figure 3i: Peddler of Erotes Mosaic (87in x 97.5in)

4. Twisted Geometry

Types of Twists

According to Merriam-Webster Dictionary, *twist* can be defined as a “spiral shape” that is “turned or changed shape under torsion.”[6] The mathematical definition of twist describes a smooth ribbon revolving around a curve.[7] Both of these definitions imply that a “twisted ribbon” must have a continuous axis for which the ribbon is rotated about. Below are two examples[8] of these types of twists, with roots in the patterns seen by atomic and molecular bonding.

Figure 4a: Helical Ribbon

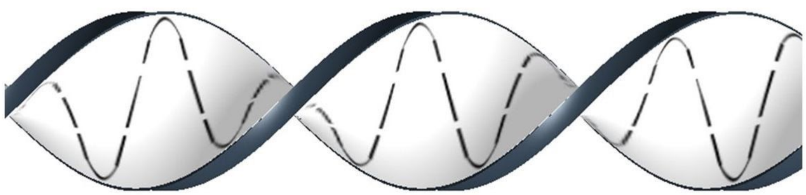

Figure 4b: Twisted Ribbon

With this definition, the twisted ribbon pattern seen in the Antioch Mosaics is not actually a “twist”. The pattern, as shown in the next section, is instead modeled by a “wave”.

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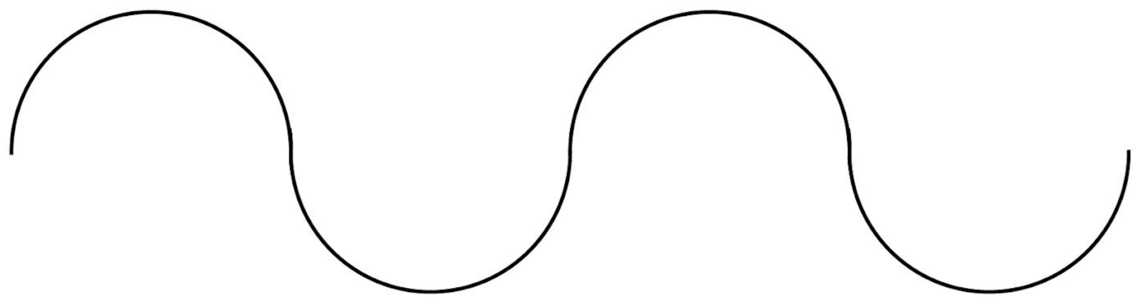
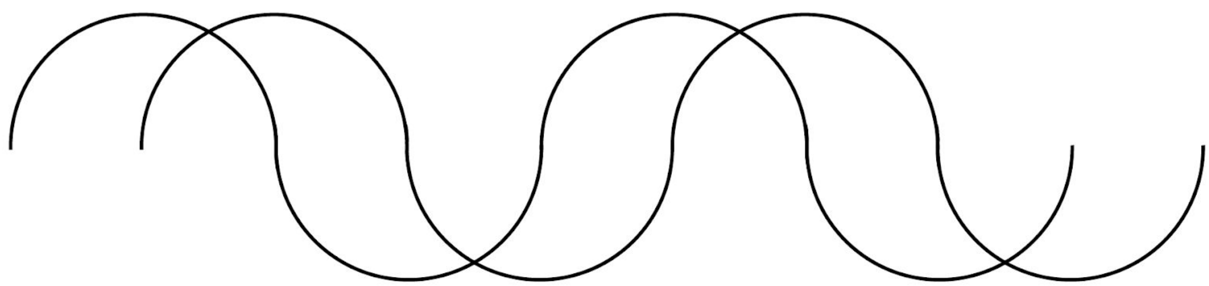
[6] “Twist.” *Merriam-Webster*, Merriam-Webster, www.merriam-webster.com/dictionary/twist.
[7] “Twist (Mathematics).” *Wikipedia*, Wikimedia Foundation, 2 Dec. 2016, en.wikipedia.org/wiki/Twist_(mathematics).
[8] Kisliuk, Bill. “Researchers Discover Sperm Move along a 'Twisting Ribbon'.” *Phys.org*, Phys.org, 22 Apr. 2013, phys.org/news/2013-04-sperm-ribbon.html.

Drawing a “Waved Ribbon”

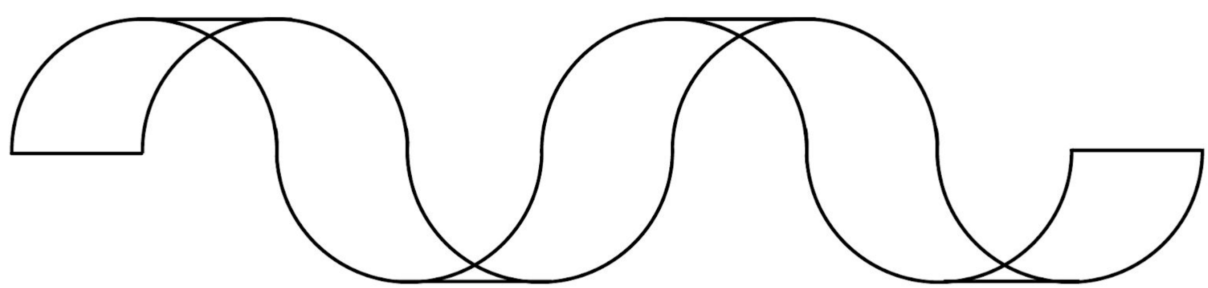
Step 1: Create sinusoidal / repeating semi-circle pattern



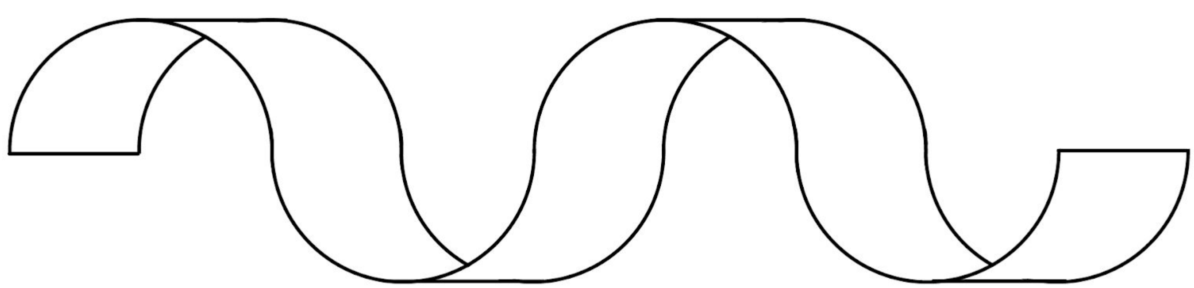
Step 2: Copy sinusoid / repeating semi-circle out of phase



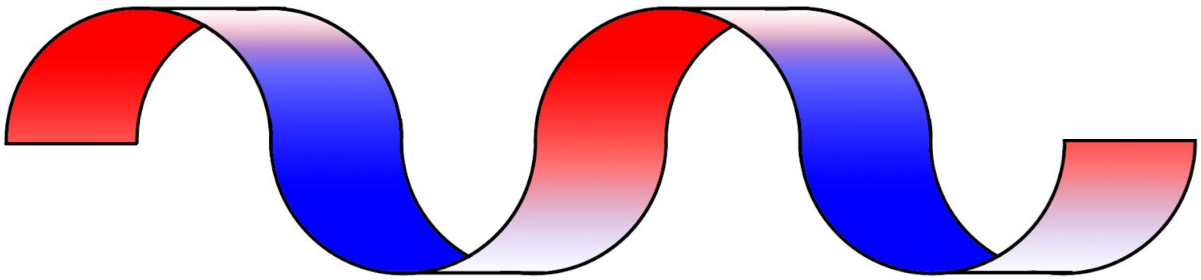
Step 3: Connect local extrema with horizontal lines



Step 4: Remove hidden lines



Step 5: Shade / color

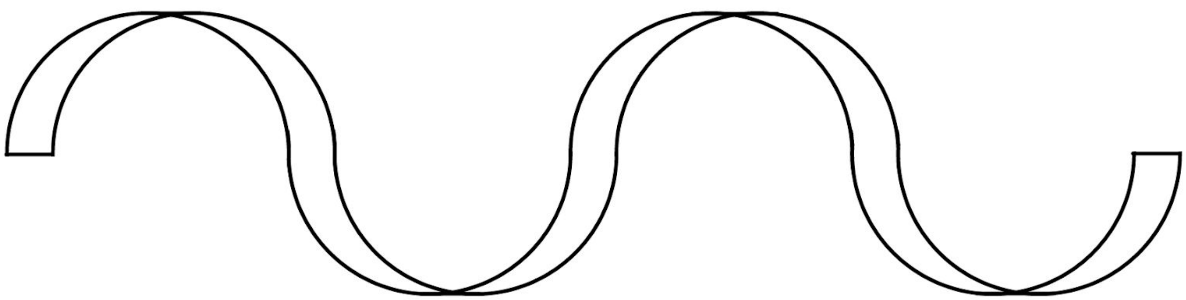


Figures 4c: Steps to Draw Waved Ribbon

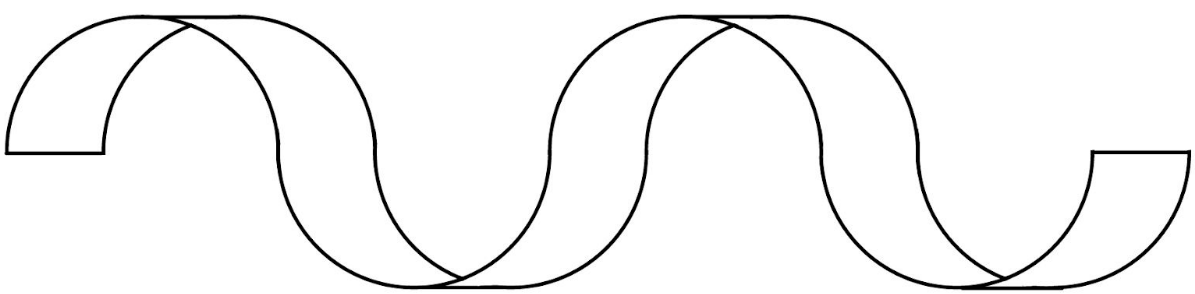
Phase Shift Variations

With a small/larger phase shift, the edges of the ribbon are closer/further apart, and the ribbon itself is thinner/wider. The following images are different representations of a ribbon with varying width, along with a stack of all the ribbons.

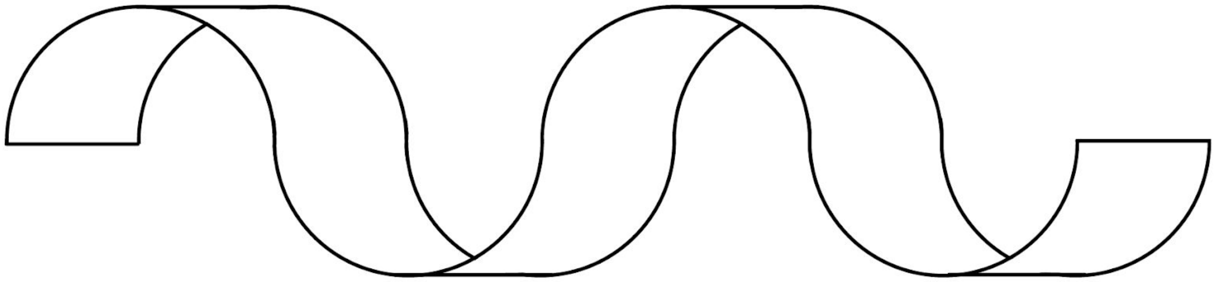
(1)



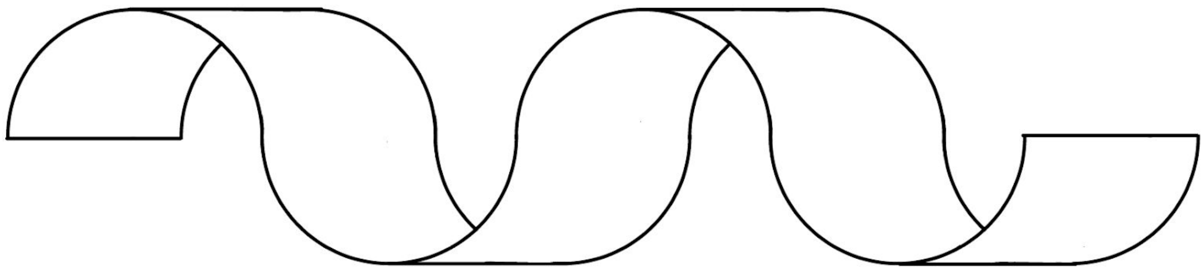
(2)



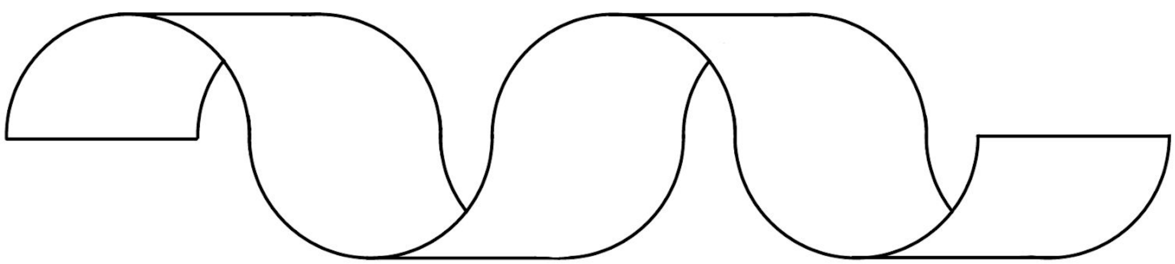
(3)



(4)



(5)



Figures 4d: Varying Phase Shifts of Waved Ribbon

(Stack)

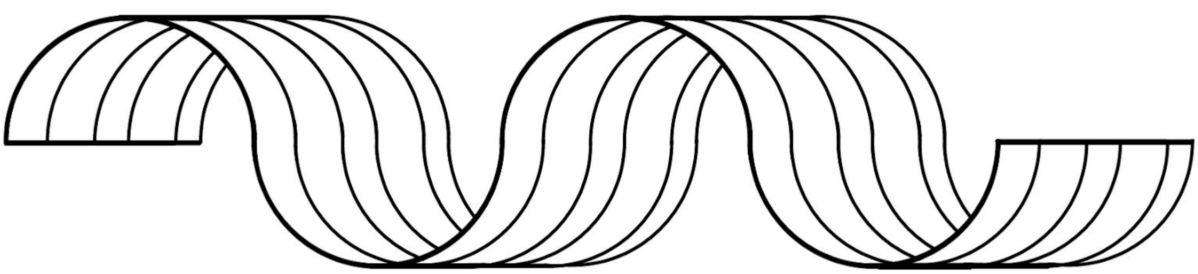


Figure 4e: Stacked Ribbons of Varying Width

5. Function Fitting

A critical investigation of this paper is an attempted mathematical model of the Twisted Ribbon pattern. Determining analytical relationships may help lead to further connections between the Antioch Mosaics and the extent of mathematical knowledge at the time. Due to the pattern's repetitive oscillating nature across the mosaics, sinusoids are the obvious functions of fit.

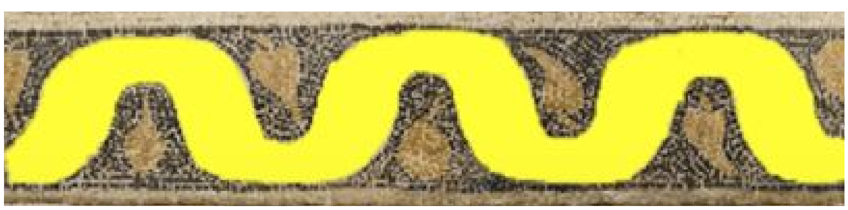
Initial manual plots of a sinusoid on top of the Animal Friendship Mosaic in the graphing program Desmos show that no part of the twisted ribbon follows the function.

Figure 5a: Sinusoid Overlayed on Twisted Ribbon

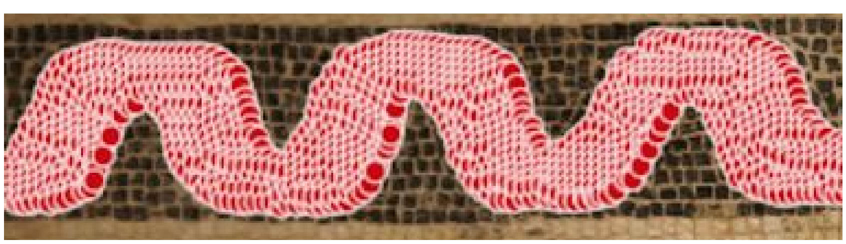
Method

After investigating several techniques and methods, a procedure for plotting the centroid of the ribbon was developed, as set out below. The process was repeated for four of the images (utilizing only one straight section of the pattern in each).

1. Align image in Adobe Lightroom so that pattern is horizontal
2. Use pen tool to shade ribbon profile in the WebPlotDigitizer software (*Figure 5b*)



3. Create points at Δx = 10 and Δy = 10, constrained to within ribbon shape (*Figure 5c*)



4. Export data as csv to Microsoft Excel for processing (averaging every 10 points)
5. Import as variables into Matlab and fit a sum of sines function (below) in the Curve Fitting Toolbox, record function coefficients and goodness of fit

$$f(x) = A\ sin(Bx + C)$$

Where the phase shift C is ignored due to its arbitrary geometric meaning in this context.

Data

(1) Animal Friendship (Image 1, pattern on bottom of mosaic section)

Coefficients (with 95% confidence bounds):

- ➔ *A = 70.15 (66.66, 73.63)*
- ➔ *B = 0.0147 (0.01464, 0.01476)*

R-square: 0.88

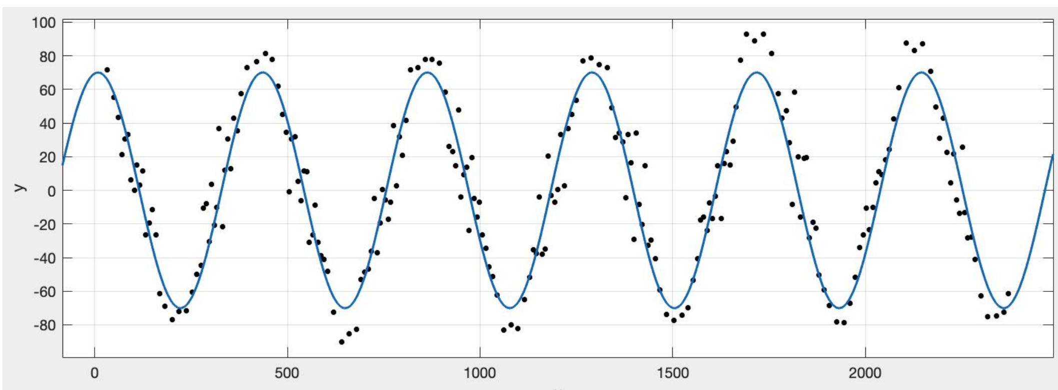


Figure 5b: Animal Friendship Image 1 Fitted Function

(2) Small Panel from House of Ge and the Seasons

Coefficients (with 95% confidence bounds):

- ➔ *A = 62.44 (59.42, 65.46)*
- ➔ *B = 0.01699 (0.01694, 0.01703)*

R-square: 0.876

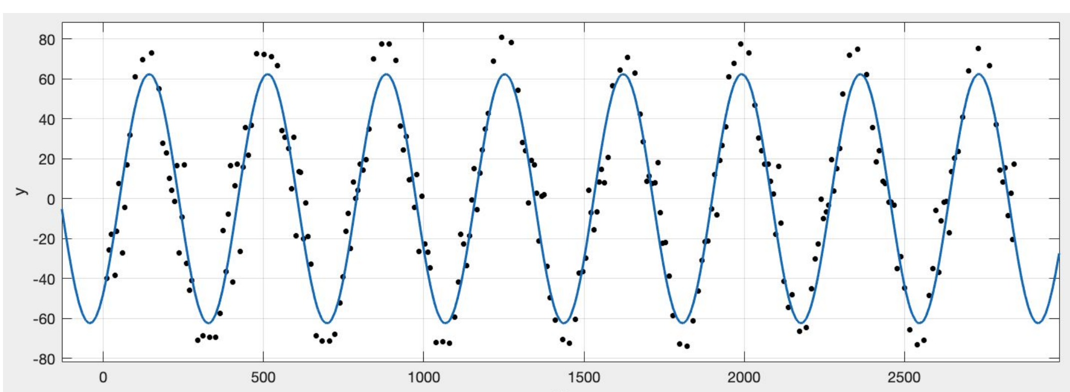


Figure 5c: Animal Friendship Image 4 Fitted Function

(3) Large Yakto Complex Mosaic (pattern on bottom of mosaic section)

Coefficients (with 95% confidence bounds):

- ➔ *A = 56.57 (52.75, 60.39)*
- ➔ *B = 0.01728 (0.01721, 0.01735)*

R-square: 0.759

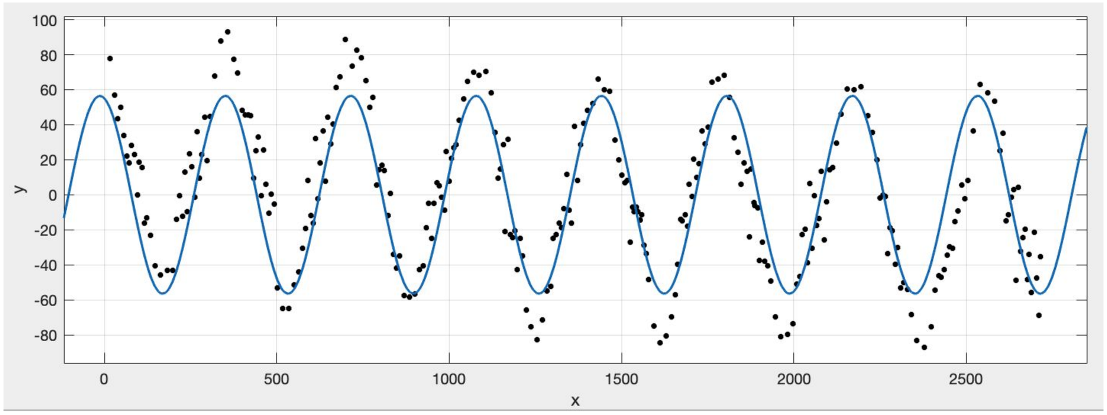


Figure 5d: Hatay Mosaic Fitted Function

(4) Hatay Mosaic (Upper pattern)

Coefficients (with 95% confidence bounds):

- ➔ *A = 20.74 (19.57, 21.91)*
- ➔ *B = 0.04561 (0.04552, 0.04571)*

R-square: 0.829

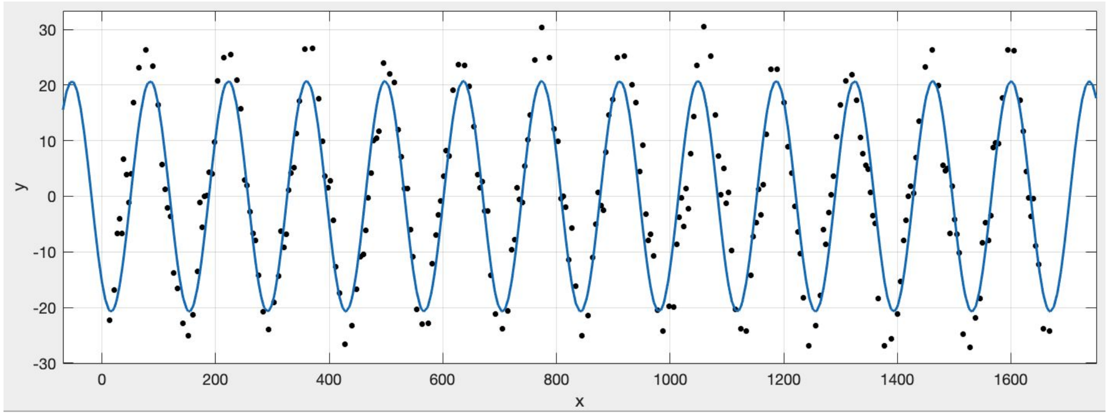


Figure 5e: Yakto Complex Mosaic Fitted Function

Results

To compare the four separate sine functions, each one is normalized by the coefficient C so that its period is exactly pi, allowing B' = 1. As previously stated, the phase shift of each function is ignored so they all begin at the origin. The amplitude is then multiplied by the same factor C to easily compare the different sinusoids. The results are displayed in the following table and figures. (1) is plotted in red, (2) in green, (3) in blue, and (4) in orange. Solid lines indicate the mean sinusoid and dotted lines are the lower and upper 95% confidence bounds of each.

Figure 5f: Table of Normalization Results

	(1) Animal 1 Bottom			(2) Small Yakto			(3) Large Yakto			(4) Hatay		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
A	70.15	66.66	73.63	62.44	59.42	65.46	56.57	52.75	60.39	20.74	19.57	21.91
B	0.0147	0.0146	0.0147	0.0169	0.0169	0.0170	0.0172	0.0172	0.0173	0.0456	0.0455	0.0457
T	427.43	429.18	425.69	369.82	370.91	368.95	363.61	365.09	362.14	137.76	138.03	137.46
C	0.0023	0.0023	0.0023	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0072	0.0072	0.0072
A'	0.164	0.155	0.173	0.169	0.160	0.177	0.156	0.144	0.167	0.151	0.142	0.159

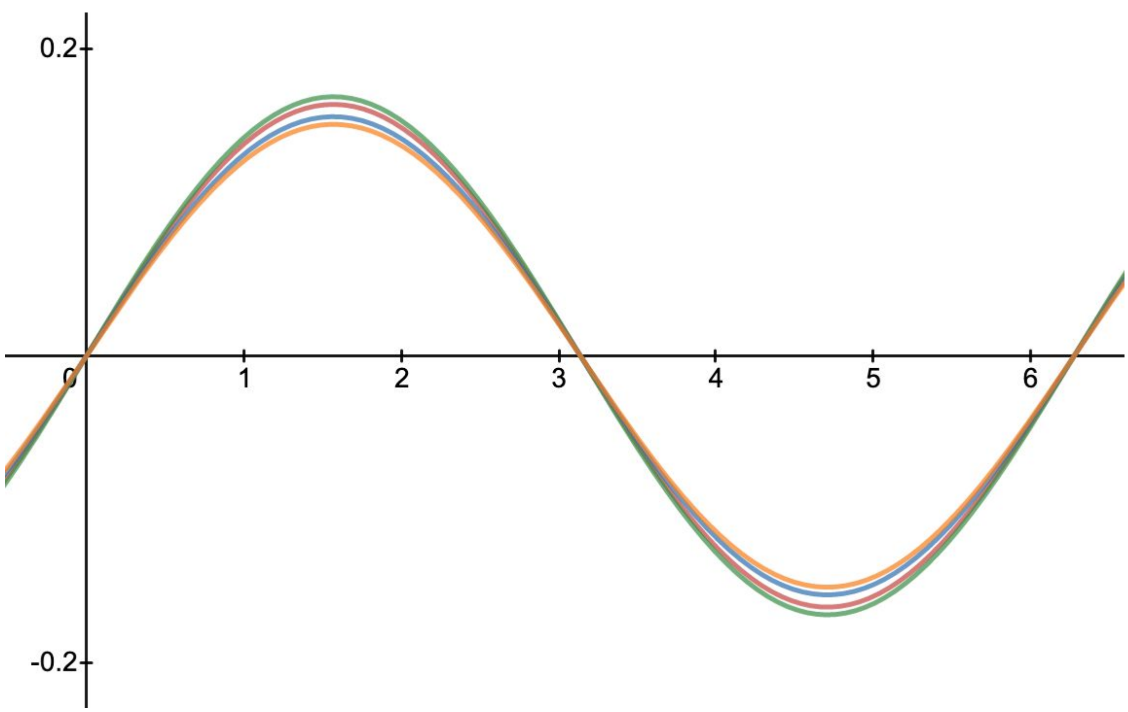


Figure 5g: Comparison of Normalized Fitted Function Means

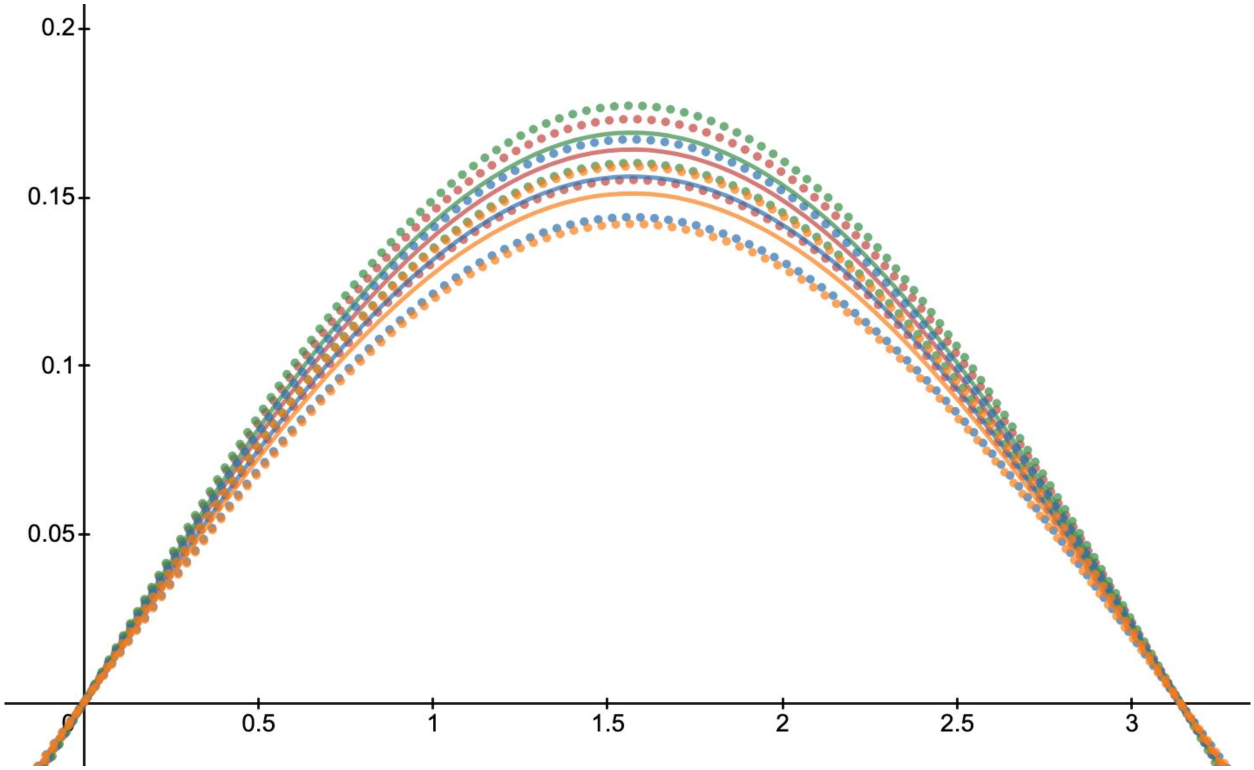


Figure 5h: Comparison of Normalized Fitted Function Means & 95% Confidence Intervals

Conclusion

Standardizing the fitted sine functions allows for pattern comparison across several mosaics. As evident in the figures above, the centroid of the twisted ribbon patterns follow very similar paths. This is supported by the low standard deviation (0.00824) of the normalized amplitudes. Beyond their similar visual appearance, this mathematically supports the hypothesis that the twisted ribbon is a repeated design feature uniform in relative size and shape across multiple mosaics. While we see the twisted ribbon as an important pattern to the Antioch mosaic designers, it does not prove they knew about sinusoids and modeled the pattern after such a wave. The actual ribbon itself does not display any representation of a sinusoid, and there is no way to know if they planned the pattern from the centroid of its area, which only models the function at an average RSquared = 0.84. In conclusion, fitting sinusoidal functions to the pattern's centroid shows how geometrically similar it is across mosaics, but does not indicate the intent or knowledge of the mosaic designers.

6. Color and Tiles

Twisted Ribbon Color Scheme

Previous studies have employed a wide range of methods to analyze the color of the marble forming the Antioch Mosaics. One particular study investigates X-ray Diffraction, Electron Paramagnetic Resonance, and StableIsotope Ratio Analysis as viable methods of Antioch Mosaic surface analysis. The report's author, Marie Jeanette Archambeault, notes the importance of these methods to not present "subjective aesthetic conclusions about a stone."[9] However, "color charts often are used as a guide,"[10] and will be the sole method of this report. Color analysis of an image of a mosaic, without the actual artwork, is not a precise procedure, as photographs taken at different times with different light conditions cannot be compared.

Because images of the House of Ge and the Seasons Mosaics are black and white, only the Animal Friendship and Hatay Mosaic are used in this section. The following are very high contrast and highly saturated alterations of the twisted ribbon images, in order to better visualize the color variations.

Figure 6a: High Contrast and Saturation of Animal Friendship

Figure 6b: High Contrast and Saturation of Hatay Mosaic

A noticable difference between the two twisted ribbon patterns in these samples is their orientation, specifically the direction that the wave transverses across the mosaic appears to be opposite. However, both mosaics feature both orientations, and so we will ignore this discrepancy.

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[9] "Sourcing of Marble Used in Mosaics at Antioch (Turkey)." *USFLDC Home - All Collection Groups*, digital.lib.usf.edu/SFS0025023/00001. pg 54

[10] "Sourcing of Marble Used in Mosaics at Antioch (Turkey)." pg 54.

Animal Friendship Tile Recreations

The Animal Friendship Mosaic alternates between red on its “underside” (the portion of the ribbon visible when it curves upward) and green on the “top”. Both of them follow a similar gradient pattern, with the darkest red/green on the top/bottom (local extrema), and the lightest at the ribbon’s vertically steepest portion.

We see 4 distinct colors in each gradient zone, which progress from darkest to lightest and back to darkest, as depicted in the figures below. The darkest red portion is approximately 6 tiles tall and the lighter tones are each 2 tiles tall, while the darkest green is 4 tiles tall, second darkest is 2 tiles tall, third darkest is 4 tiles tall, and lightest is 2 tiles tall. An interesting point to note is the rather smooth transitions between green colors, which contrasts the abrupt jump in color intensity between the middle two red colors.

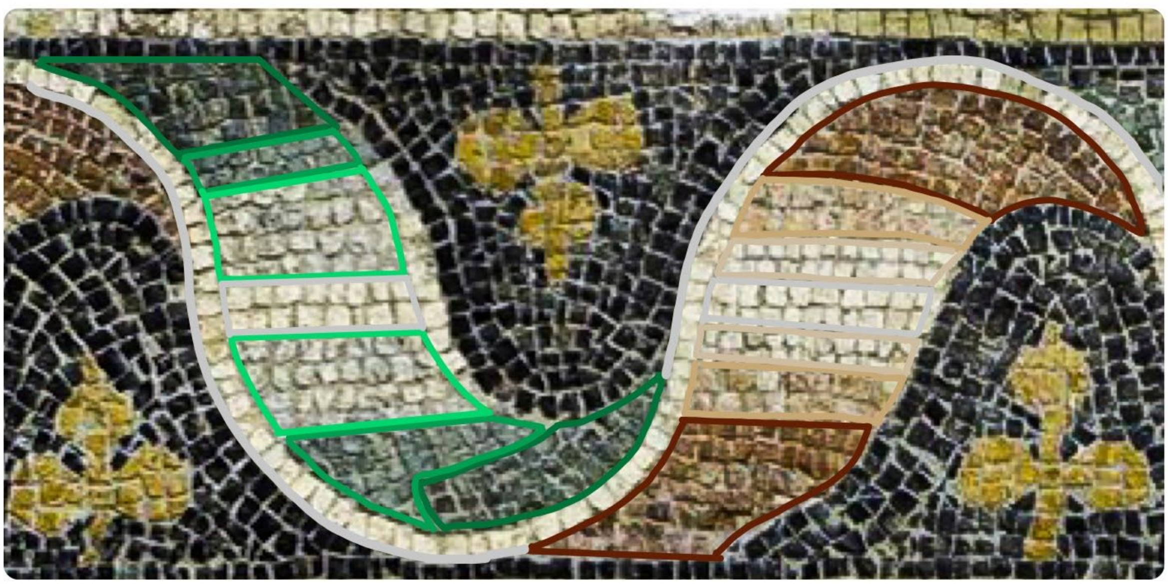

Figure 6c: Overlay of Distinct Colors in Gradient

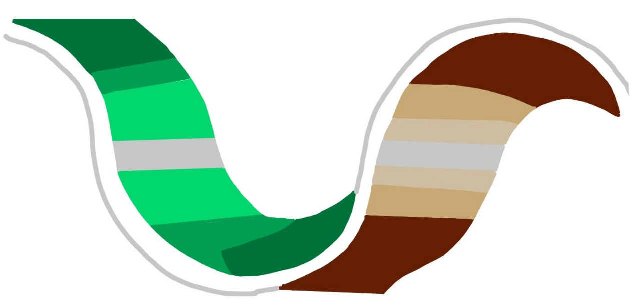

Figure 6d: Distinct Colors in Gradient

Figure 6e: Colors by Tile

Hatay Mosaic Tile Recreations

The unknown mosaic from the Hatay Museum consists of a rather different color scheme and tile pattern than the Animal Friendship Mosaic. While it is not as detailed, this twisted ribbon does also appear to be shaded on both sides by a gradient.

On the “top” part of the ribbon, where it curves upward, there are three distinct color zones. The upper and lower ones are both orange and are 1 and 2 tiles tall, respectively. The middle zone is a light orange/tan color 6 tile tall section. On the opposing “underside” of the ribbon, we see three colors across four blocks. Starting from the top, there is a very dark, 1 tile tall portion which is followed by a 3 tile tall medium tone. In the middle is a tan/orange 2 tile tall portion, followed by another 3 tile tall medium tone at the bottom. The actual original color of the medium tone is impossible to determine because of the degraded tiles.

Figure 6f: Overlay of Distinct Colors in Gradient

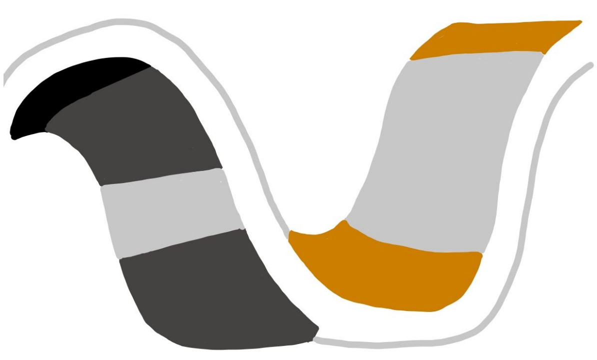

Figure 6g: Distinct Colors in Gradient

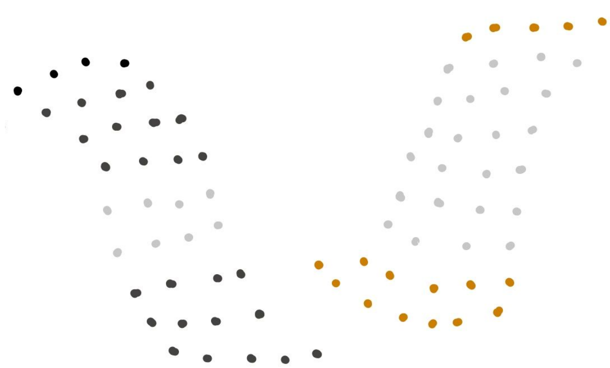

Figure 6h: Colors by Tile

Similarities

While some specifics between the colors and tiles of the patterns are different, the Animal Friendship and Hatay Mosaic's twisted ribbon border pattern share some key similarities. The first of these is the "front edge," which is a single tile wide line that follows the foremost (to the viewer) edge of the twisted ribbon as it transverses across the mosaic. The line is the same color as the lightest part of the gradient in both Animal Friendship and the Hatay Mosaic. Additionally, both patterns are surrounded by a black tiles.

7. Further Research

This paper serves as a contribution of ongoing research to the Antioch Recovery Project (http://www.antiochrecoveryproject.org) at Johns Hopkins University. Based on my findings outlined in this report, I would recommend further research into the following similar topics:

- Modeling the twisted ribbon pattern in three dimensions (possibly using a CAD software) to better visualize its transition through space
- Investigating the significance of the border pattern in a broader historical context
- Perform similar analysis on other common border patterns found in Antioch Mosaics, including the crowstep, rope, meander, wave, and ribbon
- Create a comprehensive directory of all border patterns found in the Antioch Mosaics