# Conservation and Paper Roughness of Art Artifacts

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# 1. Introduction

Surface metrology is used to discriminate surface textures that were created under different conditions or that behave differently, and to understand functional correlations involving surface textures or roughness. Functional correlations exist between surface textures and surface behavior, and between surface creation (e.g., manufacturing, wear, and fracture) and surface textures. These functional correlations can be used to design better products and processes for quality assurance.

There are several interesting challenges in discovering and documenting functional correlations quantitatively. One challenge is in finding out how to discriminate surfaces that are thought to have different textures. Another is establishing the scales of interaction that control texture related phenomena. Addressing these challenges depends on the development of better measurement and characterization methods.

This paper shows measurements on different types of paper samples provided by the Worcester Art Museum. After measurements are completed, area-scale and length-scale fractal analysis are performed by the patchwork method to investigate fundamental scales on adhesion on rough substrates, in order to find differences between two types of paper.

### *1.1 Objectives*

The objective of this project is to engage the Worcester Art Museum's interest with measurements and analyses of paper texture.

Feasibility of measurements and the possibility of discrimination of the types of paper are another objective, along with demonstrating and collaborating with the museum to obtain funding so more research can continue.

### *1.2 Rationale*

The objectives are important because we hope that the Worcester Art Museum may be interested in learning how to find the differences between paper, as well as the improvements in the process of conserving their art work. By demonstrating the capabilities of surface metrology, the rationale of obtaining funding in order to continue support of art-technology collaboration, can be achieved. The measurements performed help us gain a larger perspective on the sample of paper itself, which would lead us to our objectives. Gaining this understanding and obtaining feasible measurements along with a proving we can discriminate two types of paper were demonstrated to the art community and initiated the art-technology collaboration.

Research is taking place at University of Florence to study the effect of cleaning mechanics on the surface texture of paper. This research relates to the art community and the technology currently being used. Studying the types of cleaning and preserving tools for delicate art pieces, Piero Baglioni and his colleagues are experimenting with nano-particles composed of cobalt and iron oxide which they have combined into a polymer gel. This gel has been created to act as magnetic sponges with cavities approximately fifty nanometers in size, in an attempt to clean paper. Currently, there are gel-based systems which are being used to clean artwork; however there is a risk that this applied gel is actually harming the art piece and therefore diminishing its life-span. This is due to the fact that these gels are sticky and hard to remove without applying harsh solvents or aggressive scraping techniques which can damage the fragile pieces (Dume, 2007).

Measuring the surface texture as we are doing at WPI, however is completely non-contact and therefore does not affect the original structure of the paper itself. It gives a direct characterization of the paper in order to gain this deeper understanding of what it is composed of. Research can then made to prove how some cleaning techniques are actually damaging the paper, rather than preserving them, and attempt to find new ways of reducing wear and tear to the paper itself, eventually elongating its life-span.

### *1.3 State-of-the-Art*

Table 1 shows a table outlining the sources described below and the methods used in their research.

| **Names:** | **Measurement Technique:** | **Points:** |
|---|---|---|
| Sawoszczuk, et al. (2007) | Scanning Electron Microscopy (SEM) Measurements | Studied process of degradation of paper by studying its fiber length measurements |
| Luukkala and Pellinen (1995) | Airborne Ultrasound | Performed surface roughness measurements on paper |

**Table 1: Outline of the State of the Art references**

Surface roughness has many applications, however only two of these applications were found relating to the study of paper at this current time. Also at this time, none were found relating the study of paper to the art community in any way.

Two researchers in Finland are measuring the paper roughness by using high-frequency airborne ultrasound. Their objective was to be able to measure paper roughness using the measurement principle based on the attenuation which occurs when the ultrasound is reflected from the surface. Luukkala and Pellinen (1995) have performed such measurements using paper samples. The results are then compared with data from conventional air-leak measurements. This proposed method is non-contact. The measurements are performed using air-leak methods. This is where the roughness value of the tested sample of paper is observed as a characteristic rate of air-flow through a slit between the paper sample and the edge of a metering head which touches the sample. The head of the air-leak meter is at the circular end of the air channel and allows air-flow through the channel. The rate of air flow is a function of the pressure difference between inside the channel and outside the metering head and depends on the roughness of the measured paper. After this is setup, measurements can be taken by sending high-frequency bursts of air ultrasound towards the measured sample of paper in order to study the reflected burst at the specular angle and amplitudes of reflect bursts. This allows them to distinguish between the different surfaces of the paper by noting the attenuation (Luukkala et al. 2007).

Based on their research and their findings, they have concluded that they were successfully able to measure the roughness of five paper samples derived from this methodology and meet their objective (Luukkala et al. 2007).

Sawoszczuk with others in Poland are currently working on the process of degradation of paper by studying its fiber length. Their objective is to preserve paper by performing comprehensive characterization of deteriorating paper. Their research includes how macromolecular changes are influencing the mechanical properties of the paper. They are measuring the fibers of the paper itself and studying its morphological properties. The software used to interpret the raw data is 'MorFi LB-01 Fiber Analyzer' which is produced in Techpap, France and is used to analyze the fiber network of the paper itself. Their approach "allows for reliable statistical measurements of thousands of fibers at high speed and accurate determination of important characteristics of their shape," based on one their published journal entries (Sawoszczuk et al., 2007).

The equipment which they are using is not mentioned in great detail although the measurements were labeled ‘SEM Measurements,’ however the specific model number of equipment used has been omitted (Sawoszczuk et al., 2007).

### *1.4 Approach*

Our approach is to obtain the surface roughness of paper and somehow measure, analyze and conclude information about it. However the way that we are performing the measurements are unlike the state-of the-art, Sawoszczuk et al., Luukkala and Pellinen. For example, unlike Luukkala and Pellinen, in order to measure the paper roughness confocal and triangular sensors were used by us as opposed to an airborne ultrasound technique used in their approach. Confocal point sensors are being used frequently in many applications; however at this given time and with the research performed, no results were found connecting confocal point sensors and the application of studying surface roughness of paper.

We also used different tools to analyze our measurements. For example, the software that we are using analyzes the universal texture of the paper as opposed to software which they are using which only analyzes the individual fibers, performed by Sawoszczuk and his partners. Also unlike our measurements, Sawoszczuk et al., Luukkala and Pellinen did not involve any 3-D plots or discrimination of any kind. We performed discrimination of two types as well as 3-D fractal analysis plots, discussed later in the methods and results section. Also their measurements were of paper; however this paper was not related to art work or the art industry in any way. To contrast our approach by theirs, we are relating art and the technology as opposed to Luukkala, Pellinen and Sawoszczuk, et al.

# 2. Methods

## *2.1 Measurements*

The methods to accomplish this type of objective were to interact with the art community and demonstrate to them how surface metrology can be used and some of its capabilities. Meetings were set up to collaborate and obtain feedback from the measurements and analysis of the samples of paper they earlier provided to us. Appendix A shows a power-point demonstration from a recent meeting.

After showing results of the measurements and the analysis, they expressed a large interest in the technology. They conveyed that they were treating a particular type of paper in an attempt to clean it, however questioned if they were somehow damaging the paper in the process. This interest inspired communication and the possibility for funding to take place.

Another method utilized was to use concepts from surface metrology in order to understand the paper. Surface metrology is the technology of measuring small-scale features on surfaces and in doing so we can understand the chemical makeup of various objects around us. In order to better understand the paper, analyzing software was implemented in order to compare batches of two types of paper and results were plotted which will be discussed in-depth later.

The software used to interpret the raw measurements was Digital Surf MountainMaps and Surfract SFRAX. The software known as surface metrology and fractal analysis software package or SFRAX calculates the fractal properties of relative area and average texture depth of the surface textures. SFRAX is utilized to analyze the universal texture of the paper itself. Digital Surf MountainMaps is used to calculate the conventional surface texture parameters; a complete list is shown in Appendix F. It is also used to perform filtering tools to remove bad points of the raw data.  Finally, scale based F-tests are performed to find the scale, if any, at which fractal properties are statistically different (Brown, 2008).

The technologies used to obtain the measurements were the UBM Measurement and Analysis System; LT-8010 and LC-2210 lasers were used. The results of the analyses are explained in full detail in the results section.

The subsequent flow chart shows the sequence of necessary steps followed in order to accomplish the objectives, and is followed by a series of sections with a detailed description of each step.

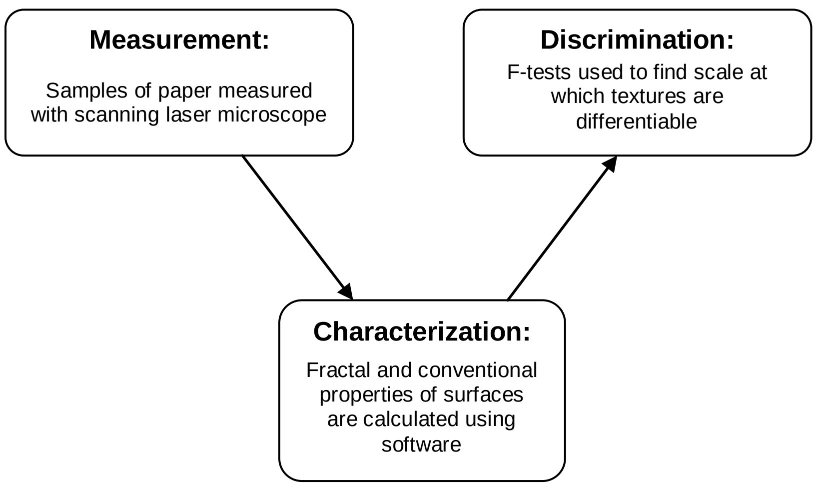


**Figure 1: Flow Chart of Sequence of Events**

Samples of paper were provided by the art museum in two categories untreated and treated.  French, Italian and wood-stained paper were provided by the art museum to be measured and analyzed. All measurements and analysis was shared and communication with the art museum continued throughout the project.

UBM scanning laser microscope took the measurements, located in the surface metrology lab at Worcester Polytechnic Institute. More on the confocal point sensor laser and how it works can be found in Appendix E.

UBM equipment was used to perform the tests on various types of paper. It measures the external and internal noise which is experienced by the system while the measurements are taking place. The measurements are performed on the scale of microns and due to this; there is a concern that ambient vibrations along with the equipment motors movements can somehow skew the final outcome of the measurements. Due to this concern, noise testing has been performed. The reason for measuring the noise is to estimate its impact on the measurements. After arbitrary parameters were entered into the UBM software analysis of the ambient noise was retrieved from the system. After observing this noise, we concluded that the amount of noise was so small that it was negligible for our future measurements and an offset did not have to be considered to be added to our analysis.

For each type of paper, multiple points known as batches of the sample of the paper were performed. These batches are systematically arranged to start for the top-left area of the paper sample to bottom-right and were in the range of six to nine measurement points. Each file in the batch was then named to correspond with that particular type of paper, for example the first sample of paper consisted of type untreated French was labeled 'UnFrench1'. Before each test, a check was made to confirm that the height sensor was behaving properly by moving the height sensor and noting its uppermost and lowermost limits. Once the sample of paper was in the range of the sensor, the table was aligned to the upper-left hand corner of each measurement area with the laser. The UBM software recorded the position of the laser, which was used to confirm that each type of paper was measured in the same way. The UBM was then ready to begin measuring the sample of paper. The following table shows the parameters used for the measurement:

| | Parameter | Value |
|---|---|---|
| **Area** | Length | 0.40 mm |
| | Width | 0.40 mm |
| | Sampling Interval | 2 μm |
| **Light Source** | Wavelength | 780 nm |
| | Spot Diameter min/max | 70-90 μm |
| | Pulse Width | 12.5 μm |
| | Power | 3 mW |
| **Data Acquisition** | Sampling Rate | 40 KHz |
| | Response Frequency | 16 KHz |
| | Response Time | 100 μs |
| | Averaging | 128 pts |
| | Measurement Rate | 100 pixel/s |
| | Table Speed | 1 mm/s |

**Table 2: Table of Measurement Parameters**

These parameters were consistent with each type of paper in order for all of the measurements to be consistent with each other. After the UBM was programmed and ready, the measurement test was started and after approximately twenty minutes per measurement point, it finished its gathering of raw data. After this the files were renamed corresponding to their respective type and saved in an .UB3 file format. After all measurement points were taken per paper type, they were transferred to another computer which hosted software to manipulate the measurement. This raw data was manipulated in order for analysis to be performed. This consisted of a combination of leveling, thresholding, and performing a linear regression to remove any inherent slope from the measurement.

These filtering tools were provided by MountainsMaps software. This software aided us in calculating conventional parameters, which will be discussed in detail later in the methods. After these conventional parameters were calculated, filtering tools were applied to get rid of the black-spots or drop-out area or points which contained bad data. These filtering tools consisted of leveling as well as further thresholding of the data right after. After this analysis, we noticed a great improvement in the data and saved the files to a .SUR extension. This was done so that it would be compatible with the software used to calculate the fractal properties of the surface, which will be discussed later in the methods. The values obtained from the conventional parameters are discussed in detail in the results section.

### *2.2 Characterization*

Characterization is done using MountainMaps software along with the table of conventional parameters shown in Appendix F. The surface files were characterized using this table which lists the conventional surface parameters which were calculated for every surface file and re-saved as a .SUR using the MountainsMap software.

Another method used to characterize the surface textures was scale sensitive fractal analysis. This tool was used with SFRAX and is a method that analyzes the surface area, linear profiles and the surface depth and volume. SFRAX was used for fractal analysis of the surface texture. One type of analysis performed was area-scale analysis. This was performed in order to calculate the relative area of the surface texture of each measurement across a range of scales which can be done using four corners full overlap technique. These curves are then graphed by the program and organized together by the type.

### *2.3 Discrimination*

Discrimination of the surface textures was also performed using SFRAX by implementing F-tests. This is a type of statistical method used to compare the difference in the standard deviation of two different types of data. After many batches of measurements are obtained, area-scale analysis can be performed. After this, the results of the analysis which consisted of a collection of area-scale analyses can then be used to form these F-tests. The process consists of the relative areas at each scale as two separate samples from the populations to be calculated. The mean square ratio is calculated at each scale and then is plotted on a graph. The mean square ratios as a function of scale are generated using SFRAX (Brown 1993).

The level of confidence can be varied, however in our case it was set to 90% confidence level and points were noticed to be well over this confidence level. This indicates that the two surfaces were in-fact discriminated using relative areas over those particular scales. This method uses the same conventional parameters earlier mention along with average texture depth and relative area (Brown 1993).

## 3. Results

### *3.1 Measurement*

The representative topographic surface of one of the types of paper, wood-stained is shown in Figure 4. The measurement on the left shows the raw data produced by the UBM machine before any filtering tools have been applied to it. The noticeable features of the black spots will cause a problem when attempting to analyze this data and can be see in the figure.

The image on the right in Figure 2 displays the measurement after filtering tools such as leveling and thresholding have been applied to it through the software. It is evident that most, if not all, of the black spots have disappeared. This measurement is now ready to be analyzed.

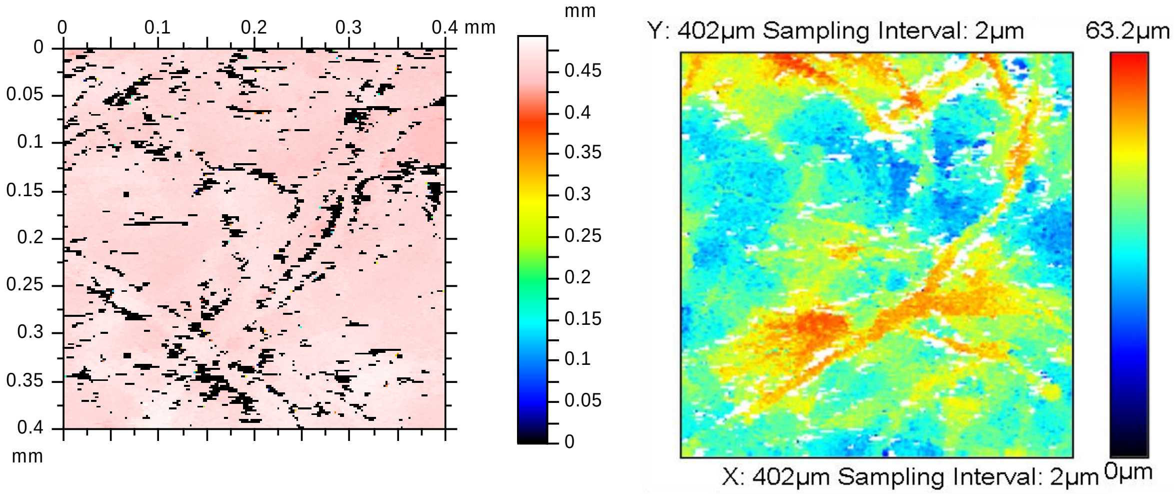


**Figure 2: An example of a measurement of wood-stained paper before and after filtering**

The image on the right, after filtering, is now ready to be imported into SFRAX, where it can be analyzed to see if two different types of paper are statistically different and if they are, at what confidence level we are able to tell them apart. The relative area of the measurement point is also able to be discriminated with respect to its scale. These two analyses are discussed in greater detail in the characterization and discrimination sections. More measurements can be found in Appendix C.

### *3.2 Characterization*

Area-scale analysis (ASME/ANSI B46.1 2002) finds the area of the surface at progressively smaller scales. SFRAX is used calculate the relative areas as a function of scale from measurements of the rough surface. The software, in order to generate the plot uses a patchwork method where virtual tiling algorithm is utilized which consists of applying triangular tiles also known as patches, shown in Figure 3. These patches, with the same area but not necessarily the same shape, are then virtually tiled onto a measured surface. The apparent area is calculated by covering the surface with this patchwork of triangular tiles with progressively smaller areas. An example of this would be z = z(x, y) or a regular grid in x and y (Brown 2001).

Figure 3 shows an example on how area-scale is performed with untreated French.

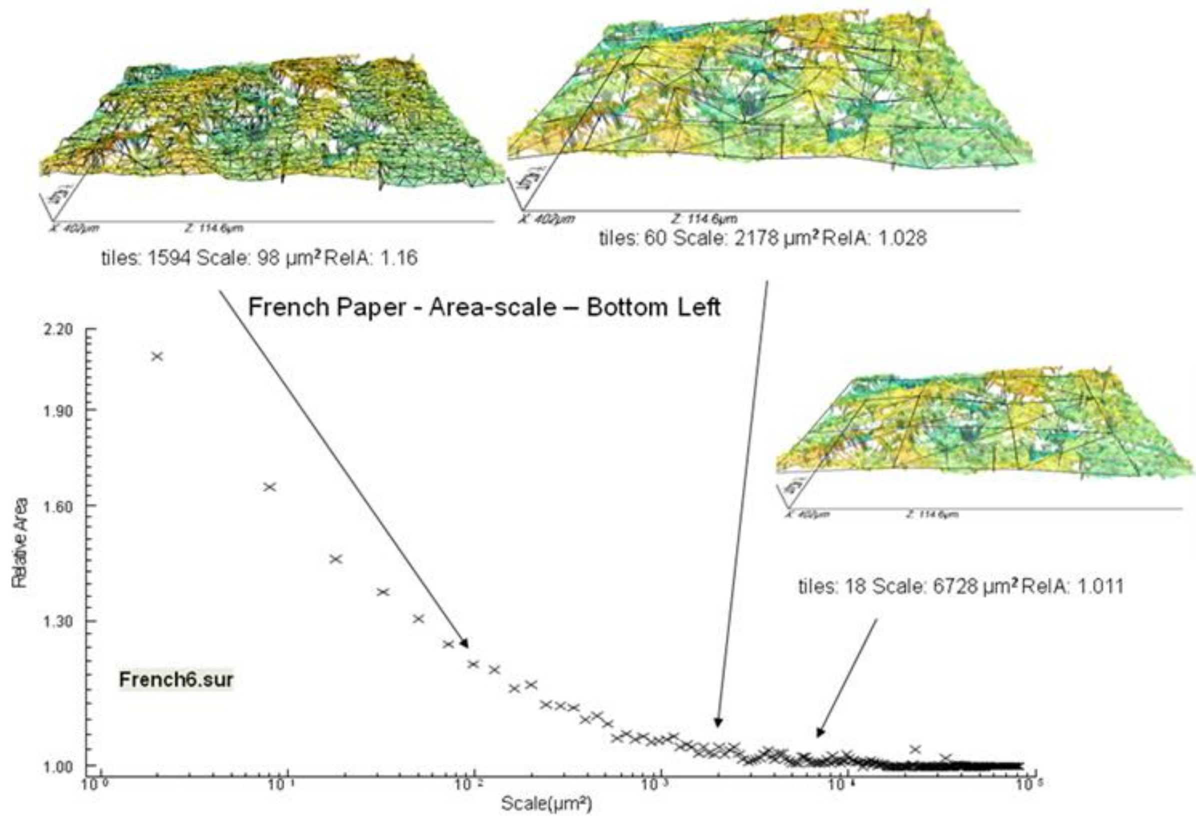


**Figure 3: Area-scale analysis**

The area of the tile represents the scale. These virtual tilings are then repeated so that a wide range of scales can be represented. An example of this is that the area at a particular scale is equal to the number of tiles used in the tiling and then multiplied by the area of that specific tile. With these calculations the relative area can be determined by dividing the measured area by the nominal area of the surface covered in these tiling (Brown 2001).

"The dependency of the area on the scale of measurement or observation is a fractal property. The fractal dimension, which could be used to characterize the complexity of the measured surface over some particular range of scales, can be determined from the slope of a log-log plot of the relative area versus scale, i.e., area-scale plot: Das = 2 – 2(slope)" (Brown 2001).

After one area-scale analysis is performed on one measurement, the same is performed on all within the same category, for example all of the untreated French measurements can be compared together as well as all of French measurements can be compared with all of the wood-stained measurements. An example of a results plot comparing all the measured point is shown in Figure 4. The relative area is plotted as function of scale in micrometers squared. The French type of paper is categorized together and is shown in blue while the wood-stained is displayed in red. We can see the difference between the two types of paper because the graphs do not overlap each other. This difference will be highlighted using F-tests mentioned in greater detailed in the discrimination section.

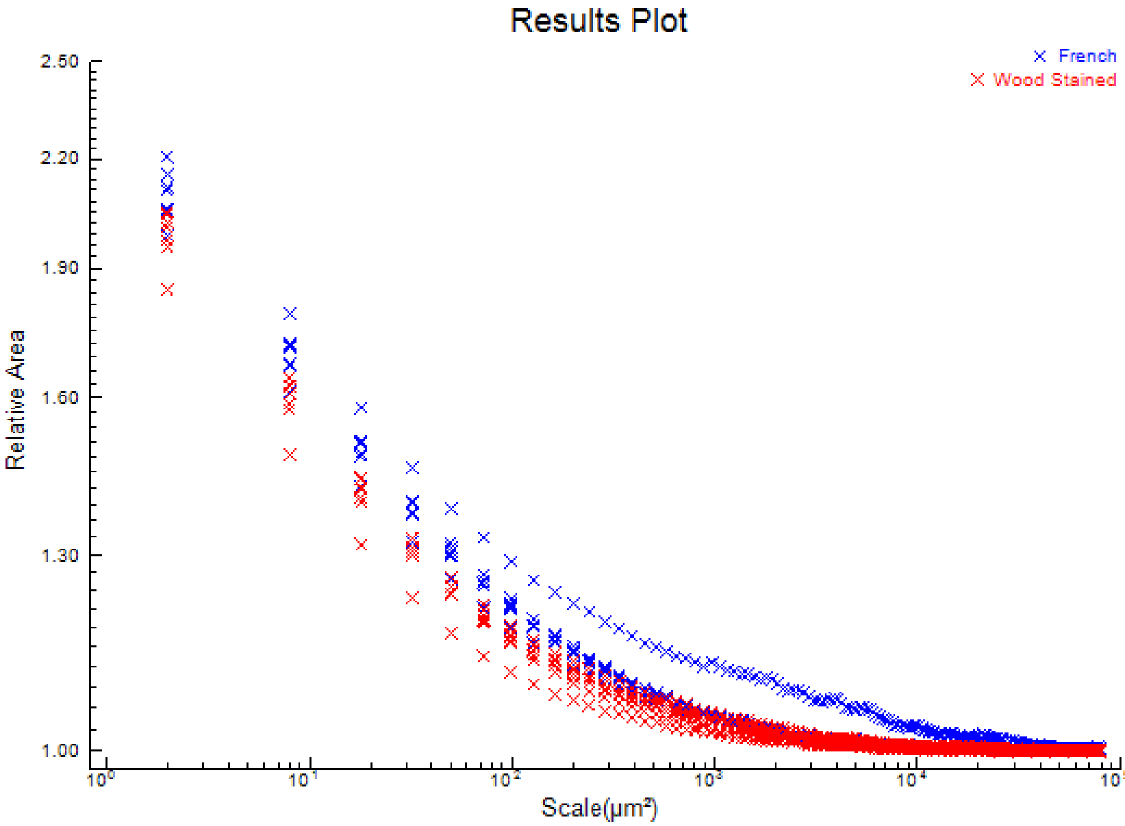


**Figure 4: Results Plot**

### *3.3 Discrimination*

Scale based F-tests are performed to find the scales at which fractal properties become discriminated. As mentioned earlier, an F-test is a statistical method for comparing the difference in the standard deviation of two sets of data and determines if two types of papers are statistically different. Figure 5 shows scale based F-test of two types of untreated paper, French and wood-stained. Discrimination of the fractal parameters was performed using the F-test function in SFRAX at a 90% confidence level.

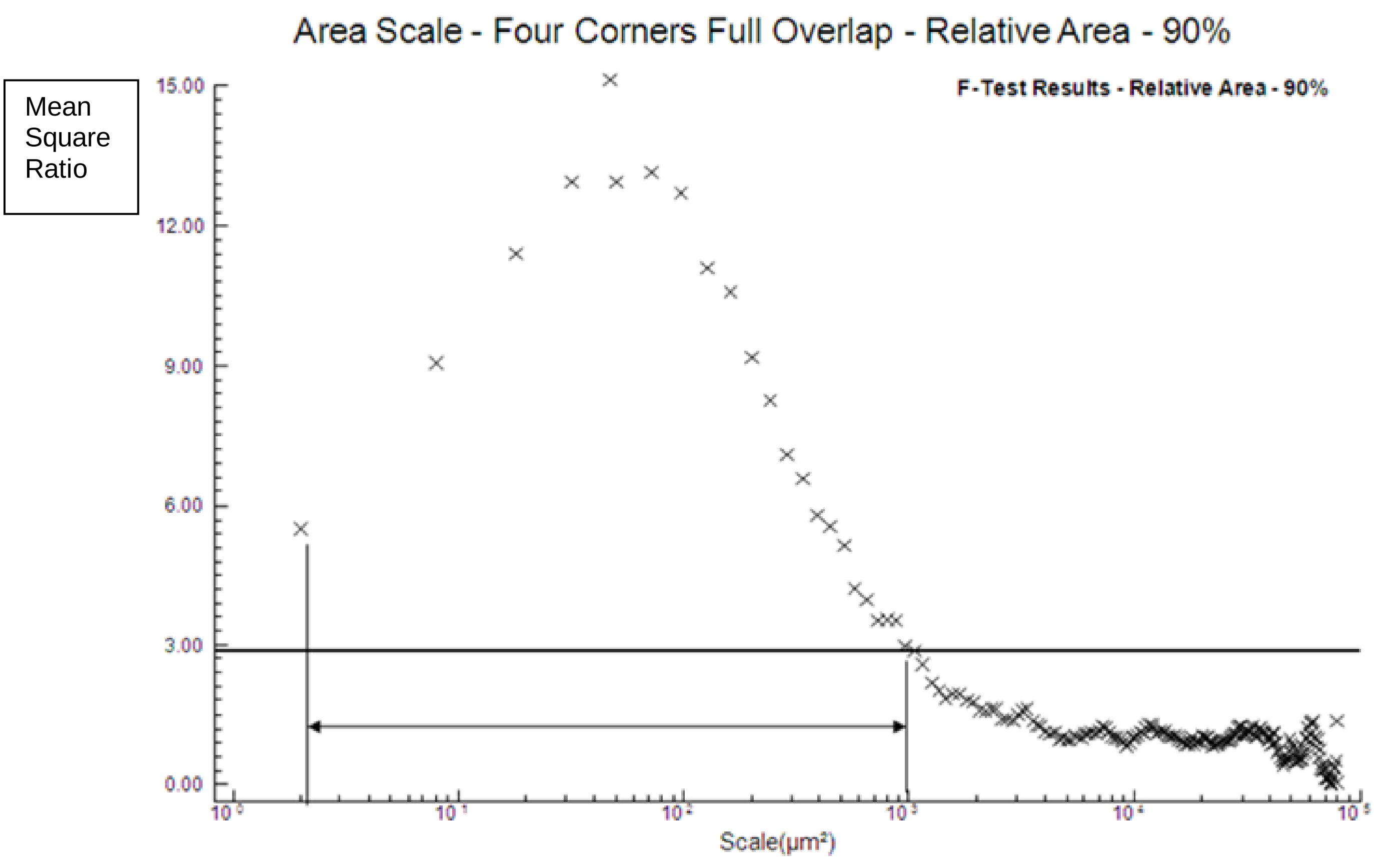


**Figure 5: Scale based F-test of untreated a sample of French Paper versus wood-stained Paper**

The discernability at 90% confidence ranges from 2 to 1000 μm$^2$ shown by the arrow in the figure. This is a plot of mean square ratio as a function of scale, which displays graphically at what scales the two surfaces are able to be discriminated.  Table 3 shows the scale of discrimination from the F-tests, where ‘u’ represents untreated and‘t’ represents treated. The ‘F’, ‘I’ and ‘W’ represent French, Italian and wood-stained respectively.

| | Ft | Fu | It | Iu | Wt | Wu |
|---|---|---|---|---|---|---|
| Ft | X | | | | | |
| Fu | 2-1000 | X | | | | |
| It | 100-300 | 90-1000 | X | | | |
| Iu | 100-300 | 2-1000 | 90-1000 | X | | |
| Wt | 2-1000 | 2-1000 | 2-1000 | 90-1000 | X | |
| Wu | 2-1000 | 2-1000 | 2-1000 | 2-1000 | 2-1000 | X |

**Table 3: Range of Discrimination in micro-meters squared**

## 5. Discussion

Fractal analysis techniques, especially relative-area, can be used to tell apart surfaces with a much higher success rate than conventional parameters, such as those in MountainMaps. The tests prove that two samples of paper provided by the museum are in-fact, with a high confidence level, different from each other. The measurements were in-fact feasible and the F-tests were able to prove that all types of paper were discriminated successfully.

Collaborations with Worcester Art Museum are still continuing as of this day and are growing. These collaborations allow the sharing of information, knowledge and communication back and forth. As mentioned earlier, the measurements for this particular study along with the analysis were demonstrated to the art museum. Also mentioned earlier, funding with the museum would enhance this application of surface metrology and would allow this research to continue. During a last meeting, they have expressed large interest in knowing if they have causing any damage to the paper after applying some type of treatment to it in an attempt to clean the paper. Overall, the calibrations with the museum were a success.

## 6. Conclusion

Relative-area can be used to tell apart surfaces and identify the scale ranges where they are different statistically.

## 7. References


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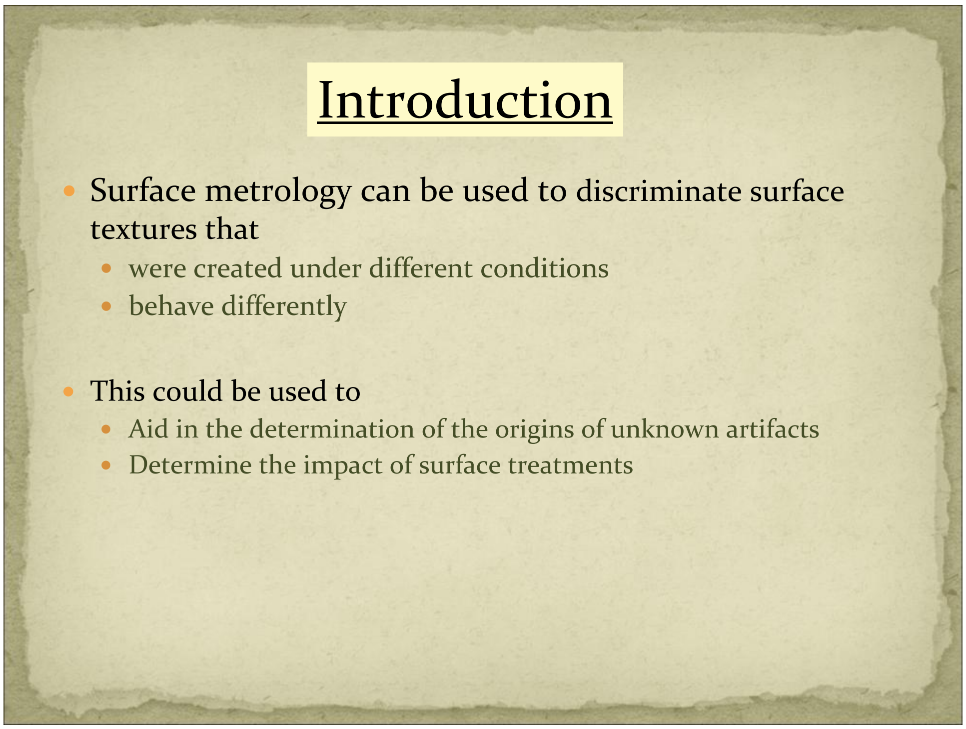
## 8. Appendices

# *Appendix A: Amy Christ Power-point Presentation*



# Methods

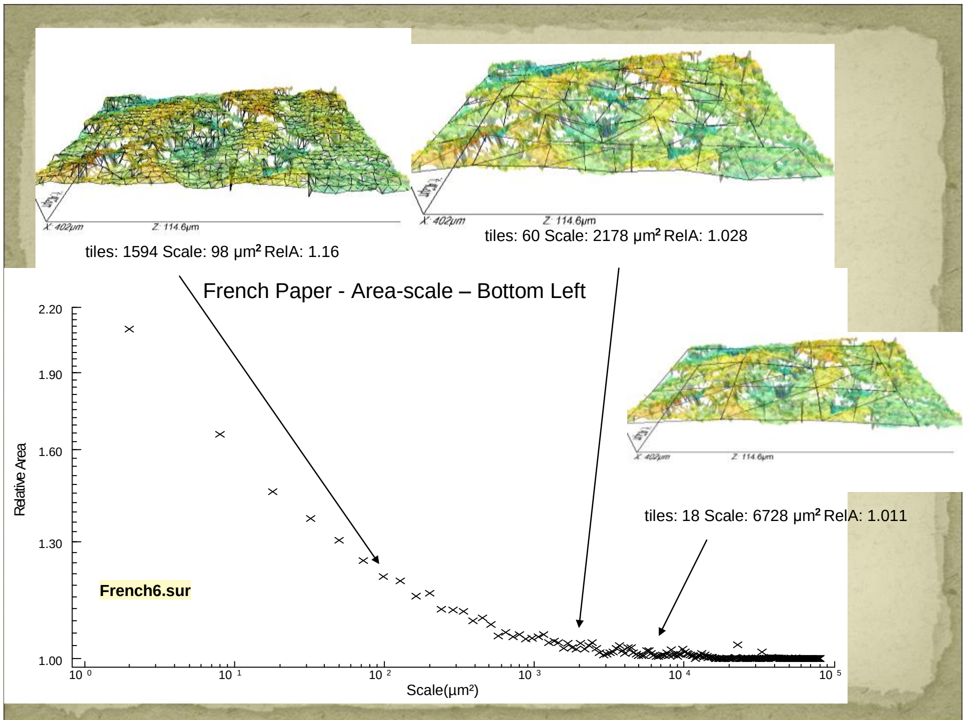
- Measured on a scanning laser microscope
  - untreated paper.
- Measured surfaces were threshold and level the surfaces to get rid of most of the non-measured points (Mountains Map)
- Scale-sensitive fractal analyses were run using the software 'Sfrax'.
- F-test analysis were used to determine if the surfaces were statistically different as a function of scale

# Measurements

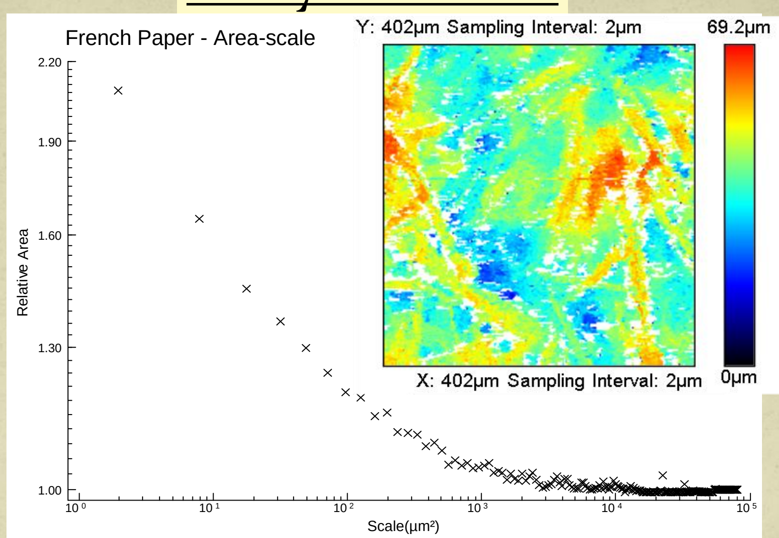
The UBM uses a Keyence LC-2210 confocal point sensor, which reflects a laser light source from a surface and through a detector pinhole to determine height information.

# Measurements

The UBM uses a Keyence LC-2210 confocal point sensor, which reflects a laser light source from a surface and through a detector pinhole to determine height information.

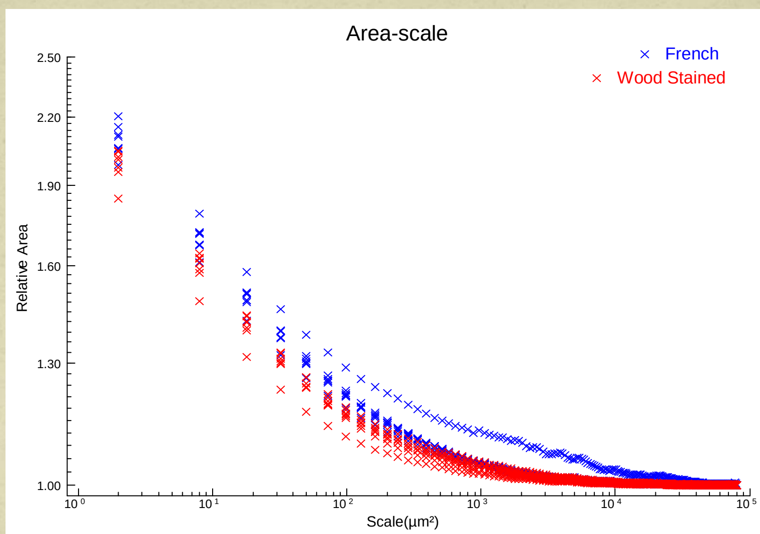



# Analysis Results

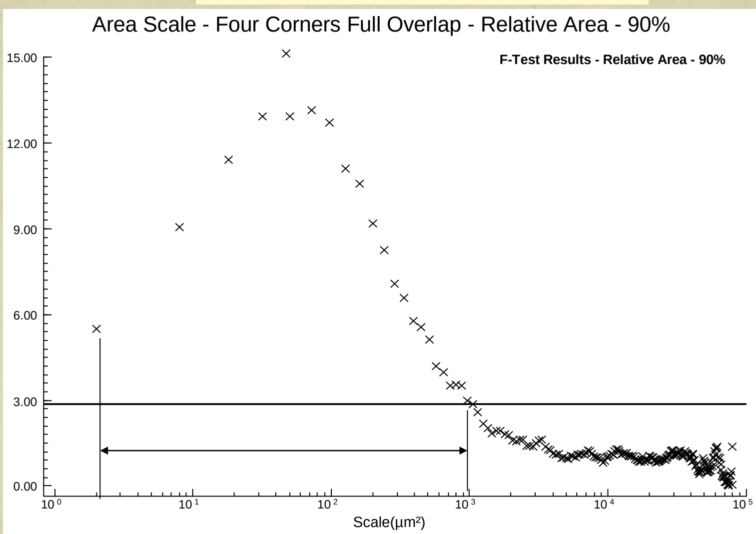



For more analysis please refer to the appendix.

# French vs. Wood-stained

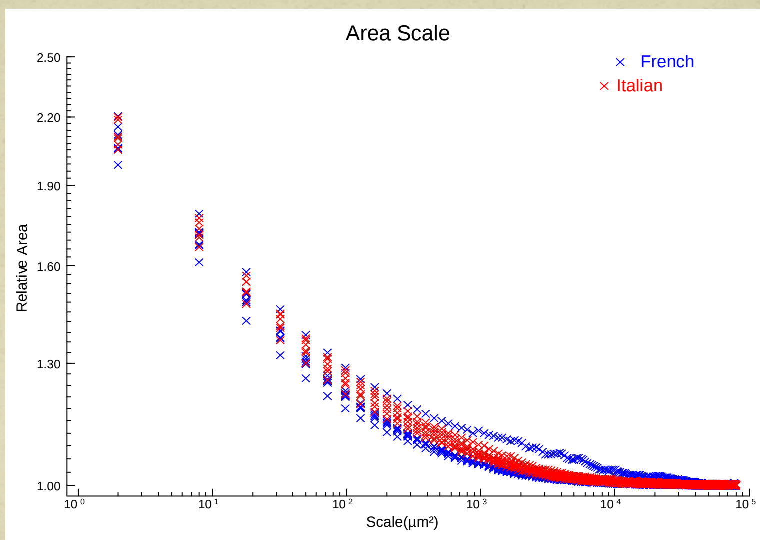



# French vs. Wood-stained

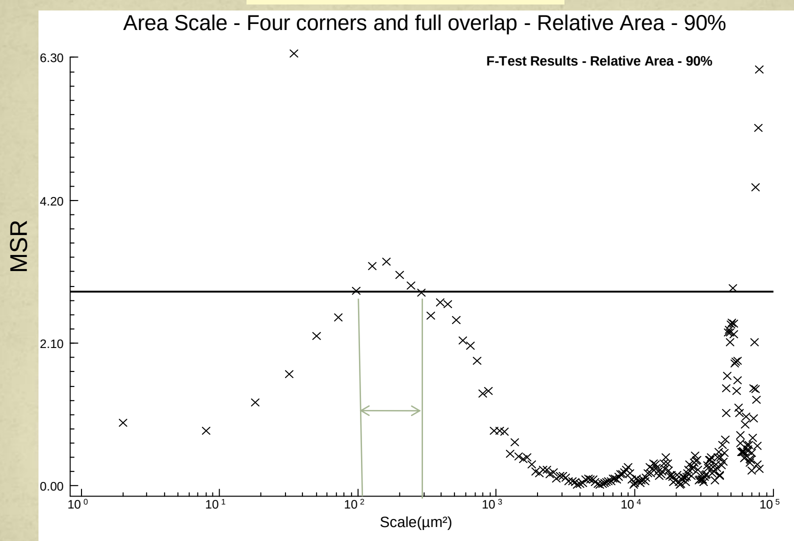



Discernability at 90% confidence from 2 to 1000 μm²

# French vs. Italian

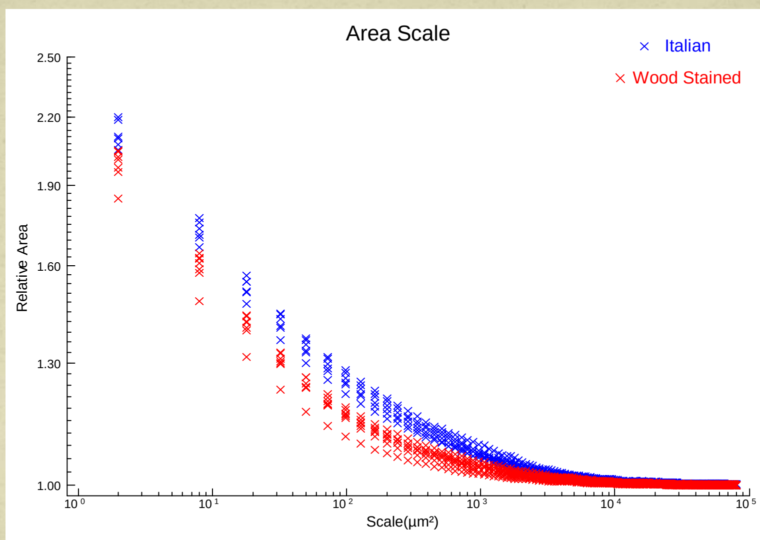



# French vs. Italian

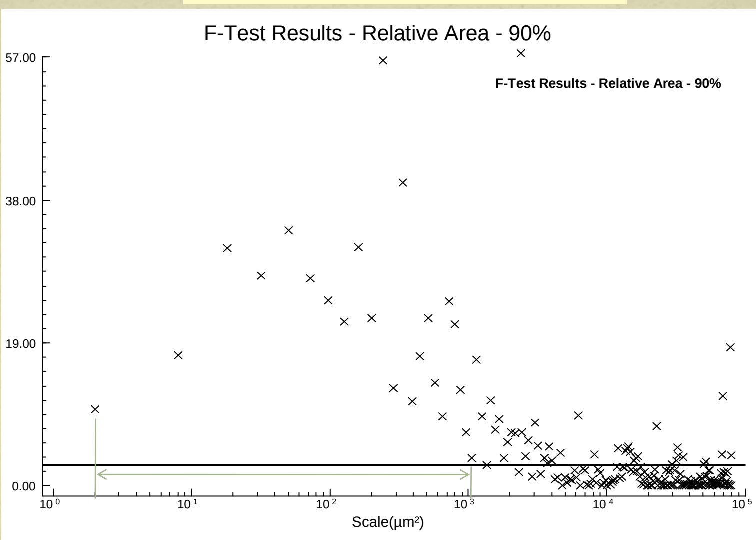



Discernability at 90% confidence from 100 to 300 µm²

## Italian vs. Wood-stained

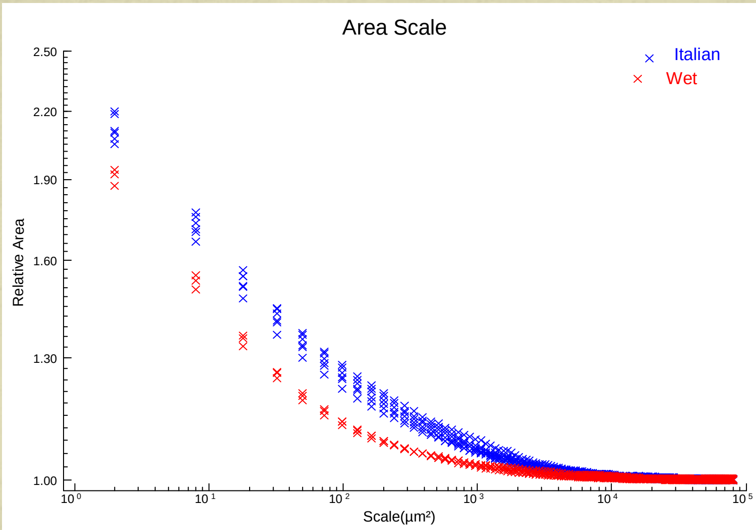



## Italian vs. Wood-stained

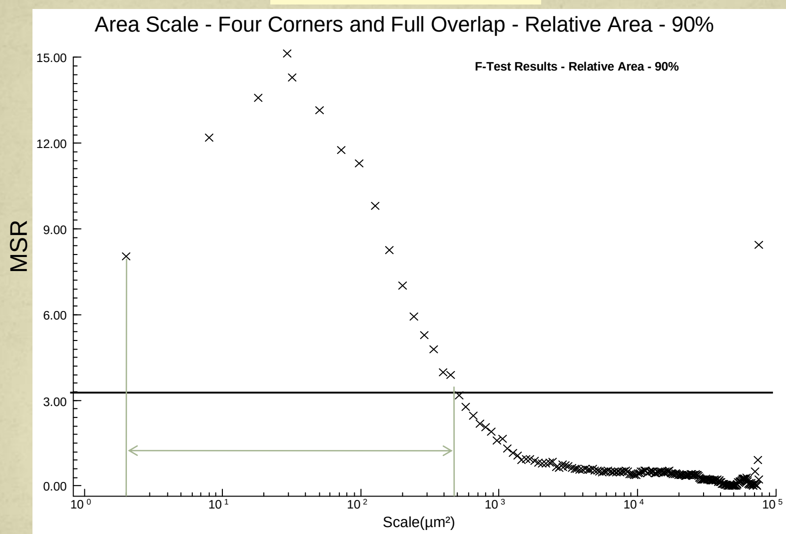



Discernability at 90% confidence from 2 to 1000 µm²

# Italian vs. Wet




# Italian vs. Wet

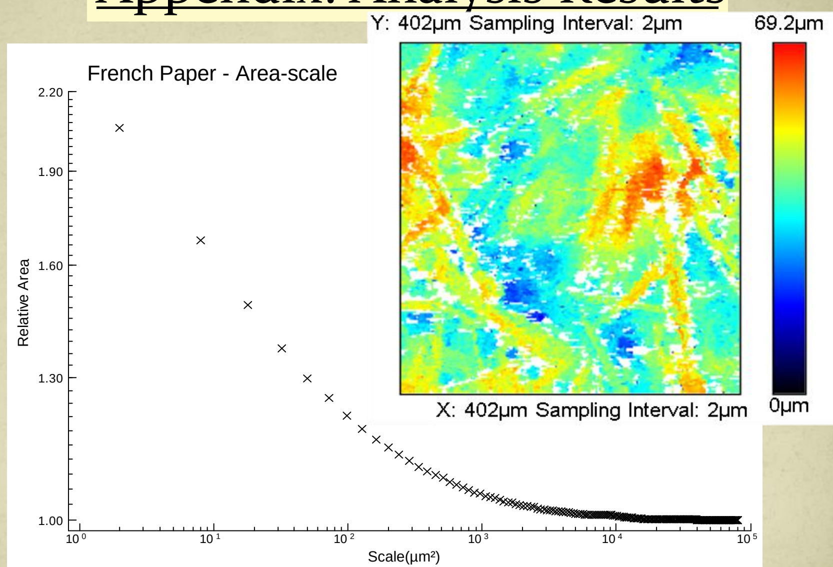


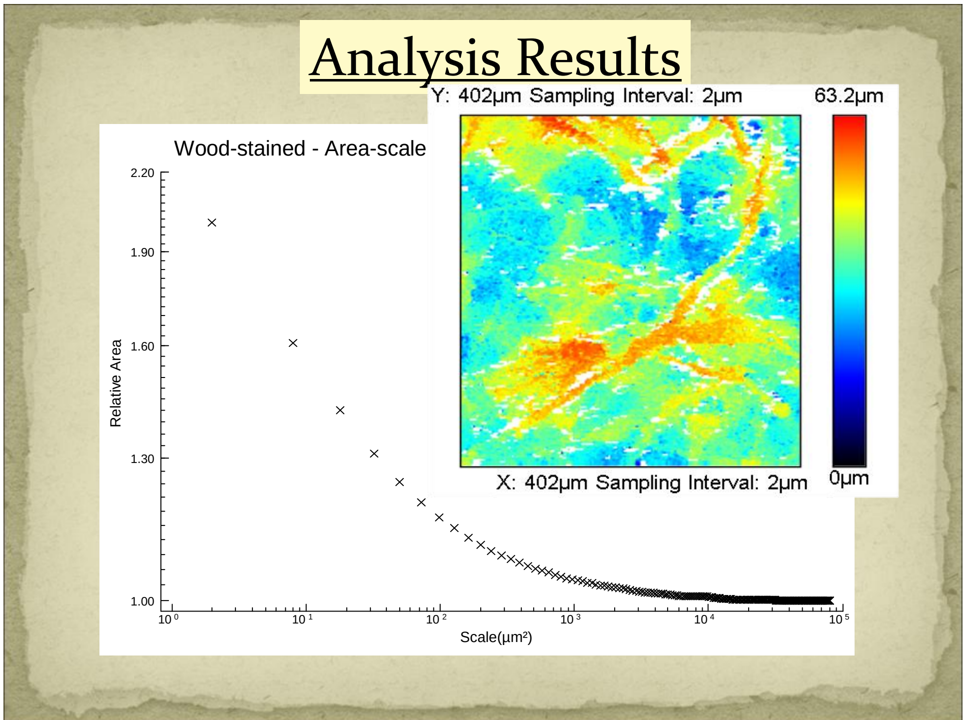

Discernability at 90% confidence from 2 to 500 µm²

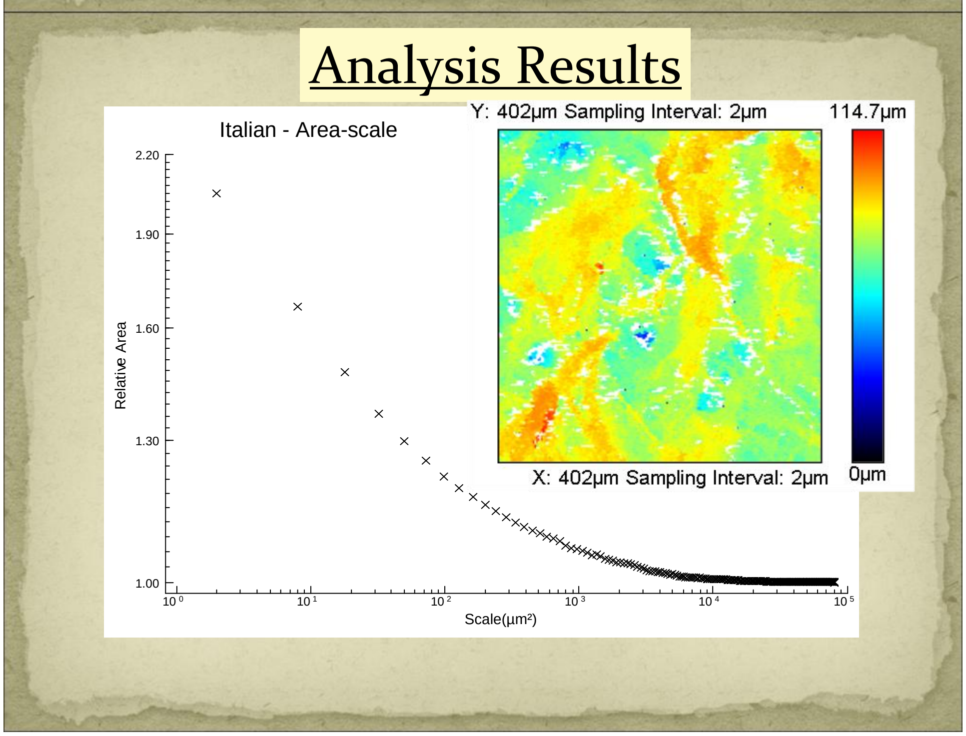
# Conclusion

- With a at least 90% confidence level, all the pairs of paper surfaces are statistically different over some range of scales.
- The scale range and maximum confidence depends on the papers being compared.

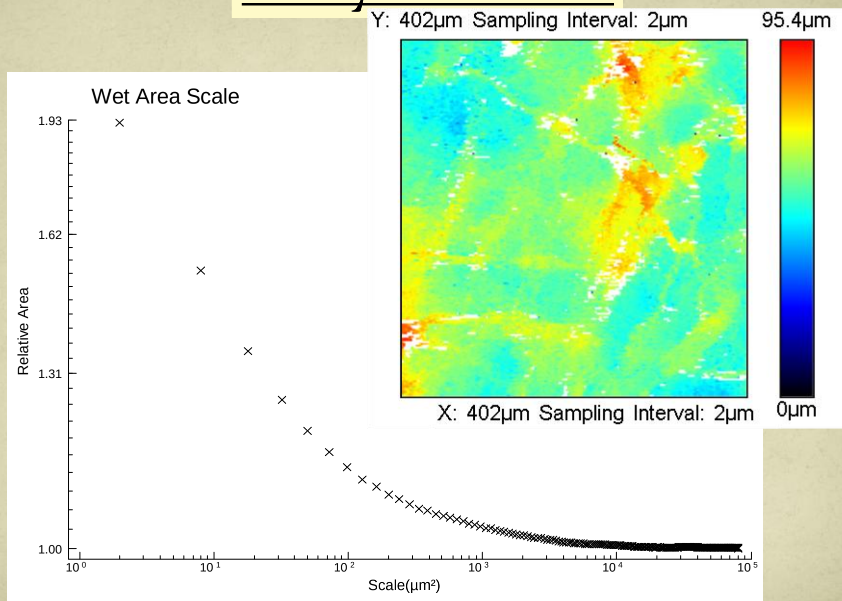
# Appendix: Analysis Results



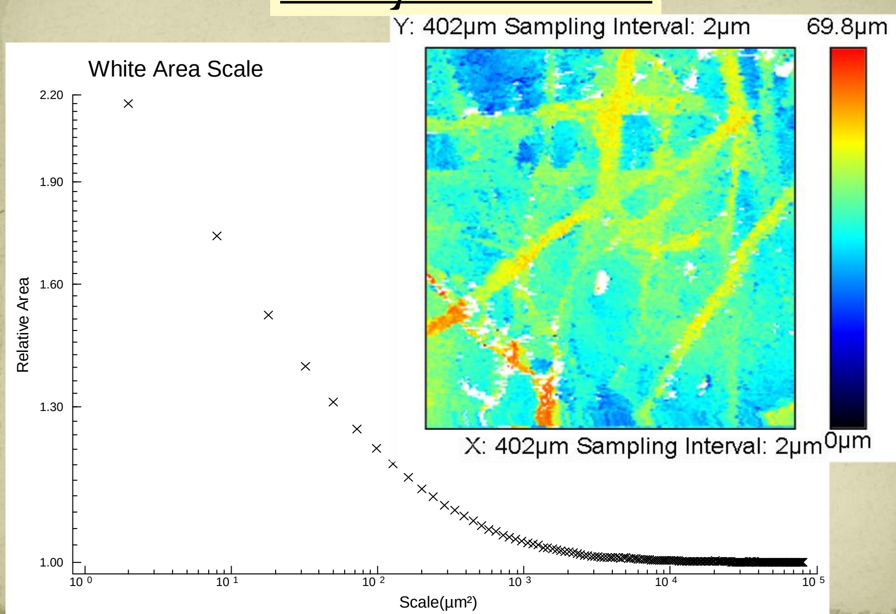

Analysis Results
Wood-stained - Area-scale
Relative Area
2.20
1.90
1.60
1.30
1.00
Scale(µm²)
Y: 402µm Sampling Interval: 2µm
63.2µm
X: 402µm Sampling Interval: 2µm
0µm


Analysis Results
Italian - Area-scale
Relative Area
2.20
1.90
1.60
1.30
1.00
Scale(µm²)
Y: 402µm Sampling Interval: 2µm
114.7µm
X: 402µm Sampling Interval: 2µm
0µm

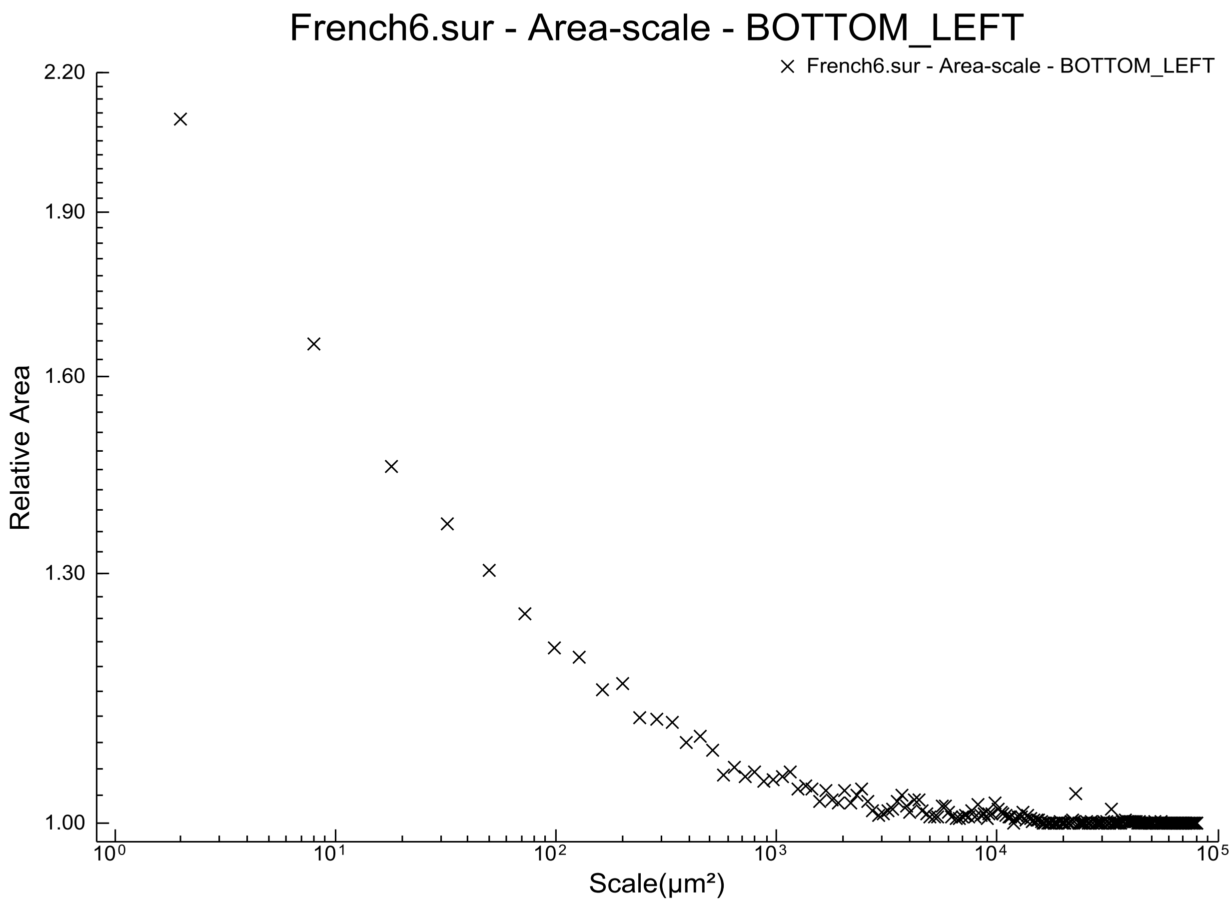
## Analysis Results

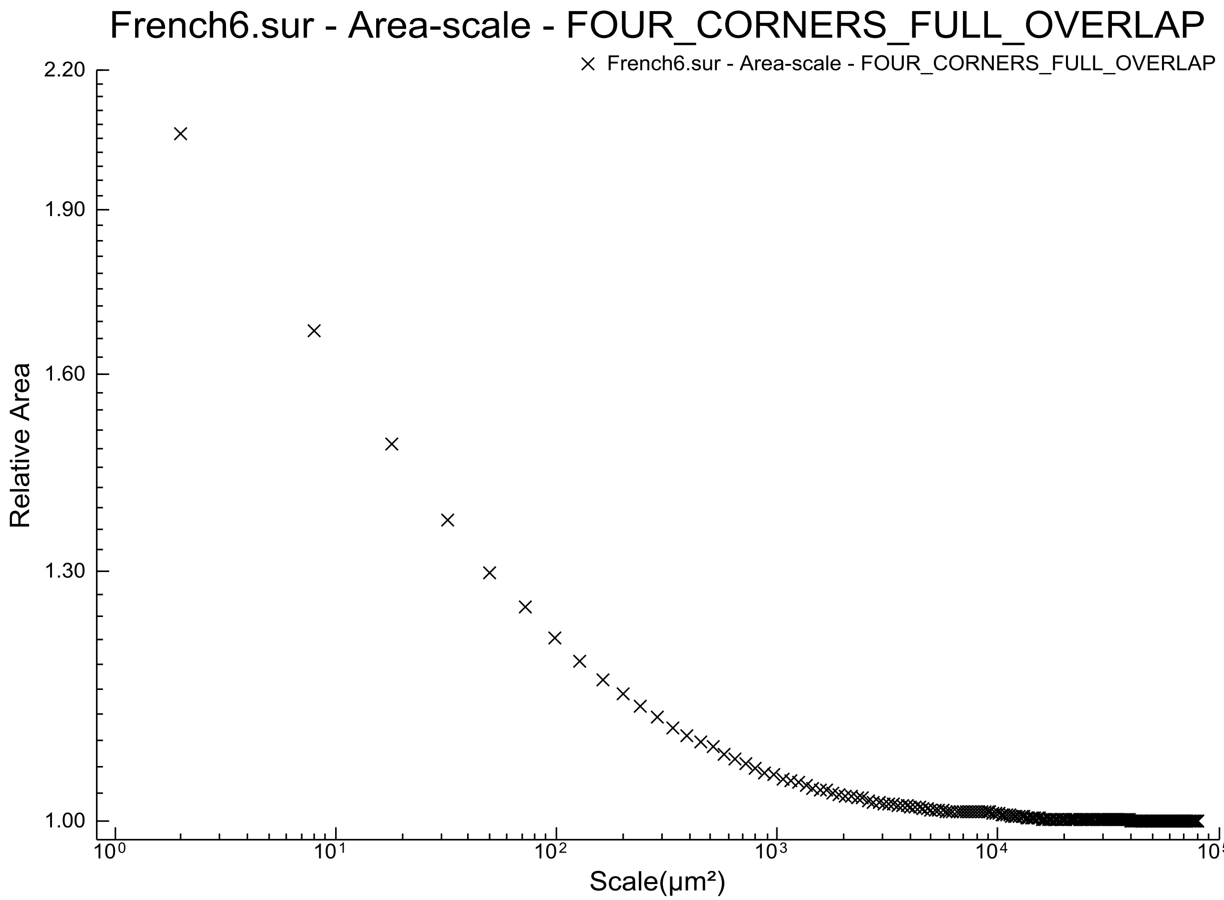


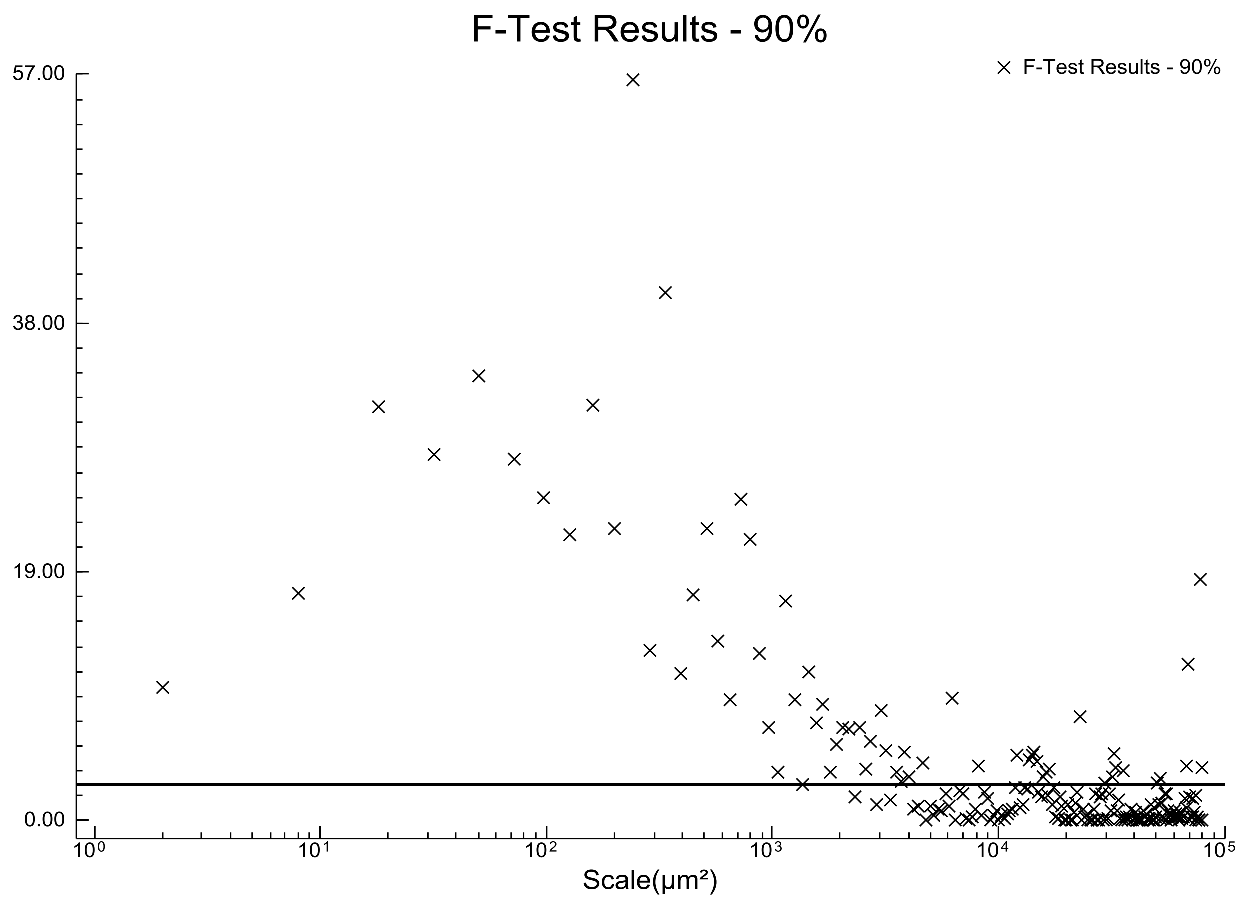

## Analysis Results

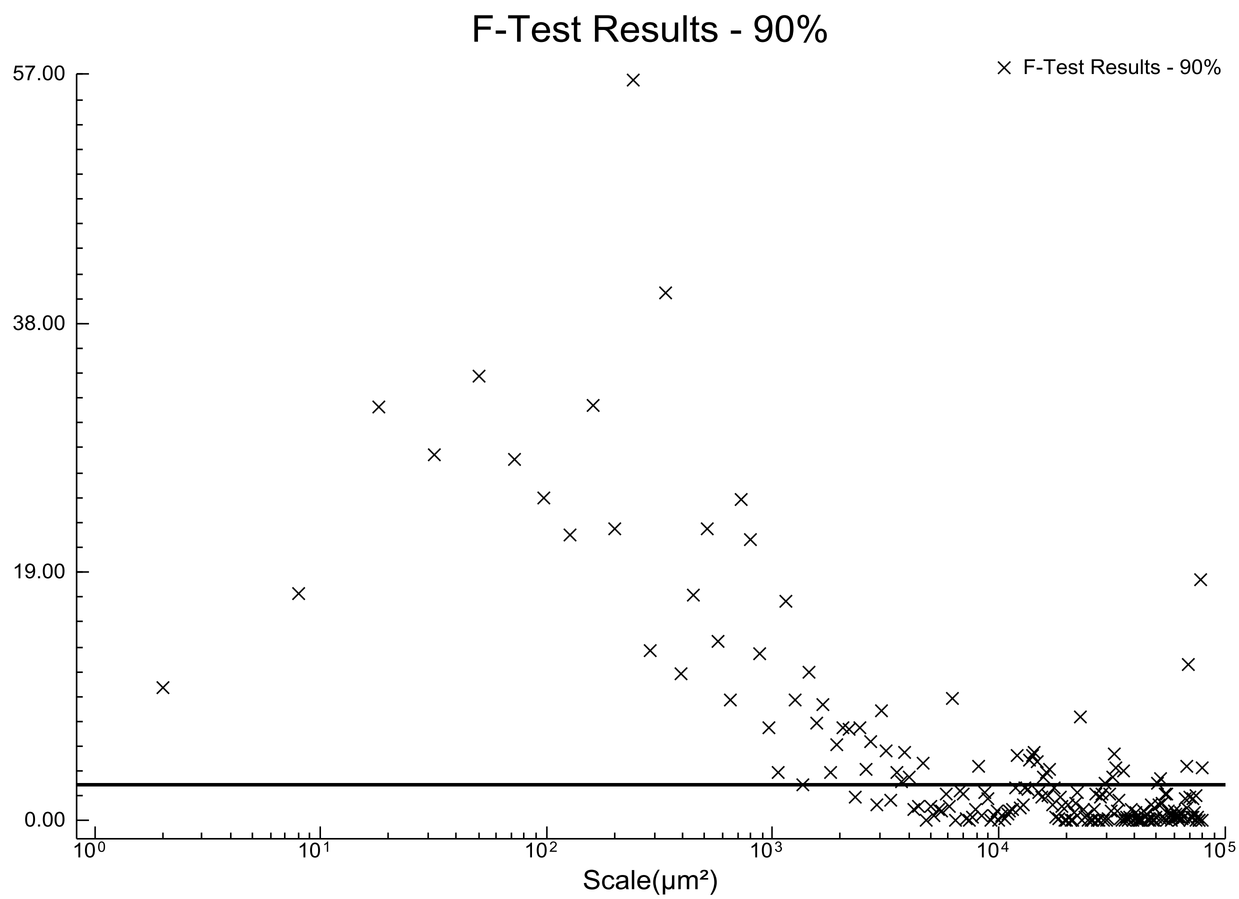


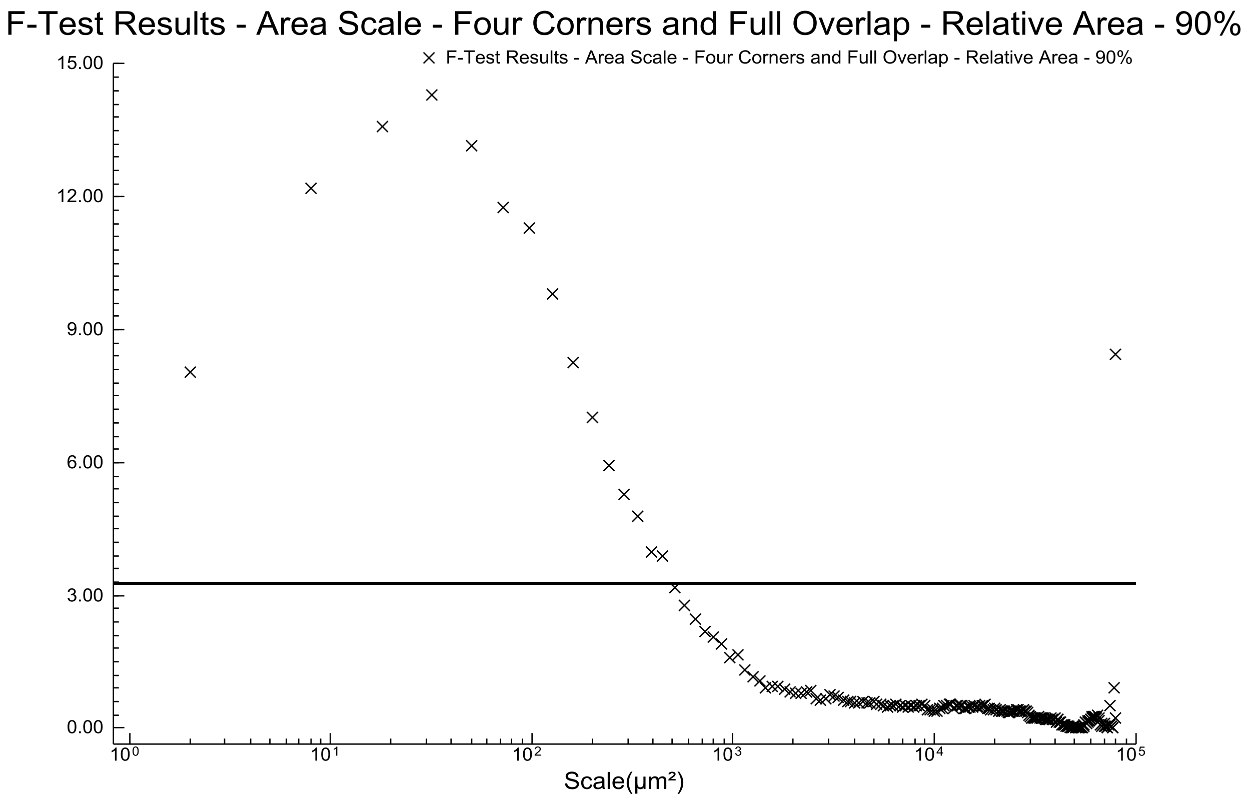
## *Appendix B: SFRAX Analysis*

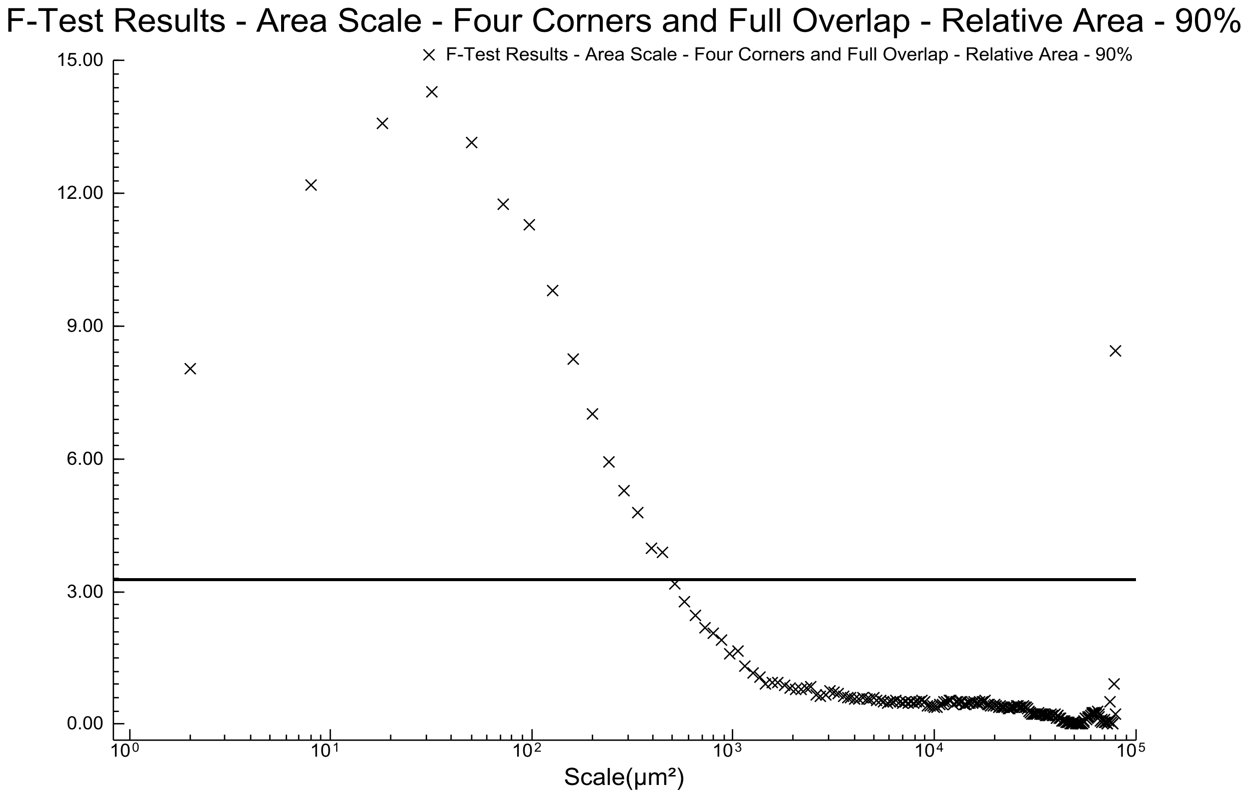


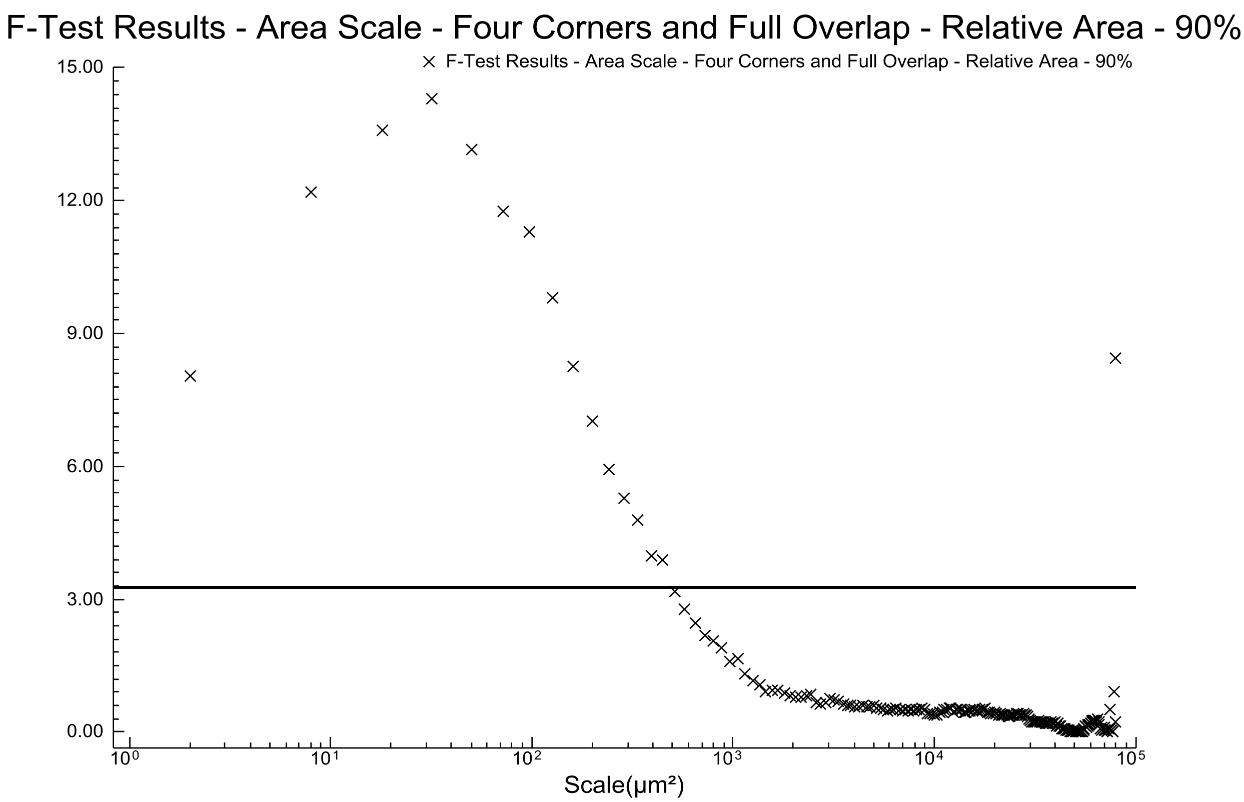

French6.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
French6.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
Relative Area
2.20
1.90
1.60
1.30
1.00
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(μm²)

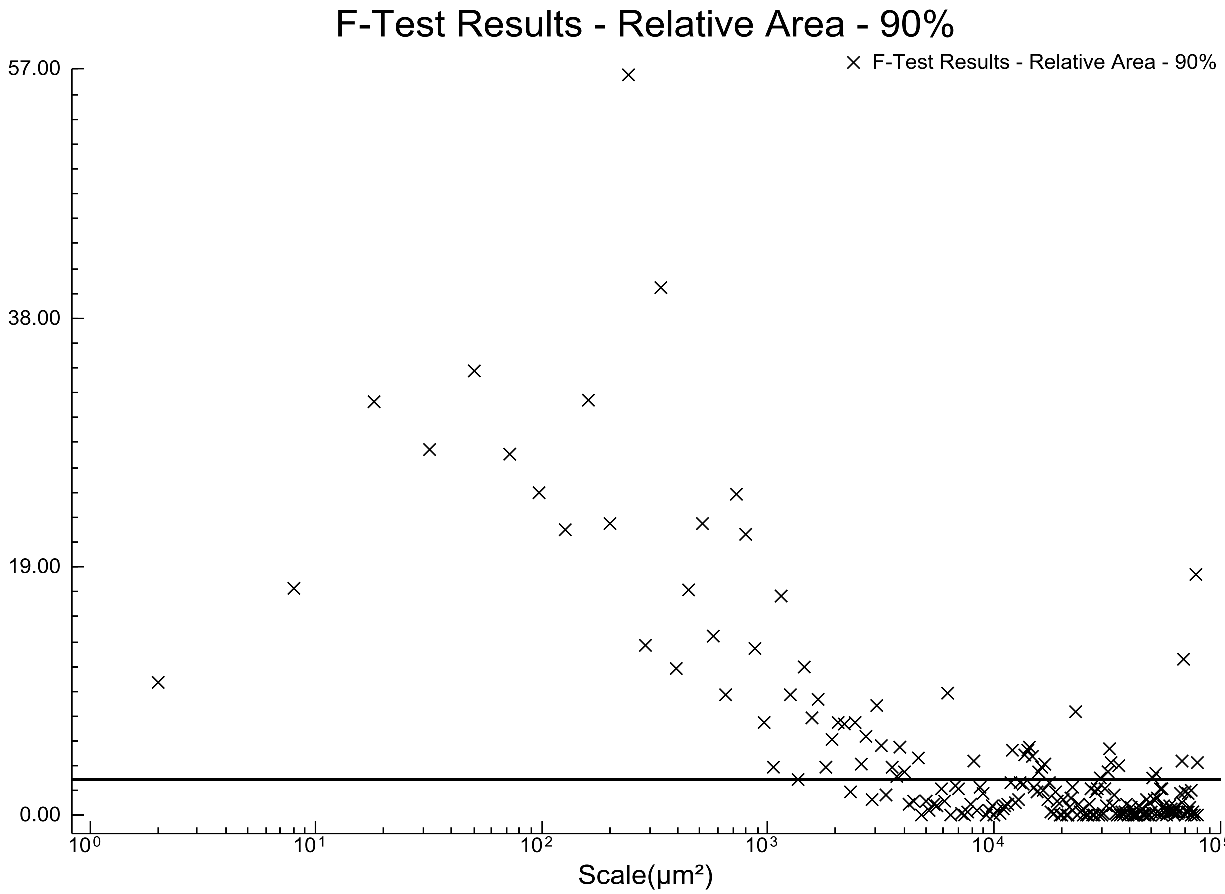

F-Test Results - 90%
F-Test Results - 90%
57.00
38.00
19.00
0.00
10⁰
10¹
10²
10³
10⁴
10⁵
Scale(µm²)

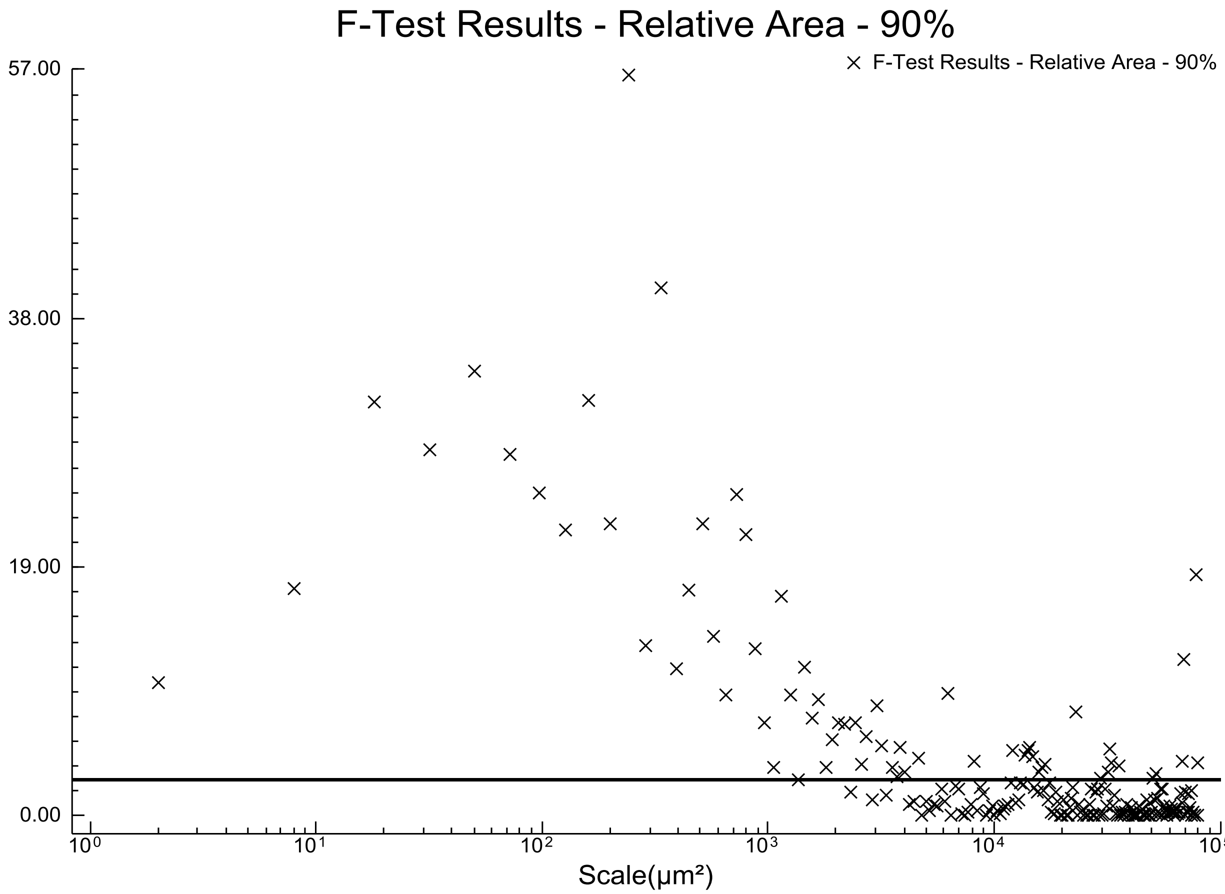

F-Test Results - 90%
F-Test Results - 90%
57.00
38.00
19.00
0.00
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(μm²)

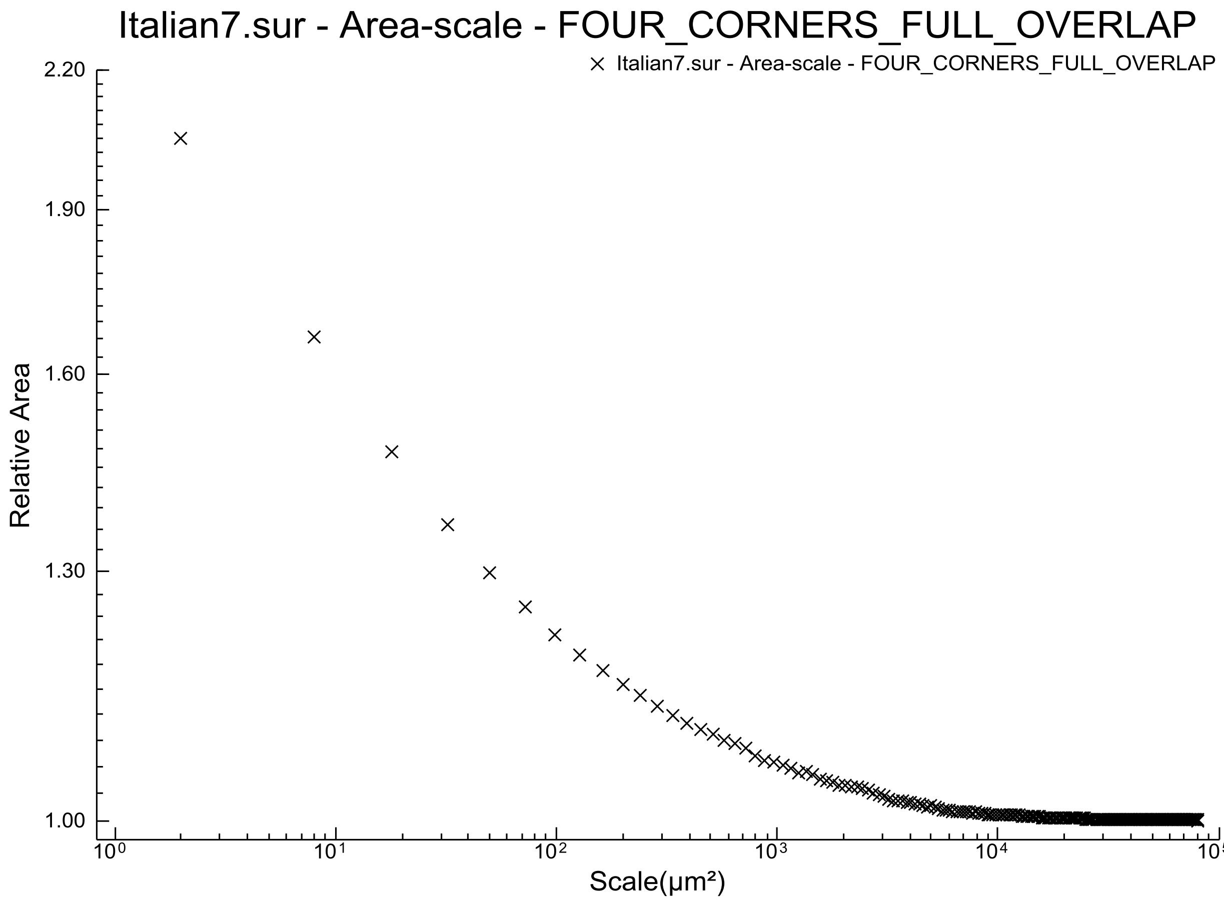

F-Test Results - Area Scale - Four Corners and Full Overlap - Relative Area - 90%
F-Test Results - Area Scale - Four Corners and Full Overlap - Relative Area - 90%
15.00
12.00
9.00
6.00
3.00
0.00
10⁰
10¹
10²
10³
10⁴
10⁵
Scale(μm²)

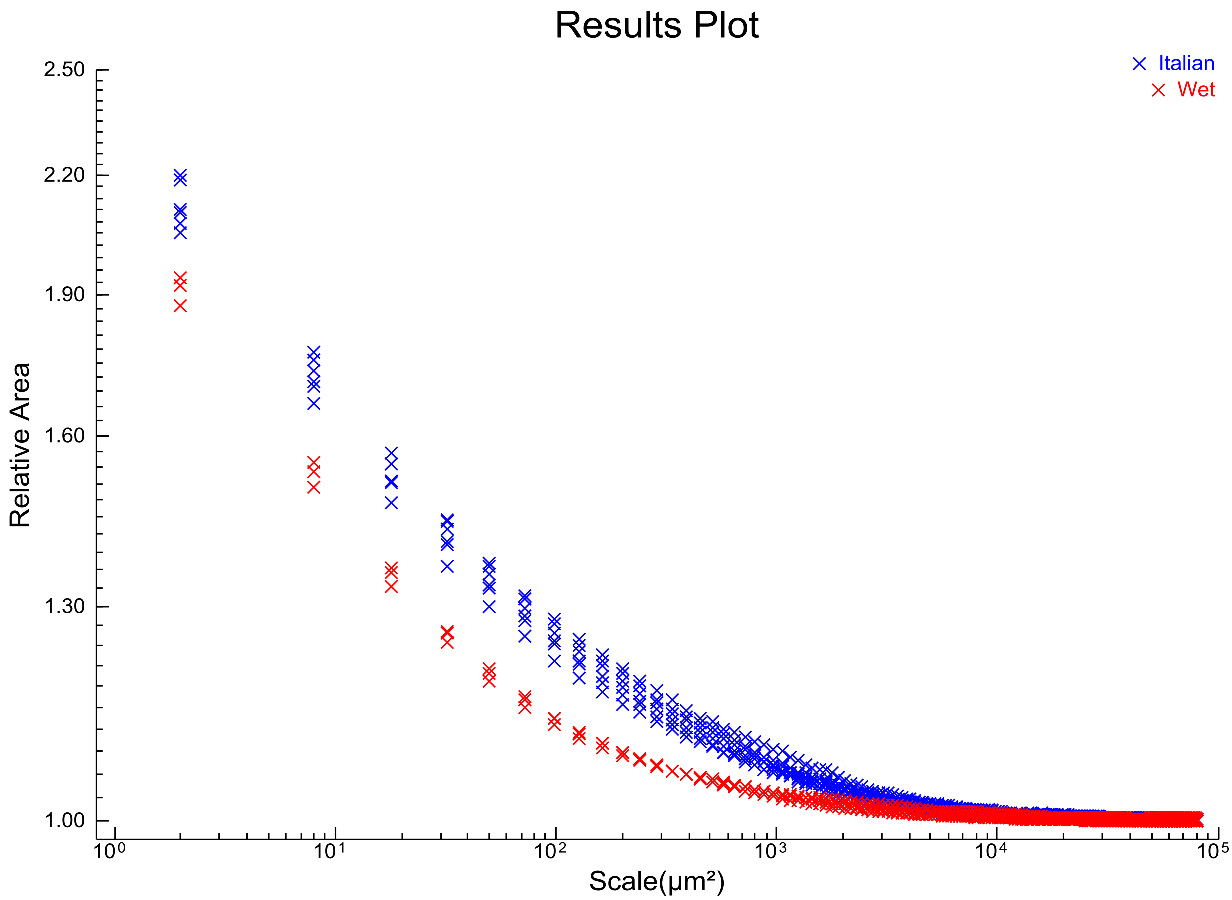

F-Test Results - Area Scale - Four Corners and Full Overlap - Relative Area - 90%
F-Test Results - Area Scale - Four Corners and Full Overlap - Relative Area - 90%
15.00
12.00
9.00
6.00
3.00
0.00
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(μm²)

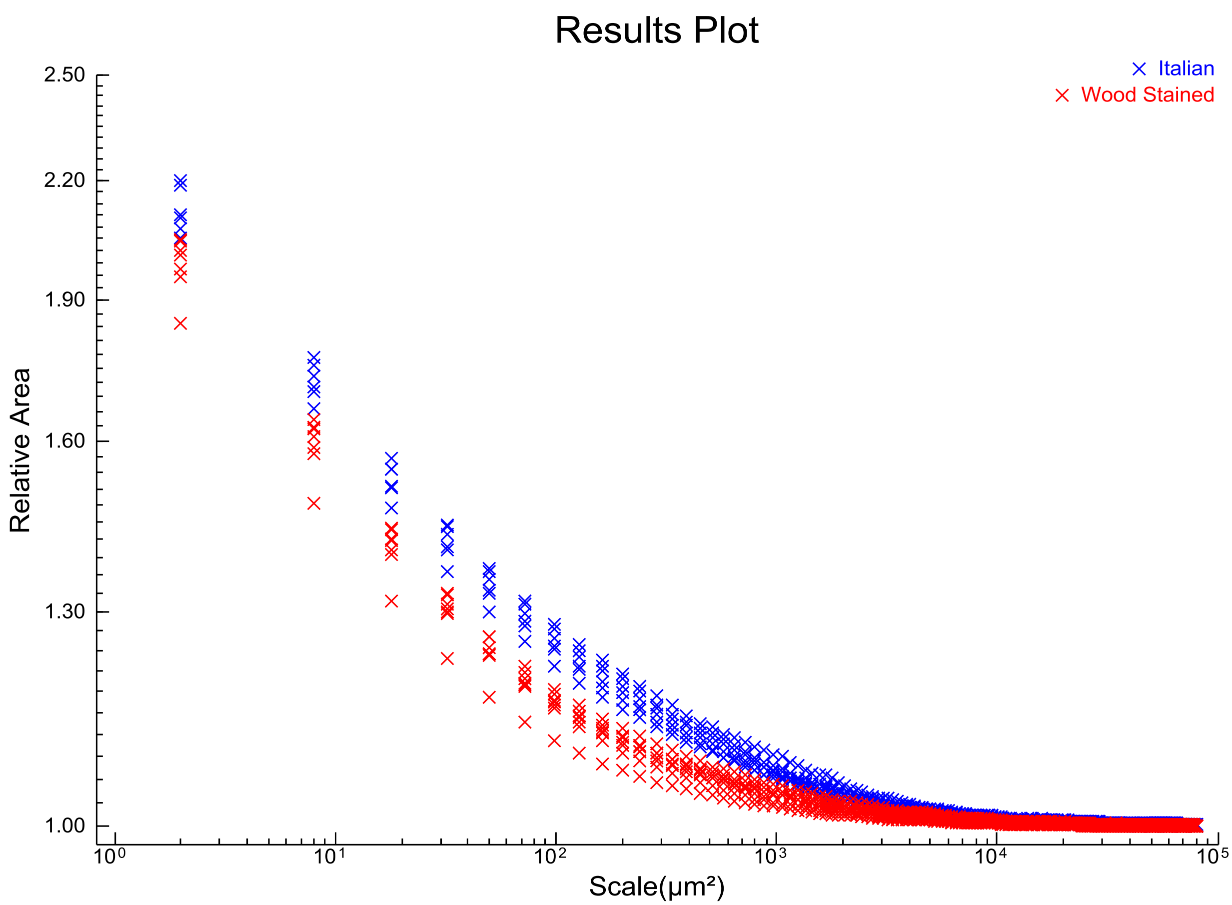

F-Test Results - Area Scale - Four Corners and Full Overlap - Relative Area - 90%
F-Test Results - Area Scale - Four Corners and Full Overlap - Relative Area - 90%
15.00
12.00
9.00
6.00
3.00
0.00
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(μm²)

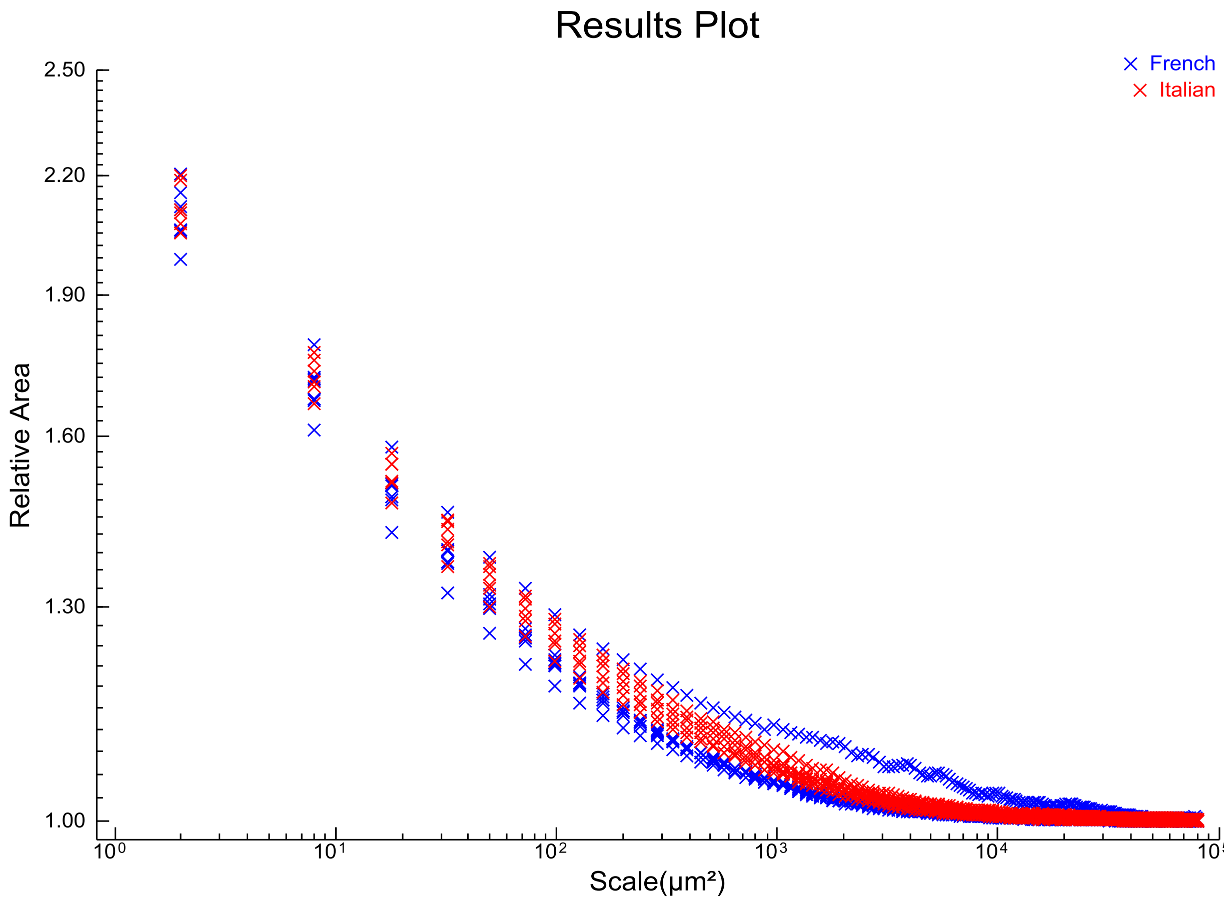

F-Test Results - Relative Area - 90%
F-Test Results - Relative Area - 90%
57.00
38.00
19.00
0.00
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(μm²)

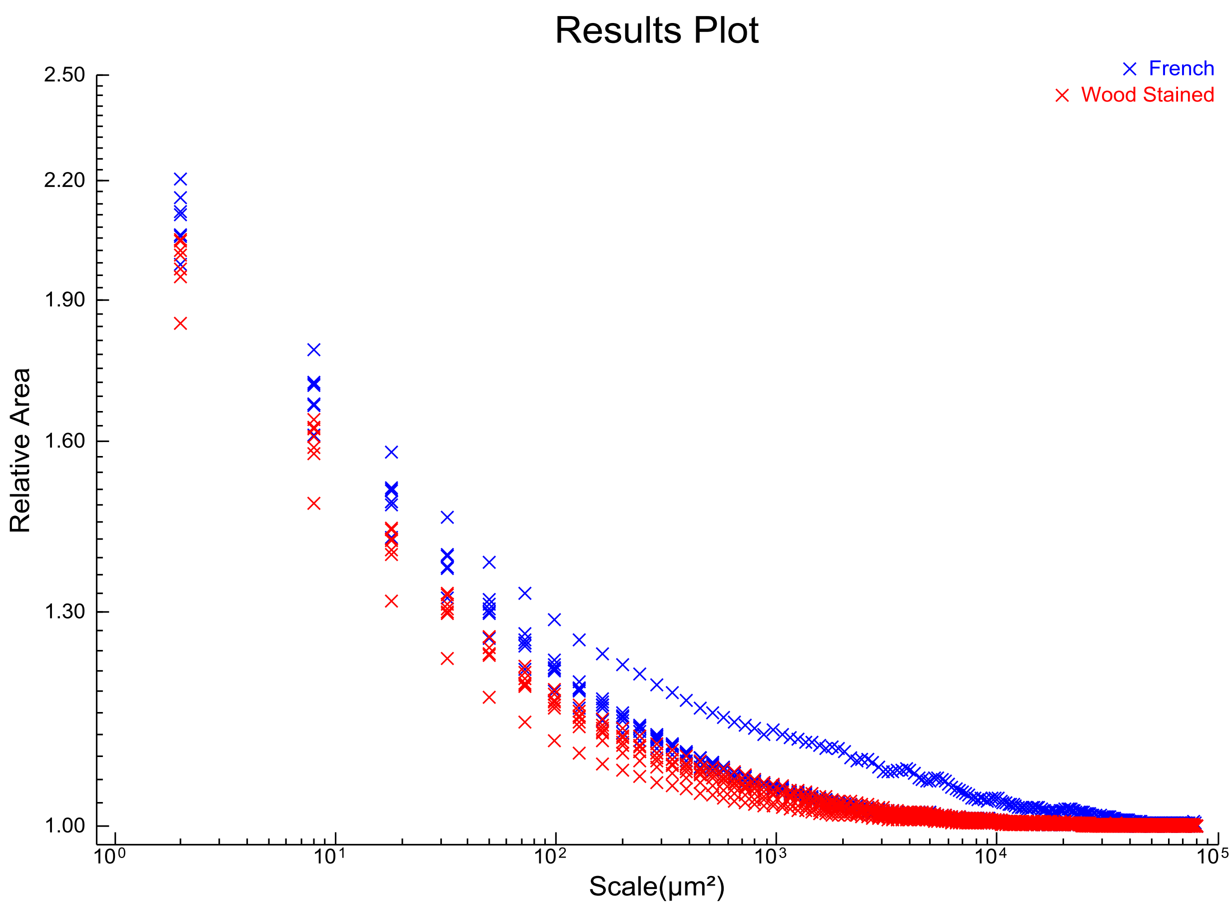

F-Test Results - Relative Area - 90%
F-Test Results - Relative Area - 90%
57.00
38.00
19.00
0.00
10⁰
10¹
10²
10³
10⁴
10⁵
Scale(µm²)


Italian7.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
Italian7.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
Relative Area
2.20
1.90
1.60
1.30
1.00
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(µm²)

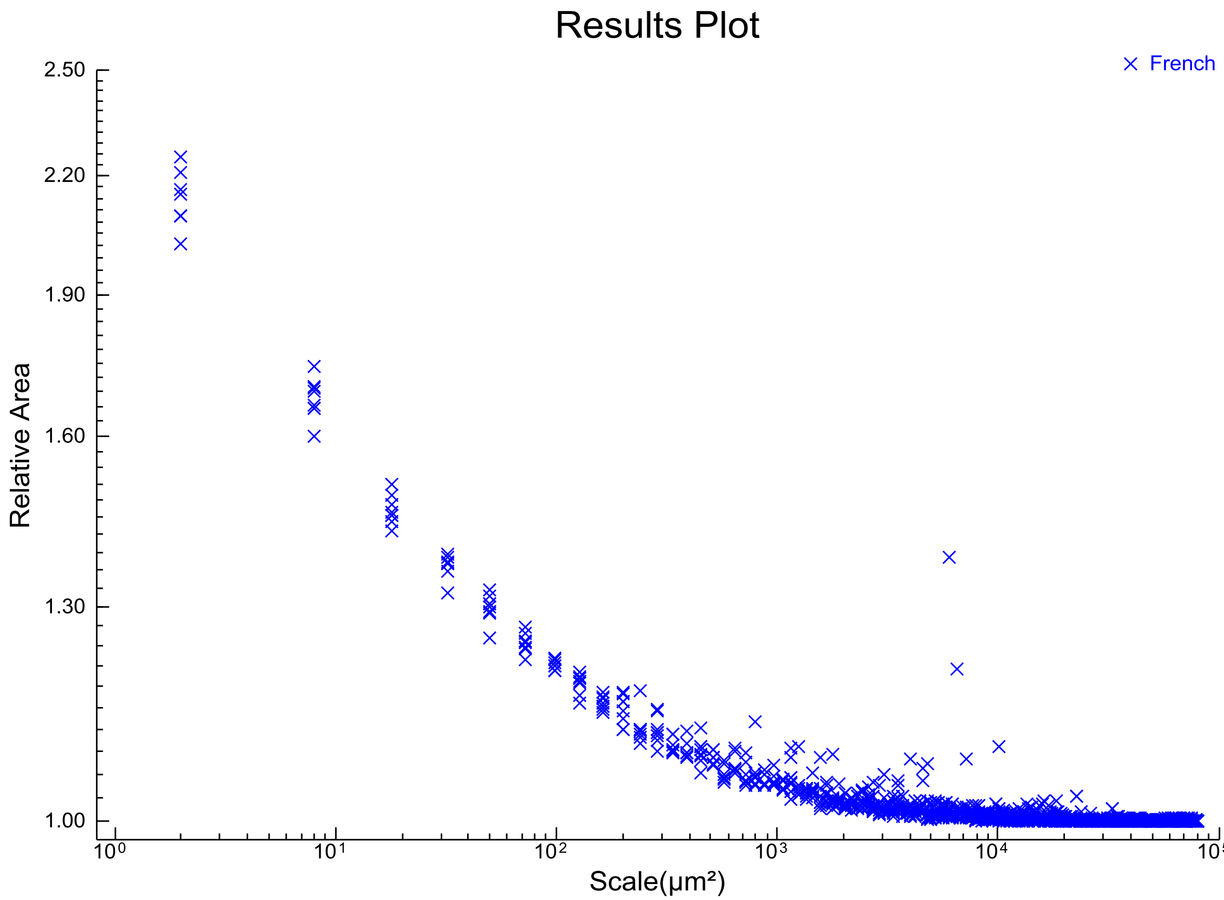

Results Plot
Italian
Wet
Relative Area
2.50
2.20
1.90
1.60
1.30
1.00
Scale(μm²)
10⁰
10¹
10²
10³
10⁴
10⁵

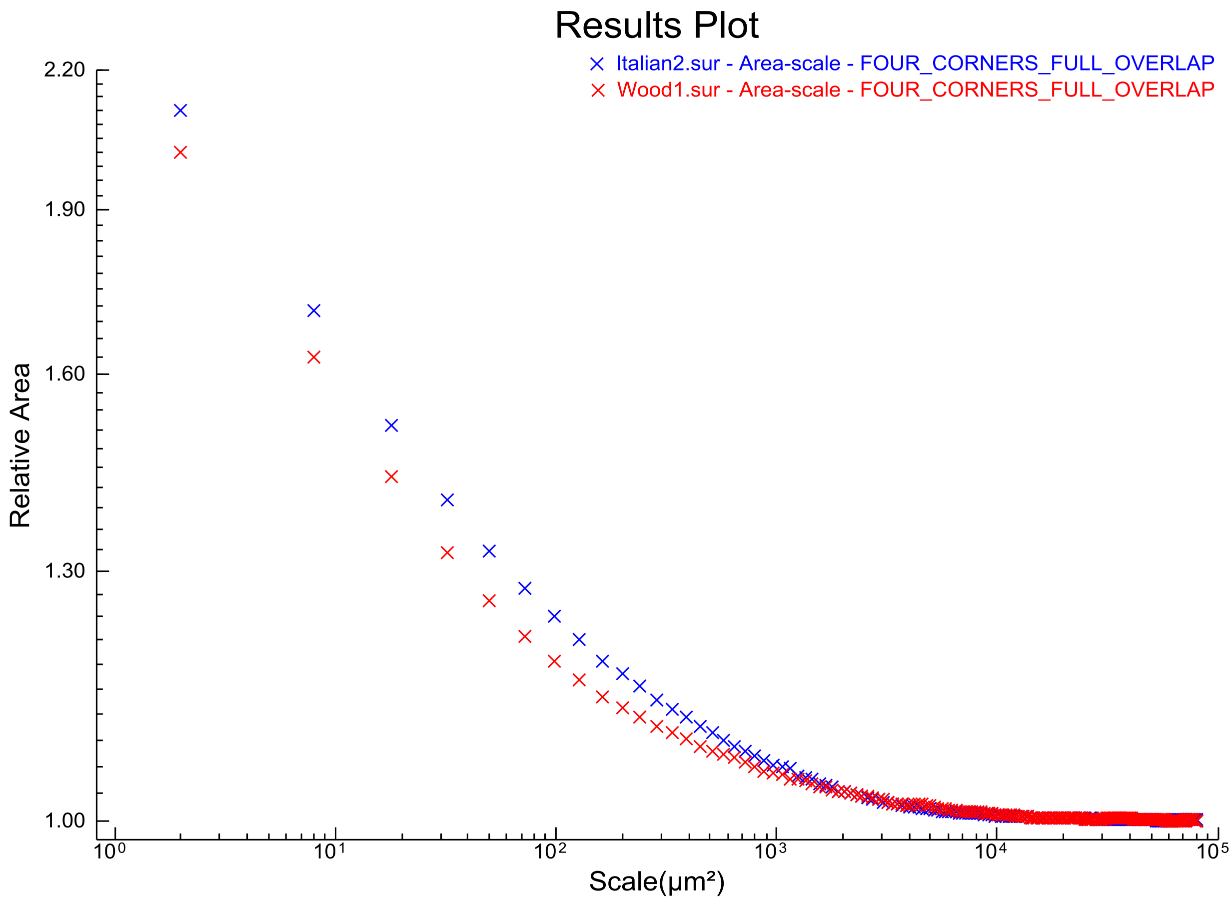

Results Plot
Italian
Wood Stained
Relative Area
Scale(μm²)
2.50
2.20
1.90
1.60
1.30
1.00
10⁰
10¹
10²
10³
10⁴
10⁵

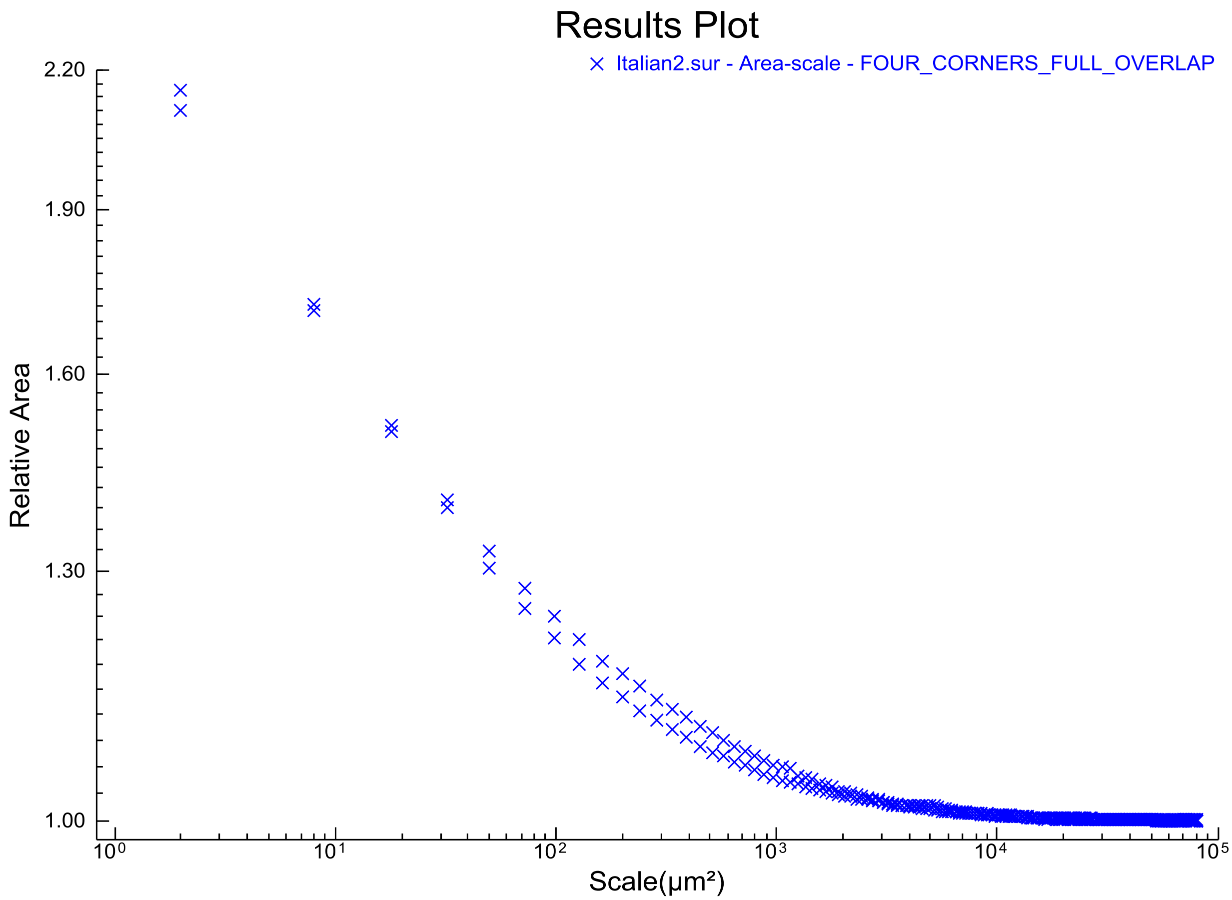

Results Plot
French
Italian
Relative Area
Scale(μm²)
2.50
2.20
1.90
1.60
1.30
1.00
10⁰
10¹
10²
10³
10⁴
10⁵



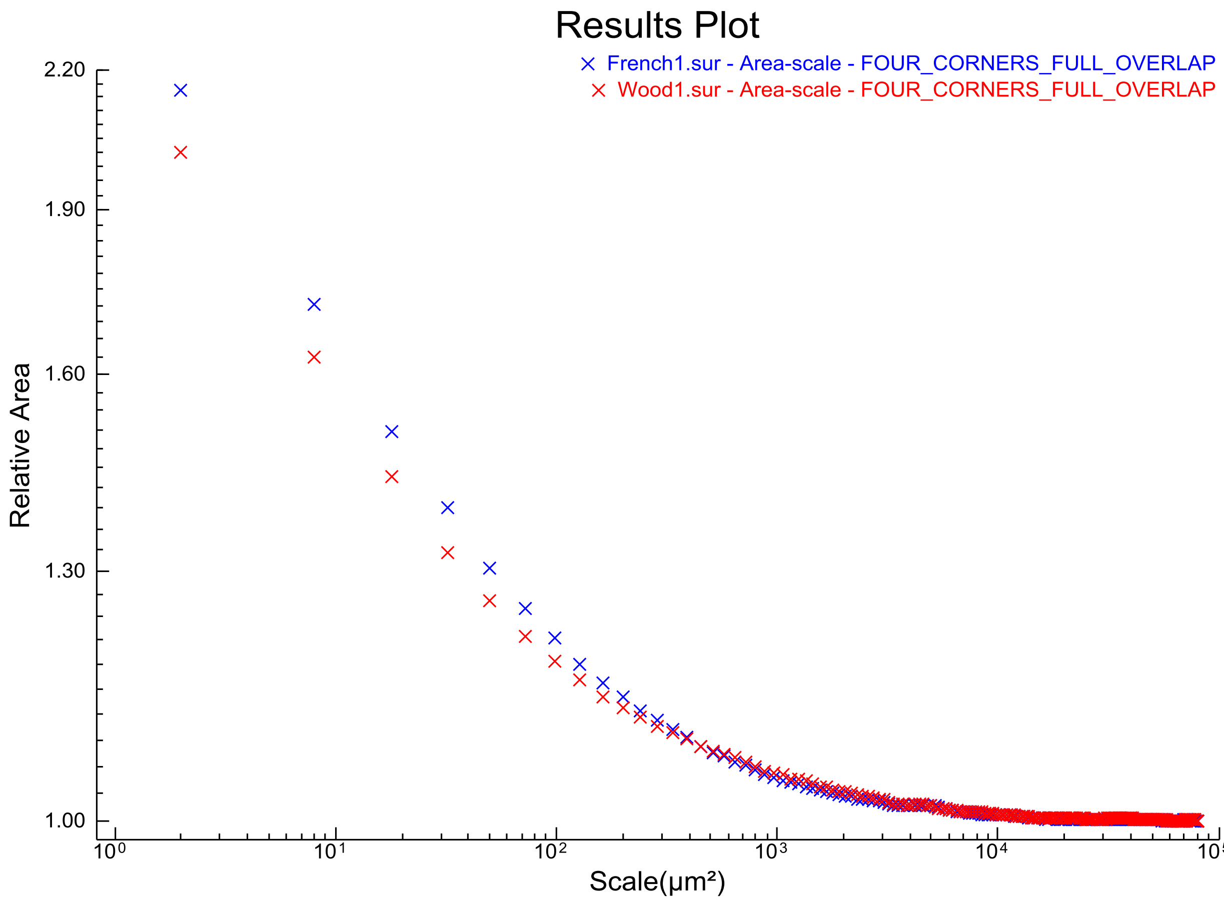
Results Plot
French
Wood Stained
2.50
2.20
1.90
1.60
1.30
1.00
Relative Area
10⁰
10¹
10²
10³
10⁴
10⁵
Scale(μm²)


Results Plot
French
2.50
2.20
1.90
1.60
1.30
1.00
Relative Area
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(µm²)

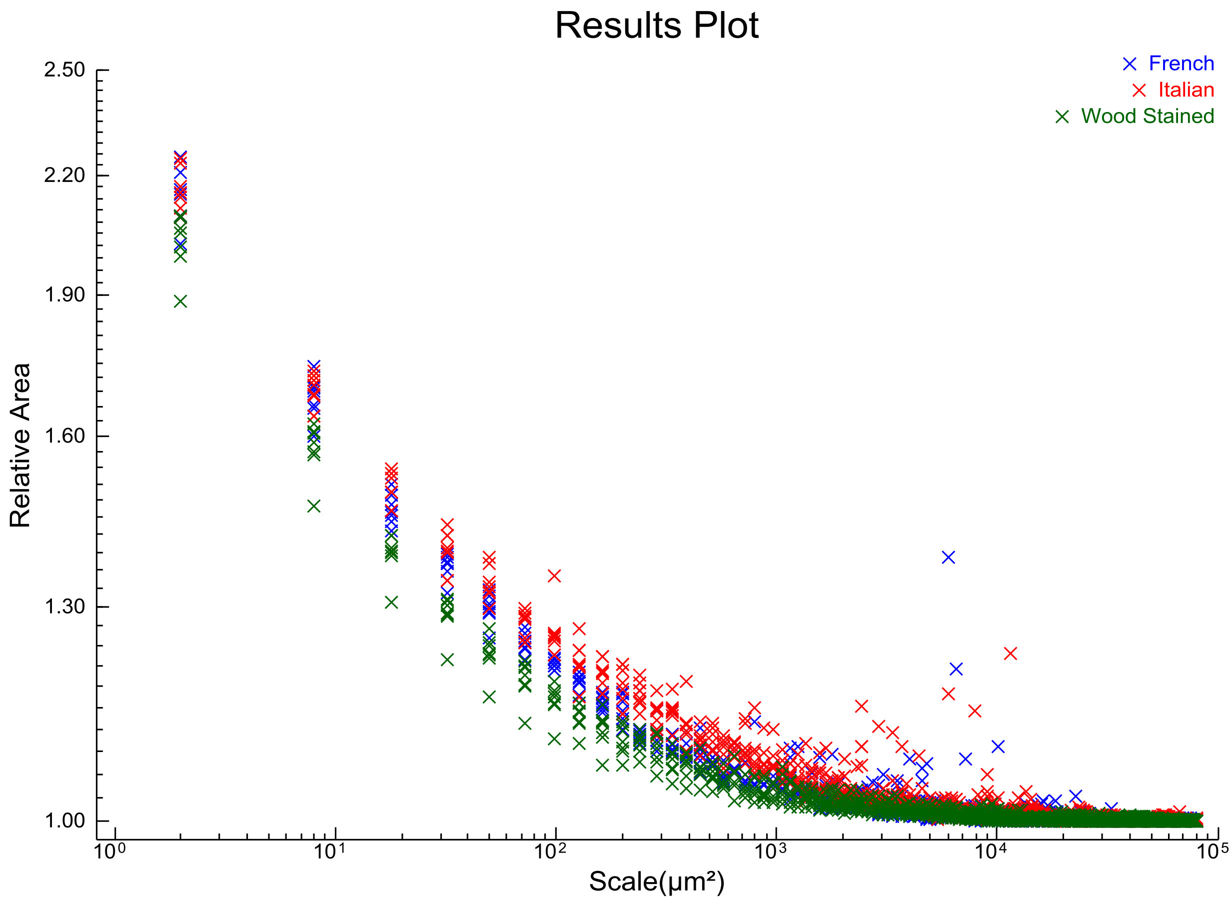

Results Plot
Italian2.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
Wood1.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
Relative Area
2.20
1.90
1.60
1.30
1.00
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(μm²)

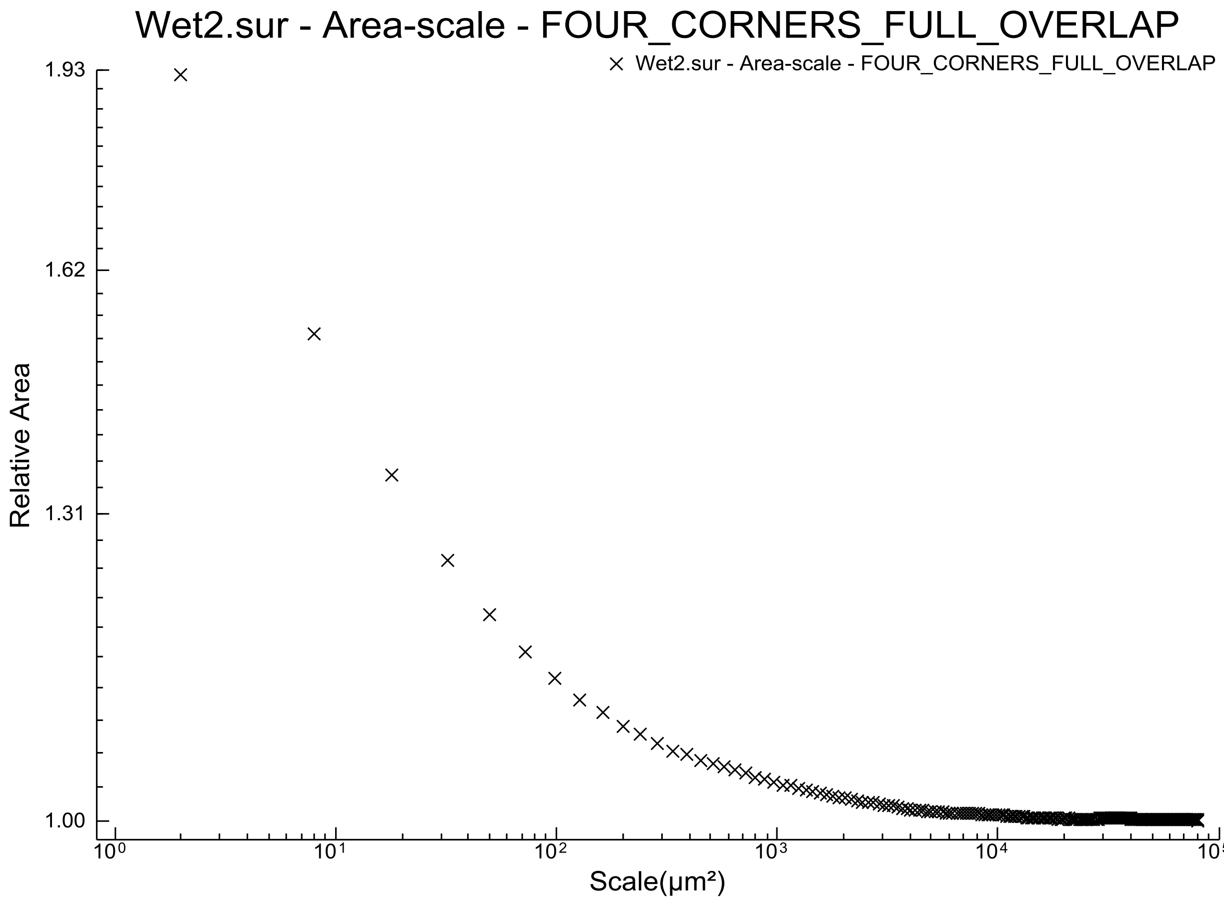


Results Plot
Italian2.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
2.20
1.90
1.60
1.30
1.00
Relative Area
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(μm²)

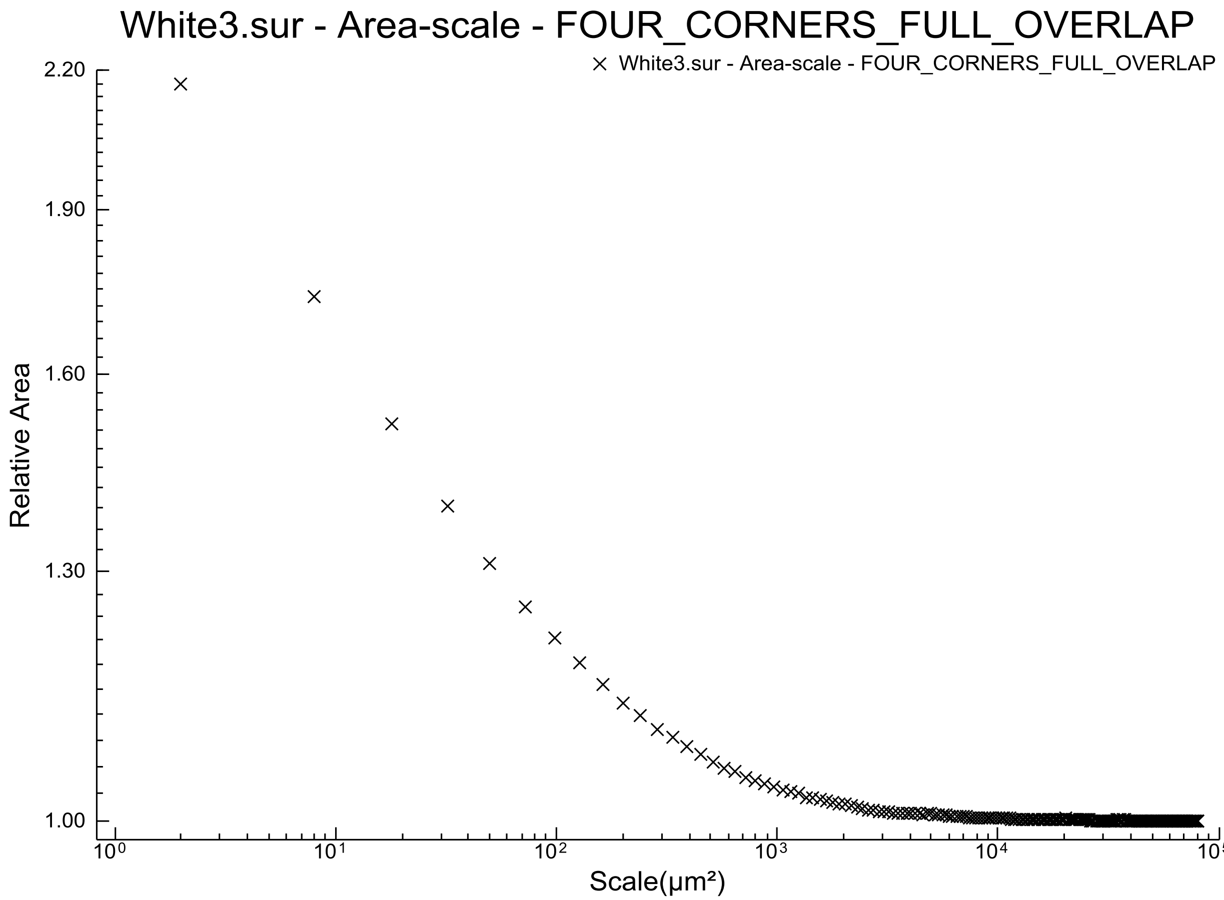


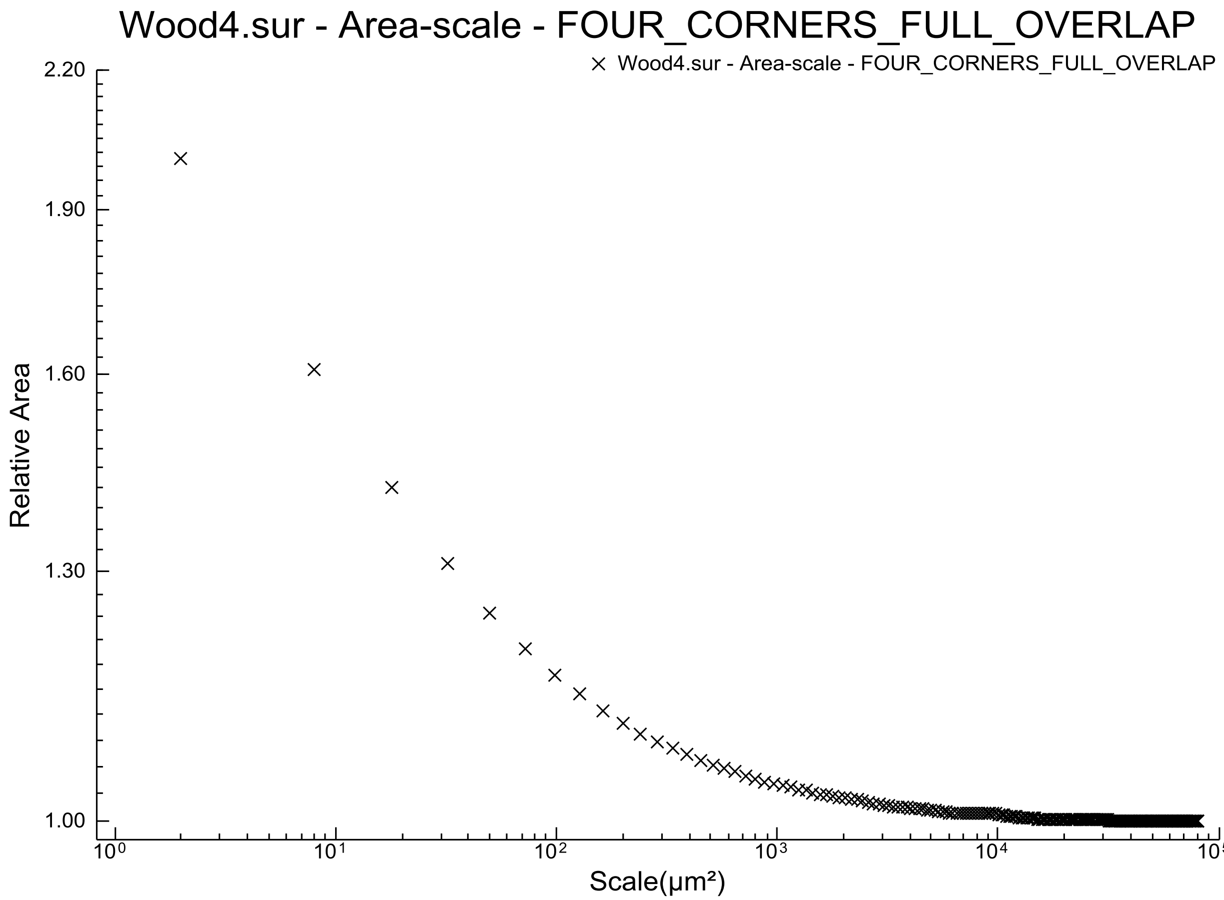
Results Plot
French1.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
Wood1.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
2.20
1.90
1.60
1.30
1.00
Relative Area
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(µm²)


Results Plot
French
Italian
Wood Stained
Relative Area
2.50
2.20
1.90
1.60
1.30
1.00
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(μm²)

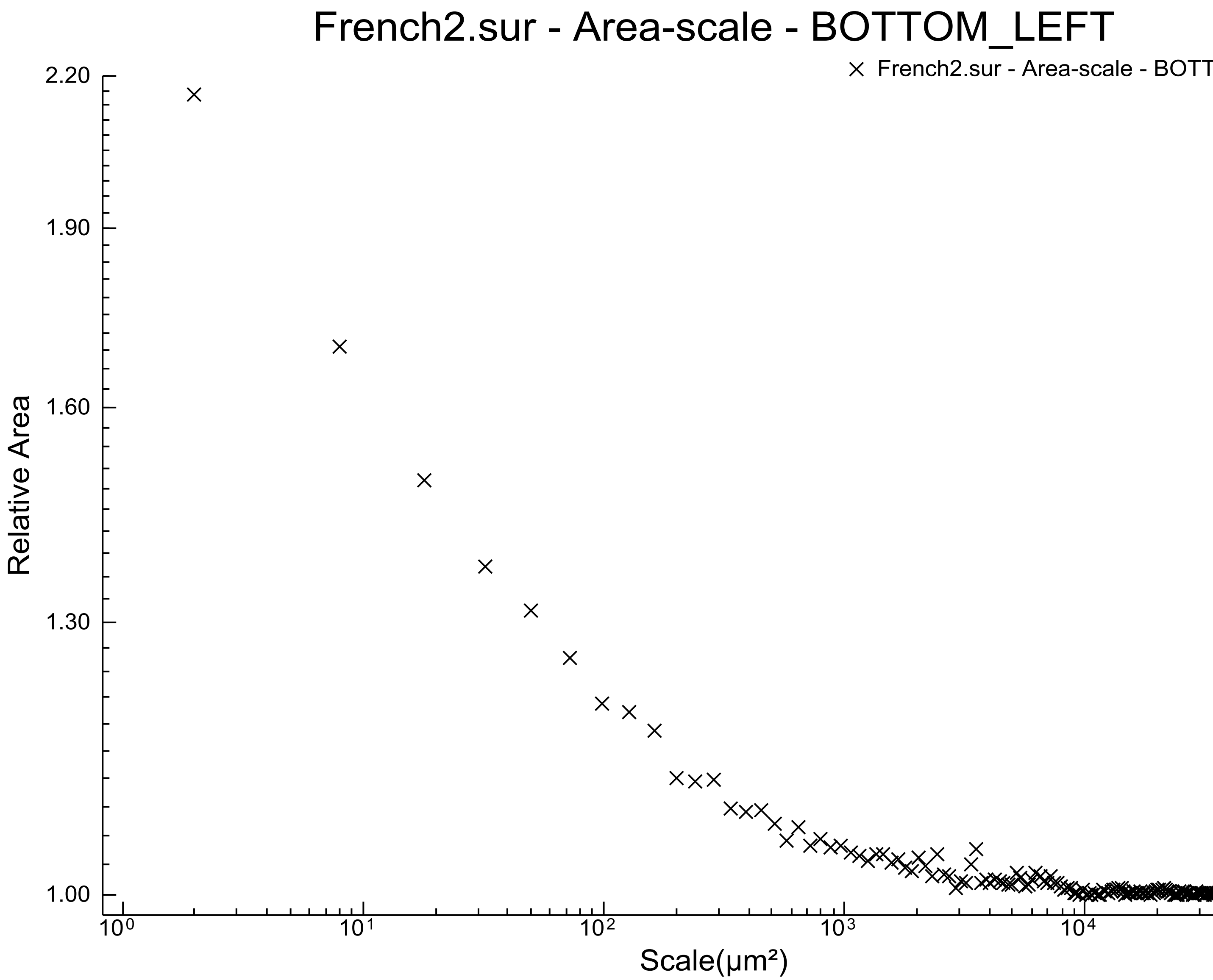


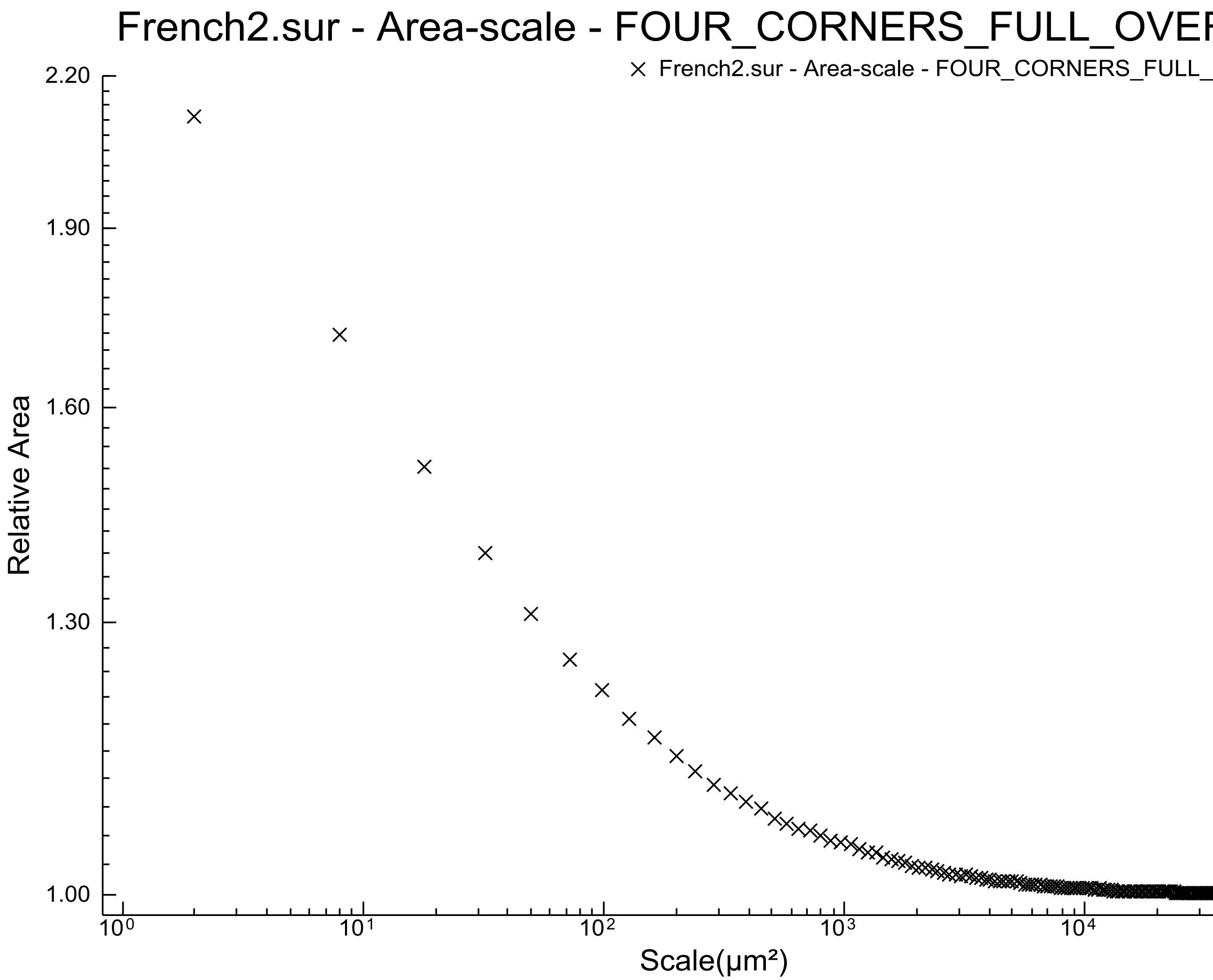
Wet2.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
Wet2.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
1.93
1.62
1.31
1.00
Relative Area
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Scale(µm²)

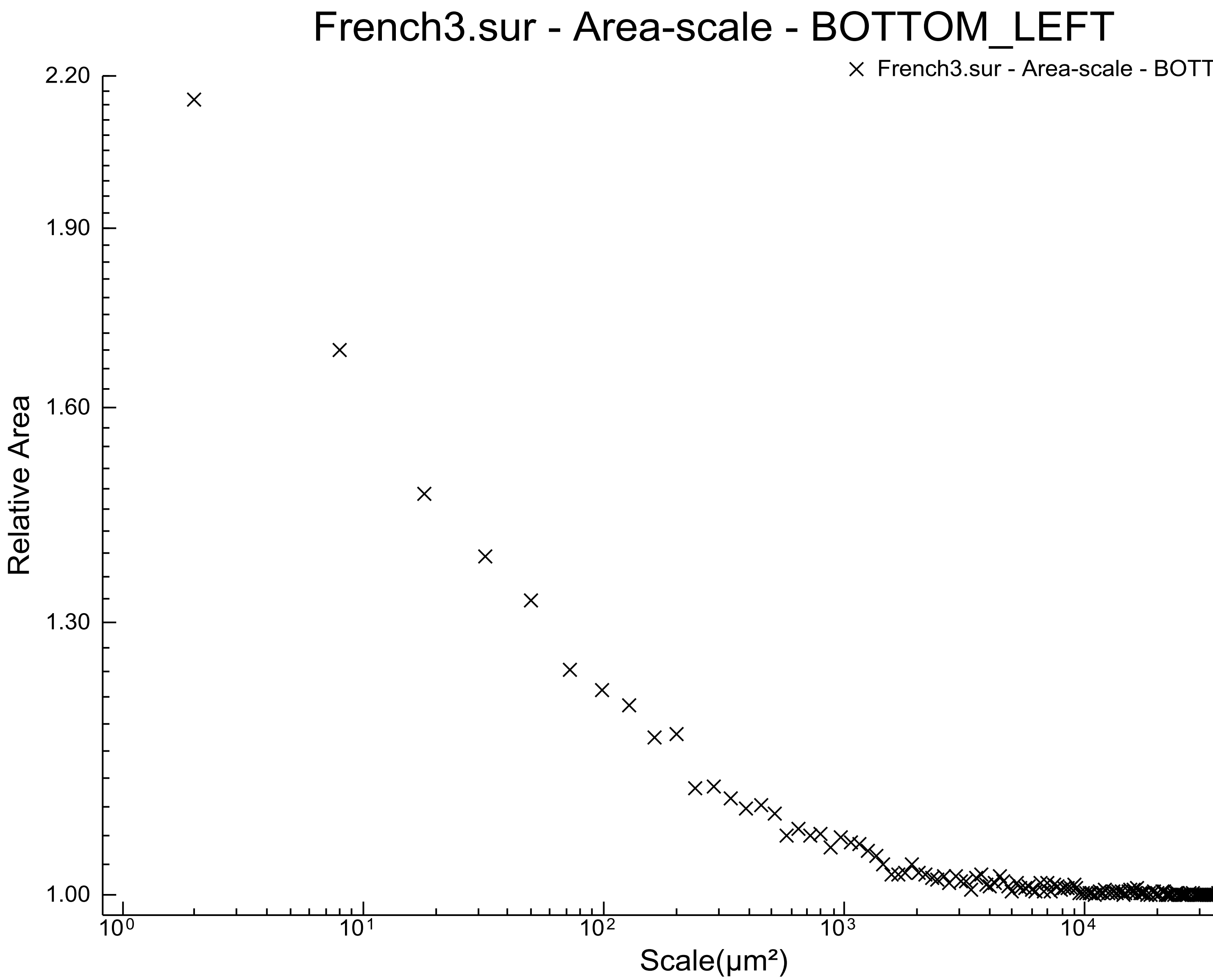

White3.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
White3.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
2.20
1.90
1.60
1.30
1.00
Relative Area
10⁰
10¹
10²
10³
10⁴
10⁵
Scale(µm²)



Wood4.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
× Wood4.sur - Area-scale - FOUR_CORNERS_FULL_OVERLAP
Relative Area
2.20
1.90
1.60
1.30
1.00
Scale(μm²)
10⁰
10¹
10²
10³
10⁴
10⁵

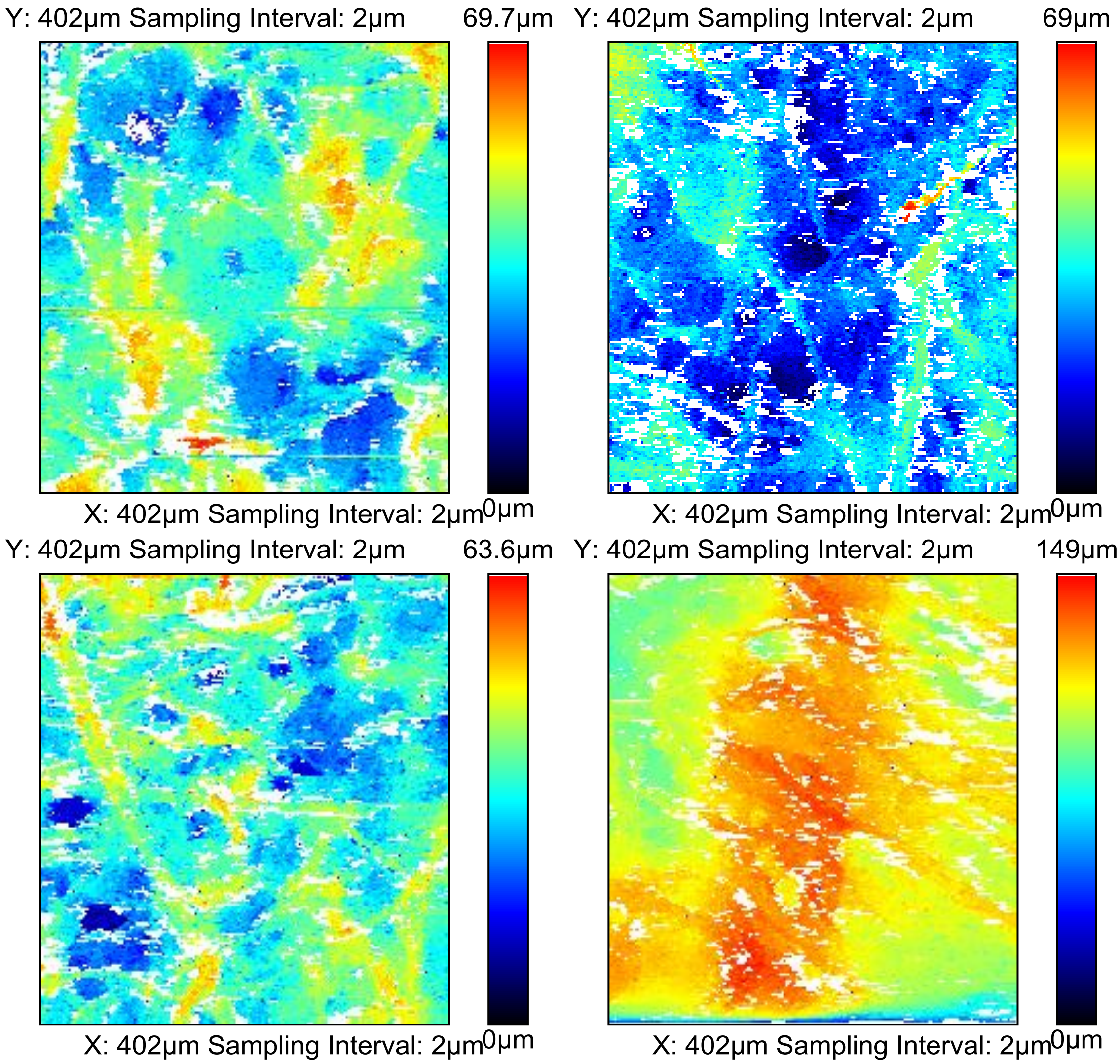

French2.sur - Area-scale - BOTTOM_LEFT
French2.sur - Area-scale - BOTT
2.20
1.90
1.60
1.30
1.00
Relative Area
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
Scale(µm²)

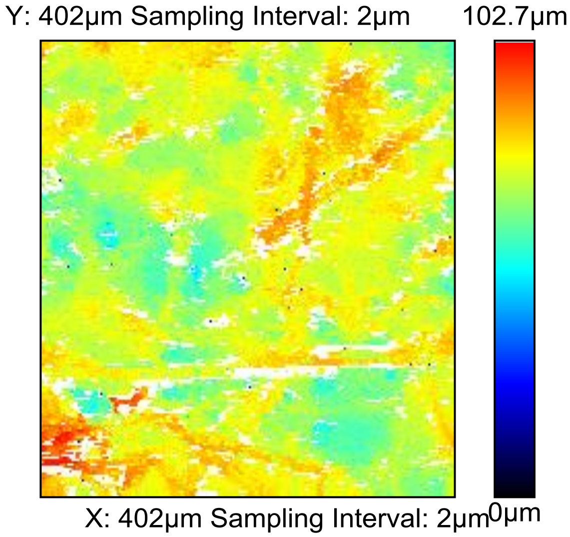

French2.sur - Area-scale - FOUR_CORNERS_FULL_OVE
French2.sur - Area-scale - FOUR_CORNERS_FULL_
Relative Area
2.20
1.90
1.60
1.30
1.00
Scale(μm²)
10⁰
10¹
10²
10³
10⁴

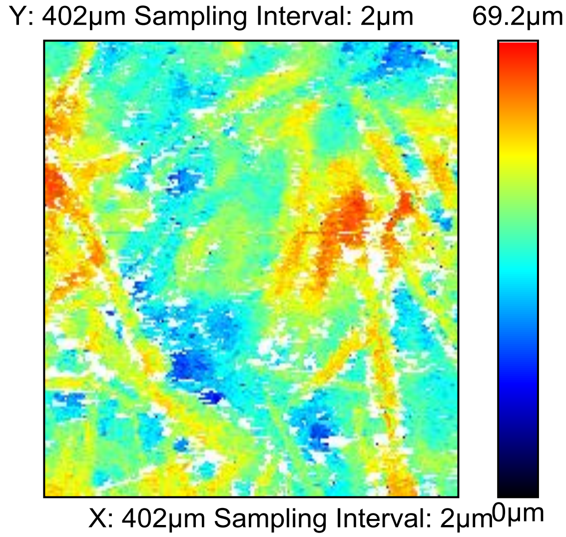

French3.sur - Area-scale - BOTTOM_LEFT
French3.sur - Area-scale - BOTT
2.20
1.90
1.60
1.30
1.00
Relative Area
10⁰
10¹
10²
10³
10⁴
Scale(µm²)

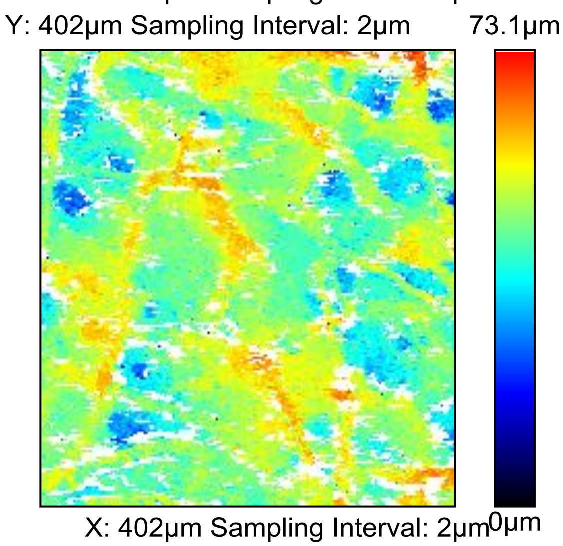
## *Appendix C: Measurements after Filtering*

### French Paper

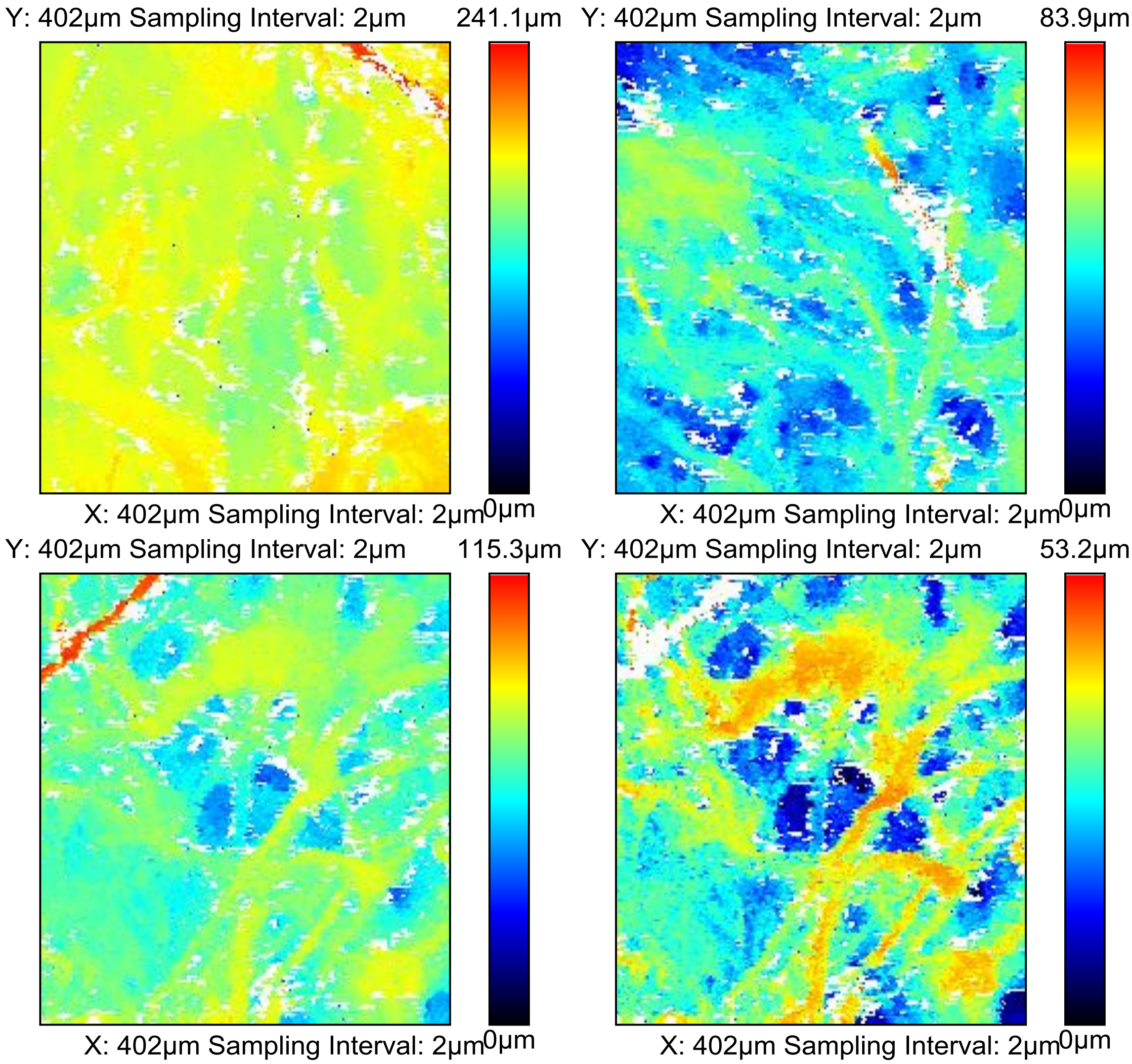


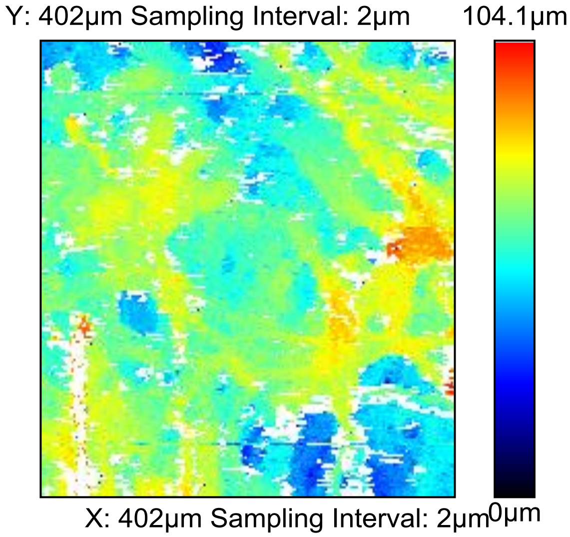


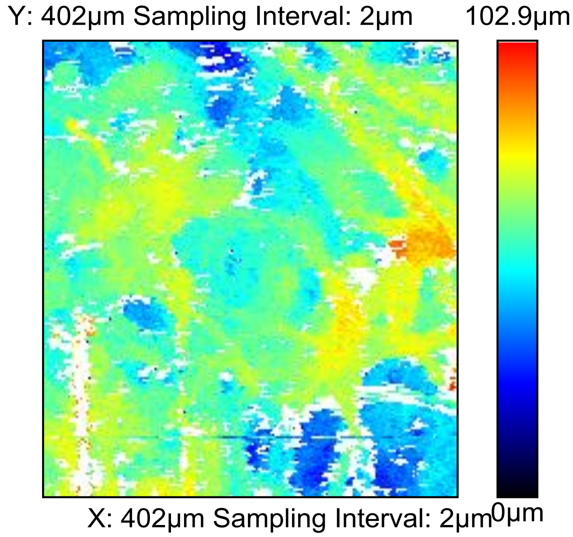



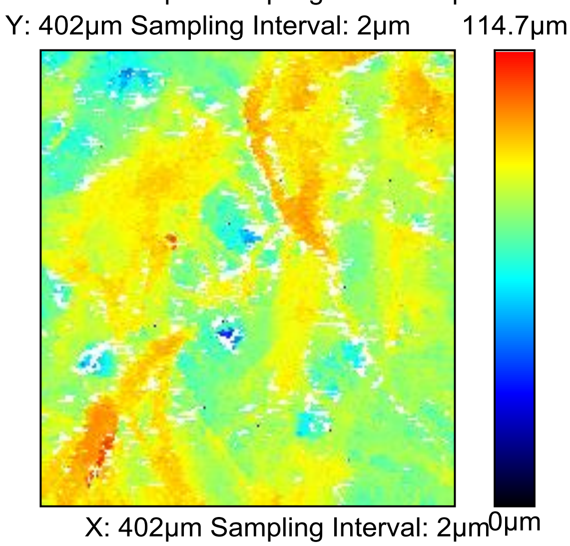




## Italian Paper

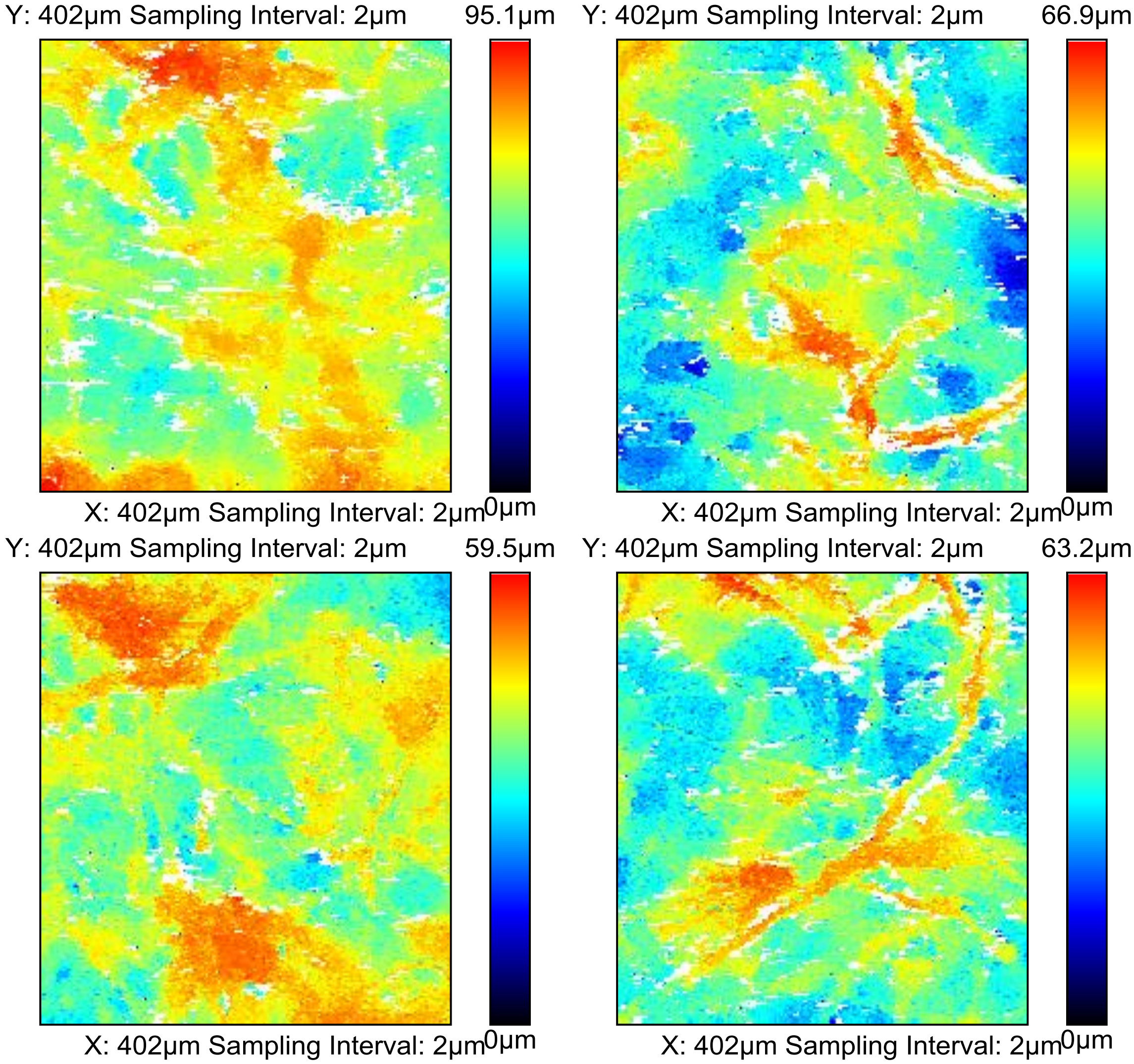

Y: 402μm Sampling Interval: 2μm
241.1μm
X: 402μm Sampling Interval: 2μm
0μm
Y: 402μm Sampling Interval: 2μm
83.9μm
X: 402μm Sampling Interval: 2μm
0μm
Y: 402μm Sampling Interval: 2μm
115.3μm
X: 402μm Sampling Interval: 2μm
0μm
Y: 402μm Sampling Interval: 2μm
53.2μm
X: 402μm Sampling Interval: 2μm
0μm

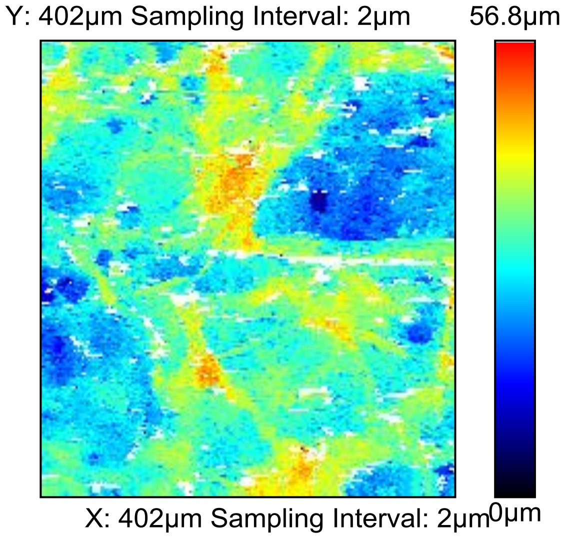

Y: 402μm Sampling Interval: 2μm
104.1μm
X: 402μm Sampling Interval: 2μm
0μm

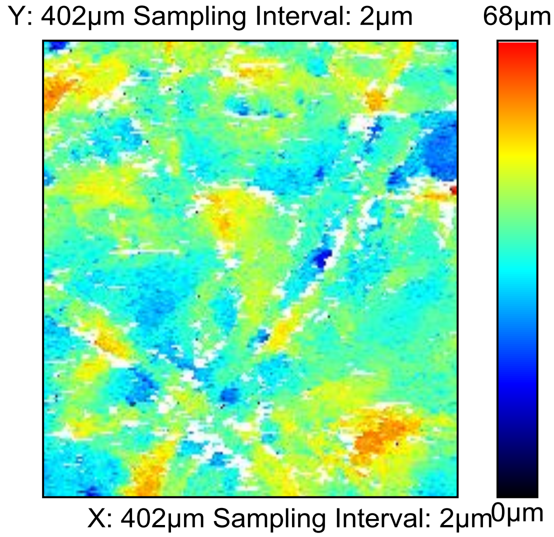

Y: 402μm Sampling Interval: 2μm
102.9μm
X: 402μm Sampling Interval: 2μm
0μm

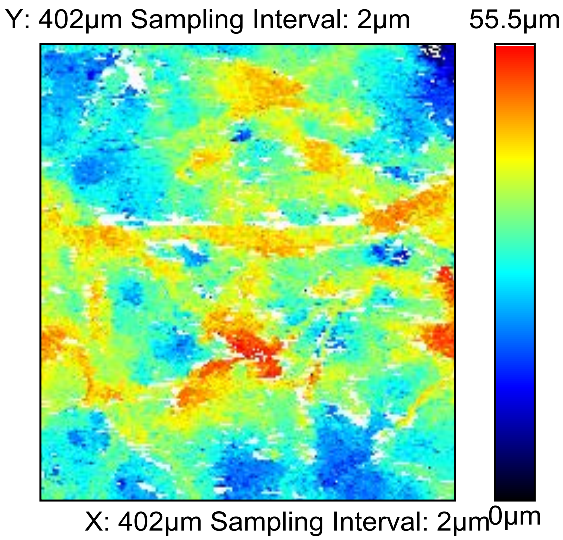

Y: 402μm Sampling Interval: 2μm
114.7μm
X: 402μm Sampling Interval: 2μm
0μm

## Wood-paper

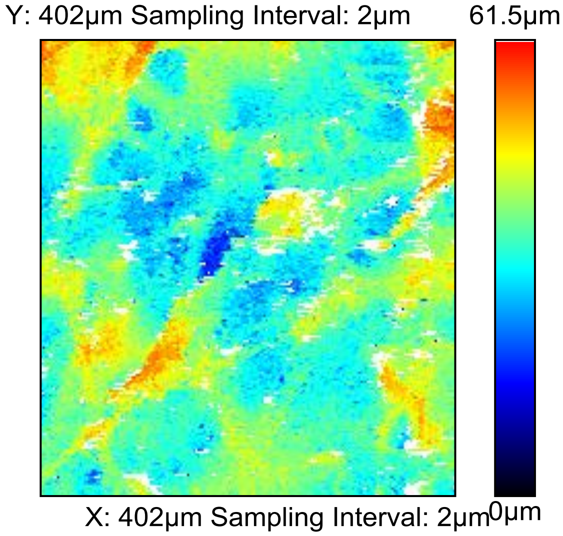

Y: 402µm Sampling Interval: 2µm
95.1µm
0µm
X: 402µm Sampling Interval: 2µm
Y: 402µm Sampling Interval: 2µm
66.9µm
0µm
X: 402µm Sampling Interval: 2µm
Y: 402µm Sampling Interval: 2µm
59.5µm
0µm
X: 402µm Sampling Interval: 2µm
Y: 402µm Sampling Interval: 2µm
63.2µm
0µm
X: 402µm Sampling Interval: 2µm

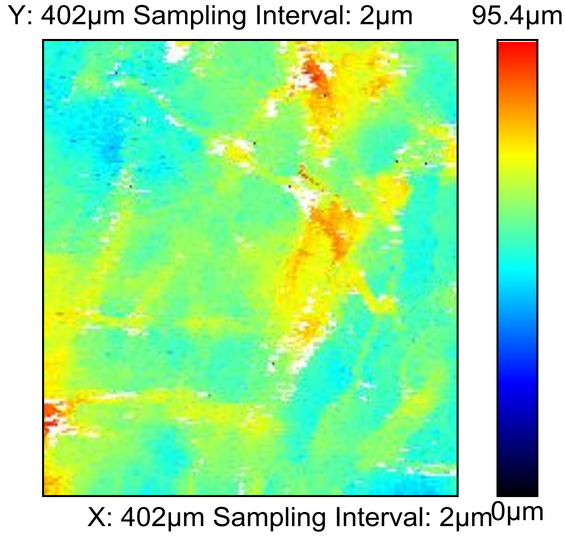

Y: 402µm Sampling Interval: 2µm
56.8µm
0µm
X: 402µm Sampling Interval: 2µm

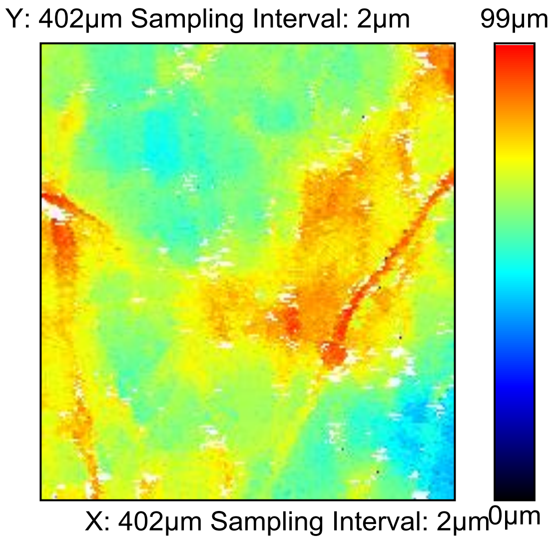

Y: 402µm Sampling Interval: 2µm
68µm
0µm
X: 402µm Sampling Interval: 2µm


Y: 402µm Sampling Interval: 2µm
55.5µm
0µm
X: 402µm Sampling Interval: 2µm

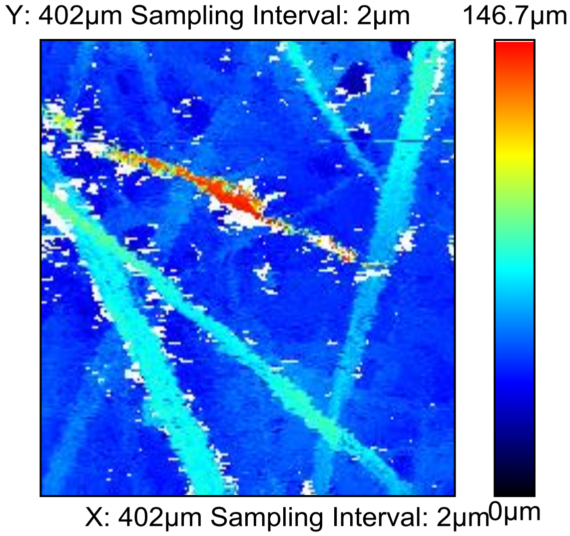
## Wet Paper

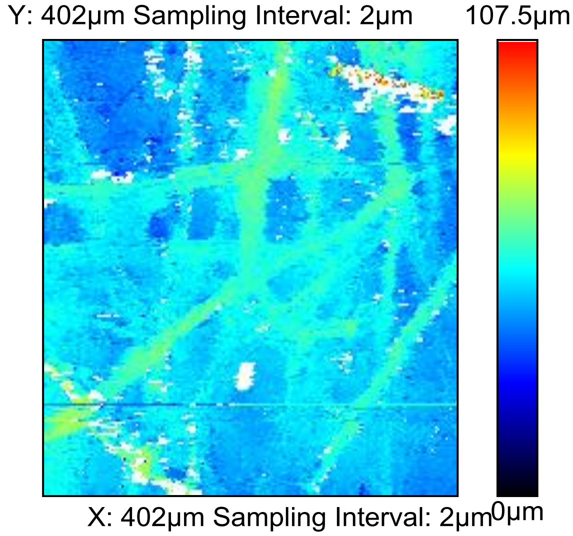

Y: 402µm Sampling Interval: 2µm
61.5µm
X: 402µm Sampling Interval: 2µm
0µm

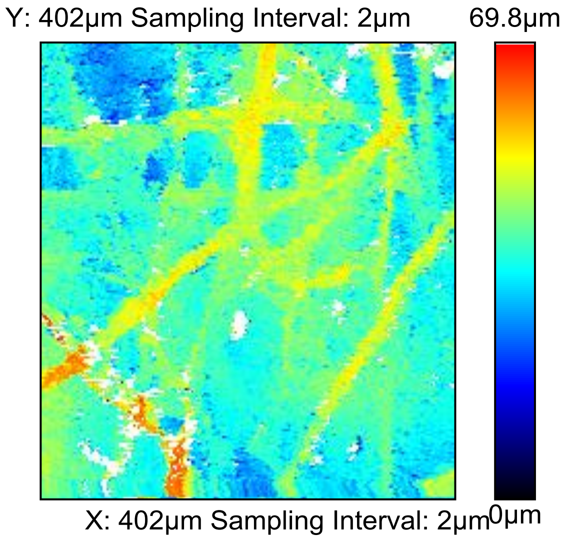

Y: 402µm Sampling Interval: 2µm
95.4µm
X: 402µm Sampling Interval: 2µm
0µm


Y: 402µm Sampling Interval: 2µm
99µm
X: 402µm Sampling Interval: 2µm
0µm

**White Paper**




## *Appendix D: Grants for Funding*

Our methods also included researching art grants that Worcester Polytechnic Institute may obtain in order to continue the study of this topic. Collaborations with the Worcester Art Museum and others around the country are being researched currently to see if funding can be possible. This would leave the possibility of expanding and optimizing this application as well along with obtaining more advanced technology which would further add to the research.

The American Institute for Conservation of Historic and Artistic Works (AIC, 2000) exists to support the conservation professionals who preserve our cultural heritage and in 2001, after a sizable endowment gift from the Andrew W. Mellon Foundation, they have started a professional development program for conservators. “This foundation continually strives to increase funding for grants and scholarships, to support a range of educational programs, and to help elevate the status of conservation in the eyes of the public according to an AIC source (AIC, 2000)”.  There may be a possibility of expanding this application of measuring the surface roughness which can develop into further financial support for this research.  Using search-engines and keywords such as ‘preservation of art’ and ‘conservation of art,’ this grant was discovered. Although many more grants are possible, this was the only one found using these specific keywords.

Grants at other museums as well as the AIC, earlier mentioned, can benefit this research as well as other research similar to this to continue. This topic can be further expanded and used in a wide-array of applications such as findings the origin of a particular art artifact or concluding if a particular artist actually drew up a questionable painting, although more research would have to be done to accomplish this.

## *Appendix E: Confocal Point Sensors*

A confocal point sensor reflects a laser light source from a surface and through a detector pinhole to determine height information. The laser beam is shown through an objective lens that rapidly oscillates on a vertical axis (Solarius, 2007).

Explaining briefly how confocal point sensors work, light intensity reaches its maximum value when the surface which is being measured crosses the focus of the lens. Also, when the distance between the surface and the lens is greater than or less than the radius of curve of the lens, the light which is reflected reaches the pinhole; this is faint and cannot be detected. Height measurements are recorded when this maximum intensity of light goes through the pinhole (Solarius, 2007).

This process is illustrated in the following picture:

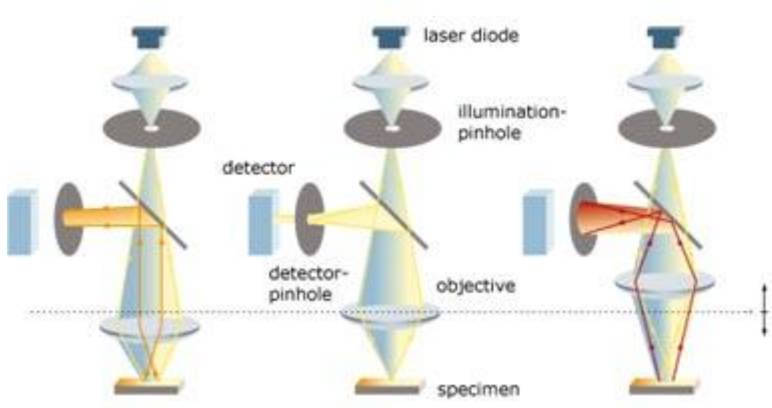



Image from http://www.solarius-inc.com/assets/tech_lase_confprinciple.jpg

**Figure 6: Measurement principal of a confocal point sensor**

## *Appendix F: Conventional Parameters*

| Symbol | Description | Definition (ASME B46) |
|---|---|---|
| **Sa** | **Average Roughness** | $S_a = \frac{1}{MN}\sum_{k=0}^{M-1}\sum_{l=0}^{N-1} \lvert z(x_k, y_l) - \mu \rvert$ † |
| **Sq** | **Root Mean Squared (RMS) Roughness** | $S_q = \sqrt{\frac{1}{MN}\sum_{k=0}^{M-1}\sum_{l=0}^{N-1} \left[ z(x_k, y_l) - \mu \right]^2}$ † |
| **Sp** | **Maximum Peak Height** | $S_p = Z_{max}$ † |
| **Sv** | **Maximum Valley Depth** | $S_p = Z_{min}$ † |
| **St** | **Maximum Peak to Valley Distance** | $S_t = Z_{max} - Z_{min}$ † |
| **Ssk** | **Surface Skewness** | $S_{sk} = \frac{1}{MNS_q^3}\sum_{k=0}^{M-1}\sum_{l=0}^{N-1} \left[ (z(x_k, y_l) - \mu \right]^3$ † |
| **Sku** | **Surface Kurtosis** | $S_{ku} = \frac{1}{MNS_q^4}\sum_{k=0}^{M-1}\sum_{l=0}^{N-1} \left[ z(x_k, y_l) - \mu \right]^4$ † |
| **Sz** | **Ten Point Height** | $S_z = \frac{\sum_{i=1}^{5}(z_{pi} - \mu) + \sum_{i=1}^{5}(z_{vi} - \mu)}{5}$ † |
| **Pa** | **Unfiltered Average Roughness** | $Pa = \frac{1}{lb}\int_{lb} \lvert z(x) \rvert dx$ * |
| **Pq** | **Unfiltered RMS Roughness** | $Pq = \sqrt{\frac{1}{lb}\int_{lb} z^2(x) dx}$ * |

† - Equation from http://www.imagemet.com/WebHelp/spip.htm#roughness_parameters.htm
* - Equation from http://www.digitalsurf.fr/en/guideparam2D.htm

**Figure 7: Table of Conventional Parameters**