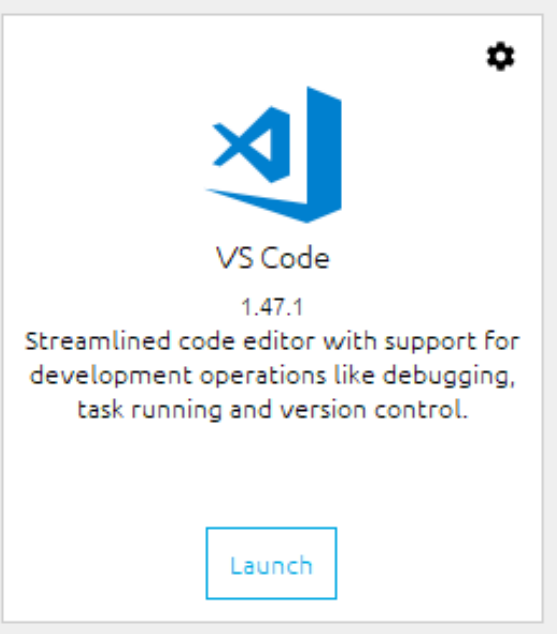
Standard Operating Procedure: SOFIA

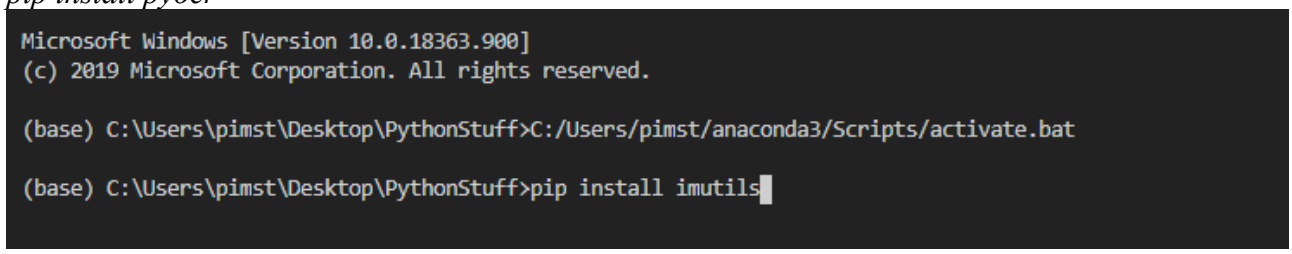
**Requirements:**
python3 code editor (64-bit of your OS, if applicable): https://www.anaconda.com/products/individual

**Setting up Python**
Run the anaconda installer

1. Run the installer and keep pressing “Next” or “Agree” until you can install.
2. Run Anaconda Navigator.
3. In the Anaconda Navigator menu install VS Code.



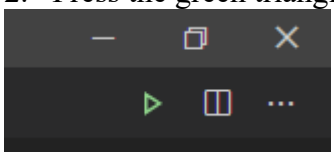

4. Launch VS Code
5. Install the following one at a time by copying the line and pasting it in the terminal at the bottom of the screen. Note: required libraries may be different on Non-Windows OS
   *conda install -c conda-forge numpy*
   *conda install -c conda-forge imutils*
   *pip install opencv-python*
   *conda install -c conda-forge pathlib*
   *conda install -c conda-forge shapely*
   *pip install pyocr*



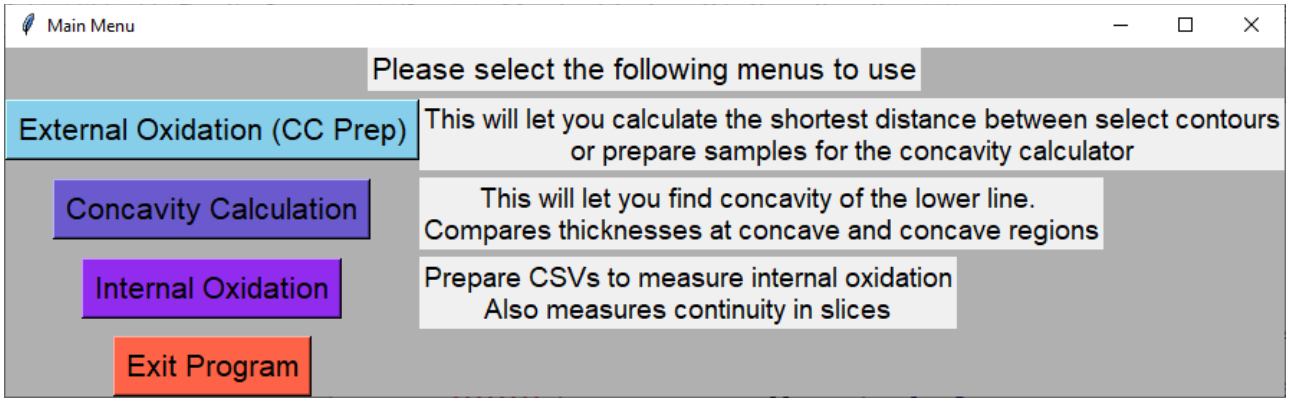

6. After installing the modules, restart VS Code.

**Using the program**

1. Open SOFIA.py in VS Code. You should see code**.**
2. Press the green triangle in the top right corner to run the script**.**



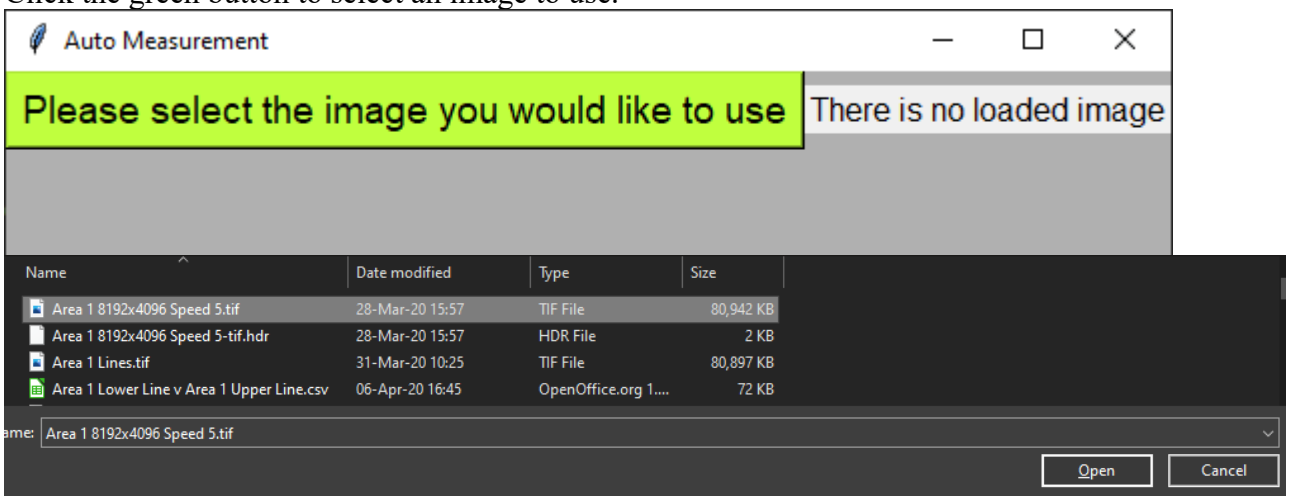
3. When you open the script you should see the following. If you get any errors make sure you have the required modules installed.



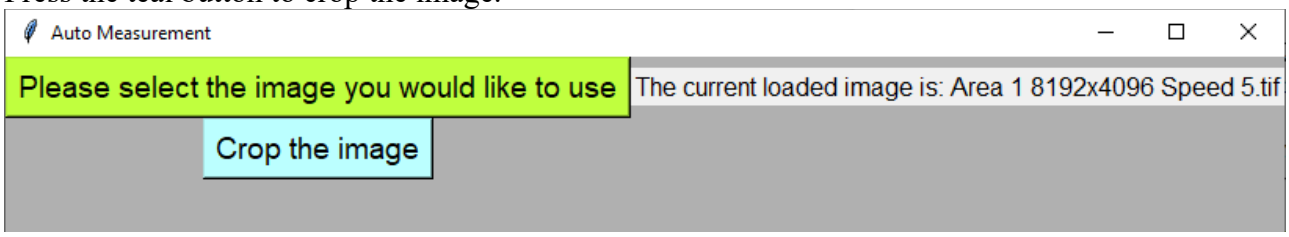

4. The three options specialize in different types of oxidation. “External Oxidation (CC Prep)” focuses on continuous and semi-continuous layers. “Concavity Calculations” is an extension of “External…” which loads previous data to fit a polynomial to it and figure out concavity distributions. “Internal oxidation” specializes in porous or distributed internal oxidation. It will measure depth and distribution of internal oxides.

**External Oxidation (CC Prep) Menu**

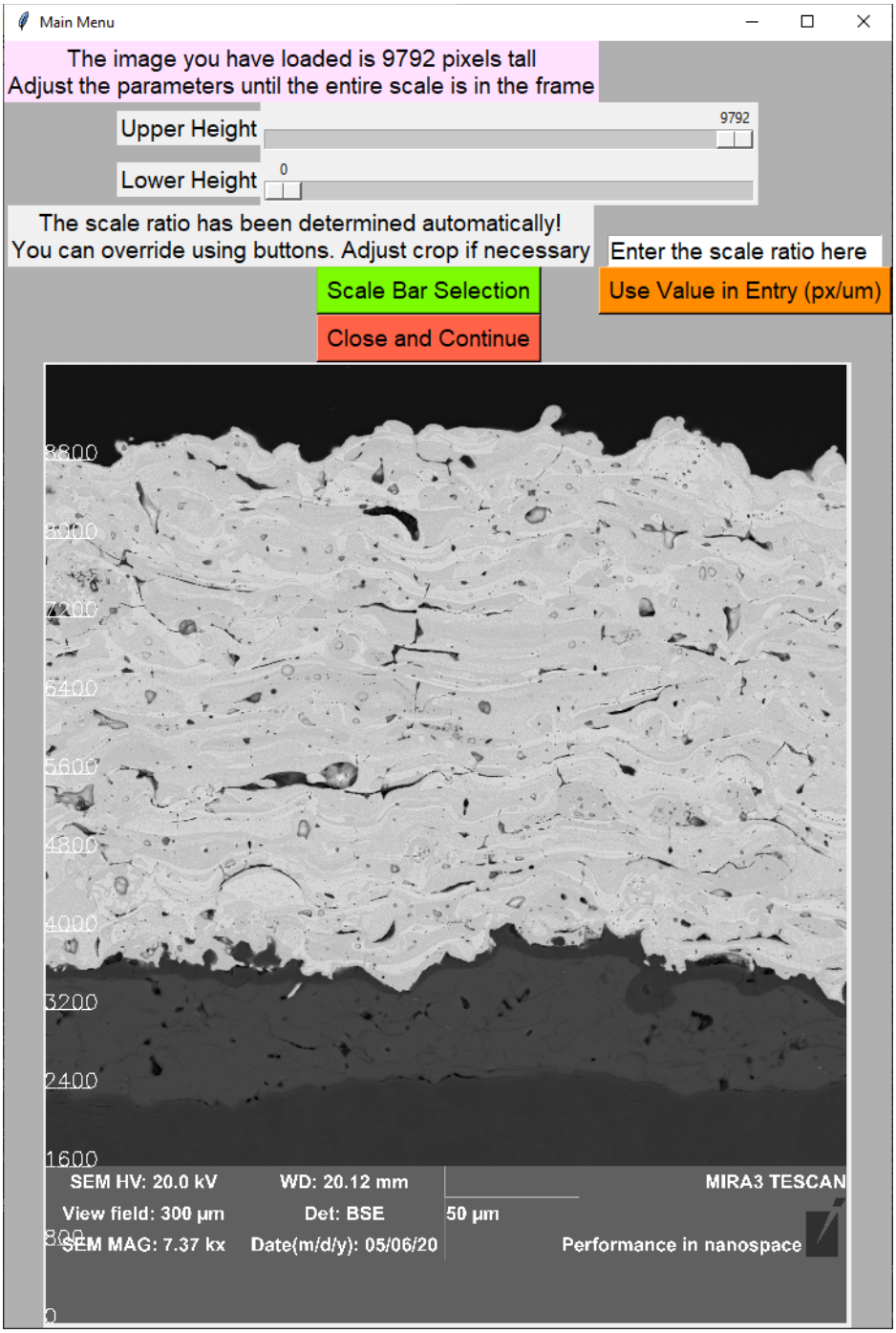
5. Click the green button to select an image to use.



6. Press the teal button to crop the image.

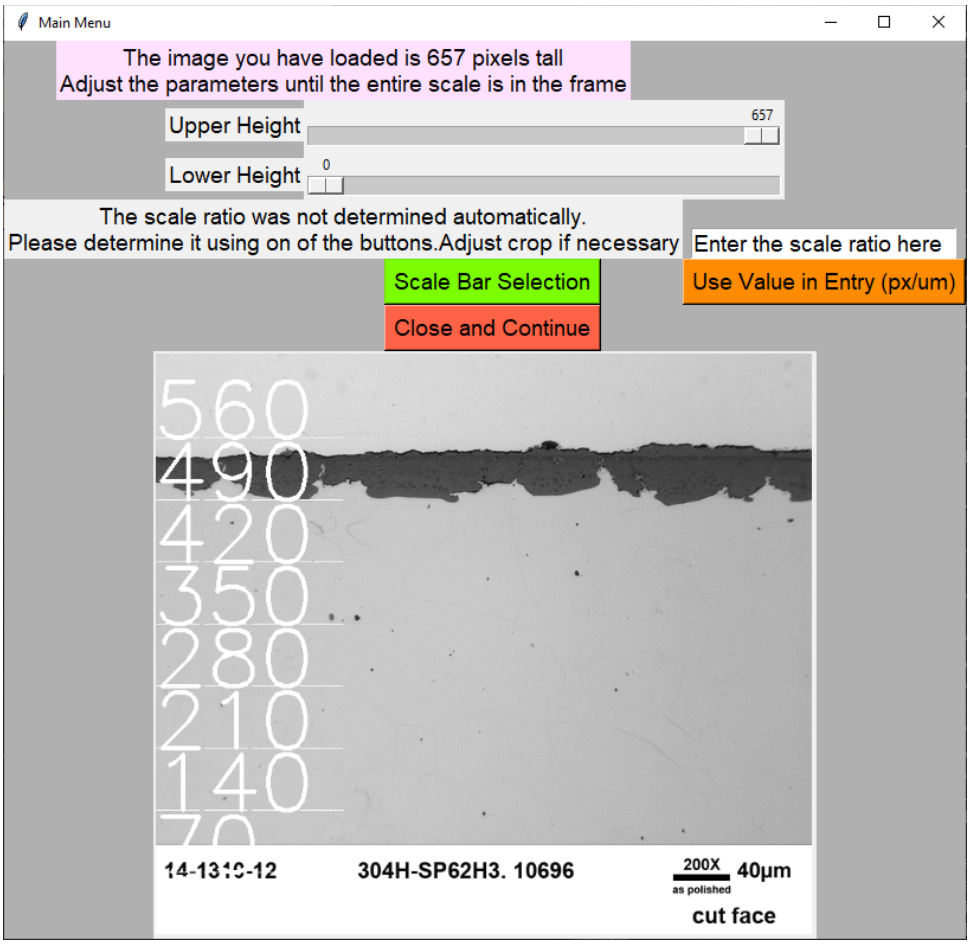



7. A new menu will open to let you crop the image to isolate the features of interest.

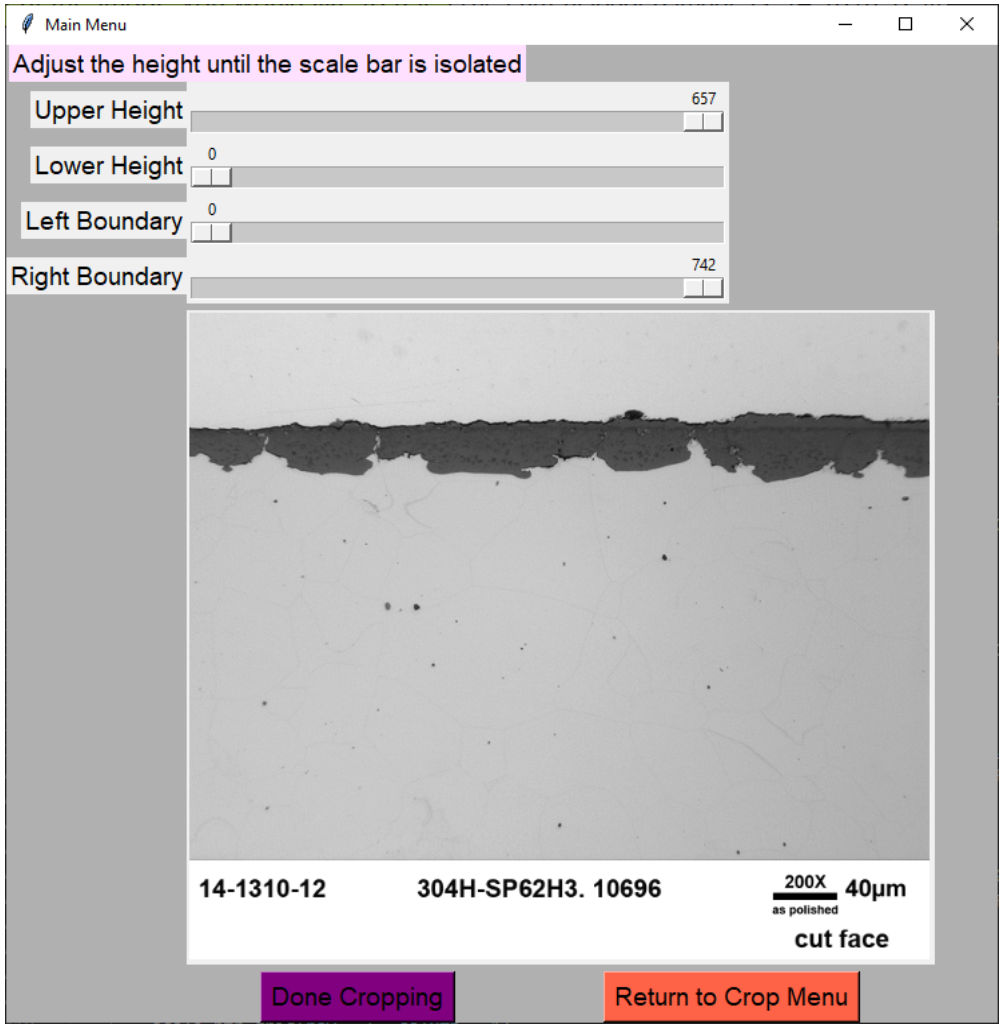


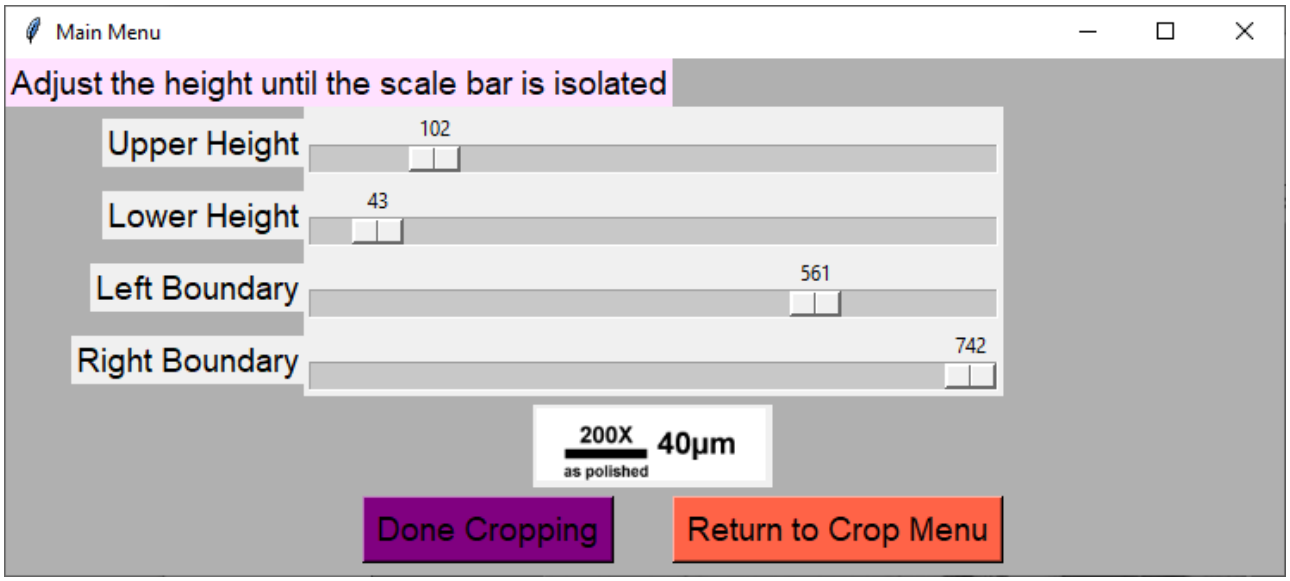

8. Depending on the source of the image, the script might read the scale bar automatically. If this is the case you will see the message above saying “The scale ratio has been determined…” If you see this message you can skip to step 11.

9. If the scale ratio is not automatically determined, you can enter it into the entry box above the orange button or you can press “Scale Bar Selection” to manually isolate the scale bar. If you supply a scale ratio in the entry, be sure to press the button below to update the value (you will see the scale ratio message change). You can continue to step 11, otherwise follow the directions for “Scale Bar Selection.”

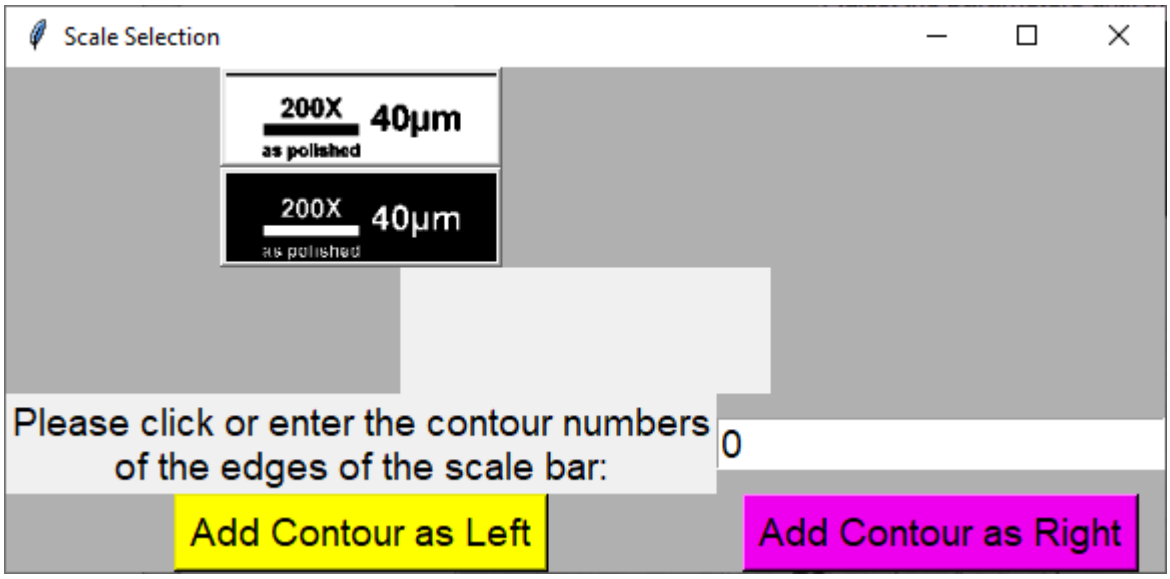


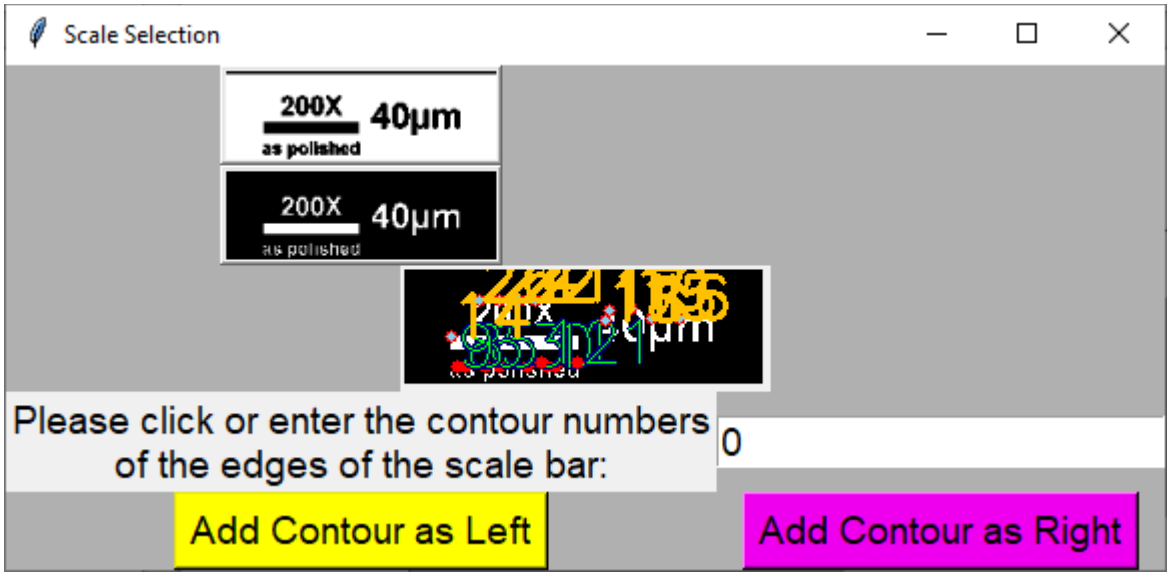

10. After pressing the “Scale Bar Selection” button you will be greeted by another menu with sliders. Adjust the sliders to isolate the scale bar.



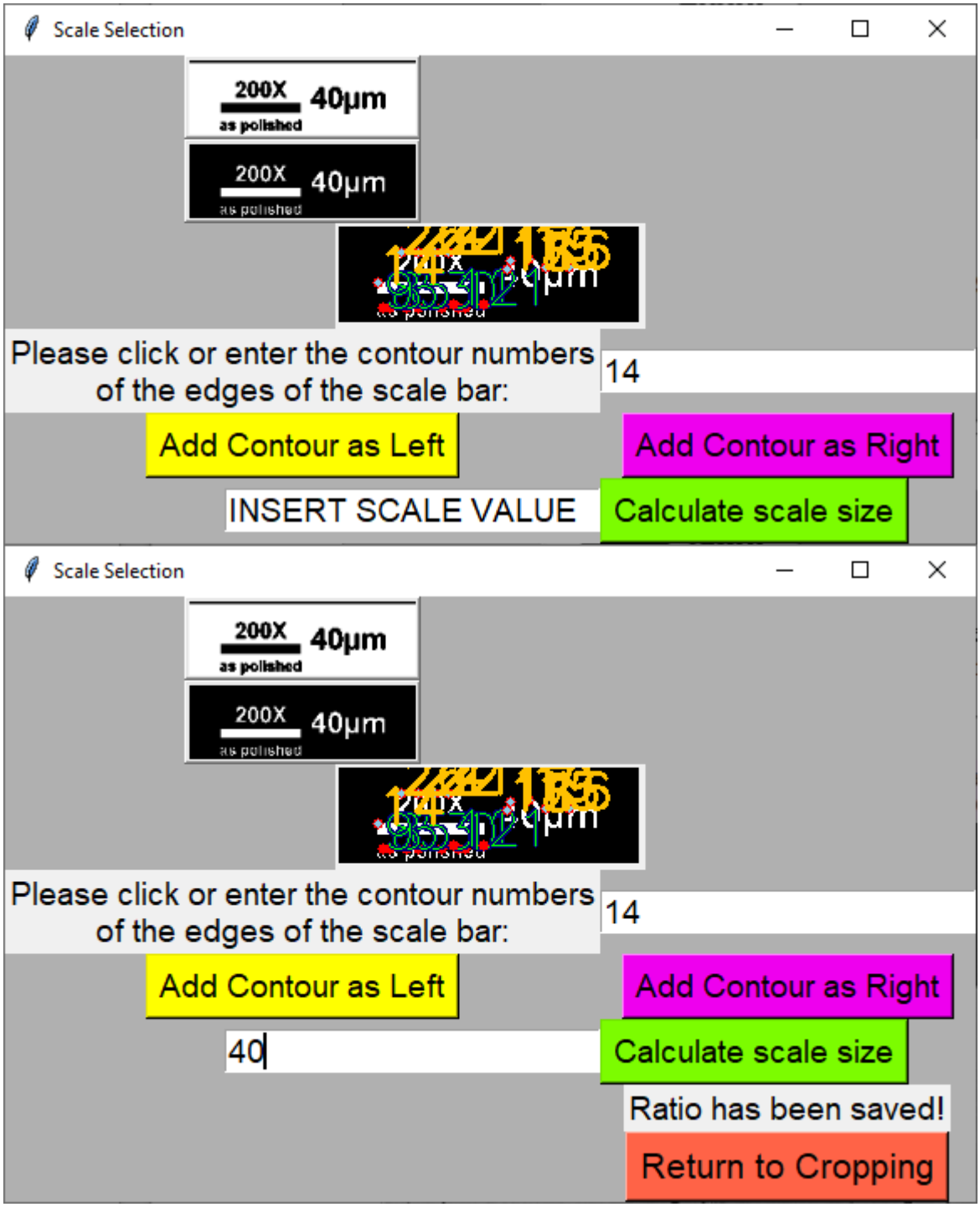




11. When the scale bar is isolated, as seen above, press “Done Cropping” to move to the next menu. On the new menu, click on the image that shows the scale bar in white. This will update the gray box below the images.



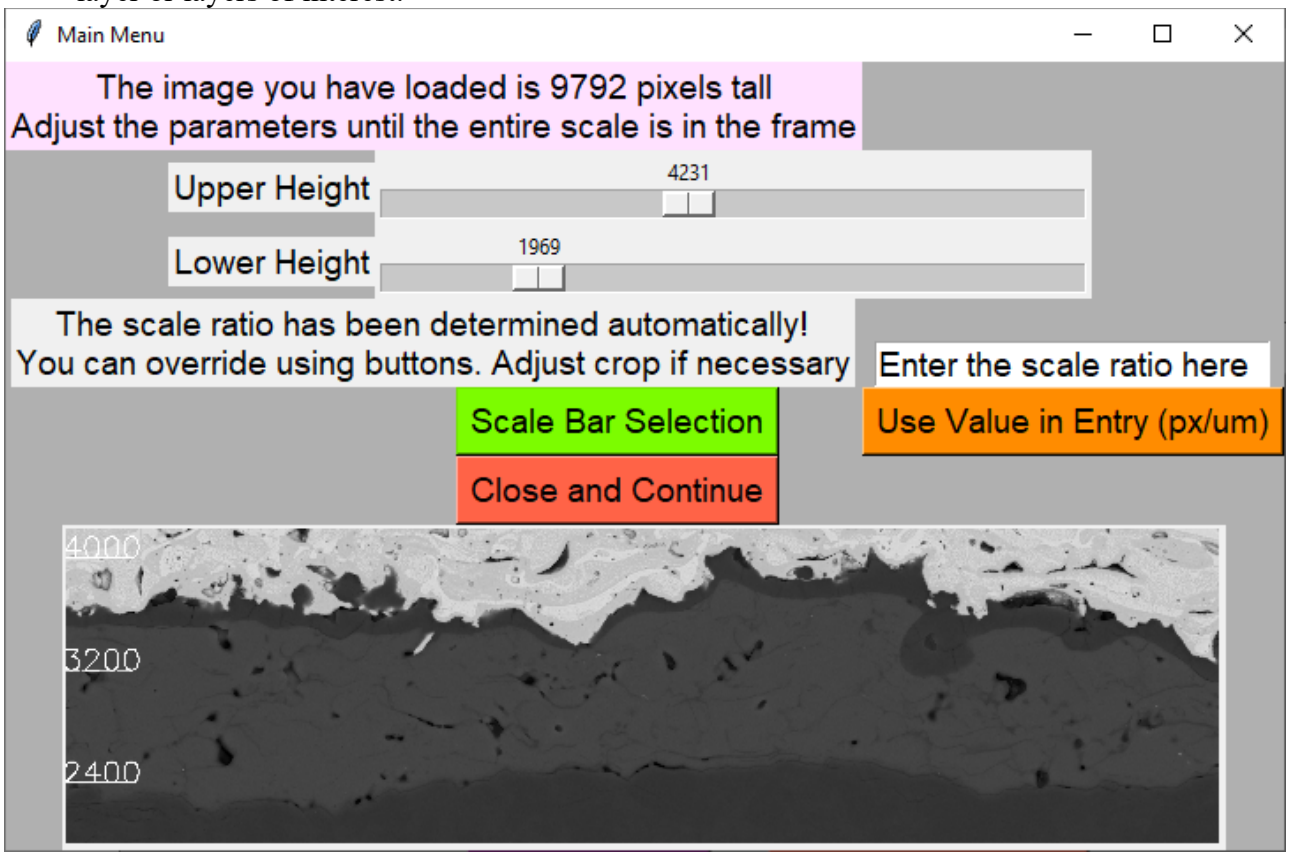




12. The computer has taken outlines of the shapes in the scale bar box. You can select the scale bar by clicking near the nodes marked on image, this will update the entry with the number of the contour. All contours above a certain size are marked with a red dot and the 10 largest areas are indicated with a teal dot with a red outline (additionally, the contour number is gold instead of green with a blue outline). If you are satisfied with the contour number in the entry box press the buttons according to the respective position of the scale bar. For a continuous scale bar (like the one above or a “fork” with a line that connects the segments) you can use a single contour node to mark the left and right sides of it as the scale bar. For tally mark scale bars, select the leftmost and rightmost nodes and use the buttons to tell the script that they are the scale bar.
13. Once you have marked both sides of the scale bar, the script will show an additional entry box to input the length of the scale bar in µm.

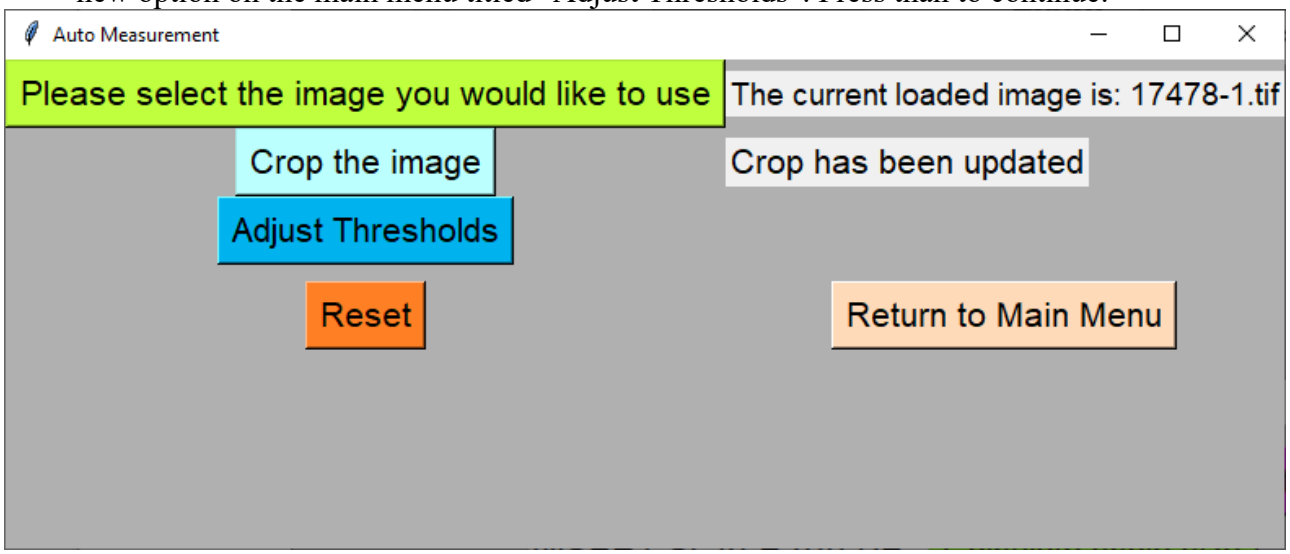



14. Enter the real world length of the scale bar and press “Calculate Scale Size” to save the scale bar ratio and continue with the cropping.

15. The cropping of the image can be adjusted by moving the sliders. Move them until you have the layer or layers of interest.

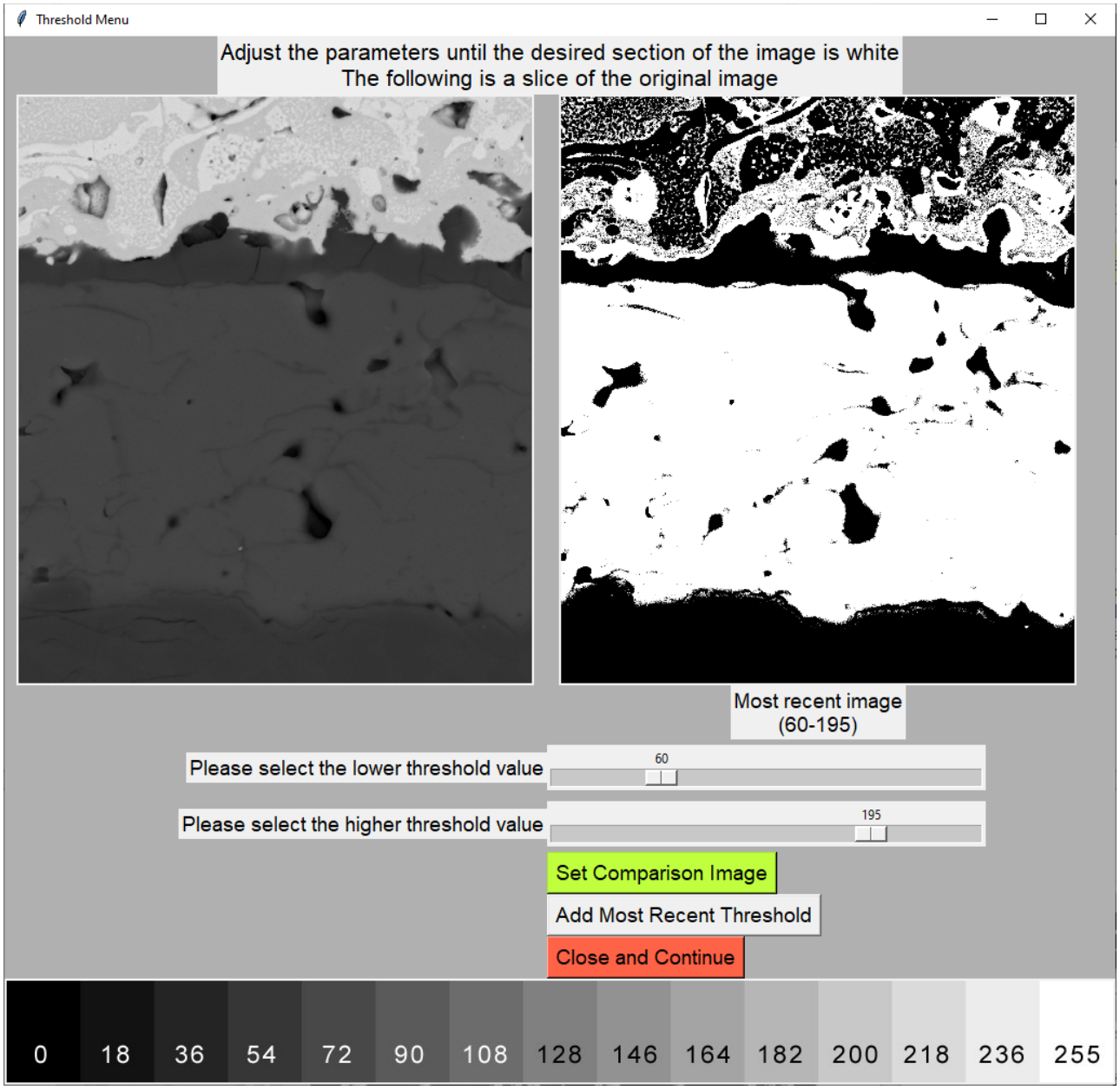



16. When the window shows the regions that you want press “Close and Continue”. You will see a new option on the main menu titled “Adjust Thresholds”. Press than to continue.

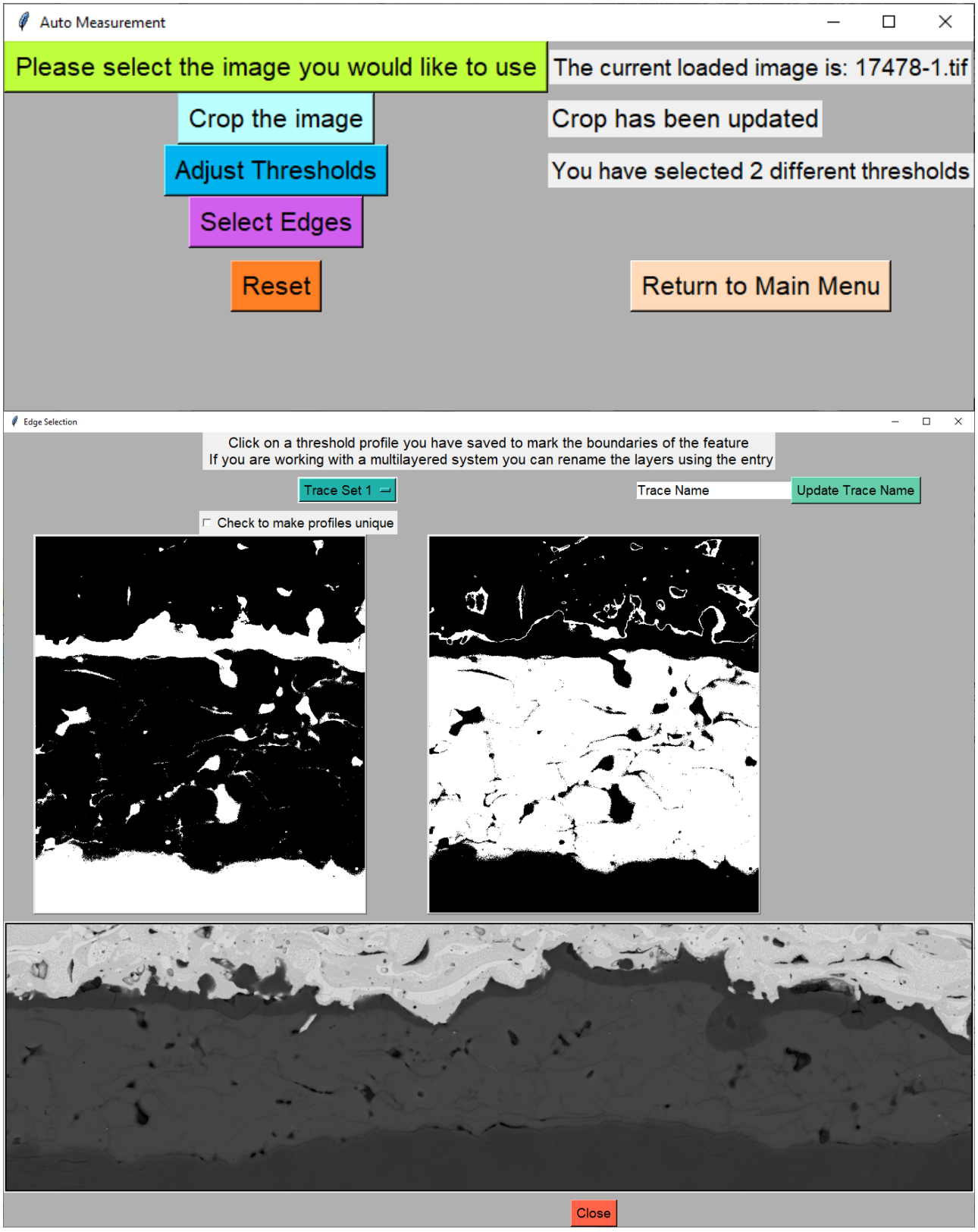



17. On the new window created you can adjust thresholds (gray values of the image). Adjust the sliders to change the thresholds. The image on the left is the original image, the middle is the current threshold settings. You can keep a copy of the current threshold profile by pressing “set comparison image” this will let you see what details are added or lost when you adjust the sliders. When you the feature you want has defined edges and is white you can press “Add Most

Recent Threshold" to save the profile for later. Up to three different profiles can be saved at once.

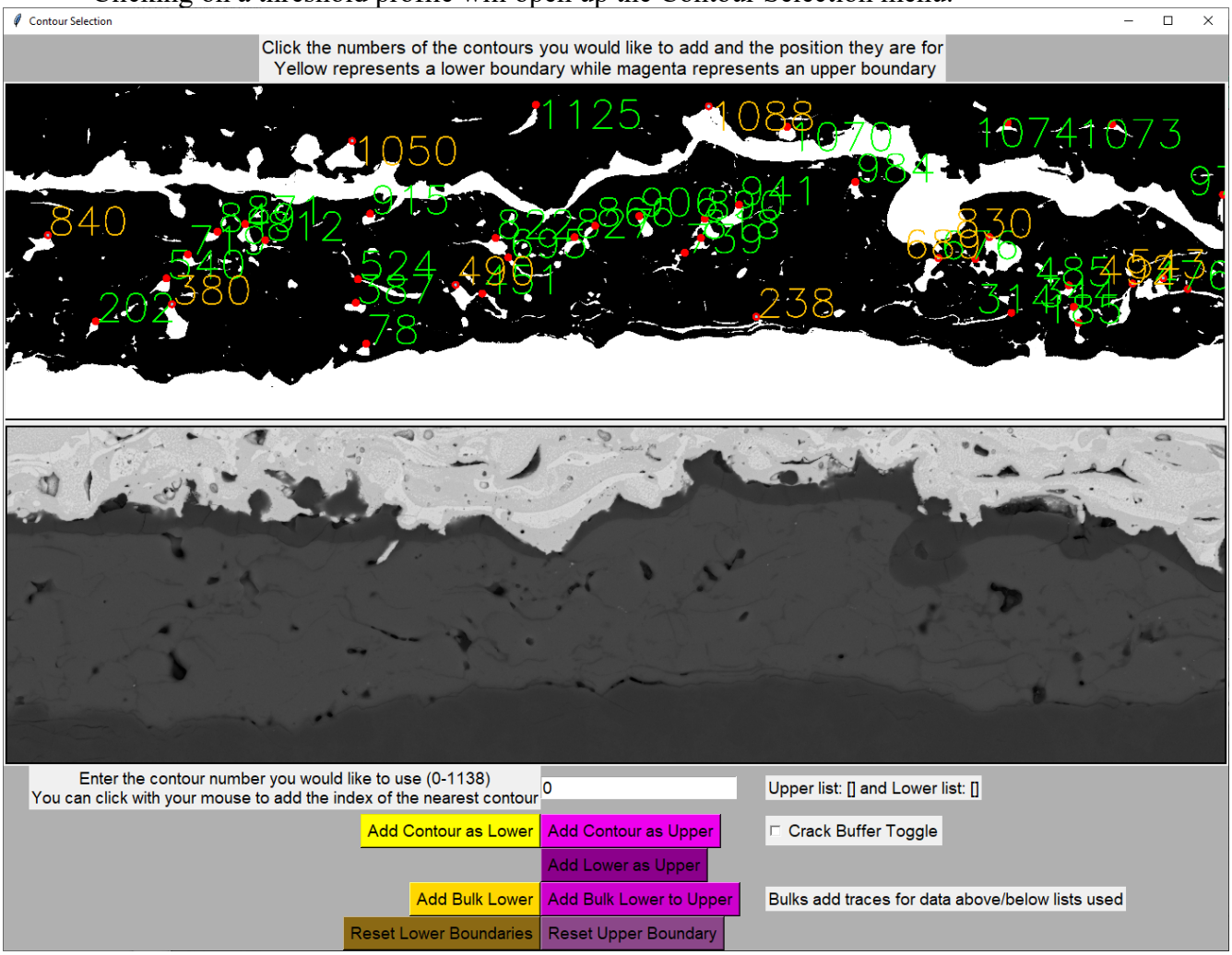



18. Once you have the profiles you want, press "Close and Continue" and you will see a new button on the main menu titled "Select Edges". Pressing this option will open a menu to select different threshold profiles.




19. On the Edge Selection menu you will see the threshold profiles you have saved and the crop image from earlier. This menu will also have a text box that you should use to name the feature of the image you are working with. If you have multiple threshold profiles you will see up to three threshold images. Use the drop box to specify what layer the data from the next step is

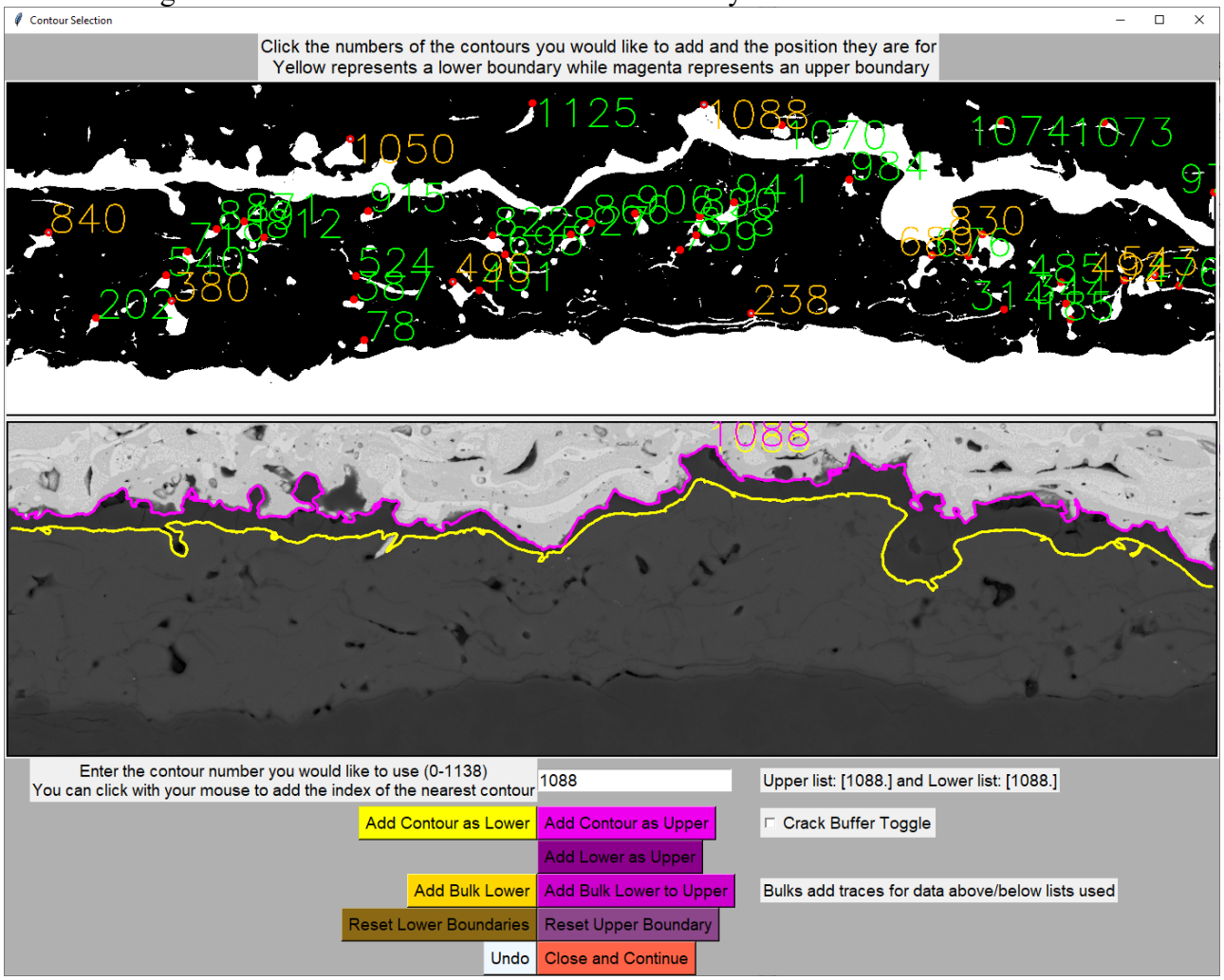
supposed to go to. By default the script assumes you are working with one layer, so check the box that says “Check to make profiles unique” to make sure that each layer is saved separately. Clicking on a threshold profile will open up the Contour Selection menu.



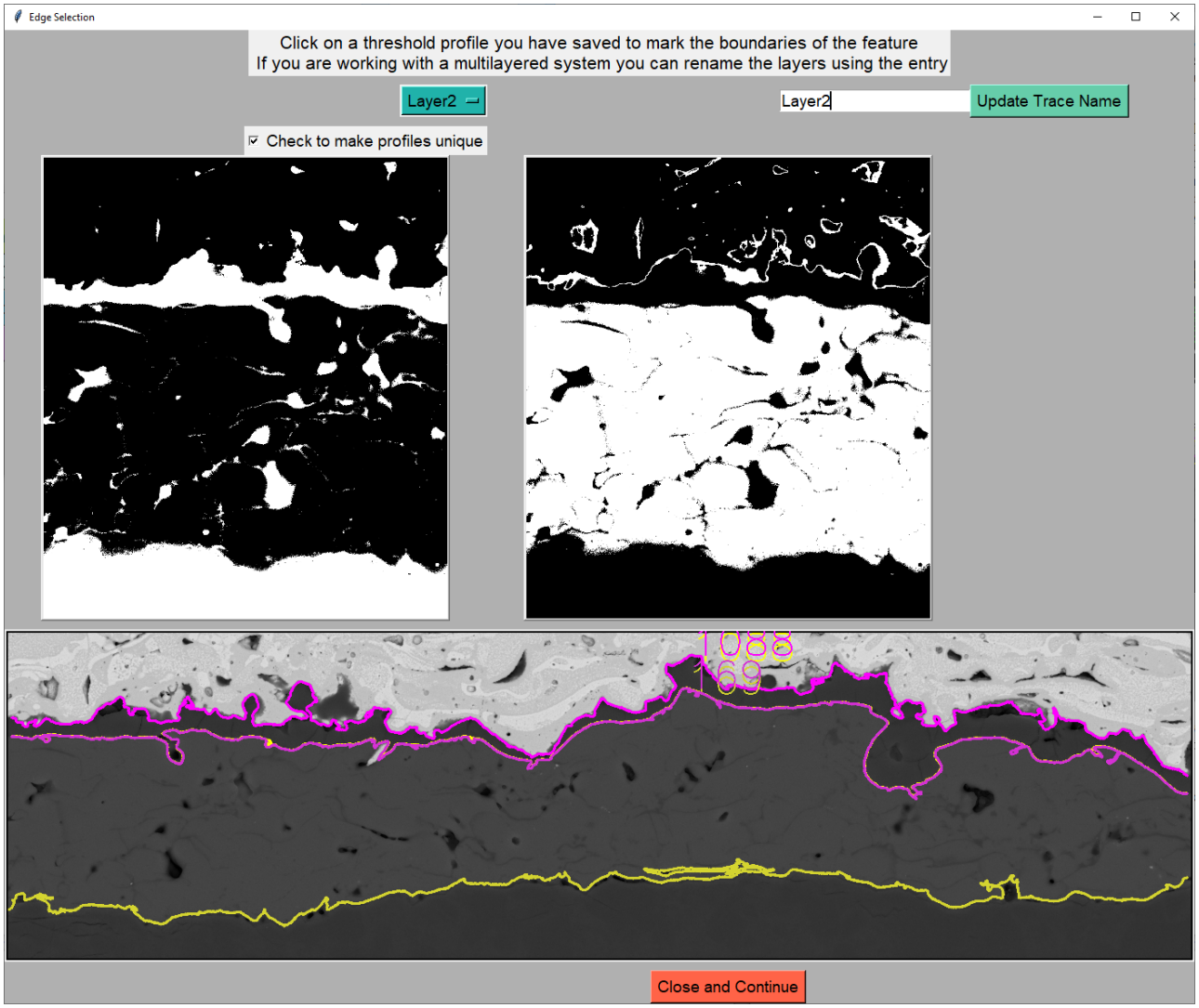

20. The top image shows the thresholded image with contours labeled. Click the nodes that are in the top left of the white sections that are a part of the feature of interest. All of the nodes have a red dot, but the teal dot in the center means that it is in the ten largest regions. Additionally, the ten largest regions have golden numbers to help them stand out. There are several buttons and options on the screen. The buttons are described as follows:
    - “Add Contour as Lower” will add the bottom half of the image to a list used to represent the bottom of the feature (such as a scale)
    - “Add Contour as Upper” will add the top half of the image to a list used to represent the top of the feature (such as a scale)
    - “Crack Buffer Toggle” can be used if there are deep cracks on the sides of the boundaries. (Prevents the sides of a rectangle from being counted as either the top or the bottom)
    - “Add Lower as Upper” will add the bottom half of the image to a list used to represent the bottom of the feature (intended for complicated scales or if using multiple thresholds)
    - “Add Bulk Lower” requires contours that have been defined as upper boundaries. It will automatically add the lower half of all contours below the previously selected upper boundary contours. (Intended for complicated scales)

- “Add Bulk Lower to Upper” requires contours that have been defined as lower boundaries. It will automatically add the lower half of all contours above the previously selected upper boundary contours. (Intended for complicated scales)
- “Reset Lower Boundaries” clears the lower boundary data from the current threshold profile
- “Reset Upper Boundaries” clears the upper boundary data from the current threshold profile

21. When you press one of the buttons the lower image will update showing the data you have selected so far. Yellow will show the lower boundary and magenta will show the upper boundary. The numbers of the contours are also labeled on the image and in the status bar next to the entry box. The script will prevent you from adding the same data to the list multiple times. When contours are selected through a non-bulk method an undo button will be added. Pressing the undo button will remove the most recently added data.

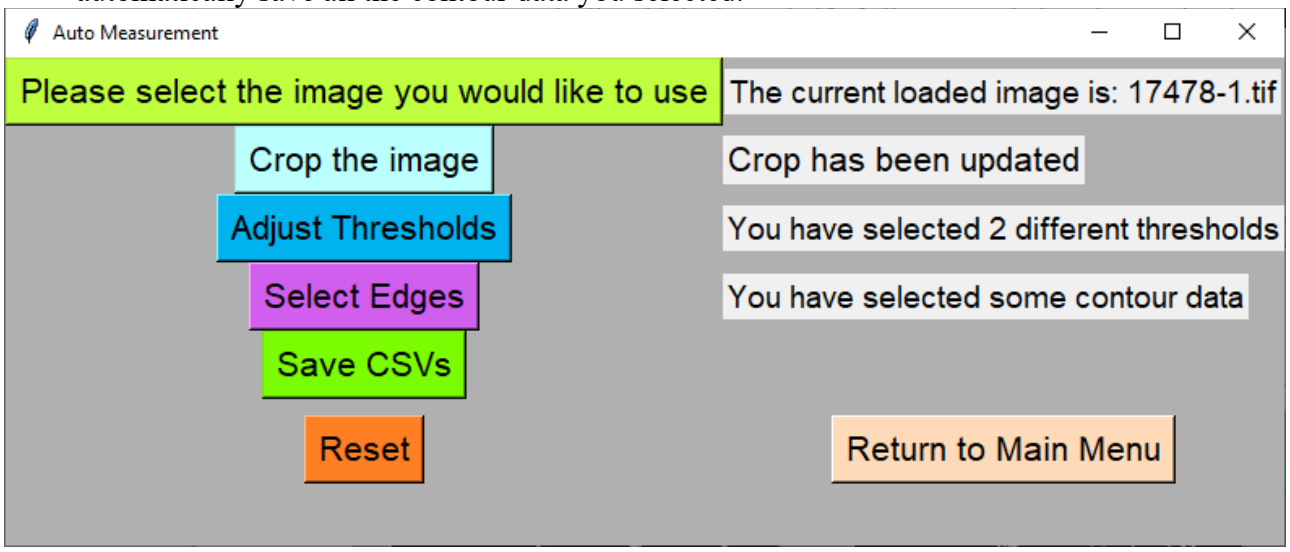



22. When you have added data to define the upper and lower boundaries a button to exit the menu labeled “Close and Continue” will be created. When you have added all of the contours that you want you can press that button to continue the process. (Note: If you are using multiple threshold profiles repeat steps 13-17 until satisfied, you should see the yellow and magenta lines darken on the Edge Selection menu to show the different data lists of the different layers)

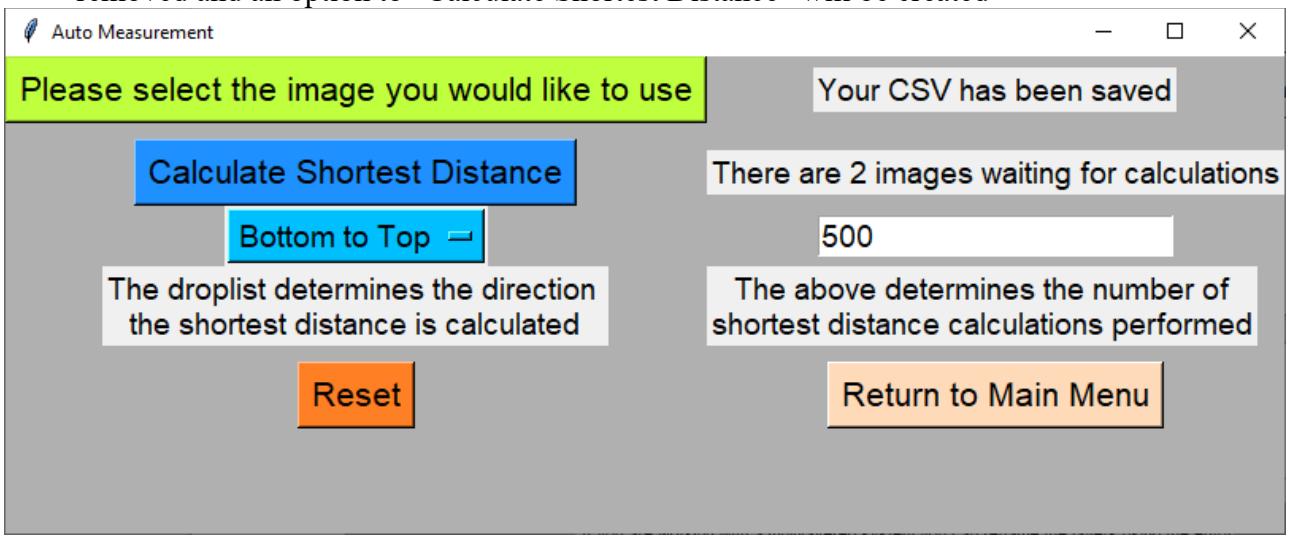



23. Press the “Close and Continue” button on the Edge Selection menu to continue.

24. On the main menu a new button will be available labeled “Save CSVs”. Press this button to automatically save all the contour data you selected.




25. When data has finished saving all of the buttons besides the image selection button will be removed and an option to “Calculate Shortest Distance” will be created




26. You can repeat steps 1-20 as many times as you would like before doing the calculations. Note that when you open the Crop Menu the scale ratio from the previous image is used. This can be overridden by redoing the automatic scale reader or by one of the manual methods described in step 5. The script saves the data from the images in the folder “unworkedcsv” which can be found where SOFIA.py is located. The number of data sets waiting for calculations is listed next to the “Calculate Shortest Distance” button.
27. Below the “Calculate Shortest Distance” button is a drop list that contains a couple of calculation options:
    - “Bottom to Top” measures the shortest distance by taking steps along the lower boundary and looking for the shortest distance to the upper boundary within a certain horizontal spread.
    - “Top to Bottom” will be flagged as “reverse” in the output data. It does the previously described process except the roles of the lower and upper boundaries are swapped.
    - “Both” performs the above actions

- "Vertical Line" measures the unadjusted vertical distance from the lower boundary to the upper boundary
- "All of the Above" performs all of the previously described measurement methods

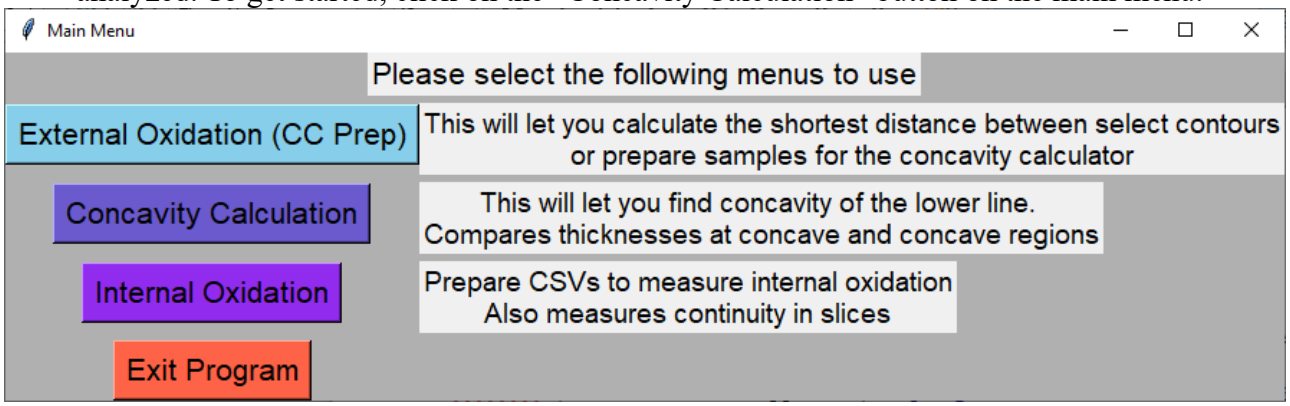
28. By default there is a box next to the drop list that says 500, this indicates that there will be around 500 steps (size of data set limiting). This number can be adjusted to any integer if you want to do more calculations (assuming the data supports it).
29. When you are satisfied with the settings press the "Calculate Shortest Distance Button." The results from the calculations can be found in a spreadsheet titled "SOFIA External Summary.csv" found in the same folder that SOFIA.py is located in. Here you will find the name of the image, the region, the threshold profile, calculation direction, scale ratio, mean, Q1, Q2, Q3, standard deviation, and the number of calculations performed. There is also a calculation for trapezoidal and polygon method where the thickness of the layer is approximated by creating a polygon using the upper and lower boundary and dividing its area by the length of the lower boundary.

| | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Image/Thresholds | Pixel Ratio | Mean | Median | Q1 | Q3 | SD | Trapezoidal | Polygon | Calculation Count | | | |
| 2 | 17478-1-000-063 | 27.28 | 6.01467 | 5.61987 | 3.84932 | 7.7313 | 2.89031 | 4.37618 | 4.3785 | 495 | | | |
| 3 | 17478-1-000-063 | 27.28 | 6.03272 | 4.77251 | 3.35382 | 6.71889 | 4.40412 | -4.37618 | 4.3785 | 498 | | | |
| 4 | 17478-1-000-063 | 27.28 | 6.03272 | 4.77251 | 3.35382 | 6.71889 | 4.40412 | -4.37618 | 4.3785 | 498 | | | |
| 5 | 17478-1-000-063 | 27.28 | 6.03133 | 4.80065 | 3.35586 | 6.80119 | 4.39122 | -4.37618 | 4.3785 | 1990 | | | |
| 6 | 17478-1-000-063 | 27.28 | 2.98776 | 2.98776 | 2.80561 | 3.16991 | 0.36429 | -4.37618 | 4.3785 | 2 | | | |
| 7 | 17478-1-000-063 | 27.28 | 6.03206 | 4.79701 | 3.36166 | 6.79385 | 4.39151 | -4.37618 | 4.3785 | 11935 | | | |
| 8 | 17478-1-000-063 | 27.28 | 6.03272 | 4.77251 | 3.35382 | 6.71889 | 4.40412 | -4.37618 | 4.3785 | 498 | | | |
| 9 | 17478-1-000-063 | 27.28 | 6.03272 | 4.77251 | 3.35382 | 6.71889 | 4.40412 | -4.37618 | 4.3785 | 498 | | | |
| 10 | Area 3-ExtFix-161-226 | 3.78 | 16.93122 | 16.93122 | 16.93122 | 16.93122 | 0 | -16.90888 | 16.90888 | 566 | | | |
| 11 | 21-0361-04-000-195 | 1.575 | 10.69823 | 9.09068 | 6.86772 | 14.19726 | 5.0673 | -11.36498 | 11.48191 | 384 | | | |
| 12 | 17478-1-000-063-Reverse | 27.28 | 6.01467 | 5.61987 | 3.84932 | 7.7313 | 2.89031 | 4.37618 | 4.3785 | 495 | | | |
| 13 | 17478-1-000-063 | 27.28 | 6.03272 | 4.77251 | 3.35382 | 6.71889 | 4.40412 | -4.37618 | 4.3785 | 498 | | | |
| 14 | 17478-1-000-063 | 27.28 | 6.03272 | 4.77251 | 3.35382 | 6.71889 | 4.40412 | -4.37618 | 4.3785 | 498 | | | |
| 15 | 17478-1-000-063-Reverse | 27.28 | 6.01467 | 5.61987 | 3.84932 | 7.7313 | 2.89031 | 4.37618 | 4.3785 | 495 | | | |
| 16 | 17478-1-000-063 | 27.28 | 6.03212 | 4.811 | 3.35345 | 6.79711 | 4.39097 | -4.37618 | 4.3785 | 995 | | | |
| 17 | 17478-1-000-063-Reverse | 27.28 | 6.00546 | 5.598 | 3.81408 | 7.76399 | 2.86319 | 4.37618 | 4.3785 | 1030 | | | |
| 18 | 17478-1-000-063 | 27.28 | 6.03133 | 4.80065 | 3.35586 | 6.80119 | 4.39122 | -4.37618 | 4.3785 | 1990 | | | |
| 19 | 17478-1-000-063-Reverse | 27.28 | 6.00175 | 5.59812 | 3.81364 | 7.76795 | 2.8494 | 4.37618 | 4.3785 | 2060 | | | |
| 20 | 17478-1-000-063 | 27.28 | 6.03206 | 4.79701 | 3.36166 | 6.79385 | 4.39151 | -4.37618 | 4.3785 | 11935 | | | |
| 21 | 17478-1-000-063-Reverse | 27.28 | 6.00429 | 5.60898 | 3.81408 | 7.77126 | 2.85338 | 4.37618 | 4.3785 | 12355 | | | |
| 22 | Area 3-ExtFix-161-226 | 3.78 | 16.93122 | 16.93122 | 16.93122 | 16.93122 | 0 | -16.90888 | 16.90888 | 566 | | | |
| 23 | Area 3-ExtFix-161-226 | 3.78 | 16.93122 | 16.93122 | 16.93122 | 16.93122 | 0 | -16.90888 | 16.90888 | 566 | | | |
| 24 | Area 3-ExtFix-161-226 | 3.78 | 16.93122 | 16.93122 | 16.93122 | 16.93122 | 0 | -16.90888 | 16.90888 | 566 | | | |
| 25 | 17478-1-000-063 | 27.28 | 6.03303 | 4.77455 | 3.36366 | 6.80378 | 4.39196 | -4.37618 | 4.3785 | 597 | | | |
| 26 | 17478-1-000-063-Reverse | 27.28 | 5.99506 | 5.60767 | 3.82358 | 7.81024 | 2.83539 | 4.37618 | 4.3785 | 589 | | | |
| 27 | 17478-1-000-063-Reverse | 27.28 | 6.01467 | 5.61987 | 3.84932 | 7.7313 | 2.89031 | 4.37618 | 4.3785 | 495 | | | |
| 28 | 17478-1-Test-000-063 | 27.28 | 6.03272 | 4.77251 | 3.35382 | 6.71889 | 4.40412 | -4.37618 | 4.3785 | 498 | | | |

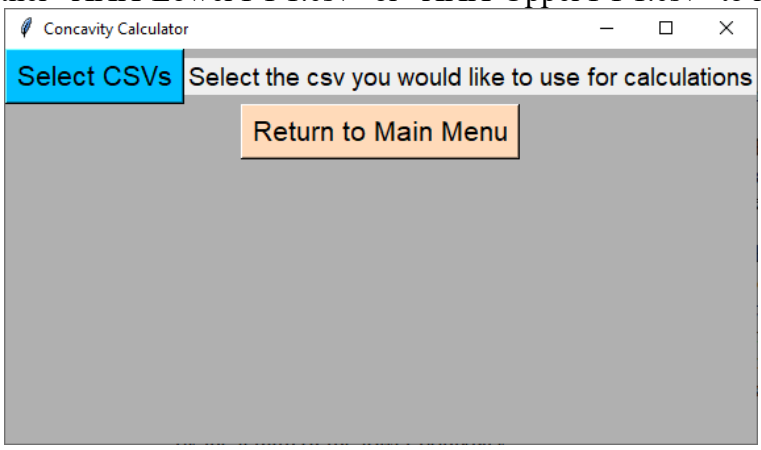
30. Additional information can be found in a folder titled "workedcsv" in the same folder as "SOFIA External Summary.csv" that will contain the CSVs used as well as a CSV that contains the x value of the data points used and the thickness calculated at those points. A box plot is generated that can be used to check for data distribution. If there is a large amount of outliers and they were not expected it is recommended that you redo the calculations using a different threshold profile or checking that your boundaries are labeled correctly. "XXX-LinesYYY.png" shows the results from the calculations showing where the steps were taken and where the shortest distance was from that point. Surface roughness ($R_a$) is listed in "XXX-SurfaceRoughnessYYY.csv" the calculation is performed using a line of best fit and Riemann sums instead of integrating (due to complexity of the interfaces varying between images an $n^{th}$ degree polynomial cannot be used accurately ). It is assumed that the lower boundary of the layer is a metal-oxide interface and the upper boundary is an oxide-mount interface.

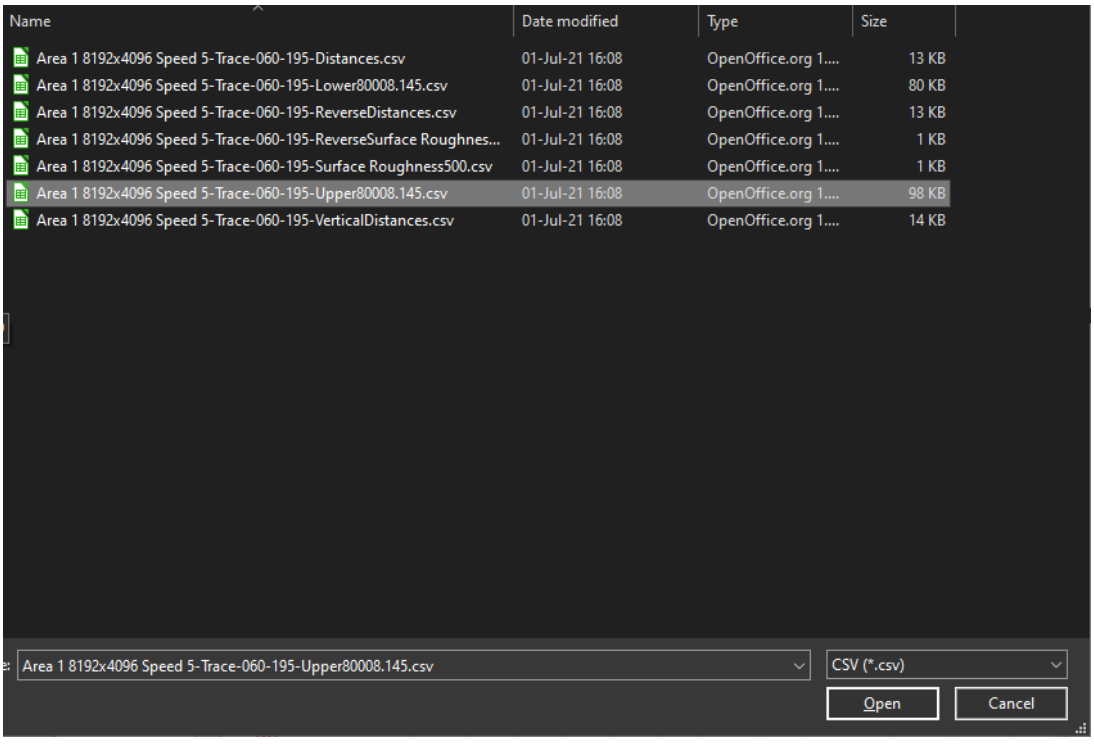
**Concavity Calculation**

1. After completing an external oxidation calculation there are a couple of CSVs formed that can be used for more calculations. One of these calculations is a concavity calculation where the shape of the interface is fitted to a polynomial and the "sharpness" of the hills and valleys are analyzed. To get started, click on the "Concavity Calculation" button on the main menu.

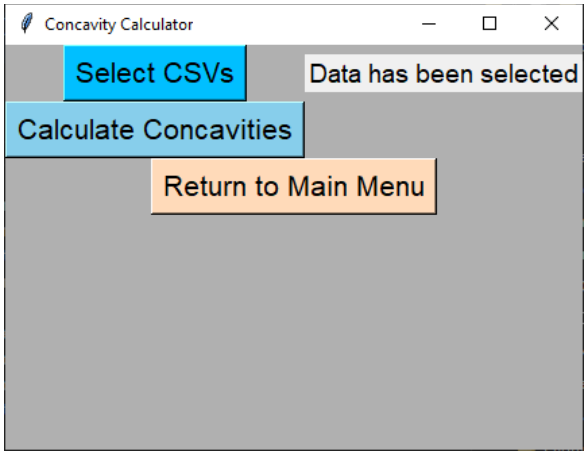



2. You will then be greeted by a screen that asks you to load CSV data. Press "Select CSVs" to open a file explorer menu to select data. Open the folder for the image you want to work with and click on either "XXX-LowerYYY.csv" or "XXX-UpperYYY.csv" to load the data.

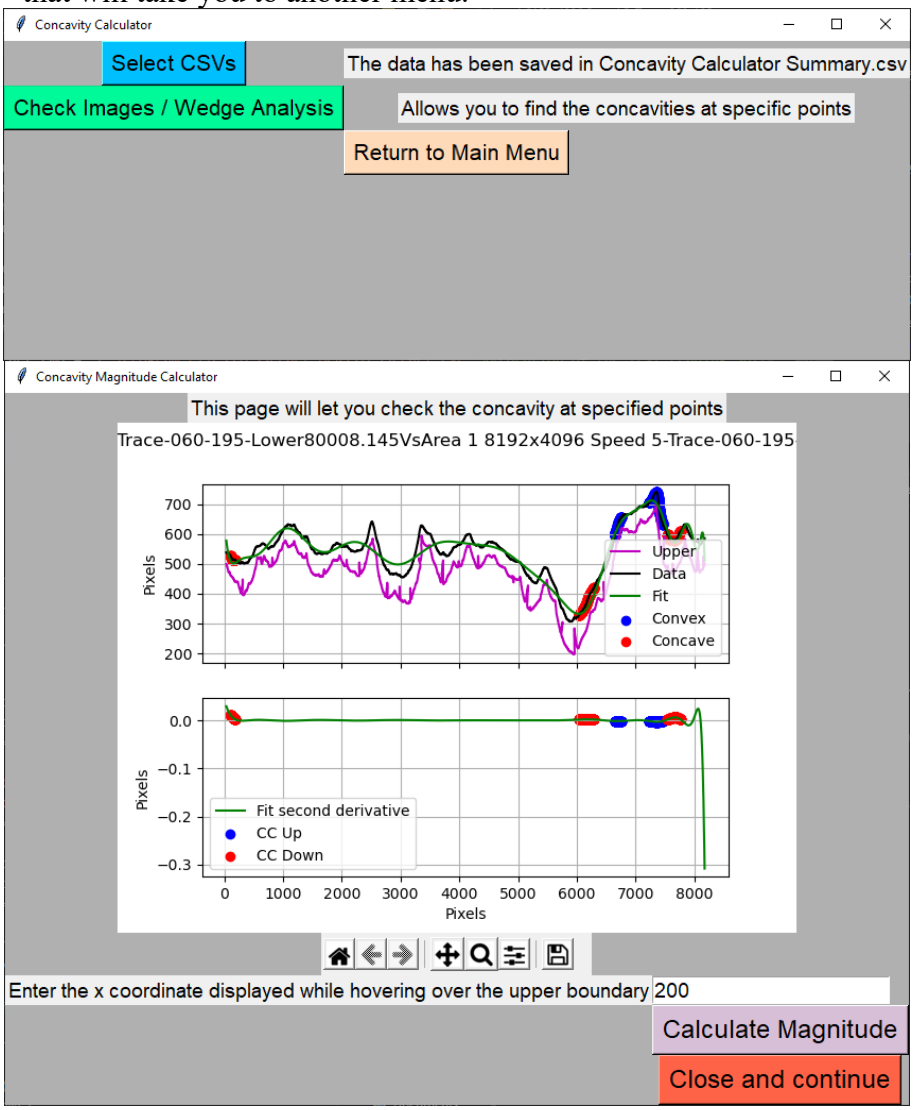


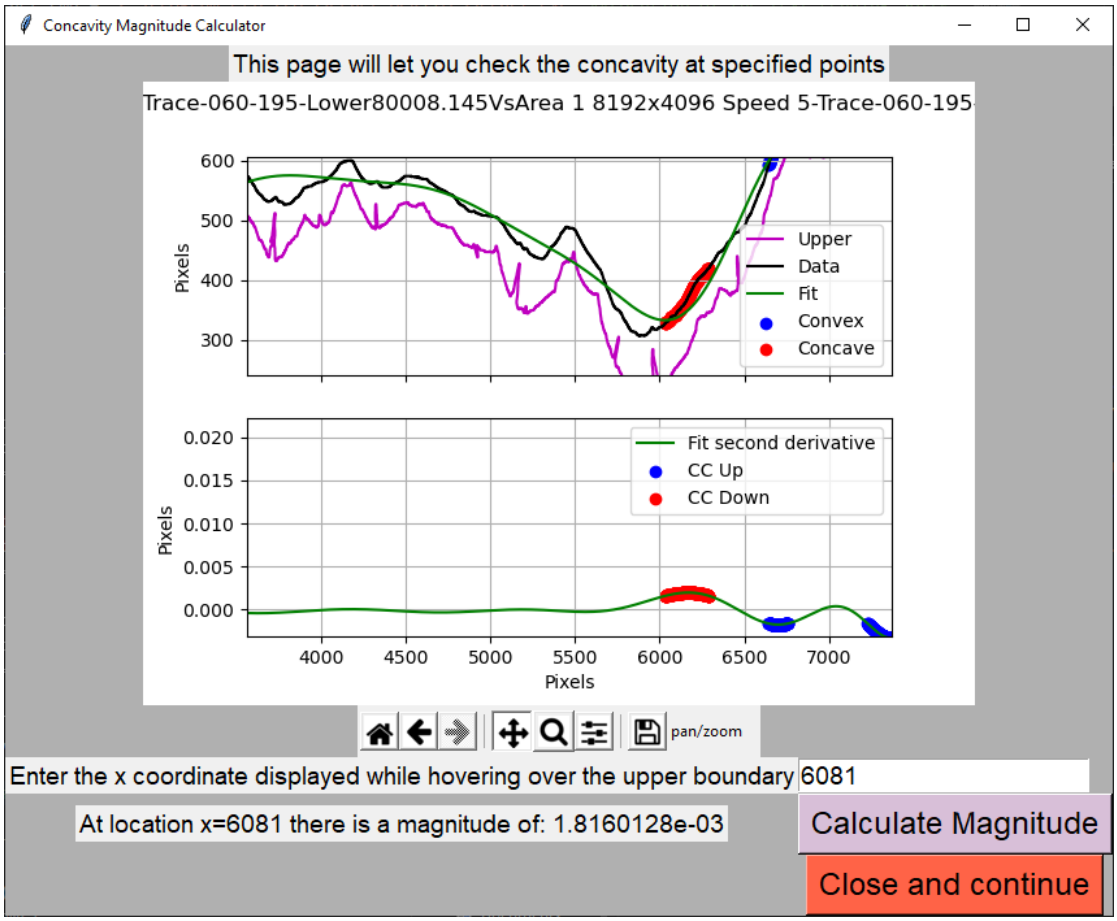
3. When the data has been loaded, you will see a new button labeled “Calculate Concavities”. Press that to perform the main set of calculations.




4. When the calculations are done you will see a new button labeled “Check Images / Wedge Analysis” that will take you to another menu.



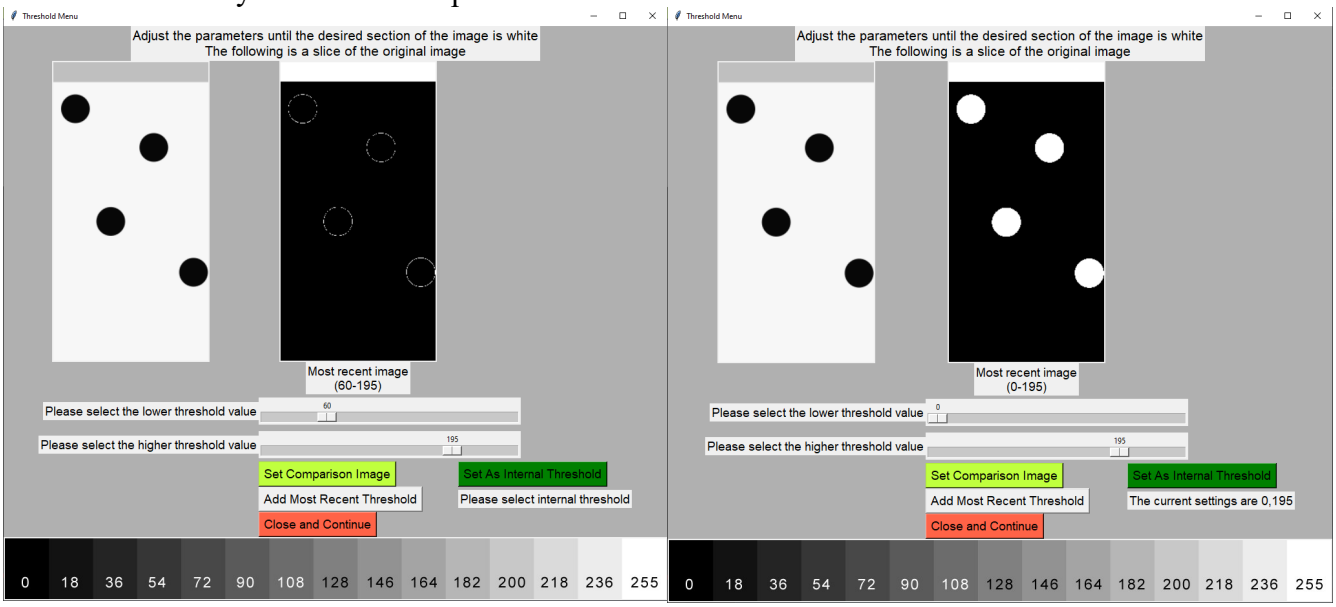
5. This menu graphs what the computer determined to be convex and concave regions. The top graph shows the upper and lower boundaries with a polynomial fit (of degree 70) applied to the upper boundary. The second derivative of that polynomial is taken to measure concavities. This is what is labeled in the second graph. The edges of the graph always have a sharp rise or drop, so the initial scale is bad. Click on the pan tool (the icon with the four arrows). You can adjust the scale of the graphs by holding the right mouse button and dragging the mouse up or down to stretch or compress the graph vertically. Moving the mouse left or right will cause the image to stretch or compress horizontally. You can pan around the image by holding the left mouse button and moving your mouse. The magnifying glass icon can be used to crop regions of the image. You can reset the view by pressing the house icon. When you move your mouse around it tells you the current x location of the mouse. This value can be entered into the entry box. When you press "Calculate Magnitude" it will calculate the magnitude of the concavity of the x value in the entry box. A status box will be created that tells you information about that x position.



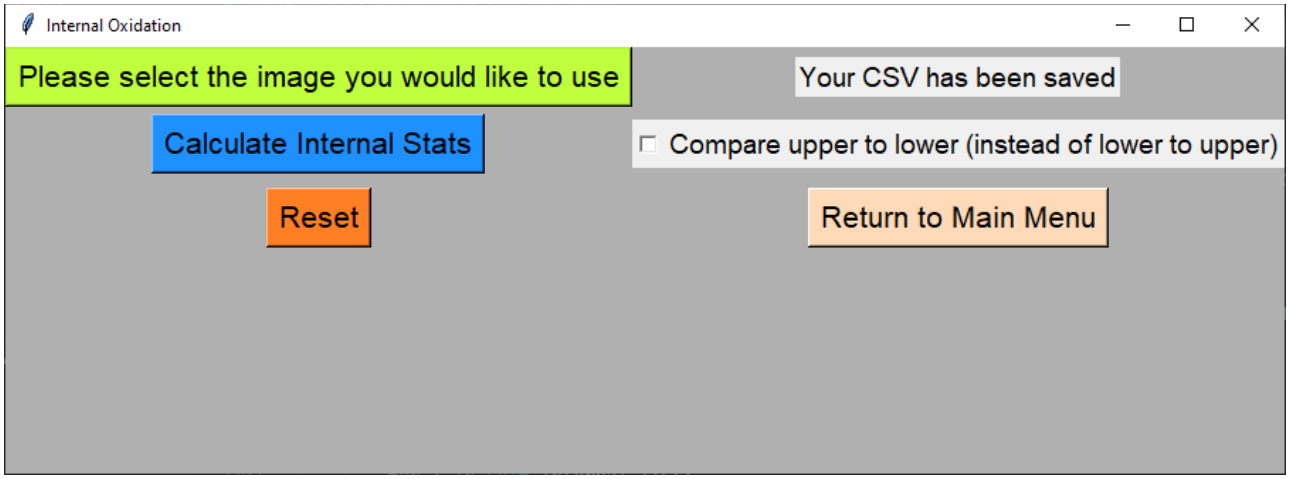

6. The results from the concavity calculations earlier can be found in the "Worked Concavity" folder where SOFIA.py is stored. They are defined as follows:
   - "XXX-Concavity.csv" – Contains information of shortest distance calculations performed for regions that were determined to be significantly concave or convex. The information from that csv is graphically represented in
   - "XXX-Concavity-Boxplot.png" – Shows side-by-side boxplots of the convex and concave regions.
   - "XXX-Concavity-Curves.png" – Shows the traces of the boundaries and highlights what regions of the upper boundary were concave and convex.

## Internal Oxidation

1. Follow steps 1-24 of External Oxidation. Notice that there is a change on the "Threshold Menu" in step 17. There is now an option to "Set as Internal Threshold." In case the upper boundary interface is not in the same threshold profile as the internal oxides, this is a required step to declare what threshold profile shows the internal oxides. The status bar below the button will indicate if you have set the profile.

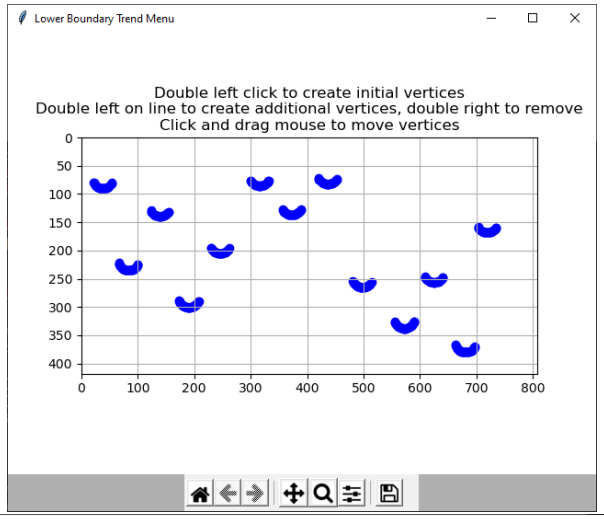


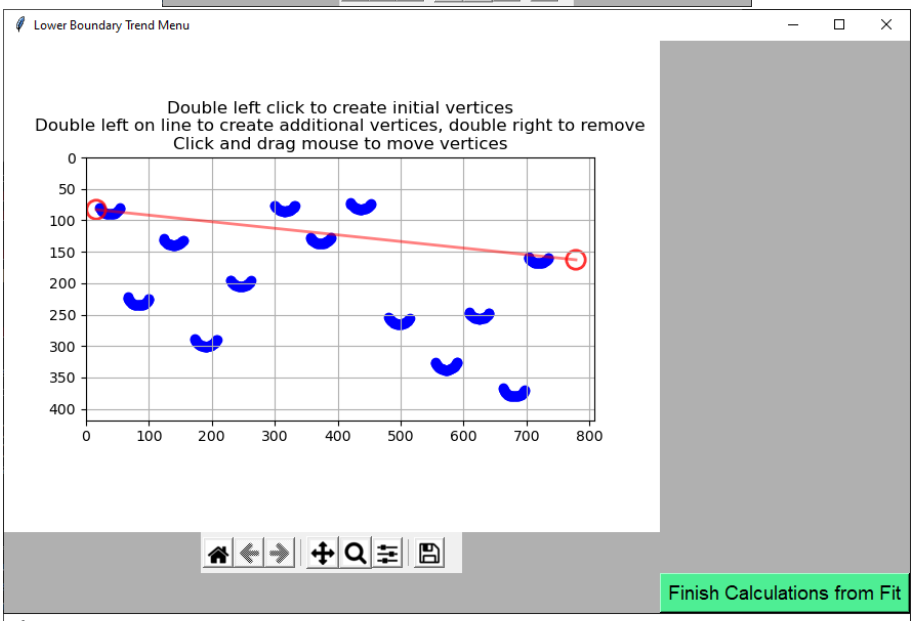

2. The process continues as normal after this. It is recommended that you declare the upper boundaries then do "Add Bulk Lower" to rapidly add the internal oxides.
3. Once the CSVs have been saved the Internal Oxidation menu will look like the following. You can check the box to make measurements from the upper boundary to the lower boundaries instead of the standard lower to upper. There is also the option to "Calculate Internal Stats" that will continue the process.

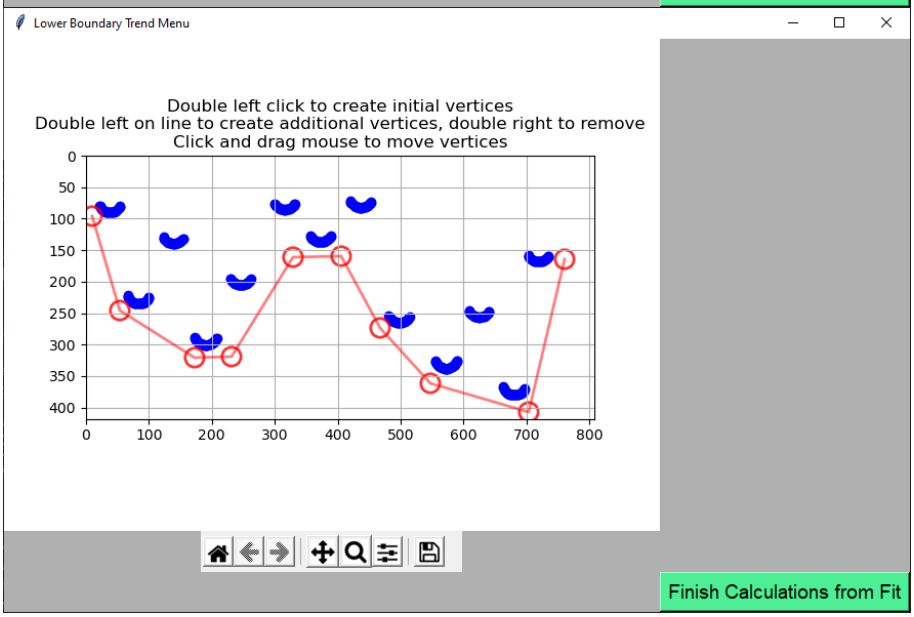



4. Pressing the button will open up a new menu called "Lower Boundary Trend Menu" which contains a plot of the lower boundaries of the internal oxides. You can interact with this plot to define the general boundary of the internal oxides. Start by double clicking with the left mouse button on one side of the image and doing the same on the other. You will now have a red line segment going across the image. Additional vertices can be added by double clicking on the line. Extra vertices can be removed by double clicking with the right mouse button. All the

vertices can be dragged around by holding down the right mouse button and moving the mouse. Do not rush the movement of new vertices as this might result in you moving the line segments instead of the vertex.



5. When you are satisfied with the general boundary you created, press “Finish Calculations from Fit” to complete the calculations for Internal Oxidation.
6. When the calculations you will find the results in a folder called “worked-internalcsv” where SOFIA.py is located. In this folder you will find several images and CSVs defined as follows:
    - “XXX.png” – Shows the upper and lower boundaries of the internal oxides. A scalebar is also added for future reference.
    - “XXX-LineBoundary.png” – Shows the position of the user-made trend line segments for the lower boundary relative to the upper and lower boundaries.
    - “XXX-Circularity.csv” – Contains information about the different internal oxide locations such as the shortest distance to the upper boundary and the circularity.
    - “XXX-Centroids.png” – Graphically shows labeled centroids to help the user see where the circularity csv did its measurements.
    - “XXX-Continuity.csv” – Contains information about the micron depth slices that span between the line segment boundary and the upper boundary. The total area of internal oxides at the depth is recorded and compared to the total area of that depth to make an approximate continuity.
    - “XXX-Slices.png” – Show the slices for the continuity csv. This should follow the trend of the user-made line segments.
    - “XXX-Line BoundaryCalc.csv” – Contains the shortest distance information of the user-made trend line segments to the upper boundary.
    - “XXX-LowerYYY.csv” and “XXX-UpperYYY.csv” – contain lower and upper boundary information respectively.
7. A general summary of the shortest distance calculations based off the line segment boundary is located in “Internal Oxidation Summary.csv” located in the same folder as SOFIA.py