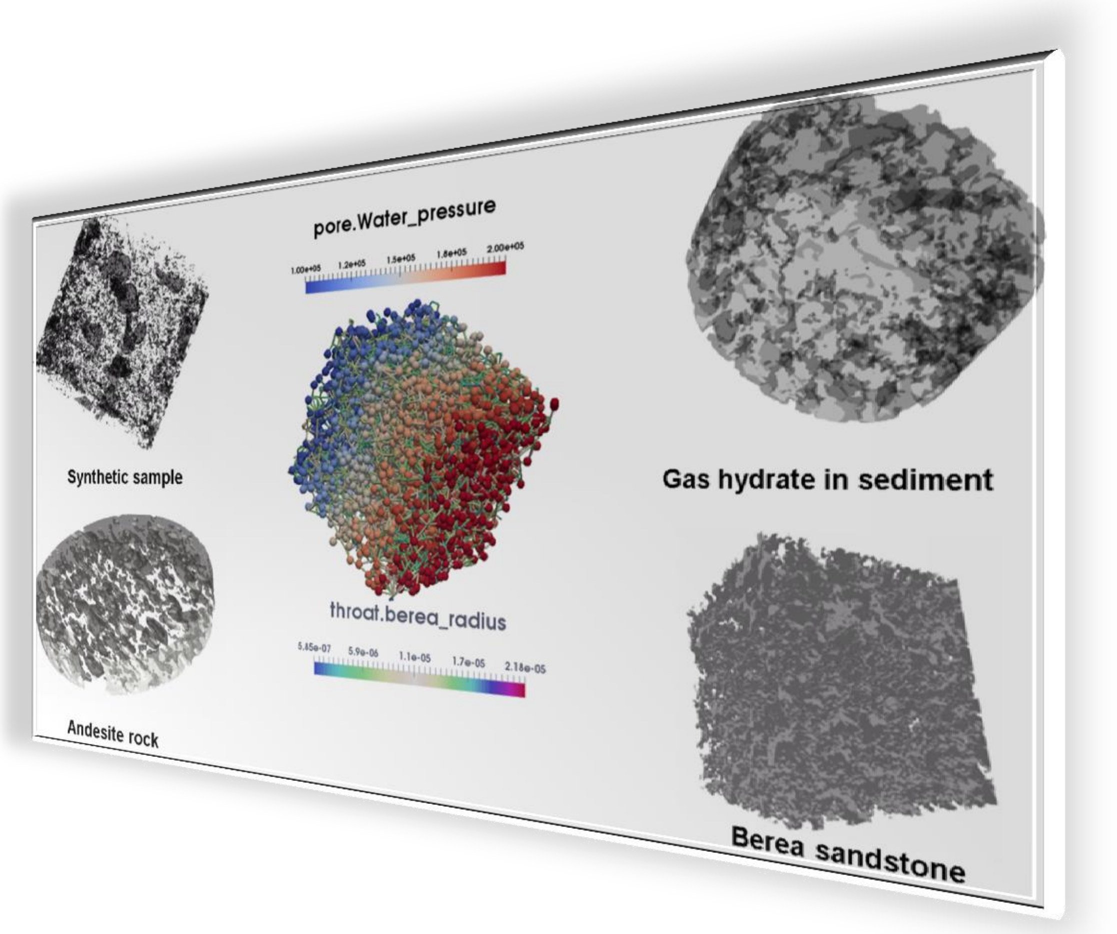


User Manual

APS
ADAPTIVE SOLUTIONS

TECHNISCHE
UNIVERSITÄT
DARMSTADT

Table of Contents

Tables

Figures

1. Introduction to CobWeb 1.0

CobWeb 1.0 is a sophisticated and practical image analysis and visualisation software based on Machine Learning (ML) techniques. It is tailored for accurate image segmentation and representative elementary volume analysis (REV) of digital rock images and geomaterials obtained from X-ray tomography imaging. The graphical user interface (GUI) is simple and intuitive, and the analysis and subsequently generated figures can be used for presentations and publication.

We hope you enjoy working with CobWeb 1.0!

Disclaimer: CobWeb 1.0 IS NOT FOR CLINICAL USE

This manual assumes that you are familiar with Microsoft Windows® operating systems. If you need help with features specific to Windows systems, please refer to the documentation supplied by your computer.

1.1 Overview

The software was developed to assist the geoscientific community. Through years of research, we came to the conclusion that software available to the community working at pore-scale analysis and modelling pore-scale community lacks accurate image segmentation approaches and is manually driven. Image segmentation is essential for generating representative pore network models or for performing pore scale simulations, which help to monitor transport processes and thermal properties within desired REVs. Discrepancies due to inaccurate segmentation of artefacts can cause anomalies and thereby lead to inaccuracies in upscaling studies. Therefore, at the core of this software, a robust workflow has been implemented to perform accurate image segmentation based on the state-of-the art machine learning libraries with minimum manual intervention.

The current version is capable of processing (reconstructed) XCT files in .tiff and .raw format. Tools to zoom in, zoom out, crop and for color scale assist in the interpretation of XCT data. Noise filters such as non-local means, anisotropic diffusion, median and contrast adjustments are implemented to increase signal to noise ratio. The user can choose from five segementation algorithms, namely kmeans, fuzzy c-means (unsupervised), support vector machine (supervised), bragging and boosting (enable classifiers) for accurate segmentation and cross-validation. Material properties like relative porosities, pore size distribution, volume fraction (pore, matrix, mineral phases) can be quantified and vizualised.

1.2 About the Manual

CobWeb is designed to be as intuitive as possible, but you might occasionally need help. To locate information on particular functions, refer to this manual which includes a comprehensive table of contents and an index to help you find the information you need.

The manual contains information about

- System requirements
- Getting started
- Importing and exporting data
- Limitations
- Index

1.3 Services

Technical Support: If none of the resources mentioned in the user manual is of help, you can contact the software support team at info@wille-geotechnik.com

Sale Support: For sales and product information and training courses, please contact our sales representatives at:

APS Antriebs-, Prüf und Steuertechnik GmbH
Tel: +49 (551) 30752-0
Fax: +49 (551) 30752-20

1.4 Feedback

We are interested in your constructive comments and feedback. If you desire any new feature which could improve your work, please get in contact with our software engineers. Send your feedback to us via our website:

http://www.wille-geotechnik.com/en/contactus.html

Or per post:
APS Antriebs-, Prüf und Steuertechnik GmbH
Götzenbreite 12
D-37124 Rosdorf
Tel: +49 (551) 30752-0
Fax: +49 (551) 30752-20

2. System Requirements

CobWeb 1.0 is a software package designed for analysis and visualisation of voxel data obtained from industrial CT instruments. It can be used for application in geosciences, animations and many other related fields. It is not suitable for CT reconstruction.

Table 1: Product information

Product name	**CobWeb**
Release	**1.0**
CT instruments[a]	- **CT reconstruction** ○ **Cone beam** ○ **Fan beam** ○ **Parallel beam**
Document ID	**CobWebUserManual-v001-en**

[a] contact APS Antriebs-, Prüf und Steuertechnik GmbH for details on CT instruments

2.1 Operating System

The software has been tested and approved for following operating systems:

Table 2: Supported operating systems

Platform	Operating System
Windows:	**Windows 7 Professional 64 bit** **Windows 8.1 Professional 64 bit** **Windows 10 Professional 64 bit**

2.2 Hardware

The volume rendering, image processing, data loading and processing capability rely on a suitable graphic card, CPU and hard drive. Therefore, we recommend a dedicated workstation with the following configuration:

Table 3: Recommended hardware settings

Description	Features
Processor	- **Minimum:** **Intel® Core™ i5, or AMD Bulldozer.** - **Recommended:** **Latest Intel or AMD multi-core processors, e.g., Intel® Core™ i7 or Xeon® E5 processors with 2.4 GHz or higher**
RAM	- **Minimum:** **CobWeb 1.0 requires a minimum of 8 GB memory** - **Recommended:**

	Data sets with 1024^3 pixels minimum 16 GB or higher **Data sets with 2048^3 pixels minimum of 32 GB or higher**
Graphics Card	**Dedicated NVIDIA or AMD graphics cards with at least 1 GB VRAM and OpenGL 3.3 support** • **CobWeb 1.0 has been tested on NVIDIA® GeForce GTX 430** • **Recommended:** ○ **NVIDIA® GeForce GTX 770 or higher** ○ **AMD FirePro™ 3D V5900 or higher** ○ **AMD Radeon™ HD 7950 or higher**

2.2.1 Display

Minimum display resolution: 1920 x 1080.

2.2.2 User Rights

Please make sure every user has user or administration rights.

2.2.3 Recommended Setup

For industrial purpose with work station or PC

- 64-bit CobWeb 1.0
- Intel® Xeon® i7 processors and 32 GB RAM
- 64-bit hardware
- 64-bit operating system

NOTE: CobWeb 1.0 should be executed on your local machine.
It is not recommended to use different types of graphic cards on the same computer.

2.2.4 Third Party Software

CobWeb 1.0 is developed using MATLAB R2015b. Therefore, an appropriate MATLAB compiler license is required to run the software. This has been included with the installation package or otherwise can be downloaded from the link given in the following table.
A plugin for additional reporting, analysis and animation has been configured in CobWeb 1.0.

Table 4: Third party applications and plugin

Product Name	Application and Version
MATLAB®	**R2015b (9.0) 64-bit windows runtime license** https://de.mathworks.com/products/compiler/matlab-runtime.html
Microsoft® Excel	**Reporting and Analysis** • Microsoft® Excel 15 (part of Microsoft® Office 2013) • Microsoft® Excel 16 (part of Microsoft® Office 2016) • **Microsoft® Office 365 versions are not supported.**
ParaView	**Animation and Volume Rendering** • ParaView 5.0.1 or higher should be installed https://www.paraview.org/download/
DSI Studio	**Animation and Volume Rendering** • DSI studio http://dsi-studio.labsolver.org/

2.2.5 Remote Access

Remote access to CobWeb 1.0 is not recommended. You should run the software locally on your own computer. If you use remote access to run CobWeb 1.0, you may encounter problems such as low performance, a corrupt user interface display, application crashes, etc.

3. Installation Instruction

3.1 MATLAB Runtime License

Step 1

- The CobWeb 1.0 application is compiled using the MATLAB 2015b compiler.
- The MATLAB Compiler Runtime (MCR) enables you to run applications compiled within MATLAB using the MATLAB Compiler.
- The MCR does not require a MATLAB license and can be used to run the MATLAB compiled program on computers which do not have MATLAB installed.

Therefore, the first step is to install MCR:

Table 5: MCR Installation

Product Name	Application and Version
Windows®	Double click the self-extracting MATLAB Runtime installer that you downloaded from the web or supplied by APS GmbH R2015b runtime will have the name MCR_R2015b_win64_installer.exe. Double clicking the installer extracts the necessary files and automatically starts the installer.

3.2 ParaView

Step 2

ParaView

- ParaView used for volume rendering.

Table 6: ParaView Installation

Product Name	Application and Version
Windows®	https://www.paraview.org/download/ Version v5.0 or higher Download ParaView-5.0.1-Qt4-OpenGL2-Windows-64bit.exe. Double clicking the installer extracts the necessary files and automatically starts the installer.

3.3 Microsoft® Excel

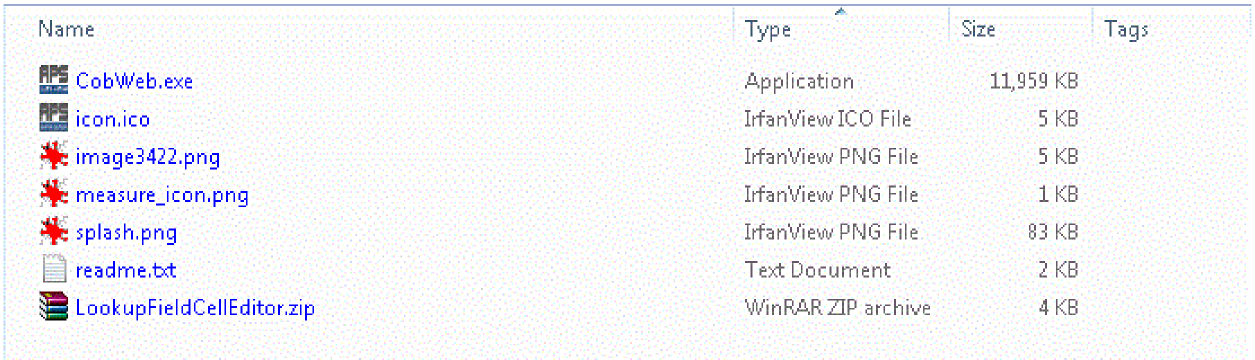
Step 3

The optional reporting functions using an Excel Add-In support the following Microsoft® Excel versions:

- Microsoft® Excel 13 (part of Microsoft® Office 2010) and higher

3.4 CobWeb

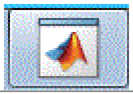
Step 4



Name	Type	Size	Tags
CobWeb.exe	Application	11,959 KB	
icon.ico	IrfanView ICO File	5 KB	
image3422.png	IrfanView PNG File	5 KB	
measure_icon.png	IrfanView PNG File	1 KB	
splash.png	IrfanView PNG File	83 KB	
readme.txt	Text Document	2 KB	
LookupFieldCellEditor.zip	WinRAR ZIP archive	4 KB	

Figure 1: CobWeb executable and associated files.

Table 7: CobWeb executable installation

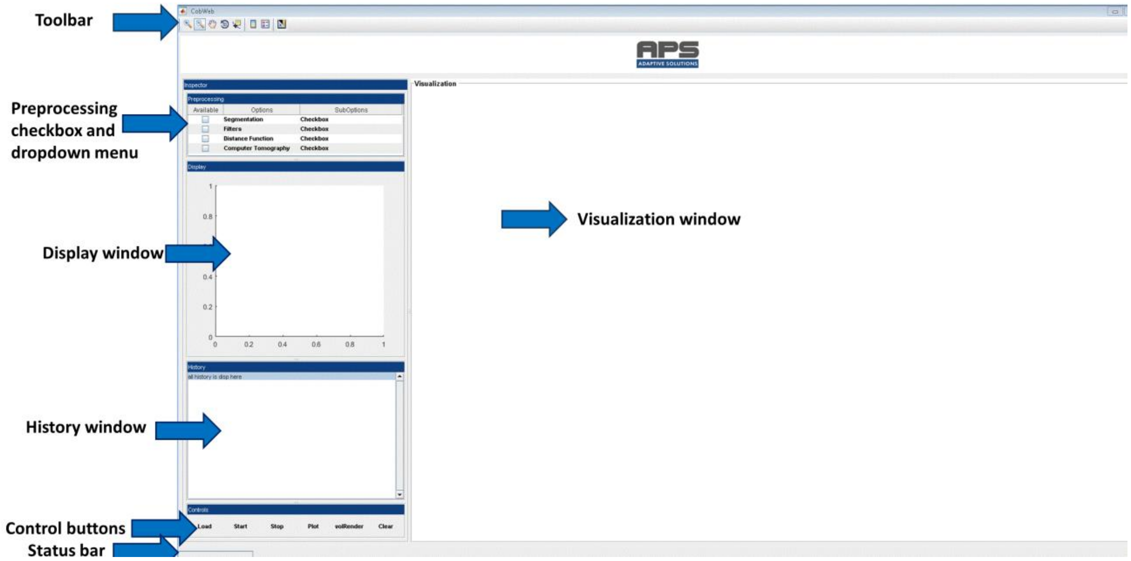
Product Name	Application and Version
Windows®	The CD or zip file supplied by APS GmbH should contain the files shown in Figure 1. Double click the CobWeb.exe executable. If the MCR shown in Step 1 has been installed properly, the APS splash screen will be displayed during the installation purpose. The splash screen will disappear after a few seconds and the CobWeb application will be docked on the toolbar. The following icon will appear: 

Maximise the application by right clicking and selecting maximise. The CobWeb 1.0 interface consists of seven main elements:

- Toolbar

- Preprocessing options
- Display window
- History window
- Control panel (buttons)
- Visualisation window
- Status bar

Figure 2 displays the main elements’ respective locations.



Available	Options	SubOptions
☐	Segmentation	Checkbox
☐	Filters	Checkbox
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

Figure 2: The CobWeb 1.0 interface after startup

4. Getting Started

4.1 CobWeb 1.0 Interface & Tools

It is essential to become familiar with various parts of the CobWeb 1.0 interface and tools before starting work with it.
The seven main parts of CobWeb 1.0 interface are:

- Toolbar
- Preprocessing options
- Display window
- History window
- Control panel (buttons)
- Visualisation window
- Status bar

4.1.1 Toolbar

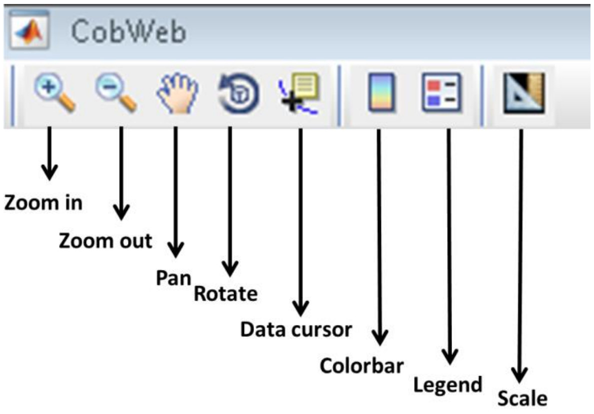


Figure 3: Tools available in the toolbar

Zoom: *The zoom in and zoom out tools are used to magnify and reduce within the 2D slice window.*

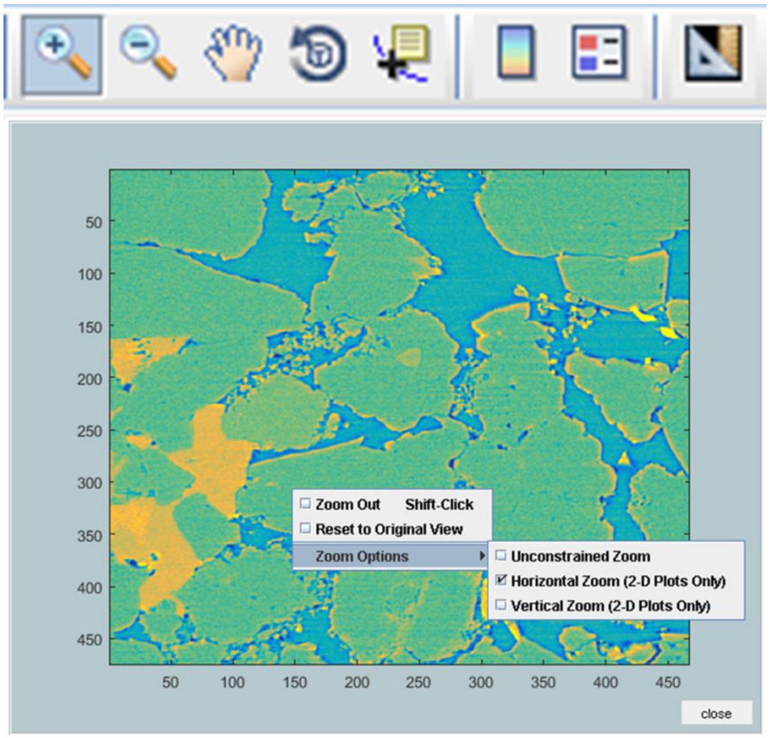


Figure 4: Zoom toolbar and right click menu options

Figure 4 displays how right clicking on the displayed image opens uimenu with other options such as vertical zoom and horizontal zoom.

- Select the **Zoom in** or **Zoom out** option from the **toolbar** by left clicking.
- Then, placing the mouse cursor on the 2D image, **left click** to zoom in and out.
- You can also zoom in and out by **left clicking,** then **holding** and **dragging left to right** on an ROI.

Pan: *The pan tool can be used to navigate within the 2D slice in a horizontal or vertical direction*.

- The pan function is **activated** by selecting it from **the toolbar** and placing it on the border of the 2D window frame and thereafter using left click to move the frame.

Rotate: *The rotate tool can be used to rotate the 3D rendered plot or 2D slice plot.*

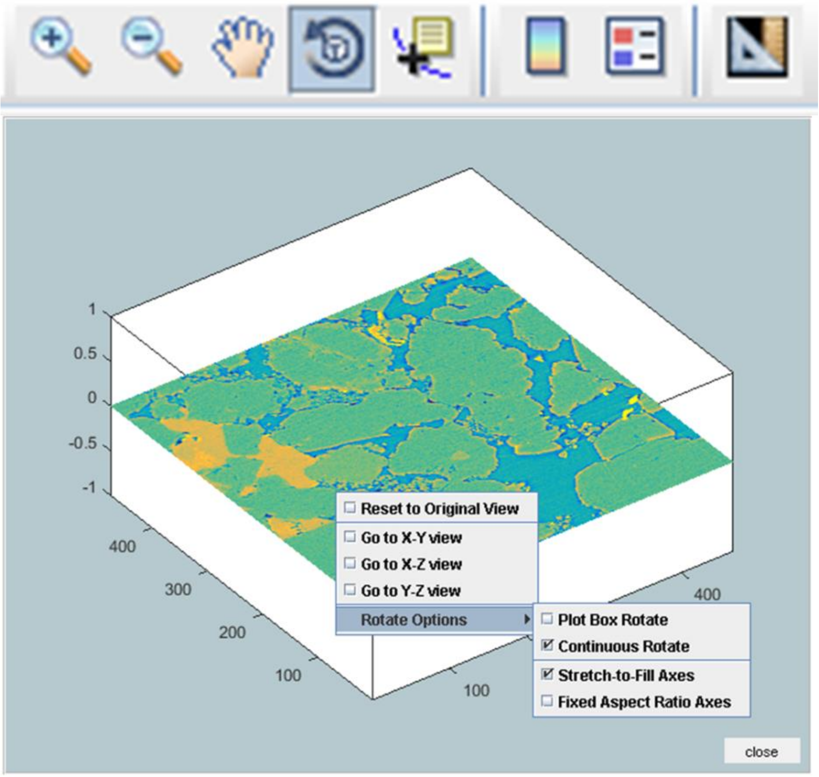


Figure 5: Rotate tool and right click menu options

- As demonstrated in Figure 5, after selecting the pan option from the toolbar, left click and hold on the displayed image and move the cursor left and right to rotate the image. The image can be rotated in a clock-wise or anti-clockwise direction.
- Right clicking opens a uimenu with further sub options (see Figure 5).

Data cursor: *The data cursor gives the position and the value of the point selected depending on the datatype 16-bit or 8-bit, as shown in Figure 6. Several options and sub options are available for the user.*

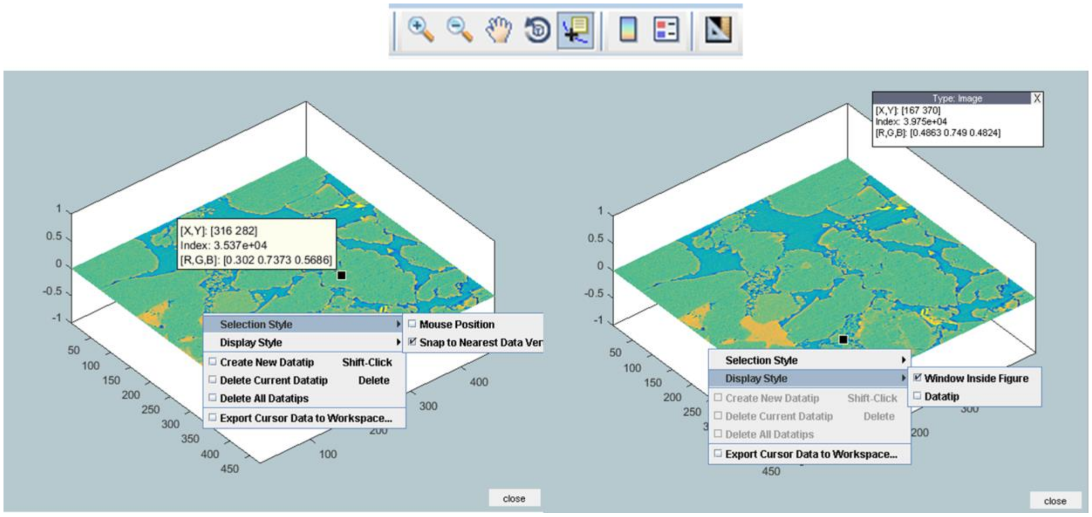


Figure 6: Data cursor tool and right click menu options. The left and right plots show the dataview option either as the datapin (left) or window (right) option.

- Figure 6 (left) shows the mouse position datapin option.
- Figure 6 (right) shows the window option.

Colorbar: *The colorbar option displays a vertical colorbar to the right of the current axes or chart. Colorbars display the current colormap and indicate the mapping of data values in the colormap.*

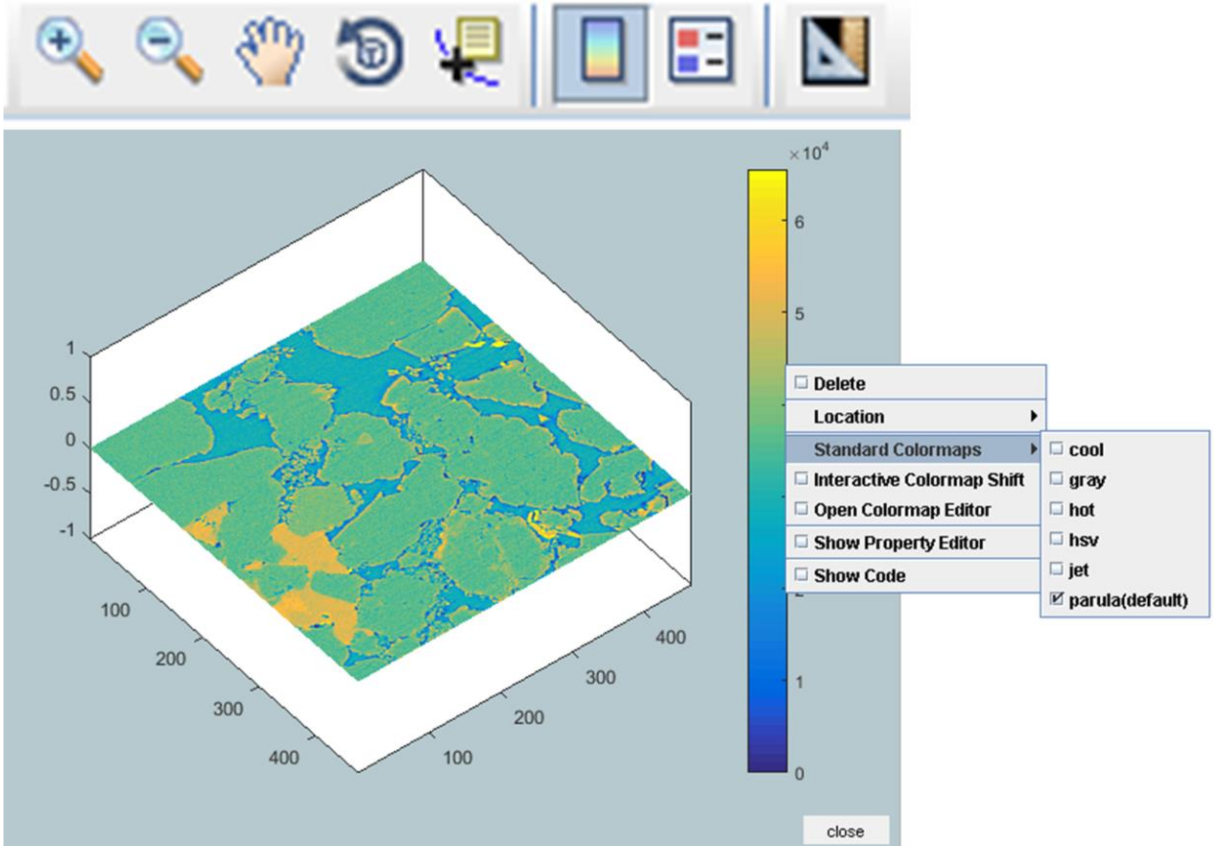


Figure 7: Colorbar tool and right click menu options

Figure 7 shows the available colormaps for visualisation.

Legend: *This option inserts a legend representing the data points.*

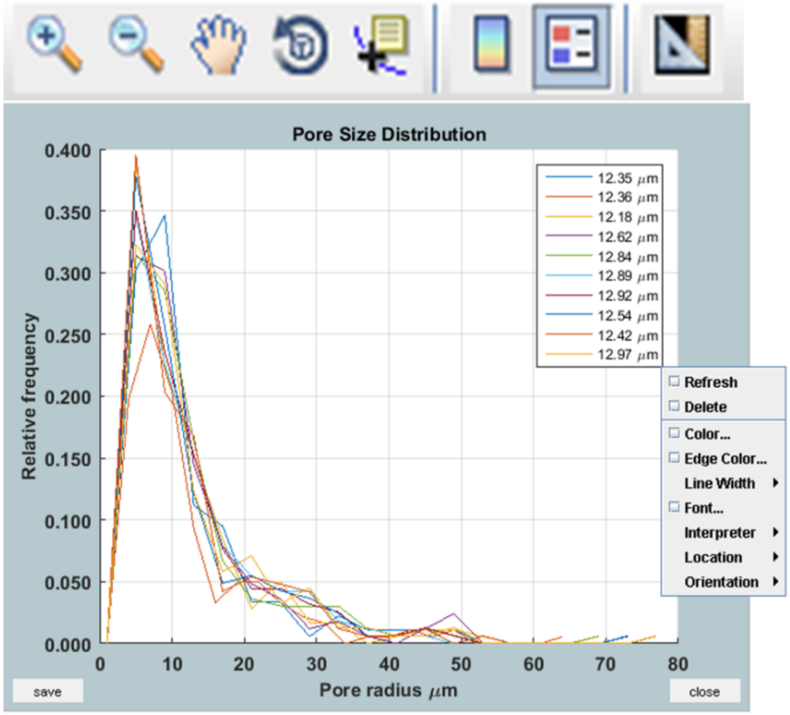


Figure 8: Legend tool and right click menu options

NOTE: Legend option activated on analysis plots, such as geometrical properties (pore size distribution, porosity, volume fraction), validation properties (entropy, roc curves and 10-fold cross validation).

Scale: *The scale tool is used to measure the distance of the XCT material. Based on the given resolution of the image, the distance is converted to millimetre scale.*

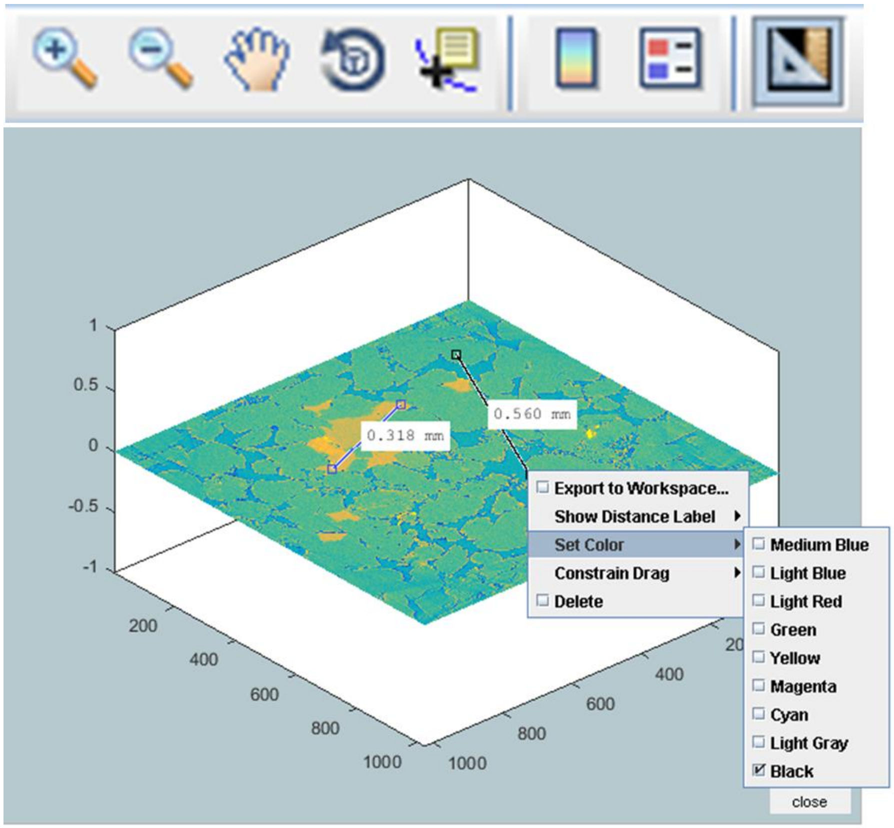
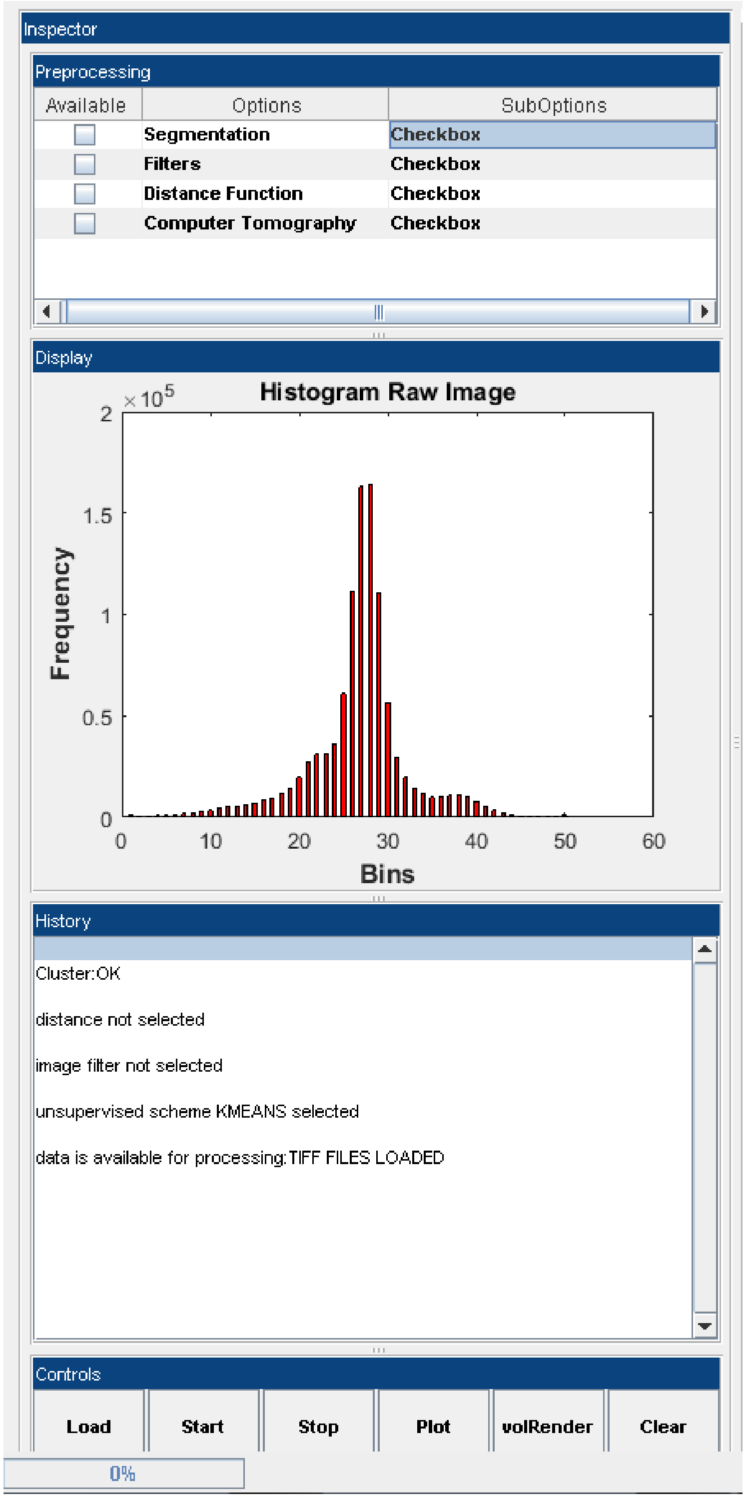


Figure 9: Scale tool and right click menu options

As shown in Figure 9, a right click on scale displays different colour shades and several sub options.

4.1.2 Inspector

The Inspector panel, which lies on the right side of the CobWeb layout (shown in Figure 10), is where the initialisation (Preprocessing panel), visualisation (Display window), information (History window) and control (Controls buttons) can be accessed.



Available	Options	SubOptions
☐	Segmentation	Checkbox
☐	Filters	Checkbox
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

Cluster:OK

distance not selected

image filter not selected

unsupervised scheme KMEANS selected

data is available for processing:TIFF FILES LOADED

Figure 10: Inspector panel and its subpanels

4.1.3 Preprocessing Panel

The preprocessing panel is a uitable which gives a list of different options and sub options. By selecting relevant checkboxes, the options can be initialised. Then, by choosing appropriate sub options, specific actions can be performed.

Segmentation: *Segmentation is an image analysis step where a grayscale image is divided into clear partitions (clusters) based on its grayscale intensity. Geometrical analysis or analysis of information such as pore size distribution, porosity, and volume fraction can be performed or extracted only from segmented images.*

To **start** the **XCT analysis** using CobWeb 1.0, it is **mandatory** to **select** the **option segmentation** and one of one of **its sub options**. **Failing** to do so will display an **error** in the history panel: "**segmentation not initialised"**.

To enable segmentation: **first, left click** to select the **checkbox** in the first column; **second,** click on the **drop-down menu** in the first row and select one of the segmentation schemes, as shown in Figure 11.

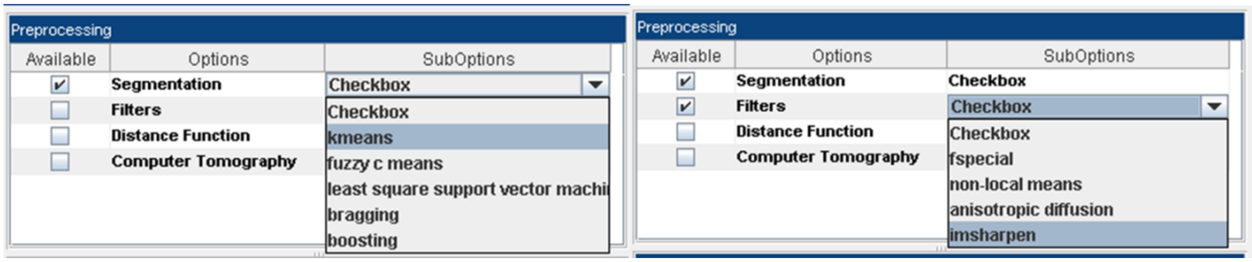


Figure 11: Left side, option -> sub options for different types of segmentation. Right side option -> sub options for different types of image filters

---

Filters: *Image filtration is a preprocessing step performed before segmentation. Image filtration helps reduce different kinds of artefact in XCT images and increases the accuracy and convergence rate of the segmentation algorithms*.

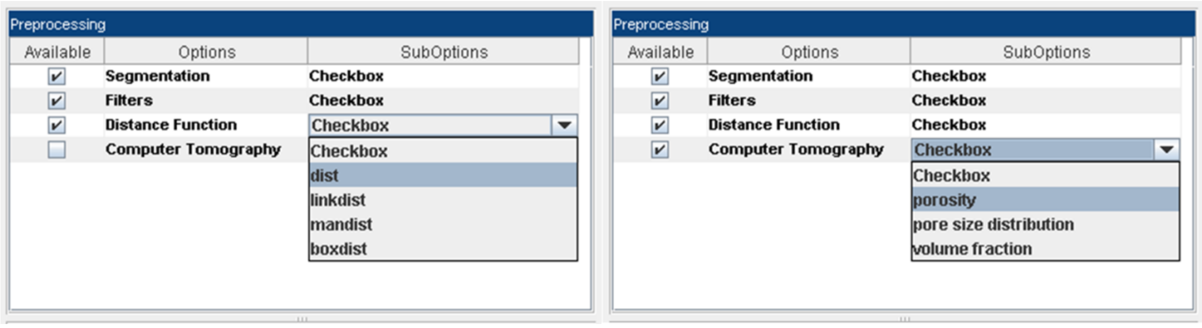
To enable the filers: **first, left click** to select the **checkbox** in the first column; **second** click on the **drop-down menu** in the second row and select one of the filter schemes as shown in Figure 11.

Distance function: *The distance function is used in combination with segmentation schemes. In general, it helps in finding distance between observations in close vicinity. In other words, it helps in segregating clusters.*

They are several options of distance function available, as shown in **Figure 12**. **By default, K-means** calculates cluster **centroids** with the **squared Euclidean distance** function.

To enable the distance functions: **first,** left click **to** select the **checkbox** in the first column; **second,** click on the **drop-down menu** in the third row and select one of the distance schemes as shown in Figure 12.

NOTE: The **distance function** option is **not applicable** to segmentation schemes **Least Square Support Vector Machine, Bragging, Boosting**.



Available	Options	SubOptions
☑	Segmentation	Checkbox
☑	Filters	Checkbox
☑	Distance Function	Checkbox
☐	Computer Tomography	

Available	Options	SubOptions
☑	Segmentation	Checkbox
☑	Filters	Checkbox
☑	Distance Function	Checkbox
☑	Computer Tomography	Checkbox

Figure 12: Left side, option -> sub options for different types of distance functions. Right side, option -> sub options of geometrical characteristics

Computer Tomography: *Geometrical analysis such as porosity, pore size distribution and volume fractions (pore, mineral and matrix) can be obtained for a chosen 2D or complete 3D segmented stack.*

The geometrical parameters can be calculated only after segmentation has been completed. To view the respective geometrical parameter, select the **checkbox** beside the option *computer tomography* with **left click,**. **then** click on the **drop-down menu** to select the relelvant sub option as shown in Figure 12. Thereafter, **click** the **plot** button in the **controls** panel.

NOTE: Geometrical parameters can also be plotted by placing the **cursor** on the **segmented slice**, **right click** and navigate to the respective option as shown in Figure 13.

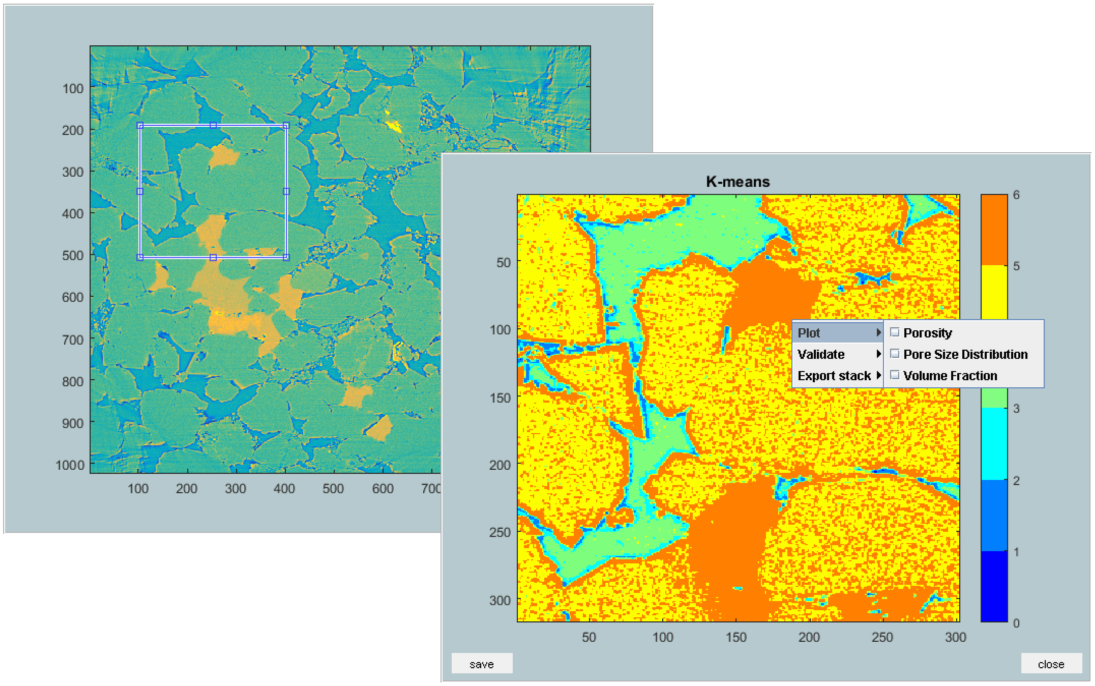
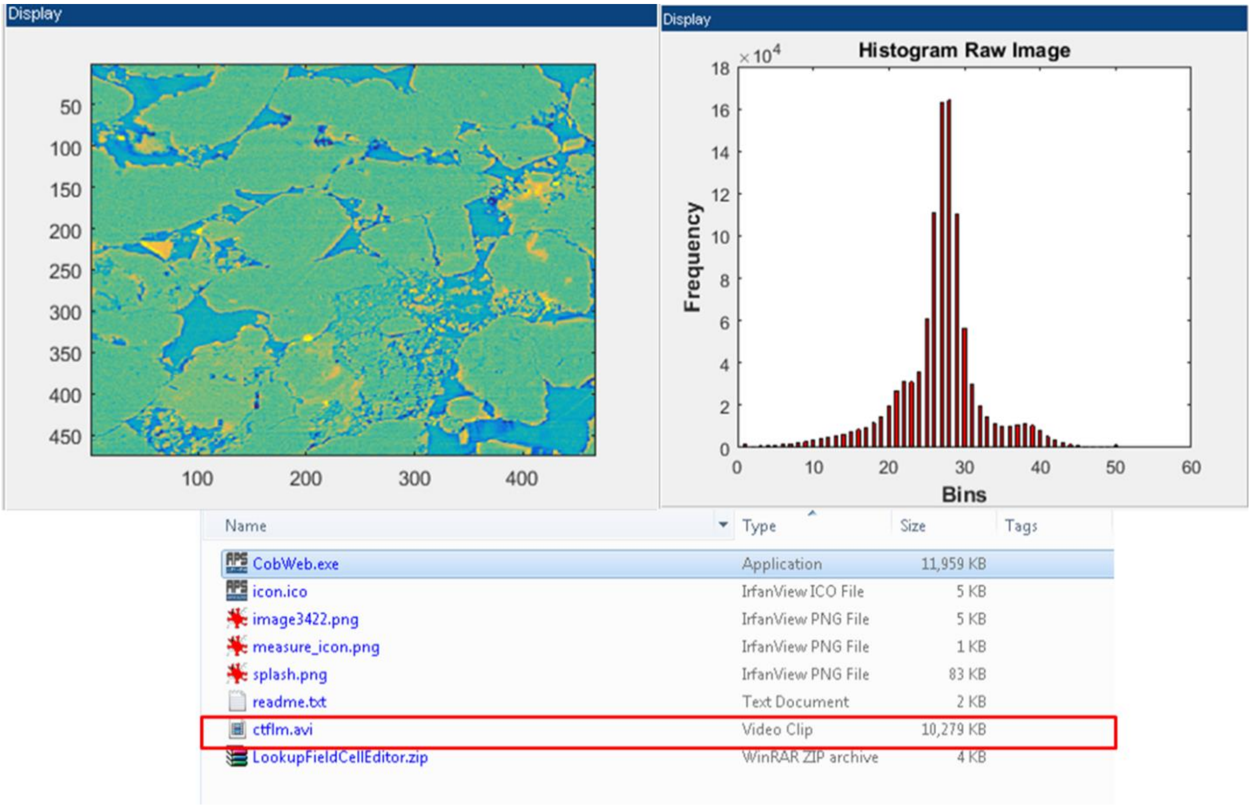


Figure 13: Evoking geometrical parameters with a right click

4.1.4 Display Window

The display window can be used to get an overview of the XCT raw images and histogram characteristics. Once the XCT stack has been loaded, at the first instance a film of 2D slices is displayed shown in the left plot in Figure 14. The film is stored by default in the base folder, which is marked with a red box in Figure 14. Once the film is completed a histogram plot of the last raw image is displayed, as shown in Figure 14.

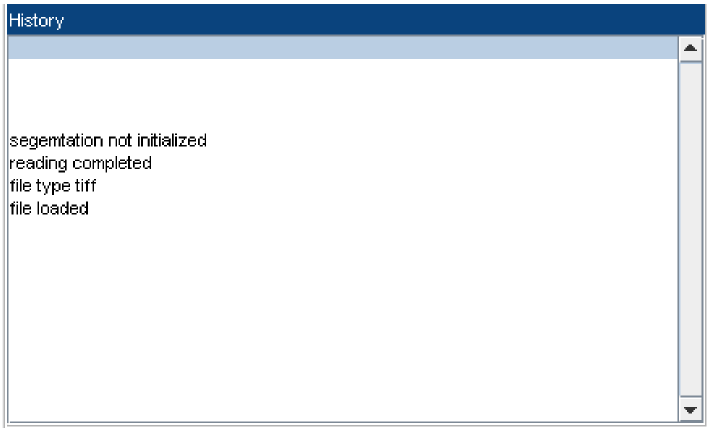


Name	Type	Size	Tags
CobWeb.exe	Application	11,959 KB	
icon.ico	IrfanView ICO File	5 KB	
image3422.png	IrfanView PNG File	5 KB	
measure_icon.png	IrfanView PNG File	1 KB	
splash.png	IrfanView PNG File	83 KB	
readme.txt	Text Document	2 KB	
ctflm.avi	Video Clip	10,279 KB	
LookupFieldCellEditor.zip	WinRAR ZIP archive	4 KB	

Figure 14: CobWeb 1.0 Display window displays XCT film of the 2D slices and histogram characteristics of the XCT images. The XCT film is saved in the base folder in .avi format.

4.1.5 History Panel

The history panel displays information about the parameters selected, possible errors and possible suggestions.



```
segemtation not initialized
reading completed
file type tiff
file loaded
```

Figure 15: CobWeb 1.0 history window

4.1.6 Control Panel

The control panel contains six buttons and a status bar. The buttons turn red during processing and turn transparent once processing has been finished. The progress can also be monitored in the status bar.

Load: Clicking on the load button allows the XCT stack or images in RAW and TIFF format to be loaded.
Start: The Start button initiates processing.
Stop: The Stop button stops the execution of the process. The user needs to start again from step **Load**.
Plot: The Plot button plots the respective analysis in the visualisation
VolRender: Plots the 3D volume rendered plot of the XCT slices.
Clear: Clear all information.

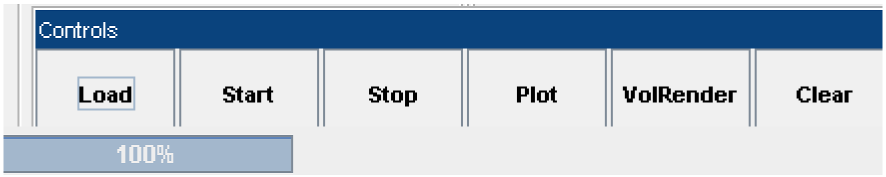


Figure 14: Control panel of the CobWeb 1.0

NOTE: The stop function does not always stop execution for files that run a long time or files that call built-ins or MEX-files that run a long time.

---

5. Demonstration

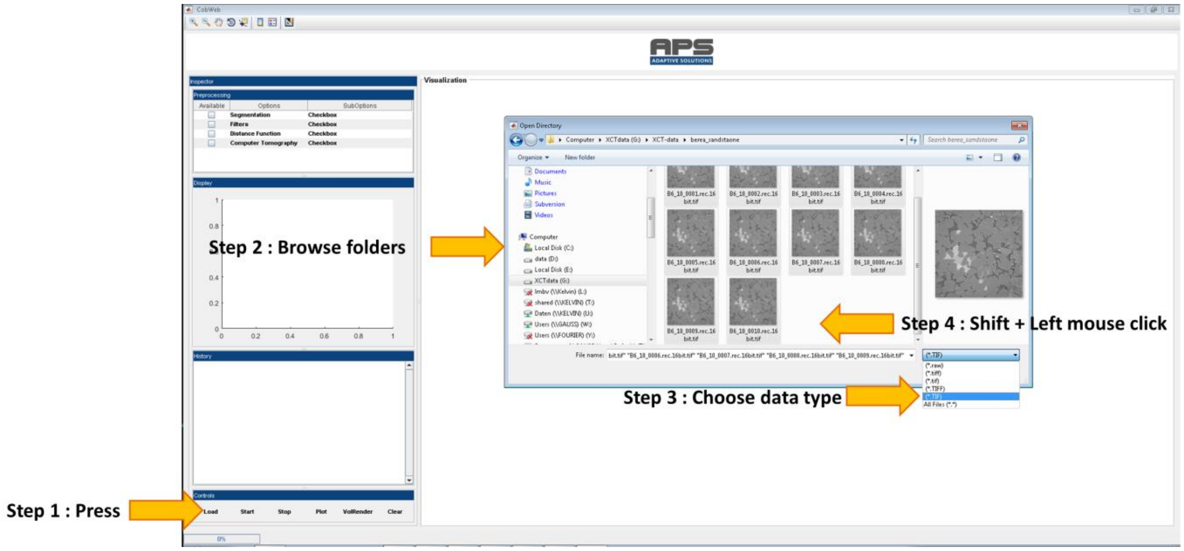
This section will discuss step-by-step how to read, processes and analyse XCT data using CobWeb 1.0. All operations are performed using the **Control Buttons** in the **Control Panel**.

5.1 Loading TIFF Data

CobWeb 1.0 can only read the data types specified in Table 9.

Table 8: Data types

Data Type	
Image Slices	
TIFF	grayscale (8 bit, 16 bit)
Volume	
TIFF	grayscale (8 bit, 16 bit)
RAW	signed/unsigned 8 bit integer
RAW	signed/unsigned 16 bit integer
RAW	signed/unsigned 32 bit integer (20 bit effective range)



Step 1 : Press

Step 2 : Browse folders

Step 3 : Choose data type

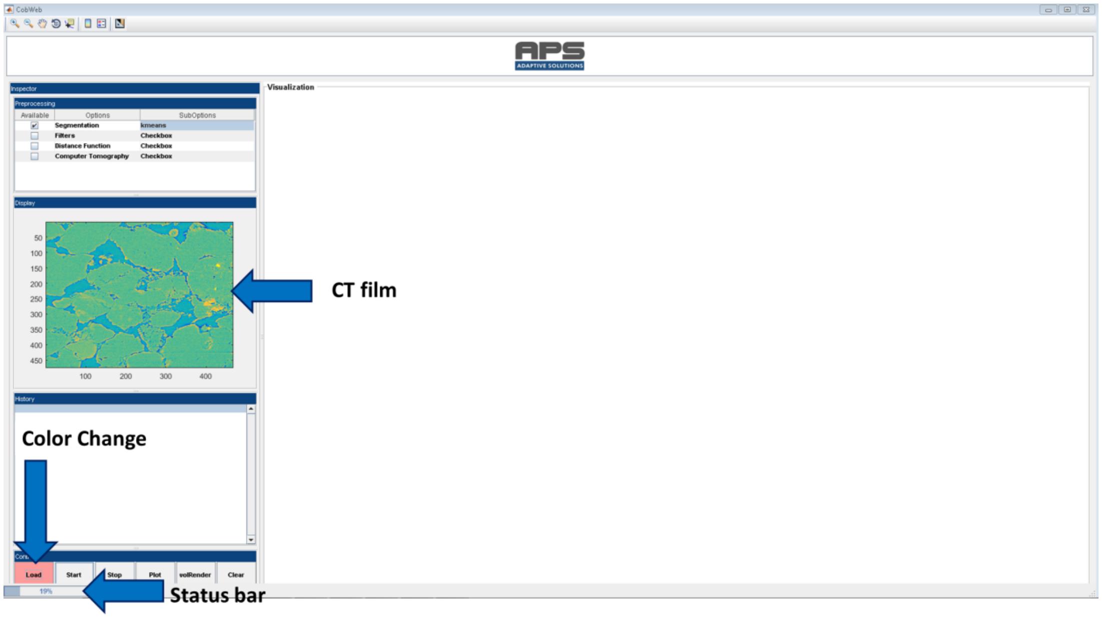
Step 4 : Shift + Left mouse click

Figure 15: The figure schematically denotes the steps to load TIFF files in to CobWeb 1.0

TIFF image files and TIFF stacks (volume) can be loaded in CobWeb 1.0. CobWeb 1.0 can only handle grayscale XCT files.

- Step 1 (Figure 15): **Left click** the **Load** button. This will open a file explorer panel.
- Step 2 (Figure 15): Browse to the location of the TIFF files.

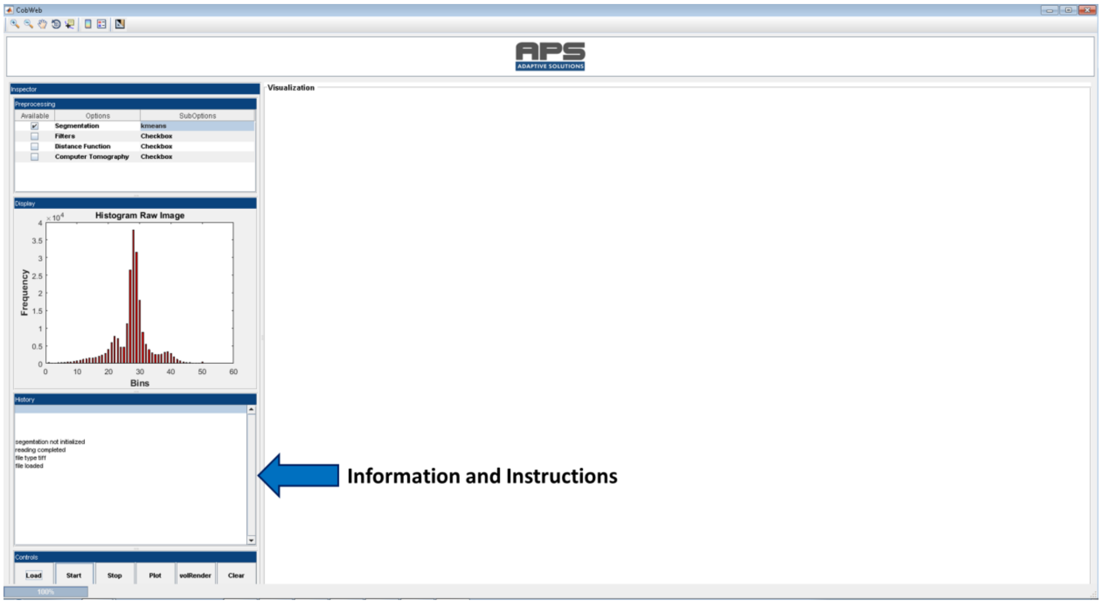
- Step 3 (Figure 15): From the drop-down menu, choose either TIFF file type or the All files option to display tiff files or all files, respectively.
- Step 4 (Figure 15): By clicking the Shift key on your keyboard + left click, the desired number of slices can be selected. Then click on the OK button on the explorer panel.
- The loading process can be **abandoned** by clicking on the **cancel** button.



Available	Options	SubOptions
☑	Segmentation	kmeans
☐	Filters	Checkbox
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

Figure 16: Loading process

- Figure 16: During the loading process, the **Load** button turns **red.**
- Figure 16: The loading process can be **monitored** using the **status bar.**
- Figure 16: The display window displays slices (2D film) during the loading process.



Available	Options	SubOptions
☑	Segmentation	kmeans
☐	Filters	Checkbox
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

```
segemtation not initialized
reading completed
file type tiff
file loaded
```

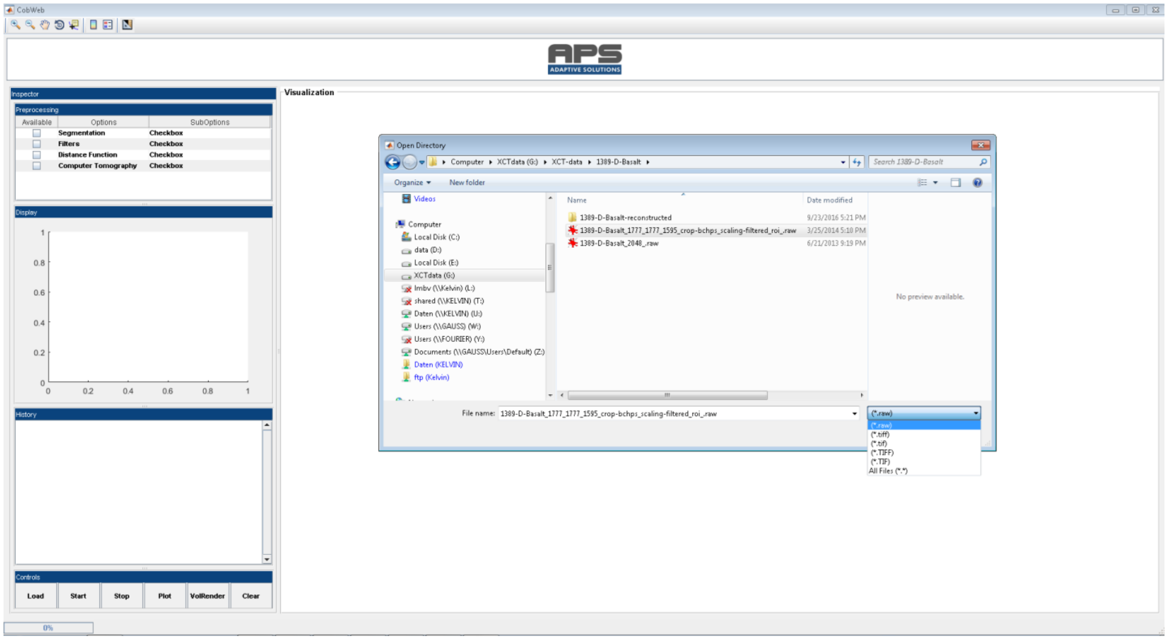
Information and Instructions

Figure 17: Files loaded

- Figure 17: The colour of the **Load** button turns transparent when the loading/reading is finished.
- Figure 17: Information, such as the data type and the next steps, is displayed in the history panel.

5.2 Loading RAW Data

NOTE: The dimension and the data type of the 3D stack should be known beforehand.

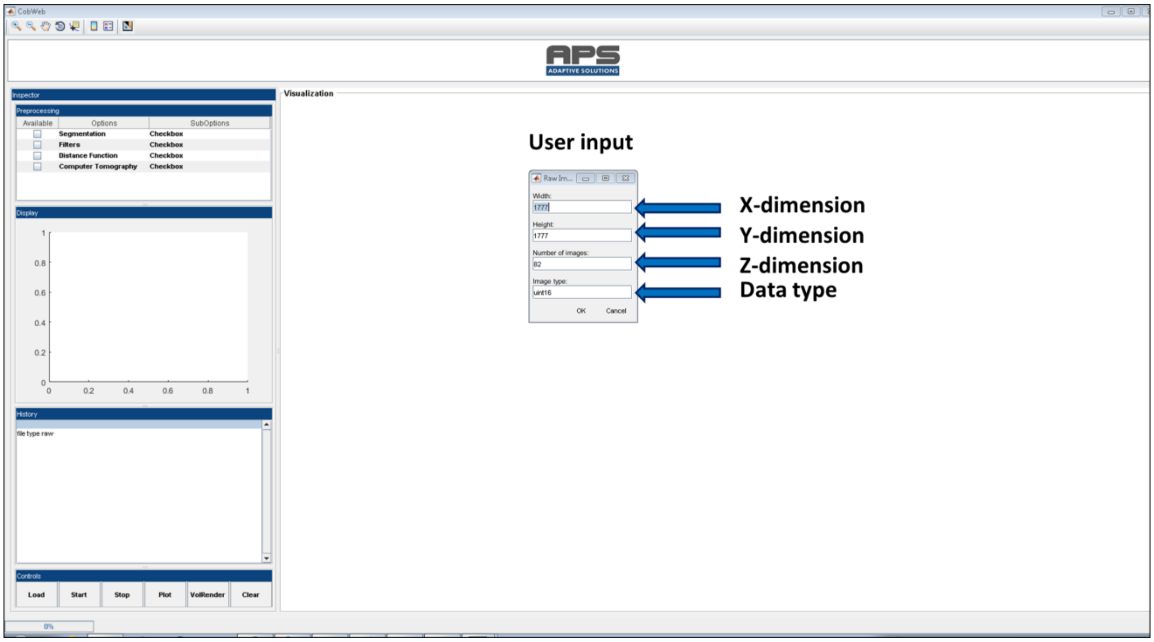


File name: 1389-D-Basalt_1777_1777_1595_crop-bchps_scaling-filtered_roi_.raw

(*.raw)

Figure 18: Loading a RAW file

- RAW files can be loaded in a similar manner to that shown in Figure 15.
- Figure 18: Instead of TIFF, the **RAW option** has to be selected from the **drop-down menu**.
- The loading process can be **abandoned** by clicking the **cancel button** or **closing the pop-up menu**.



file type raw

User input

Width: 1777

Height: 1777

Number of images: 82

Image type: uint16

X-dimension

Y-dimension

Z-dimension

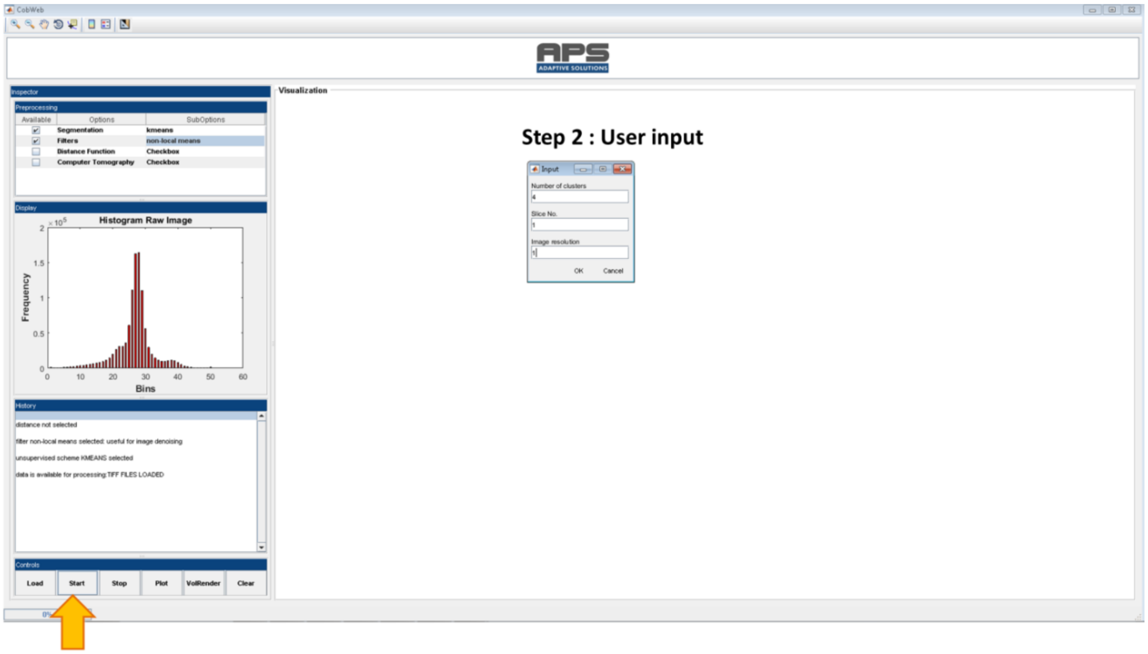
Data type

Figure 19: Dimensions of RAW data are to be given by the user

- Once the correct file has been selected, a **pop-up menu appears** where the dimensions of the **Width (X-dimension), Height (Y-dimension), Number of images ((Z-dimension)** and **data type** have to be **entered by the user,** as shown in Figure 19.

5.3 Image Processing

After loading the relevant file, the next step is to start processing.



Available	Options	SubOptions
☑	Segmentation	kmeans
☑	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

```
distance not selected
filter non-local means selected: useful for image denoising
unsupervised scheme KMEANS selected
data is available for processing:TIFF FILES LOADED
```

Step 2 : User input

Number of clusters: 4

Slice No.: 1

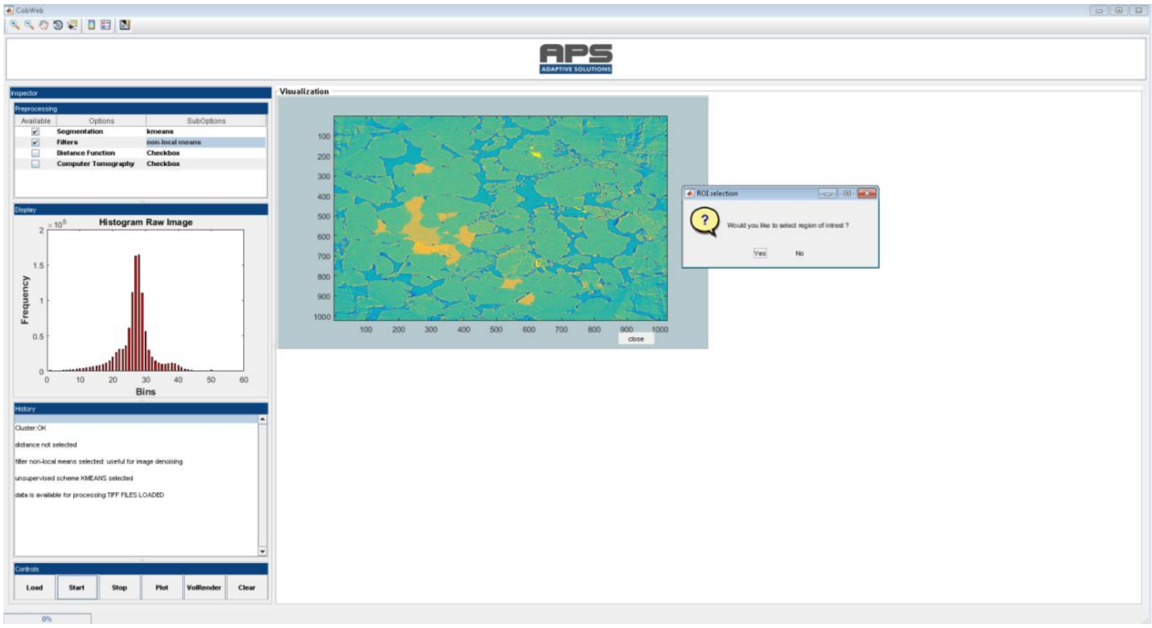
Image resolution: 1

Step 1 : Press

Figure 20: Processing XCT data

- Step 1 (Figure 20): **Click on the Start button** to initialise image processing
- Step 2 (Figure 20): Enter the initializing parameters in the pop-up menu.
    - Cluster – Integer value
    - Slice number – Integer value
    - Image resolution – Integer value (in micrometre)

5.3.1 Representative Elementary Volume Selection



Available	Options	SubOptions
☑	Segmentation	kmeans
☑	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

Cluster:OK

distance not selected

filter non-local means selected: useful for image denoising

unsupervised scheme KMEANS selected

data is available for processing:TIFF FILES LOADED

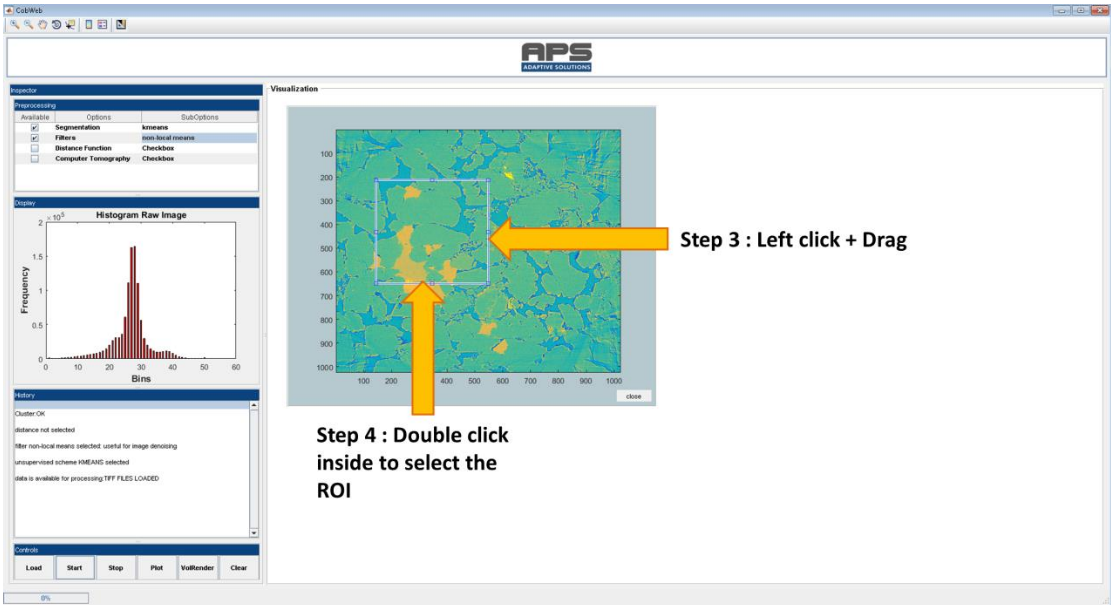
ROI selection

Would you like to select region of intrest ?

Figure 21: ROI selection pop-up menu

Once the initiating parameters are correctly entered:

- Figure 21: ROI selection option pop-up
    - The **Yes** option **activates** the **crop settings**
    - Selecting the **No** option means the **complete image** will be **processed**



Available	Options	SubOptions
☑	Segmentation	kmeans
☑	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

Cluster:OK

distance not selected

filter non-local means selected: useful for image denoising

unsupervised scheme KMEANS selected

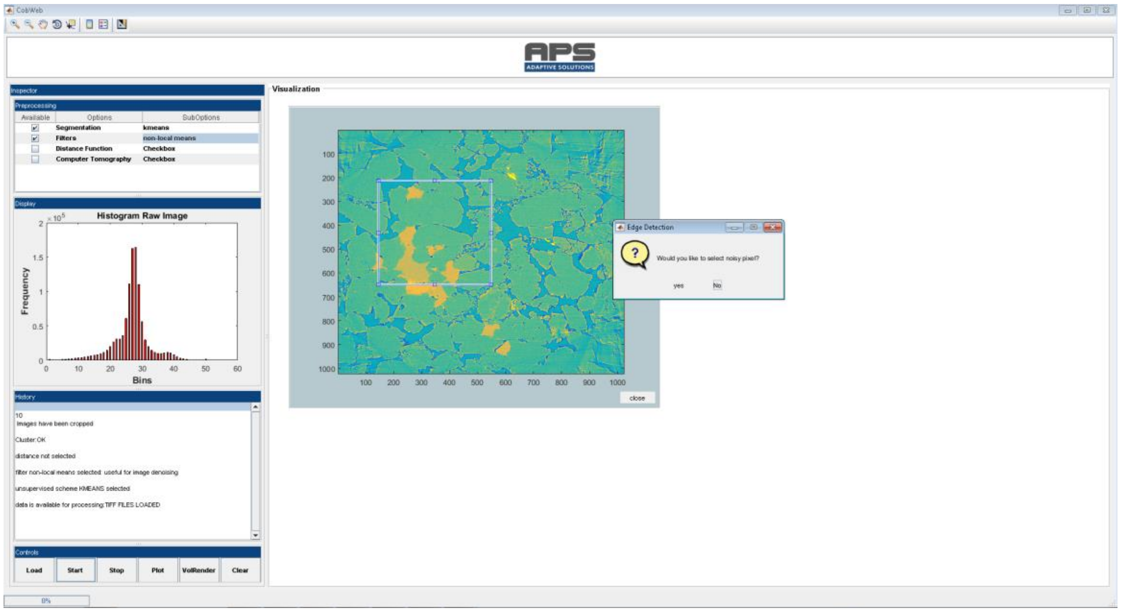
data is available for processing:TIFF FILES LOADED

Step 3 : Left click + Drag

Step 4 : Double click inside to select the ROI

Figure 22: ROI cropping

- Step 3 (Figure 22): ROI can be fixed (selected) by **dragging the bounding box** to the desired size using **left click**.
- Step 4 (Figure 22): Double click inside the bounding box to crop the ROI region.



Available	Options	SubOptions
☑	Segmentation	kmeans
☑	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

```
10
 Images have been cropped
Cluster:OK
distance not selected
filter non-local means selected: useful for image denoising
unsupervised scheme KMEANS selected
data is available for processing:TIFF FILES LOADED
```

Would you like to select noisy pixel?

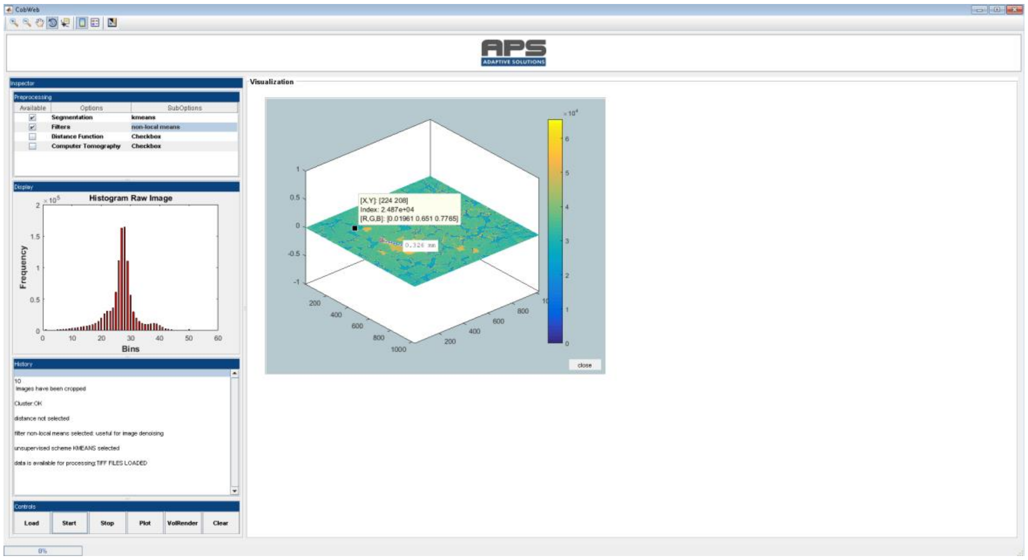
Figure 23: Noise pixel selection

- As shown in Figure 23, there is a possibility to assist the segmentation algorithm by giving a priori information about the noisy pixel. This option is **not useful for REV/ROI analysis**.
- Figure 23: This step can be **ignored** by clicking the default option **No**.

5.3.2 Image Inspection

Limitation: To view the image characteristics, the Start process must be interrupted.

- This is done by **closing the pop-up window** in Figure 21
- Doing so breaks the processing chain and thus the image characteristics can be inspected using toolbar options as shown in Figure 24.
- A **disadvantage** is that **processing** must be **initialised again** by clicking the start button (see section 6.3 for more information).



Available	Options	SubOptions
☑	Segmentation	kmeans
☑	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

```
10
 Images have been cropped

Cluster:OK

distance not selected

filter non-local means selected: useful for image denoising

unsupervised scheme KMEANS selected

data is available for processing:TIFF FILES LOADED
```

```
[X,Y]: [224 208]
Index: 2.487e+04
[R,G,B]: [0.01961 0.651 0.7765]
```

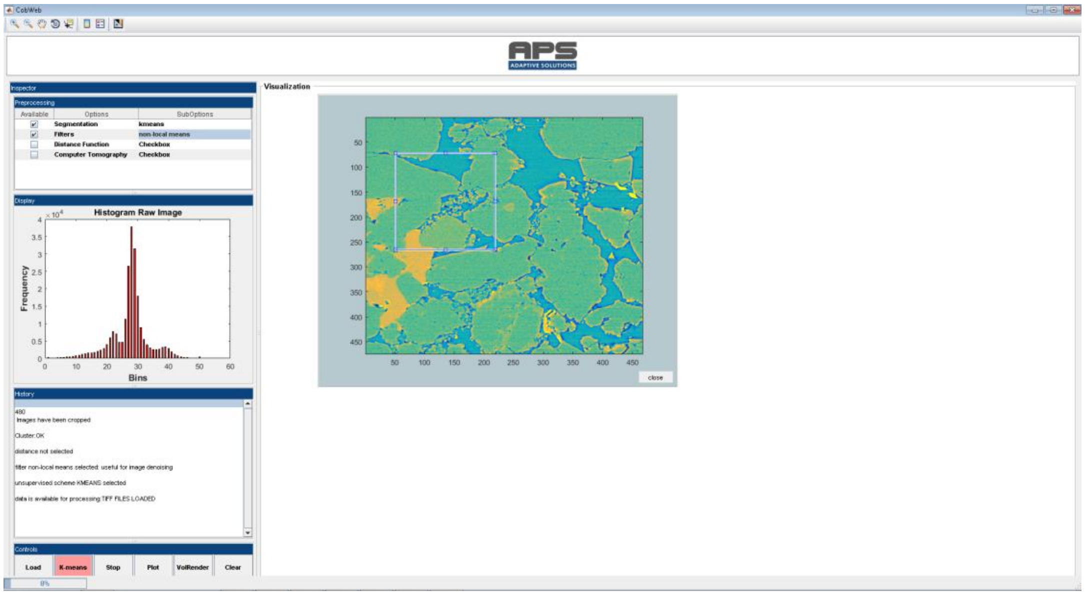
Figure 24: Image inspection

5.3.3 Image Segmentation – Unsupervised Machine Learning Techniques

The bullet points mentioned below are **relevant** if the **algorithms K-means and Fuzzy C-means** are **chosen** in the **preprocessing uimenu**.

Brief description: *The user must input the number of clusters. Based on the input (numerical value), the REV or the complete stack is segmented.*

- Once the steps specified from 6.3 to 6.3.1 are performed, the image filtration and image segmentation starts.



Available	Options	SubOptions
☑	Segmentation	kmeans
☑	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

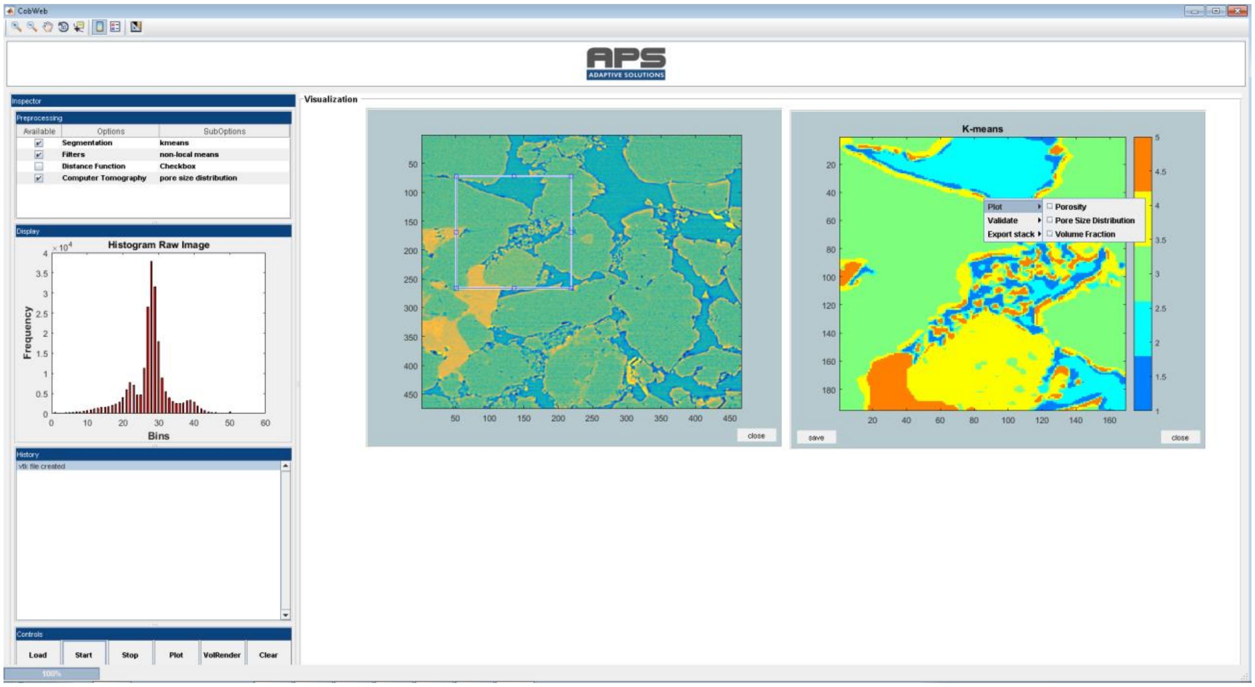
```
480
 Images have been cropped

Cluster:OK

distance not selected

filter non-local means selected: useful for image denoising

unsupervised scheme KMEANS selected

data is available for processing:TIFF FILES LOADED
```

Figure 25: Image processing

- Figure 25 shows a snapshot of the CobWeb interface during segmentation. The **text** of the Start button **changes** to the segmentation algorithm (**Start -> K-means**) and the **colour** of the button changes to **red**.
- Once the processing is finished, **updated information,** such as processing time and setting, is displayed in the **history window**.

NOTE: Not just one slice but all slices or the volume data has been processed.

NOTE: If the segmentation **stops** for some **unknown reason** (Ping sound), either **re-click** the **start button** (with red background colour and text) or **clear** the setting by clicking the **Clear button** and start again by loading the file.



Available	Options	SubOptions
☑	Segmentation	kmeans
☑	Filters	non-local means
☐	Distance Function	Checkbox
☑	Computer Tomography	pore size distribution

vtk file created

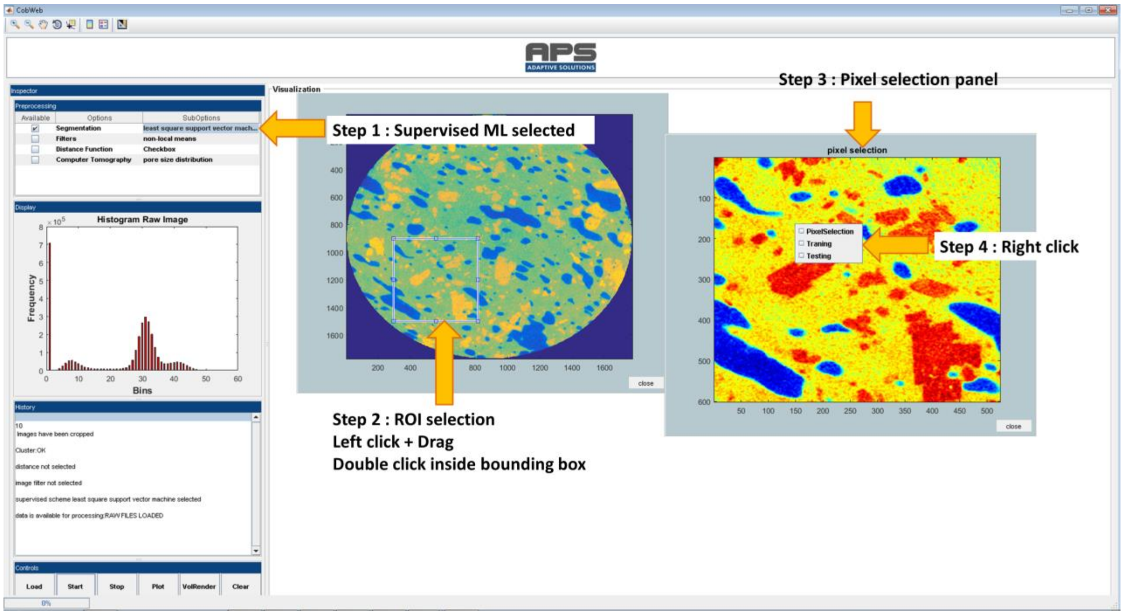
Figure 26: K-means segmentation

- Figure 26 shows how, by clicking the **Plot** button (left click), the segmented slice is **displayed** in a **separate pan window**.

5.3.4 Image Segmentation — Supervised Machine Learning Technique

The bullet points mentioned below are **relevant** if the algorithm **Least Square Support Vector Machine, Bragging and Boosting** are selected from the preprocessing uitable.

Brief description: *In the case of supervised ML techniques, the user selects different cluster centres (phases). These user inputs are used by the ML algorithm to train the model. After the training is completed, the REV is segmented into respective user defined phases.*



Available	Options	SubOptions
☑	Segmentation	least square support vector mach...
☐	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	pore size distribution

```
10
 Images have been cropped
Cluster:OK
distance not selected
image filter not selected
supervised scheme least square support vector machine selected
data is available for processing:RAW FILES LOADED
```

Step 1 : Supervised ML selected

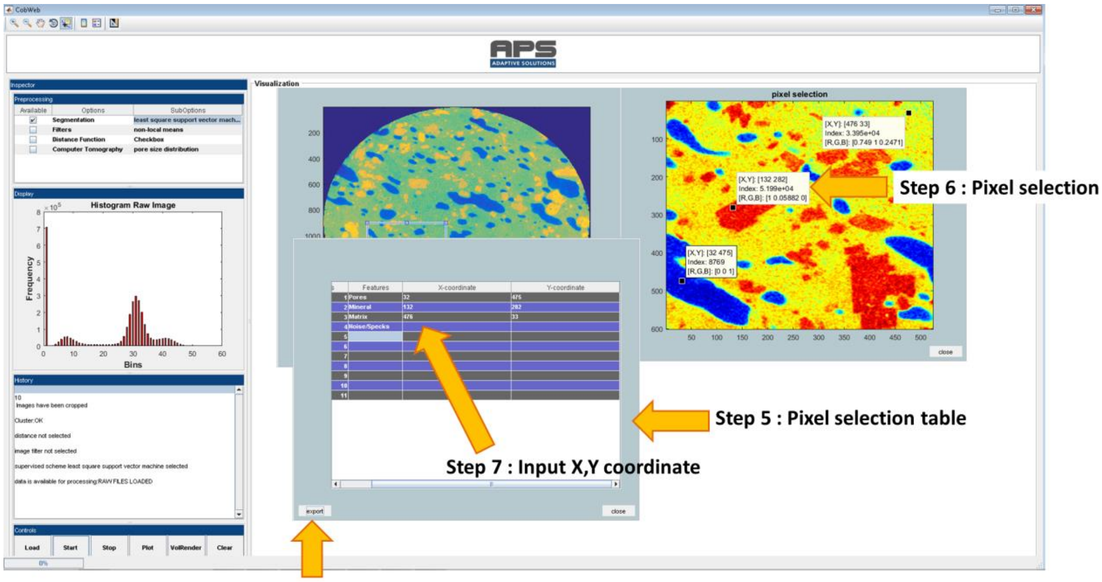
Step 2 : ROI selection
Left click + Drag
Double click inside bounding box

Step 3 : Pixel selection panel

Step 4 : Right click

Figure 27: Image segmentation with supervised ML techniques

- Step 1 (Figure 27): Select one of the **supervised algorithms**.
- Step 2 (Figure 27): The action in Step 1 shows the ROI selection. For further details about image preprocessing and REV selection, please see section 6.3 to 6.3.1
- Step 3 (Figure 27): Once the ROI is selected, the ROI is displayed in a separate window panel: “Pixel selection”.
- Step 4 (Figure 27): **Right click** on the **ROI image** and select the first option **Pixel Selection**, this will pop up a pixel table panel.



Available	Options	SubOptions
☑	Segmentation	least square support vector mach...
☐	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	pore size distribution

```
10
 Images have been cropped
Cluster:OK
distance not selected
image filter not selected
supervised scheme least square support vector machine selected
data is available for processing:RAW FILES LOADED
```

```
[X,Y]: [476 33]
Index: 3.395e+04
[R,G,B]: [0.749 1 0.2471]

[X,Y]: [132 282]
Index: 5.199e+04
[R,G,B]: [1 0.05882 0]

[X,Y]: [32 475]
Index: 8769
[R,G,B]: [0 0 1]
```

	Features	X-coordinate	Y-coordinate
1	Pores	32	475
2	Mineral	132	282
3	Matrix	476	33
4	Noise/Specks		
5			
6			
7			
8			
9			
10			
11			

Step 5 : Pixel selection table

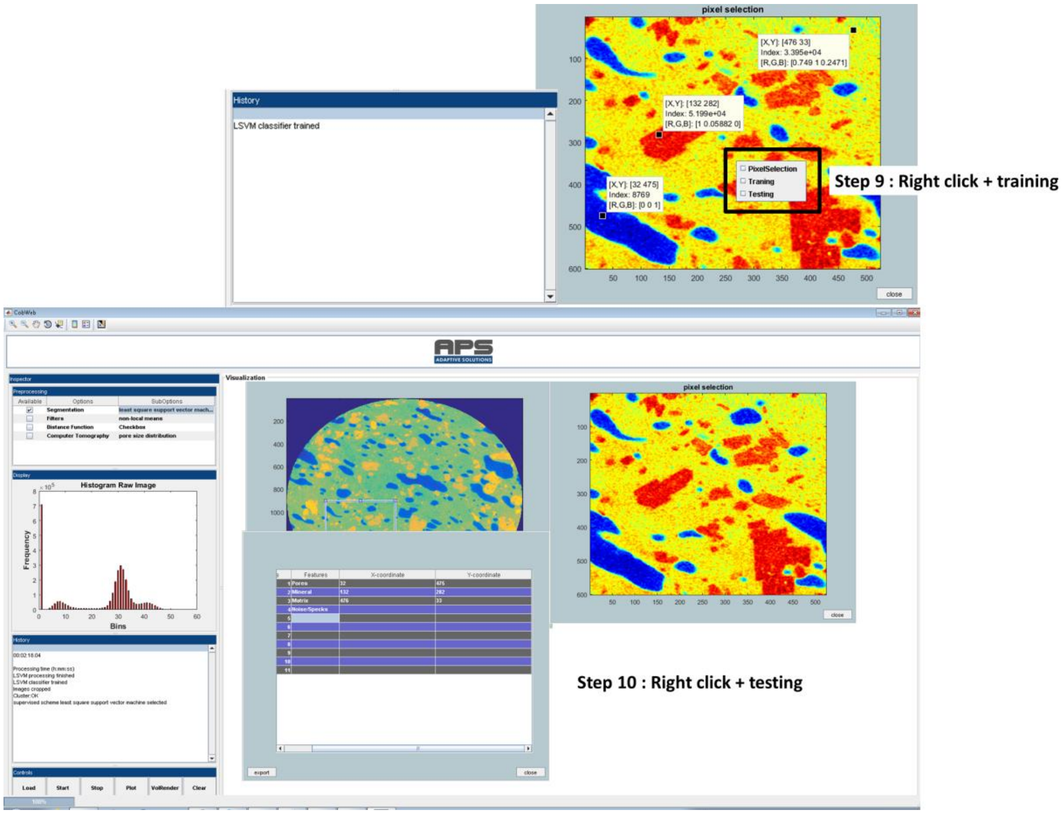
Step 6 : Pixel selection

Step 7 : Input X,Y coordinate

Step 8 : Click export button

Figure 28: Input of pixel information

- Step 5: Figure 28 shows the pixel selection panel.
- Step 6 (Figure 28): Using the data cursor tool from the toolbar, different cluster centres (phases) can be investigated.
- Step 7 (Figure 28): Features (pore, mineral, matrix, noise etc.) and their respective X, Y coordinates obtained in Step 6 must be typed into the pixel table.
- There is the possibility to define up to eleven features in a serial order without any gaps.
- Step 8 (Figure 27): Click the export button. The export function transfers this information (internally) to the training model.



Step 9 : Right click + training

LSVM classifier trained

00:02:18.04

Processing time (h:mm:ss)
LSVM processing finished
LSVM classifier trained
Images cropped
Cluster:OK
supervised scheme least square support vector machine selected

	Features	X-coordinate	Y-coordinate
1	Pores	32	475
2	Mineral	132	282
3	Matrix	476	33
4	Noise/Specks		
5			
6			
7			
8			
9			
10			
11			

Step 10 : Right click + testing

Figure 29: Training and testing supervised ML technique

- The next step is to train the model
- Step 9 (Figure 29): **Right click** on the **ROI image** and select the second option, **"Training"**. Once the model is suitably trained the information is displayed in the history panel.
- The last step is initializing segmentation
- Step 10 (Figure 29): **Right click** on the **ROI image** and select the third option, **"Testing"**.
- Once processing has finished, the information is displayed in the history panel. Thereafter, the segmented image can be viewed by clicking the plot button.

6. Visualisation

This chapter covers visualisation of different parameters such as:

- Geometrical properties
    - Relative porosity
    - Pore size distribution
    - Volume fraction
- Validation matrices
    - Entropy
    - Receiver operation characteristics
    - 10-fold cross validation
- Export
    - ParaView format
    - Excel format
    - MATLAB format
    - ASCII format
- Volume rendering with ParaView
    - Pore phase
    - Matrix phase
    - Mineral phase

6.1 Geometrical Properties

To derive geometrical properties, it is necessary that segmentation has already completed.

6.1.1 Relative Porosity

- Figure 30 shows plotting porosity. **Right click** on the segmented slice select **Plot -> Porosity**.
- A processing menu pop-up appears with three options: **Complete stack, Slice-by-Slice** and **Cancel**.
    - **Complete stack**: The porosity of the complete stack is plotted.
    - **Slice-by-Slice**: The porosity of the selected slice is plotted.
    - **Cancel**: The process is abandoned.

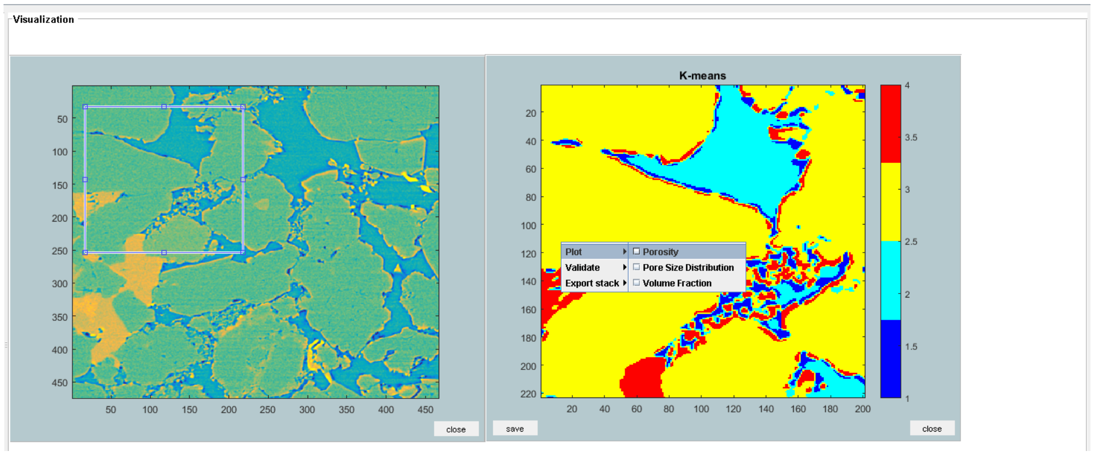
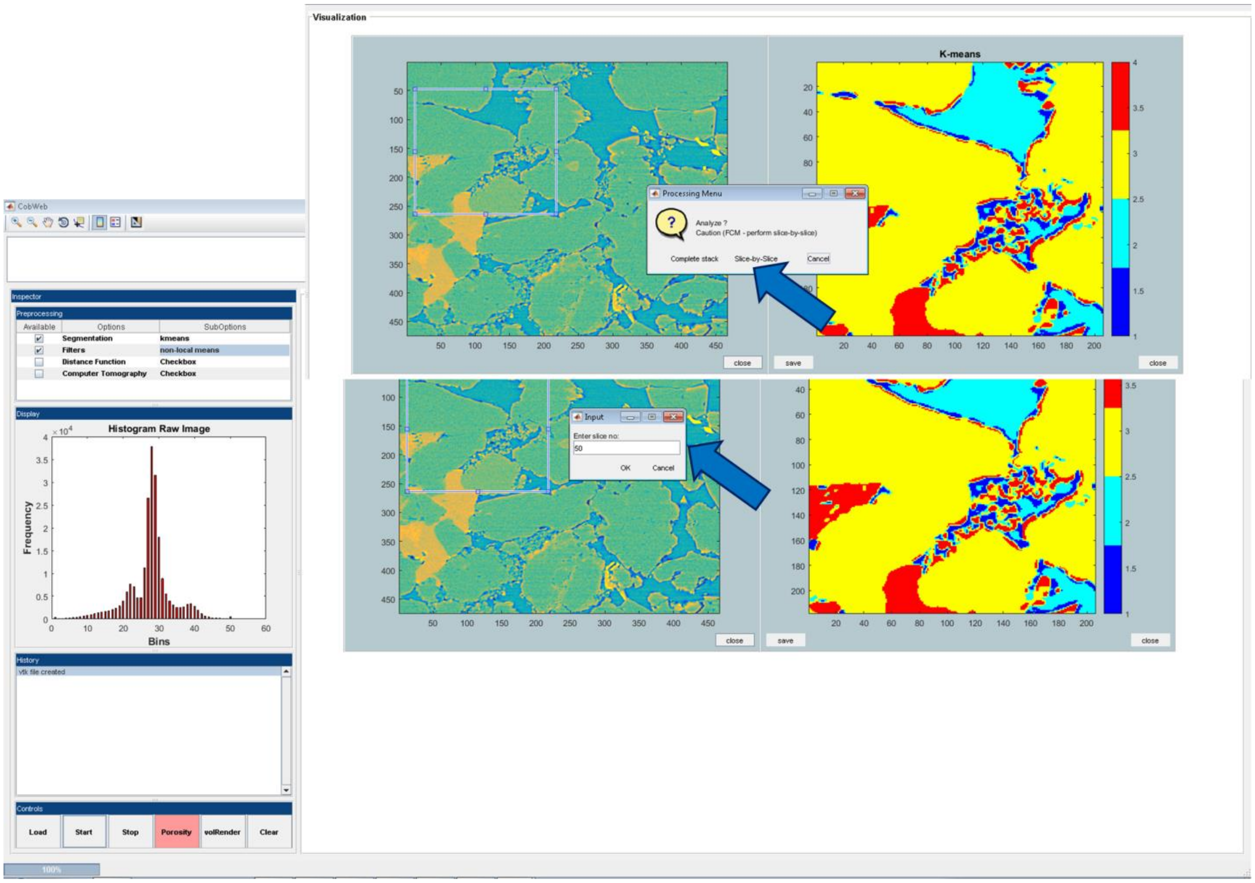


Figure 30: Plotting porosity



Analyze ?
Caution (FCM - perform slice-by-slice)

Enter slice no:
50

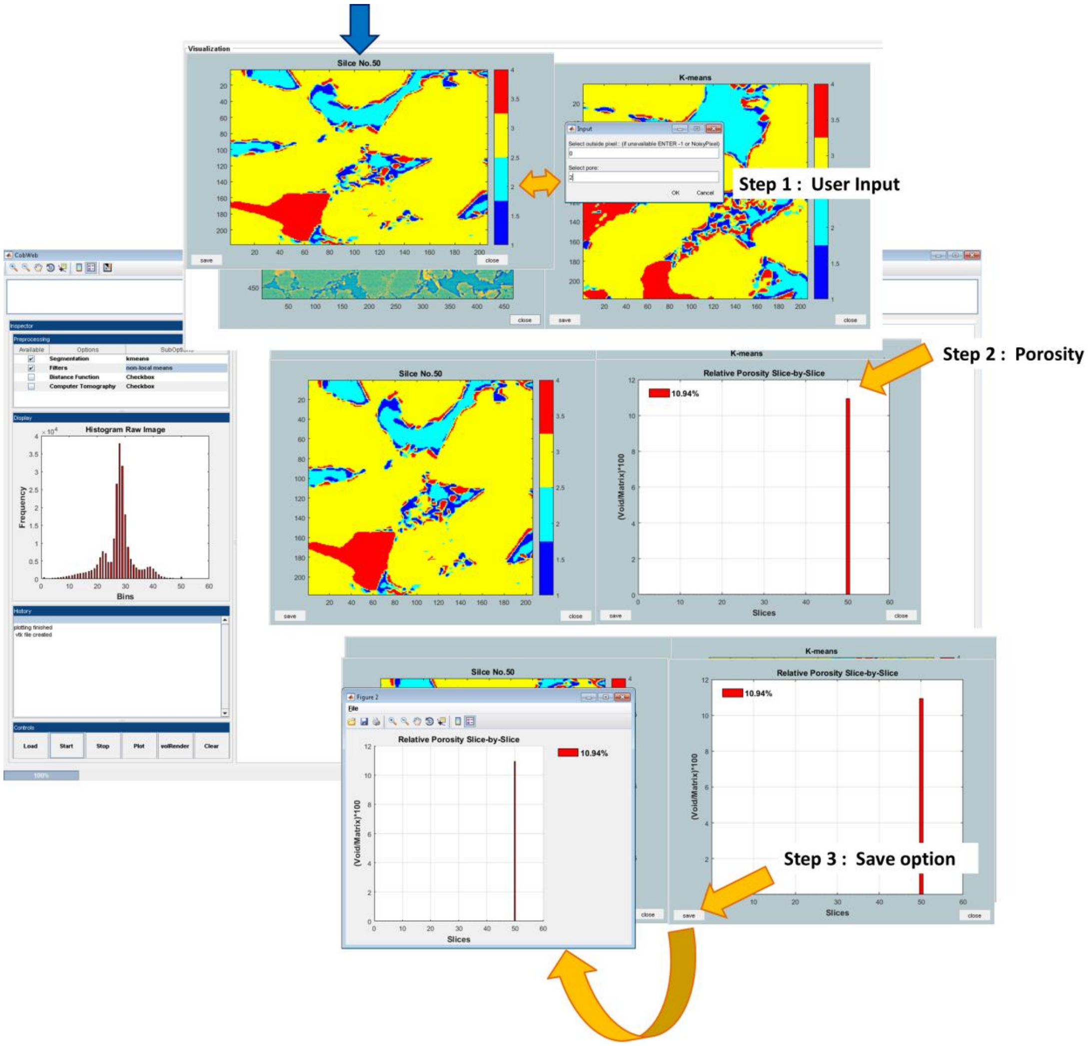
Available	Options	SubOptions
☑	Segmentation	kmeans
☑	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

vtk file created

Figure 31: Porosity processing menu and input

- Figure 31 displays the **Slice-by-Slice** option **selected** and the **slice numbe**r to be **typed** by the user **as input**.
- By clicking the save option on the window panel the current plot can be saved at a desired location.

NOTE: The status bar might show a 100% status, but the plot is not shown. **Please be patient, the display of the plot window depends on your system configuration.** The plot appears as soon as the message **plotting finished** is display in the **history window**.



Step 1 : User Input

Input

Select outside pixel : (if unavailable ENTER -1 or NoisyPixel)

0

Select pore:

2

Step 2 : Porosity

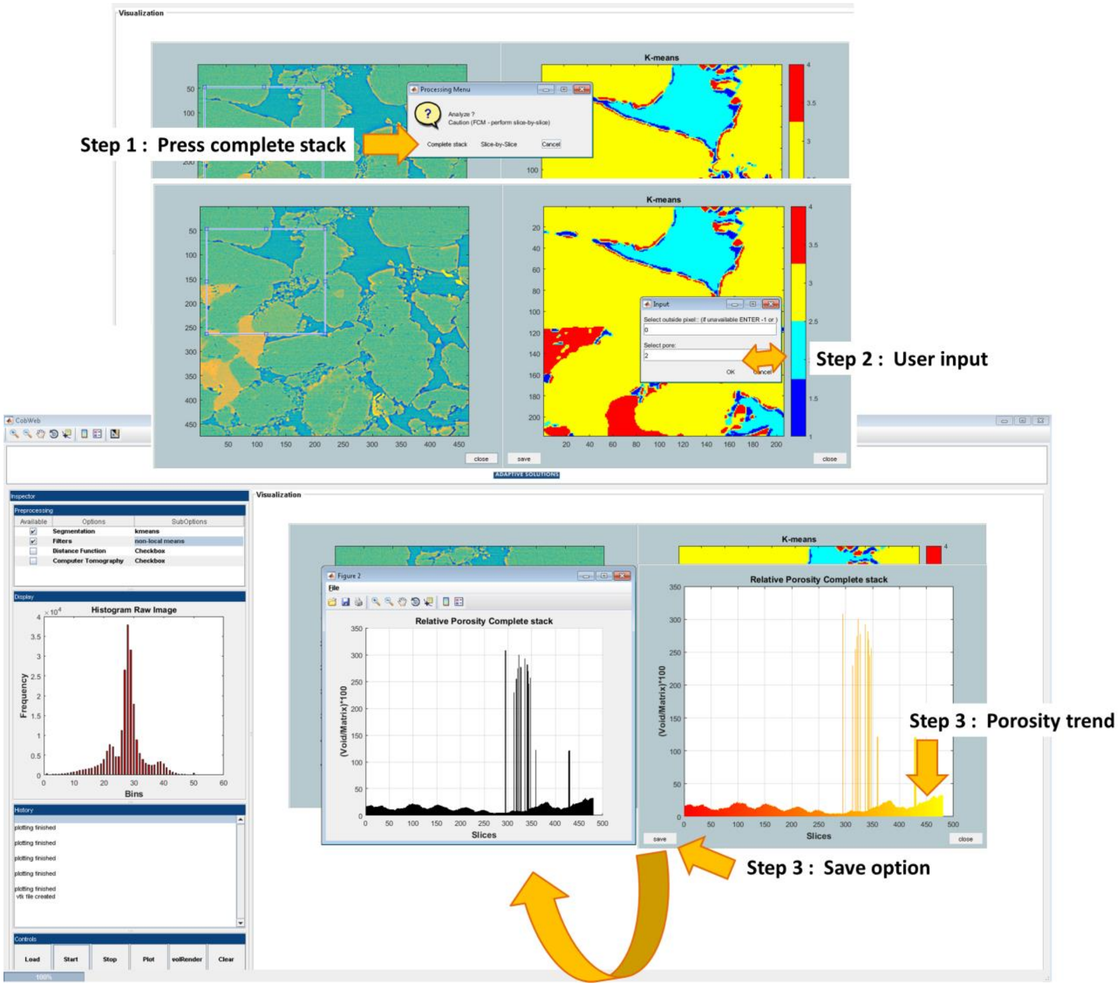
Step 3 : Save option

History

plotting finished
vtk file created

Figure 32: Porosity of single slice

- Figure 32 displays the slice (no. 50) in a new window.
- Step 1 (Figure 32): **Enter** the **cluster number** assigned to the **pore phase** and noise phase. If the noise phase is not displayed or has not been assigned a cluster value, enter zero.
- Figure 32 displays **the slice** (no. 50) plotted in a **new window. Input** in this case no. 2.
- Step 2 (Figure 32): **Relative porosity** of the **single slice** is plotted in a **new window**.
- Step 3 (Figure 32): By clicking the save option, the image can be exported into the desired image format.


Step 1 : Press complete stack

Step 2 : User input

Step 3 : Porosity trend

Step 3 : Save option

Processing Menu

Analyze ?
Caution (FCM - perform slice-by-slice)

Input

Select outside pixel : (if unavailable ENTER -1 or)

0

Select pore:

2

History

plotting finished
plotting finished
plotting finished
plotting finished
plotting finished
vtk file created

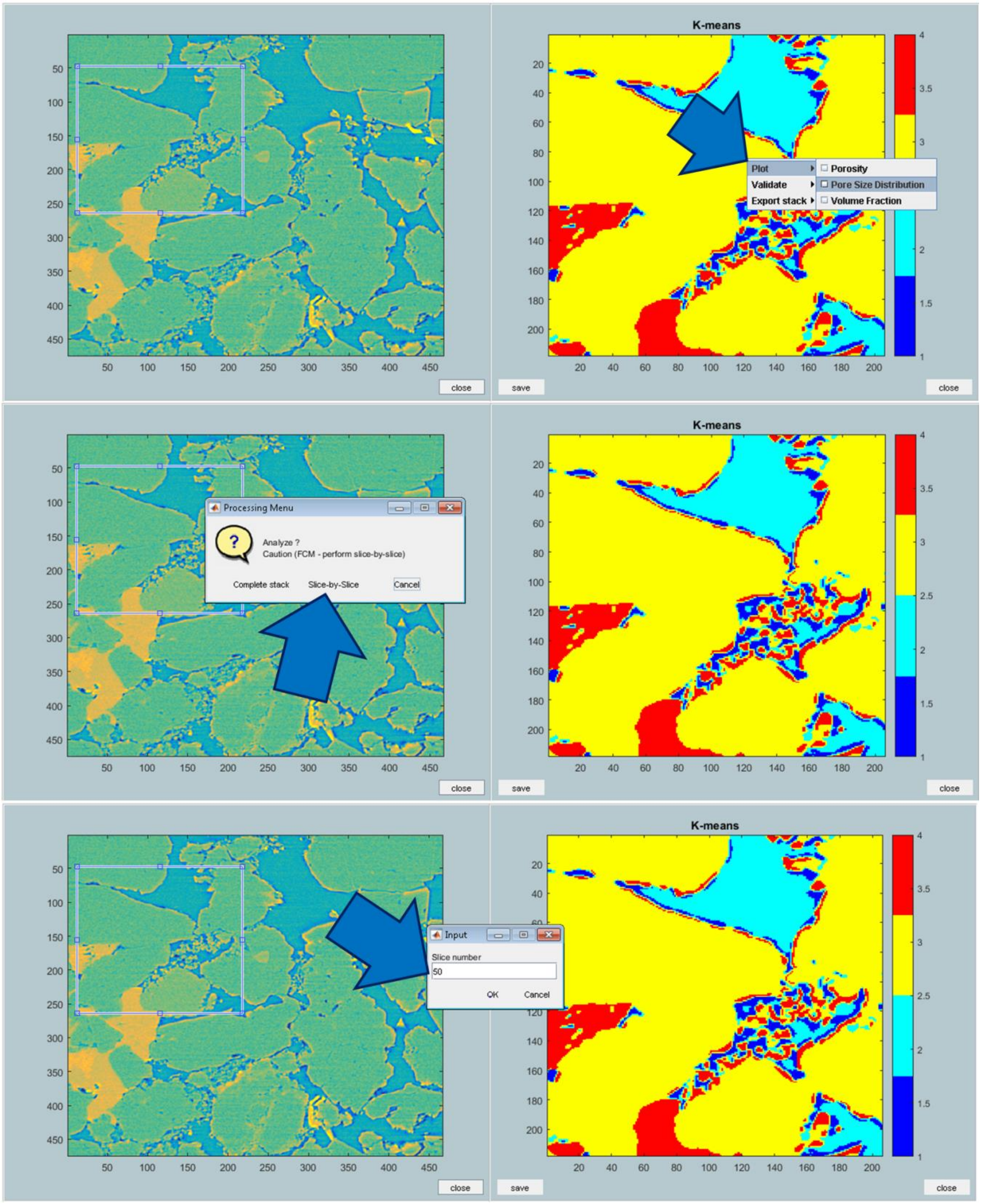
Figure 33: Porosity of complete stack

- Step 1 (Figure 33): The porosity of the REV can be plotted by clicking complete stack option.
- Step 2 (Figure 33): **Enter** the **cluster number** assigned to the **pore phase** and the noise phase. If the noise phase is not displayed or has not been assigned a cluster value, enter zero.
- Step 3 (Figure 33): By clicking the save option, the image can be exported into a desired image format.

6.1.2 Pore Size Distribution

- To plot pore size distribution: **right click** on the segmented slice and select **Plot -> Pore Size Distribution** (PSD), as shown in Figure 34.
- A processing menu pop-up appears with three options: Complete stack, Slice-by-Slice and Cancel.

- **Complete stack**: The PSD of the complete stack is plotted.
- **Slice-by-Slice**: The PSD of the selected slice is plotted.
- **Cancel**: The process is abandoned.



Processing Menu

Analyze ?
Caution (FCM - perform slice-by-slice)

Input

Slice number: 50

Figure 34: Pore size distribution processing menu and input

- Figure 34 displays the **Slice-by-Slice** option where the **slice number** has to be **entered by the user.**
- The **slice** (no. 50) is then displayed in a **new window**, as shown in Figure 34.

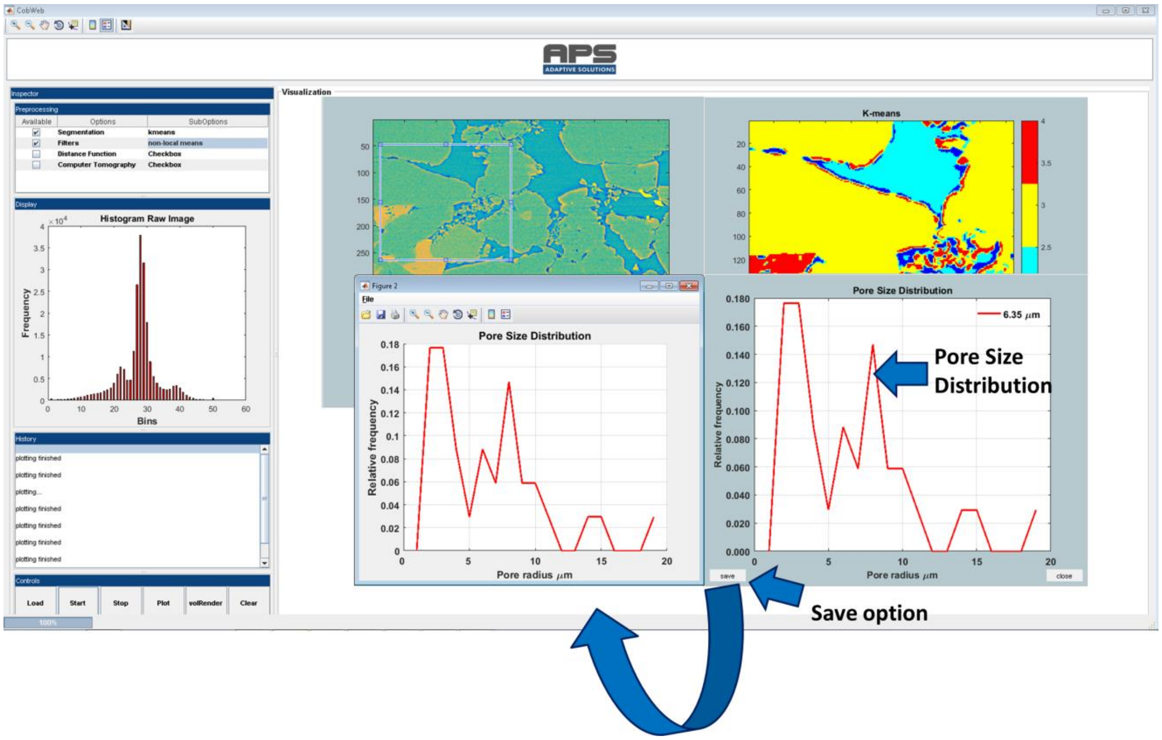
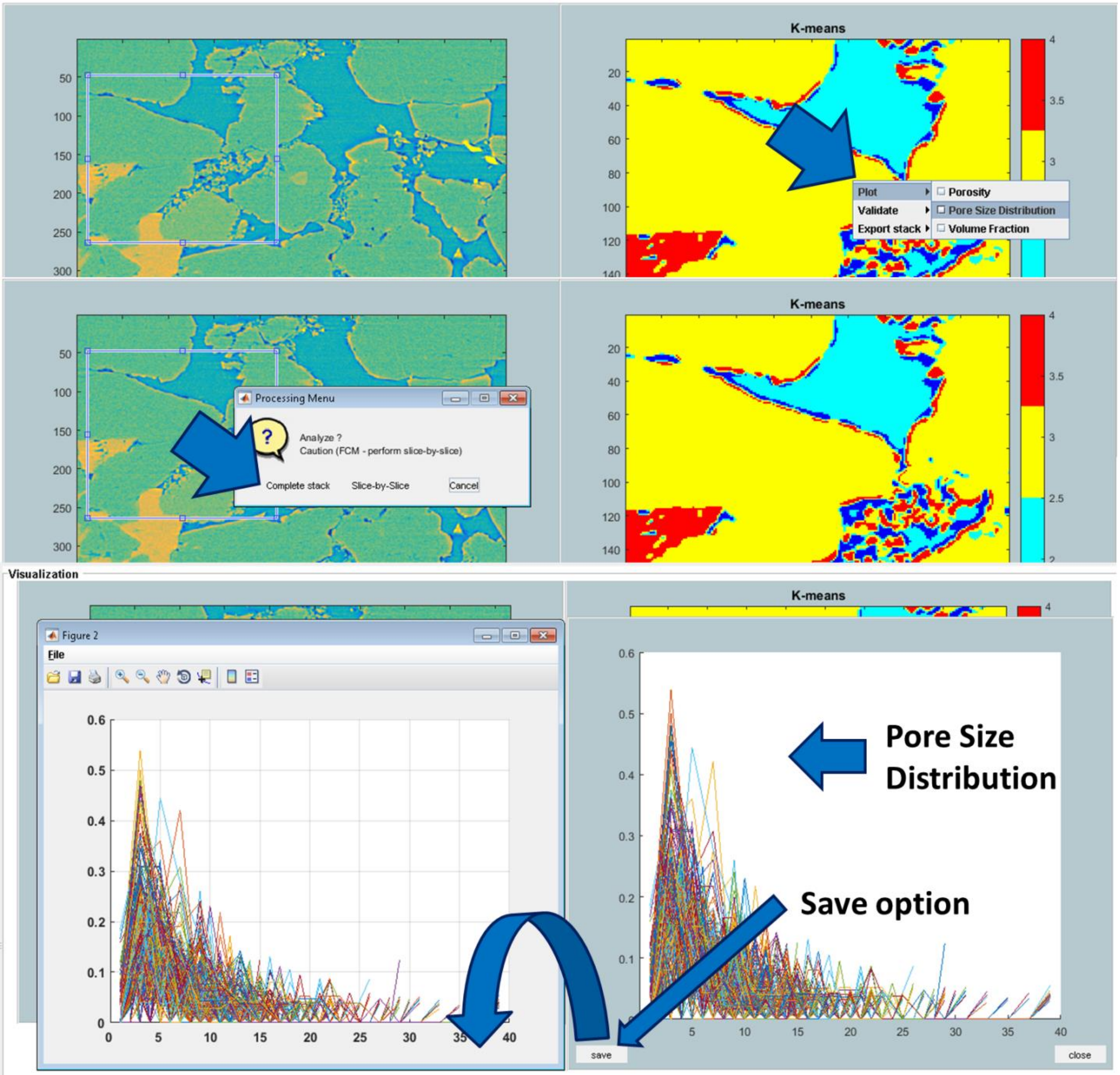


Figure 35: Pore size distribution of single slice

- The PSD of the respective slice is plotted in a new window, as shown in Figure 35.
- By clicking the save option, the plotted PSD can be saved in a desired image format.



Analyze ?
Caution (FCM - perform slice-by-slice)

Pore Size Distribution

Save option

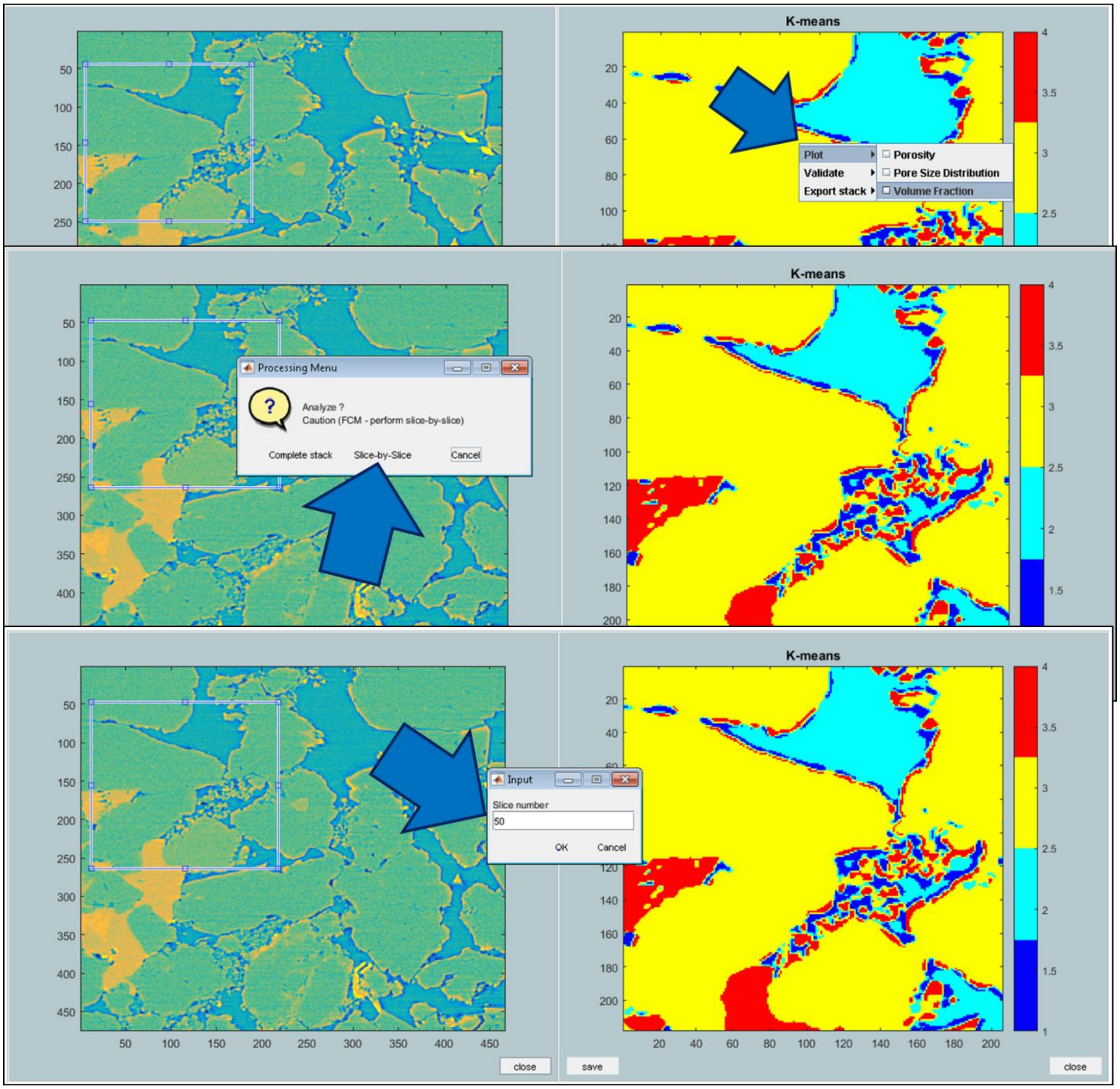
Figure 36: Pore size distribution of complete stack

- Figure 36 displays the steps to retrieve the PSD of the REV and the option to save the plot.

NOTE: The status bar might show a 100% status, but the plot is not shown. **Please be patient, the display of the plot window depends on your system configuration.** The plot appears as soon as the message **plotting finished** is display in the **history window**.

6.1.3 Volume Fraction

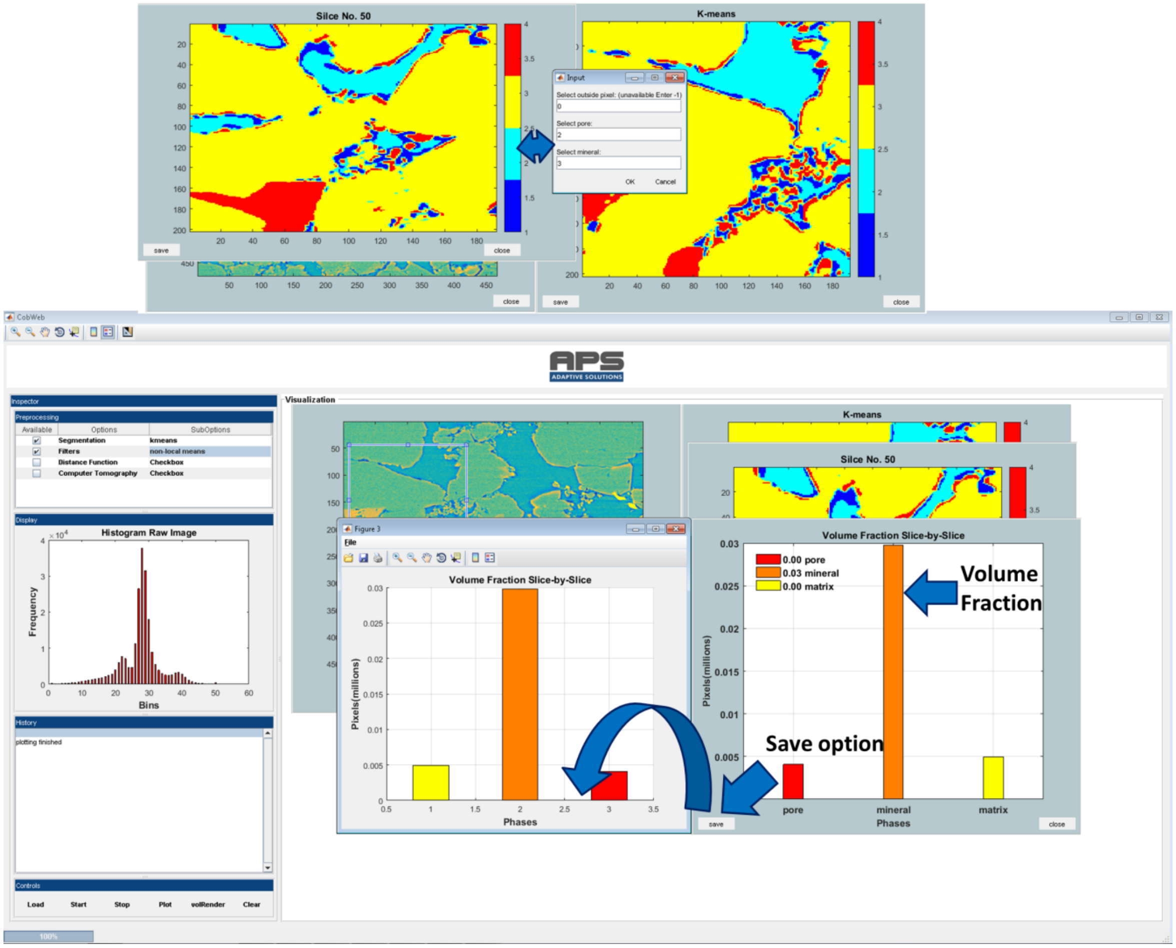
- To plot volume fraction, **right click** on the segmented slice and select **Plot -> Volume Fraction**, as shown in Figure 37.
- A processing menu pop-up appears with three options: Complete stack, Slice-by-Slice and Cancel.
    - **Complete stack**: The volume fraction of the complete stack is plotted.
    - **Slice-by-Slice**: The volume fraction of the selected slice is plotted.
    - **Cancel**: The process is abandoned.



Analyze ?
Caution (FCM - perform slice-by-slice)

Slice number
50

Figure 37: Volume fraction processing menu and input



Input

Select outside pixel: (unavailable Enter -1)
0

Select pore:
2

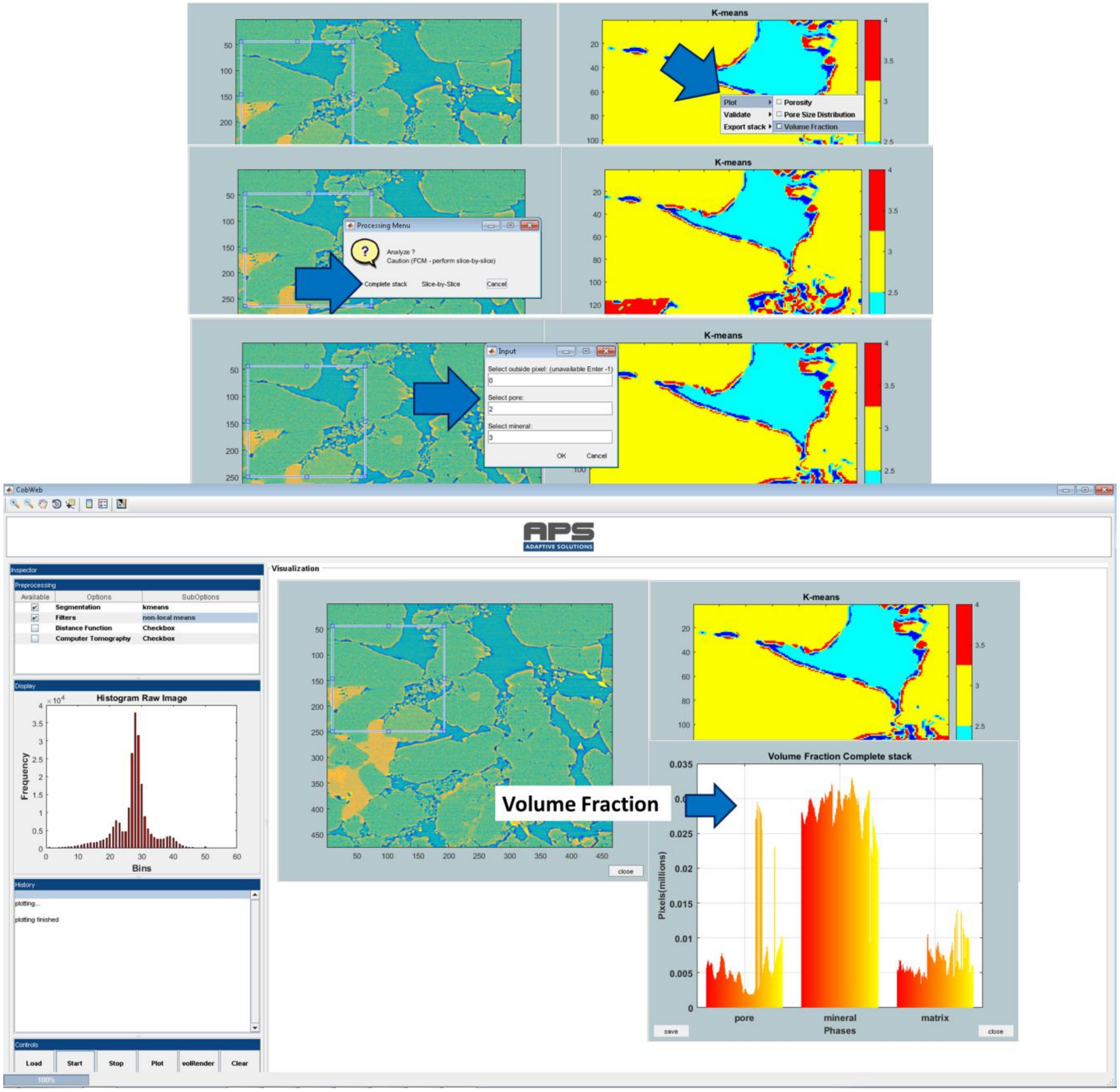
Select mineral:
3

Available	Options	SubOptions
☑	Segmentation	kmeans
☑	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

plotting finished

Figure 38: User input and volume fraction of single slice

- Figure 38 (top panel) shows the **slice** (no. 50) plotted in a **new window**.
- Figure 38 (top panel): The **user** assigns the cluster number to the **pore phase** and the **mineral phase** (in this case, pore = 2 and mineral = 3).
- Figure 38 (bottom panel) shows the **save option**. By clicking the save button, the plotted image can be saved in the desired image format.



Processing Menu

Analyze ?
Caution (FCM - perform slice-by-slice)

Input

Select outside pixel: (unavailable Enter -1)
0
Select pore:
2
Select mineral:
3

Available	Options	SubOptions
☑	**Segmentation**	**kmeans**
☑	**Filters**	**non-local means**
☐	**Distance Function**	**Checkbox**
☐	**Computer Tomography**	**Checkbox**

History:

plotting...
plotting finished

Figure 39: Volume fraction of complete stack

- Figure 39 (top, middle and bottom panels) shows the steps to retrieve the volume fraction of the REV. In this case, the plotted image cannot be saved in the desired file format due to technical limitations.

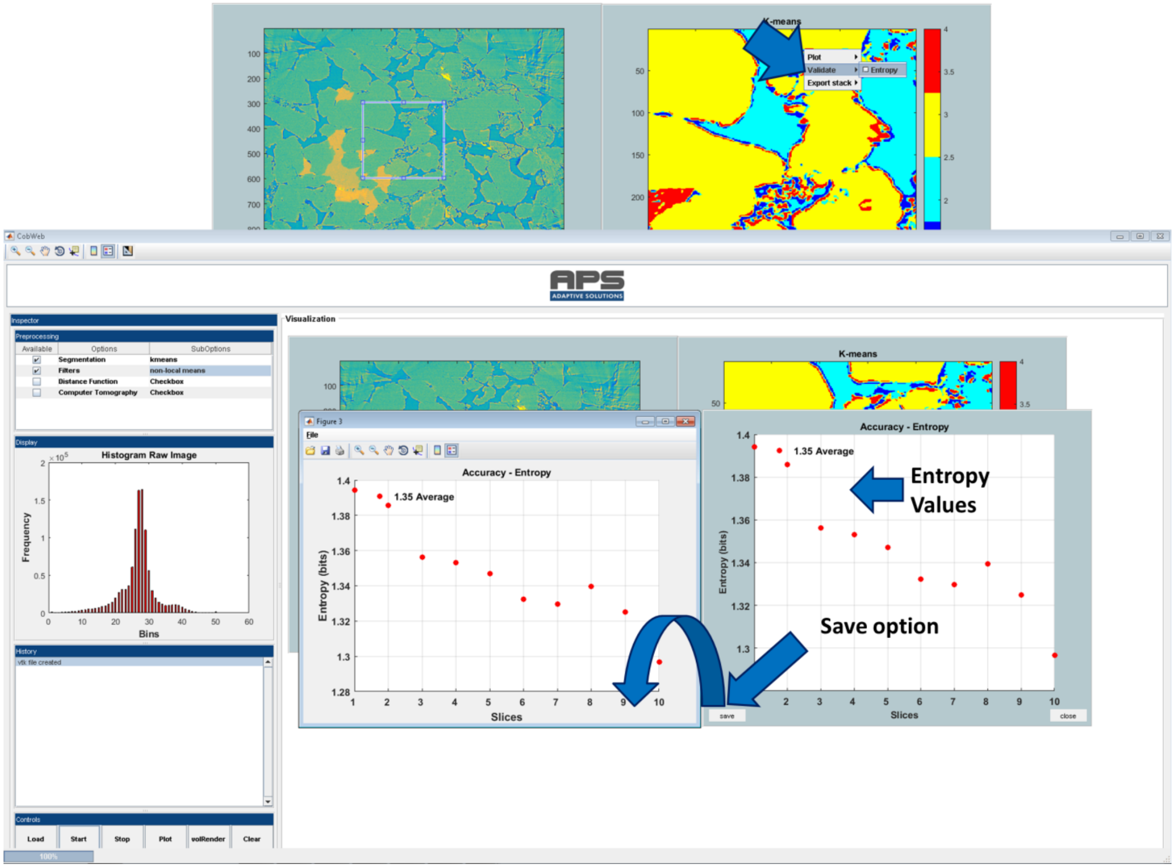
NOTE: The status bar might show a 100% status, but the plot is not shown. **Please be patient, the display of the plot window depends on your system configuration.** The plot appears as soon as the message **plotting finished** is display in the **history window**.

6.2 Validation

The validation analysis is performed to check the accuracy of the segmentation algorithms. Table 10 gives an overview of the algorithms and their respective metrics.

Table 9: Metrics for validation

Algorithms	Validation Metrics
K-means	Entropy
Fuzzy C-means	Entropy
Least Square Support Vector Machine	Receiver Operation Characteristics
Bragging	K-fold Cross Validation
Boosting	k-fold Cross Validation

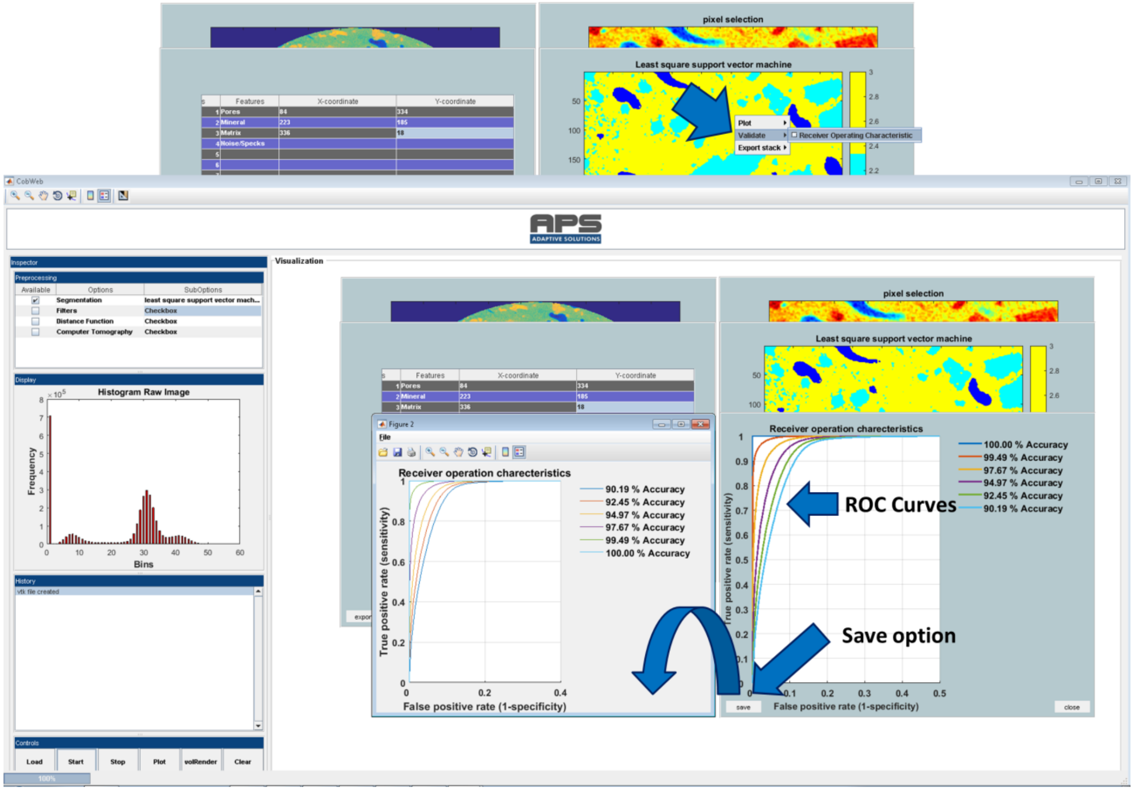


Available	Options	SubOptions
☑	Segmentation	kmeans
☑	Filters	non-local means
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

History: vtk file created

Figure 40: Plotting entropy

- Figure 40 (top panel) shows plotting Entropy. Right click on the segmented image and select validation → Entropy
- Figure 40 (bottom panel) shows how the plotted Entropy can be saved in the desired image format by clicking the save option.



s	Features	X-coordinate	Y-coordinate
1	Pores	84	334
2	Mineral	223	185
3	Matrix	336	18
4	Noise/Specks		
5			
6			

Available	Options	SubOptions
☑	Segmentation	least square support vector mach...
☐	Filters	Checkbox
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

Figure 41: Plotting receiver operational characteristics (ROC)

- Figure 41 (top panel:, To plot receiver operation charecteristics (ROC), right click on the segmented image and **select validation → Receiver Operation Charecteristics**.
- Figure 41 (bottom panel): The plotted ROC can be saved in the desired image format by clicking the save option (see Figure 41).

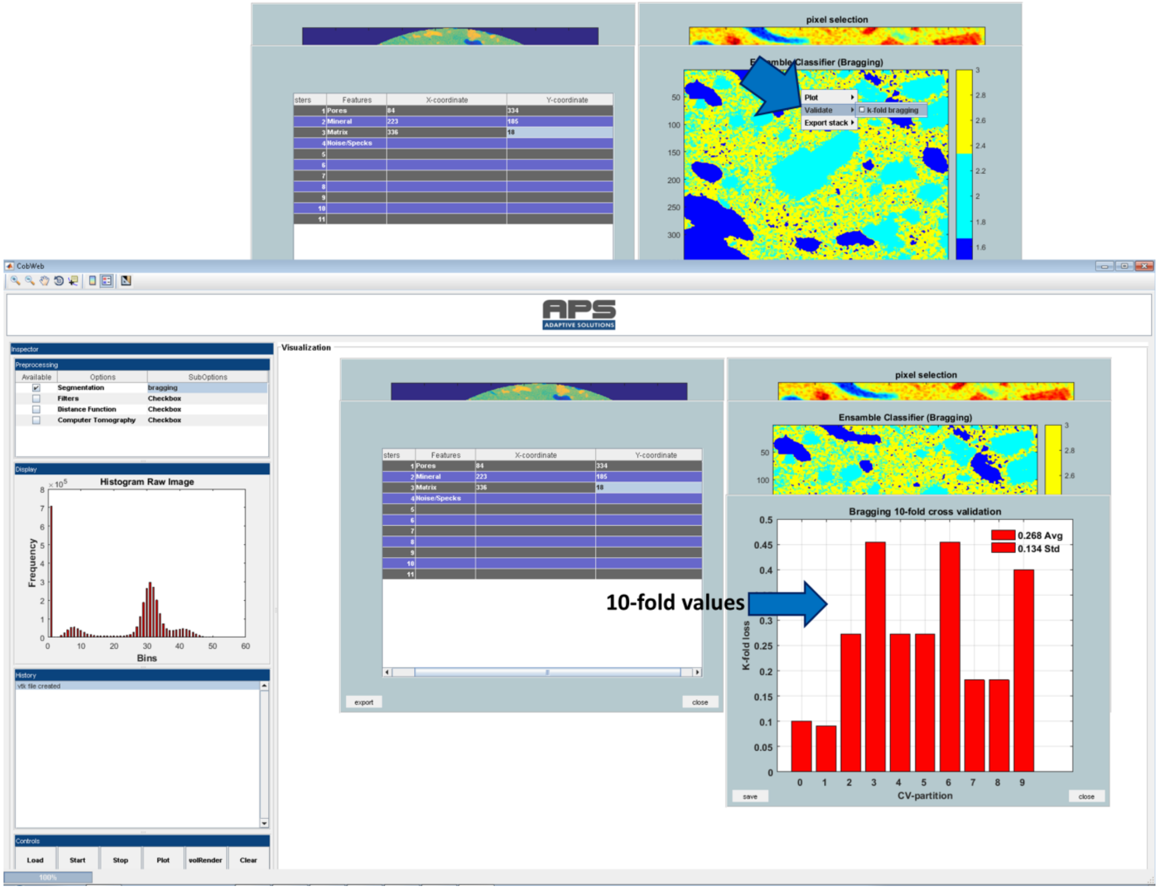


Figure 42: Plotting k-fold cross-validation

- Figure 42 (top panel) shows the plotting of K-fold cross validation. **Right click** on the segmented image and **select validation → k-fold bragging**.
- Figure 42 (bottom panel) show the plotted k-fold plot can be saved in the desired image format by clicking the save option.
- In the case of K-fold cross validation for Boosting, follow the same procedure as shown in the above bullet points.

6.3 Export

The processed XCT data can be exported into different formats. Table 10 gives an overview of the different file formats and associated CobWeb products-

Table 10: Plugins and their respective file formats

Export Plugins	File Format	CobWeb Products
ParaView	**.vkt**	Segmented stack, as shown in Figure 43
Excel	**.xlsx**	• Relative porosity • Pore size distribution

		• Volume fraction • Entropy • ROC • K-fold Shown in Figure 44 and Figure 45
MATLAB	**.mat**	• Pore size distribution • Volume fraction • Entropy • ROC • K-fold Shown in Figure 44 and Figure 45
ASCII	**.txt**	• Pore size distribution • Volume fraction • Entropy • ROC • K-fold Shown in Figure 44 and Figure 45

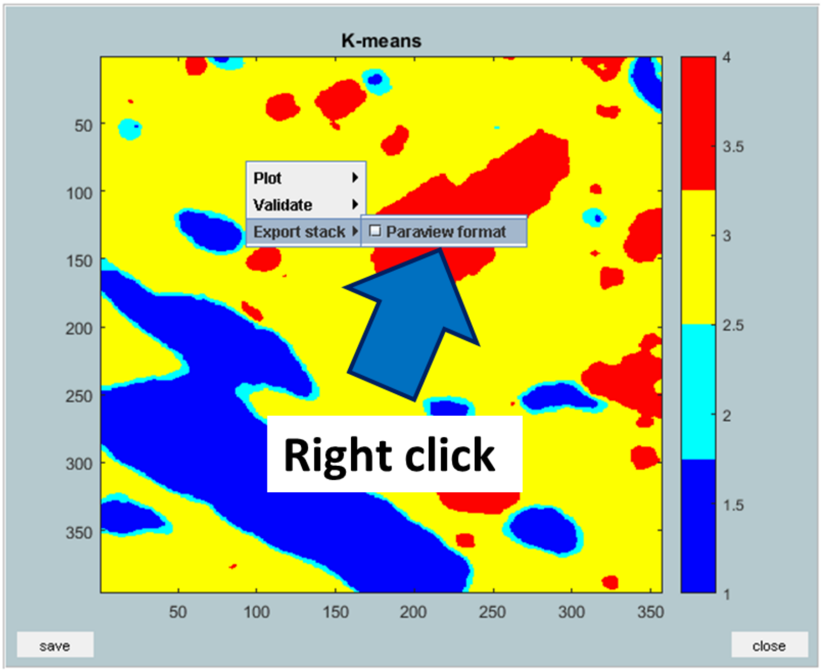


Figure 43: Export stack to ParaView

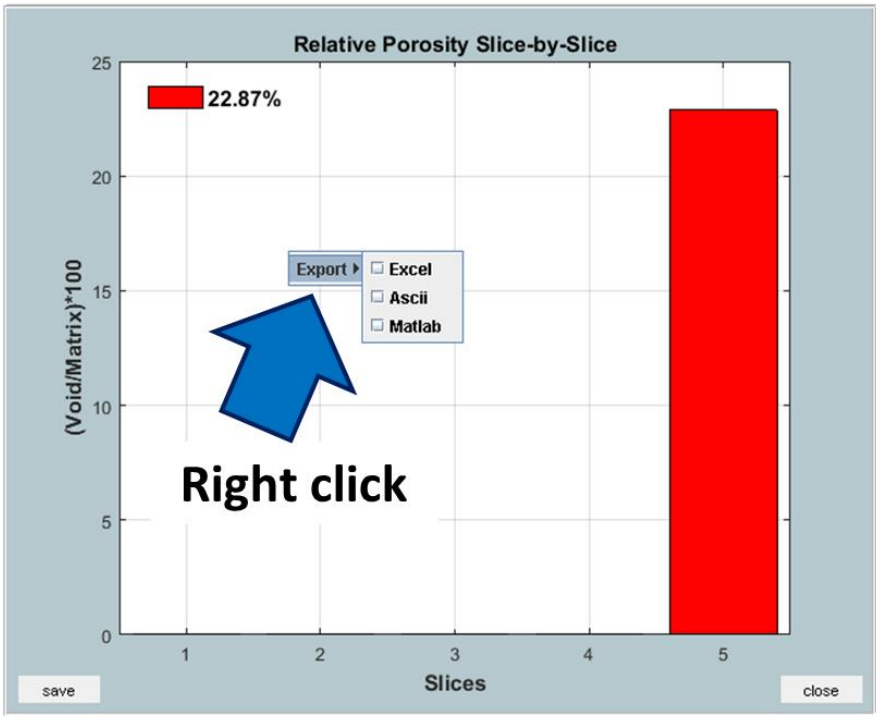


Figure 44: Export geometrical parameters

Figure 45: Export validation metrics

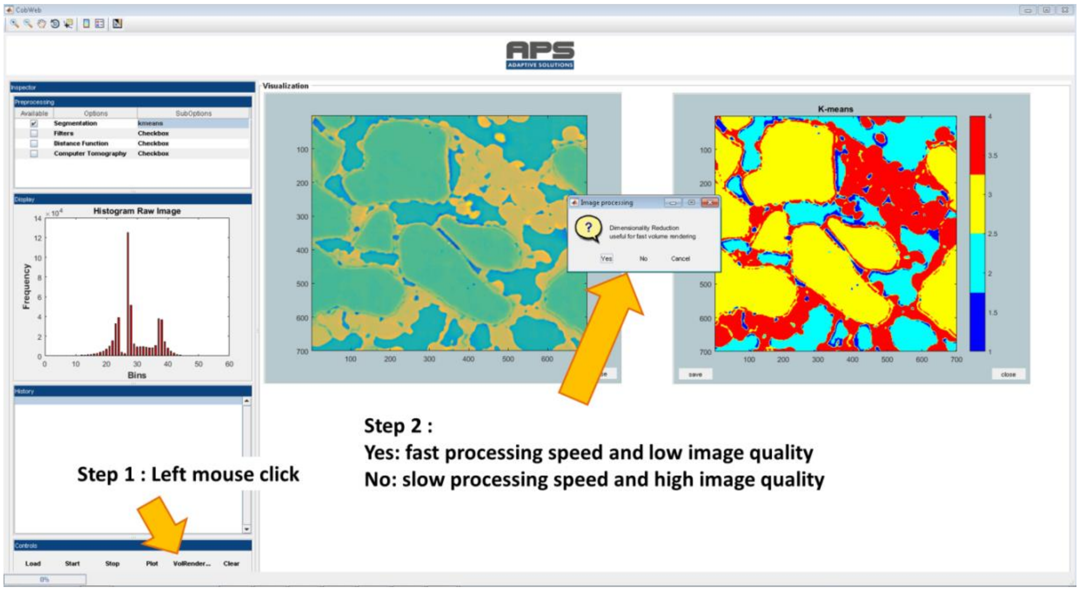
6.4 Volume Rendering

The volume rendering function is demonstrated here using a gas hydrate dataset, which was obtained from synchrotron measurements. CobWeb 1.0 is limited with respect to its volume rendering capabilities compared to other XCT analysis software. This may be improved in future.

As an alternative, the data can be exported into .vkt format and can be visualised using the open source visualisation software ParaView.

6.4.1 Volume Rendering with CobWeb 1.0

- The complete REV can be rendered in CobWeb 1.0 by clicking the volume rendering button in the control panel.



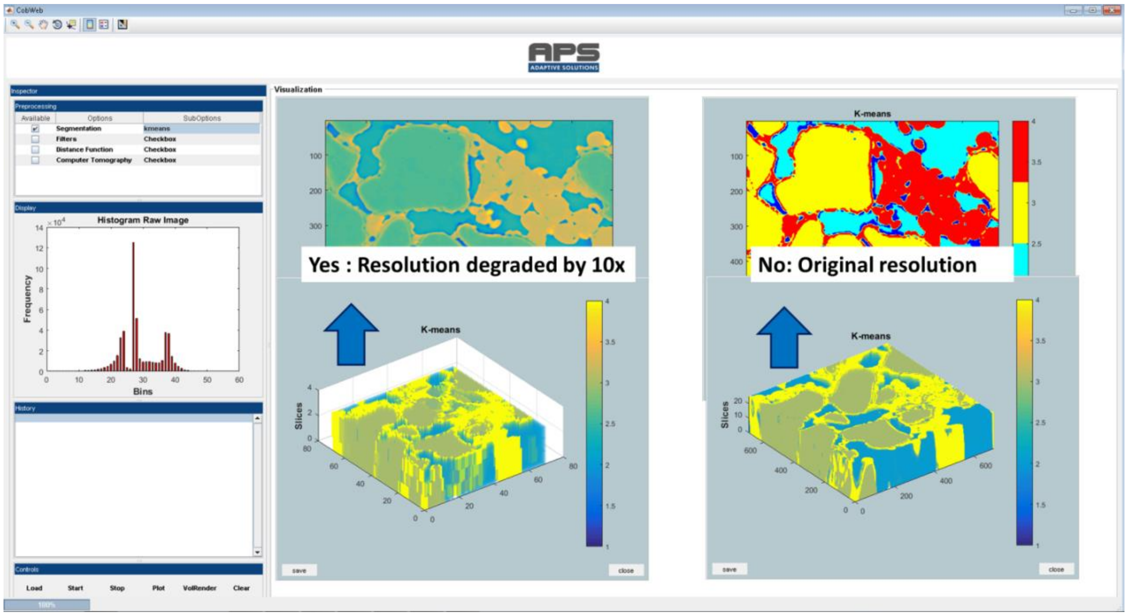
Dimensionality Reduction
useful for fast volume rendering

Step 1 : Left mouse click

Step 2 :
Yes: fast processing speed and low image quality
No: slow processing speed and high image quality

Figure 46: Volume rendering options in CobWeb 1.0

- Step 1 (Figure 46): **Click on** the **VolRendering** button on the **control panel.**
- Based on the system configuration, the REV stack can either be plotted in reduced resolution or in the original resolution.
- Step 2 (Figure 46): By choosing (clicking) the **Yes option**, the resolution of the REV stack will be reduced by a factor of 10, thereby **optimizing processing speed** and **degrading image quality**.
- Step 2 (Figure 46): By choosing (clicking) the **No option,** the REV is **rendered** in its **original resolution**. RAM capacity above 40 GB is best suited for this option.



Available	Options	SubOptions
☑	Segmentation	kmeans
☐	Filters	Checkbox
☐	Distance Function	Checkbox
☐	Computer Tomography	Checkbox

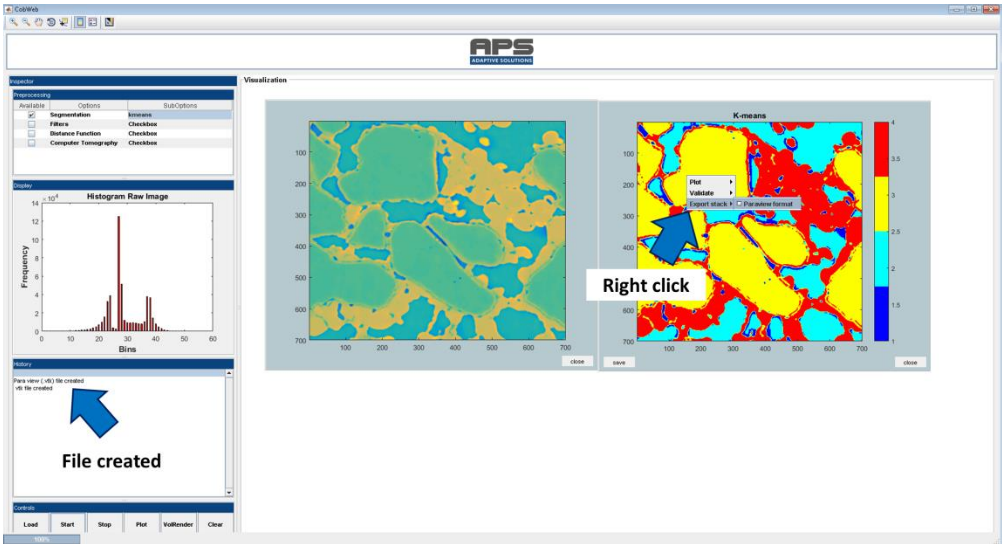
Figure 47: Volume rendering using CobWeb 1.0

- Figure 47 displays the rendered REV of gas hydrate in reduced (Yes option selected) and high resolutions (No option selected).

6.4.1 Volume Rendering with ParaView

To visualise the data in ParaView:

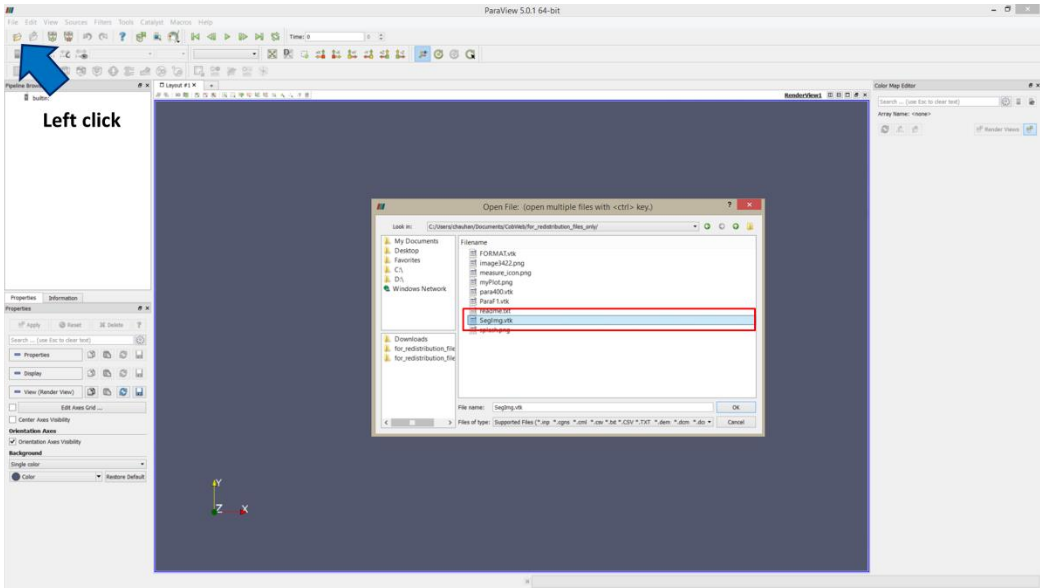
- Export the segmented stack into the ParaView format, as shown in Figure 48.
- The file can be saved at a desired location. Once the file has been created, the information is updated in the History window.



Para view (.vtk) file created
vtk file created

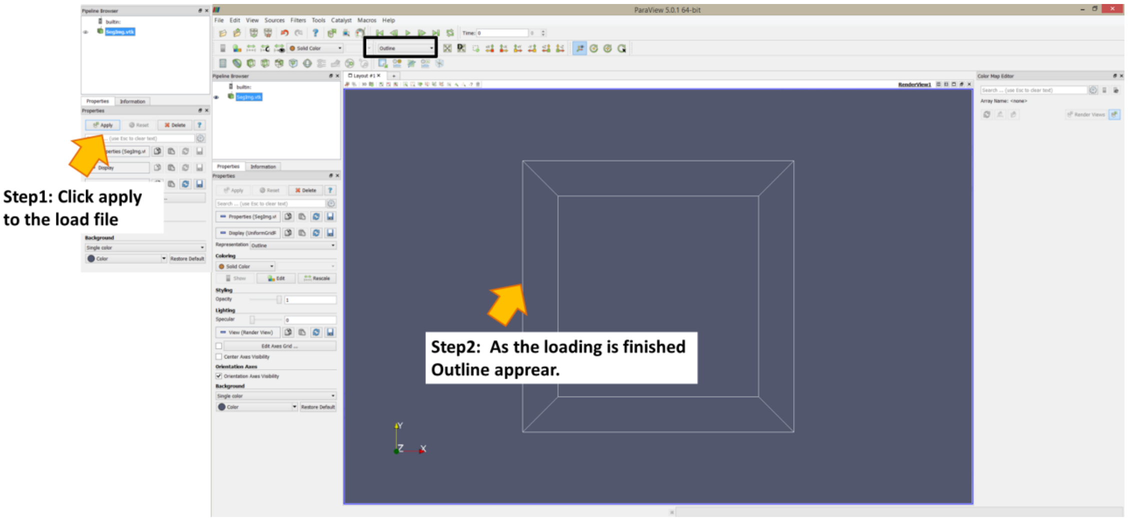
Figure 48: Export segmented REVs in .vkt format

- Figure 49 displays steps to load the .vkt file into ParaView. This is done by clicking on the folder button or using the file menu to import the file.



Look in: C:/Users/chauhan/Documents/CobWeb/for_redistribution_files_only/
File name: SegImg.vtk
Files of type: Supported Files (*.inp *.cgns *.cml *.csv *.txt *.CSV *.TXT *.dem *.dcm *.do

Figure 49: Loading VKT file in ParaView

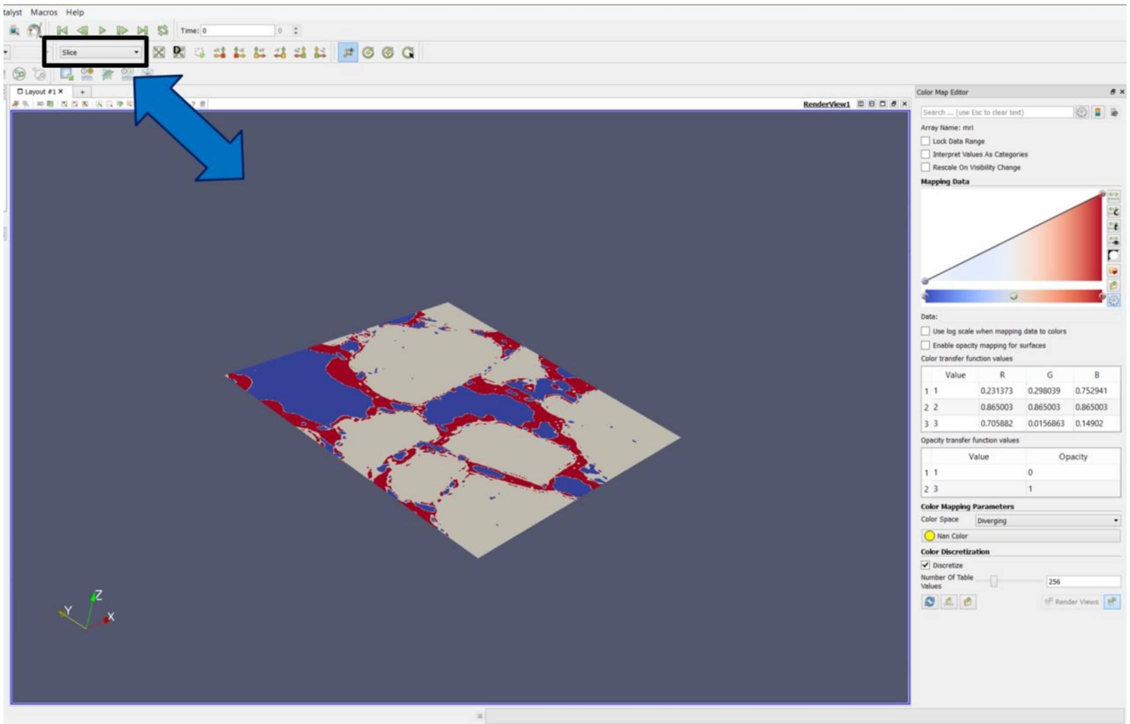


Step1: Click apply to the load file

Step2: As the loading is finished Outline apprear.

Figure 50: VKT file loaded in ParaView

- Step 1 (Figure 50): Once the file has been loaded, click the apply button to send the data to be read into ParaView. The reading may take time, depending on the system configuration.
- Step 2 (Figure 50): If the reading has been successfully completed, an outline or bounding box appears.



Search ... (use Esc to clear text)

Array Name: mri

☐ Lock Data Range

☐ Interpret Values As Categories

☐ Rescale On Visibility Change

Data:

☐ Use log scale when mapping data to colors

☐ Enable opacity mapping for surfaces

Color transfer function values

	Value	R	G	B
1	1	0.231373	0.298039	0.752941
2	2	0.865003	0.865003	0.865003
3	3	0.705882	0.0156863	0.14902

Opacity transfer function values

	Value	Opacity
1	1	0
2	3	1

Color Mapping Parameters

Color Space: Diverging

Nan Color

Color Discretization

☑ Discretize

Number Of Table Values: 256

Render Views

Figure 51: Slice mode in ParaView

- Figure 51: It is **advised** to view the **stack first in slice mode**. This can be done through the drop-down menu, marked in Figure 51 with a black box.

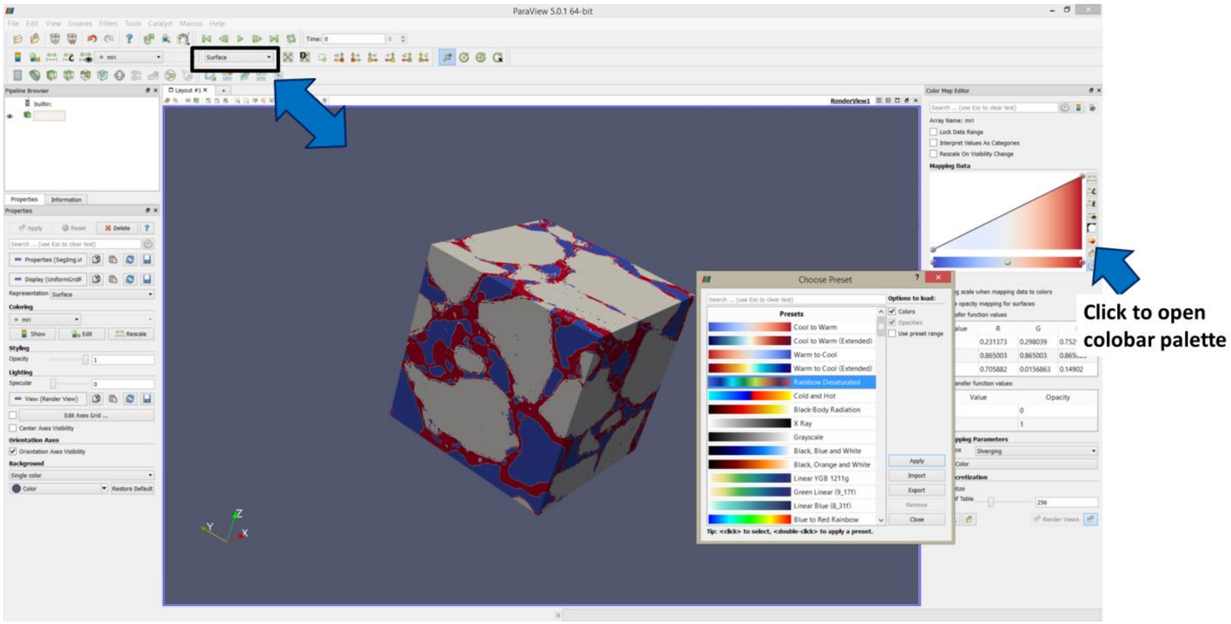


Figure 52: Surface mode in ParaView

- Figure 52: By changing the option from Slice -> Surface, using the drop-down menu highlighted in the black box, the complete stack can be further visualised in surface mode.
- Figure 52: To choose a different colour palette, left click on the icon.

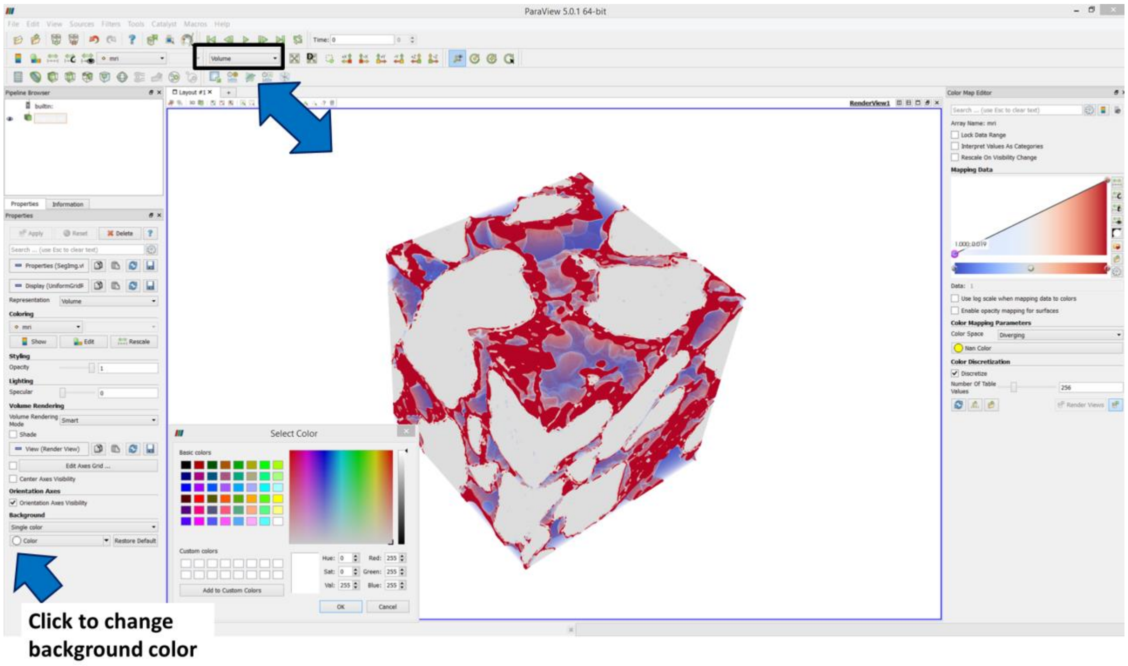
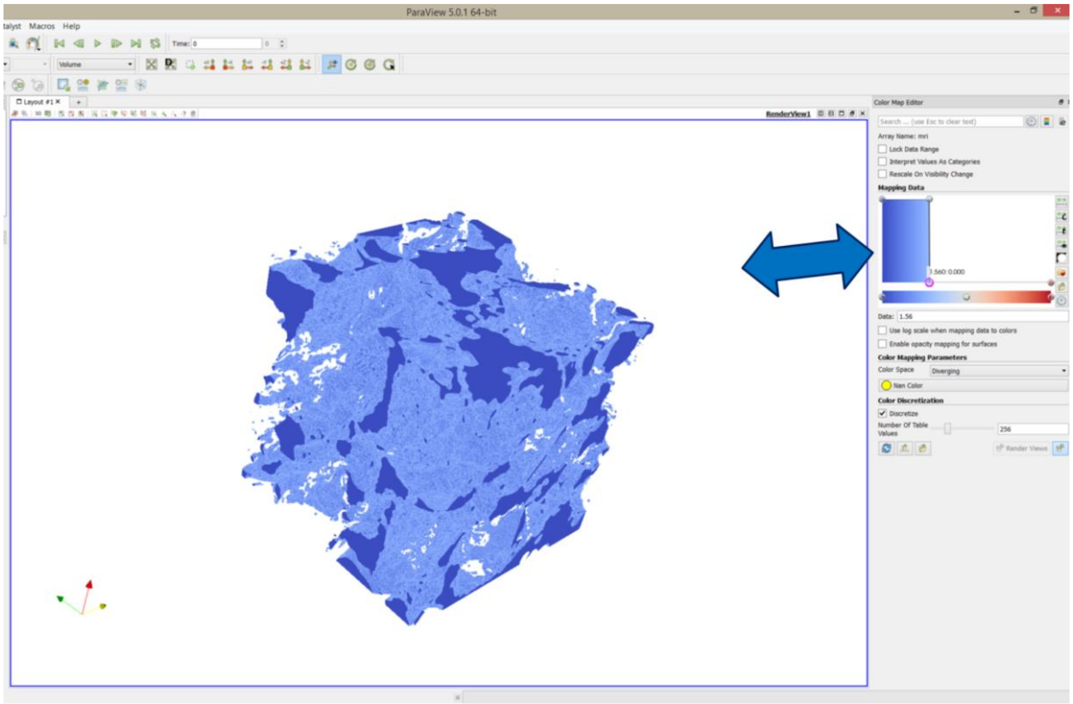


Figure 53: Volume rendered mode in ParaView

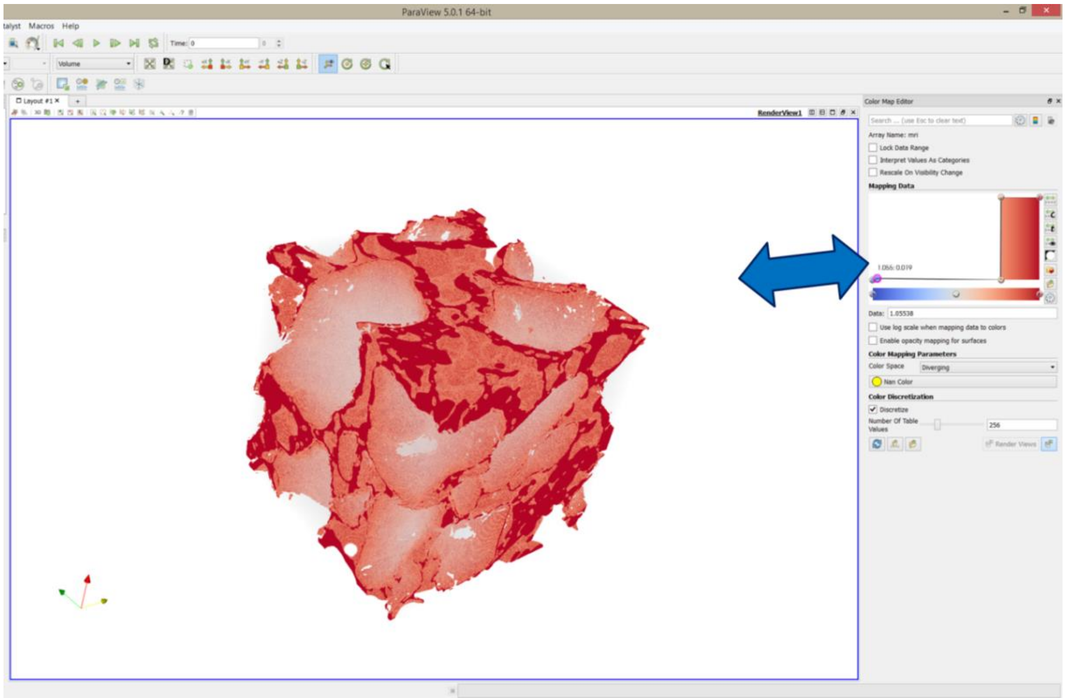
- Figure 53 shows the volume rendered plot. This is achieved by selecting the volume option highlighted by the black box in Figure 53. The stack can be further modified with different textures and opacity.
- Figure 53 also points out the option to change the background colour.



Array Name: mri
☐ Lock Data Range
☐ Interpret Values As Categories
☐ Rescale On Visibility Change
Data: 1.56
☐ Use log scale when mapping data to colors
☐ Enable opacity mapping for surfaces
Color Mapping Parameters
Color Space: Diverging
Nan Color
Color Discretization
☑ Discretize
Number Of Table Values: 256

Figure 54: Pore volume in ParaView

- By altering the colorbar, different phases can be highlighted or suppressed.
- Figure 54: The pore phase is extracted by maximizing the blue phase and flattening the other phases.
- Figure 54: Different phases, in this case pore, hydrate and gas, can be extracted by altering the colour scale as shown in Figure 54, 55 and 56.



Array Name: mri

☐ Lock Data Range

☐ Interpret Values As Categories

☐ Rescale On Visibility Change

Data: 1.05538

☐ Use log scale when mapping data to colors

☐ Enable opacity mapping for surfaces

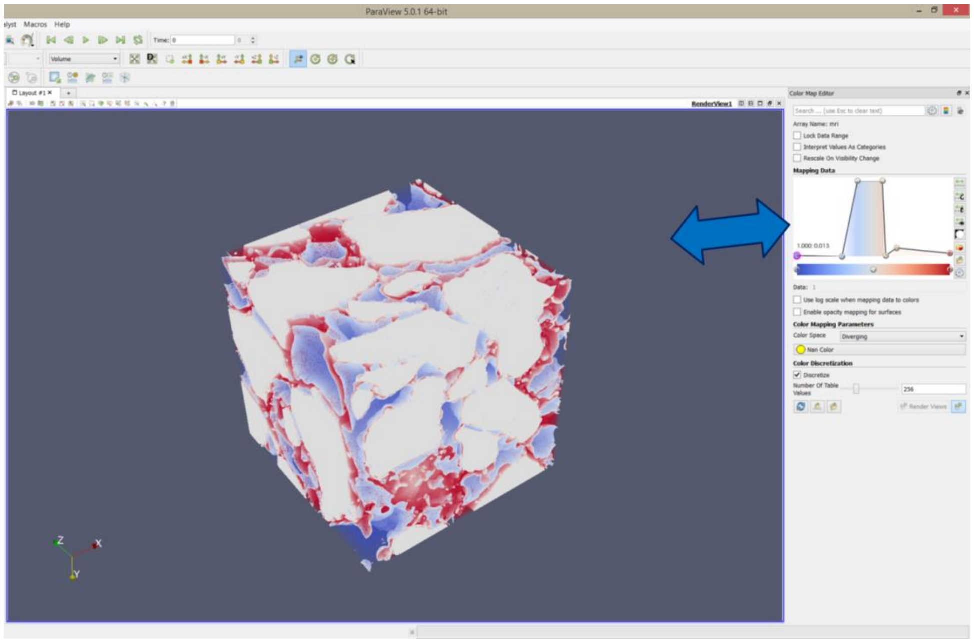
Color Space: Diverging

☑ Discretize

Number Of Table Values: 256

Figure 55: Hydrate volume in ParaView

- Figure 55: The **gas-hydrate phase** is extracted by **maximizing** the **red phase** and **flattening** the **other phases**.



Array Name: mri

☐ Lock Data Range

☐ Interpret Values As Categories

☐ Rescale On Visibility Change

Data: 1

☐ Use log scale when mapping data to colors

☐ Enable opacity mapping for surfaces

Color Space: Diverging

☑ Discretize

Number Of Table Values: 256

Figure 56: Gas volume in ParaView

- Figure 56: The **matrix phase** is extracted by **maximizing** the **gray phase** and **reducing** the **other phases**.

ParaView is a state-of-the-art open source visualisation software and can perform many other functions which cannot be covered in this manual. For more information, please refer to online tutorials and the documentation guide on ParaView website.

https://www.paraview.org/documentation/

7. Limitations

Table 11: Limitation of CobWeb 1.0

CobWeb 1.0
The number of interations in the case of FCM is hard coded up to 80 • 80 iterations give a fair balance between accuracy and speed
In the case of FCM segmentation the colour scheme differs from slice-to-slice • For example, cluster 4 might get the colour red for slice no. 1 and the colour blue for slice no. 50 This is caused by the MATLAB FCM library as it chooses random starting points to initialise clusters.
Some of the distance functions may not work for K-means or FCM • The distance functions were configured for self-organised maps (SOM) • The SOM segmentation scheme was removed as it was not compatible with the standalone mode.
Filters • Non-local means is only implemented as a 2D filter because filtration is done slice-by-slice • Filtration works in tandem with segmentation, thus, viewing slices after filtration is not possible.
The stop button does not instantaneously stop or kill the process.
In LSSVM segmentation, based on the user-supplied X, Y coordinate, an area around the coordinate axis is scanned and pixel values are extracted. The grid size of this area is fixed to 36 x 36 pixels. This implementation gave the best balance between accuracy and speed. But in some cases, this might cause discrepancies in segmentation based on different feature ratios.
The generated 2D XCT film has a low visualisation quality. • We recommend using ParaView to generate XCT film.
CobWeb's volume rendering capabilities are limited. Therefore for superior volume rendering results, we recommend using ParaView, as explained in section 7.4.1.
CobWeb 1.0 can read only RAW and TIFF files.

8. Trouble Shooting

Table 12: Troubleshooting

Problems	Possible Causes	Possible Solutions
3D Rendering problems, **such as** the **graphical window not upload**ing, **texture not appear**ing.	Outdated graphic card.	Upgrade graphic card.
	If onboard graphic card is installed.	The onboard graphic card may be inefficient for the CobWeb 1.0. Update.
Performance is low.	There is not enough RAM available due to other running applications.	Close other applications and if possible restart CobWeb 1.0.
Performance is extremely low when working with large data sets.	The size of the data sets exceeds the installed RAM capacity.	If possible install more RAM or select less number of data slices. Or use different sizes or ROI (region of interest).
The application hangs or crashes when working with large data sets.	The size of the data sets exceeds the installed RAM, the swap space is not activated or too small.	• Activate the swap space. • Enlarge the size of the swap space to about the order of magnitude of the RAM. • Install more RAM. • Reduce the size of the data set, select fewer slices.
On a **PC or notebook with two graphic cards: The application crashes.**	Automatic switching between the graphics cards does not work properly.	Deactivate the onboard graphic card in the BIOS in order to use the dedicated graphic card of the notebook or PC.
The application crashes when trying to open an animation saved to an .avi file using a third-party codec package.	• The codec is not compatible with the selected settings of the .avi. • Most codecs are continuously being developed and are not always free of bugs. • A 32-bit version instead of a 64-bit version of the codec is installed.	• Install the 64-bit version of this codec. • Select a different codec.
CobWeb 1.0 does not start for a user with administrator rights.		Go to the CobWeb 1.0 folder and start the executable .exe directly.
When double clicking a file	The files are not linked to	Go to the CobWeb 1.0 folder and start the

in Windows Explorer, it is not opened by CobWeb.	the executablefile of CobWeb 1.0.	executable .exe directly.