# ImportGeo-Vol

User Guide

GeoDict release 2022

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GeoDict

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# ImportGeo submodules

The three ImportGeo submodules can handle and import most 2D and 3D image file formats into GeoDict.

- ImportGeo-Base loads structure files with a GeoDict file format. For more information, check the ImportGeo-Base handbook of this User Guide.
- ImportGeo-Vol is used to import most image file formats for 3D visualization, 3D image processing and segmentation. On imported gray value images, ImportGeo-Vol can perform 3D processing with a variety of filtering techniques. Subsequent segmentation converts gray values to material index values typically stored in the GeoDict Binary file format.
- ImportGeo-CAD imports surface triangulation files that describe only the surface geometry of a three-dimensional object. During import, these files can be converted to 3D material models. For more information, check the ImportGeo-CAD handbook of this User Guide.

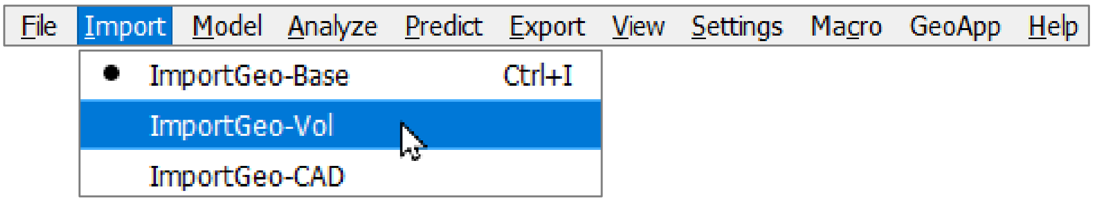
The three ImportGeo submodules import the following file formats:

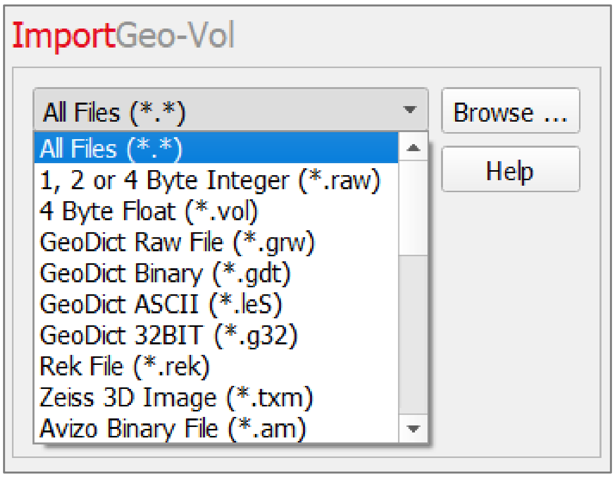
| ImportGeo **submodule** | **File formats** | | | |
|---|---|---|---|---|
| ImportGeo-**Base** | GeoDict Binary (*.gdt) | GeoDict Analytic (*.gad) | GeoDict ASCII (*.leS) | GeoDict 32BIT (*.g32) |
| ImportGeo-**Vol** | 1, 2 or 4 Byte Integer (*.raw) | 4 Byte Float (*.vol) | GeoDict Raw File (*.grw) | GeoDict Binary (*.gdt) |
| | GeoDict ASCII (*.leS) | GeoDict 32BIT (*.g32) | Rek File (*.rek) | Zeiss 3D Image (*.txm) |
| | Avizo Binary File (*.am) | WiseTex Vox File (*.vox) | IASS File (*.iass) | TIF Image File (*.tif) (*.tiff) |
| | BMP Image File (*.bmp) | CUR Image File (*.cur) | GIF Image File (*.gif) | ICO Image File (*.ico) |
| | JPEG Image File (*.jpeg) | JPG Image File (*.jpg) | PBM Image File (*.pbm) | PGM Image File (*.pgm) |
| | PNG Image File (*.png) | PPM Image File (*.ppm) | SVG Image File (*.svg) | SVGZ Image File (*.svgz) |
| | XBM Image File (*.xbm) | XPM Image File (*.xpm) | | |
| ImportGeo-**CAD** | STL File (*.stl) | OBJ File (*.obj) | | |

For complete information on GeoDict file formats and file formats supported by GeoDict, see **File Management** in the Base Reference handbook of the GeoDict2022 User Guide.

# IMPORTGEO-VOL

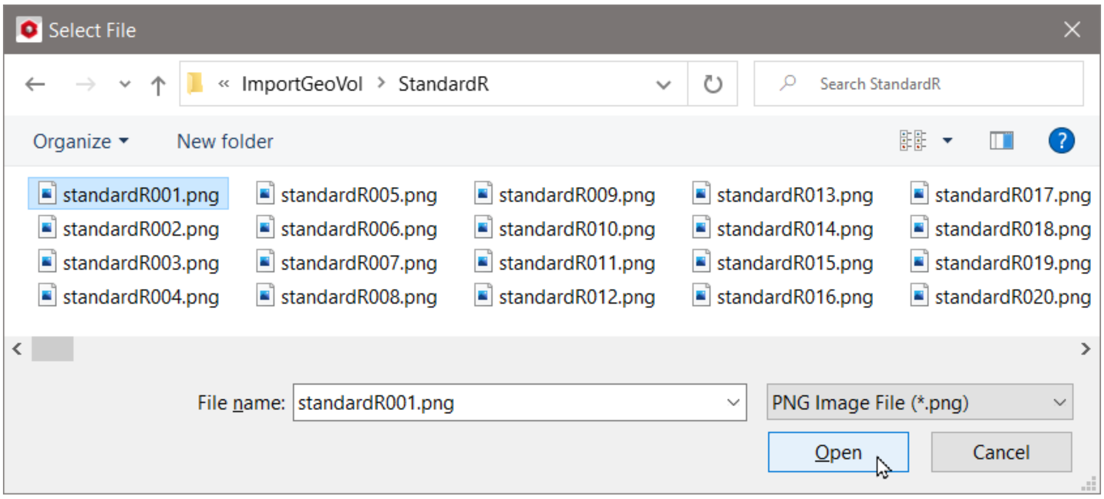
To convert volume and image formats, such as µCT-scans, into 3D material models, select **Import** → **ImportGeo-Vol** in the menu bar. The **ImportGeo-Vol** section opens at the left of the GeoDict GUI.



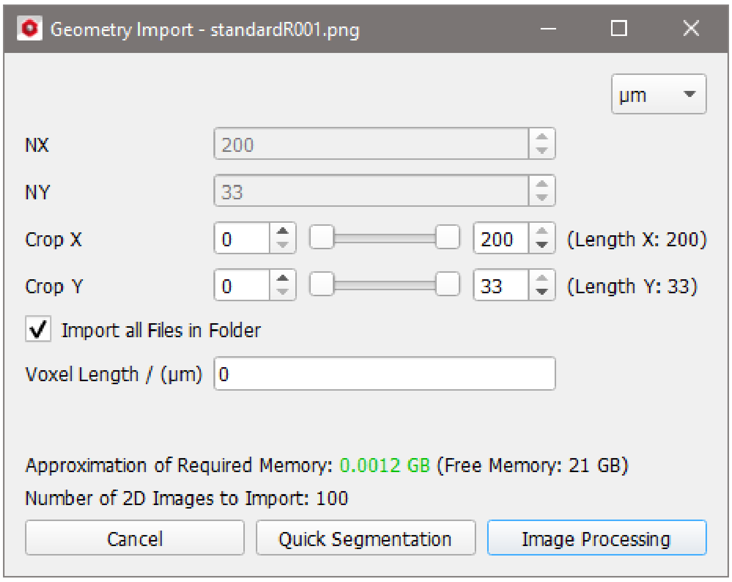

The data format to be imported is selected from the pull-down menu in the **ImportGeo-Vol** section. With the default **All Files (*.*)** files of all file types available in the pull-down menu can be imported.

After selecting the format (here *.png), clicking **Browse** opens the **Select File** dialog to locate a file of that format in the chosen project folder. Select the filename and click **Open**.




In the **Geometry Import** dialog, for most formats, the size of the file's structure is automatically entered.

The amount of approximately required memory and free memory are displayed and indicate the amount of working memory available.



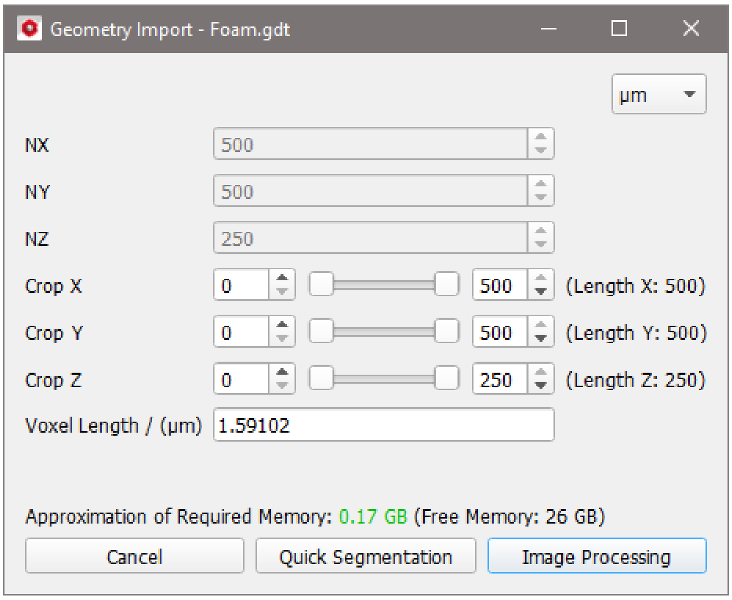

At the bottom, the **Quick Segmentation**, and **Image Processing** buttons can be clicked:

- **Quick Segmentation:** For many of the importable file formats, the structure appears in the visualization area after clicking **Quick Segmentation**.

  For other files, such as *.raw image files, or stacks of *.png files, that are considered a three-dimensional image with gray values (e.g., from 0 to 255), clicking **Quick Segmentation** opens the **3D Image Quick Segmentation** dialog. This dialog shows a histogram with the number of voxels for each of these gray values and enables a simple global segmentation without further 3D Image Processing. For more information see *Quick Segmentation for 3D images with ImportGeo-Vol* on pages 13ff.

- **Image Processing:** allows more complex image processing through which images can be cut, resized, rotated, and segmented by thresholding and filtering. For more information see *3D Image Processing in ImportGeo-Vol* on pages 18ff.

After selecting the file format to be imported, click **Browse...** to locate the file. Depending on its file format, a dialog opens containing various options and parameters defining each file format, in preparation for the import.



The available units (**m**, **mm**, **µm**, **nm** and **Inch**) are selectable from the pull-down menu at the top right of every dialog.

At the bottom of every dialog, the voxel size in the desired unit can be defined in **Voxel Length**. **Voxel Length** and the size of the selected image of the structure in voxels (**NX**, **NY**, **NZ**) are shown for all the formats for import.

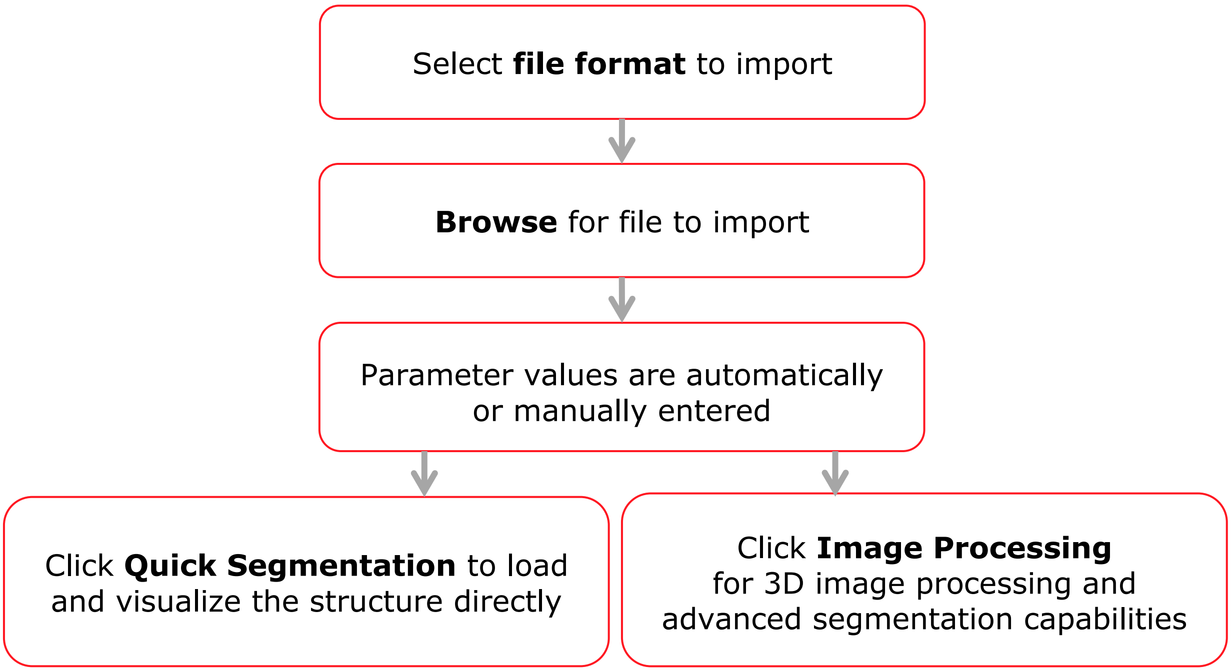
**NX**, **NY**, and **NZ** specify the size of the structure in voxels. For most file types, these values are entered automatically. For RAW format files (*.raw), you need to know these values and enter them here. For *.gad files (**G**eoDict **A**nalytic **D**ata), they can be arbitrarily defined.

The double sliders allow restricting the portion of the 3D image to be loaded. The left-hand sliders define the number of voxels which are cut away at the start of the image in each direction, and the right-hand sliders define the last voxel to be imported in each direction.

By default, ImportGeo imports the complete image from the hard drive. The values for **NX**, **NY**, and **NZ**, and the first and last voxel positions might be changed for very large images that would not fit in memory. It is possible to focus on any sub-cuboid of the original image by adjusting the sliders.

For most importable file formats, the size parameters are automatically entered after browsing for the file and loading it. Clicking **Quick Segmentation** brings in the structure saved in the selected file, so that it is displayed in the visualization area.

All file formats listed above can be processed (i.e., the objects in the structure can be cut, resized, rotated, thresholded, and filtered) before the file is finally imported into GeoDict.

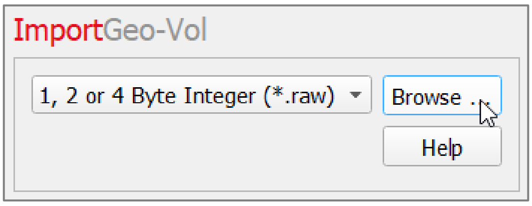


# File Formats for ImportGeo-Vol

The following pages describe the import of the various file types listed in page 1.

## 1,2, or 4 Byte Integer (*.raw)

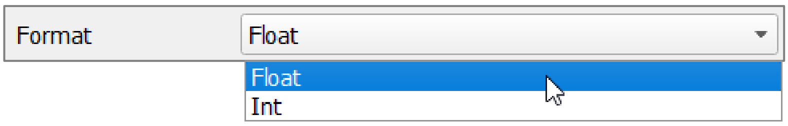
The RAW format describes grayscale three-dimensional (or volume) images. In a RAW image file, the **Header Size** specifies the length of the header of the selected image file in bytes. A typical convention for **Header size** is 2048. A RAW file is a simple binary file, in most cases, without header information. A RAW file is created, e.g., when taking tomographic images. Thus, the creator of a RAW file must provide the information on the size needed for import, as it should be provided from the person taking the tomography.




For a file containing a three-dimensional image with **NX** by **NY** by **NZ** voxels with format **Int**, the file consists of either **Header Size** + **1** x **NX** x **NY** x **NZ** bytes, **Header Size** + **2** x **NX** x **NY** x **NZ** bytes or **Header Size** + **4** x **NX** x **NY** x **NZ** bytes.

The position of the byte (or 2 bytes or 4 bytes) in the **Int** file determines the position of the corresponding voxel. In case of a single byte (or 8-bit images), all gray values from 0 to 255 may be present. In images with 2 bytes per voxel (or 16-bit images), gray values from 0 to 65535 can be represented. Finally, images with 4 bytes per voxel (or 32-bit images) can represent roughly 4 billion gray values.

If the RAW file to load contains floating point values, in the **Geometry Import** dialog select **Float** from the pull-down menu for **Format**. For images in float format the file can consist of either **Header Size + 4 x NX x NY x NZ** bytes or **Header Size** + **8** x **NX** x **NY** x **NZ** bytes.

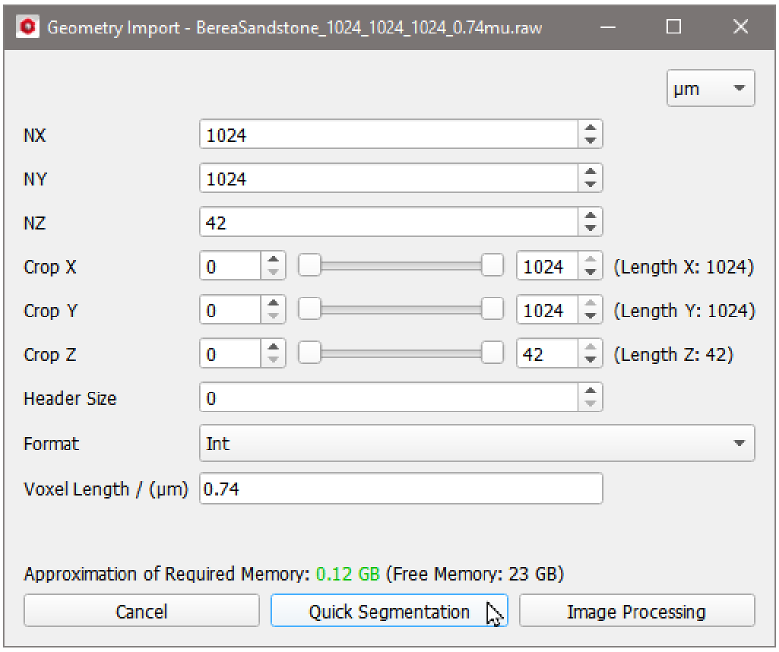



GeoDict cannot automatically retrieve the dimensions of an image saved in **RAW** format. The parameters **NX**, **NY** and **NZ** and the **Header Size** must be known before loading the file.

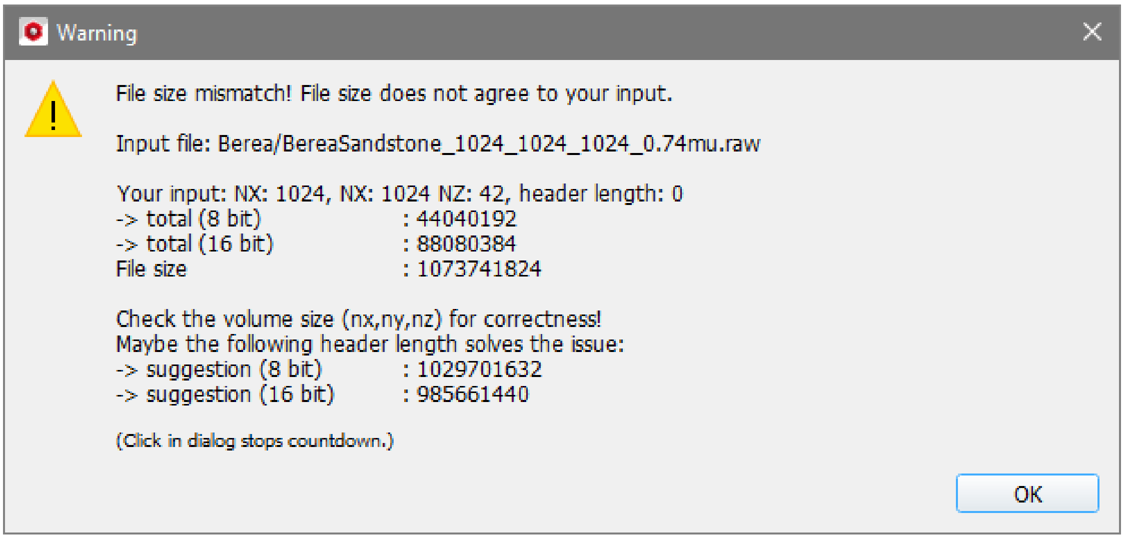
In case the user simply clicks **Quick Segmentation** in the **Geometry Import** dialog after browsing for a *.raw file, a warning appears stating that the file length does not agree with the entered size.

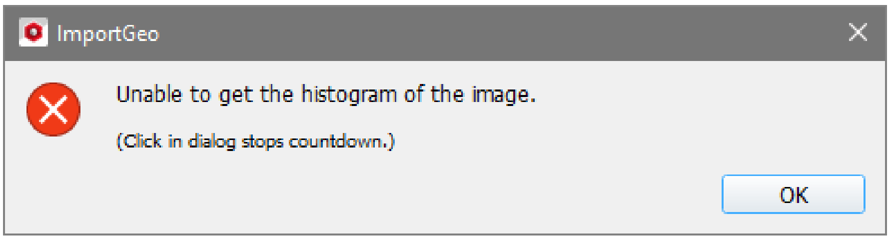
In the following, the Berea sandstone of Andrä et al. (2013) is used in an example to describe the workflow before segmenting or processing the image.

Here, with the values of NX=1024, NY=1024 and NZ=42, the file length with the **Header Size** (0) comes up to approx. 44 million bytes (Header size + NX x NY x NZ = 0 + 200 x 33 x 1) in case of an 8 bit image, but this is incorrect and, as a result, the .raw file is not loaded.




A warning appears comparing the selected file size and the calculated byte size with respect to the input values for 8 bit and 16 bit integer values. The **Warning** suggests an input value for **Header Size**, which is necessary for *.raw files with header information. Values up to 2048 (bytes) may typically be expected here.

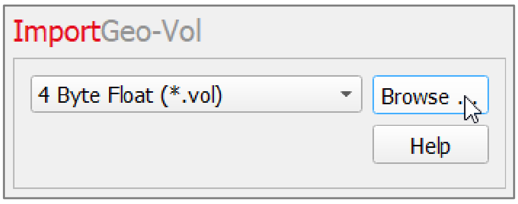


It is a recommended habit to include file dimensions and voxel size in the name of *.raw* files. Accordingly, the correct values are here extracted from the file name of the Berea sandstone structure *BereaSandstone_1024_1024_1024_0.74mu.raw*. In other cases, the taker of the tomography provides the correct values in an additional readable file or as header of the raw file, so that the values can be extracted using a text editor (e.g., Notepad++).

Click **Quick Segmentation** to segment the image without image processing, as it is described on pages 13ff. Click **Image Processing** to open the image in the **3D Image Processing** dialog, which is described on pages 18ff.

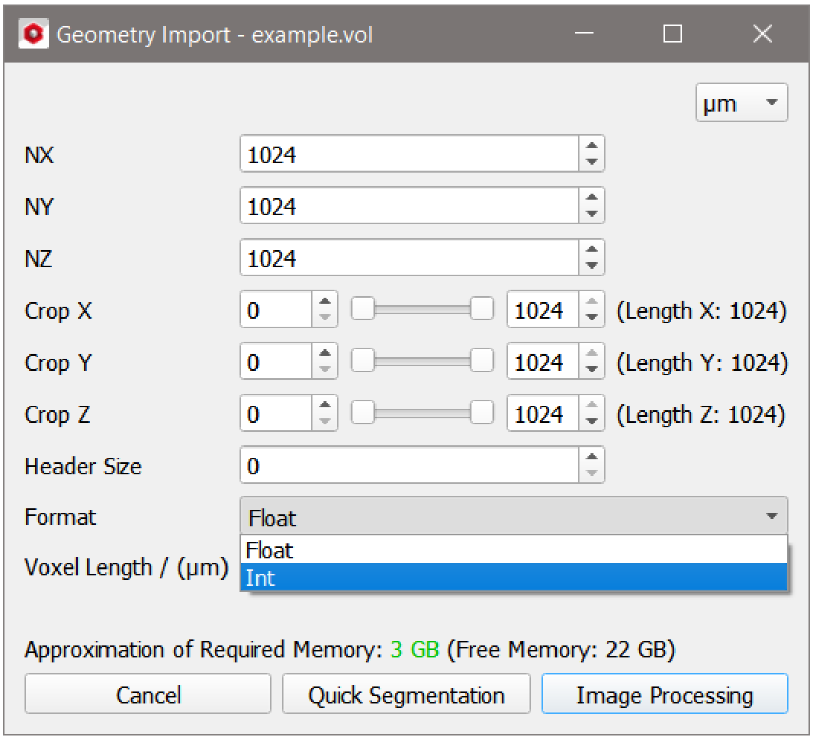
## 4 Byte Float or Int (*.vol)




**VOL** files are 3D image data files with variable length header. GeoDict assumes **VOL** files to contain floating-point representations of three-dimensional (or volume) images. The import dialog also offers the option to import 32 Bit Integer values.

The ordering of the information is the same as for the RAW file format and, as in the RAW file format, a file header may be present.

Different from RAW files, always 4 bytes are used in the representation of the image, and these 4 bytes may be read as floating-point number or integer value. Like in the RAW files, the **Header Size**, the number of voxels (**NX**, **NY** and **NZ**) and the **Voxel Length** are not contained in the file and must be entered in the **Geometry Import** dialog by the user before importing.




Some other software packages do not follow GeoDict's naming scheme, and produce **VOL** files with integer values in them, usually with 16-bit information. Should the user have trouble importing **VOL** files and suspect that the file contains integer data rather than floating point data, it might be useful to try and change the **Format** option (see image above) to **Int** type and then import the file with ImportGeo**.**

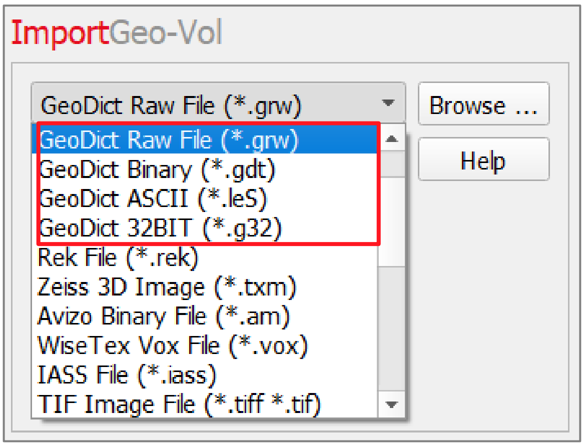
In the **Geometry Import** dialog, the imported structure can be chosen to be in format **Float** (floating point) or **Int** (integer).

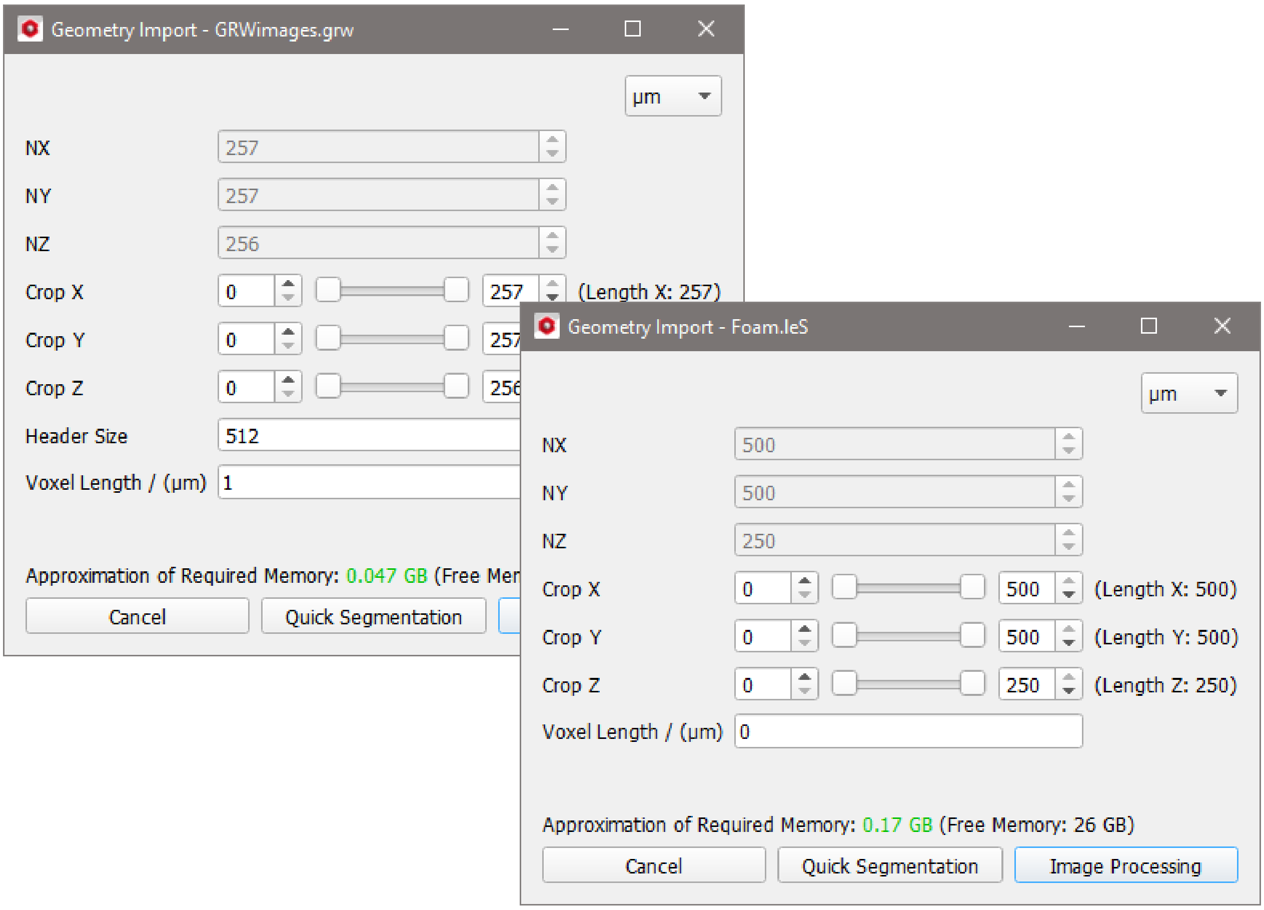
Click **Quick Segmentation** to segment the image without image processing, as it is described on pages 13ff. Click **Image Processing** to open the image in the **3D Image Processing** dialog, which is described on pages 18ff.

## GeoDict File Formats (grw, gdt, leS, g32)

For the import of the GeoDict file formats **GRW** (GeoDict Raw), **GDT** (GeoDict Binary), and **G32** (GeoDict 32BIT) the dimension parameters and the voxel length are automatically read from the file.

For the import of **LES** files (GeoDict ASCII) the **Voxel Length** must be entered.

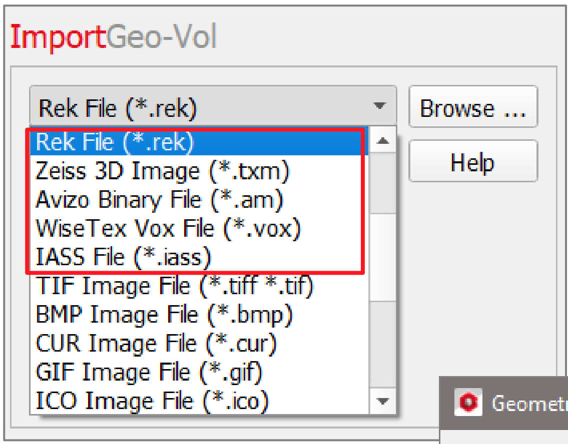



Click **Quick Segmentation** to segment the image without image processing, as it is described on pages 13ff. Click **Image Processing** to open the image in the **3D Image Processing** dialog, which is described on pages 18ff.

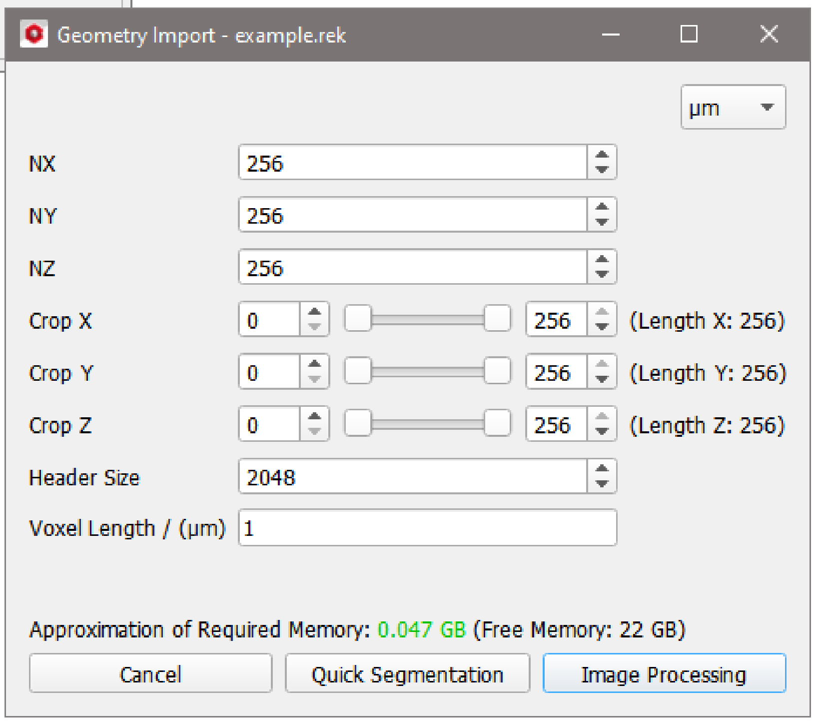
## Other 3D Data File Formats (REK, TXM, AM, VOX, IASS)

For the import of **REK** files (Fraunhofer), **TXM** files (Zeiss), **AM** files (Avizo), **VOX** files (WiseTex) and **IASS** files (Fraunhofer), the dimension parameters and the voxel length are available from the header of the file and are automatically read from the file.




**REK** files are reconstruction files from Fraunhofer containing data from 3D computer tomography.

**IASS** files are the native 3D image data format of the Fraunhofer ITWM's MAVI (Modular Algorithms for Volume Images).

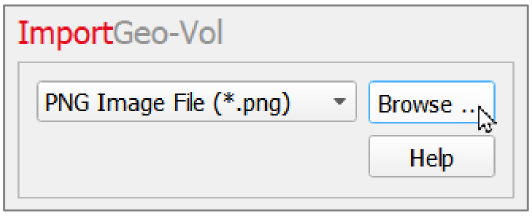


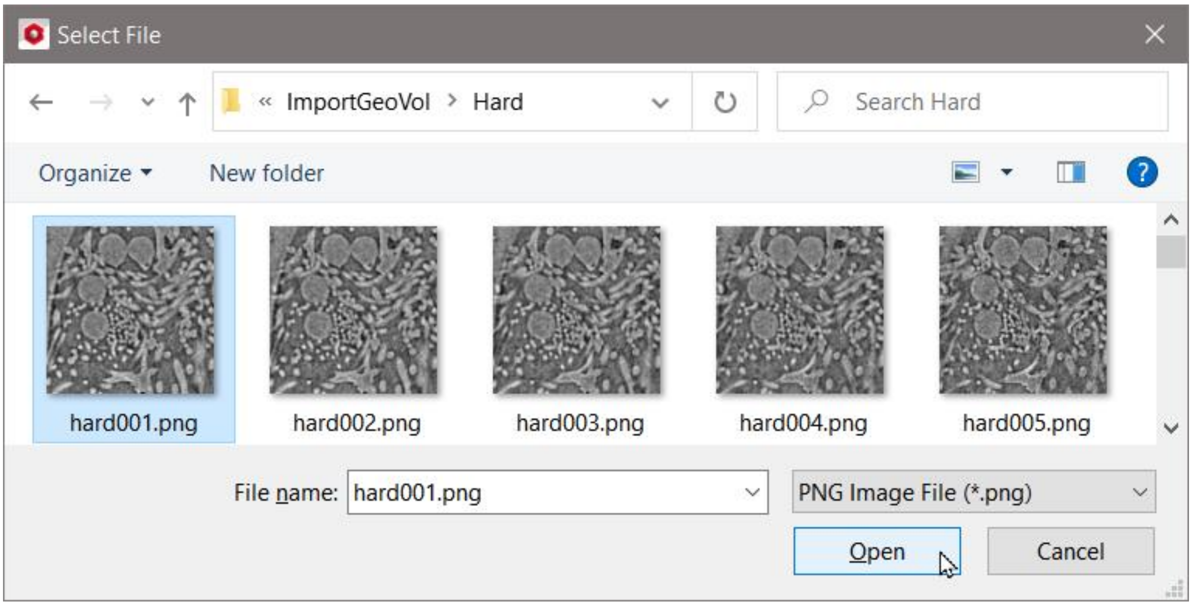

Click **Quick Segmentation** to segment the image without image processing, as it is described on pages 13ff. Click **Image Processing** to open the image in the **3D Image Processing** dialog, which is described on pages 18ff.

## Image File Formats (TIF, BMP, CUR, GIF, ICO, JPEG, JPG, PBM, PGM, PNG, PPM, SVG, SVGZ, XBM, XPM)

Single 2D images or complete structure data consisting of a stack of 2D images, in any of the importable image formats, can be imported using ImportGeo-Vol. The images in a stack form layers in the XY-plane. Then, each of the images is one layer in the Z-direction. TIF-images in 3D-format can also be imported.

To import a single image or a stack of images, in an importable image format, select that format from the pull-down menu. Click **Browse** and select one of the files in the stack of interest.

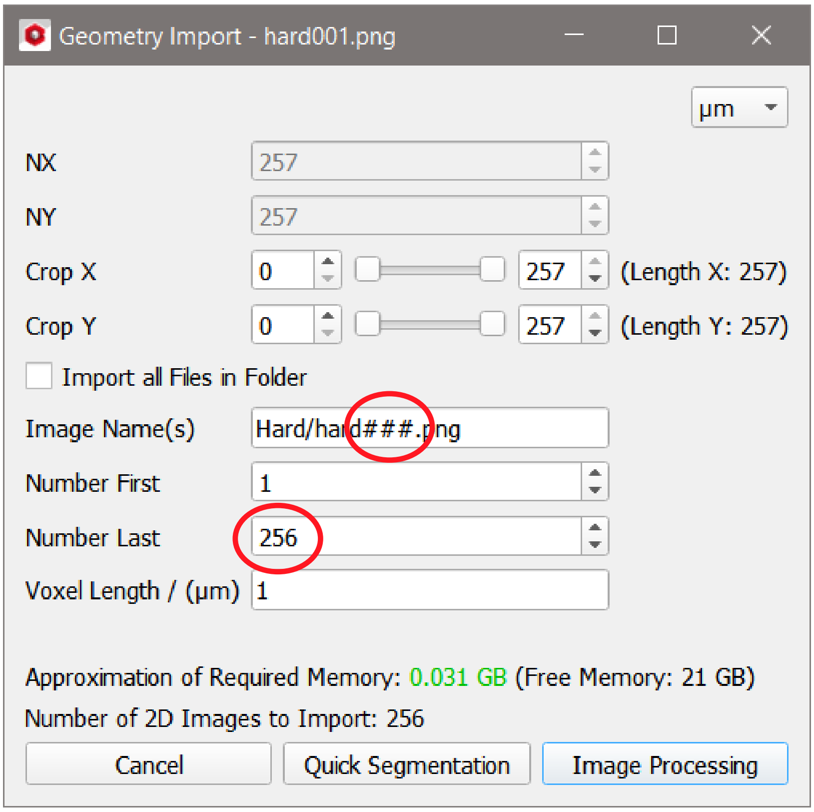



After clicking **Open**, the **Geometry Import** dialog opens. The dimensional values in the X and Y-direction are automatically filled in for all image type files, but they can be changed to import only a part of the single image or structure (**Crop X**, **Crop Y**). The default voxel length must be changed to the one in the resolution data provided with the stack of CT images. All images in a stack must have the same resolution.

If not all images in the selected folder should be imported uncheck **Import all Files in Folder**. Then, the relative path to the image file and its name displays in the field **Image Name(s)**. Adjust the **Image Name(s)**, and the values for **Number First** and **Number Last**.

For the import, the images must be given as a stack of files, with the same file name followed by numerically correlated numbers.




Checking **Import all Files in Folder** has the same effect as:

a. changing the numbers in **Image(s) Name** by as many "#"s as the image number (e.g., 001 = ###) and

b. entering the first image and last image number values for the range of images to load.

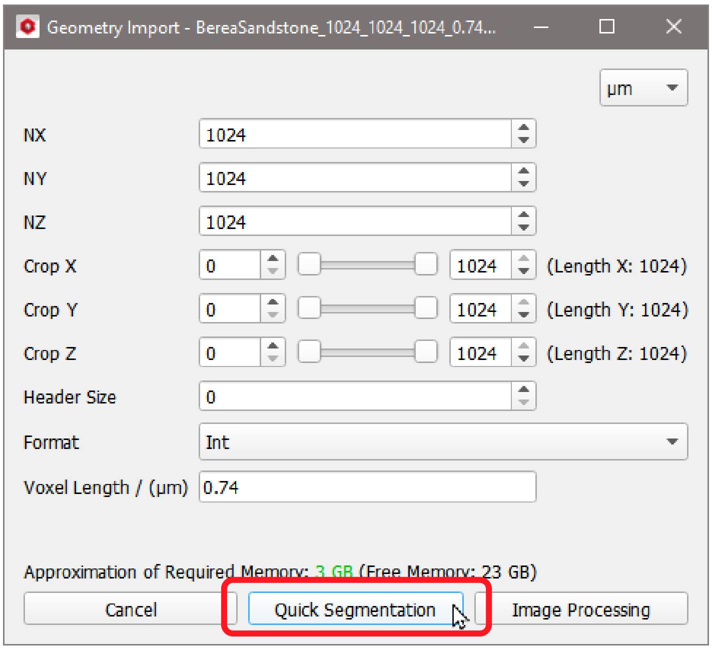
Click **Quick Segmentation** to segment the image without image processing, as it is described on pages 13ff. Click **Image Processing** to open the image in the **3D Image Processing** dialog, which is described on pages 18ff.

# QUICK SEGMENTATION FOR 3D IMAGES WITH IMPORTGEO-VOL

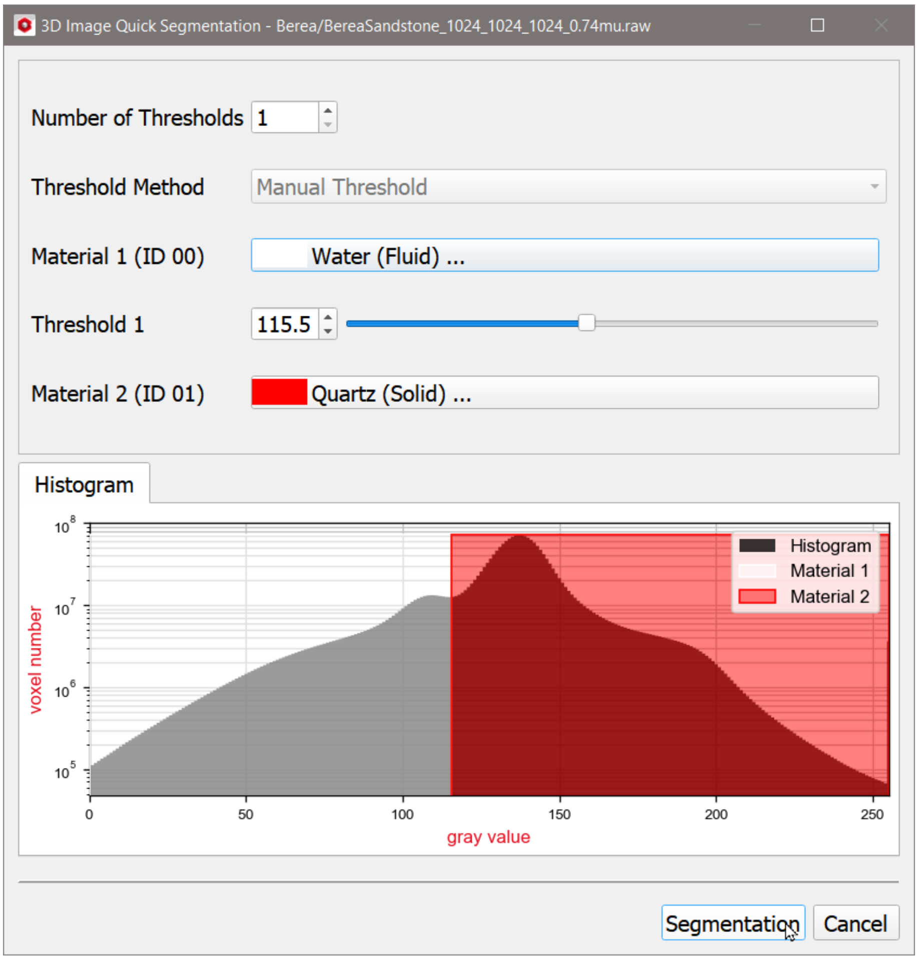
Images are loaded with ImportGeo-Vol by clicking **Quick Segmentation** in the **Geometry Import** dialog.

When the 3D image can be read properly (e.g., the image dimensions must be set correctly in case of a **RAW format** as described on page 5), this opens the **3D Image Load** dialog.

The Berea sandstone of Andrä et al. (2013) is used here to describe the workflow when following the **Quick Segmentation** button. For non-binary 3D image scans, it is highly recommended to continue with **Image Processing** as described on pages 18ff., which also enables to use the entire range of segmentation capabilities in GeoDict.



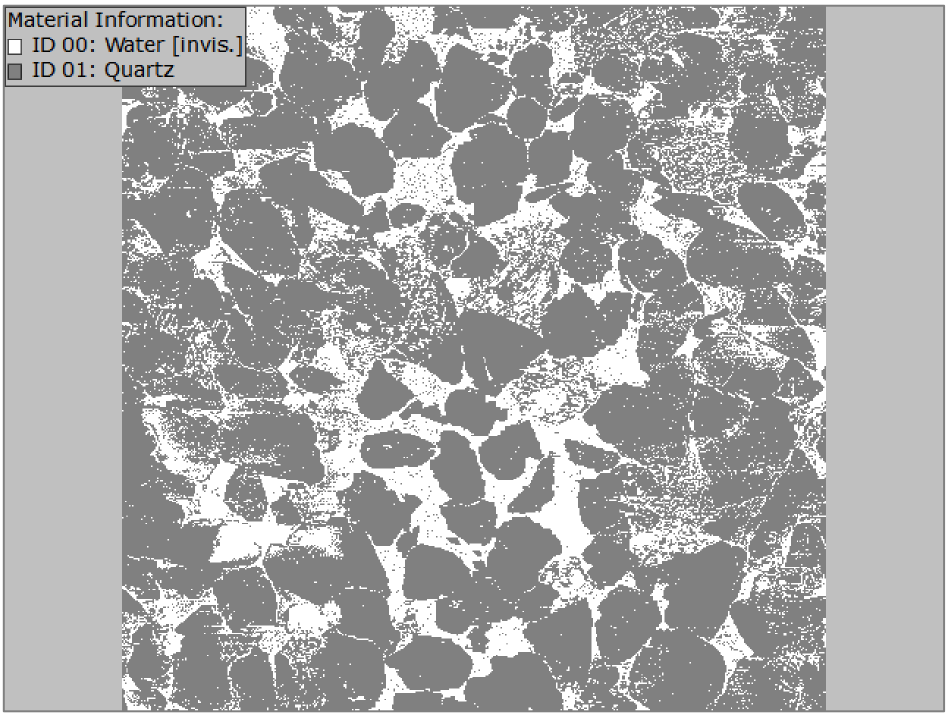

In the dialog, the 3D image can be manually segmented via global gray value threshold(s) without opening the **3D Image Processing** dialog.



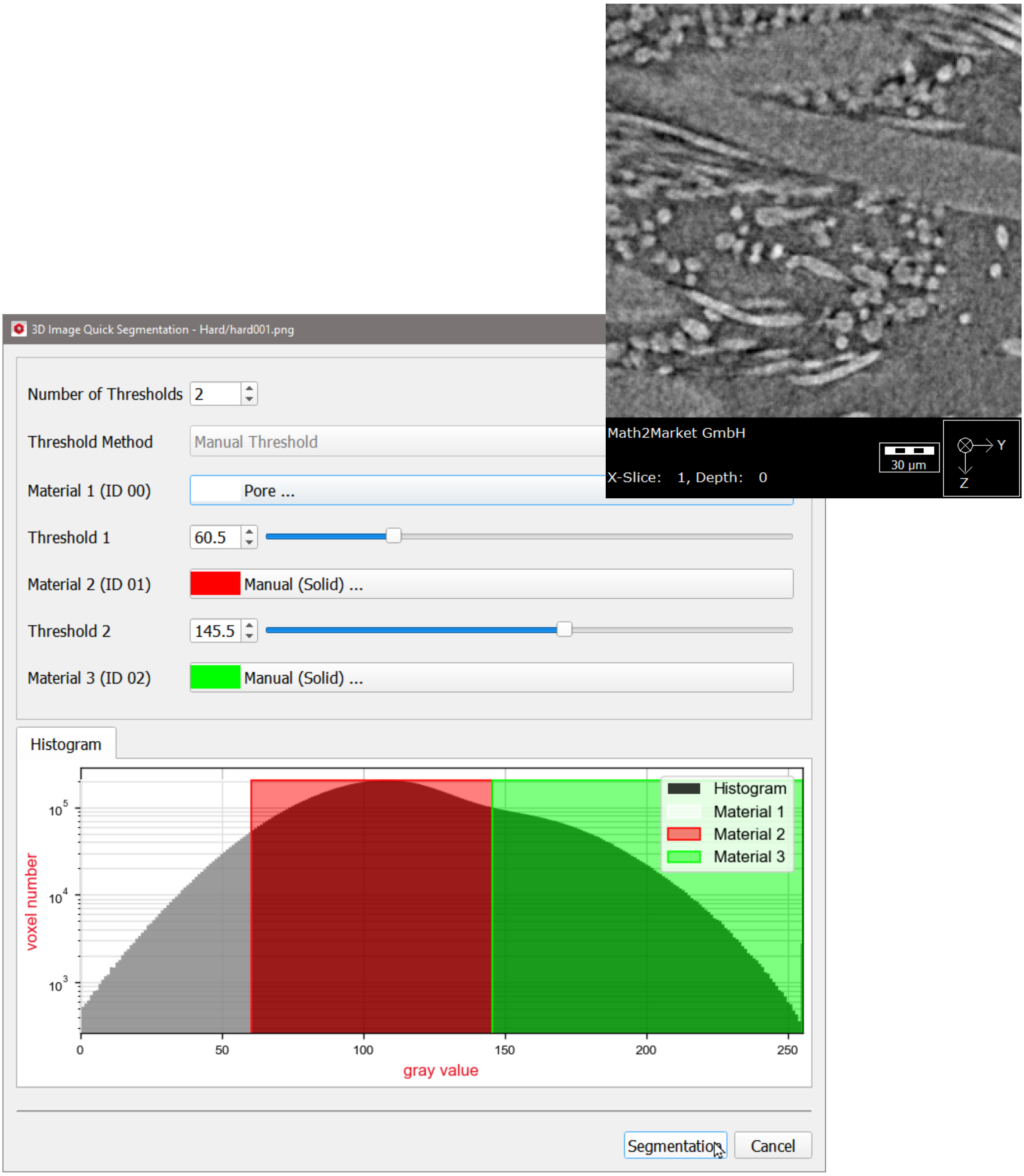
For the segmentation, first the **Number of Thresholds** may be defined. If the information is available, the constituent materials for the segmented material phases can also be set (e.g., Water and Quartz). The gray value thresholds between the chosen materials may be adjusted by entering a number or moving the slider left and right. The histogram shows the gray values (from 0-255 in case of 8-bit images) on the X-axis and the frequency of corresponding voxels on the Y-axis logarithmically. Typically, peaks indicate different materials. However, often peaks are not easily distinguished from each other. Please see the **Image Processing** section on page 18ff to learn more about distinguishing materials by filtering 3D images.

In the **3D Image Quick Segmentation** dialog in the example above, pore space and solid fraction may be distinguished with a threshold at 115.5. Then, clicking **Segmentation** segments the image. The file information is processed, and the file is imported and visualized in the **Visualization area** of the GeoDict GUI.

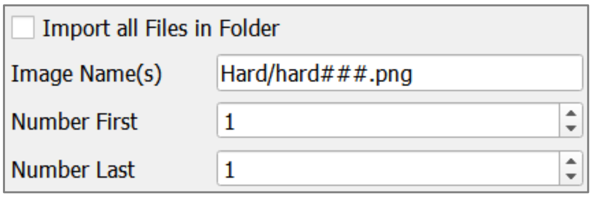
The 2D View visualization shows Quartz grains and pore space. However, a great amount of noise is visible in the image, meaning that solid voxels are wrongly located in the pore space and vice versa. Thus, this 2D View visualization hints at the need for a proper **Image Processing**. In general, if threshold values are not known a priori, it is recommended to continue with **Image Processing** instead of clicking **Quick Segmentation**.

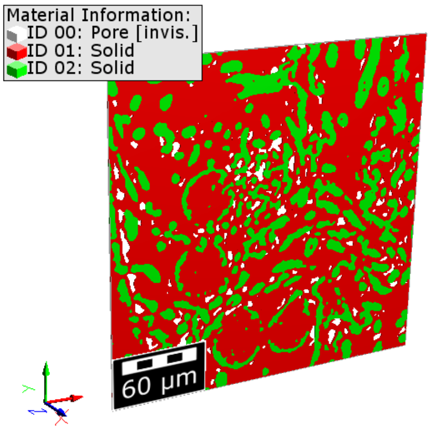


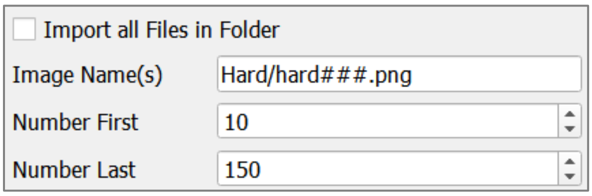
In the following, the **Quick Segmentation** feature is explained on another sample (see also Single 2D images above). After clicking **Quick Segmentation**, the gray values in the image file(s) can be assigned to Material IDs (and their colors) for visualization in GeoDict. It is possible to set up to 15 thresholds.

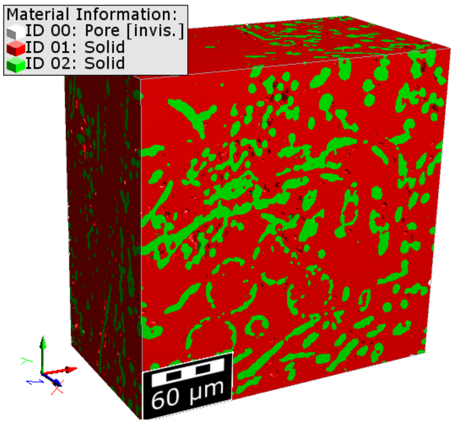


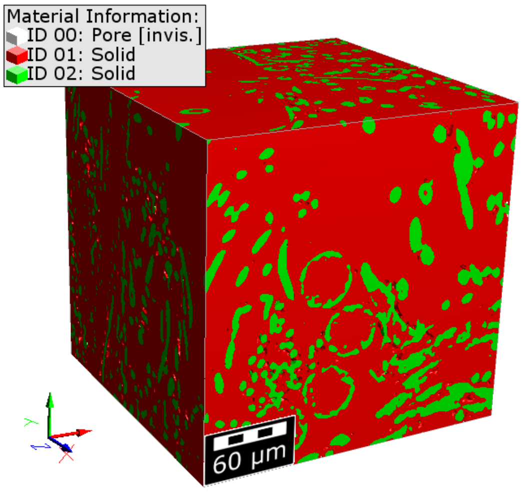

After setting these thresholds, clicking **Segmentation** loads the cutout specified in the **Import Geometry** dialog. In the following the number of imported images is changed with the parameters **Number First** and **Number Last** to import a single image file, a range of image files, or the complete stack of image files to form a structure.

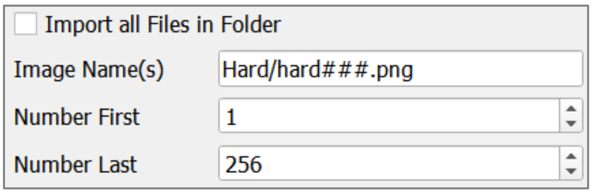


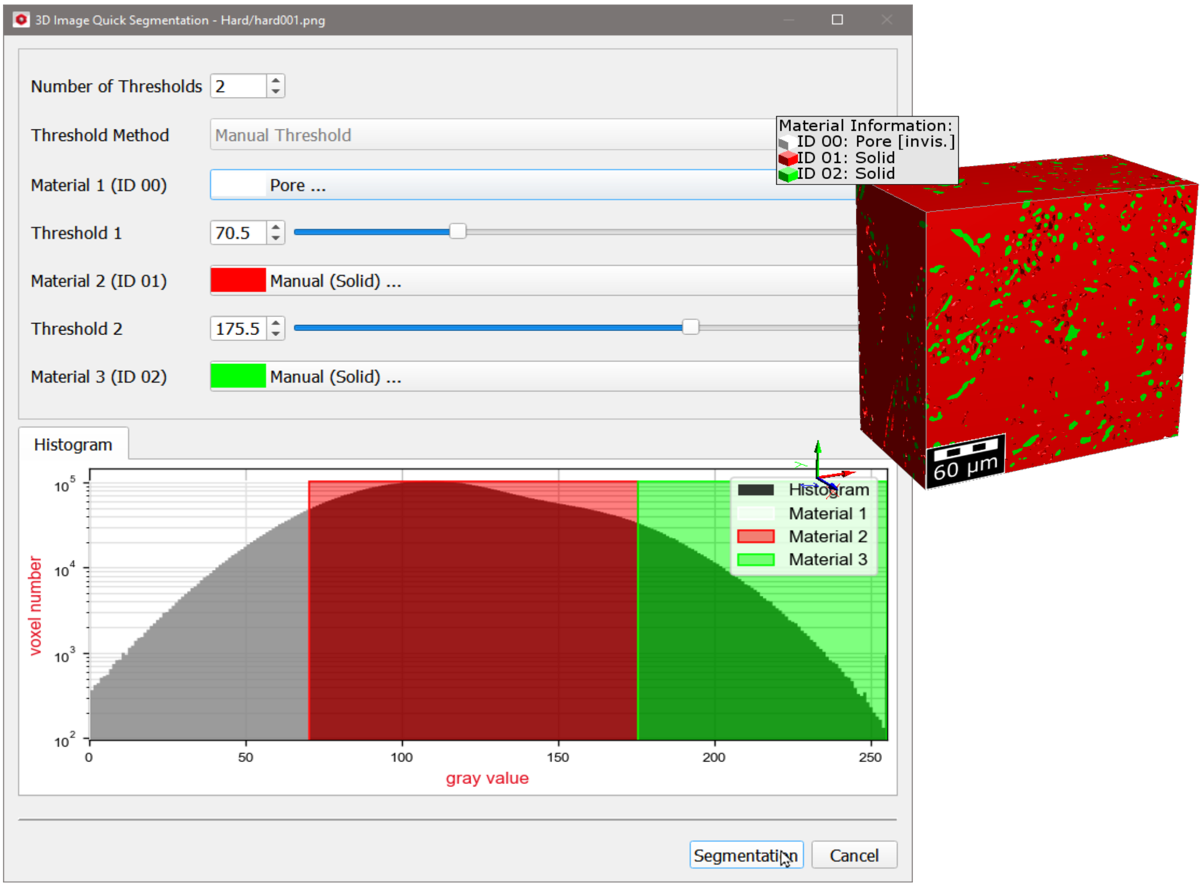



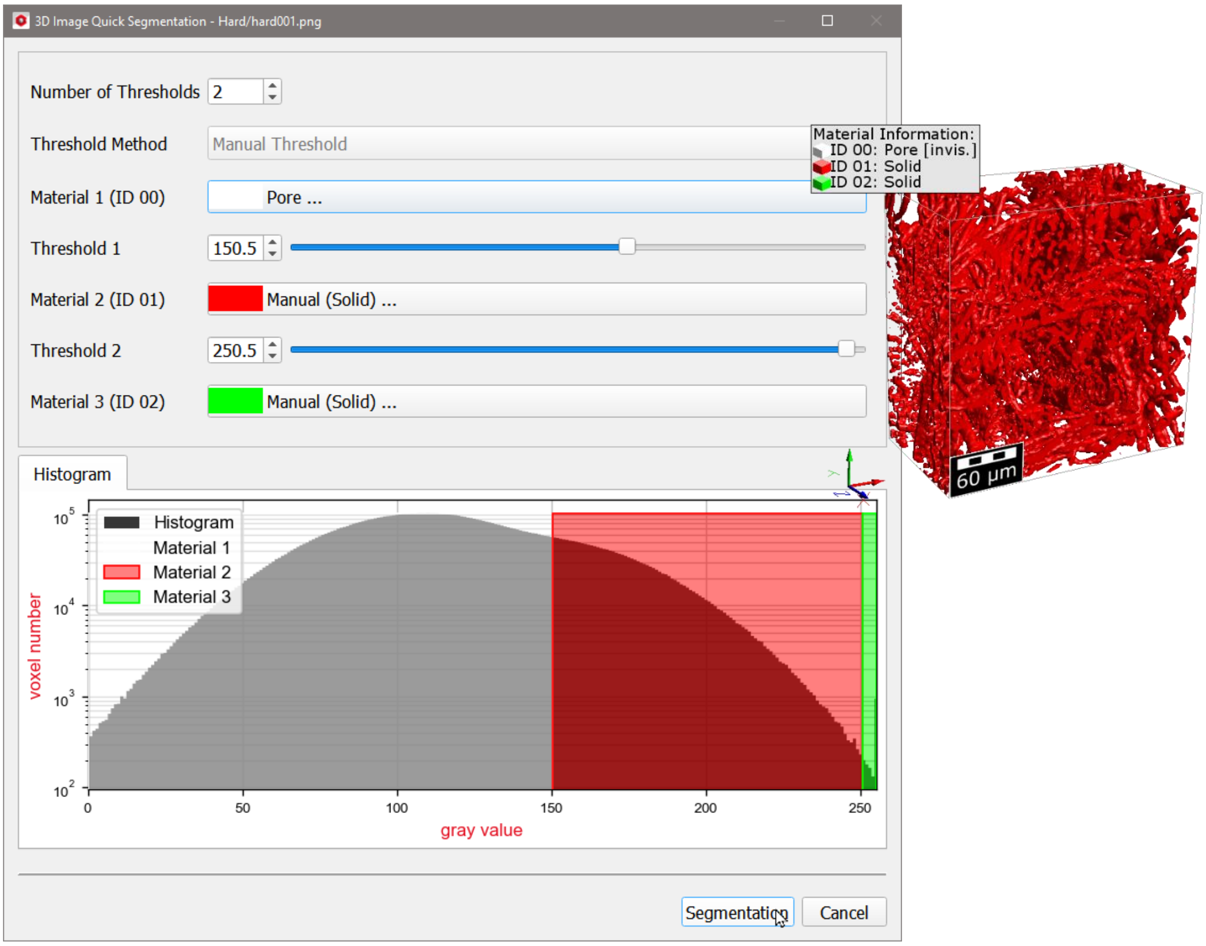





Move the threshold value sliders around before loading the stack of images and see the **Image Segmentation** section on pages 76ff for more information on thresholding values.


3D Image Quick Segmentation - Hard/hard001.png
Number of Thresholds 2
Threshold Method Manual Threshold
Material 1 (ID 00) Pore ...
Threshold 1 70.5
Material 2 (ID 01) Manual (Solid) ...
Threshold 2 175.5
Material 3 (ID 02) Manual (Solid) ...
Histogram
voxel number
gray value
Histogram
Material 1
Material 2
Material 3
Segmentation
Cancel
Material Information:
ID 00: Pore [invis.]
ID 01: Solid
ID 02: Solid
60 µm

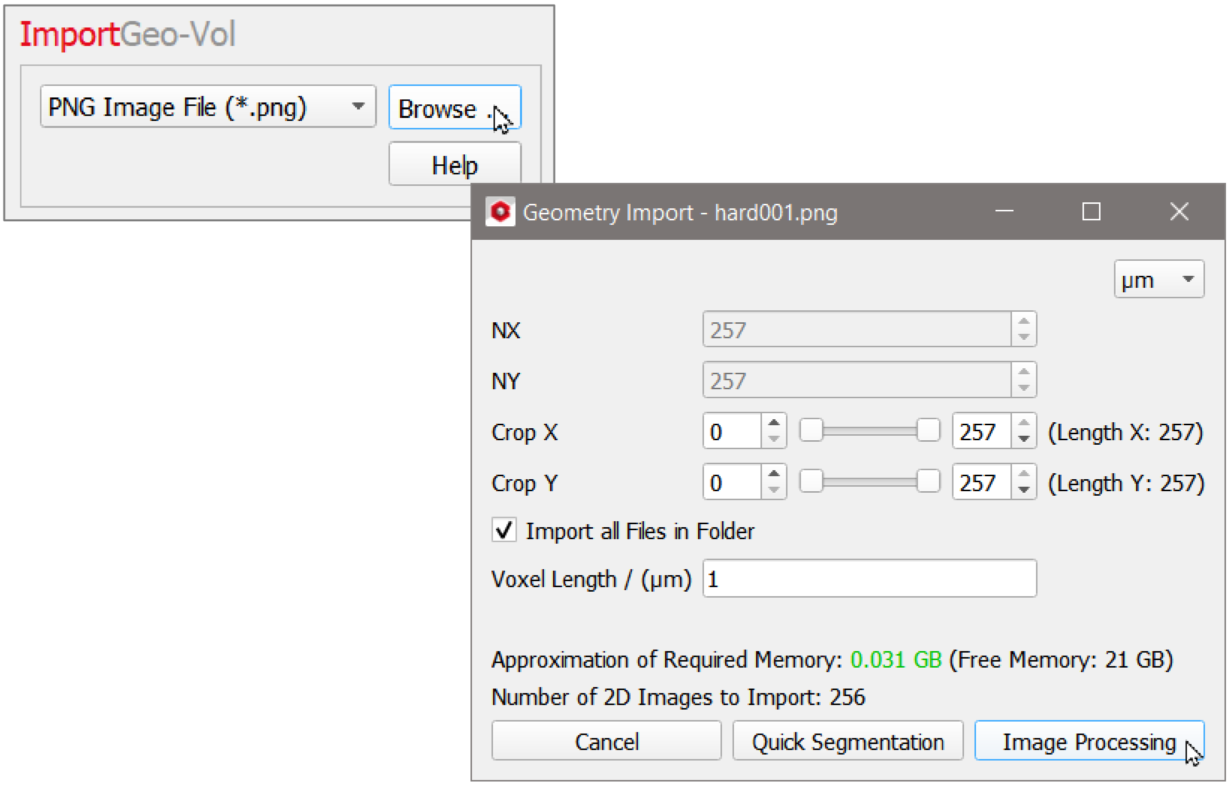

3D Image Quick Segmentation - Hard/hard001.png
Number of Thresholds 2
Threshold Method Manual Threshold
Material 1 (ID 00) Pore ...
Threshold 1 150.5
Material 2 (ID 01) Manual (Solid) ...
Threshold 2 250.5
Material 3 (ID 02) Manual (Solid) ...
Histogram
voxel number
gray value
Histogram
Material 1
Material 2
Material 3
Segmentation
Cancel
Material Information:
ID 00: Pore [invis.]
ID 01: Solid
ID 02: Solid
60 µm

## 3D Image Processing in ImportGeo-VOL

Advanced **3D Image Processing** is available for all file formats imported with ImportGeo-Vol. Images can be cut, resized, rotated, filtered, and segmented by different methods. This processing is not available for files imported with ImportGeo-Base (GeoDict format files) or ImportGeo-CAD (STL format files).

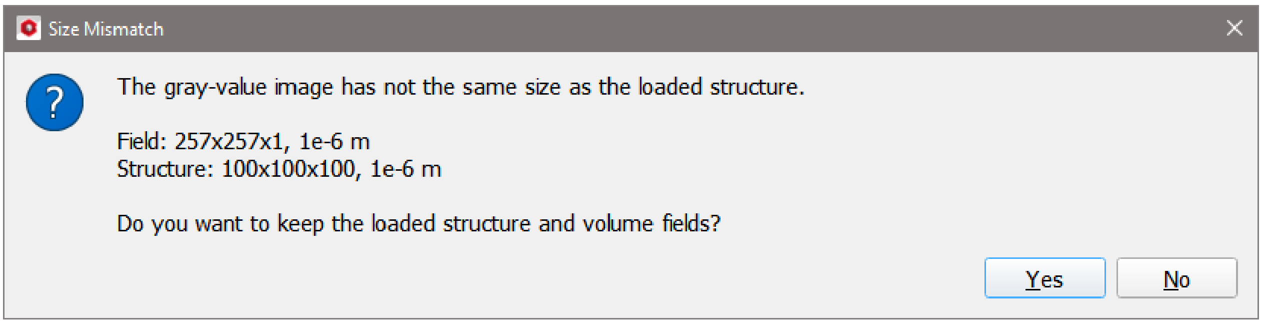
To process an image file or a stack of image files for import, click **Browse...**, find them, fill in the needed parameters in the **Geometry Import** dialog, and then click **Image Processing**.

See above on page 1, the table of file formats to import and a more detailed description on importing specific data.




After clicking **Image Processing**, the gray value image is loaded as a volume field in the GeoDict visualization area, and the **3D Image Processing** dialog opens.

If a structure or volume fields with dimensions different to the loaded gray value image are in memory, a message dialog appears, asking if the loaded structure and volume fields should be kept in memory. If clicking **Yes**, they are kept, and the gray value image is loaded additionally. If clicking **No**, they are discarded from GeoDict.

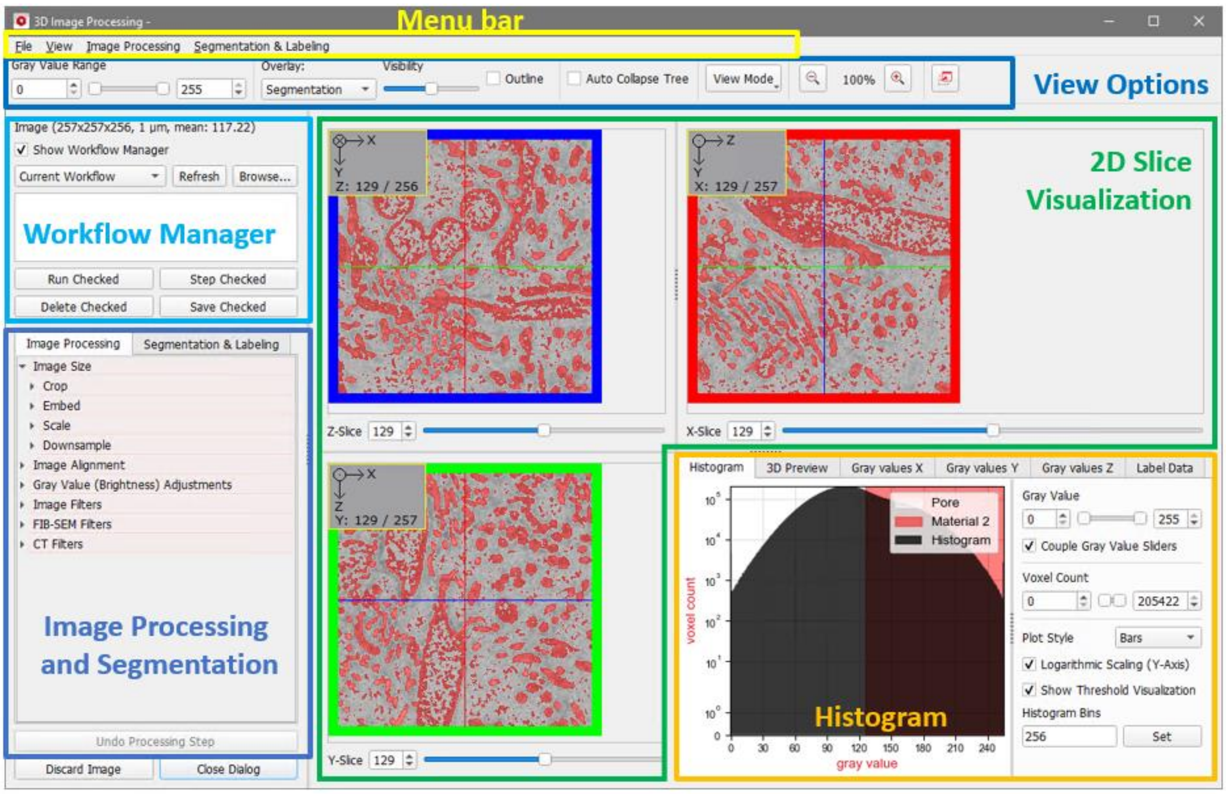


All steps done in the image processing tab are not only visualized in the **2D Slice Visualization** area in the **3D Image Processing** dialog, but also in the main GeoDict GUI, where the view can also be switched to 3D by selecting **View → 3D Rendering**.

A short introduction on visualization in GeoDict can be found on pages 79ff and for detailed information refer to the Visualization handbook of this User Guide.

The different sections of the **3D Image Processing** dialog provide various tools for individual image processing and segmentation.

- The **Menu** bar at the top offers a quick access to the File, View, Image Processing and Segmentation & Labeling pull-down menus.
- The quick access bar for **View Options** shows often required view settings.
- The **2D Slice Visualization** section shows the image scan in all three directions.
- The **Histogram** section contains image statistics and related view settings.
- The **Workflow Manager** displays all steps of the Image Processing workflow.
- The **Image Processing and Segmentation** section contains two tabs.
  - The **Image Processing** tab contains all available tools for cropping, resizing, rotating and filtering the gray value images.
  - The **Segmentation & Labeling** tab contains all available tools for segmenting and labeling the gray value images.




Clicking **Undo Processing Step**, located below the **Image Processing and Segmentation** panel, reverses the last image processing step.

The image processing can be aborted either by clicking **Discard Image** or by clicking **Close Dialog**.

**Discard Image** closes the dialog and removes the gray value image from the memory and thus, from the GeoDict visualization area.

**Close Dialog** only closes the dialog, while the gray value image is still in memory and shown in the visualization area.

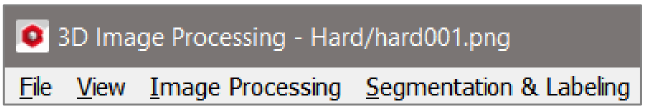
Otherwise, the dialog stays open, even after segmenting or labeling an image.

The processing of files for import can be done in several steps. The user simply applies different processing tools in the **Image Processing** tab and then moves to the **Segmentation and Labeling** tab to segment the image with the chosen method or label the image with the watershed algorithm.

Then a result file (.gdr) for the image processing and segmentation/labeling is created and the segmented (.gdt) structure or labeled (.g32) image is saved in a new folder according to the given **Result File Name** as described on page 76. New and improved 3D models can be created anytime by using different processing, segmentation, or labeling parameters.

## Menu bar

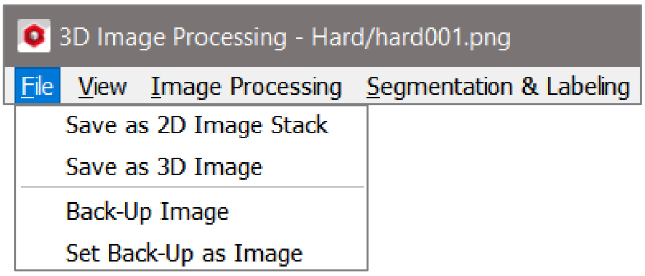
From the menu bar in the 3D Image Processing dialog, **File** options are accessible offering options to store the image as 2D image slice(s) or as 3D image data, or to back-up the current processing status of the gray value image. The **View** menu tree contains many of the available view settings. The other two tabs lead to all available **Image Processing** and **Segmentation & Labeling** tools.




## File

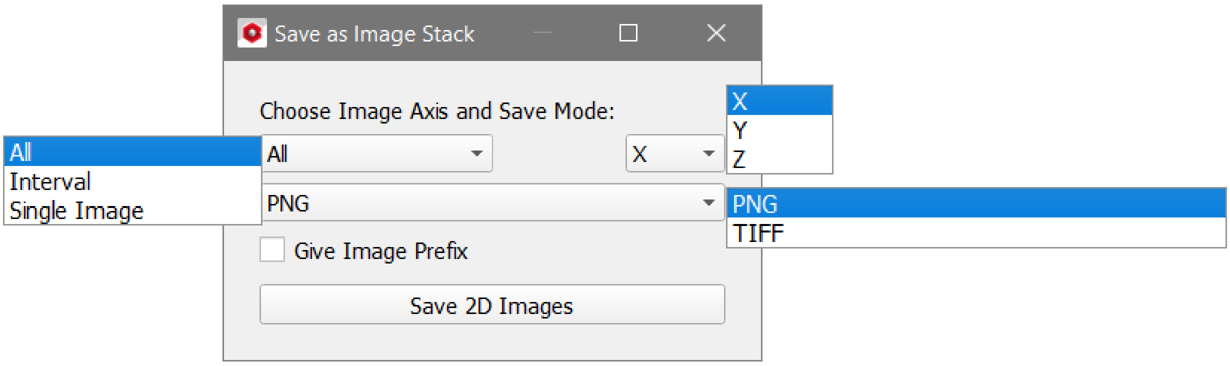
From the **File** menu, the image can be saved as 2D Image Stack or 3D Image. This way, the processed images also can be saved again as grayscale data before (or instead of) importing them in GeoDict.

Also, the current image processing status can be saved temporarily by choosing **Back-Up Image** and loaded again with **Set Back-Up as Image**.



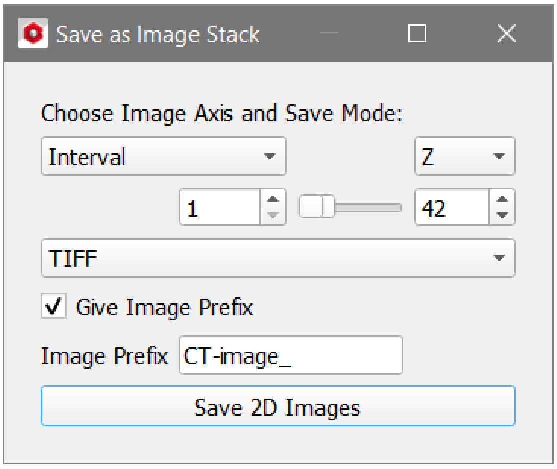

### Save as 2D Image Stack

The 2D images shown in the 2D preview areas can be saved as a stack of 2D images corresponding to one of the directions (**X**, **Y**, or **Z**). Select to save the whole stack of 2D images (**All**), some of them (**Interval**) or just one of them (**Single Image**). After clicking **Save 2D Images**, the user creates and/or selects a folder where to save the 2D images.



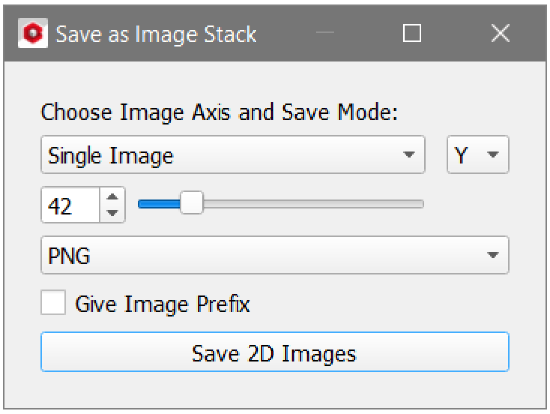

**All** slices may be saved as 2D Images either in 8-bit **PNG** file format or as 8-/16-bit **TIFF** files depending on the data. Note that 32-bit image data is converted to 16-bit upon import and will thus also be exported as 16-bit TIFF files.

The names of saved 2D images contain the selected direction, the slice number, and start with either the folder name or a prefix when choosing **Give Image Prefix**.




If **Interval** is selected, (for example, here 42), images in Z-direction are saved as 2D .tiff files in the afterwards chosen folder.

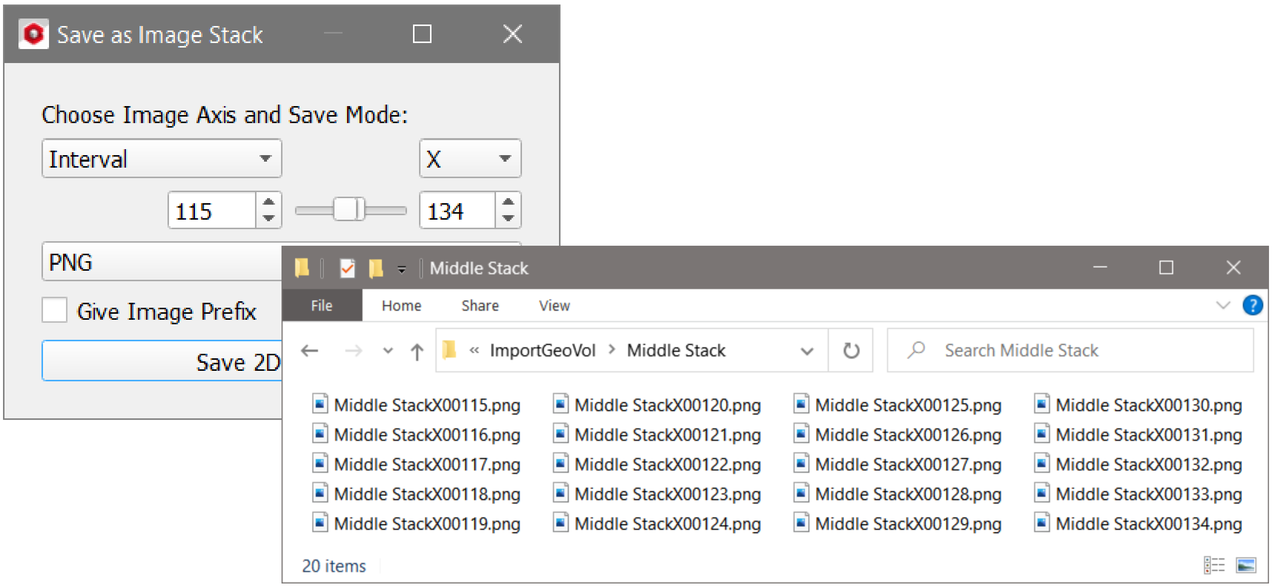
The images are named from "*CT-image_Z00001.tif*" to "*CT-image_Z00042.tif*".



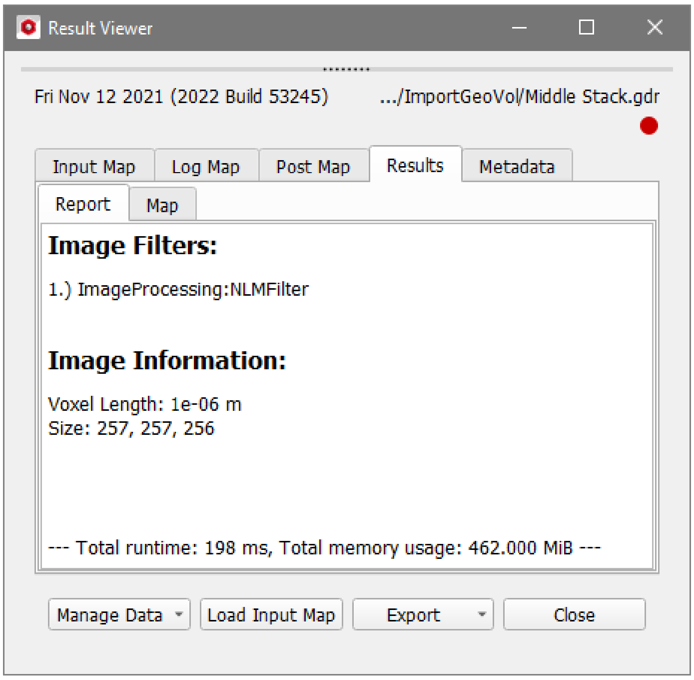

Also, a **Single Image** may be saved as 2D image.

For example, here, slice 42 on the Y-direction would be saved as .png image.

As another example, here, twenty 2D images in Y-direction are saved in the folder **Middle Stack**. The names of the twenty saved .png images contain the folder name, the selected direction, and the slice number.



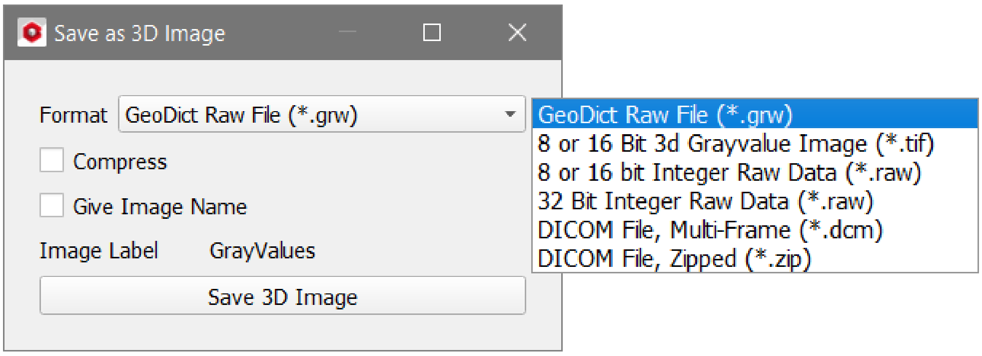
Additionally, a GeoDict result file (*.gdr) with the same name as the selected folder is saved to the current project folder containing information about the applied filters and the original image dimensions. Open the result file in the **Result Viewer** by selecting **File** → **Open Results (*.gdr)** from the menu bar in the GeoDict main window.



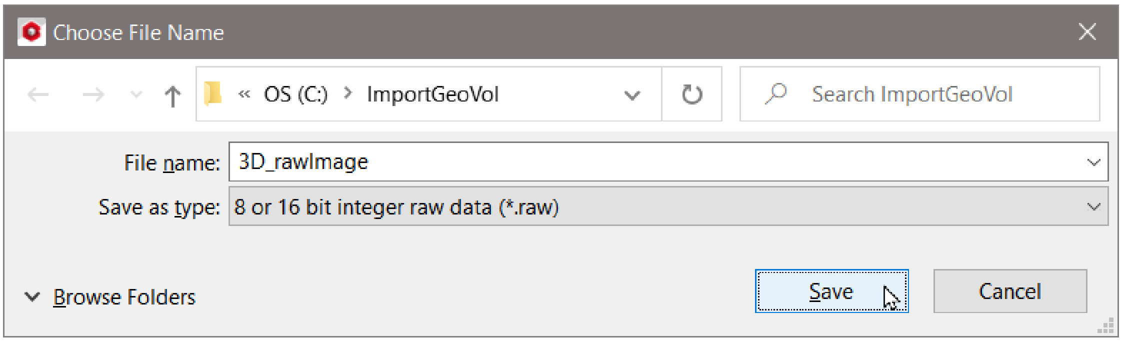

## Save as 3D Image

3D images can also be saved in a single 3D data file as:

- GeoDict Raw File (***.grw**),
- 8- or 16-Bit 3d Gray Value Image (***.tif**),
- 8- or 16-Bit Integer Raw Data (***.raw**),
- 32 Bit Integer Raw Data (***.raw**) if necessary
- DICOM File, Multi-Frame (***.dcm**)
- DICOM File, Zipped (***.zip**).



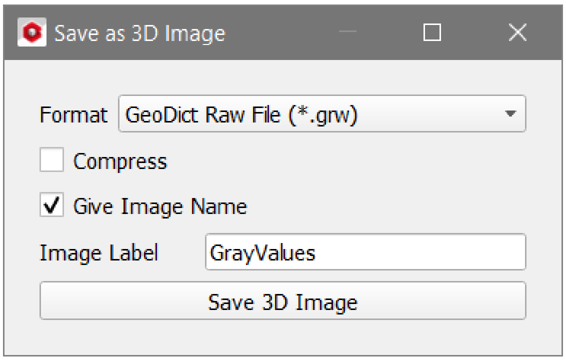

After clicking **Save 3D Image**, a file name for the file in RAW format must be entered before clicking **Save**. Here it is 3D_rawImage:




In case of storing the data in the GeoDict **.grw** file format, there is also the option to compress the image or to label the stored volume field.

If **Compress** is checked, the raw part of the image is compressed. Thus, the image data is compressed, while the header stays uncompressed.

To define an **Image Label**, check **Give Image Name**. This label is visible e.g., when loading the gray values into GeoDict as volume field. Then the name appears in the **Project Status** section and as a title of the gray value legend. If **Give Image Name** is not selected, the name of the saved guf file is used for that purpose.

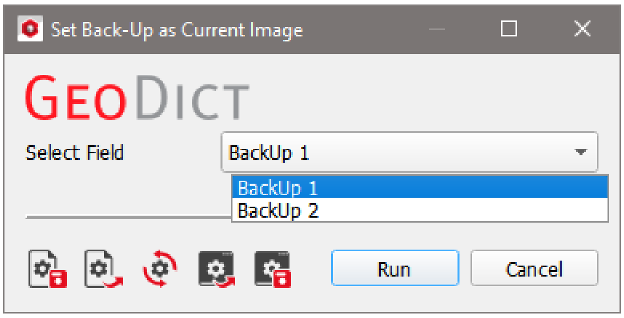



A ***.grw** file is a GeoDict Universal File with a standardized header describing the 3D data format. This header may be read with an editor such as Notepad++.

Additionally, a GeoDict result file (*.gdr) with the image name is saved to the current project folder containing information about the applied filters and the image dimensions. Open the result file in the **Result Viewer** by selecting **File** → **Open Results (*.gdr)** from the menu bar in the GeoDict main window.

## Back-up Image and Set Back-up as Image

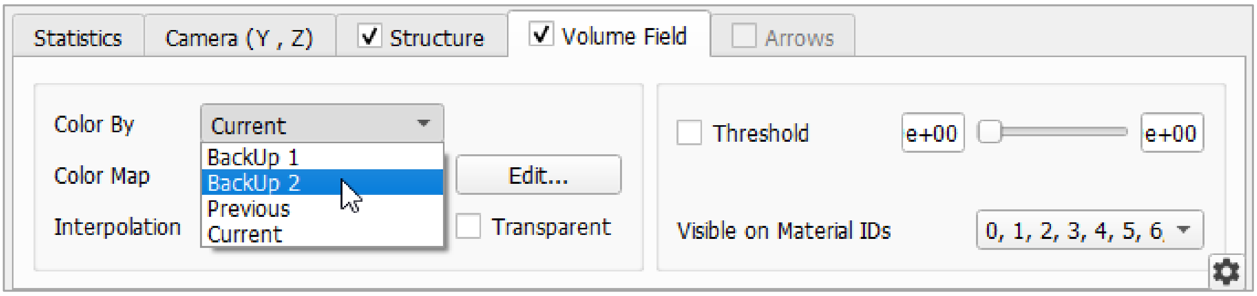
Also, the current image processing status can be saved temporarily by choosing **Back-Up Image**. This back-up can be loaded again by clicking **Set Back-Up as Image**. Then a dialog opens where the user can choose the desired **BackUp** field from the pull-down menu for **Select Field**.



The backup images are deleted from the GeoDict memory when the **3D Image Processing** dialog is closed.

The maximum number of backups is only limited by the memory available.

After applying any image processing tools the previous backups are also loaded in the GeoDict visualization area as separate volume fields. They can be visualized in the GeoDict visualization area by switching to the **Volume Field** tab in the visualization panel and selecting the desired **BackUp** from the pull-down menu for **Color**. There, also the **Previous** image can be selected. In the **3D Image Processing** dialog this is loaded when clicking **Undo Processing Step**.

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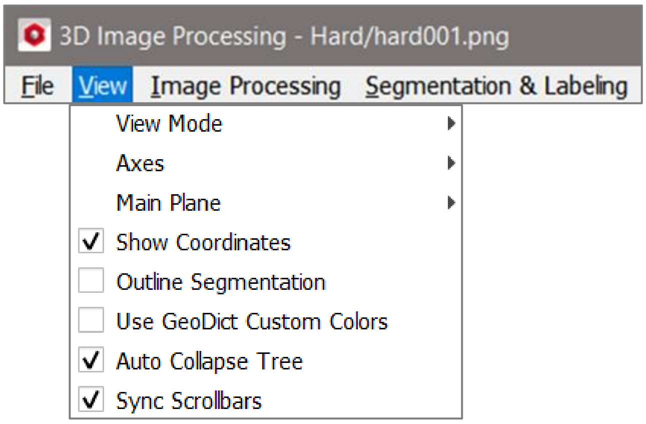
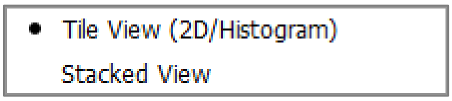
## VIEW

The **View** menu contains all available options for representation of the gray value image as 2D slices in the **2D Slice Visualization** section.

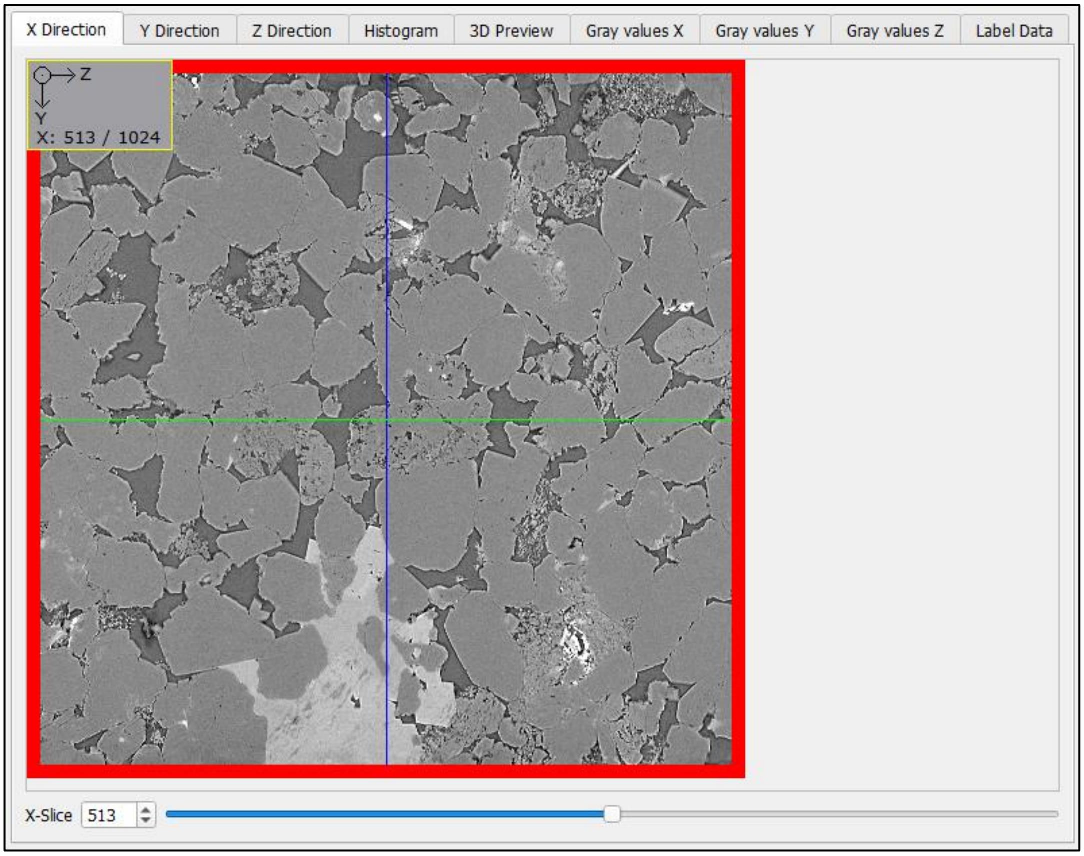



The **View Mode** allows selecting between **Tile View** and **Stacked View**.

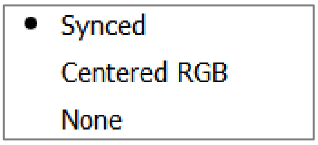


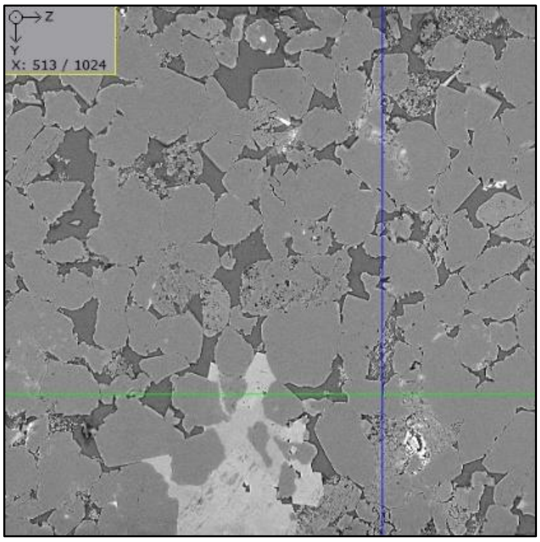

With the **Tile View**, the three 2D slices (for the X-Y, the X-Z, and the Y-Z planes), and the histogram section are displayed as shown in the screenshot of the **3D Image Processing** dialog on page 19.

In the **Stacked View**, only one of the 2D slices or tabs of the **Histogram** is displayed. Here, the user may focus on either of these by choosing the desired visualization from the available tabs.



The selection in **Axes** controls the display of the lines giving orientation in the 2D image slices.



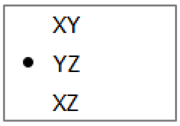




For **Synced,** the lines show the intersection of the two remaining directional axes in RGB colors interactively, as shown in the screenshot on the right.

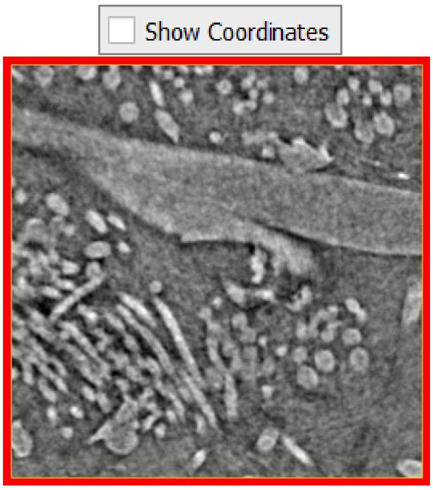
For **Centered RGB**, the lines always are displayed in the center.

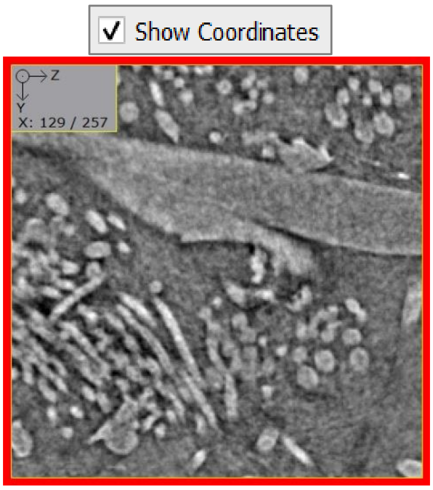
For **None**, the lines are invisible.

From the **View** menu, the **Main Plane** may be set. This choice affects only the visualization in **Tile View**. The chosen plane is shown on the upper left (here, YZ) and the order of the axes is changed according to the choice.



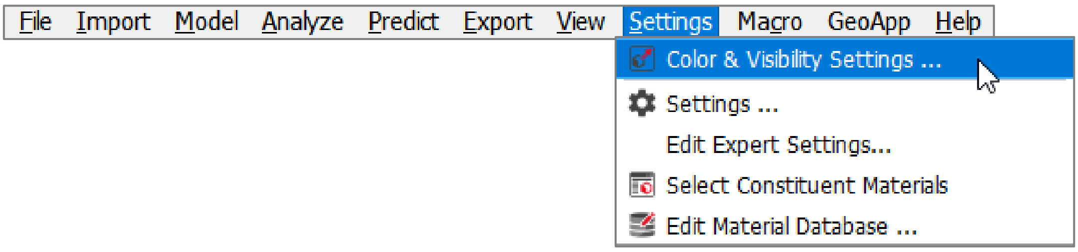

Checking or unchecking **Show Coordinates** controls if the legend in the upper left corner is displayed. It contains the information of plane and slice on the preview areas for the three directions.




**Outline Segmentation** refers to the representation of the thresholding settings and is explained in more detail later in the **Image Segmentation** section on pages 76ff.

**Use GeoDict Custom Colors** changes the colors of the representation of the global thresholding settings to the colors that are currently defined in the GeoDict GUI. The Color Settings are available from **Settings → Color & Visibility Settings** in the GeoDict GUI menu bar:



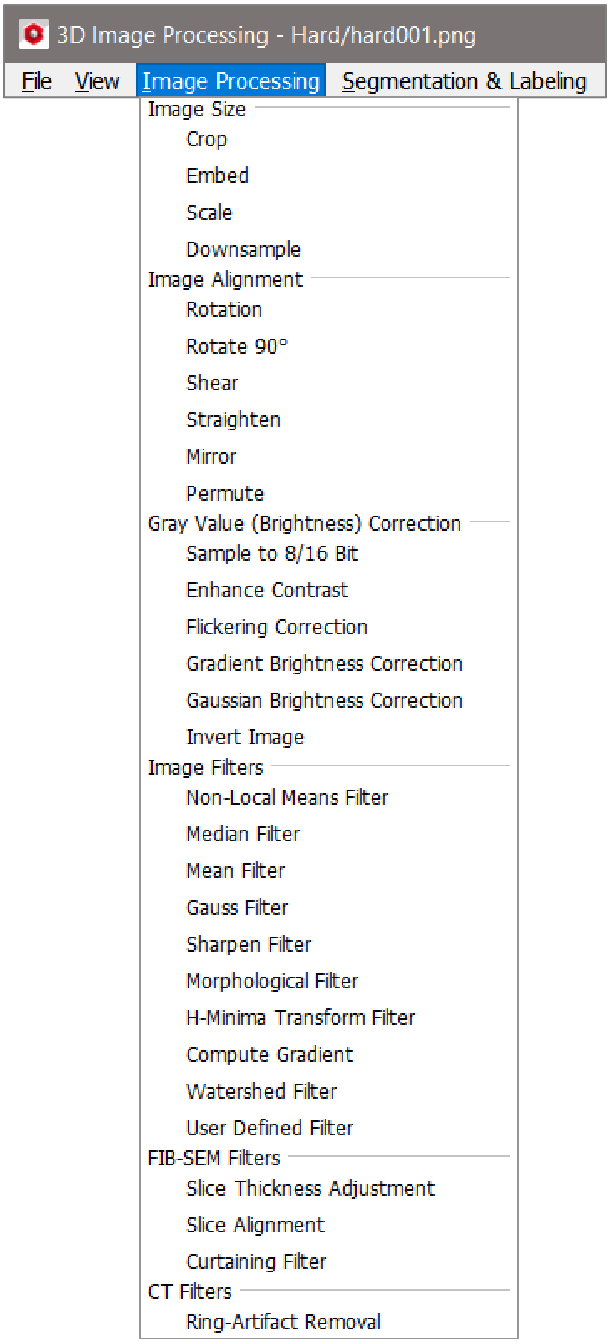

When the **Auto Collapse Tree** option is checked, the user only sees in the **Image Processing and Segmentation** section (left of the dialog), the feature currently chosen from the **Image Processing** or **Segmentation & Labeling** menu. All other tree paths are collapsed automatically after another selection in the respective tab for convenience and simplification.

Checking **Sync Scrollbars** synchronizes the 2D slices in the **Tile View** when scrolling the excerpt up and down or left and right.

## Image Processing

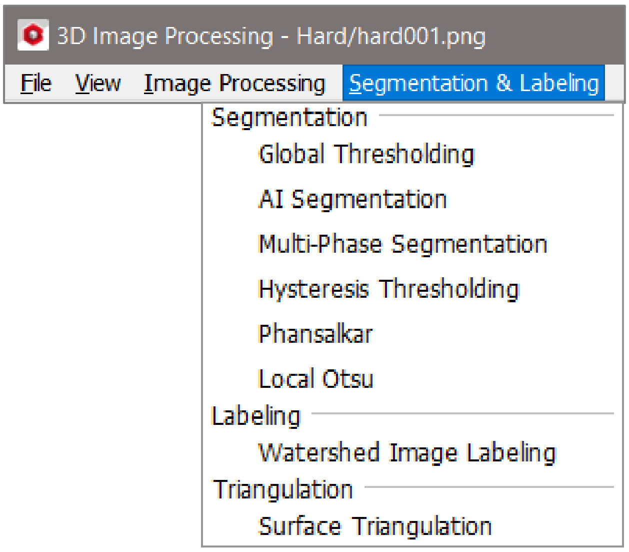
The **Image Processing** menu is an overview of the 3D Image Processing tools in GeoDict.

When clicking on the names of the various feature, the user is forwarded directly to the according tool, filter, or thresholding method in the **Image Processing** tab to the left of the **3D Image Processing** dialog.



## SEGMENTATION & LABELING

The **Segmentation & Labeling** menu is an overview of the 3D Image Segmentation and labeling tools in GeoDict.

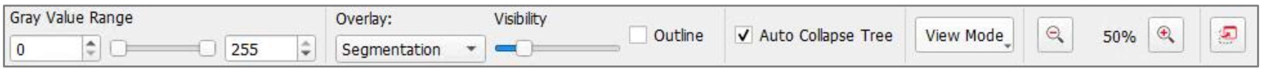



When clicking on the names of the features, the user is forwarded directly to the according method in the **Segmentation & Labeling** tab to the right of the **3D Image Processing** dialog.

## VIEW OPTIONS

The **View Options** section offers a quick access to the most used visualization settings and is therefore always displayed.

Among other options, set the **Gray Value Range** to be viewed, choose between the two **View Mode**s (see **View** menu described on page 26), or **Zoom** in and out by a factor 2 per click.



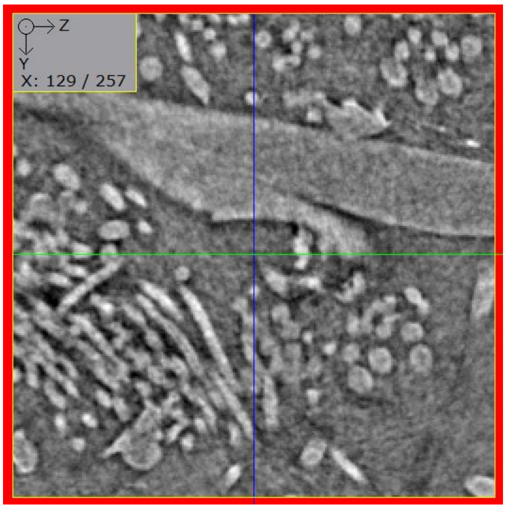

- Adjusting the **Gray Value Range** narrows or widens the interval, within which the gray values brighten from black to white. You may move the slider or directly enter specific numbers to change the interval. For more details, see page 30.
- From the **Overlay** pull-down menu select the desired processing visualization. For more details, see page 32.
- The **Visibility** slider increases or decreases the color-coded visibility of the current segmentation thresholds. See page 33 for more details.
- **Outline** changes the representation of the thresholds from coloring full materials to coloring the interfaces between the currently set thresholds. Refer to page 33 for more details.
- When **Auto Collapse Tree** is checked, the user only sees in the Image Processing and Segmentation section (left of the dialog), the image processing feature currently chosen from the respective tab. Other tree paths are collapsed automatically.
- The **View Mode** options **Tile View** and **Stacked View** change the visualization area from showing 2D slices of all three directions and the histogram section to showing only one of the directions or one of the tabs of the histogram section. Refer to the **View** menu on page 26 for more details.
- The **Zoom** buttons at the right of this view section zoom in and out of the 2D slices by a factor of 2. Note that continuous zooming is possible by right-clicking into the image, holding the mouse button, and moving forward and backward.
- Raise the **GeoDict Main Window** by clicking on the corresponding icon , to spare time searching for this window in the taskbar.

## GRAY VALUE RANGE

Adjusting the **Gray Value Range** narrows or widens the interval, within which the gray values brighten from black to white.

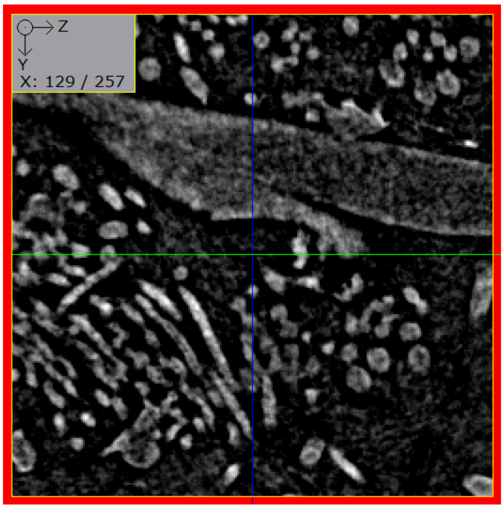

Move the slider or directly enter specific numbers to change the interval.

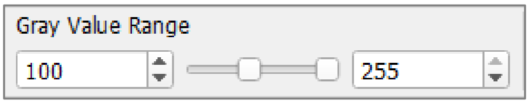
In the following images, observe the difference with varying settings.



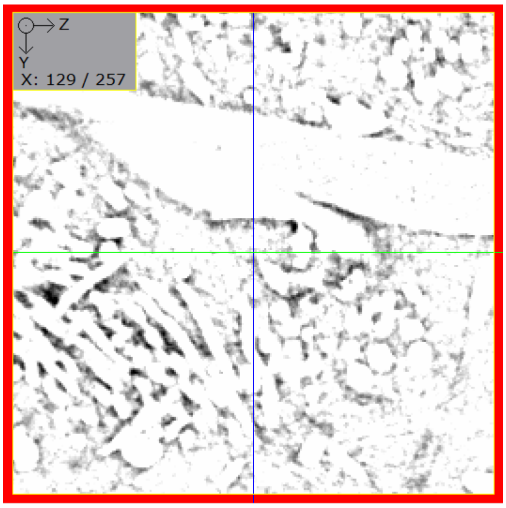


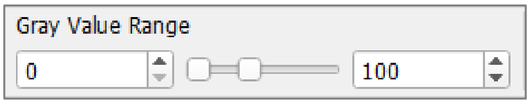
By setting the gray value range from 0 to 255, the gray values are shown for the full data range.



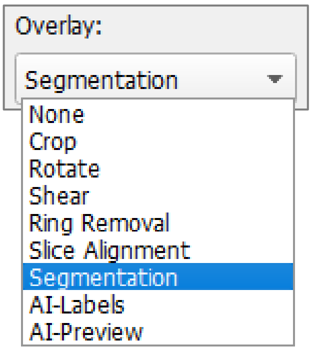

When the gray value range is selected from 100 to 255, the gray values between 0 and 100 are assigned the color black, while the rest becomes relatively darker.




The higher range of gray values is taken out of the image when setting the gray values range from 0 to 100. The voxels with gray values from 0 to 100 become relatively brighter, whereas those with values 101 and higher are assigned the color white.

## OVERLAY




From the **Overlay** pull-down menu select the desired overlay for the 2D Slice Visualization section. The selection is also fitted automatically, if the corresponding options in the **Image Processing and Segmentation** section are edited.

The available overlays are **None**, **Crop**, **Rotate**, **Shear**, **Ring Removal**, **Slice Alignment**, **Segmentation**, **AI-Labels** and **AI-Preview**.

If **None** is chosen, there is no overlay displayed in the **2D Slice Visualization** section.

The first five options after **None** correspond to the **Image Processing** tab and the last three visualize options available in the **Segmentation & Labeling** tab.

### Image Processing overlays

The option **Crop** corresponds to the feature **Image Size – Crop**. If selected, a yellow rectangle displays the cutout resulting from the entered values. Examples are given on page 41.

The option **Rotate** corresponds to the feature **Image Alignment** – **Rotation** and displays the resulting new axes, if the visualization of the axes is turned, as described on page 27.

The overlay **Shear** corresponds to the option **Image Alignment – Shear**, as described on page 48.

If **Ring Removal** is selected, a yellow ring is displayed on the images, visualizing the values entered for the option **CT Filters – Ring-Artifact Removal**. For further description see page 74.

The overlay **Slice Alignment** corresponds to the feature **FIB-Sem Filters – Slice Alignment (Z-Direction)** described on page 70. If selected, a red rectangle in the X-Y-plane displays the cutout resulting from the entered values.

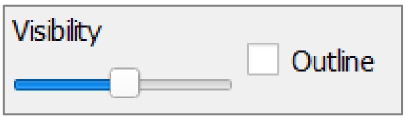
### Segmentation & Labeling overlays

The overlay **Segmentation** is selected by default and shows the resulting segmentation if the **Visibility** is turned on, as described in the next chapter. The visualized segmentation corresponds to the values entered for the options in the **Image Segmentation** section described on page 76ff.

The overlays **AI-Labels** and **AI Preview** correspond to the **AI-based Segmentation** method described on pages 82ff.

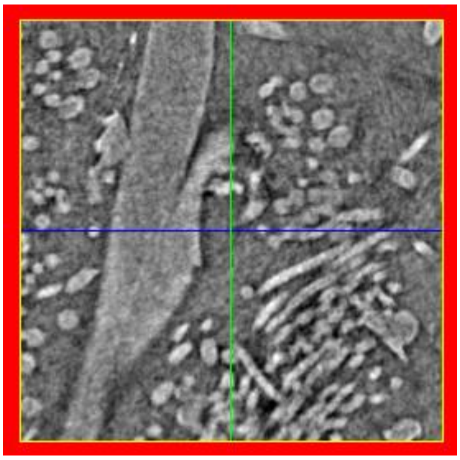
## Visibility and Outline

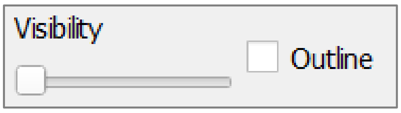
The slider for **Visibility** and the checkbox for **Outline** control the visualization of the threshold(s) used for segmentation. By moving the **Visibility** slider, the appearance of the threshold(s) is changed in the **2D Slice Visualization** section.



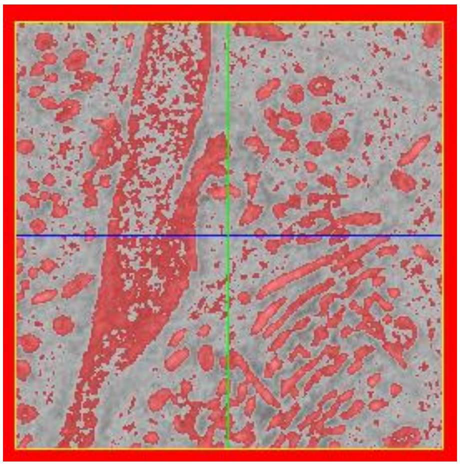

When checking **Outline**, only the interface between segmented phases is overlaid with the given thresholding color(s).

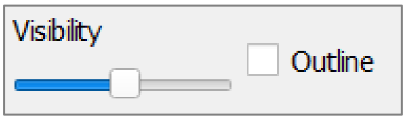
In the following images, observe the difference with varying settings.



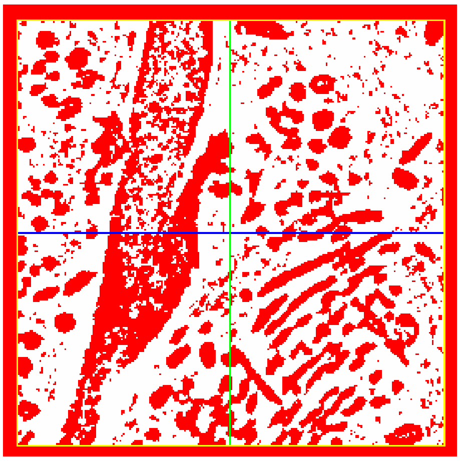


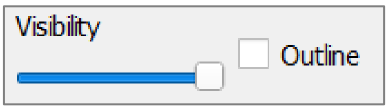

Here, the thresholded image is not visible and only the image gray values are shown.



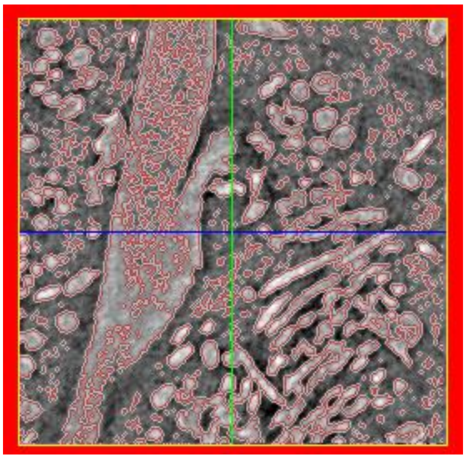


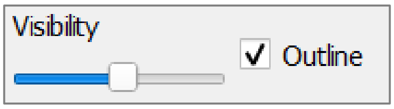

With intermediate **Visibility**, an overlay of the thresholded image and the gray value image is shown.



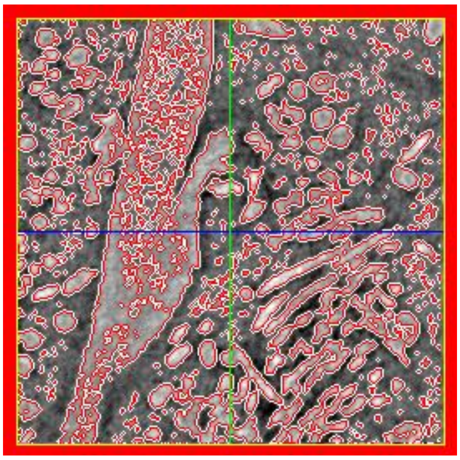


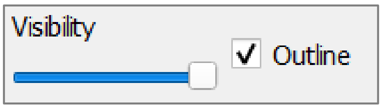

With **Visibility** at its maximum, only the thresholded image is shown.






With **Outline** checked and intermediate **Visibility**, the interface between segmented phases is slightly overlaid with the given thresholding color.

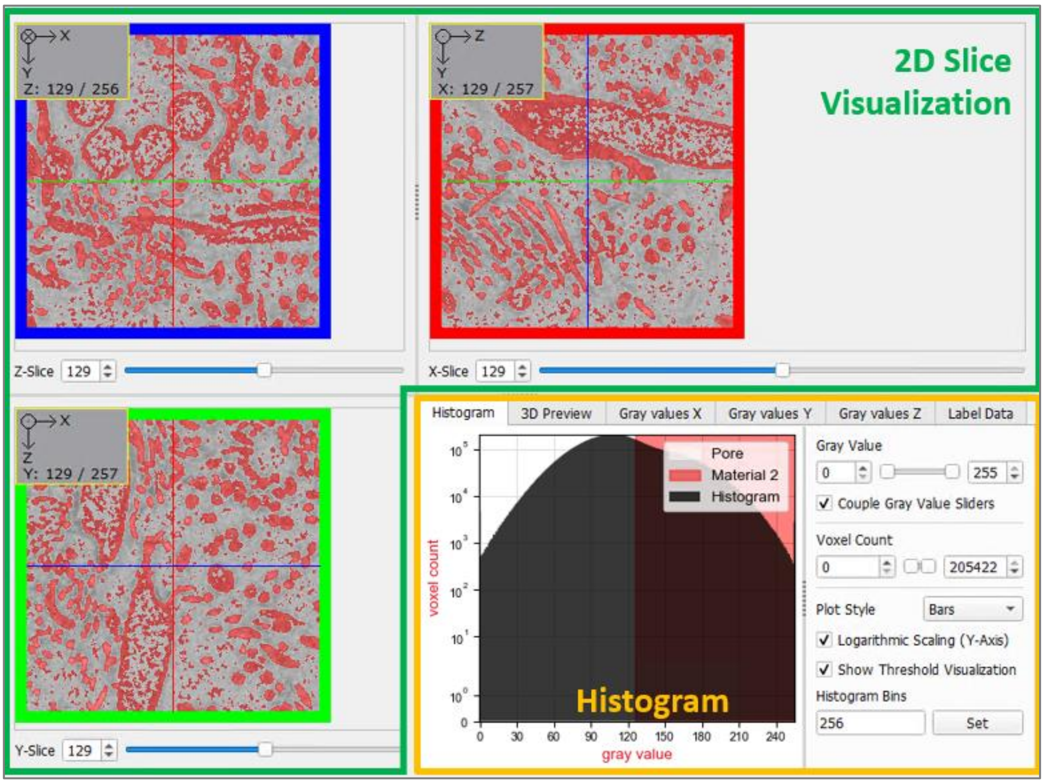





With **Outline** checked and increasing **Visibility**, these interfaces become increasingly highlighted.

## 2D Slice Visualization

In the default **Tile View**, the **2D Slice Visualization** section contains the preview areas for the **X-Y plane**, the **Y-Z plane**, and the **X-Z plane**.




Below the 2D images, the values in **Z-Slice**, **X-Slice**, and **Y-Slice** control which slices are shown above in the preview areas. These values can be quickly changed by resting the mouse cursor on the field box and using the mouse wheel. The slice that is being shown also moves in the three-dimensional representation in the **3D Preview** tab in the **Histogram** section.

Zoom in and out either by using the corresponding buttons in the **View Options** section or click and hold **CTRL** and scroll the mouse wheel while resting the cursor on a gray value image slice. For continuous zooming, right-click into the 2D image, hold the mouse button, and move the mouse forward and backward to zoom in and out.

**Pan** the image by left-clicking.

For more information about 2D visualization, please also refer to **View** menu described on page 26 and the **View Options** section on page 30.

As the gray value image is also loaded to the GeoDict visualization are, also consider the possibility of advanced 3D visualization described in the Visualization handbook of this User Guide.

## HISTOGRAM

The **Histogram** section contains statistical information on the gray value image in several tabs.

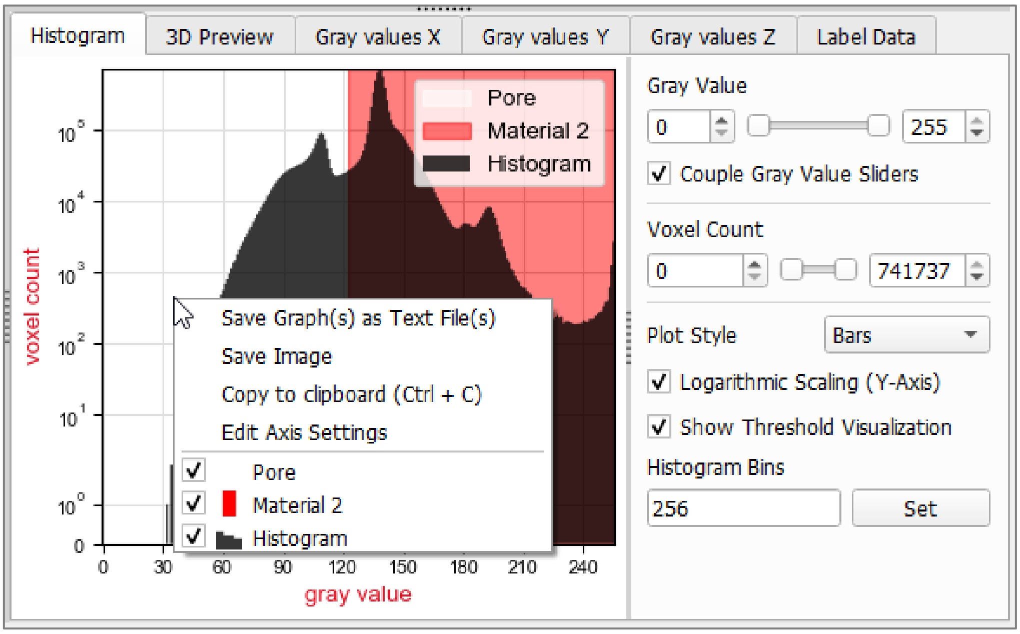

The **Histogram** shows the frequency of all gray values as absolute numbers potentially providing information on the number of distinguishable material phases.

The **3D Preview** shows the currently selected X-, Y-, and Z-slices in a 3D representation. For more details see page 38.

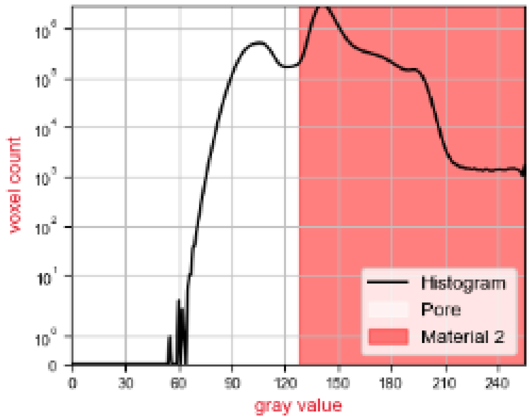
In the **Gray Values X, Y, Z** tabs, the slice mean of the gray values is plotted including a quadratic fit.

### HISTOGRAM

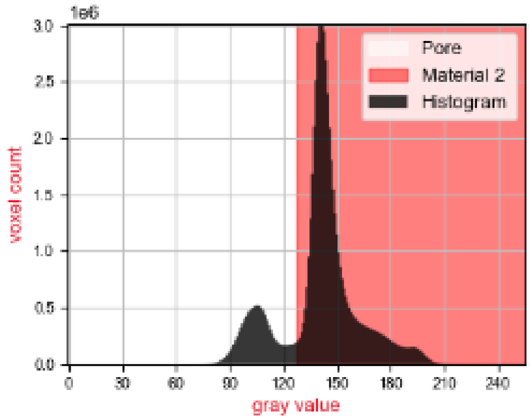
The appearance of the histogram, on the bottom right, is controlled through the options right next to it and by the context menu accessible by right-clicking in the plot. The histogram plots the number of voxels against the gray values (in the given gray values range) and shows how many voxels have a particular gray value.



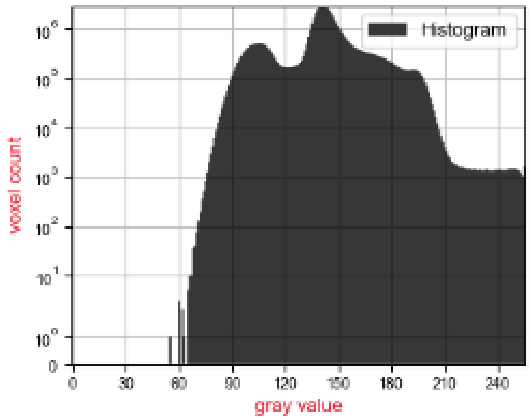

The ranges for **Gray Value** and **Voxel Count** control the horizontal and vertical axes of the histogram. To focus on a region of the plot, change the range of values for voxel count and gray value. Interactively, the histogram changes and shows the portion of the plot corresponding to the new range of values. Moving the sliders allows a sort of zooming in and out of the plot in order to focus on a range of values.



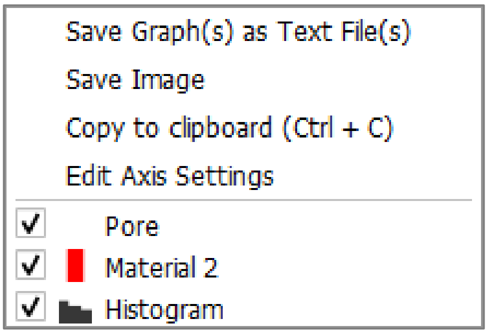

The **Plot Style** can be changed from the default **Bars** to a **Line** plot depending on the favorite visualization.




**Logarithmic Scaling** of the **Y-Axis** may be deactivated to highlight the gray value ranges of material phases.




For another form of the histogram plot, choose to not **Show Threshold Visualization**.



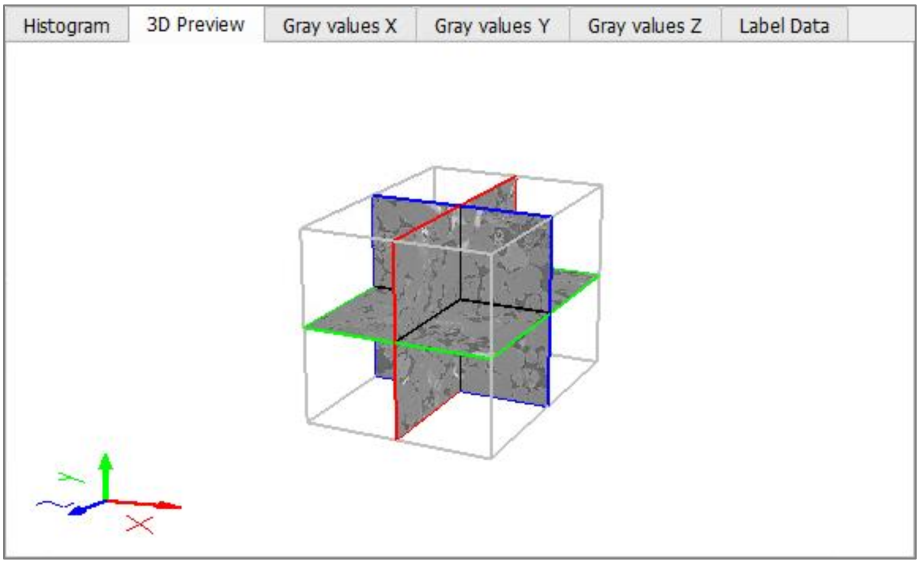

Right-click into the plot to further change the appearance, save the image (.png or .svg), copy the image to the clipboard or store all graph values in a .txt file. The context menu is the same as for the **Result Viewer** plots, and therefore is described in the Result Viewer handbook of this User Guide.

## 3D Preview

The **3D Preview** displays the 2D slices that are currently chosen in the **2D Slice Visualization**.

A 3D representation of these slices is visualized and updates interactively when changing the current slice selection.

For full 3D visualization options, please refer to the Visualization handbook of this User Guide.

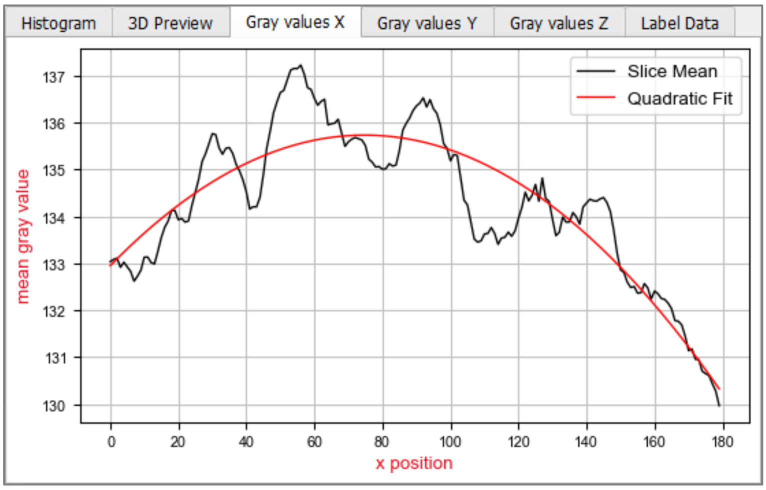



## Gray Values X, Y, Z

For each of X-, Y-, and Z-axis, the gray value distribution is plotted in 1D as **Slice mean**.

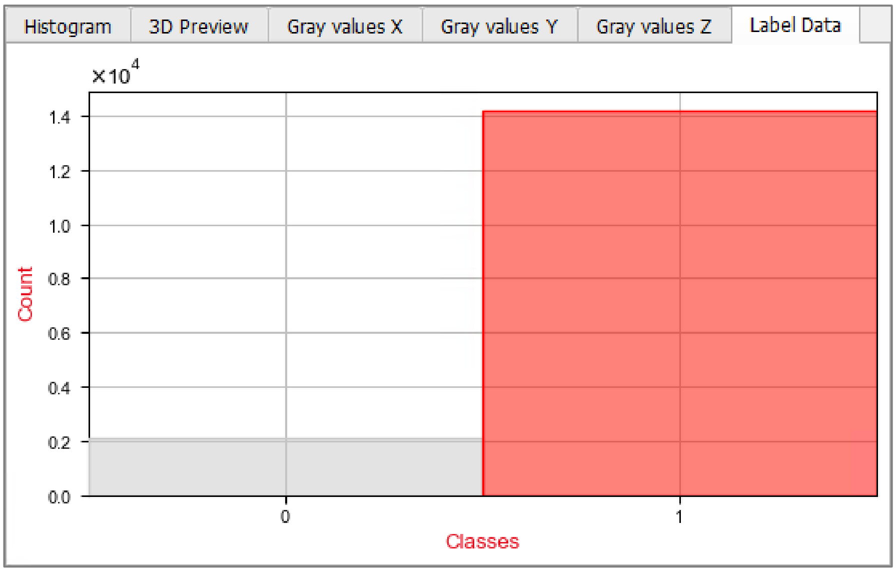
Additionally, a **Quadratic Fit** is calculated and plotted.

These graphs may indicate brightness gradients in the scans. The **Gradient Brightness Correction** and **Gaussian Brightness Correction** filters handle these brightness artifacts as described on pages 55 and 56, respectively.



## Label Data

In the **Label Data** tab find a plot corresponding to the labels of the **AI Segmentation** described starting on page 82.

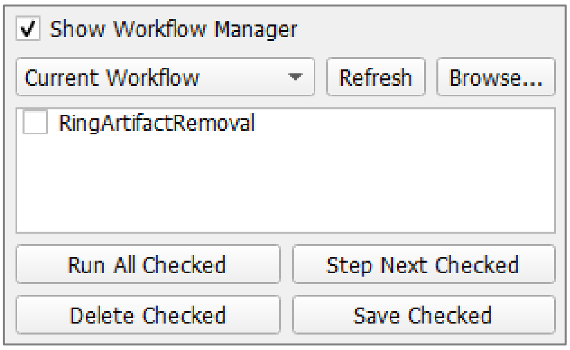



If no labels are given, the plot is empty. If voxels are labeled in the **AI Segmentation** section, the plot shows, how much training data there is for all material **Classes**. This helps to evaluate if the **Count** of labeled voxels is similar enough for all materials, and thus enabling the user to improve the labeling.

In the example above, much more voxels are labeled red (solid material) than are labeled white (pore space). Probably, the results of the **AI Segmentation** then will not be as good, as if they were equally labeled.

## Workflow Manager

Check **Show Workflow Manager** to display the **Workflow Manager**, on the top left side of the **3D Image Processing** dialog. This section displays either the **Current Workflow** or a chosen predefined workflow. The current workflow contains all image adjustments and filters that were applied (*e.g., Ring Artifact Removal Filter*).

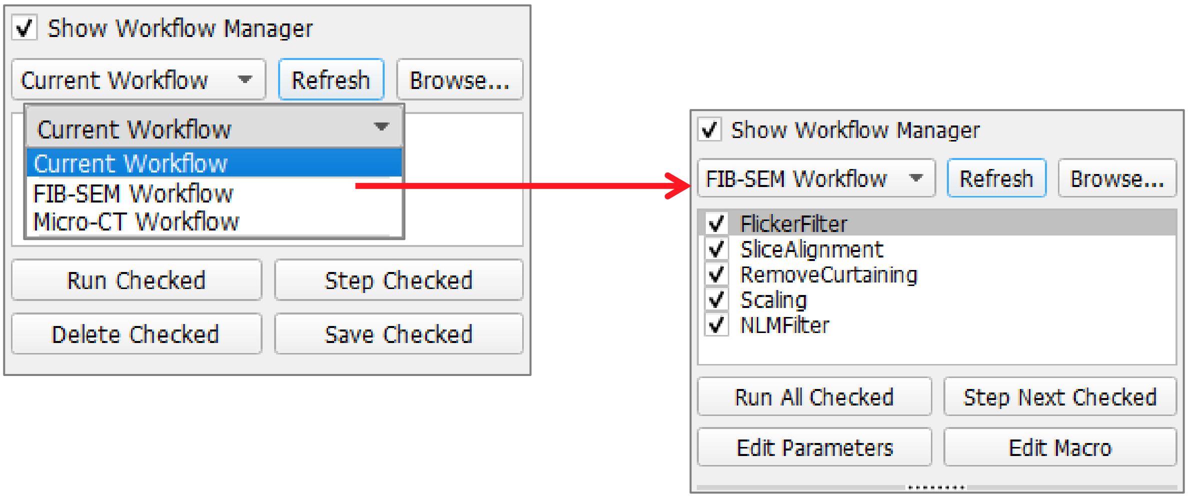



If a new workflow was added to the workflow folder during the current GeoDict session either by moving a GeoPy (GeoDict Python) file to the GeoDict settings folder or by using the **Save Checked** button, click **Refresh** to display the new workflow in the pull-down menu.

Clicking **Browse** and adds the selected GeoPy macro to the pull-down menu.

The workflow buttons offer the possibility to run the entire workflow again (**Run all Checked**) or run only single steps (**Step Next Checked**). Features can be deleted (**Delete Checked**) or saved (**Save Checked**) to a new predefined workflow.

Predefined workflows contain a set of image processing tools. The GeoDict settings folder already offers two predefined workflows:



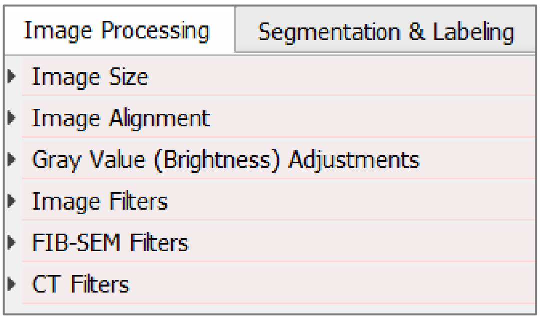

- The **FIB-SEM Workflow** (shown here) uses **Flickering Correction** (page 54), **Slice Alignment** (page 70), **Curtaining Filter** (page 73), **Scale** of image (page 43), and the **Non-Local Means Filter** (page 59).
- The **Micro-CT Workflow** combines **Gradient Brightness Correction** (page 55), **Enhance Contrast** (page 53), and **Non-Local Means Filter** (page 59).

Predefined workflows may be controlled by variables, but they can be edited (**Edit Parameters**) to adjust a workflow to the user's needs.

With **Edit Macro**, the chosen workflow script is opened for editing. To learn more about GeoPy macros refer to the Automation by scripting handbook of this User Guide.

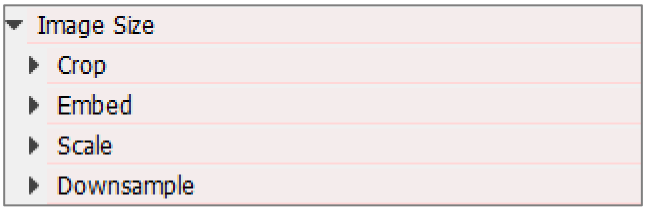
## Image processing tools

The image processing tools are located in the **Image processing** tab in the **Image Processing and Segmentation** section of the **3D Image Processing** dialog, directly below the **Workflow Manager** section. The tools are organized in trees to be expanded and collapsed.




## Image Size

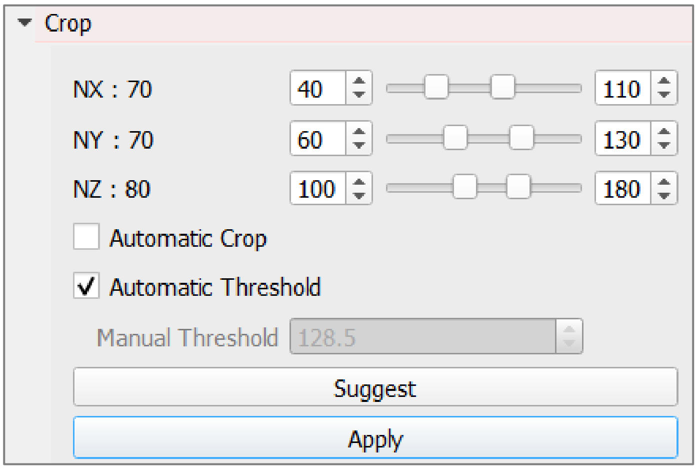
The **Image Size** tree contains the panels **Crop**, **Embed**, **Scale**, and **Downsample**, to control the image size and the resolution.

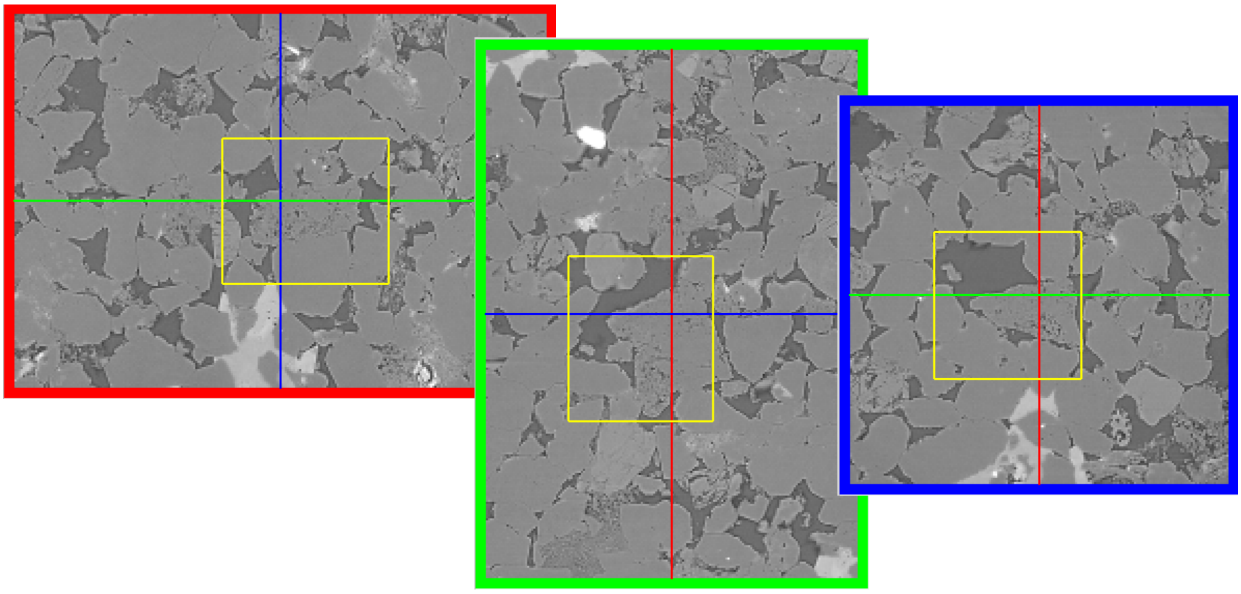



### Crop

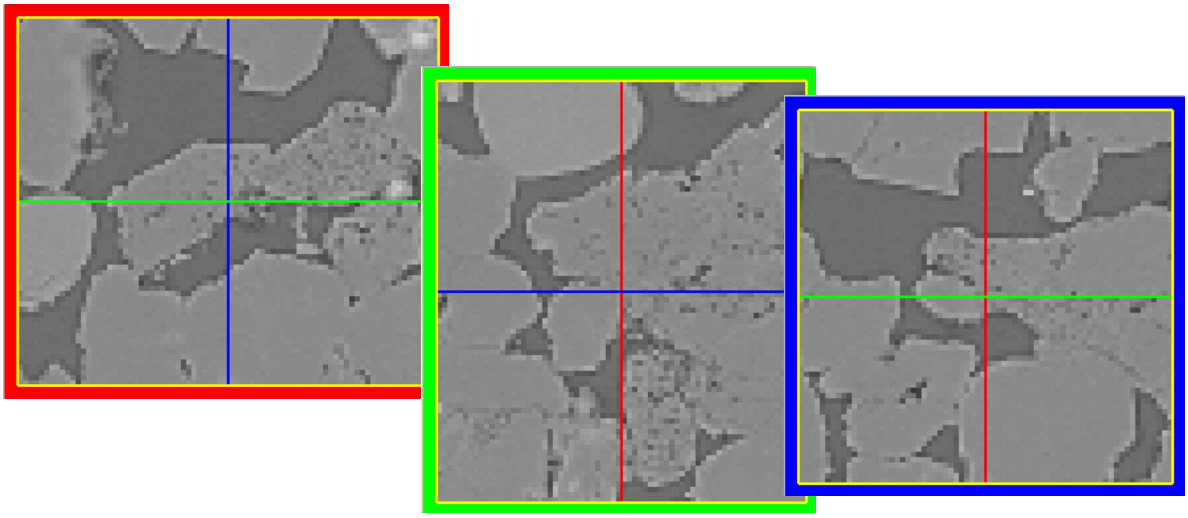
By selecting dimensional parameters in the **Crop** panel, a piece that the user wants to import as 3D model can be cut out. Starting at the left positions of the sliders (**NX**, **NY**, **NZ**: numbers of voxels in X-, Y-, and Z-direction) a box is cut out to the right positions of the sliders.

When the sliders are moved, the new positions of the sliders define a region that appears highlighted in the 2D preview areas of the three directions as yellow lines forming a rectangle. Here illustrated for a 3D gray value image of a Berea sandstone:





The values for NX, NY, and NZ indicate the size the domain will have after clicking **Crop 3D Image**. Here it is 70 x 70 x 80 voxels. The cropped box appears in the 2D preview areas.



If **Automatic Crop** is checked, the entered cropping parameters are ignored when clicking **Apply**. Instead, all pure-background regions around the structure are cropped, according to the current threshold.

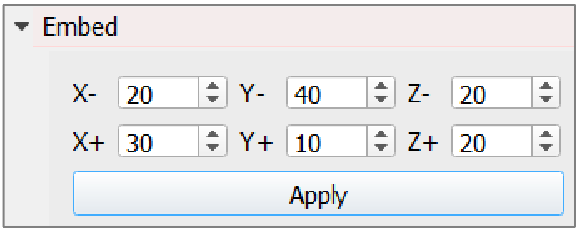
If **Automatic Threshold** is enabled, the Otsu method is used to threshold the image. Otherwise enter a **Manual Threshold**.

Clicking **Suggest** preloads the sliders with values such that all pure-background regions are cropped away, according to the current threshold.

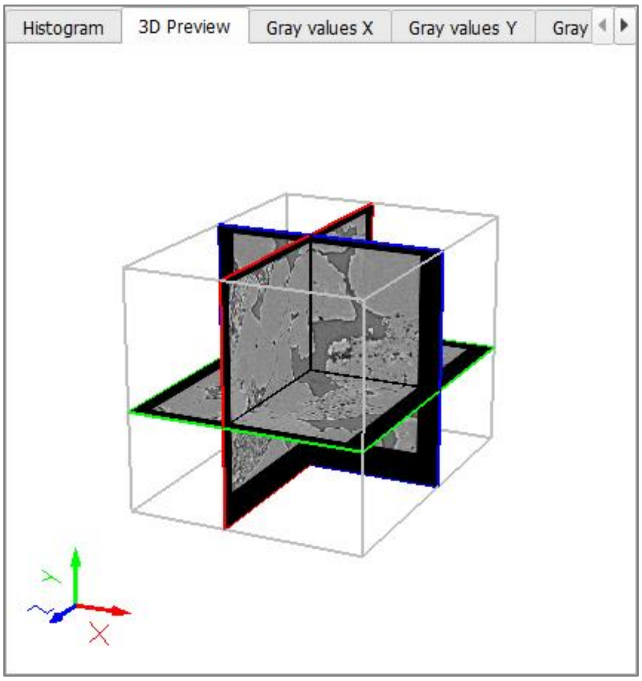
Clicking **Apply** crops the structure with the current settings.

## Embed

Embedding adds empty voxels (voxels with a gray value of 0) around the current structure. Enter the amount as desired for the directions **X-**, **Y-**, **Z-**, **X+**, **Y+**, and **Z+**. Then click **Apply** to embed the image.

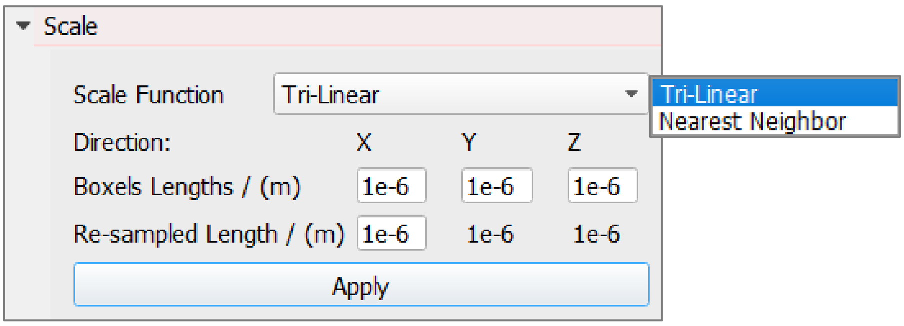



The embedding effect can easily be observed in the **3D Preview** (shown here).




## Scale

In the **Scale** panel, for the **Scale function**, the user can choose between [Tri-linear](#) interpolation and [Nearest Neighbor](#) interpolation. Both are methods of multivariate interpolation in one or more dimensions.



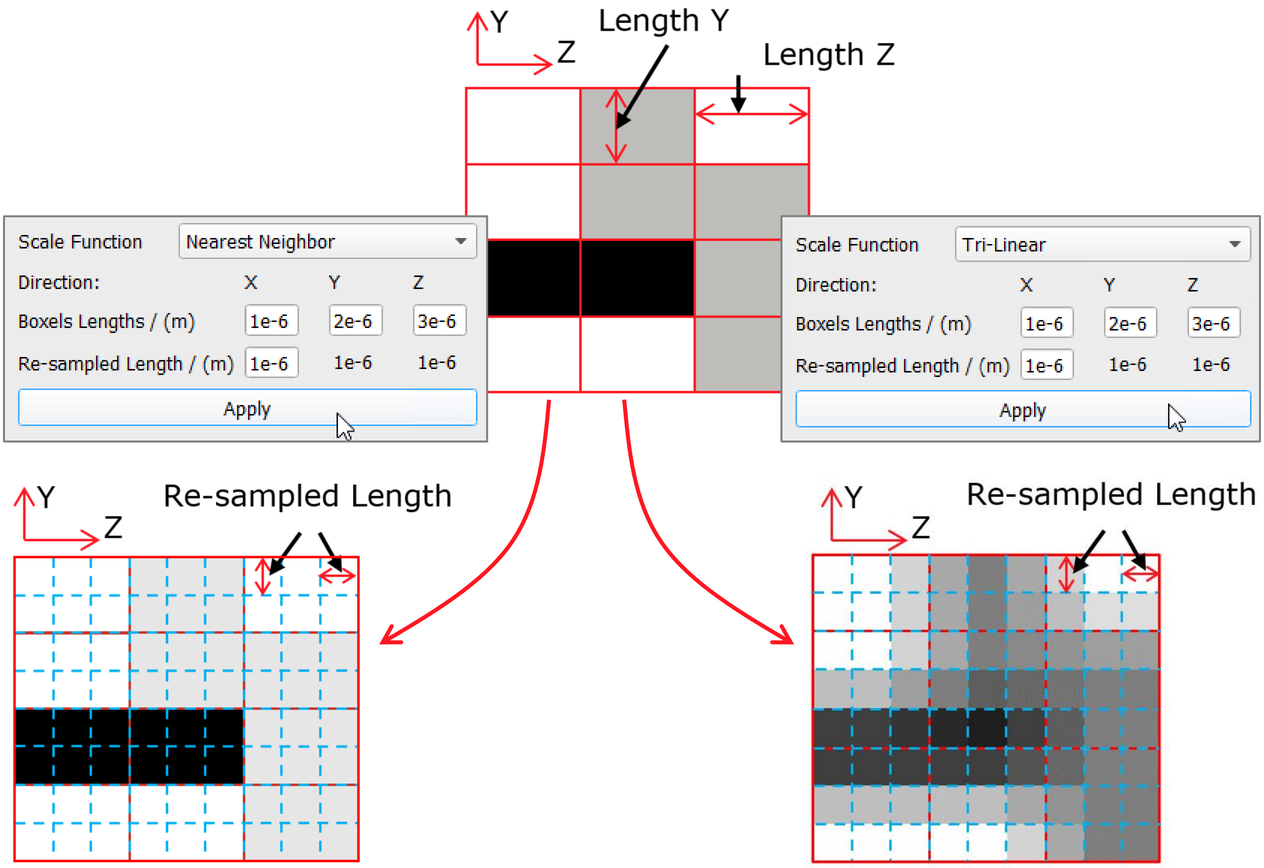

**Boxels Lengths** refer to the current lengths in the structure model, in the three directions. These values are automatically entered from the **Voxel Length** defined by the user at the bottom of the **Geometry Import** dialog.

For FIB-SEM scans, for example, the length in Z-direction usually differs from the other two and corresponds to the spacing between images. This spacing is defined at the time of taking the stack of FIB-SEM images and should be included as data with the image files. Importing the stack directly, without accounting for the spacing distortion, results in a stacked structure, which does not replicate the original scanned one.

To account for this spacing distortion, the length in Z-direction is entered and **Apply** is clicked. GeoDict scales only the voxels in that direction and completes the missing slices to make a uniform object. The size of the scaled object shown as NX, NY, and NZ in the **Crop** panel changes accordingly to reflect the fill-in.

The **Re-sampled Length** value is used to re-sample the physical structure size (voxel length) uniformly in all directions with a grid adapted to the re-sampled length value and, thus, coarsen or refine the imported structure.

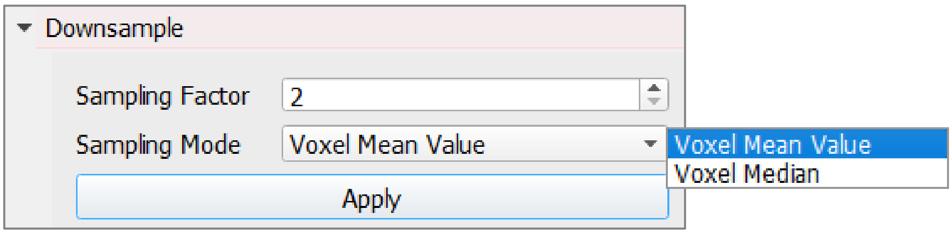
In the following example observe the difference between the two options for **Scale Function**. While the resulting number of voxels is the same for both options, **Tri-Linear** additionally interpolates gray-values for a smoother transition.



### DOWNSAMPLE

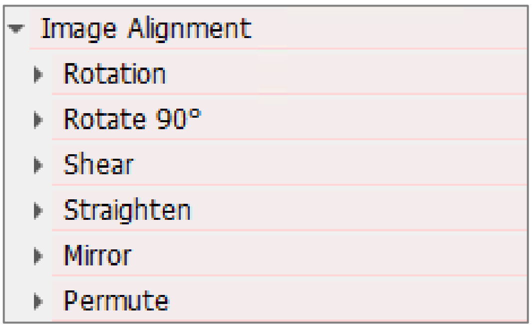
Downsampling is the process of combining multiple voxels to one in order to reduce the structure size. The user chooses to apply the **Sampling Factor** to the **Voxel Mean Value** or the **Voxel Median** in the **Sampling Mode** pull-down menu.

Clicking **Apply** samples the structure with the current parameters.



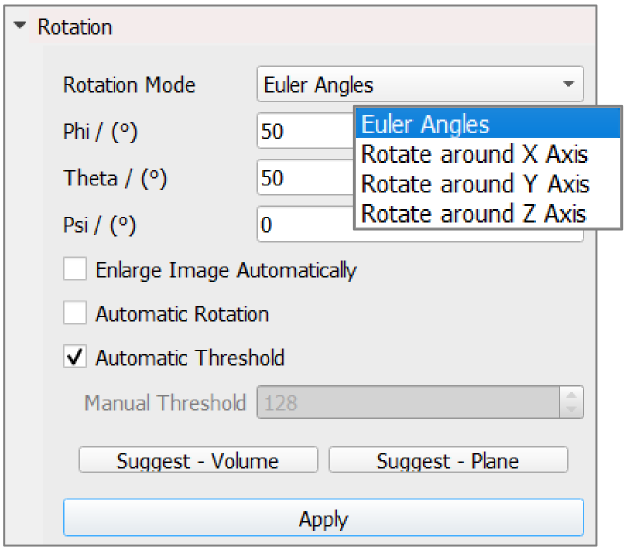

## IMAGE ALIGNMENT

The **Image Alignment** tree contains the panels affecting the orientation of a 3D image: **Rotation**, **Shear**, **Straighten**, and **Permute**.




### ROTATION

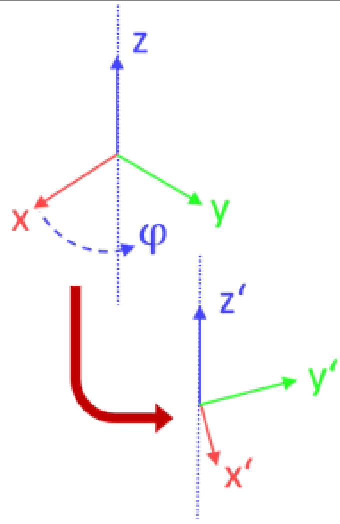
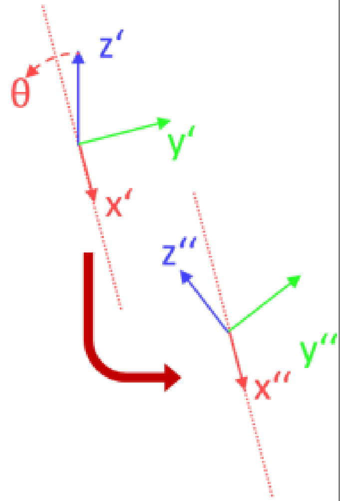
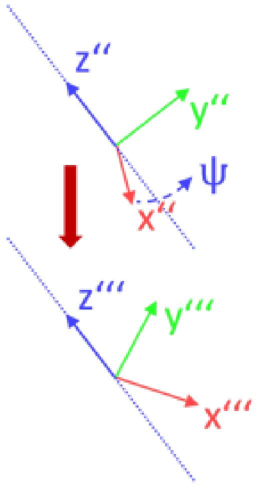
The three-dimensional rotation of the image is defined in the **Rotation** panel. Values for the **Phi**, **Theta**, and **Psi** Euler rotation angles or an angle to simply turn about one axis are entered and the image is rotated by clicking **Apply**.



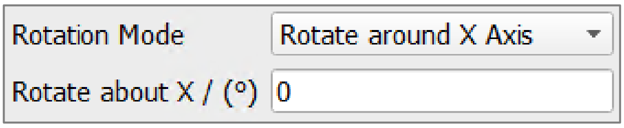

This feature is particularly useful when the images are not aligned to the inherent axis of the structure and empty space is found around the images. The Euler rotation angles are applied following the order **Phi** → **Theta** → **Psi**.

For **Rotation Mode** select **Euler Angles**, **Rotate around X**, **Y**, or **Z Axis**.

The Euler rotation angles are applied following the order Phi → Theta → Psi.

| Z-axis fixed | new X-axis fixed | new Z-axis fixed |
|---|---|---|
| **Phi** applies rotation around existing Z-axis | **Theta** applies rotation around the new X-axis | **Psi** applies rotation around the new Z-axis |
|   |   |   |

For **Rotate around X**, **Y**, or **Z Axis** enter the angle for the rotation about X, Y or Z.




**Enlarge Image Automatically** can be checked to avoid having to crop the image after the rotation.

If **Automatic Rotation** is checked, the entered parameters for the rotation angles are ignored when clicking **Apply**. Instead, the Euler rotation angles are calculated automatically based on principal component analysis for the imported gray value image. From the pull-down menu for **Rotation Mode** select **Volume** or **Plane**.

For **Volume** the algorithm tries to align the structure to all three coordinate axes.

For **Plane** only two major axes are aligned. Aligning only to two major axes can minimize unwanted rotations inside a planar structure.

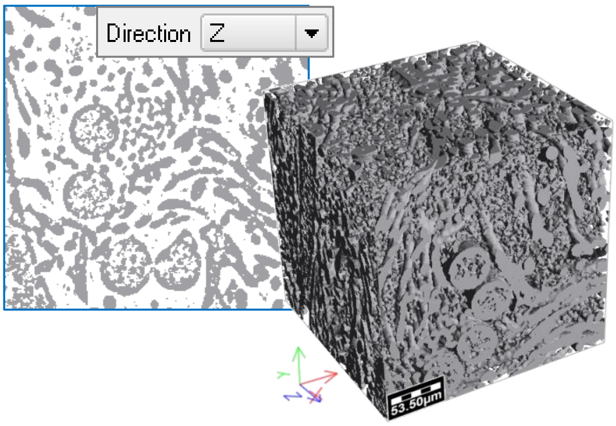
To suggest a rotation, the current threshold settings are used. If **Automatic Threshold** is enabled, the Otsu method is used to threshold the image. Otherwise enter a **Manual Threshold**.

Values for the Euler rotation angles can also first be suggested by clicking **Suggest - Volume** or **Suggest – Plane**. These options enter the suggested parameters for **Phi**, **Theta** and **Psi**.

Clicking **Apply** rotates the structure with the current settings.

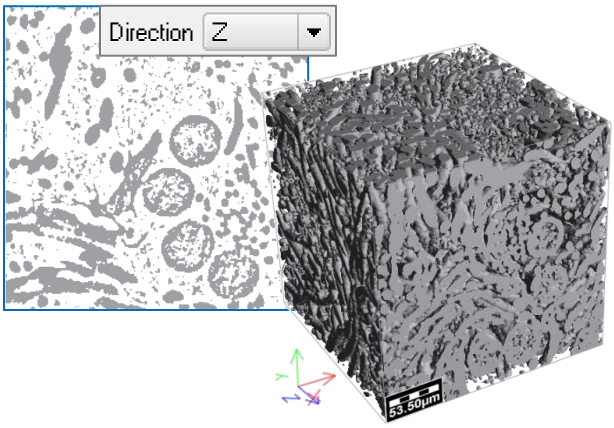
For example, here, a structure model is obtained first without rotation. Then, to obtain a structure that has been rotated only about the Y-axis by 90 or by 180 degrees, the following **Euler Angles** are used:

| Rotation Mode | Euler Angles |
|---|---|
| Phi / (°) | 0 |
| Theta / (°) | 0 |
| Psi / (°) | 0 |



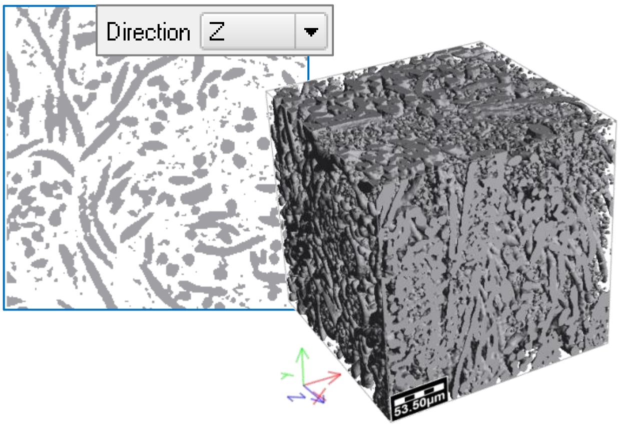

90° around Z-axis (fixed) +90° around new X-axis (fixed) + -90° around new Z-axis (fixed)

| Rotation Mode | Euler Angles |
|---|---|
| Phi / (°) | 90 |
| Theta / (°) | 180 |
| Psi / (°) | -90 |



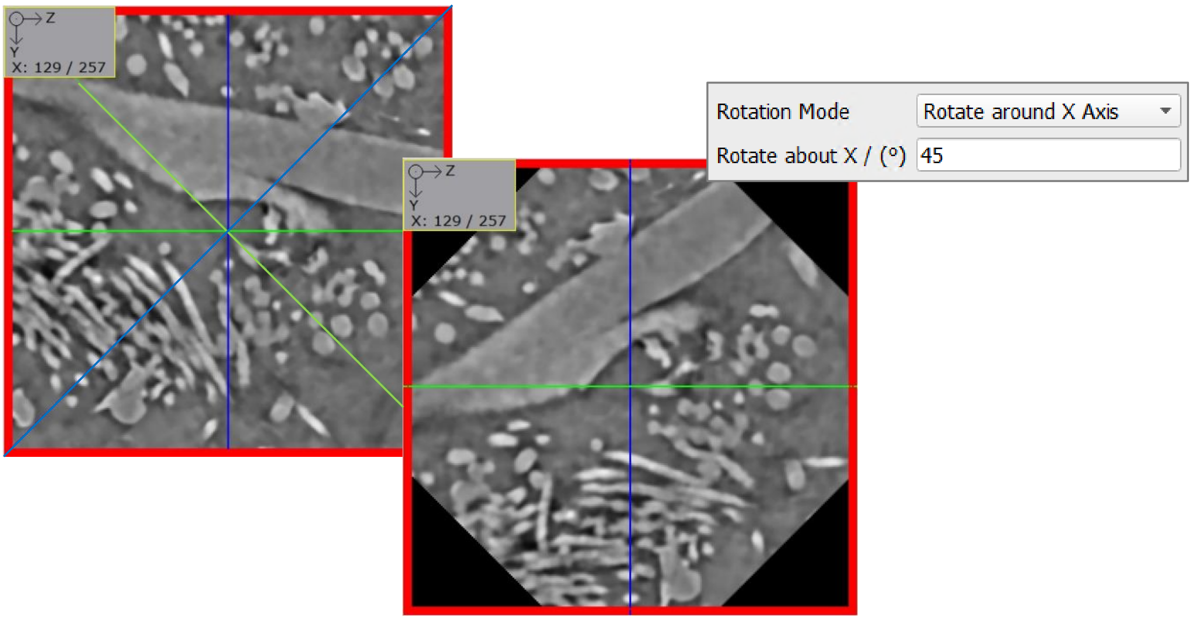

90° around Z-axis (fixed) + 180° around new X-axis (fixed) + -90° around new Z-axis (fixed)

| Rotation Mode | Euler Angles |
|---|---|
| Phi / (°) | 90 |
| Theta / (°) | 90 |
| Psi / (°) | -90 |




Of course, these two rotations can be obtained much easier, when selecting **Rotate around Y-Axis** for **Rotation Mode**, but the example helps to understand the **Euler Angles**. As they can rotate the 3D image in each desired direction, they are more powerful if the image should not only be rotated about one axis.

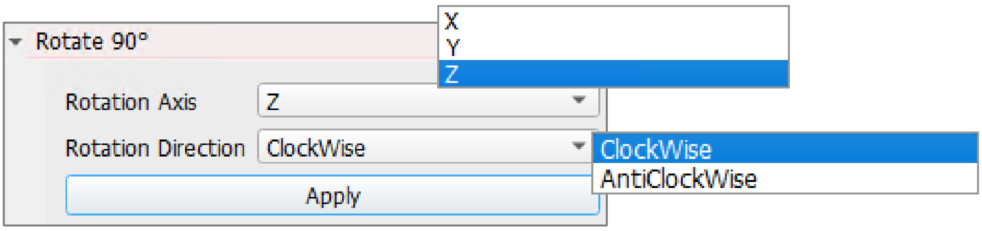
If **Rotate** is selected for **Overlay**, the resulting rotation is visualized in the **2D Slice Visualization** area. The diagonal red, green, and blue lines show the resulting center line. In the following example, the image is rotated about the X-axis. Therefore, in the YZ-plane a blue and a green diagonal can be observed. After rotating, these are the new center lines.




## Rotate 90°

The **Rotate 90°** option allows to simply turn the image by 90°. For more complex rotation options use the **Rotation** option described above.

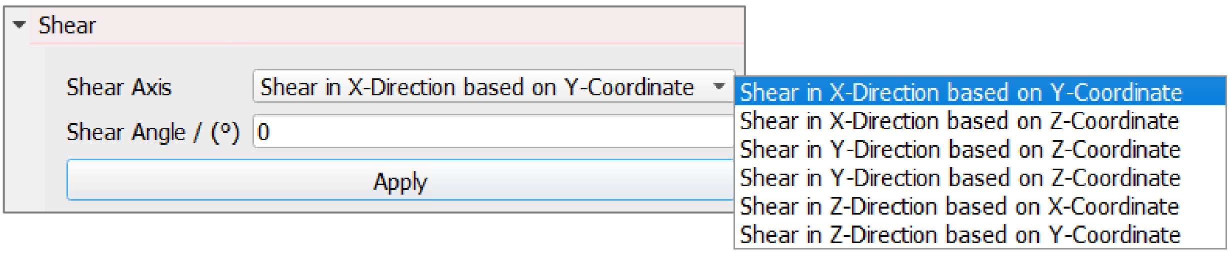
Select if the image should be rotated **ClockWise** or **AntiClockWise** around the selected **Rotation Axis**.




Click **Apply** to rotate the structure as defined.

## Shear

The **Shear** option allows to correct sheared volumes, occurring for example in FIB-SEM images.




For **Shear Axis** choose the shear direction and the coordinate that the **Shear Angle** is based on.

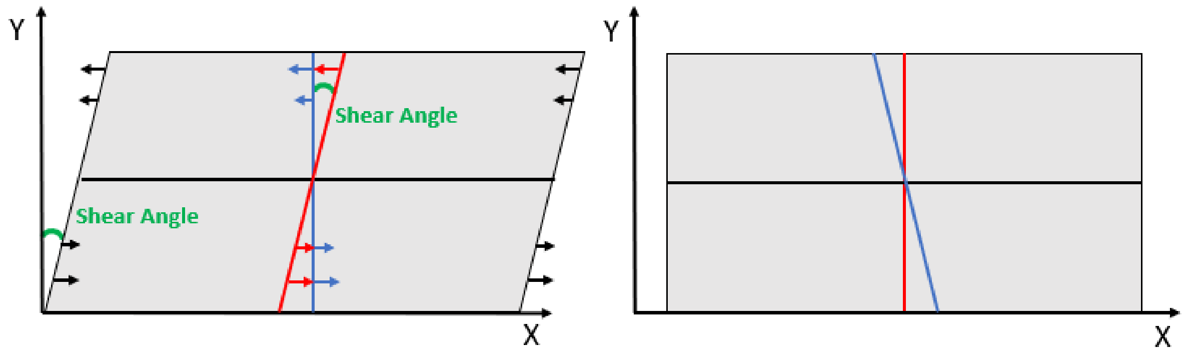
Clicking **Apply** shears the structure with the current settings.

By **Shear**ing the image, each voxel in shear direction (defined via **Shear Axis**) is displaced upon consideration of the **Shear Angle**.

The figure below schematically describes the handling of a sheared image. Here, the image is sheared in X-direction resulting in a parallelogram.

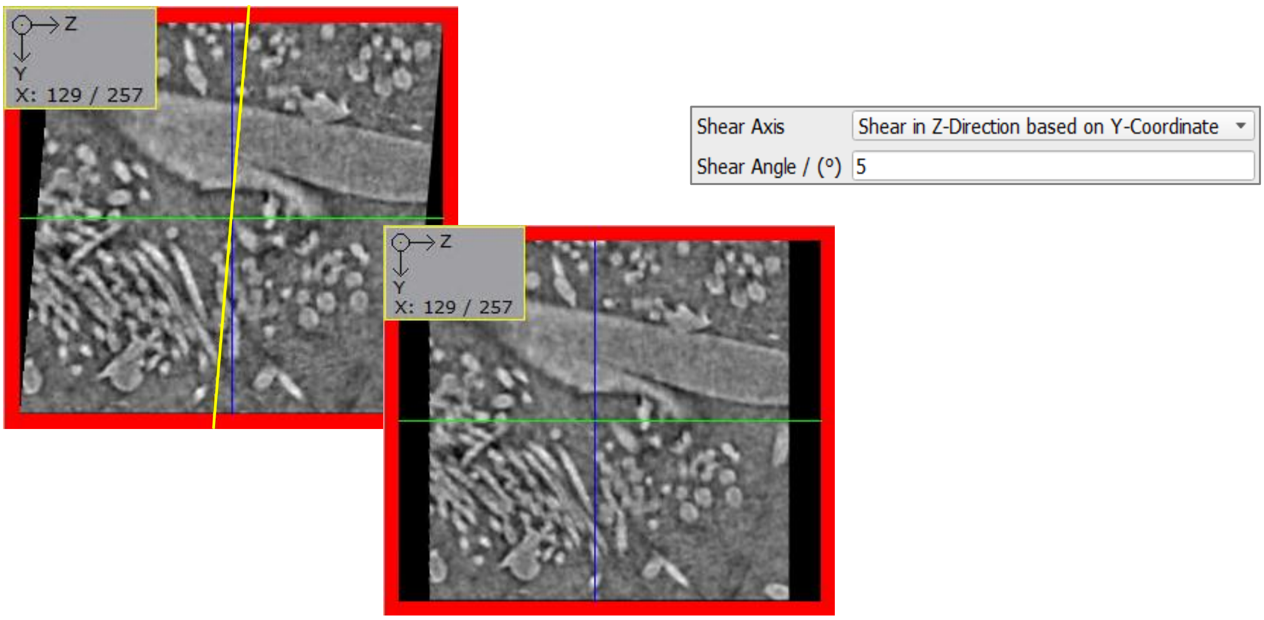
- To correct the image (into a rectangle), this direction must be defined in **Shear Axis** as "Shear in X-Direction based on Y-Coordinate".
- Then, the **Shear Angle** must be determined. Upon entering an angle, a yellow line appears in the according 2D slice, which will be the new "center line" after clicking Apply.

Gray values are moved as indicated by the arrow lengths below. To learn more about the applied method refer to shear mapping on Wikipedia.



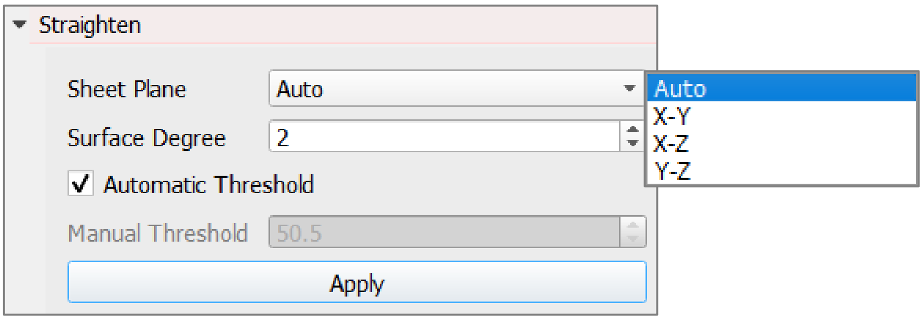

**Shear in X-Direction based on Y-Coordinate**

In the following example, the gray value image needs to be sheared in Z-direction based on Y-coordinate. The **Shear Angle** is set to 5°. As **Shear** is selected for **Overlay** the resulting center line is visualized with a yellow line.



## STRAIGHTEN

The images of structures captured in a µCT scanner may have a slight bow or warp to them. The process of straightening is especially interesting in case of flat geometries and can be used to make the structure model in the image lie flat again. For this, a surface with a given **Surface Degree** is fitted through the structure and aligned to a **Sheet Plane**.



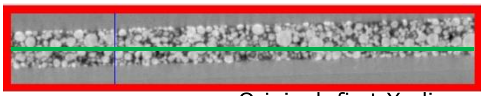

Select the sheet plane to be in **X-Y**, **X-Z**, or **Y-Z** direction or let the direction be estimated **Auto**matically.

If **Automatic Threshold** is checked the structure resulting from the Otsu threshold is straightened. Otherwise enter a **Manual Threshold**.

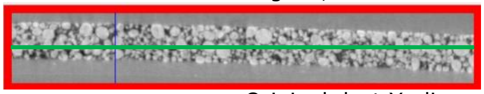
Clicking **Apply** straightens the structure with the current settings.

**Example:** Here, the bow of a grain structure is removed by applying the straightening process.

The bow can be observed in the **2D Slice Visualization** section. On the right the first and the last X-slice are shown. Observe the bow in both slices. Also, the bow can be observed in X-direction, by comparing the two slices.

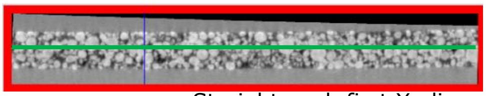


Original, first X-slice

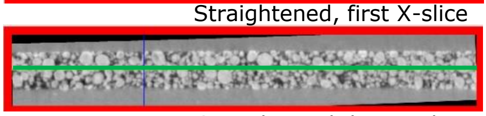


Original, last X-slice

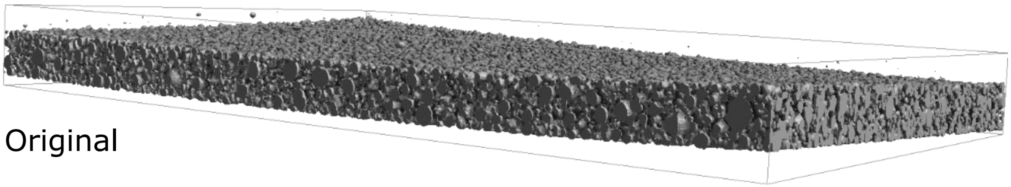
Applying **Straighten** with default settings leads to a straightened structure, shown on the right in 2D and below in 3D.



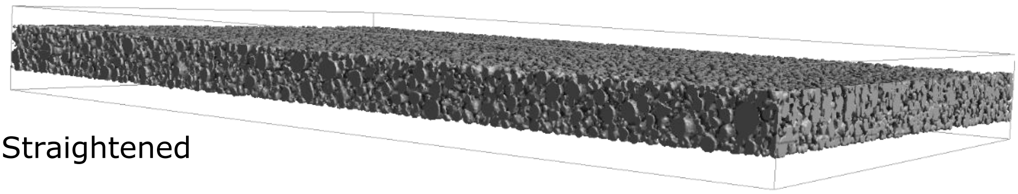
Straightened, first X-slice



Straightened, last X-slice



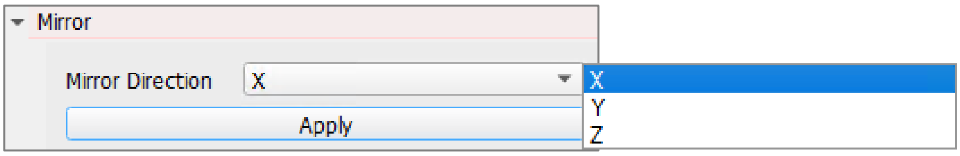
Original



Straightened

## Mirror

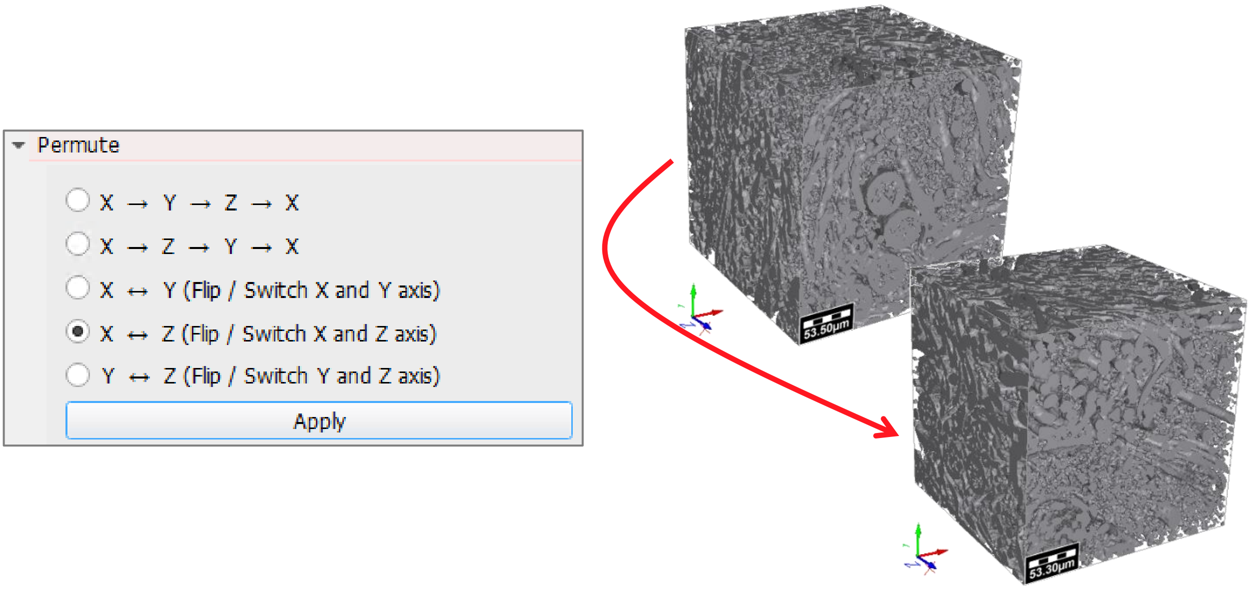
**Mirror** the image along the plane orthogonal to the selected **Mirror Direction** axis by clicking **Apply**.




In the example below, **Z** is selected as **Mirror Direction**. Thus, the image is mirrored along the XY-plane.

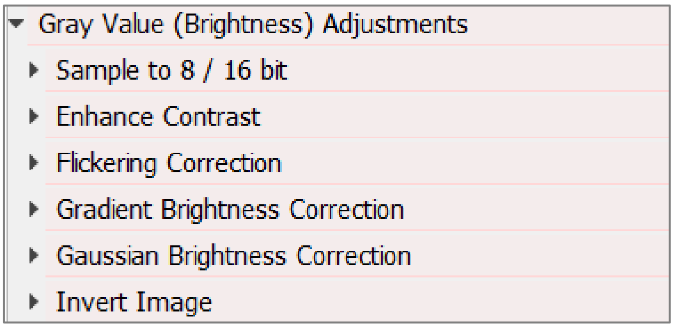

## Permute

**Permute** changes the allocation of the axes for the structure to be imported. Select the desired permutation of axes and click **Apply**. For example, if the structure's X-axis should be exchanged with the Z-axis, the user selects **X** ↔ **Z**, and clicks **Apply**. Now what used to be the X-direction has turned into Z-direction.



## Gray Value (Brightness) Adjustments

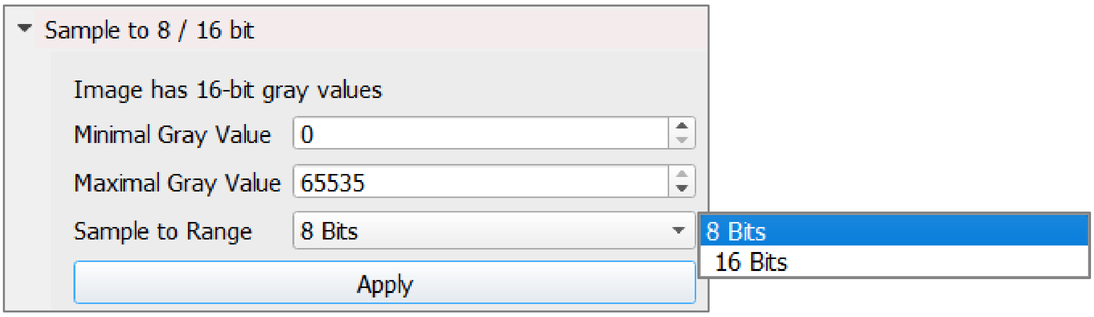
The **Gray Value (Brightness) Adjustments** tree contains the tools **Sample to 8 / 16 bit**, **Enhance Contrast**, **Flickering Correction**, **Gradient Brightness Correction**, **Gaussian Brightness Correction** and **Invert Image**. They are used for gray value adjustments related to the brightness of the image.




### Sample to 8 / 16 bit

The image can be sampled to 8-bit or 16-bit format through the **Sample to 8 / 16 bit** panel. Each pixel in the image is then represented by an 8-bit or 16-bit value, respectively.

The current image format is shown in the panel. Here, the **Image has 16-bit gray values**. So, each pixel contains a gray value between 0-65535, which is basically $2^{16}$ different values.




Enter the **Minimal Gray Value** and the **Maximal Gray Value** for the image going to be sampled. These values adjust the gray value range for the 8-bit or 16-bit image.

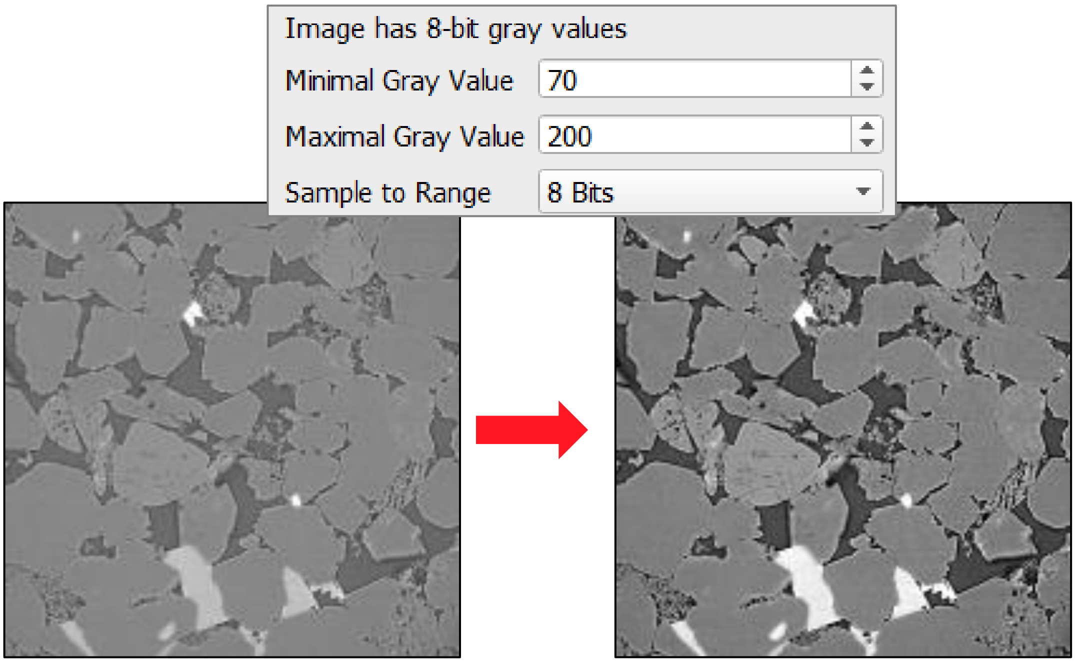
Select **8 Bits** or **16 Bits** from the pull-down menu for **Sample to Range**.

Converting 16-bit to 8-bit format is often done to reduce the large data size of 16-bit images. The gray value range reduces to 0-255 by choosing **8 Bits**.

If **16 Bits** is selected, the bit depths can be increased from 8-bit to 16-bit.

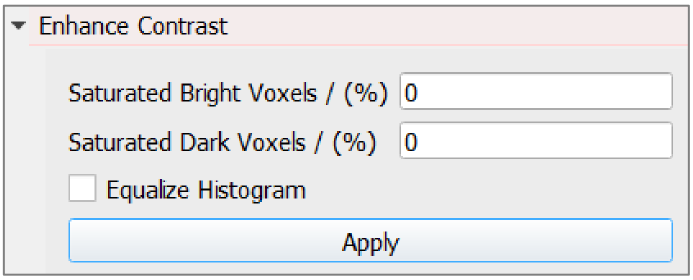
Clicking **Apply** samples the image with the current settings.

The following images show an example for changing the gray value range in an 8-bit image of a Berea sandstone. Here, the contrast between solid phases (mid and bright gray values) and pore space (dark gray values) increases by reducing the original gray value range to 70-200 instead of 0-255.




## ENHANCE CONTRAST

The new **Enhance Contrast** feature offers the possibility to increase the contrast in the 3D image data. When applying **Enhance Contrast**, keep observing the changes in the histogram.

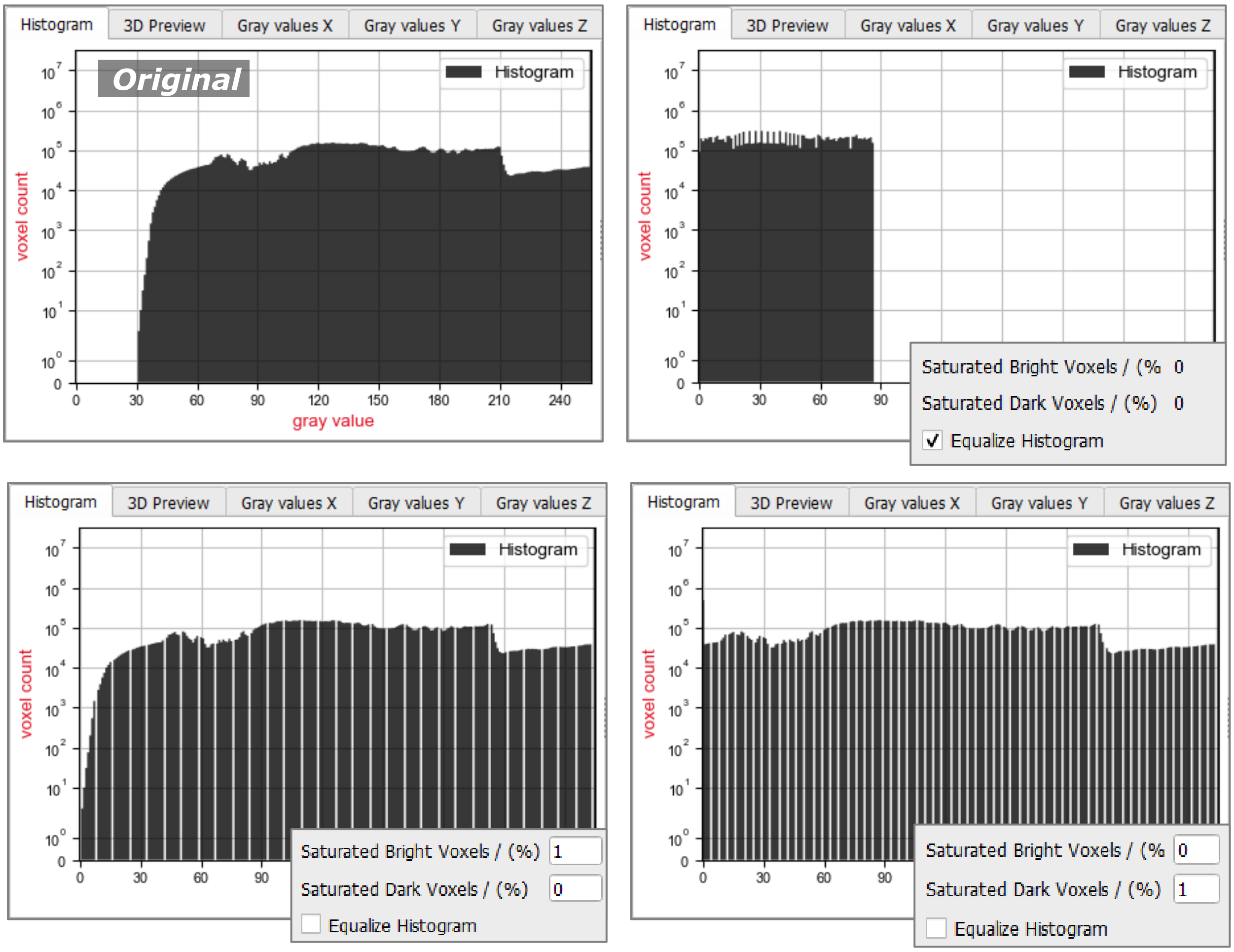



The usage of **Saturated Bright Voxels** and **Saturated Dark Voxels** changes the gray value distribution in the image. With 0% each, the gray values are automatically distributed to the entire gray value range, this is also possible with manual settings in **Sample to 8 / 16 bit**. Increasing the percentages narrows the considered gray value range by ignoring the given percent of bright and/or dark gray values, respectively. Thus, higher values will increase the contrast.

When checking the option **Equalize Histogram**, this feature equalizes the gray values in the histogram. The original distribution of gray values is then balanced, so that each gray value contains an equal number of occurrences in average.

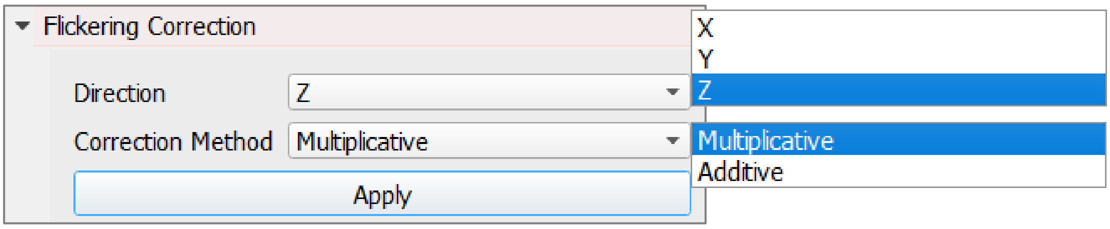
Clicking **Apply** enhances the contrast in the image with the current settings.

The examples below show histogram results for the different settings. Note the high voxel count at the maximum gray value 255, which strongly affects the gray value distribution after application of **Enhance Contrast**.




## Flickering Correction

When sliding through the image in one direction, some scans show a “flickering” in the display of the 2D slices. This is common in FIB-SEM scans and these images require a **Flickering Correction**.




First choose the **Direction**, along which the flickering occurs: **X**, **Y** or **Z**.

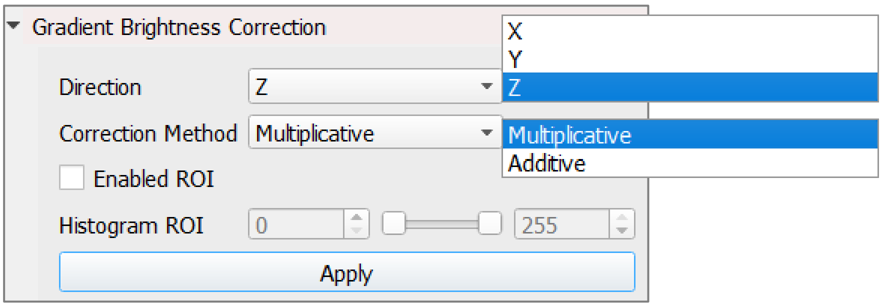
The **Correction Method** provides the two options **Multiplicative** and **Additive** both depending on the applied image acquisition device.

- If the acquisition device is linear, use **Multiplicative** correction method.
- If the acquisition device is logarithmic, use **Additive** correction method.

Clicking **Apply** applies the **Flickering Correction** according to the given settings.

## Gradient Brightness Correction

**The Gradient Brightness Correction** is required when the user observes a slow brightening / darkening when sliding through the image in one direction.



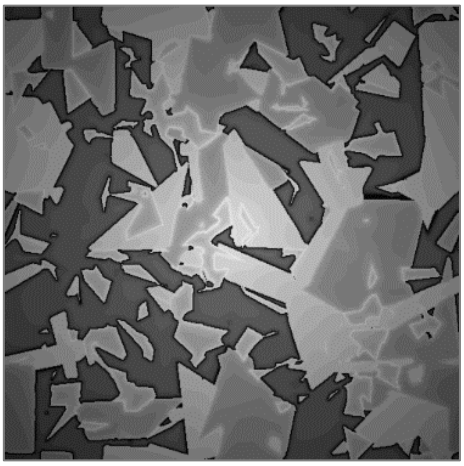

First choose the **Direction**, along which the flickering occurs: **X**, **Y** or **Z**).

The **Correction Method** provides two options, both depending on the applied image acquisition device. If the acquisition device is linear, use **Multiplicative** correction method. If the acquisition device is logarithmic, use **Additive** correction method.

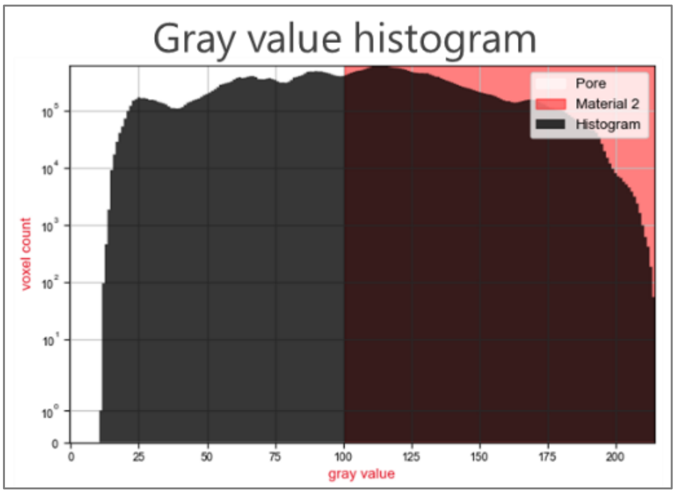
With **Enabled ROI** the gray value range can be restricted within which the correction is applied. The according minimum and maximum gray value of that range are chosen at **Histogram ROI**.

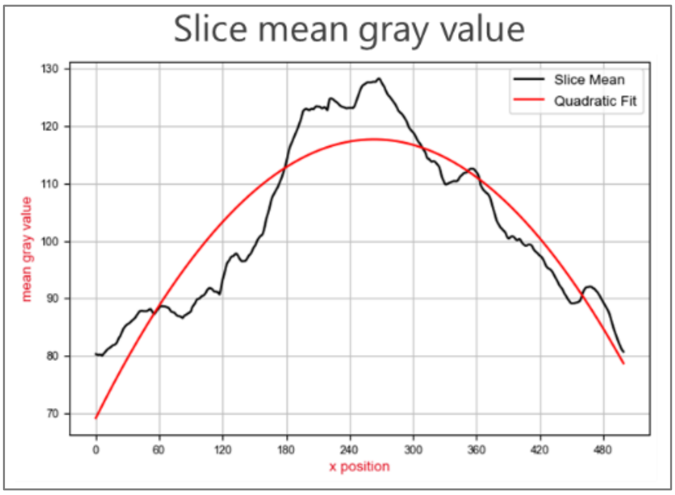
Clicking **Apply** applies the **Gradient Brightness Correction** according to the given settings.

The following example shows a brightness gradient from exterior to interior in a Z-axis slice. That gradient can also be observed in the **Slice Mean** gray value (see the **Histogram** section on page 36), shown in the following diagrams for the X-axis.

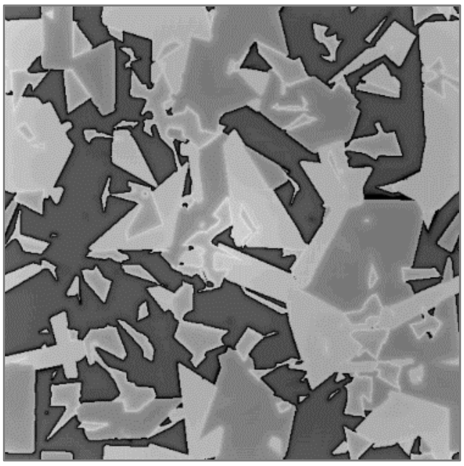


Original

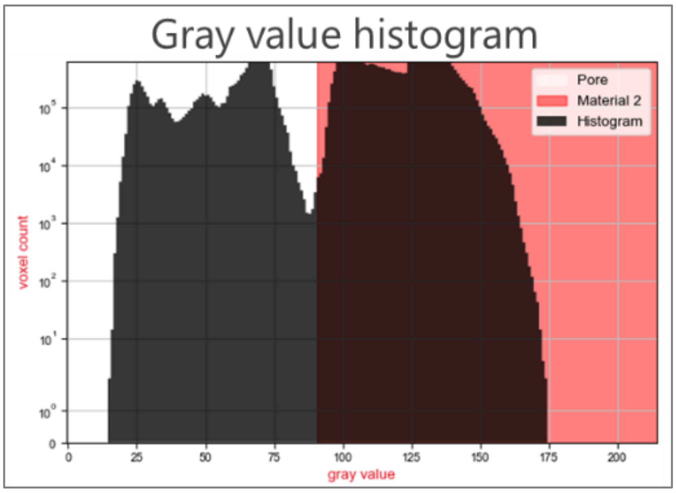


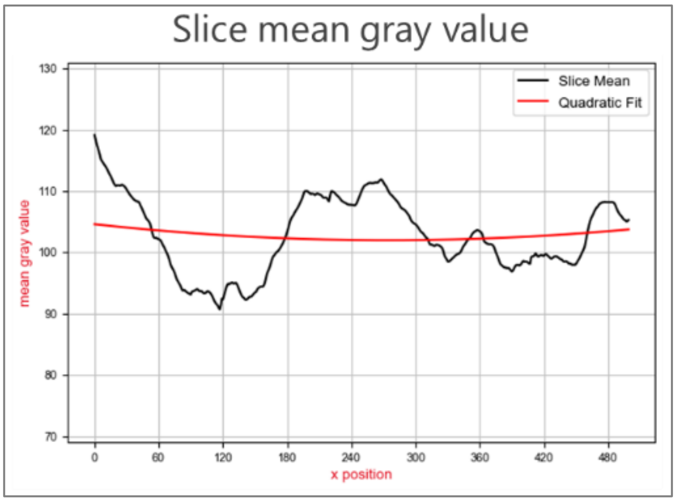



The **Gradient Brightness Correction** is applied for **Direction Z** without **Enabled ROI**. The correction improves the gray value image significantly. As a result, the gray value histogram now shows a strongly improved differentiation between pore space and solid phases. The slice mean gray values now have a linear trend along the X-axis:



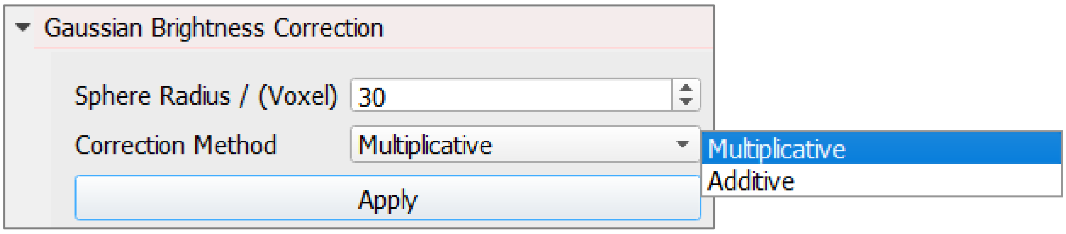
Corrected




## Gaussian Brightness Correction

The aim of the **Gaussian Brightness Correction** is to balance bright/dark regions in the image.




The **Sphere Radius** controls the size of the region, in which the correction is applied. The **Gaussian Brightness Correction** works for all types of brightness variations if the grain diameters ($d_{grains}$) are small in relation to the **Sphere Radius** ($r_{sphere}$):

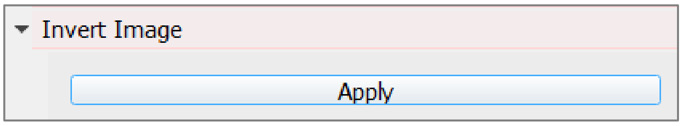
$$3 \times d_{grains} < r_{sphere}$$

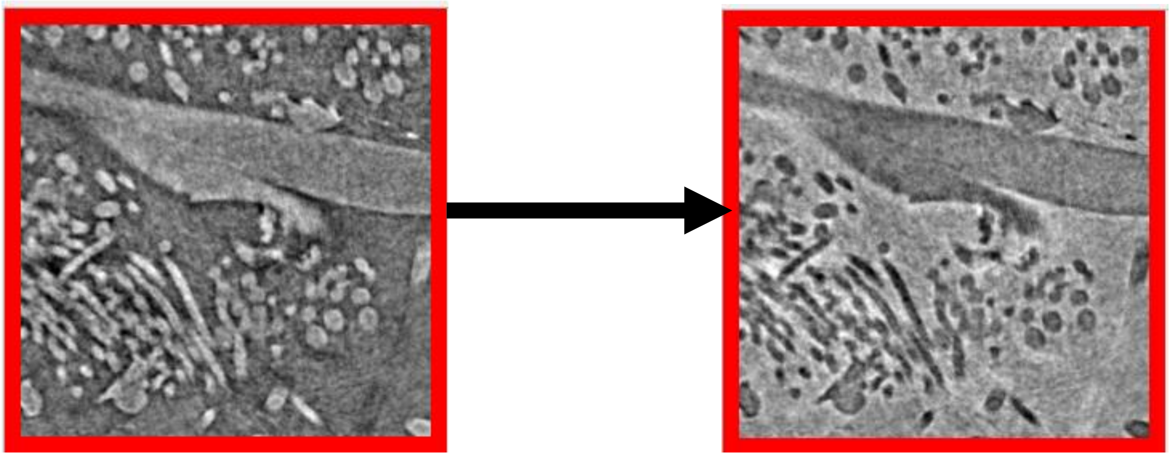
The **Correction Method** provides two options both depending on the applied image acquisition device. If the acquisition device is linear, use **Multiplicative** correction method. If the acquisition device is logarithmic, use **Additive** correction method.

Clicking **Apply** applies the **Gaussian Brightness Correction** according to the given settings.

### Invert Image

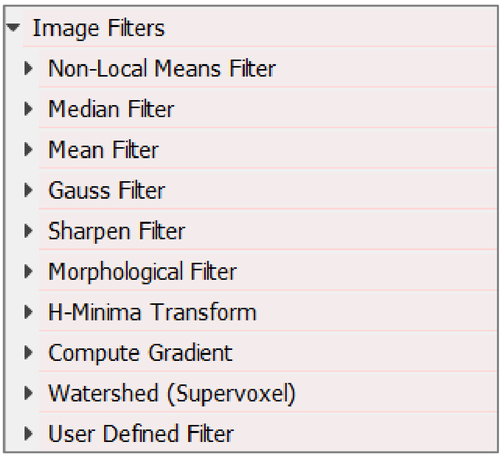
The **Invert Image** option inverts the gray values, when clicking **Apply**.



## Image Filters

The **Image Filters** tree contains the panels **Non-Local Means Filter**, **Median Filter**, **Mean Filter**, and **Gauss Filter**, as well as **Sharpen Filter**, **Morphological Filter**, **H-Minima Transform**, **Compute Gradient**, **Watershed (Supervoxel)** and **User Defined Filter**.




Clicking **Preview** for any of the filters (when this button is available) opens a dialog (**Parameter Gallery for ... Filter**) showing the effect of the entered filter parameters on the image.

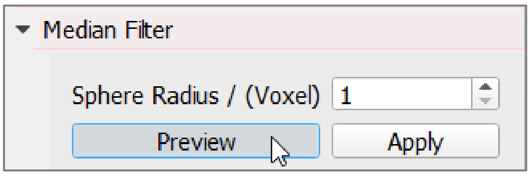
The left of the dialog allows settings for **Gray Value Range** (see page 30), **Threshold Visibility** (see page 33), **Threshold**, and some viewing parameters such as the **View**

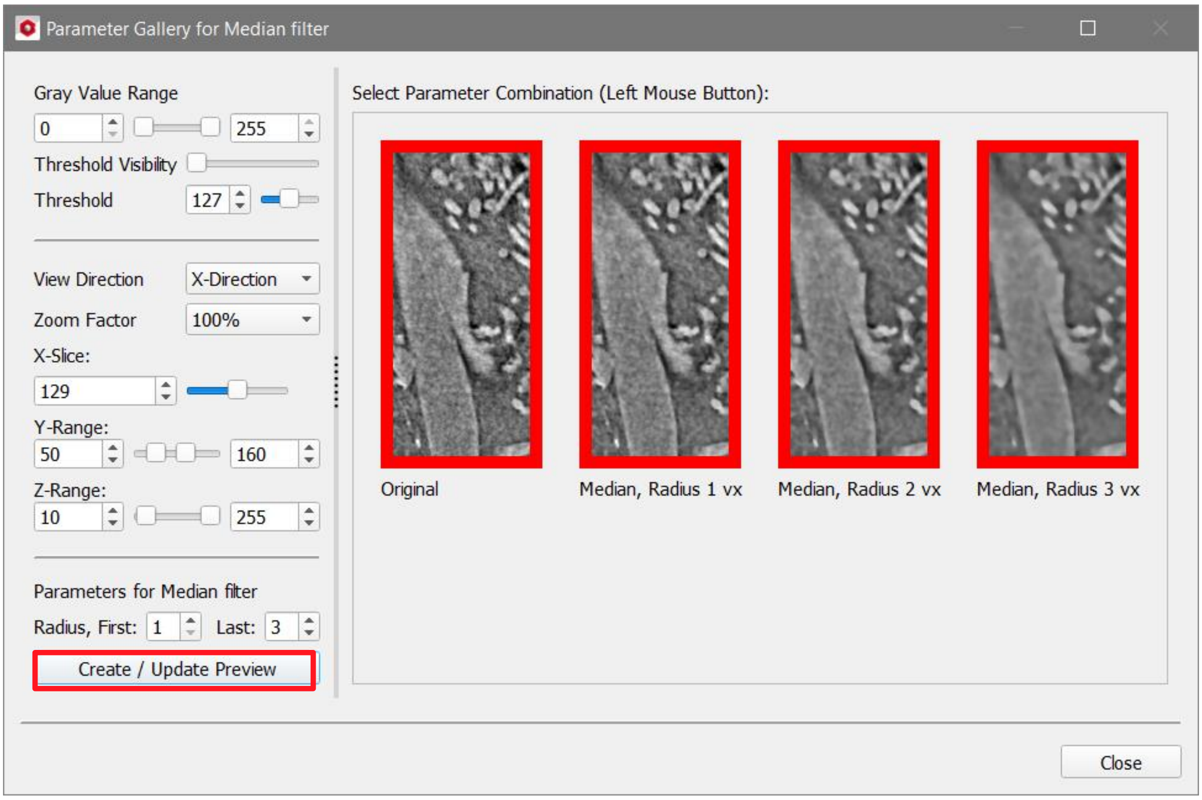
**Direction**, the **Zoom Factor**, and the **x Slice**, **y Range**, and **z Range**, which define the size of the preview sub-region and the visible plane.

Clicking **Create / Update Preview** renders a set of images that can be used to identify the wanted filter effect.

Depending on the filter, different preview parameters can be set.

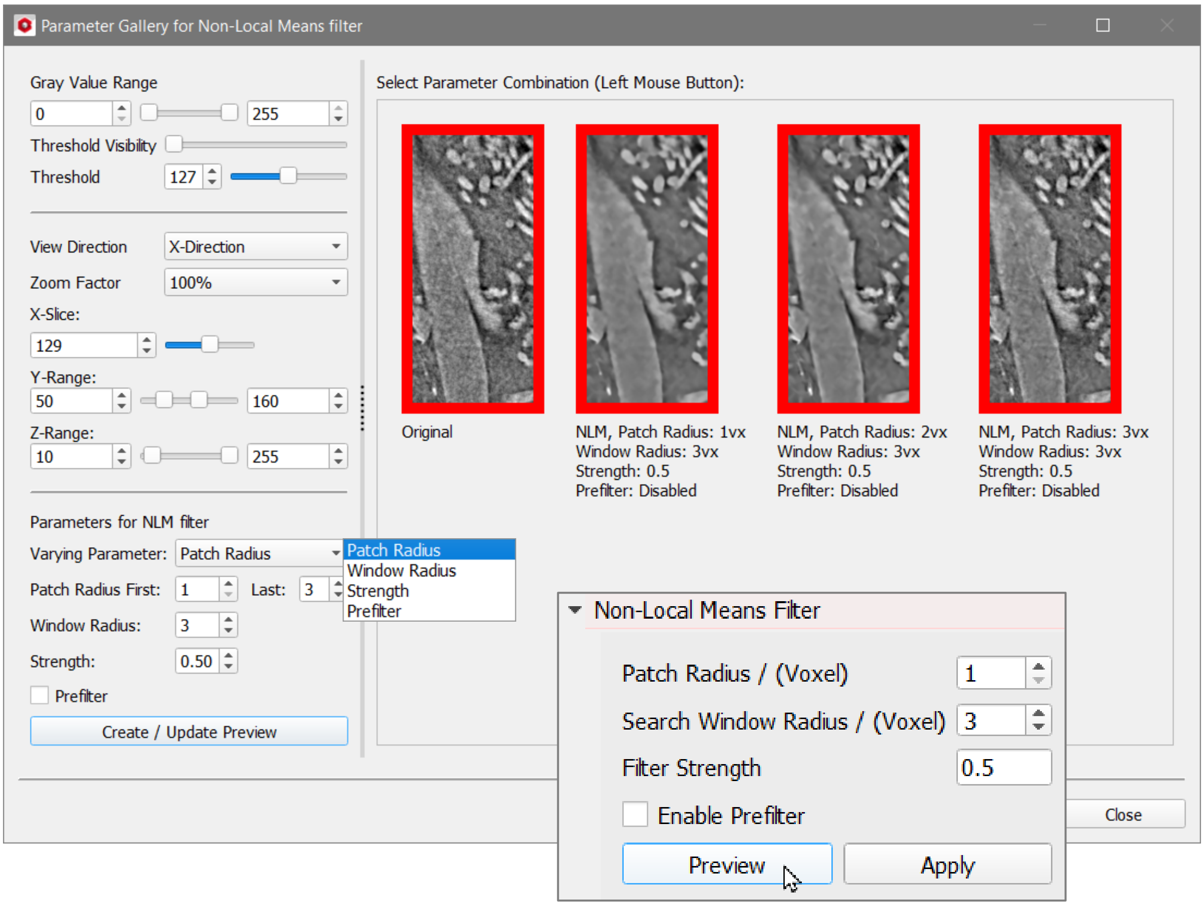
For the **Median Filter**, the **Mean Filter**, and the **Morphological Filter**, a range of Radii (here 1 to 3 voxels) can be chosen.




For the **Gauss Filter**, **Sharpen Filter**, and the **Non-Local Means Filter**, one of the parameters can be chosen to be a **Varying Parameter**, while a fixed value is entered for the other parameters.

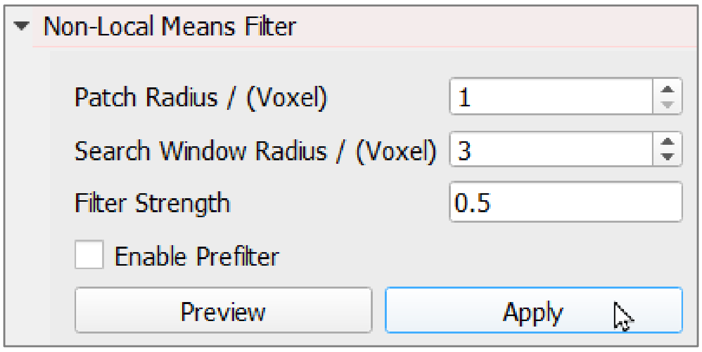
For example, here, for the **Non-Local Means Filter**, the **Patch Radius** is set to be the Varying Parameter whereas the **Window Radius**, the **Strength**, and Prefilter have fixed values.




Select the best parameter combination on the right by simply clicking on the desired image. After closing the dialog, these parameters are entered for the corresponding filter.

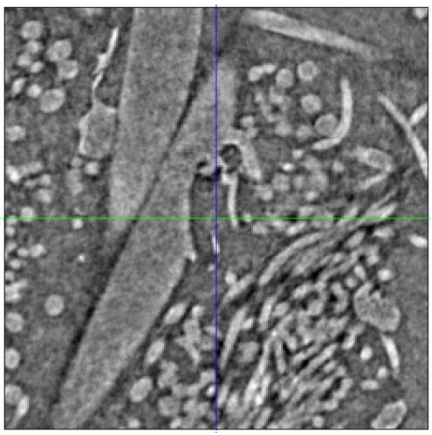
## Non-Local Means Filter

Clicking **Apply**, applies a **Non-Local Means Filtering** to the 3D image. This is a very powerful filter to reduce noise while still keeping edges sharp. To learn more about the underlying theory see e.g., Wikipedia.




The size of edges is controlled with **Patch Radius** determining the size of regions compared and **Search Window Radius**. The latter determines the neighborhood around each voxel, for which regions are compared. The amount of smoothing is controlled with **Filter Strength.** For very noisy images it can be necessary to **Enable Prefilter**. This option improves the patch comparison in this case.

The left image shows the original gray values of an image. The right image shows the same image after applying the **Non-Local Means Filter** with default settings.



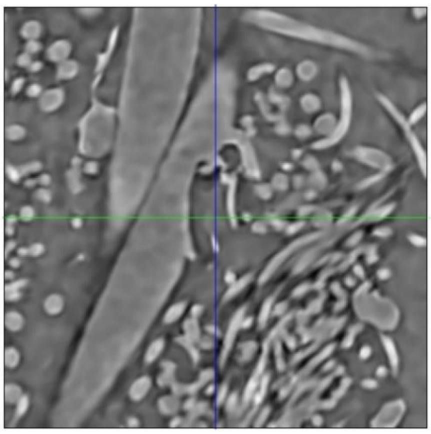
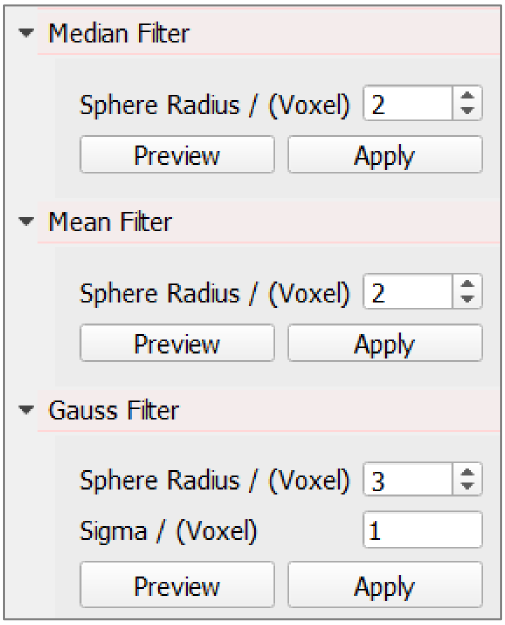


Image enhancement filters can be very time-consuming when being applied to complete 3D image data. Specially the **Non-Local Means Filter** can significantly improve the quality of segmentations, but applying it takes longer than other filters. For this reason, an option to preview the effect of the filter parameters before applying them has been added to the most filters under the **Image Filters** tree.

### Median Filter, Mean Filter, and Gauss Filter

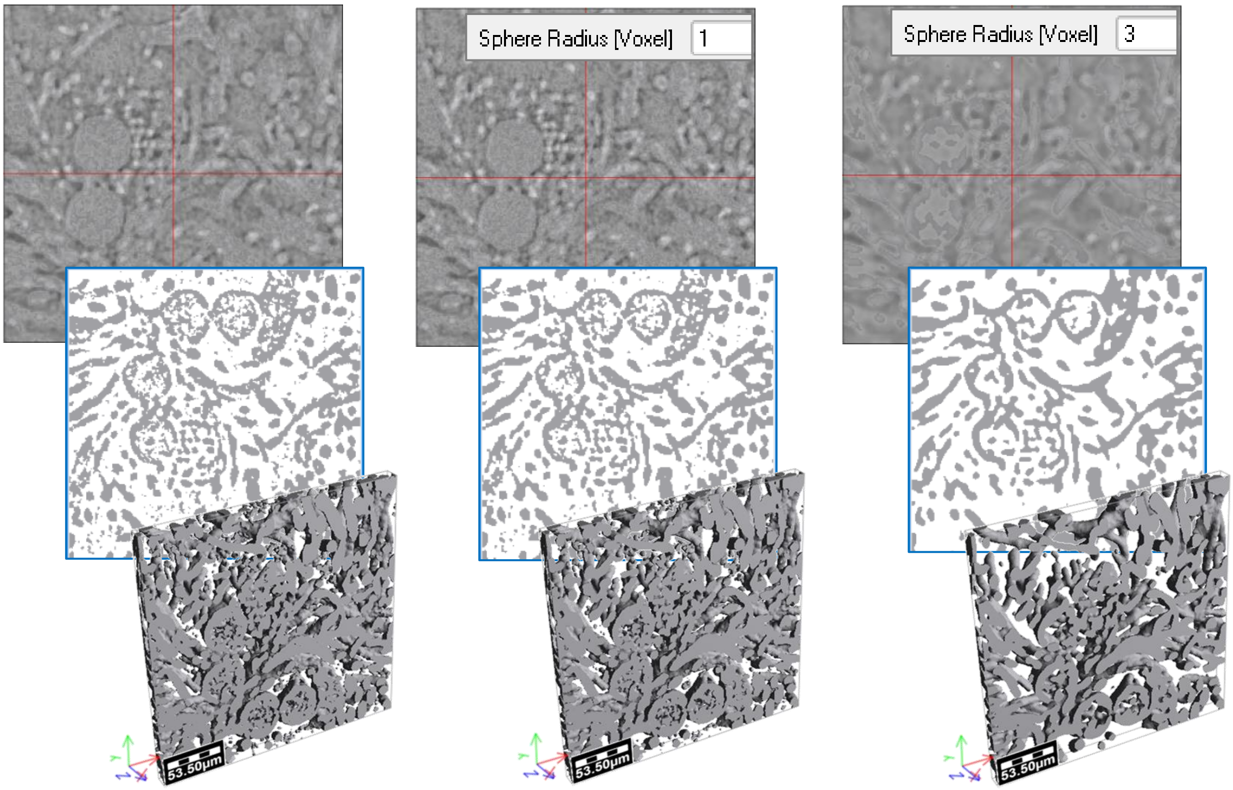
The Median filter , the Mean filter and/or Gauss filter can be applied to the 3D image to remove noise that has the specified **Sphere Radius**, or to smooth the image.

The given sphere radius defines the size of the mask used for the filtering of the 3D image. By entering the sphere radius in voxels, and clicking **Apply**, the image is immediately filtered.




Observe the cleansing effect of applying the median filter after setting the sphere radius in the original structure to 1 and then 3 voxels. Similar results are obtained applying the **Mean Filter** or the **Gauss Filter** with the same sphere radius values. Please consider that the ProcessGeo module already contains a **Cleanse** possibility for the segmented image.

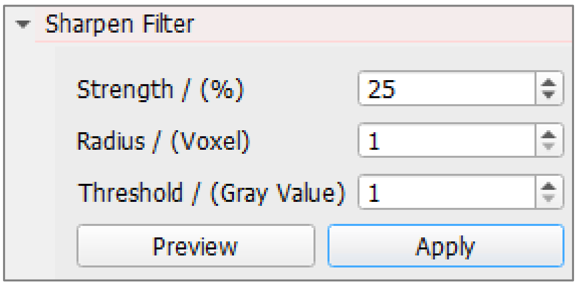
The first row shows the filtered gray values images. The second and third rows correspond to 2D and 3D Rendering views of the structure model imported after each processing.




For the **Gauss Filter**, the **Sigma** value in voxels corresponds to the standard deviation of the Gaussian filter.

## Sharpen Filter

Clicking **Apply**, a Sharpen filter is applied to improve low contrast 3D images. The amount of sharpening is controlled with the **Strength** parameter.



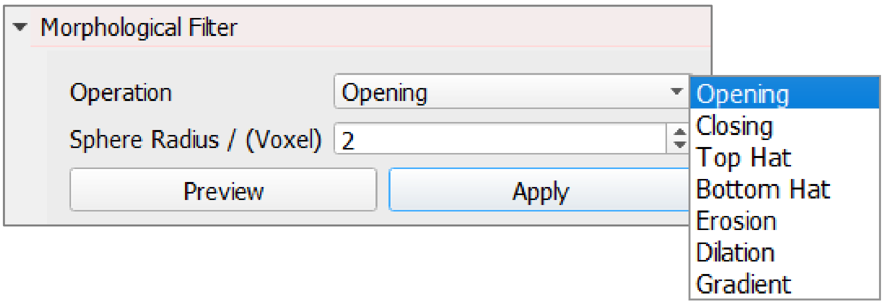

**Radius** determines the area around edges that will be sharpened.

**Threshold / (Gray Value)** restricts the sharpening to regions with a minimal difference in gray values. This allows keeping more homogenous regions from getting noisy.

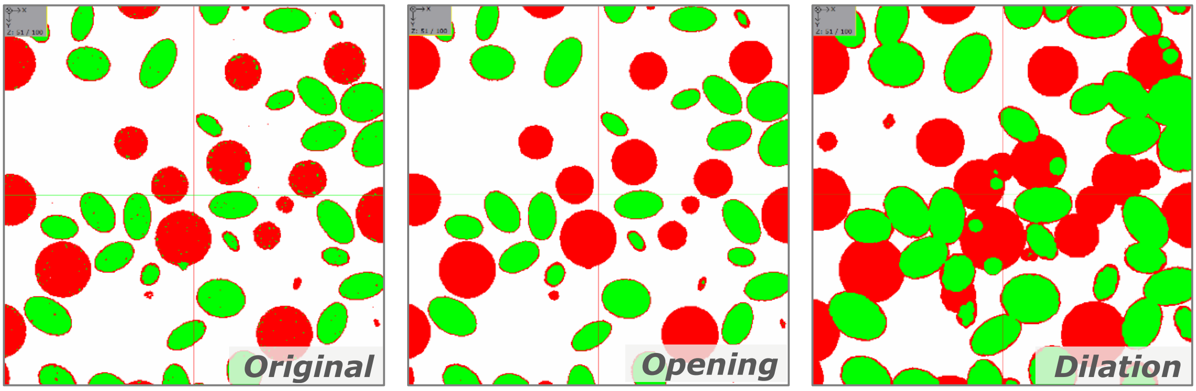
## Morphological Filter

The **Morphological Filter** contains several different **Operations**.

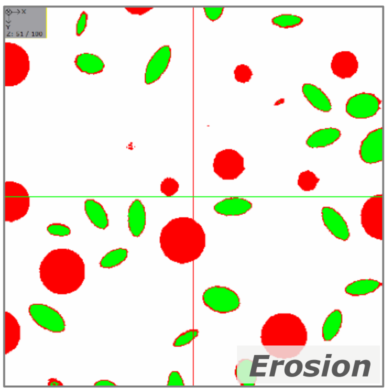
Each **Operation** requires the input of a **Sphere Radius**, controlling the size of the region, in which the filter is applied. Clicking **Apply** applies the chosen filter.




Some of the Operations are illustrated with an example based on an artificial gray value image consisting of few grains at high porosity. The 2D slice images show a multiple threshold segmentation preview as described on pages 80ff.



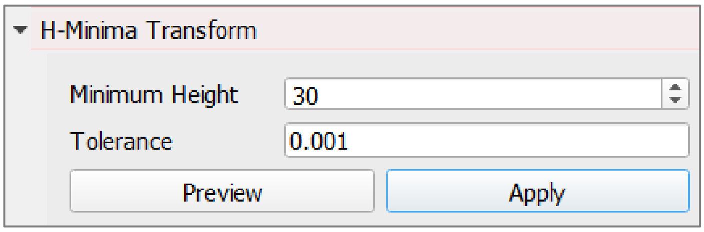

- **Opening**: Removes bright structures smaller than the given spheres. Please note, the Cleanse tool of the ProcessGeo module removes these so-called "Island artifacts" from segmented structures.
- **Closing**: Removes dark structures smaller than the given spheres. Please note, the Cleanse tool of the ProcessGeo module removes these so-called "Island artifacts" from segmented structures.
- **TopHat**: Removes bright regions larger than the given sphere.
- **BottomHat**: Removes dark regions larger than the given sphere.
- **Dilation**: Grows bright regions in the image. Assigns the brightest gray value to spheres with the given radius, in the entire image.
- **Erosion**: Grows dark regions in the image. Assigns the darkest gray value to spheres with the given radius, in the entire image.




- **Gradient**: Both **Erosion** and **Dilation** are applied to the image. Then, the erosion image is subtracted from the dilation image to mark gradients and borders.

## H-Minima Transform

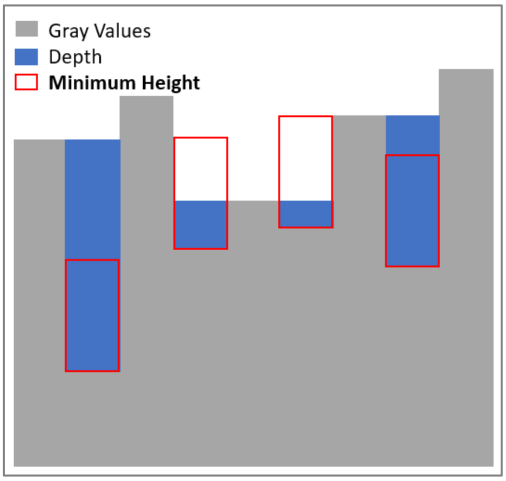
The **H-Minima-Transform** was invented to reduce the over-segmentation of the watershed algorithm, by reducing noise in the darker regions of the gray value image.

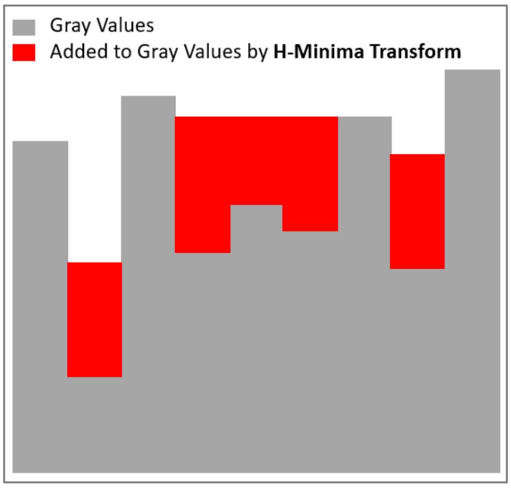


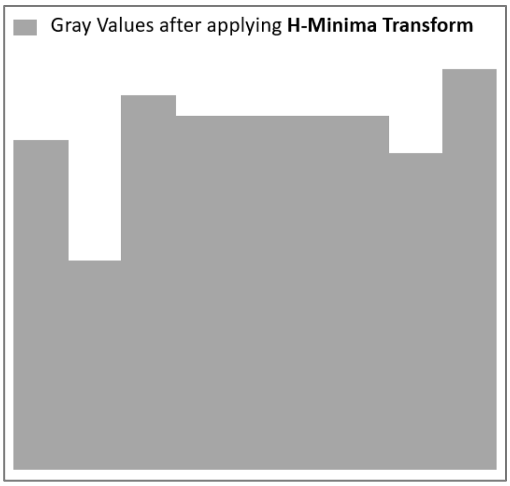

The method searches for local minima in the gray value image and suppresses them, if their depth is lower or equal than the **Minimum Height**. The depth of a local minimum is defined as the difference between the gray value in the local minimum and the next local gray value maximum.

In the simplified 2D example below, the neighboring gray values are shown in gray bars. For each local minimum the corresponding depth is visualized in blue.

For comparison, the given **Minimum Height** is visualized as a red rectangle. Observe that the depth of the two minima in the center is lower than the **Minimum Height**, while the other two have a depth higher than the **Minimum Height**. Thus, the two in the middle will get suppressed and the other two will not, as shown below.



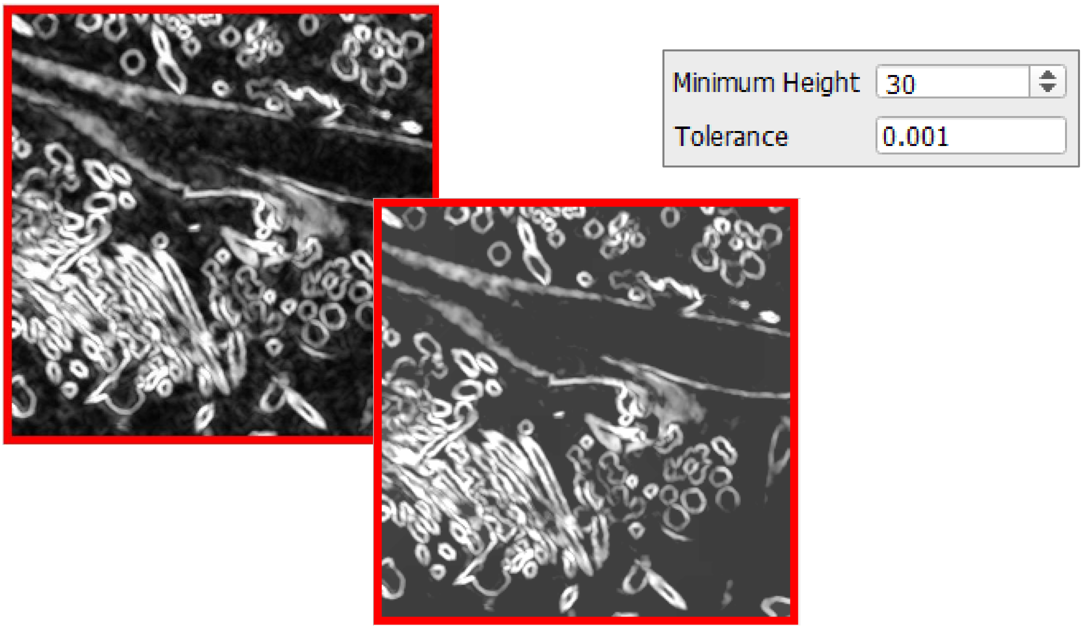



The **Tolerance** is the relative change in the image mean gray value. If 0 is entered for **Tolerance** the runtime can be very long, trying to find a perfectly stable solution. In most cases, however, a slightly higher tolerance, for example the default of 0.001, already leads to good results.

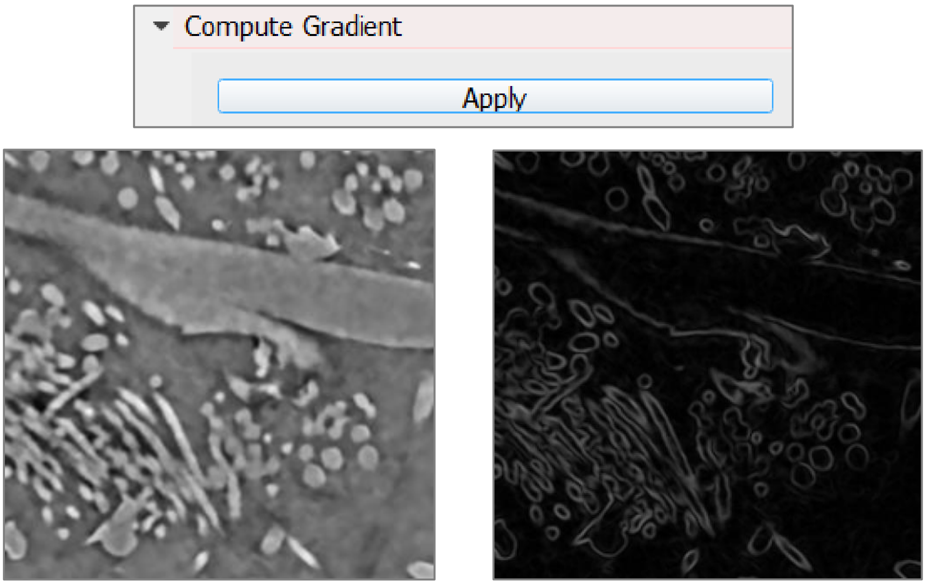
Click **Apply** to apply the filter on the gray value image.

In the following the example was already filtered with the **Non-Local Means Filter** (see page 59) and a **Morphological Gradient** (see page 62). Then, the **H-Minima Transform** is applied with a **Minimum Height** of 30.




## Compute Gradient

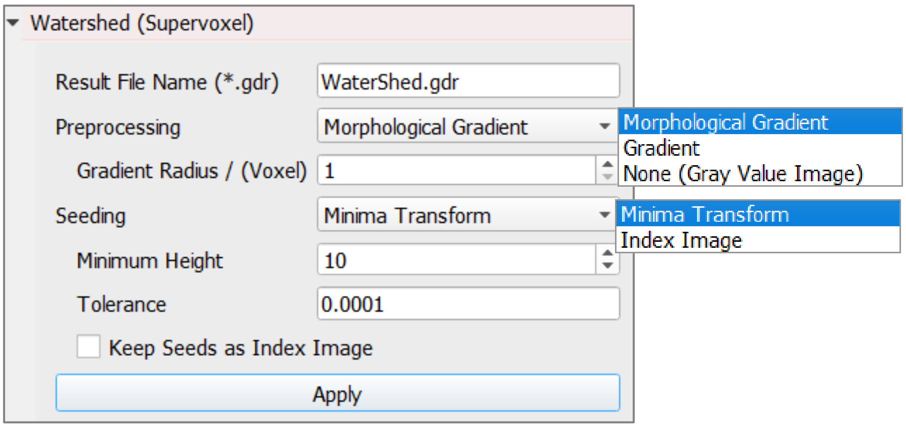
The option **Compute Gradient** computes the gradient for each voxel in the gray value image, when clicking **Apply**. This results in an image where the gray values are brighter towards the borders.



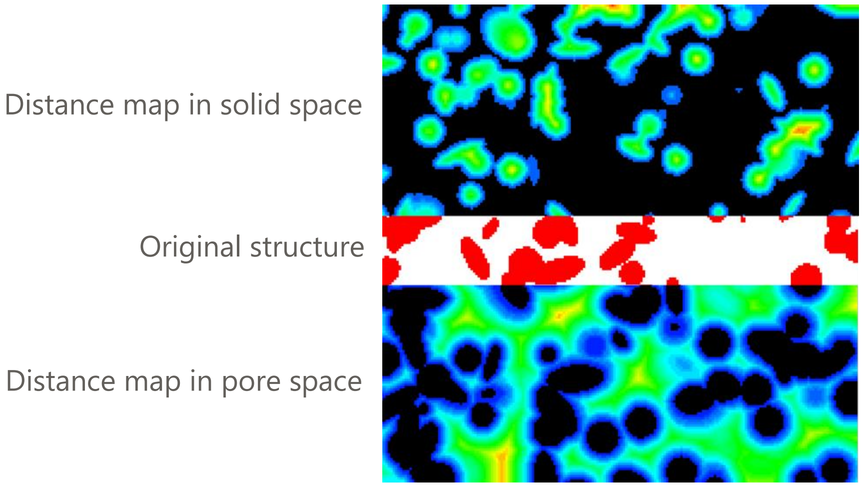
## WATERSHED (SUPERVOXEL)

The watershed transformation treats the image it operates upon like a topographic map, with the brightness of each point representing its height, and finds the lines that run along the tops of ridges.

The **Watershed (Supervoxel)** is based on the **Euclidean Distance Transform** (EDT). Watershed component seeds are placed in the local maxima of the EDT, and in those seeds, components start to "grow". In the growing process, component boundaries are formed as soon as components touch.




The implemented algorithm detects edges based on the gray value gradient or morphological gradient (see **Preprocessing** on page 66) in the imported 3D image. Subsequently, a distance map is created depending on the edge distances. Maxima in the distance map (see image below) are used as seeds for the watershed algorithm, which is performed on the distance map.



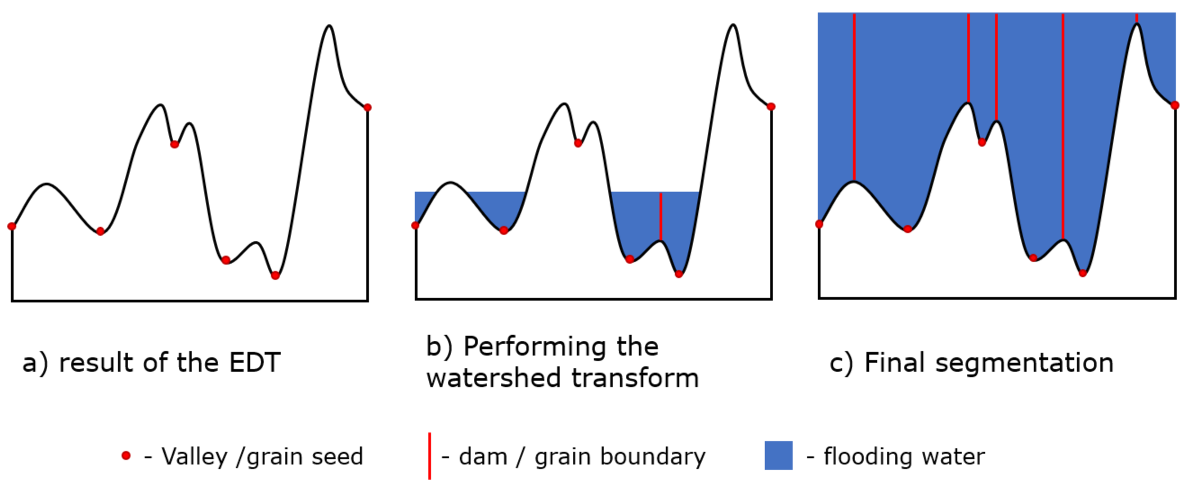

The concept behind the watershed can be understood more easily in a 2D example. In this representation, the EDT can be regarded as a topographical relief where high values represent valleys and low values represent peaks. This topography is continuously "flooded with water", starting from the deepest valleys.

As soon as the water from neighboring valley begins to mix, a dam is created (corresponding to the grain boundary). The result is a topography with water-filled valleys and dams that separate them. The identified valleys represent the watershed components and the dams that separate them denote the component boundaries.

In the figure below, the progression of the watershed algorithm is illustrated. On the left side, the topographical relief corresponding to the EDT is shown where the component seeds (valley bottom) are marked in red. This topography is successively flooded with water, and dams are formed between adjacent valleys.

Known information about the component space, i.e., the minimal component diameter, can be used to adjust the results of the **Watershed (Supervoxel)**.

Each watershed component is assigned the mean gray value of this component. This is the supervoxel. The result is a gray value image, that is much easier to segment.




If the image has artifacts in the beginning it is recommended to use other image filters as for example the **Non-Local Means Filter** described on page 59 before running the **Watershed (Supervoxel)**. Then the algorithm leads to better results.

The name for the file and folder containing the results can be entered in the **Result File Name (*.gdr)** box. Choose a name fitting the current project.

For **Preprocessing** three options are available in the pull-down menu:

- **Morphological Gradient**: A morphological gradient is computed from the gray value image, as described on page 62. Then the watershed algorithm is applied to this gradient.
- **Gradient**:A gradient is computed from the gray value image as desribed on page 64. Then, the watershed algorithm is applied on this gradient.
- **None (Gray Value Image)**: The watershed algorithm is applied to the gray value image directly. In most cases, this is not recommended.

If **Morphological Gradient** is selected, a **Gradient Radius** must be specified. The radius controls the size of the region, in which the morphological filter is applied.

For **Seeding** select how the seeds should be specified.

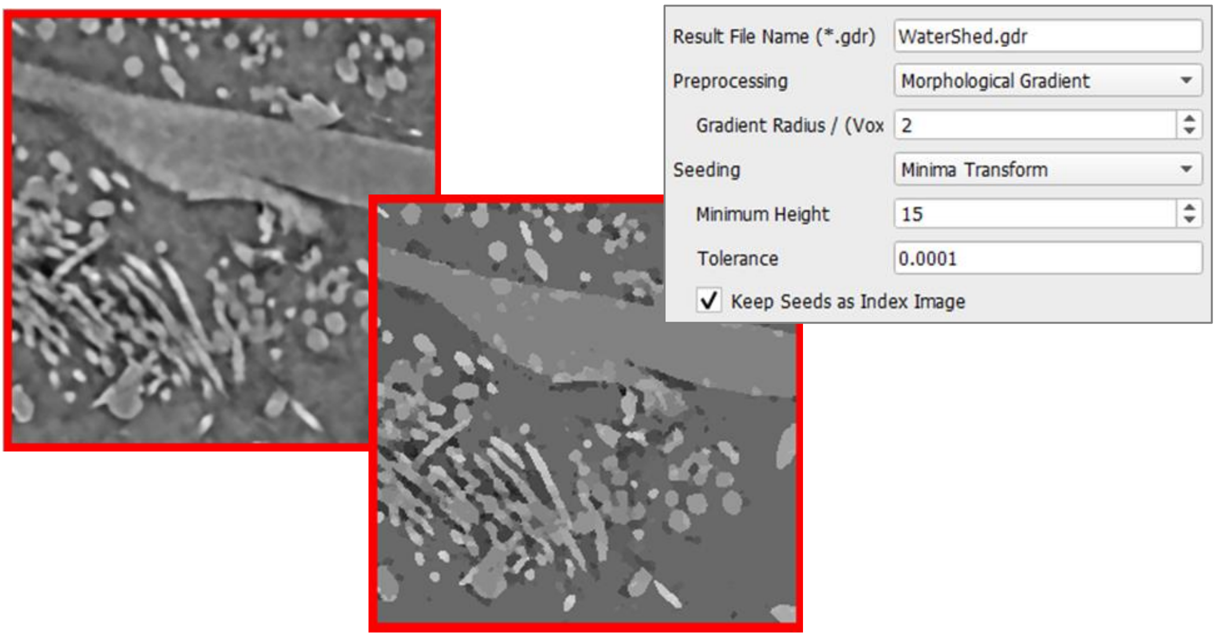
- **Minima Transform**:The seeds are specified by a H-Minima Transform.
- **Index Image**: A corresponding index image (*.g32) has to be loaded in GeoDict. Therefore, select **File** → **Load Volume Field** from the menu bar and browse for the corresponding *.g32. This file specifies the seeds.

The **Minima Transform** is controlled by the parameters **Minimum Height** and **Tolerance.** Find a detailed description on page 63.

The seeds found by the **Minima Transform** can be saved in a *.g32 file by checking **Keep Seeds as Index Image**.

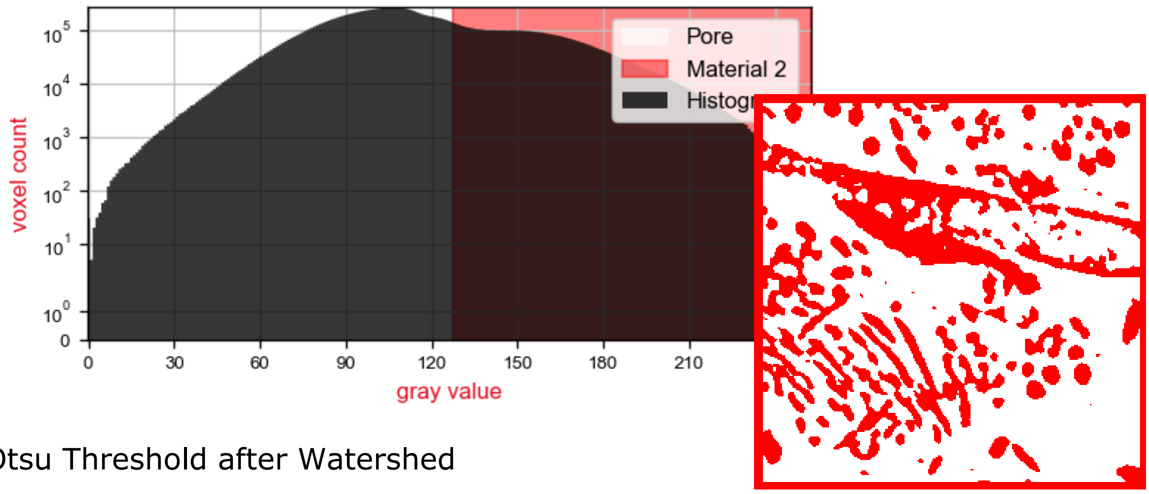
Click **Apply** to run the watershed algorithm.

In the following example, a **Morphological Gradient** with **Gradient Radius** 2 was applied and for the **Minima Transform** a **Minimum Height** of 15 was used.

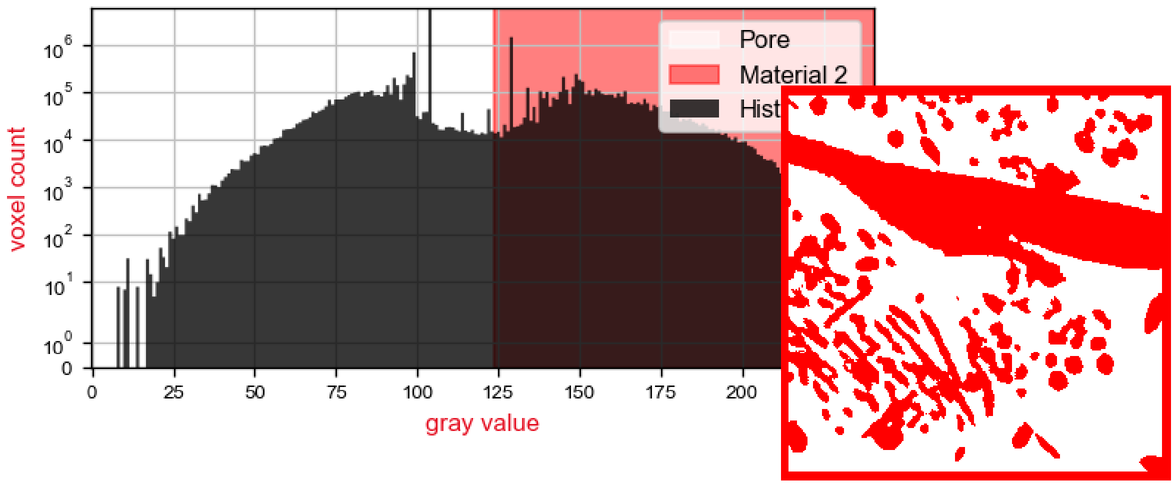



Observe the resulting difference in the **Histogram** making it possible to simply apply the automatic **Otsu** threshold.

Otsu Threshold before Watershed

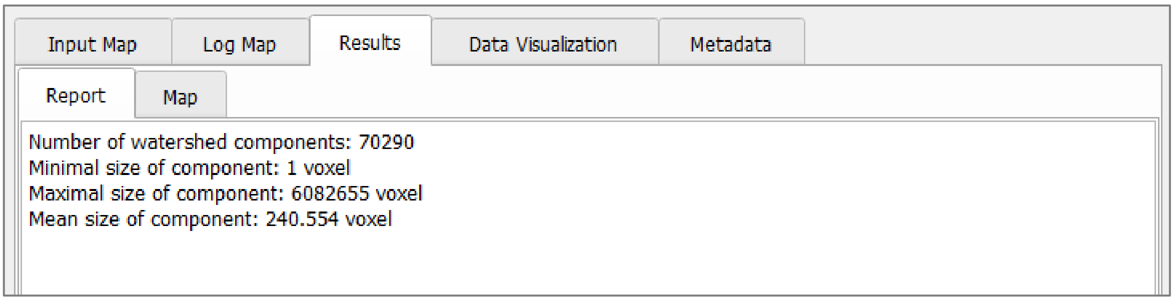



Otsu Threshold after Watershed

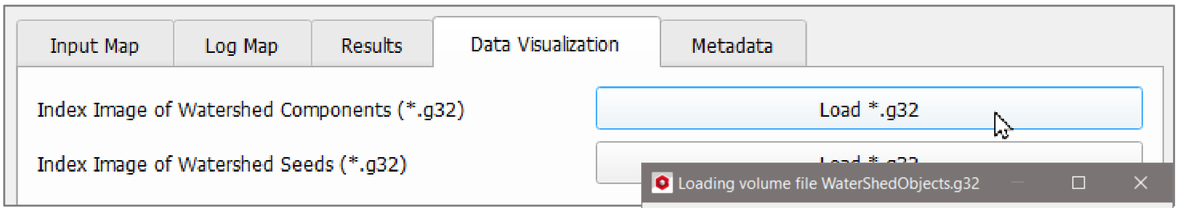


## Result

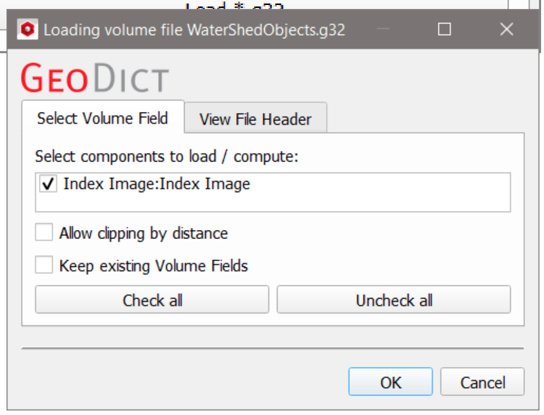
The result file with the selected **Result File Name** is opened automatically in the **Result Viewer**. Under the **Results – Report** sub-tab the number of watershed components, the minimal, maximal, and mean size of the components can be found.

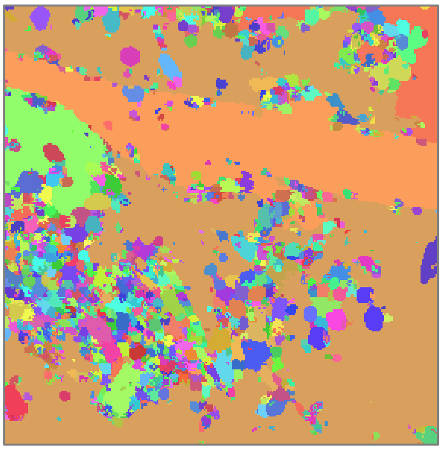


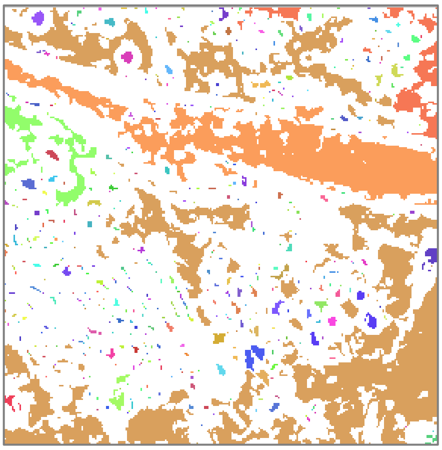

Move to the **Data Visualization** tab to visualize the **Index Image of Watershed Components** in the GeoDict visualization area by clicking **Load *.g32**. If **Keep Seeds** was checked, the **Watershed Seeds** can also be visualized by clicking the lower **Load *.g32** button. Otherwise, it is grayed out.




In the opening dialog click **OK** and the index image is loaded in GeoDict.



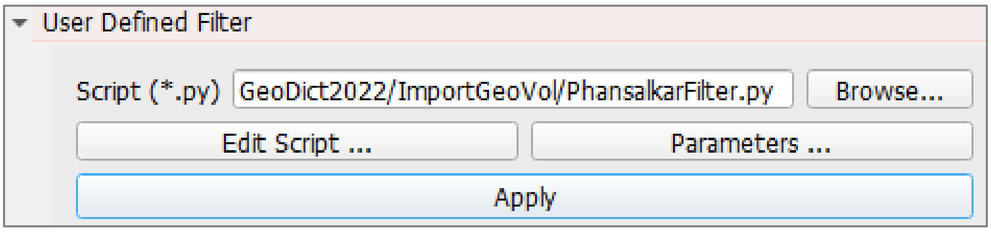


Watershed Compenents


Watershed Seeds

Find more information about GeoDict result files in the Result Viewer user guide.

### User Defined Filter

Own scripts can be used as image filters for the user's data. Examples for such user defined scripts can be found in the ImportGeo folder in the GeoDict installation folder and in the GeoDict settings folder.




Therein, the script "PhansalkarFilter.py" can be used to learn how to obtain and change the image data that is shown in the ImportGeo-Vol box. Click **Browse** to navigate to the GeoPy macro. Click **Edit Script** to open the file in a text editor. In the macro use the command

```
Im = gd.ImportGeoVol.getOriginalImage()
```

to load the actual image with the Python script and

```
img = gd.ImportGeoVol.getNewImage()
```

to create a new image.

The dimensions can subsequently be extracted with the "shape" command:

```
nx=img.shape[0]
ny=img.shape[1]
nz=img.shape[2]
```

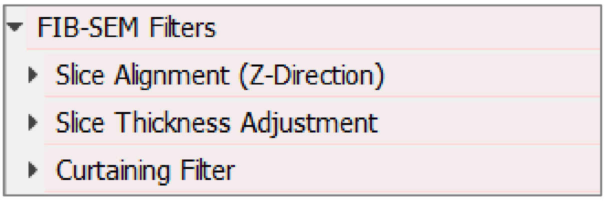
With loops over each image voxel, the Phansalkar script determines, if the according voxel should be set to white [255] or black [0]. It is sufficient to change the new image ("img"). Please refer to the section Phansalkar and the Automation & Scripting handbook of this user guide for more details on this topic.

For a parameter macro, the parameters can be edited by clicking **Parameters**.

To run the macro click **Apply**.

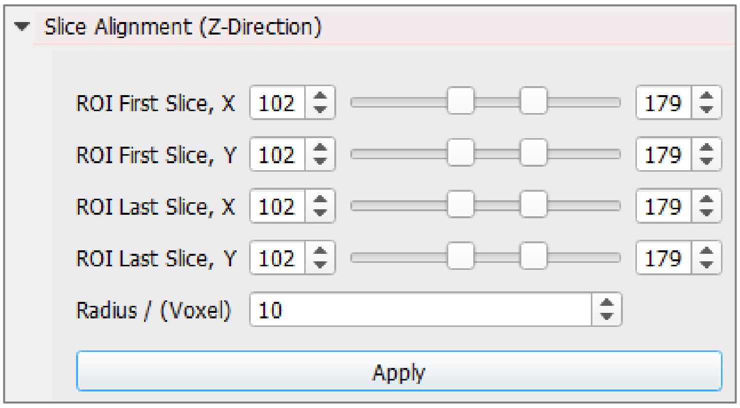
## FIB-SEM Filters

The specialized FIB-SEM Filters section contains **Slice Alignment (Z-Direction)**, **Slice Thickness Adjustment** and the **Curtaining Filter**.



## Slice Alignment (Z-Direction)

During FIB-SEM image acquisition, the alignment of the image slices typically along the Z-axis is not maintained due to e.g., specimen drift or image distortions. Accordingly, a **Slice Alignment** is necessary.

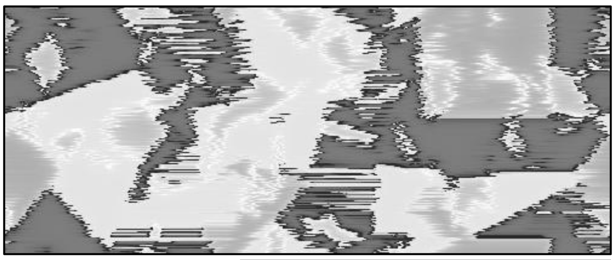



Please make sure that the image is oriented with the misalignments in Z-direction before starting to **Align Slices**. This is best observed by sliding through the 2D slices in Z-direction. Typically, offsets are visible when looking at images in X- and Y-direction. If the misalignments occur in another direction, either rotate the image as described on page 45 or permute the image, as described on page 51.

The choices for **ROI First Slice** and **ROI Last Slice** for **X** and **Y** define the region, in which the alignment is examined. Based on the findings for that region, the slice alignment is corrected for the entire image. Please note that this might lead to unavoidable boundary effects that might require a **Crop** at the image boundaries, as described on page 41. The rectangle resulting from the values for **First Slice** and **Last Slice** is visualized in red in the **2D Slice Visualization** section in the X-Y-plane if **Slice Alignment** is chosen for **Overlay**.

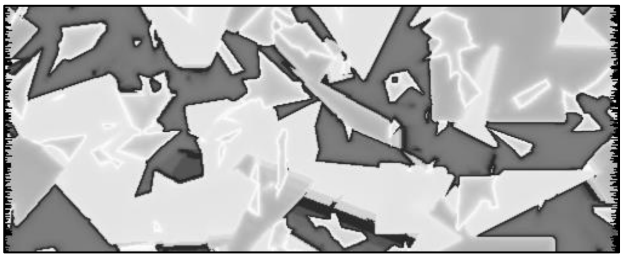
The **Radius** defines the maximum shift between two slices to search for. For many FIB-SEM images the default value of 10 is enough. However, if there are slices shifted more than 10 voxels the **Radius** setting needs to be increased.

The example on the right shows a 2D slice from X-direction of an artificially misaligned gray value image (*top*). After application of the **Slice Alignment** tool at suggested default settings (*see above*), the misalignment is entirely corrected (*bottom*).



***X-Direction, Original***

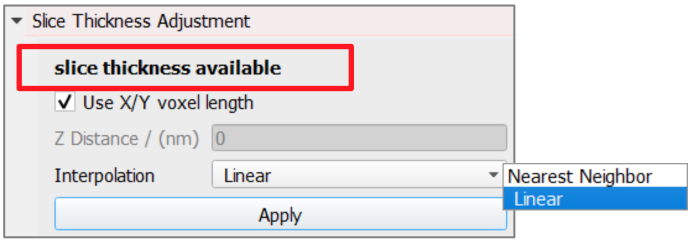
Observe the offsets on the left and right boundaries of the aligned image (*bottom*). Accordingly, the image size in X- and Y-direction increased in order to include all aligned slices in the 3D image without loss of information.

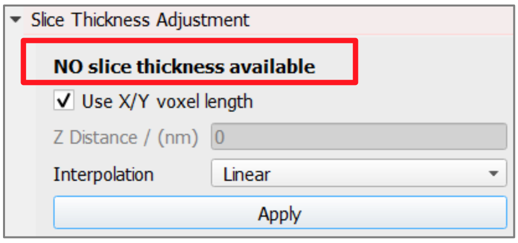


***X-Direction, Aligned***

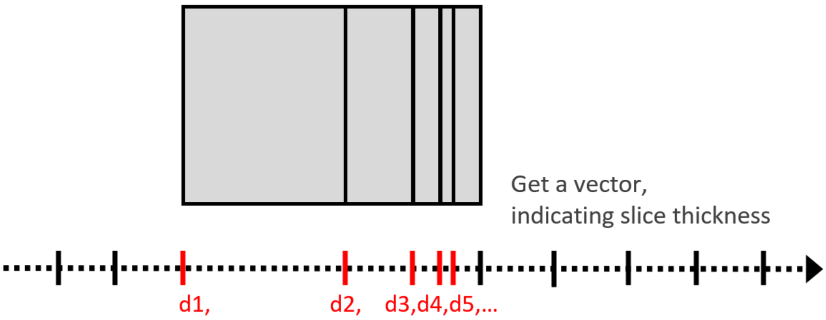
## Slice Thickness Adjustment

In FIB-SEM images the slice thickness can be different for each slice. If the image provides information about the slice thickness, as is the case e.g., for images taken by **Zeiss** machines, the **Slice Thickness Adjustment** can be applied on the image. Otherwise, **NO Slice Thickness Available** is displayed in the top of the section.




In the following figure observe how the different slice thicknesses are assigned to coordinates building a vector indicating slice thickness.




These vector entries must be provided with the considered image stack. Therefore, each image of the stack must have the ending "_z=...um" (unit must be in given in microns), where "..." of course must be replaced by the corresponding coordinate, e.g., *image_001_z=1.0um.tif*, *image_002_z=2.1um.tif*, *image_003_z=3.3um.tif*, .... FIB-SEM image stacks from Zeiss machines follow this name-scheme.

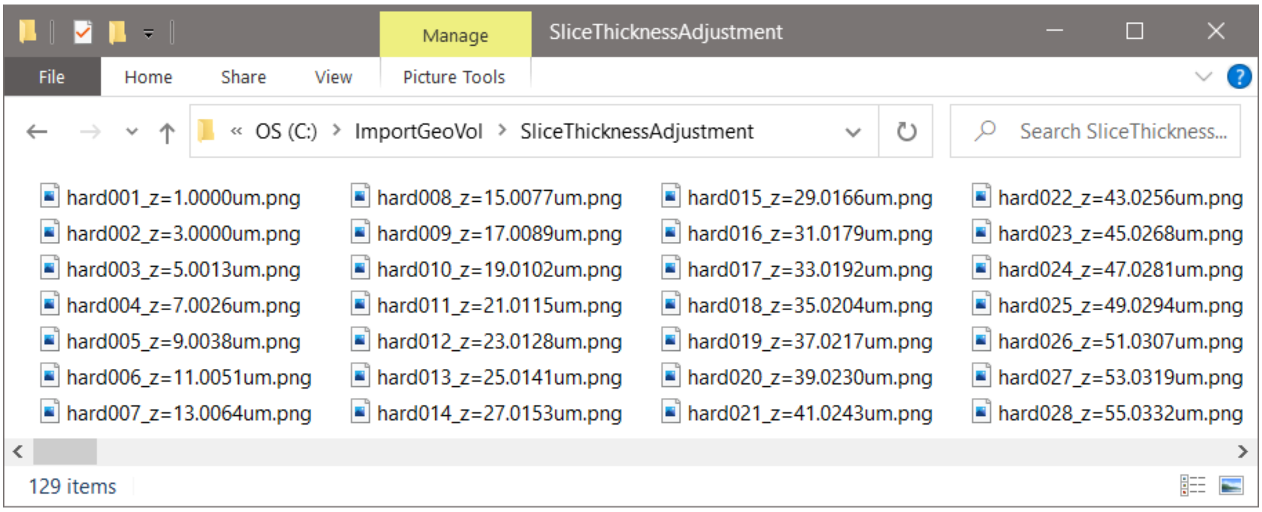
The slice thickness is adjusted by interpolating gray value images between the given Z-slices to fit the the given distance.

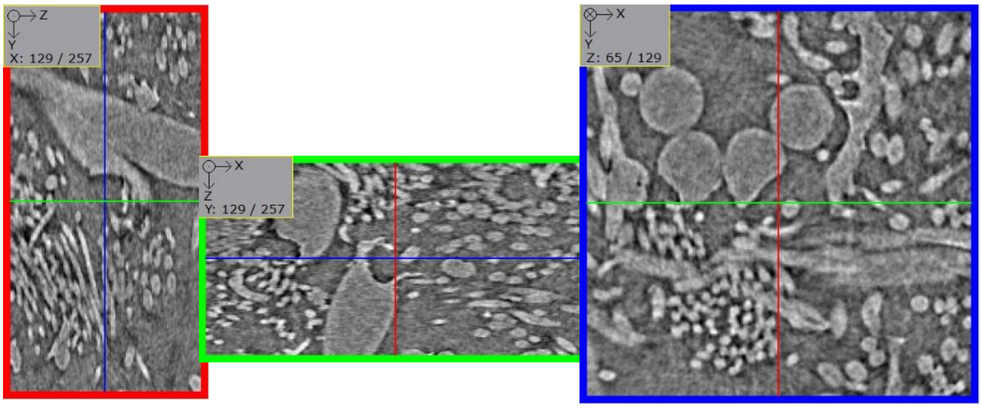
If **Use X/Y Voxel Length** is checked, the distance between the resulting Z-slices is set equal to the voxel length in the X- and Y-direction. Otherwise enter the desired **Z-Distance** in nm.

For the gray value **Interpolation** select between **Linear** and Nearest Neighbor.

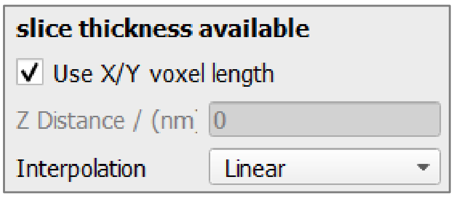
Clicking **Apply** applies the **Slice Thickness Adjustment** to the image.

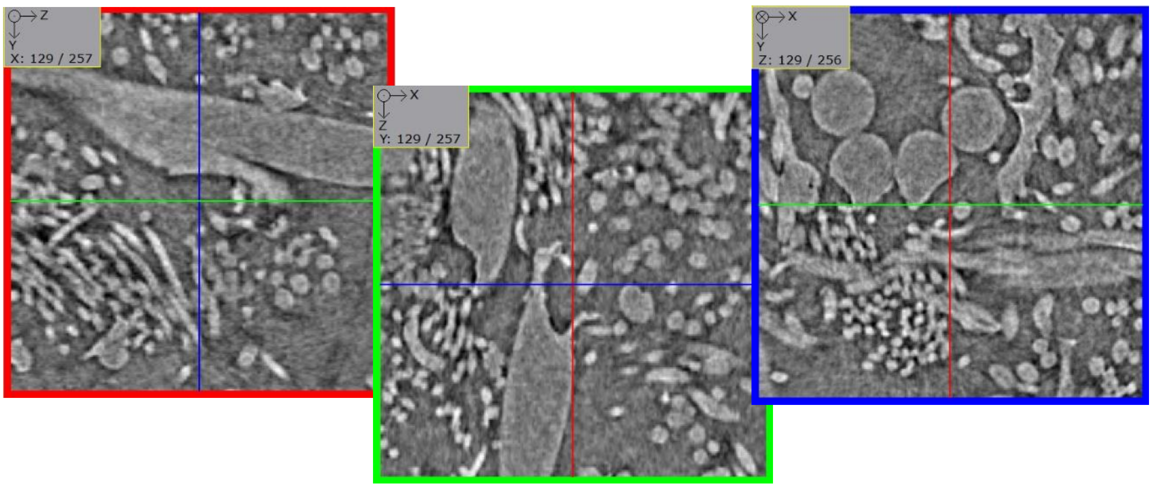
In the following example, the slice thickness between the single images is approx. 2 µm, while the voxel length in X- and Y-direction is 1 µm.




Thus, checking **Use X/Y Voxel Length** and clicking **Apply** leads to 256 slices instead of 129 and thus, the image is stretched in Z-direction.

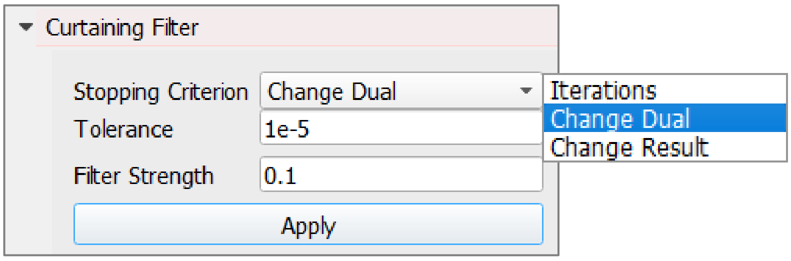


## CURTAINING FILTER

The **Curtaining Filter** removes curtaining effects, which are typical for FIB-SEM image scans. In general, the filter applies a deconvolution to receive two 3D images, one only containing the stripes of the curtaining effect while the other image is the resulting filtered image.

To learn more about this filter refer to the paper Removal of curtaining effects by a variational model with directional forward differences.




The filter includes three **Stopping Criteria**, and the corresponding values for **Tolerance** or **Iterations**, which control the computational time and the quality of the filter results. We recommend that the values for these convergence settings usually be left at default settings:

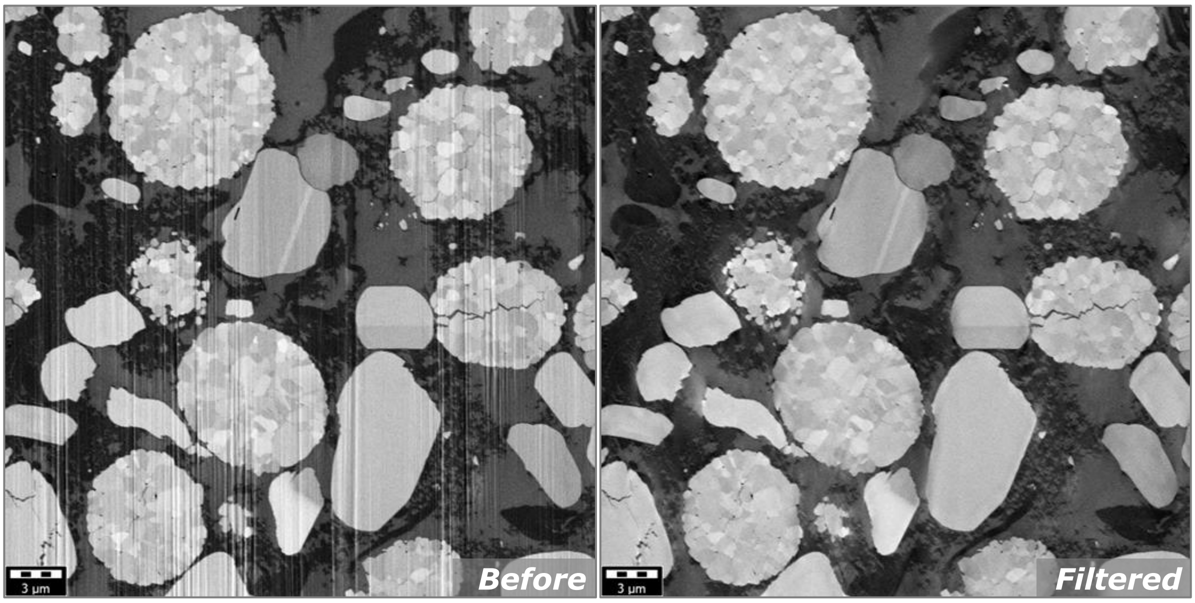
- In the **Iterations** mode, the filter stops after a given number of Iterations.
- With **Change Dual**, a tolerance value is determined internally. The filter stops iterating upon reaching the given tolerance.
- In the **Change Result** mode, the differences in the gray values between the iterations are examined for defining the tolerance value. This mode requires approx. twice the amount of working memory.

The given **Tolerances** do not depend on the image size.

The **Filter Strength** can be increased, to remove heavy stripes, or decreased, to reduce the effect of the **Curtaining Filter**.

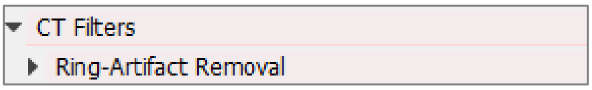
Clicking **Apply** applies the **Curtaining** according to the given settings.

The example below shows the lines that are typical for FIB-SEM gray value images (*left*) and known as Curtaining effect. After application of the **Curtaining Filter**, these lines are completely removed from the original image, enabling a proper image segmentation.



## CT Filters

The specialized CT Filters section is introduced in GeoDict 2020 and currently contains the **Ring-Artifact Removal** filter.



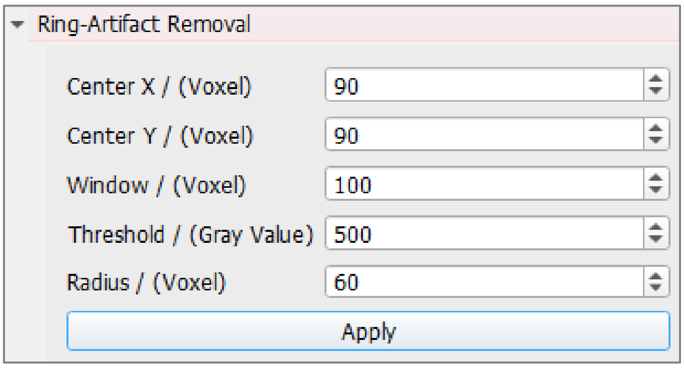

### Ring-Artifact Removal

The **Ring-Artifact Removal** removes ring artifacts from CT scans. In order to work as expected, the Z-axis must be the rotation axis, which is the standard for CT scans. If that is not the case, however, the image can either be rotated as described on page 45 or permuted as described on page 51 before applying the **Ring-Artifact Removal**.

The first step of the filter workflow is the definition of the midpoint of the rotation axis and the extent of the artifacts. Based on the midpoint, the filter looks for artifacts at every possible radius (*see blue line in image below*). At each of these radii, an extent is examined as given by the **Window** size (*see red ring in image below*). Within these extents, the effect of the Ring-Artifacts on the gray values is examined.

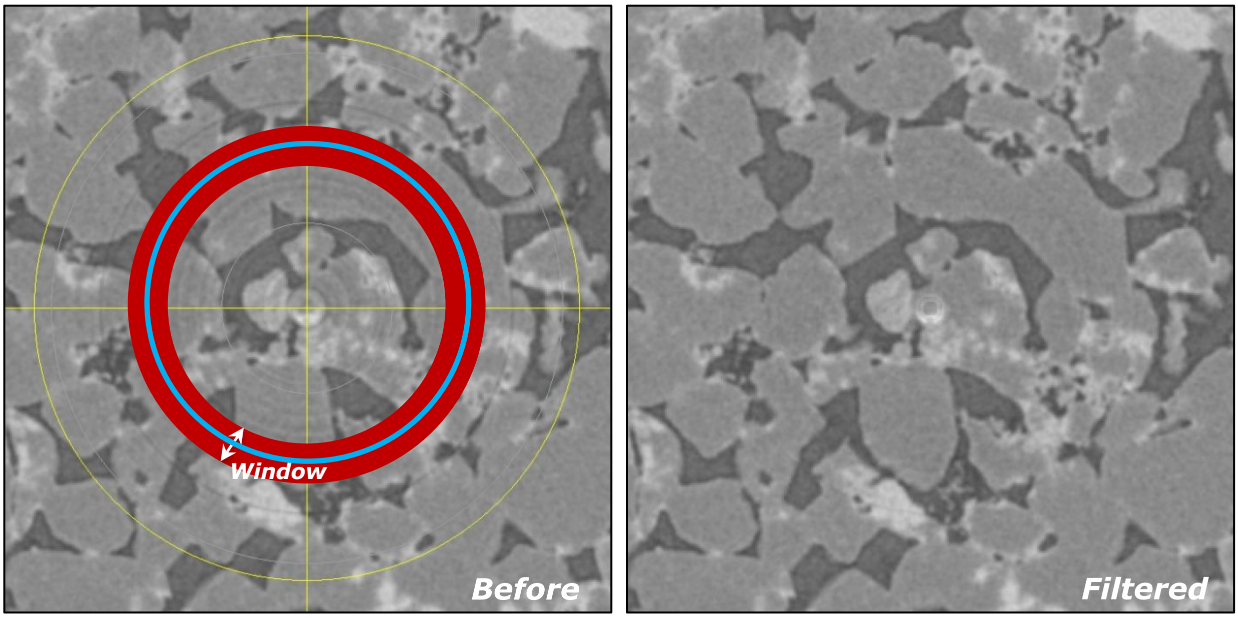
However, the algorithm requires a correction wherever multiple phases are affected. Therefore, a **Threshold** value must be given in order to define a maximum gray value range. That value varies with different materials and scans.

Please note that there is a significant difference in gray values between e.g., 8-bit and 16-bit images.




- **Center X, Y**: Find and insert the center of the Ring-Artifacts (i.e., rotation axis)
- **Window**: Determine here the extent, within which Ring-Artifacts can be identified (*see red ring below*)
- **Threshold**: Determine here the max. gray value range for the windows. This affects the correction that is applied as averaged gray value.
- **Radius**: Determine and insert the maximum extent of the Ring-Artifacts

Clicking **Apply** applies the **Ring-Artifact Removal** according to the given settings.




In the example above, **Ring-Artifact Removal** is chosen as **Overlay**. The **Ring-Artifact Removal** overlay is displayed with yellow lines. The yellow circle defines the area determined by **Center** and **Radius**.

Here, a red and a blue circle are added to visualize how the **Ring-Artifact Removal** considers each blue ring within the yellow circle. Each of these rings then build a centerline for a new red **Window**.

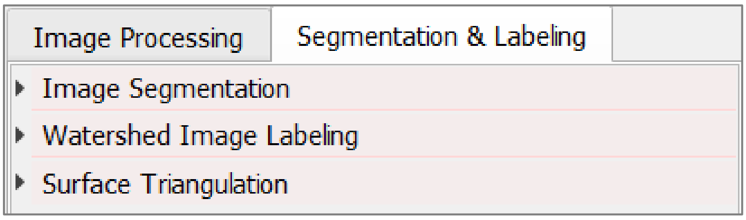
For this single blue ring, the **Ring-Artifact Removal** filter only examines values within the red area. But considering window after window, the filter checks for all possible rings inside the yellow circle.

The **Ring-Artifact Removal** calculates the variance of gray values within the blue ring in comparison with the average gray value inside the red window. If the variance is higher than the given threshold, it is assumed that there is a ring present.

Then, the gray values of the identified ring voxels are reduced to match the average gray value in the red window.

## Segmentation & Labeling tools

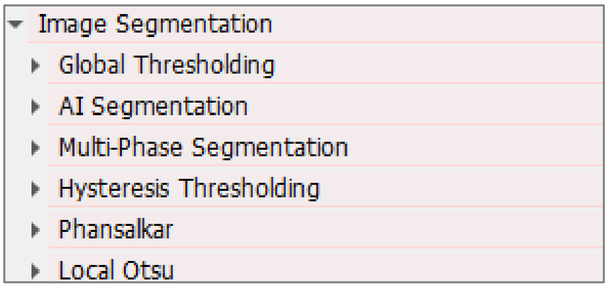
In the **Segmentation & Labeling** tab, segment and label phases in the loaded image with **Image Segmentation**, identify and label objects in the image with the **Watershed Image Labeling** or create a surface mesh with **Surface Triangulation**.




## Image Segmentation

The **Image Segmentation** panel is organized in following sections:

- **Global Thresholding**: segment the image by setting either single or multiple gray-value thresholds. This is the fastest and simplest segmentation method and works just fine in many cases.
- **AI Segmentation**: train a custom neural network by labeling the gray value voxels in the image. Although needing more time labeling the image and training the network, this is a very powerful tool for images that are hard to segment with the other methods.
- **Multi-Phase Segmentation**: define confident areas with gray value ranges. The areas in between are then computed with the watershed algorithm.
- **Hysteresis Thresholding**: accomplish edge detection using two thresholds.
- **Phansalkar**: deal with low contrast images using this local thresholding method.
- **Local Otsu**: automatically perform clustering-based image thresholding using this local thresholding method.



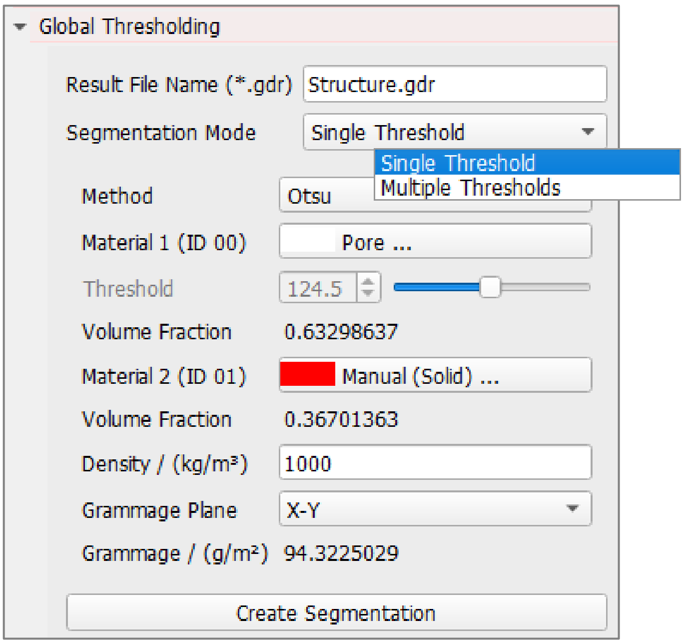

The sementation methods **Global Thresholding**, **AI Segmentation** and **Multi-Phase Segmentation** are arguably the most important segmentation methods and are compared in a small parameter study starting on page 95.

### Global Thresholding

There are various options for **Image Segmentation** via gray value thresholding. Up to 15 thresholds define gray value ranges, at which respective voxels are assigned the according material ID.

The name for the file and folder containing the results can be entered in the **Result File Name (*.gdr)** box. Choose a name fitting the current project.

Two **Threshold Modes** are available: **Single Threshold** and **Multiple Thresholds**.

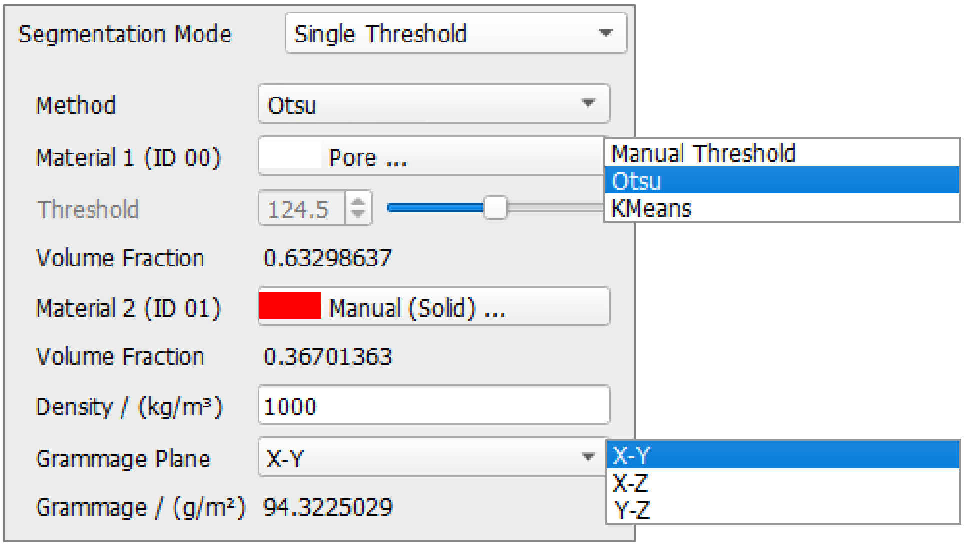



If the segmentation settings are set as desired clicking **Create Segmentation** imports the processed image and generates a 3D model that is shown in the Visualization area of the GeoDict GUI. This 3D model can be saved in GeoDict Binary (.gdt), GeoDict ASCII (.leS) or 1 Byte integer – Binary (.raw) format by selecting **File → Save Structure as...**, in the menu bar. By default, it is saved as *.gdt in the generated result folder corresponding to the result file with the name chosen for **Result File Name**.

## Single Threshold

The **Single Threshold** mode can be applied using a **Manual Threshold**, **Otsu**, or **KMeans**. For more information about the underlying theory refer to the Wikipedia pages Otsu's method and KMeans clustering.

Note that the options **Visibility** and **Outline**, which are located in the **View Options** section control the threshold visualization settings. Please refer to page 33 for more details. A single threshold can also be visualized in 3D as described on page 79.




Either use the **Otsu** or **KMeans** methods to automatically select a threshold based on the gray value distribution in the histogram or set the threshold manually with the **Manual Threshold** method.

The value of the single **Threshold** separates the gray value range into two constituent materials. By default, **Material 1** (with ID 00) is **Pore** and **Material 2** (with ID 01) is set to **Solid** while material 1 is shown in white and material 2 in red. For each **Material**, the threshold color and material selection are shown. You can assign each material ID the desired material phase by clicking the available button and following the dialog. Please refer to the Base Reference and Material Database handbooks of this User Guide for more details. The threshold color can be changed through **Use GeoDict Custom Colors** as explained in the **View** menu section on page 26 and the mentioned handbooks.

The **Volume Fraction** gives the computed volume fraction corresponding to the current **Threshold** value, and is automatically updated, whenever threshold values are changed. For example, a calculated **Volume Fraction** of 0.36 for a **Threshold** of 125 means that 36% of the structure voxels have gray values above 125 (and are assigned to Material 2).

The **Density** (kg/m$^3$) of Material 2 and the selected **Grammage Plane** (**X-Y**, **X-Z**, or **Y-Z**) are used for the calculation of the material's **Grammage**. If the density of the **Material 2** is known, it can be entered in the spin box and GeoDict automatically calculates the area density for the selected plane. The density can only be set for Material 2, the density of Material 1 is assumed to be zero. This option is useful for structures like paper, which consist of one solid material and the pore space.

## 3D Gray Value Visualization in GeoDict

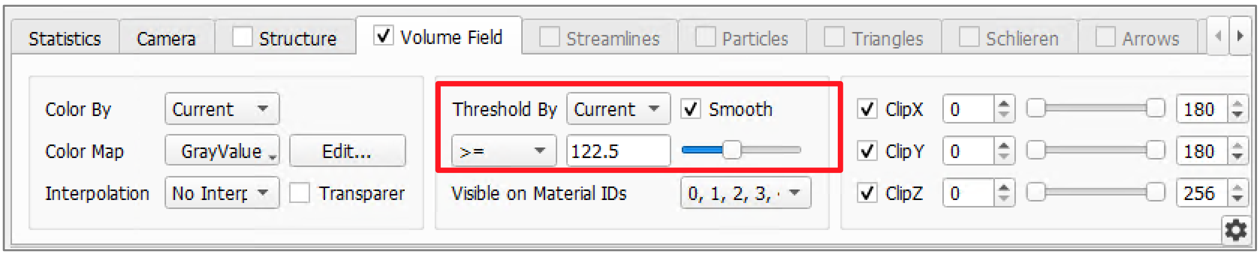
As the gray value image is also visualized in the main GeoDict GUI, the image can also be rendered in 3D.

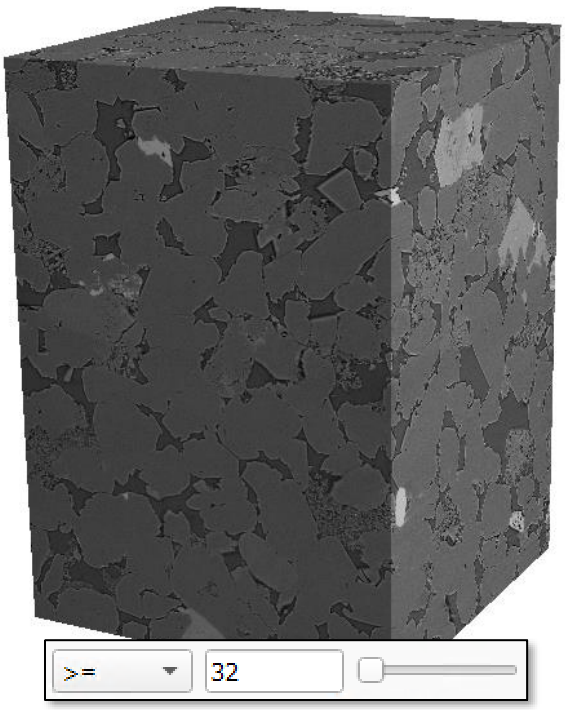
The currently loaded (and processed) gray value image can be observed in 2D in the Visualization area. To display the image in 3D change to 3D view by clicking the 

icon in the toolbar or selecting **View** → **3D Rendering** in the menu bar.

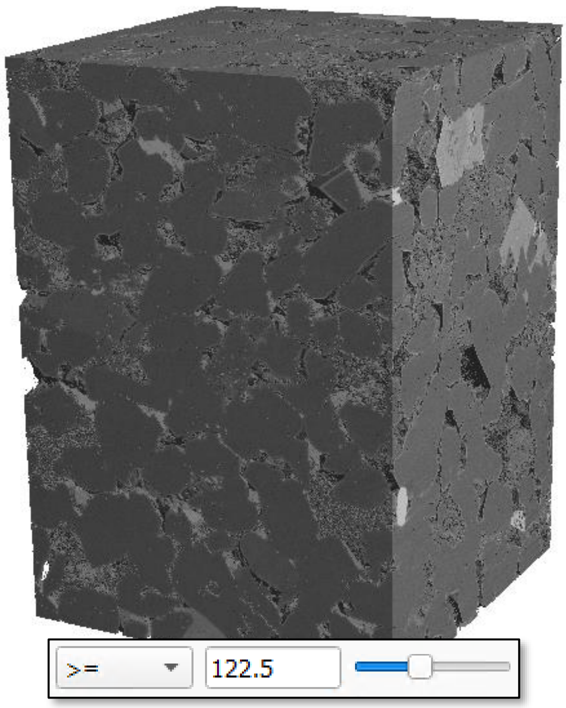
Visualize different thresholds in 3D using the **Threshold By** option in the **Visualization panel** above of the **Visualization area** in GeoDict.

For the threshold mode **>=** the dark gray values are rendered invisible in the visualization, when moving the threshold slider or entering a gray value number. Here a threshold of 122.5 is entered, which is the Otsu threshold for this image (122.5).




3D gray value representation of a Berea sandstone, showing the entire gray value range.



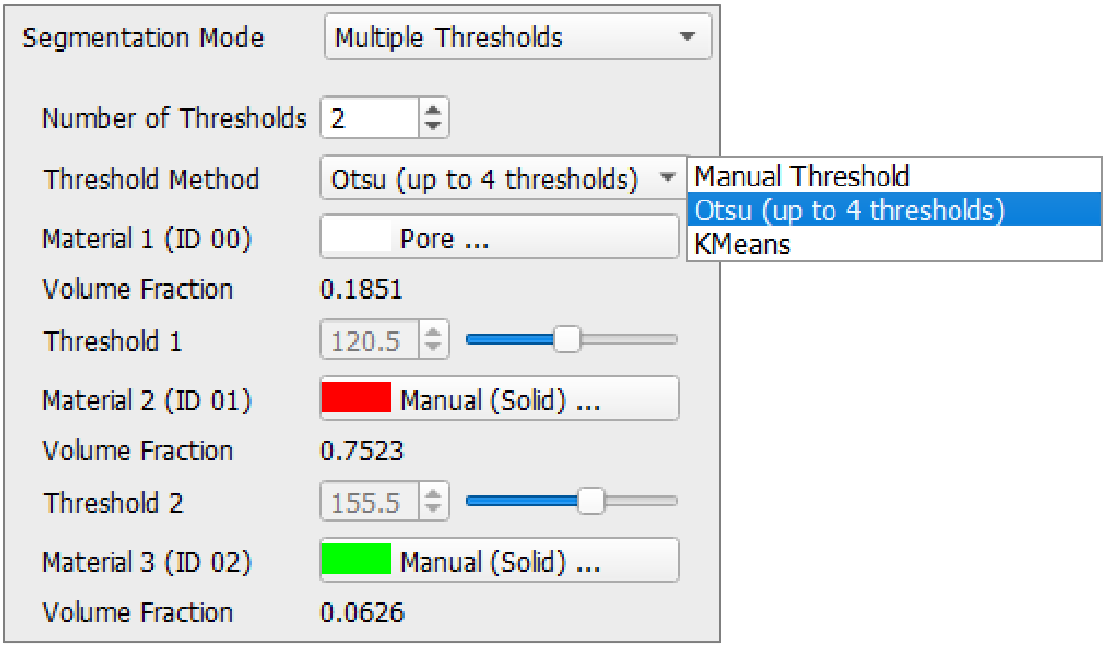

3D gray value representation of a Berea sandstone, showing the gray value range from 123-255.

Detailed information on visualization in GeoDict can be found in the Visualization handbook of this User Guide.

## Multiple Thresholds

Using **Multiple Thresholds**, more than one threshold (for more than two different materials) can be defined.

The threshold methods are: **Manual Threshold**, **Otsu** method, and **KMeans**-clustering.



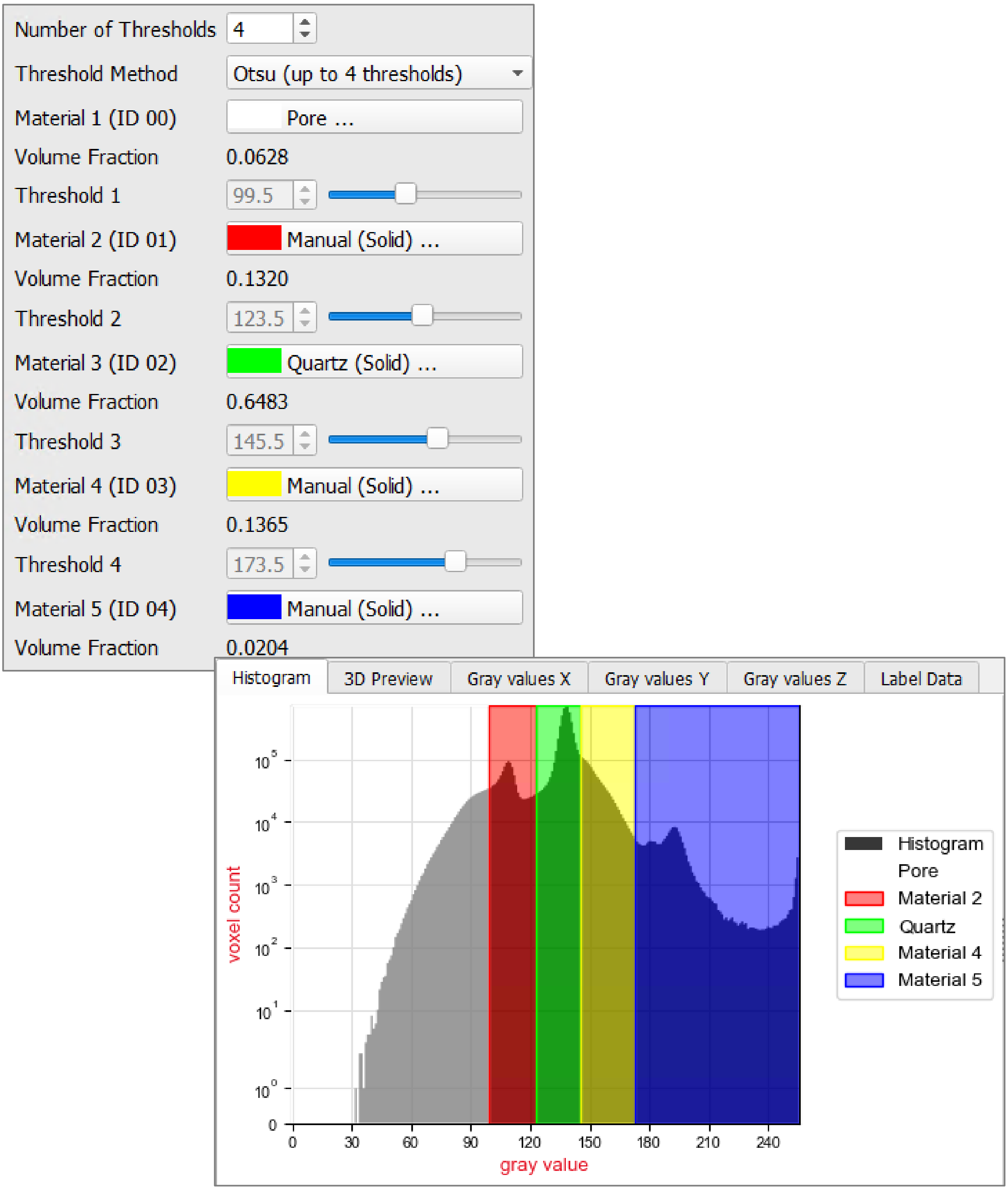

The **Otsu** method is an automatic segmentation algorithm. It can be used for up to 4 thresholds for 8bit images and up to 2 thresholds for 16bit images.

For the **Manual** or **KMeans** thresholding, up to 15 thresholds are available.

The automatic threshold methods (**KMeans** and **Otsu**) use only the histogram to do the segmentation. The **Manual** thresholds are selected by moving the sliders.

Enter the **Number of Thresholds** to be applied in the spin box. When multiple thresholds are selected, these thresholds are shown in the histogram plot, at the bottom right of the preview areas.

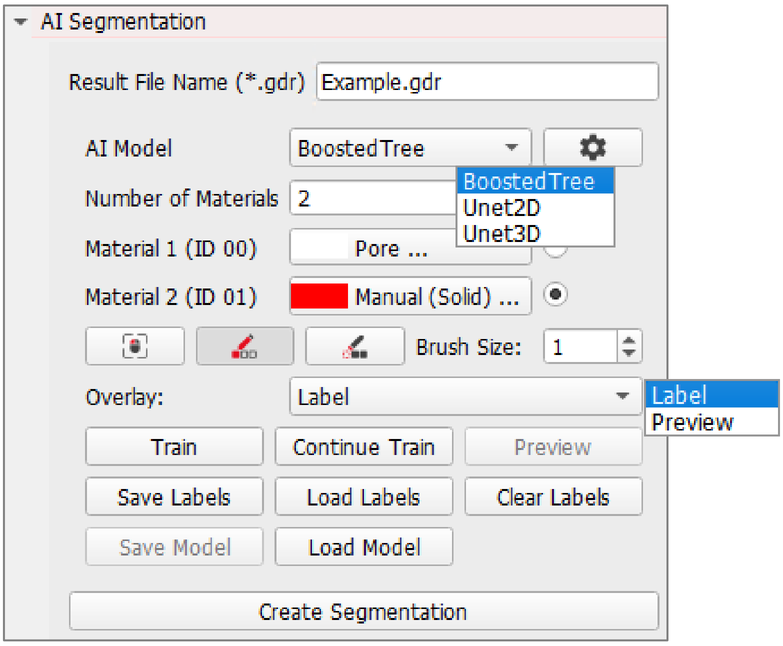
For an 8-bit excerpt of a Berea sandstone, four thresholds are set. The according five materials are shown in the histogram plot as determined by the Otsu method.


Number of Thresholds 4
Threshold Method Otsu (up to 4 thresholds)
Material 1 (ID 00) Pore ...
Volume Fraction 0.0628
Threshold 1 99.5
Material 2 (ID 01) Manual (Solid) ...
Volume Fraction 0.1320
Threshold 2 123.5
Material 3 (ID 02) Quartz (Solid) ...
Volume Fraction 0.6483
Threshold 3 145.5
Material 4 (ID 03) Manual (Solid) ...
Volume Fraction 0.1365
Threshold 4 173.5
Material 5 (ID 04) Manual (Solid) ...
Volume Fraction 0.0204
Histogram
3D Preview
Gray values X
Gray values Y
Gray values Z
Label Data
voxel count
gray value
Histogram
Pore
Material 2
Quartz
Material 4
Material 5

## AI Segmentation

The **AI Segmentation** allows to train machine learning algorithms to segment the complete gray value image based on user-defined labels. To accomplish this goal, label the image manually, train a machine learning method that learns how to segment the image based on the provided labels.

The name of the file and folder containing the results can be entered in the **Result File Name (*.gdr)** box. Choose a name fitting the current project.




The three different **AI Models**: **Boosted Tree**, **Unet 2D** and **Unet 3D** are described in the following.

### Boosted Tree

**Boosted Tree** works well for many examples and is very fast. For the training data different filters are applied to the input image:

- Gauss filter with a small standard deviation blurring the image a little bit,
- Gauss filter with a big standard deviation, blurring the image much and
- a Sobel filter, emphasizing the edges.

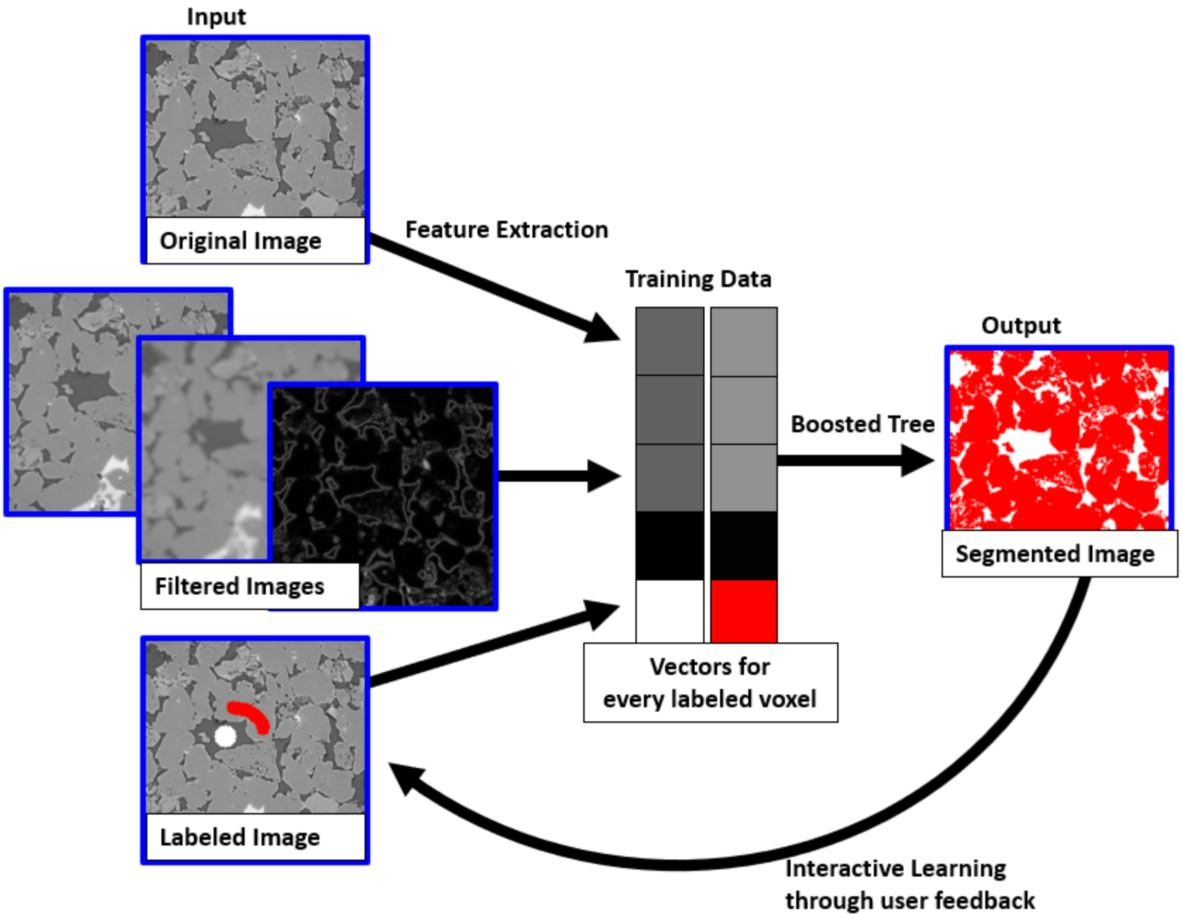
Then, for each voxel a vector is built containing the corresponding data from the original image, from each of the filtered images, from the labeled image and from the neighboring voxels, respectively.

The **Boosted Tree** algorithm learns from these vectors and segments the image.

To learn more about the extraction of training date refer to Trainable Weka Segmentation: a machine learning tool for microscopy pixel classification.

For detailed theory about the **Boosted Tree** model see Boosting Decision Trees, XGBoost: A Scalable Tree Boosting System, XGBoost Tutorials and the XGBoost Python API.

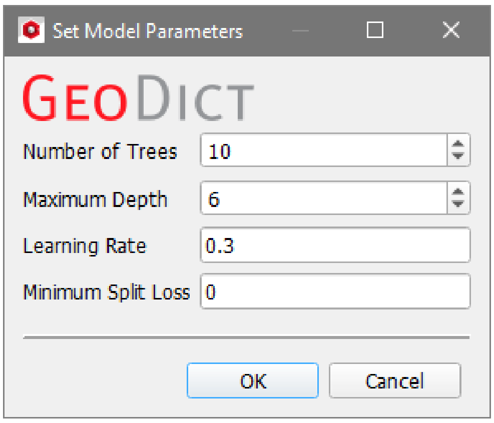
In case of big-scaled relevant features, it can be limited. That is because the decision for each pixel depends on the surroundings, especially on the Gauss kernel of a fixed size. If e.g., the image has pores of different materials but with a similar gray value and the only difference is the border to the solid material, for big pores the boosted tree method could decide wrong. In such cases, the Unet methods are recommended.




Clicking on the gearwheel icon  accesses the parameters defining the model setup. The **Set Model Parameters** dialog opens.

Following parameters can be set for the **Boosted Tree** model:

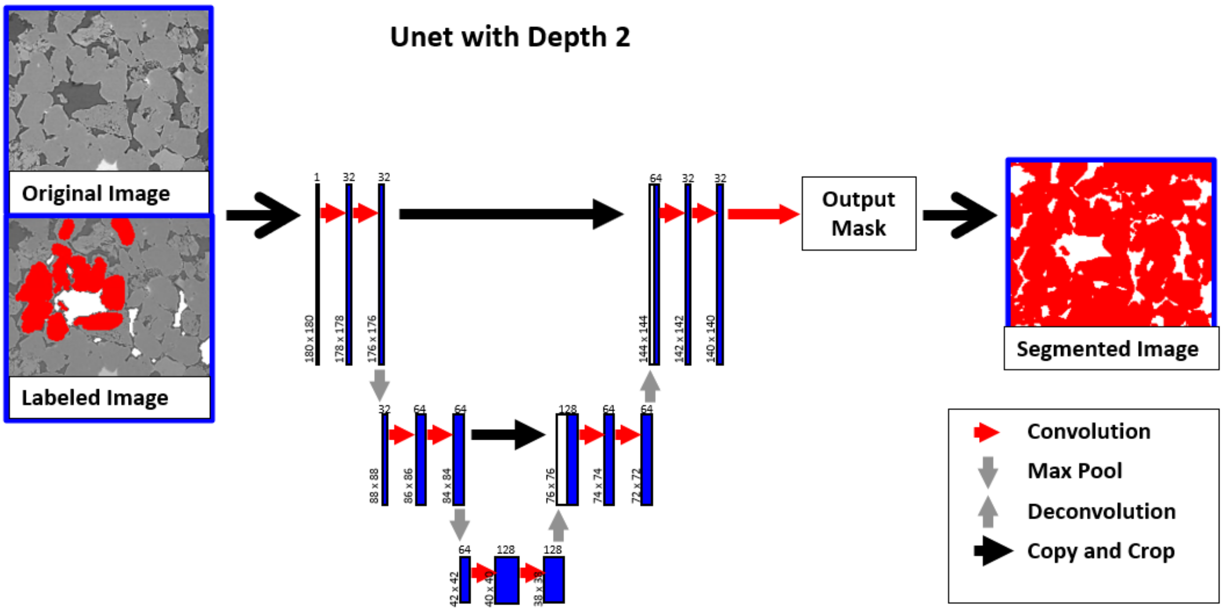
- **Number of Trees**: Defines the number of parallel trees constructed during each iteration. More trees result in a higher learning ability but can lead to overfitting. An overfit model has no good generalization ability.
- **Maximum Depth**: Maximum depth of a tree. Increasing this value will make the model more complex and more likely to overfit.
- **Learning Rate**: The learning rate is a step size shrinkage used in each update to prevent overfitting. The learning rate must be >0 and ≤1. The lower the learning rate, the longer the runtime but the higher the generalization ability of the final model.
- **Minimum Split Loss**: Minimum loss reduction required to make a further partition on a leaf node of the tree. The larger the minimum split loss, the more conservative the algorithm will be.



## Unet

The deep learning methods **Unet 2D** and **Unet 3D** require more training data. Thus, more labels must be provided manually. Then, they are more capable to analyze the scan correctly and thus, achieve better results.

The name **Unet** refers to the U-shape of the neural network diagram, consisting of a constricting branch on the left and an expanding branch on the right. The number of layers in each branch define the depth of the Unet.




For more detailed theory about the **Unet** models and the underlying architecture refer to the paper U-Net: Convolutional Networks for Biomedical Image.

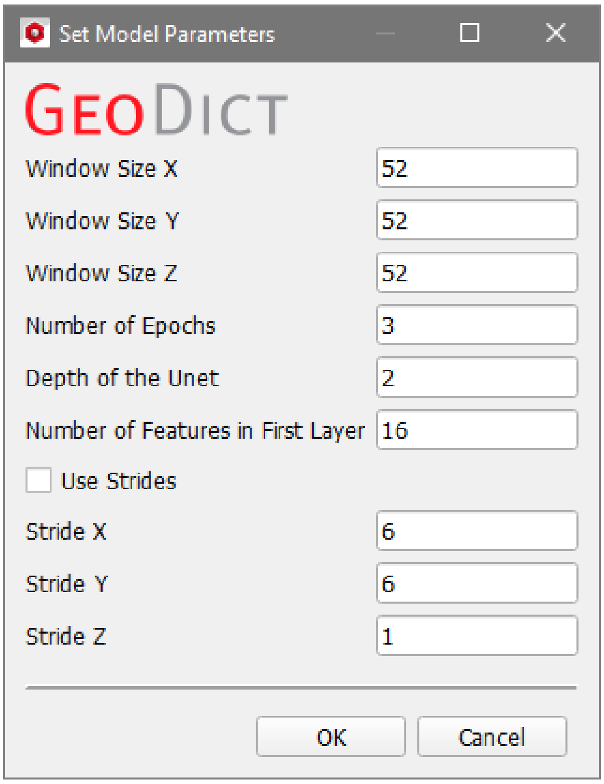
To use the **Unet** models a good graphics card is needed, i.e., a good **NVIDIA graphics card** (GPU) with compute capability of at least **3.5**. Please make sure drivers are installed and up to date. See more information on graphics cards in https://developer.nvidia.com/cuda-gpus. This webpage contains a helpful section with Frequently Asked Questions.

For Linux, the **Gnu C Library** (glibc) must be at least version **2.27**. We recommend **Ubuntu 20.04 LTS**, but for a current glibc other Linux distributions should also work.

**Unet 3D** considers the complete image, while **Unet 2D** learns from the single slices in the specified direction. The default is the Z-direction.

Clicking on the gearwheel icon accesses the parameters defining the model setup. The **Set Model Parameters** dialog opens. Following parameters can be set for the **Unet** model:

- **Window Size X, Y and Z**: For the training, the Unet algorithm subdivides the gray value image into windows of the given size in voxels. A bigger window size requires more training data and time, but the learning potential increases. The windows are placed according to the given **Stride** or around every labeled voxel.




- **Number of Epochs**: The number of times, the training data is used to train the neural network. For more epochs, the learning time grows linearly, but the learning potential increases. Too many epochs, however, can lead to overfitting.
- **Depth of the Unet**: The number of levels in a Unet. A higher depth requires more training data and increases runtime and GPU memory, but the learning potential increases.
- **Number of Features in First Layer**: The number of features that the model can learn in the first layer. More features require more training data and time, but the learning potential increases.
- **Use Strides**: Use a window stride defined by the values **Stride X**, **Y** and **Z**. These strides determine how many voxels the window is moved for each new training sample, starting in the upper left corner. Then, only the windows containing labeled voxels are taken into account. If not checked windows around every labeled voxel are used for the training.

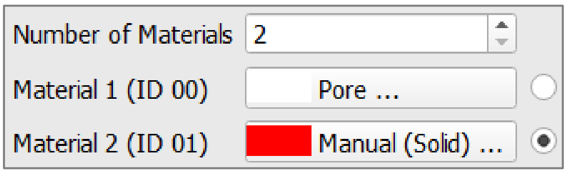
**Unet 2D** means that the windows determined by **Window Size** are 2D slices, i.e., one of the three **Window Size** parameters is 1. The default for **Window Size Z** = 1 usually leads to good results. If all three size parameters are greater than 1, automatically the **Unet 3D** model is applied.

## Comparison of Boosted Tree and Unet

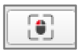
In the following table the two learning methods are compared directly.

| **Boosted Tree** | **Unet2D and 3D** |
|---|---|
| Fast training | Computationally expensive (require GPU for interactive work) |
| Can work with very little training data | Require more manual labels |
| Limited when scale of relevant features gets big | Can learn more |

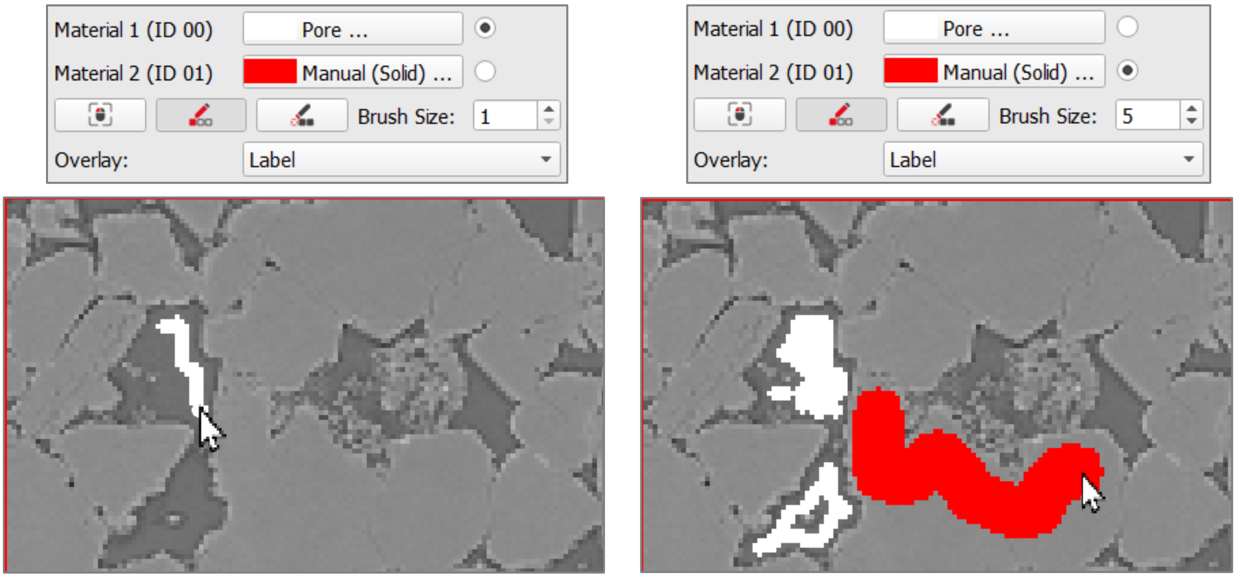
For all three models choose the **Number of Materials** to be labeled in the scan.




Specify the different materials with the material data base. The checkbox next to the material boxes determines the current material for painting the labels.

The **Navigation Mode**  allows to pan the image in the **2D Slice Visualization** section with the left mouse button and zoom in and out with the right mouse button.

Select the **Painting Mode**  to paint in the **2D Slice Visualization** area. Ensure to have the **Visibility** turned on as described on page 33ff and **AI-Labels** selected for **Overlay** as described on page 32. The **Painting Mode** allows to paint labels on the scan with the left mouse button. Switch between the materials by selecting the corresponding checkboxes. Pressing and holding shift, the navigation in the 2D Slice Visualization section works the same as in the **Navigation Mode**.



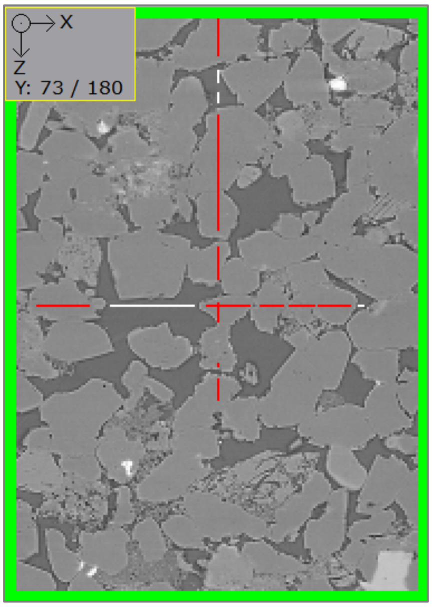

Make sure to have approximately the same amount of labeled area for the different materials, especially for the **Unet** models. Validate this in the **Label Data** tab of the **Histogram** section, described on page 39.

If a label was not painted correctly switch to the **Erasing Mode**  and erase labels in the 2D Visualization section.

Change the **Brush Size** fitting to the areas to label.

In the different view directions, observe the already existing labels from the slices labeled in the other two directions, respectively.

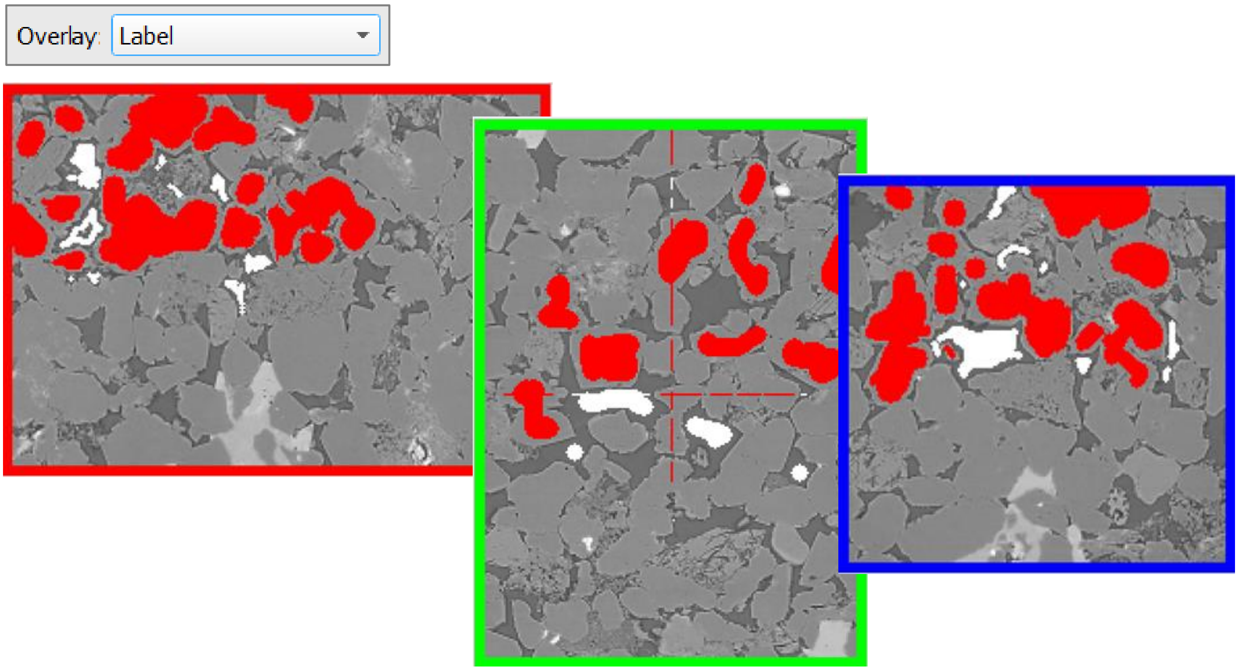
In the example on the right the center slice in X- and Y-direction got labeled. Thus, if viewed in Z-direction, two thin lines with white (material 1) and red (material 2) sections are already labeled. If labels are erased on these lines, in the respective slices in the other directions thin lines are erased. This leads to less trainings data.



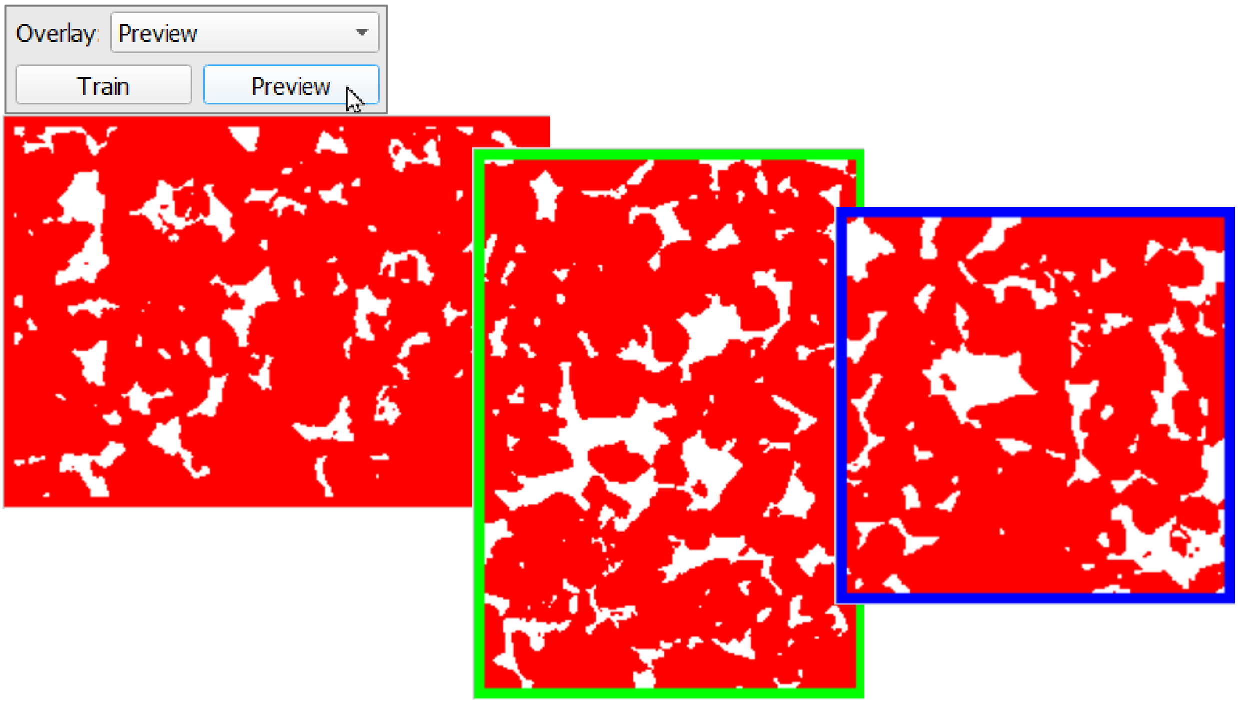

If there are more than two materials, it is important to label boundaries for the different boundary combinations.

Labels close to each other give better results. For each labeled area paint as many labels as possible to get a fully filled output window.

While it can be important to label boundaries, only label as near to the boundary as it can be ensured to label it correctly. Otherwise, wrong training data will be generated. Paint in all three directions, especially if the gray values differ much.




If enough labels are painted click **Train** to train a machine learning model. Afterwards select **Preview** to control the resulting segmentation. The **Overlay** is switched to **Preview**.




In the example above the **Boosted Tree** method was used. Thus, only few labels are needed for this gray value image of a Berea sandstone.

A previously loaded model can be improved by clicking **Continue Train**. A model is loaded either by training it before in the current **Image Processing** session or by loading a previously trained model by clicking **Load Model**.

For example, with more labeled gray values, **Continue Train** can improve the model. Note that not only the new labels are considered, but also the labels used for the loaded model to use all available information for the training.

Additionally, a model can be improved if another similar image is loaded and labeled to provide more training data.

The provided labels can be saved as ***.gld** file by clicking **Save Labels**. Load the training data again whenever needed by clicking **Load Labels**. Delete all labels by clicking **Clear Labels**.

Click **Save Model** to save a machine learning model trained by clicking **Train**. This model can be loaded again by clicking **Load Model** whenever similar scans have to be segmented. For the three different AI models the formats are *.XGBM for **Boosted Tree**, *.UNET2D for **Unet 2D**, or *.UNET3D for **Unet 3D**.

Finally, clicking **Create Segmentation** applies the model for each slice.

## MULTI-PHASE SEGMENTATION

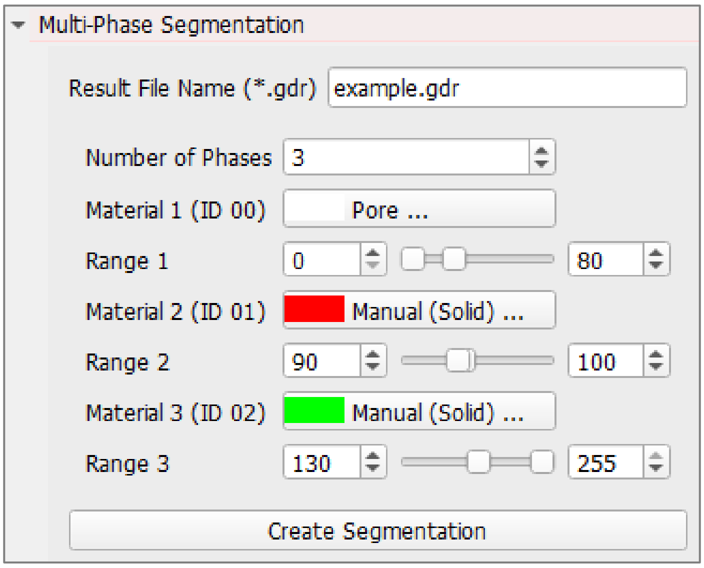
For more than two materials, the **Multi-Phase Segmentation** often leads to better results than the **Multiple Thresholds** method.

If there are bright artifacts at the borders between the different materials or the contrast is low, the **Multi-Phase Segmentation** can be used to fill these uncertain regions based on the watershed algorithm. Thus, it is very useful to avoid partial volume effects.

The name of the file and folder containing the results can be entered in the **Result File Name (*.gdr)** box. Choose a name fitting the current project.

Select the **Number of Phases** between 2 and 15.

Choose the materials for the different phases from the material data base.

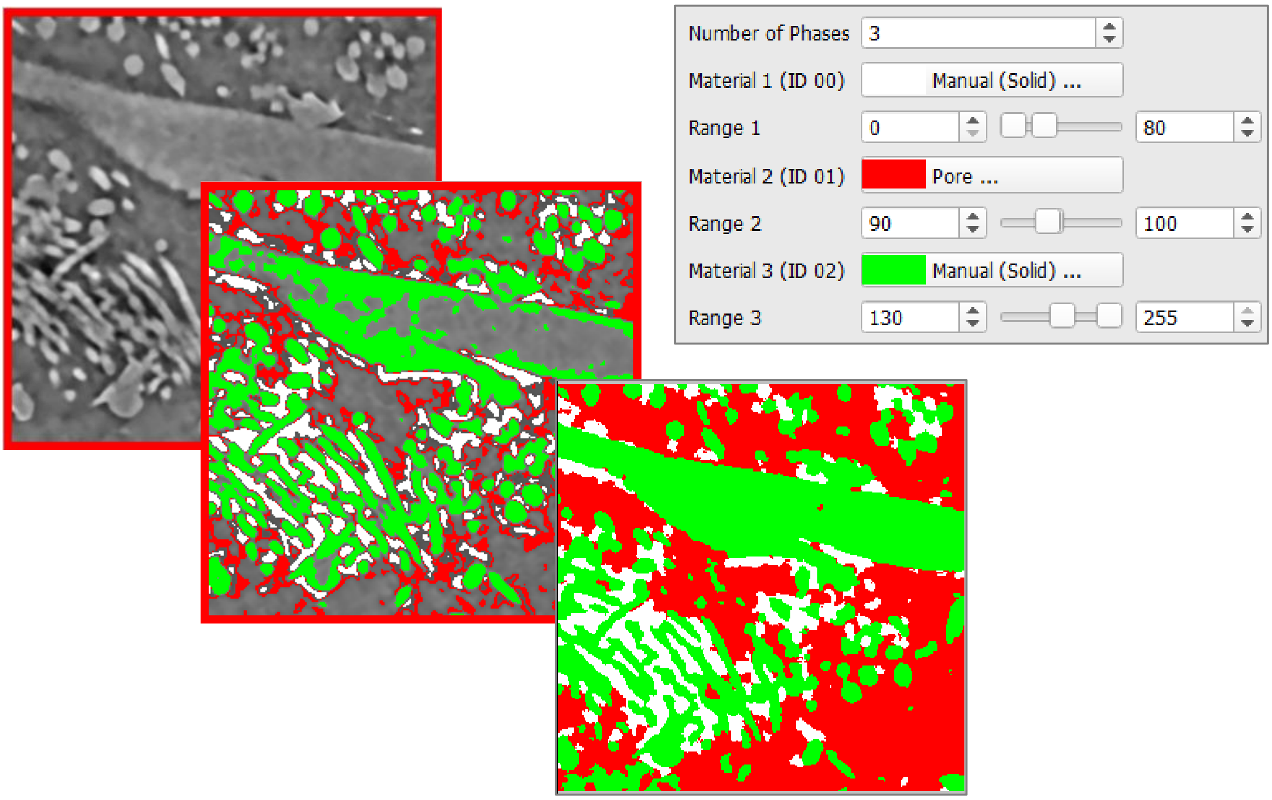



Define gray value ranges that are assigned to certain phases, by move the sliders to define the **Range** for the different phases. The higher value of each phase must be smaller equal to the lower range value of the next phase. If equal, the gray value is assigned to the next phase. For example, if Range 1 is defined as 20-50 and Range 2 is 50-70, the gray value 50 is assigned to Material 2.

All remaining uncertain areas, i.e., the gray values that are not contained in any defined range, are filled using the watershed algorithm. The watershed algorithm is described on pages 65ff.

Finally, clicking **Create Segmentation** applies the multi-phase segmentation to the image.

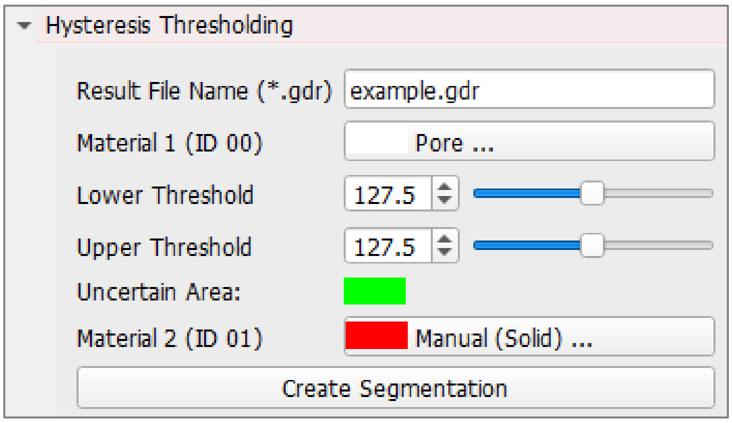
In the following example the gray values are split in three phases. **Material 1** is set to solid with a definite gray value range of 0-80. The second phase is defined as pore space with **Range 2** set to 90-100. The main solid material is defined in phase 3 with **Range 3** of 130-255. Thus, the gray values 81-89 and 101-129 are not sorted to one of the two phases, as can also be observed in the **2D Slice Visualization** section, if **Visibility** is turned on. The gray values in range 1 are marked in white, the gray values in range 2 in red and the gray values in range 3 in green. All other gray values are not marked. After creating the segmentation these are filled using the watershed algorithm.


Number of Phases
3
Material 1 (ID 00)
Manual (Solid) ...
Range 1
0
80
Material 2 (ID 01)
Pore ...
Range 2
90
100
Material 3 (ID 02)
Manual (Solid) ...
Range 3
130
255

## Hysteresis Thresholding

The name for the file and folder containing the results can be entered in the **Result File Name (*.gdr)** box. Choose a name fitting the current project.

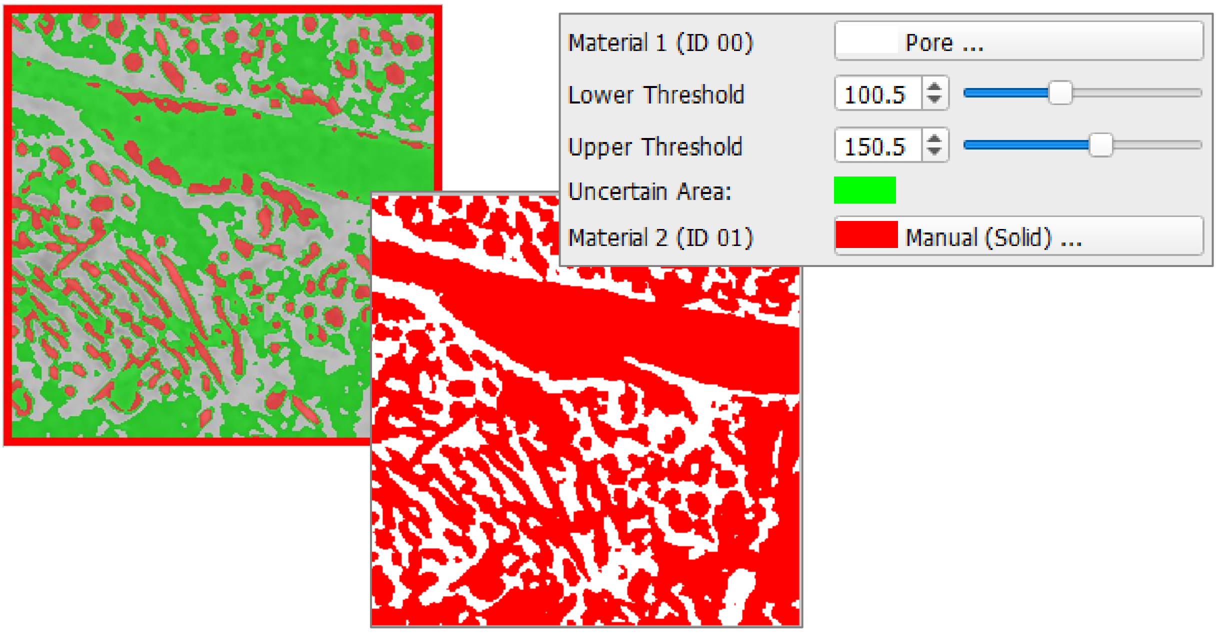
Thresholding with **Hysteresis** selected as **Method** is one way to accomplish edge detection using two thresholds.




It implements the detection of edges by suppressing all the other edges that are weak and not connected to strong edges. Low thresholded edges which are connected to high thresholded edges are retained. Low thresholded edges which are non-connected to high thresholded edges are removed.

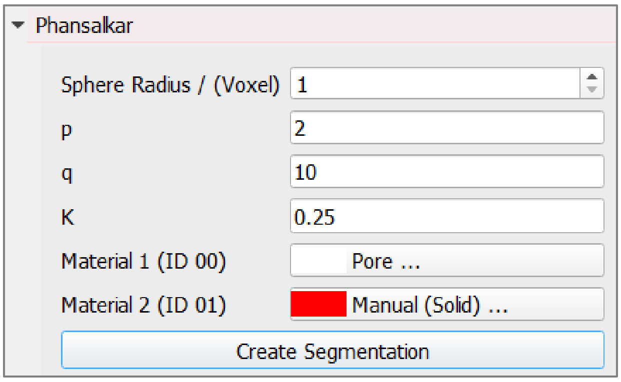
This leads to the creation of 3 classes: below low threshold (to be removed), above high threshold (to be retained), and between low and high thresholds (to be retained only if connected to an edge above high threshold).

Finally, clicking **Create Segmentation** applies the hysteresis thresholding to the image.



## PHANSALKAR

The **Phansalkar** filter is a modification of Sauvola's local thresholding method and deals with low contrast images. For detailed information about the theory also refer to literature.




The **Sphere Radius** controls the size of the region, in which the filter is applied.

The local threshold T is found from the mean (m) and standard deviation (s) of the pixel intensities as follows:

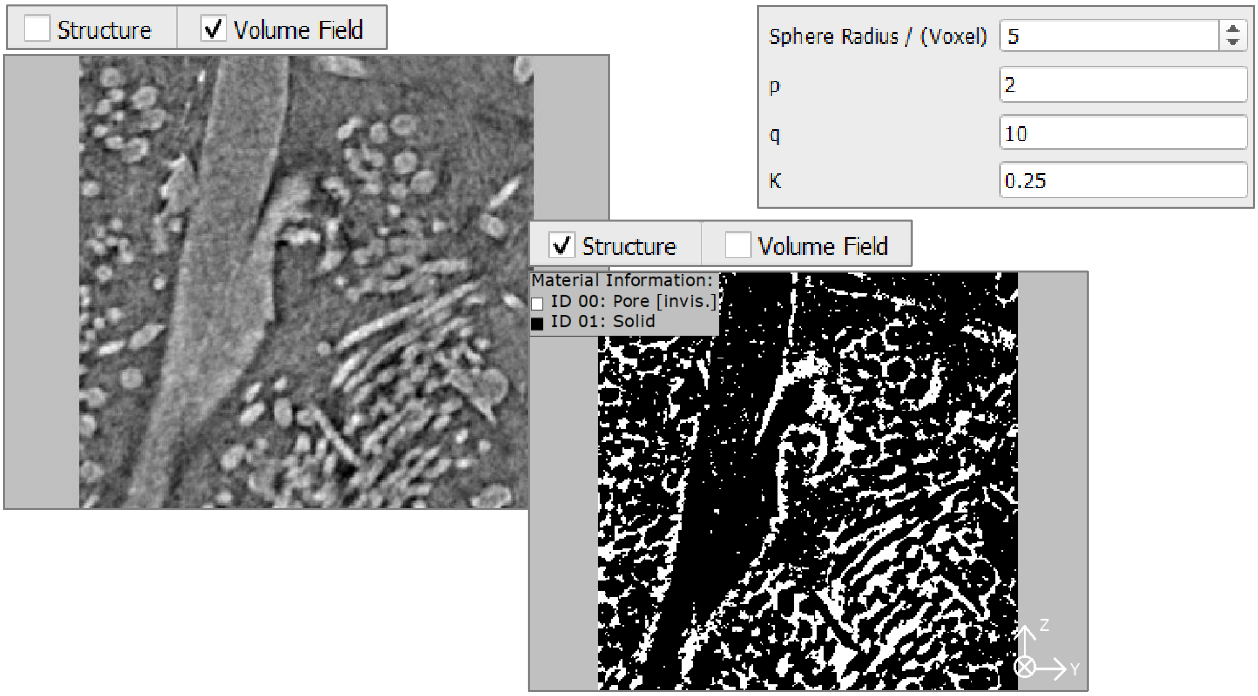
$$T = m\left[1 + \boldsymbol{p}e^{-\boldsymbol{q}m} + \boldsymbol{K}\left(\frac{s}{R} - 1\right)\right]$$

R is the dynamic range of standard deviation, which is equal to 0.5 for a normalized image, and **K** is a constant which takes values in the range [0.2, 0.5]. **p** and **q** are constants.

The local mean and standard deviation adapt the value of the local threshold.

Click **Create Segmentation** to segment the gray value image with the **Phansalkar** method. This thresholding method does not create a GeoDict result file. The resulting structure is displayed in the GeoDict visualization area. The gray value image stays in memory and can be compared to the structure. Check **Structure** and uncheck **Volume Field** in the visualization panel above of the visualization area to only visualize the structure.

To save the structure in a *.gdt file select **File** → **Save Structure as ...** from the menu bar in the main GeoDict GUI.



## Local Otsu

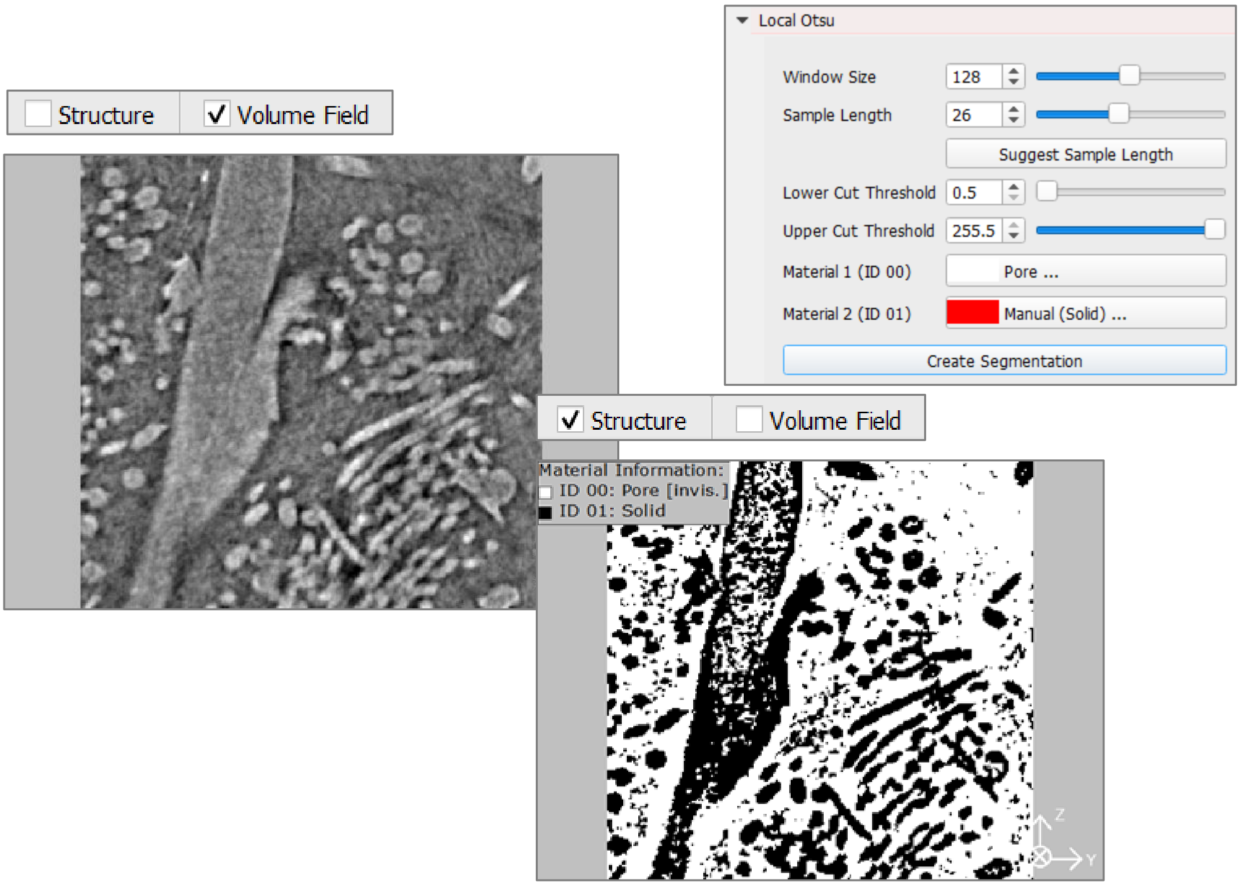
The **Local Otsu** method is used in image processing to automatically perform clustering-based image thresholding. It reduces the grayscale image to a binary image. A global Otsu thresholding is available and explained in the **Image Segmentation** chapter on page 77.

The local Otsu method circumvents potential irregularities in the complete 3D image by focusing on smaller cubes with edge length in voxels according to the assigned **Window Size**.

The parameter **Sample Length** defines the distance between these 3D regions and can be set automatically by clicking **Suggest Sample Rate**.

The **Lower** and **Upper Cut Threshold** can be adjusted to reduce noise in bright or dark regions. Depending on sample rate and window size, multiple thresholds are applied for assigning each voxel to the according phase.

Click **Create Segmentation** to segment the gray value image with the **Local Otsu** method. This thresholding method does not create a GeoDict result file. The resulting structure is displayed in the GeoDict visualization area. The gray value image stays in memory and can be compared to the structure. Check **Structure** and uncheck **Volume Field** in the visualization panel above of the visualization area to only visualize the structure.

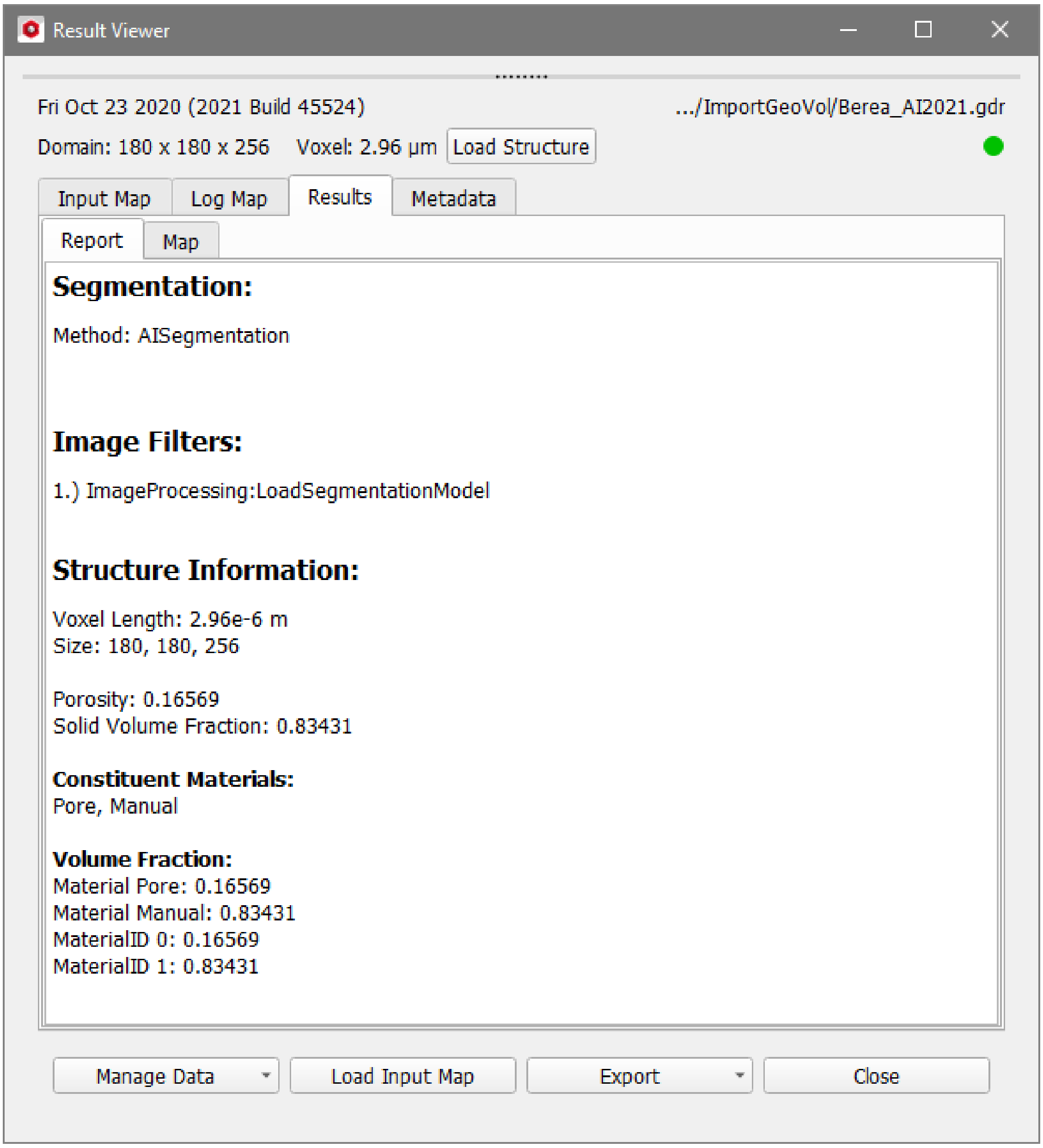



To save the structure in a *.gdt file select **File** → **Save Structure as ...** from the menu bar in the main GeoDict GUI.

## Results

After clicking **Create Segmentation** for one of the segmentation methods, the segmentation is applied for the gray value image. The generated result file with the name entered for **Result File Name** is opened automatically in the result viewer.

The **Report** tab lists the **Segmentation** method, the used **Image Filters**, and some basic **Structure Information** for the resulting structure.




Additional to the result file, a result folder with the same name is saved inside the current project folder, containing the segmented structure file (*.gdt).

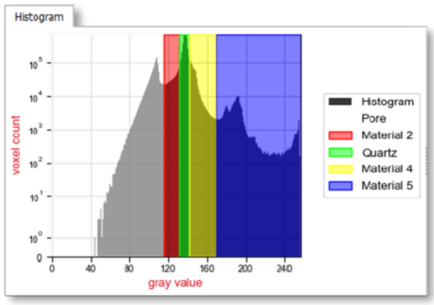
For a more detailed description of the Result Viewer options refer to the Result Viewer handbook of this User Guide.

## Comparison of Different Segmentation Methods

To compare the different segmentation methods, the Berea sandstone is segmented with **Global Thresholding**, **Multi-Phase Segmentation** and **AI Segmentation**.

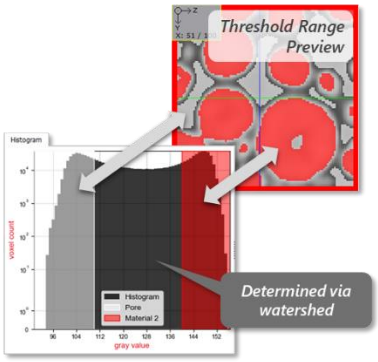
### The segmentation methods

**Global Thresholding**



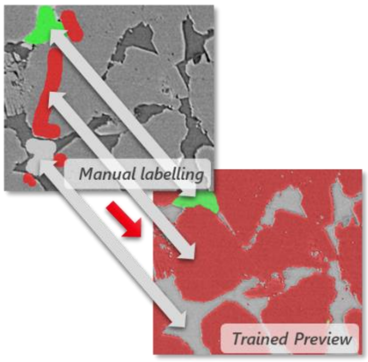

- Single or Multiple gray value thresholds
- Automatic thresholding based on gray value histogram (e.g., OTSU)

**Multi-Phase Segmentation**




- Define gray value ranges for phases
- Any remaining "uncertain" areas are automatically segmented via Watershed

**AI Segmentation**



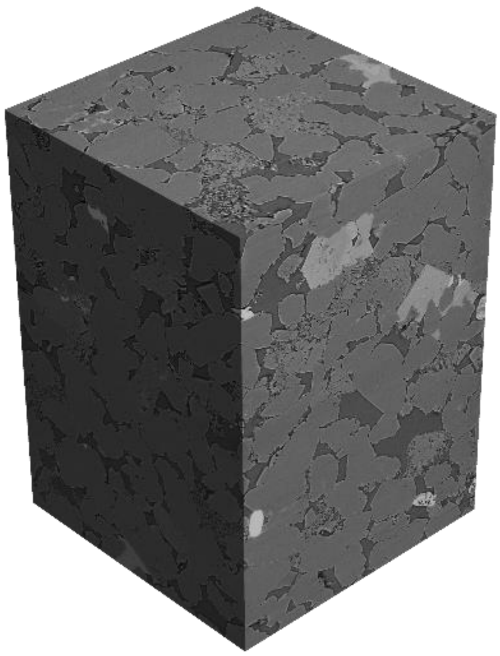

- Label multiple materials manually
- Fast Machine Learning-based Training algorithm
- Deep learning-based Training algorithm (UNet2D, UNet3D)

### The sample

**Berea Sandstone**

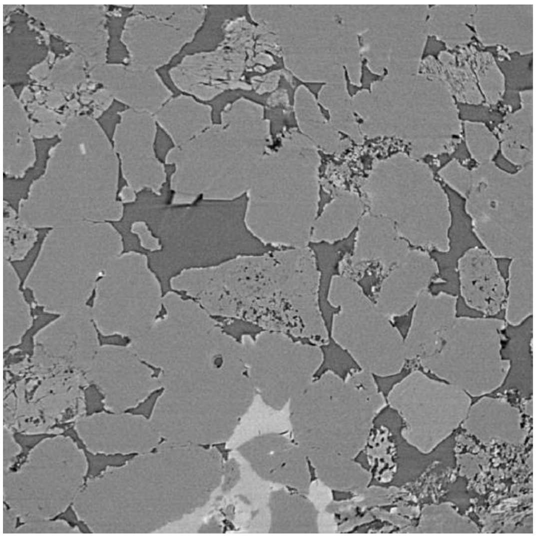
*Andrae et al. (2013a;b)*

- Dimensions: 720x720x1024 voxels
- Resolution: 0.74 µm
- Components: Quartz, Feldspar, Calcite, Zircon

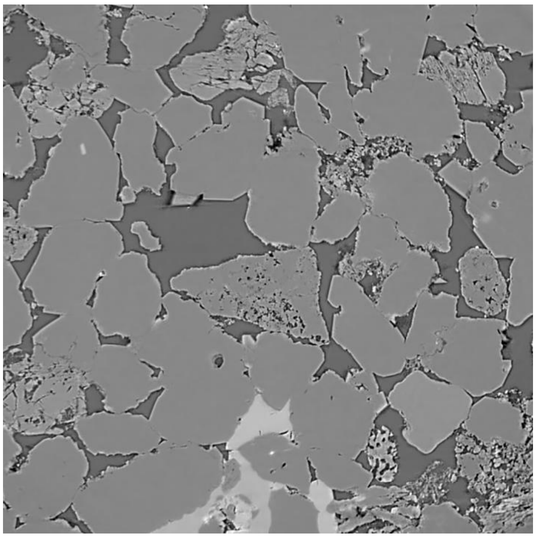


The segmentation

For the Berea sandstone a parameter study was done comparing published experimental data to GeoDict results. Segmented porosity and computed (absolute) permeability are determined for the different segmentation methods. The results showed that (in this case) the **Non-Local Means Filter** (**NLM**), described on page 59) was not needed for the AI Segmentation, but for the other two methods. Instead, after segmentation any remaining small-scaled features were reassigned with the ProcessGeo **Cleanse** feature.

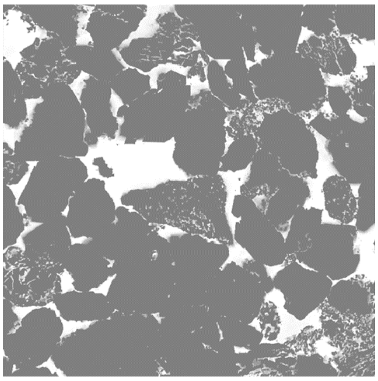


Original gray values



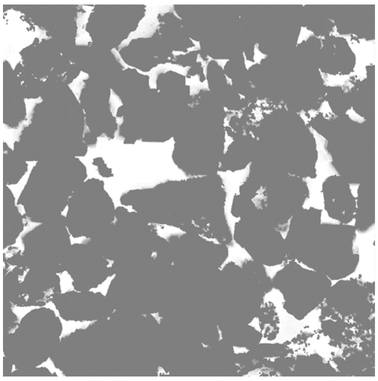
Non-Local Means (NLM) Filter

The segmentation results for the different methods applied to the Berea sandstone look as follows:



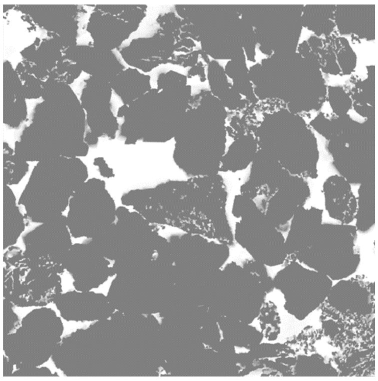
NLM +

Single Threshold (Otsu)



NLM +

Multi-Phase Segmentation



AI-based Segmentation +

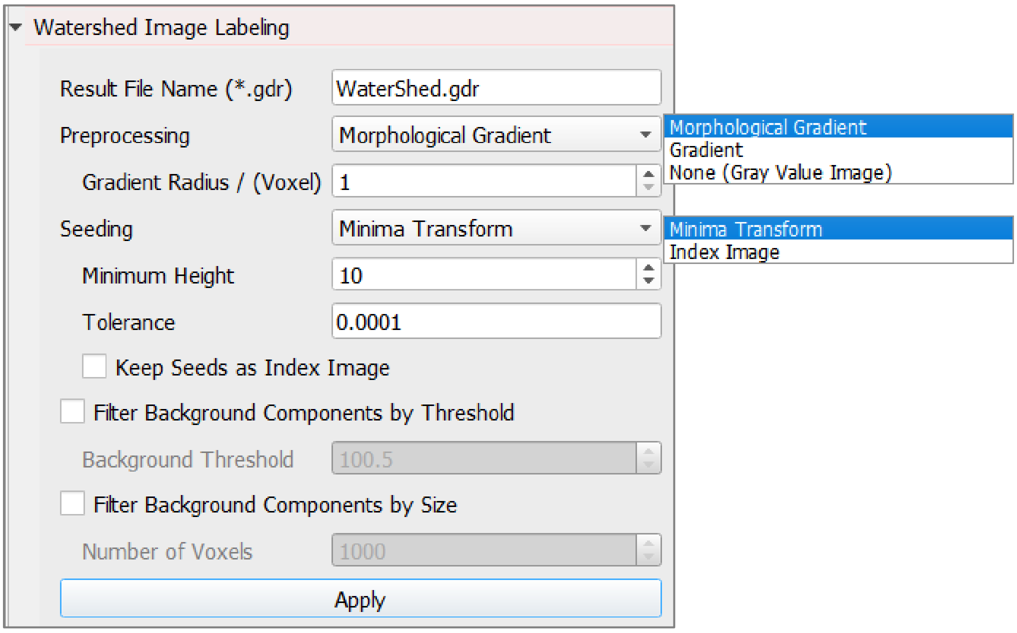
ProcessGeo - Cleanse

In a visual comparison, the **Global Thresholding** result appears to be very similar to the **AI Segmentation**. The **Multi-Phase Segmentation** removes a major part of small-scale features. Thus, a reduced porosity is to be expected for this particular result.

The comparison study shows that all the above segmentation results are within experimentally obtained data. Consecutive flow computations performed via the FlowDict module result in (absolute) permeability values that are very well in the range of lab data published by Andrä et al (2013b). The entire study *"Impact of different segmentation methods on Digital Rock Analysis results"* was presented at the iRIS conference (international Rock Imaging Summit) in 2020 and is available from the GeoDict webpage here.

## WATERSHED IMAGE LABELING

The **Watershed Image Labeling** creates a *.g32 index image from the gray value image. Thus, the result could be used e.g., in GrainFind to reconnect oversegmented objects and obtain grain statistics, as described in the GrainFind handbook of this User Guide.




The name for the file and folder containing the results can be entered in the **Result File Name (*.gdr)** box. The default name can be kept, or a new name can be chosen, fitting the current project.

The parameters and the results are the same as for the **Watershed (Supervoxel)** image filter described on pages 65ff.

Additionally, it can be selected to label components as background. The background components are labeled with index 0.

If **Filter Background Components by Threshold** is selected, the watershed components with a mean gray value lower than the threshold given for **Background Threshold** are considered as background.

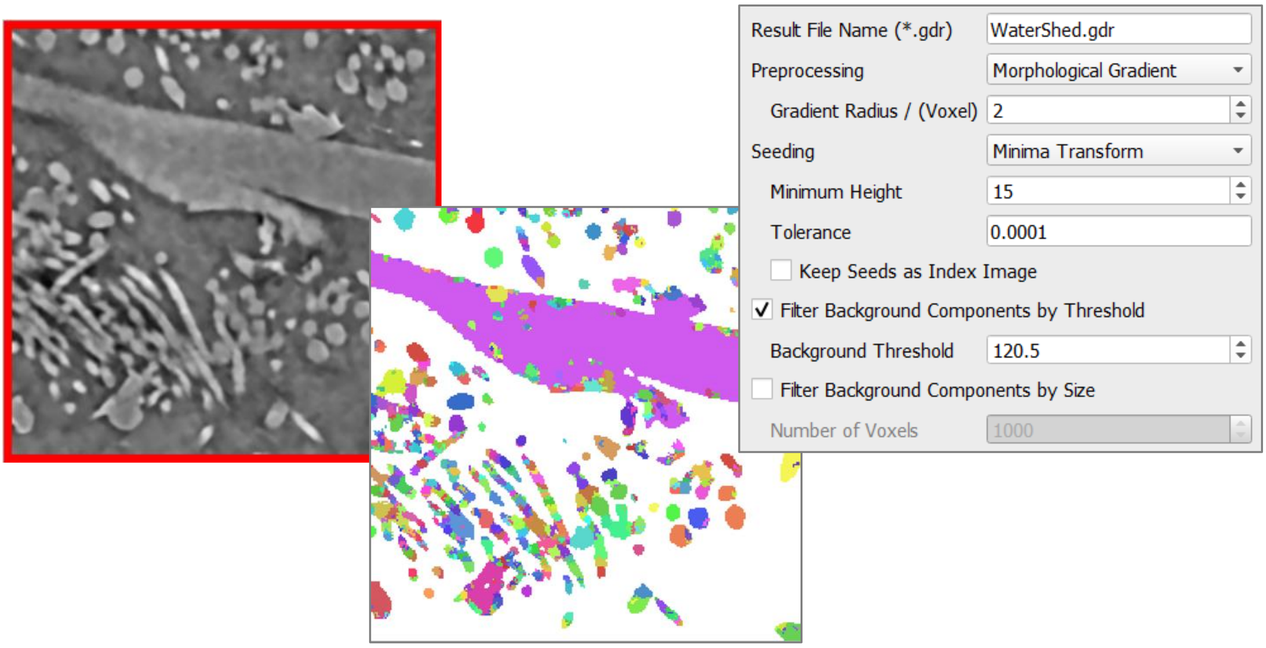
If **Filter Background Components by Size** is selected, the watershed components that consist of less voxels than the given **Number of Voxels** are considered as background.

Check both background component filters to label the components as background, that have a mean gray value lower than the given threshold, as well as consisting of less voxels than the given number of voxels.

Click **Apply** to run the **Watershed Image Labeling** process.

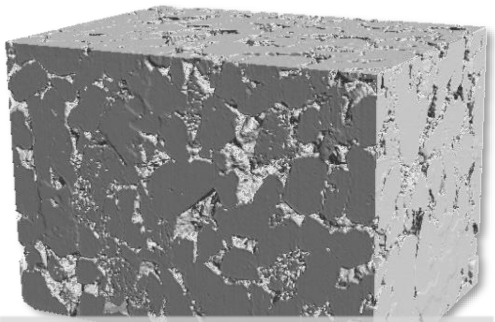
While the **Watershed (Supervoxel)** changes the image in the **2D Slice Visualization** section, the **Watershed Image Labeling** does not. Load the results from the **Result Viewer** as explained on page 68.

In the following example the same image as for the **Watershed (Supervoxel)** filter is considered. For the **Watershed Labeling** the same parameters are used. Additionally, **Filter Background Components by Threshold** was checked and a **Background Threshold** of 120.5 was entered. Thus, all components with a gray-value lower than 120.5 were assigned to index 0, which is colored in white.

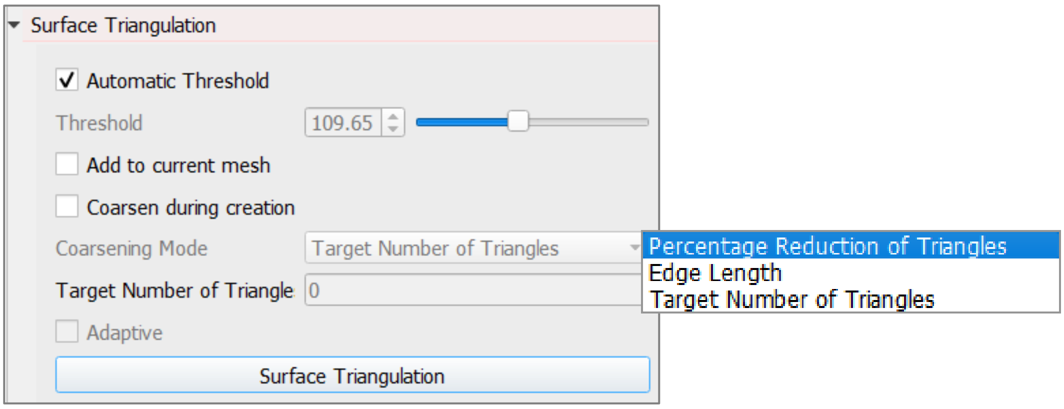


## Surface Triangulation

Create a **Surface Triangulation** for the resulting structure by creating a Surface Mesh. The structure is segmented into two phases and the iso surface wraps around the high gray value values which are assigned to Material ID 01 with normal pointing into the pore space which is assigned to Material ID 00.



***Example:*** *Surface Triangulation of a Berea sandstone, 180x180x256*




Segment the gray value image either with an **Automatic Threshold** or with a manual threshold entered for **Threshold**.

If **Automatic Threshold** is enabled, the Otsu method is used to threshold the image.

When **Add to current mesh** is selected and a mesh is already in memory, the new mesh is added to that mesh. Multiple meshes can then be edited together and be saved to a single file.

If **Coarsen during creation** is checked, the number of triangles in the generated surface mesh is reduced.

Three different modes to coarsen triangulations are provided, based on the stopping criteria for the coarsening algorithm: by **Percentage Reduction of Triangles**, by **Edge Length**, and by **Target Number of Triangles**.

The coarsening algorithm reduces the number of triangles in the generated mesh by combining short edges to longer edges.

For a detailed description and examples for the triangulation parameters see the ExportGeo-CAD & MeshGeo handbook of the GeoDict User Guide.

Click **Surface Triangulation** to start the process. After the triangulation is finished, the resulting mesh is displayed in the GeoDict visualization area.

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