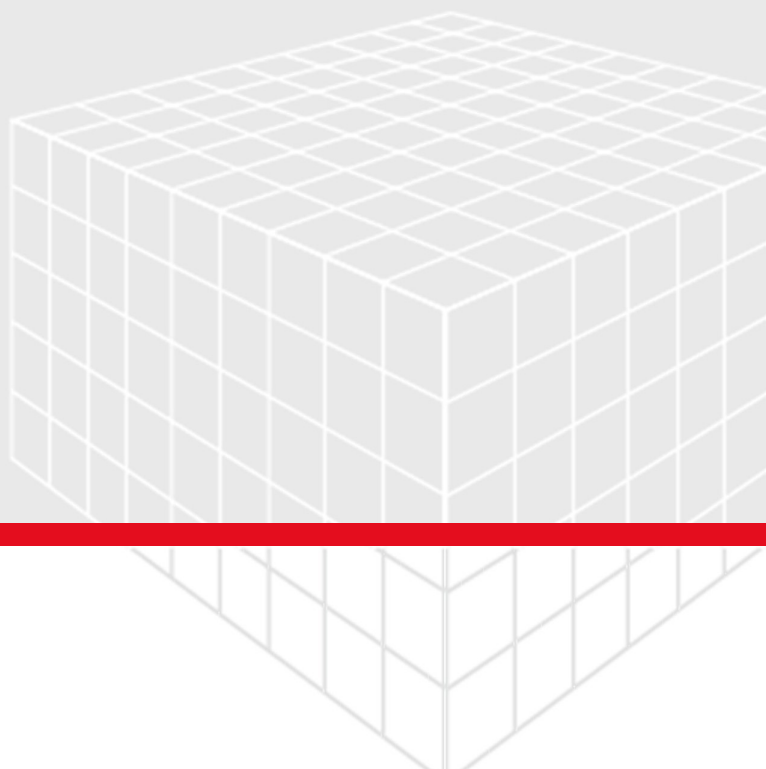


ImportGeo-Vol

User Guide

GEODICT Release 2026

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GEODICT

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ImportGeo-Vol

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1 ImportGeo-Vol

ImportGeo-Vol transforms 3D images of real materials, captured through various techniques (such as micro-CT or FIB-SEM), into digital materials (digital twin). The resulting digital twin, for which one knows the material phase associated with each voxel, is the basis for further analysis and simulations with GeoDict.

The image processing workflow starts with the import of the image, which can be in the form of a 3D image file such as *.raw or as a 2D image stack like *.png or *.tif. Following the import, the image may undergo qualitative enhancements through various image processing steps.

ImportGeo-Vol provides a complete solution for image processing providing state-of-the-art image filters, including the [non-local means filter](#)^[77] to reduce noise and specialized techniques to eliminate artifacts such as [curtaining](#)^[101] in FIB-SEM images. The final image processing step is image segmentation, where the available methods in **ImportGeo-Vol** range from simple automatic [global thresholding](#)^[108] to advanced [AI-driven approaches](#)^[111] based on neuronal networks.



New in GeoDict 2026

- Enhanced [labeling tools](#)^[121] for AI segmentation training:
 - Undo and Redo are available via buttons or keyboard shortcuts
 - The Lasso tool lets you label any shape, e.g., by tracing the outline of a grain or fiber
 - Right-clicking erases labels
 - Labels persist when you switch between different image datasets
 - The Magic Brush is now more responsive, and slice changes happen faster
- The import of [2D DICOM](#)^[15] files is now supported. Additionally, when importing other DICOM files, intermediate *.grw files are not saved on the disk anymore.
- You can save and load start-up settings for all image processing and segmentation options.

Learn to use ImportGeo-Vol

- [Importing Image Datasets](#)^[5]
Find out how to import image files into GeoDict.
- [Supported Image File Formats](#)^[8]
Discover the image file formats supported by GeoDict.
- [Quick Segmentation](#)^[18]
Perform fast image segmentation without preprocessing steps.
- [3D Image Processing](#)^[23]

Learn to use ImportGeo-Vol

Explore how to use powerful tools for image processing and segmentation.

- [References](#)¹⁴³

See the references for relevant literature.



Join the conversation

Visit the Community on [GeoDict Forum](#) to be inspired and get answers to top questions.

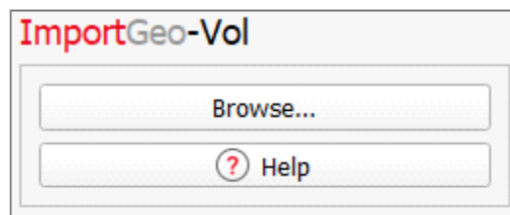
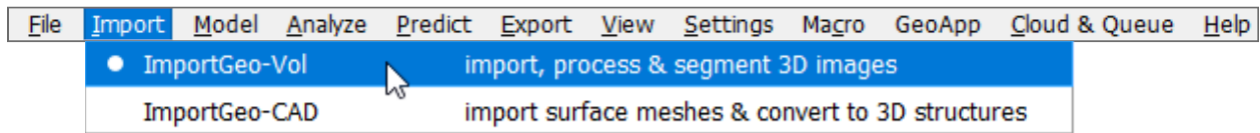
Find illustrative application examples on the [website](#).

Our tutorials and seminar videos give you a first hands-on experience. They are collected in the [Learning Center](#).

Send your [Support Request](#) to our technical Support.

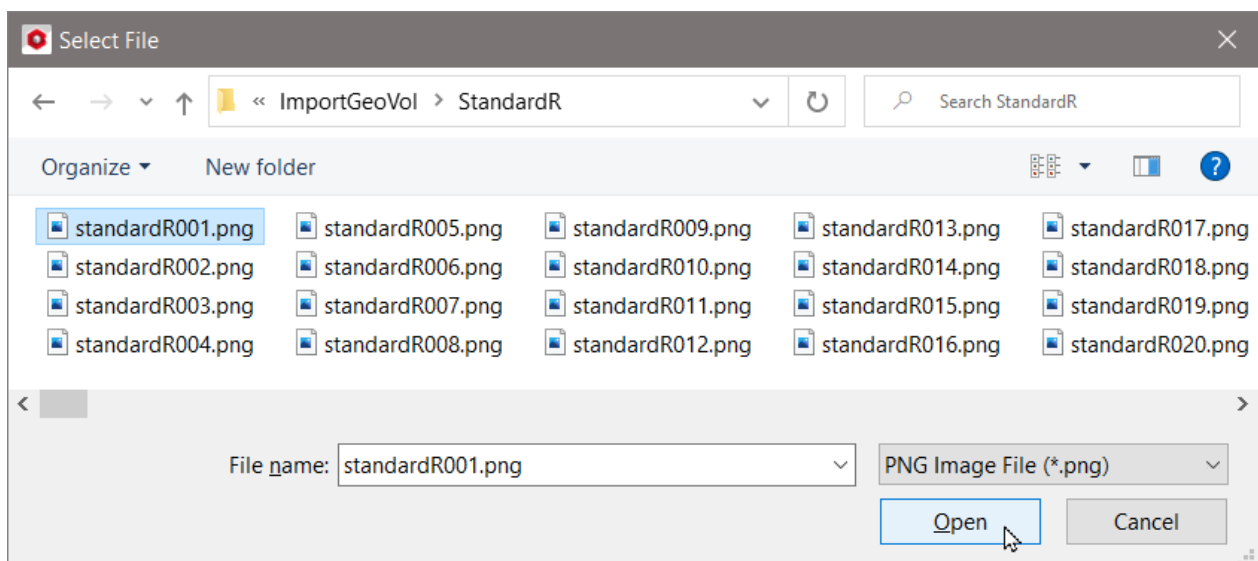
1.1 Importing Image Datasets

Select **Import** → **ImportGeo-Vol** in the menu bar to convert volume and image formats, such as micro-CT scans, into 3D material models. The **ImportGeo-Vol** module section opens on the left side of the GeoDict GUI.



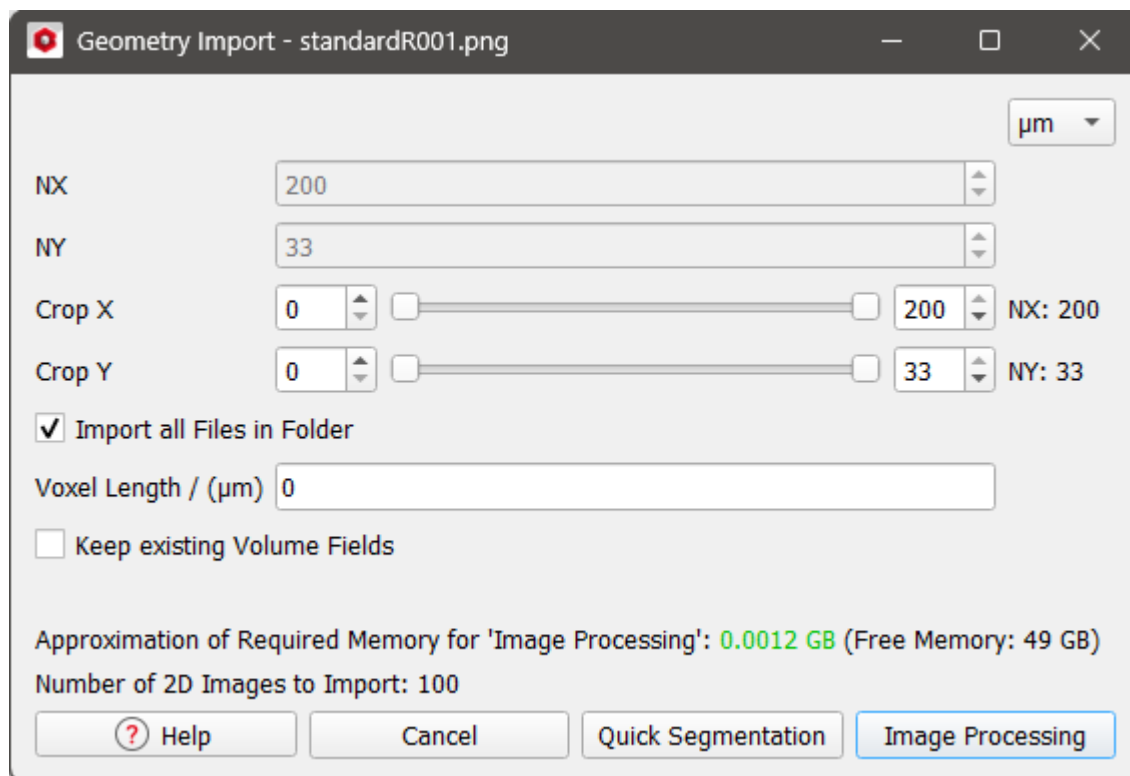
Load the Image Dataset

Click **Browse** to open the **Select File** dialog. Select either a single 3D image file or an image in a folder containing an image stack. Then, click **Open**.



Geometry Import Dialog

After clicking **Open**, the **Geometry Import** dialog will open automatically. Depending on the [file format](#)⁸, a dialog opens containing various options and parameters in preparation for the import. For most formats, the size of the geometry in the file is automatically entered. The approximately required and free memory amounts are displayed to indicate the available working memory.



Dimensions and Cropping

NX, **NY**, and **NZ** specify the size of the structure in voxels. For most file types, these values are read and entered automatically. For [RAW format](#) files, you need to know these values and enter them here.

The double sliders allow you to restrict a section 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 pixel to be imported in each direction. By default, ImportGeo-Vol imports the complete image. The values for **NX**, **NY**, and **NZ**, and the first and last voxel positions can 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.

Below the the size of the file's structure and the cropping options, define the **Voxel Length** in the selected unit.



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

Keep existing Volume Fields

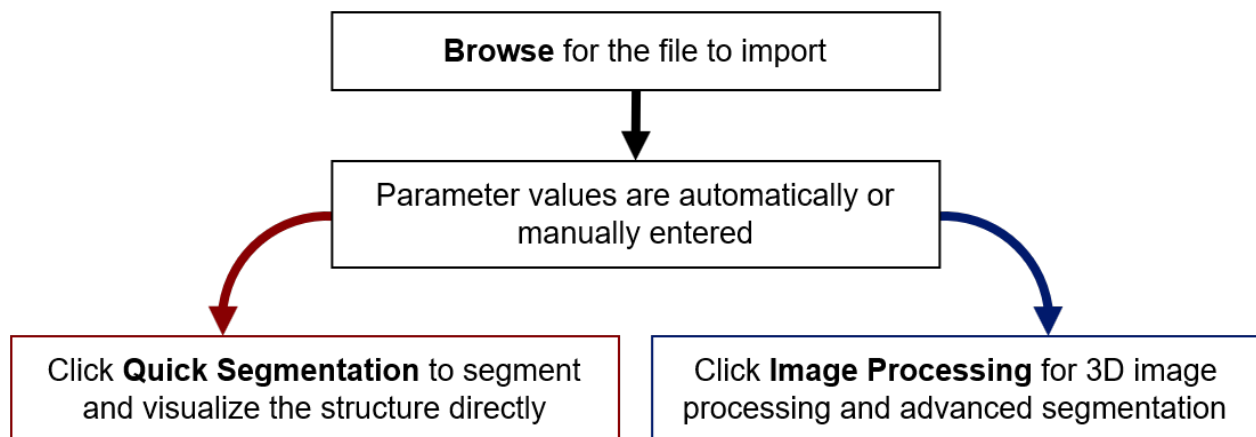
Check **Keep existing Volume Fields**, if the currently loaded volume fields, e.g., previously loaded image datasets should not be discarded. This is useful, if more than one image dataset should be used for [AI-Segmentation](#)^[11] labeling and training.

Segmentation and Processing

For most importable file formats, the size parameters are automatically entered after browsing for the file and loading it. Click **Quick Segmentation** to load the images saved in the selected file and display them in the visualization area. All [supported file formats](#)^[8] can be processed (i.e., the geometry can be cut, resized, rotated, filtered, and segmented) before the file is finally imported into GeoDict.

At the bottom of the dialog, two options for continuing are available:

- [Quick Segmentation](#)^[18]: For many of the importable file formats, the structure is directly loaded after clicking Quick Segmentation.
For other files, such as [*.raw image files](#)^[9] or stacks of [*.png files](#)^[13] 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.
- [Image Processing](#)^[23]: Allows for more complex image processing, e.g., changing image sizes or orientation, filtering the images, and finally creating a segmentation.



1.2 Supported Image File Formats

The following image file formats can be imported into GeoDict using ImportGeo-Vol:

1, 2, or 4 Byte Integer File Formats

- [1, 2, or 4 Byte Integer \(*.raw\)](#) 

4 Byte Floating or Integer File Formats

- [4 Byte Float \(*.vol\)](#) 

GeoDict File Formats

- [GeoDict Raw File \(*.grw\)](#) 
- [GeoDict Binary \(*.gdt\)](#) 
- [GeoDict ASCII \(*.leS\)](#) 
- [GeoDict 32 BIT \(*.g32\)](#) 

Image File Formats

- [TIF Image File \(*.tif, *.tiff\)](#) 
- [PNG Image File \(*.png\)](#) 
- [JPEG Image File \(*.jpeg\)](#) 
- [JPG Image File \(*.jpg\)](#) 
- [BMP Image File \(*.bmp\)](#) 
- [CUR Image File \(*.cur\)](#) 
- [GIF Image File \(*.gif\)](#) 
- [ICO Image File \(*.ico\)](#) 
- [PBM Image File \(*.pbm\)](#) 
- [PGM Image File \(*.pgm\)](#) 
- [PPM Image File \(*.ppm\)](#) 
- [SVG Image File \(*.svg\)](#) 
- [SVGZ Image File \(*.svgz\)](#) 
- [XBM Image File \(*.xbm\)](#) 
- [XPM Image File \(*.xpm\)](#) 

DICOM File Formats

- [DICOM File Formats \(*.dcm, *.dmz, *.zip, *.ima\)](#) 

Other 3D Data File Formats

- [Zeiss 3D Image \(*.txm\)](#) 
- [Avizo Binary File \(*.am\)](#) 
- [WiseTex Vox File \(*.vox\)](#) 
- [Rek File \(*.rek\)](#) 
- [IASS File \(*.iass\)](#) 



Note! If you have images in a file format that GeoDict cannot import, please email us at support@math2market.de to discuss potential implementation options.

1.2.1 1, 2, or 4 Byte Integer File Formats

The **RAW** format describes gray-scale 3D (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 the **Header Size** is 2048. A RAW file is a simple binary file, in most cases, without header information. A RAW file is created when tomographic images are taken, for example. Therefore, the person who created the file (typically the person who performed the tomography) must provide the necessary import size information.



Important! 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.

For a file containing a three-dimensional image with **NX** by **NY** by **NZ** voxels with format **Int**, the file can consist of:

- **Header Size + 1 x NX x NY x NZ** bytes
- **Header Size + 2 x NX x NY x NZ** bytes
- **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. For a single-byte image (8 bits), all gray values from 0 to 255 can be represented. Images with two bytes per voxel (16-bit images) can represent gray values from 0 to 65,535. Finally, 32-bit images can represent approximately 4 billion gray values.

If the RAW file contains floating point values, select **Float** from the pull-down menu for **Format** in the **Geometry Import** dialog. For images in float format the file can consist of:

- **Header Size + 4 x NX x NY x NZ** bytes
- **Header Size + 8 x NX x NY x NZ** bytes

Format	Float Float Int	☐ Big Endian
--------	---	-------------------------------------

Indicate whether the binary data in the selected file is stored in **Big Endian** byte order. If this box is not checked, GeoDict will assume that the image is stored in **Little Endian** byte order. In a **Big Endian** system, the most significant bytes are stored at the smallest memory address. For more details about endianness, refer to the [Wikipedia](#) page. The creator of the RAW file must provide information about how the bytes of the image are stored.

After selecting a RAW file and incorrectly specifying the parameters in the **Geometry Import** dialog, clicking [Quick Segmentation](#)^[18] or [Image Processing](#)^[23] will result in a warning stating that the file length does not agree with the entered size.

In the following example, a Berea sandstone sample ([Andrä et al., 2013](#)^[143]) is used to describe the image loading workflow. Here, with the values of NX=1024, NY=1024 and NZ=1024, the file length with the Header Size (50) comes up to 1,073,741,874 bytes (Header size + NX x NY x NZ = 50 + 1024 x 1024 x 1024) in case of an 8 bit image. This is incorrect, since the actual header size is 0 and, as a result, the RAW file cannot be loaded.

Geometry Import - BereaSandstone_1024_1024_1024_0.74mu.raw

μm

NX: 1024

NY: 1024

NZ: 1024

Crop X: 0 (Length X: 1024)

Crop Y: 0 (Length Y: 1024)

Crop Z: 0 (Length Z: 1024)

Header Size: 50

Format: Int ☐ Big Endian

Voxel Length / (μm): 0.74

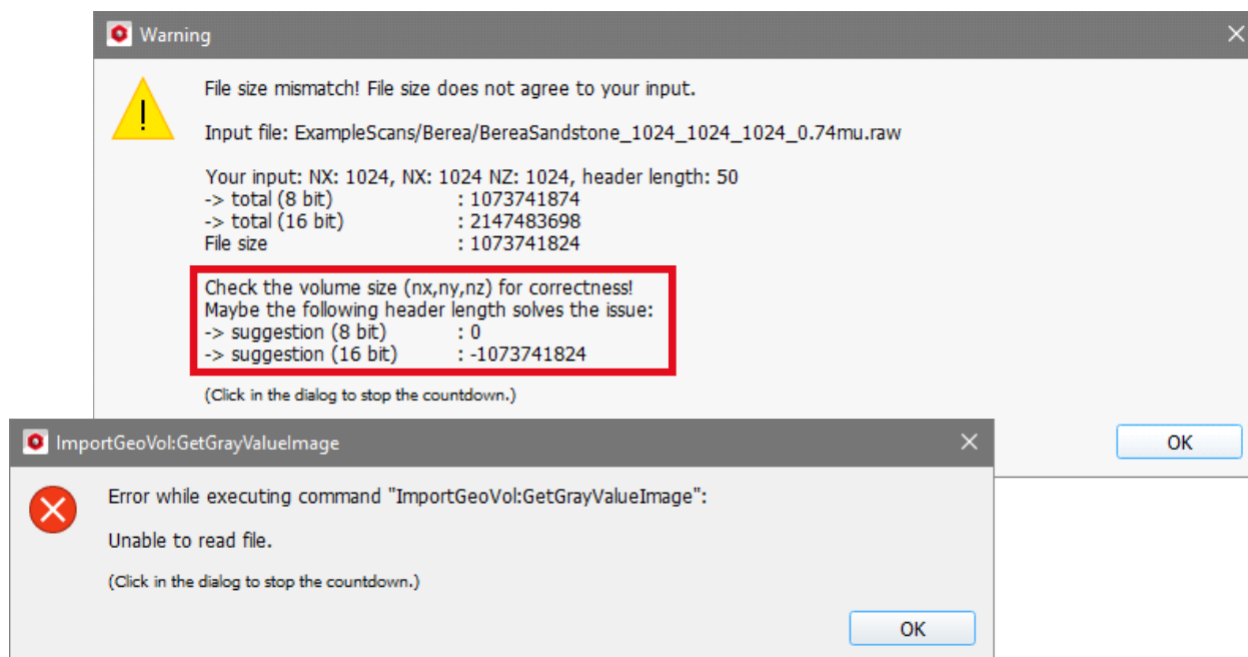
☐ Keep existing Volume Fields

Approximation of Required Memory for 'Image Processing': 3 GB (Free Memory: 27 GB)

Cancel Quick Segmentation Image Processing

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 the **Header Size**, which is necessary for RAW files with header information. Typically, values up

to 2048 (bytes) may be expected here. If no suitable suggestions are provided, it is likely that the volume dimensions of the scan were entered incorrectly. In the example below, we obtained the correct header size suggestion of 0 for the 8 bit image.



We recommend including 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 person who performed the tomography provides the correct values in an additional readable file or as a readable header in the RAW file. These values can then be extracted using a text editor, such as Notepad++.

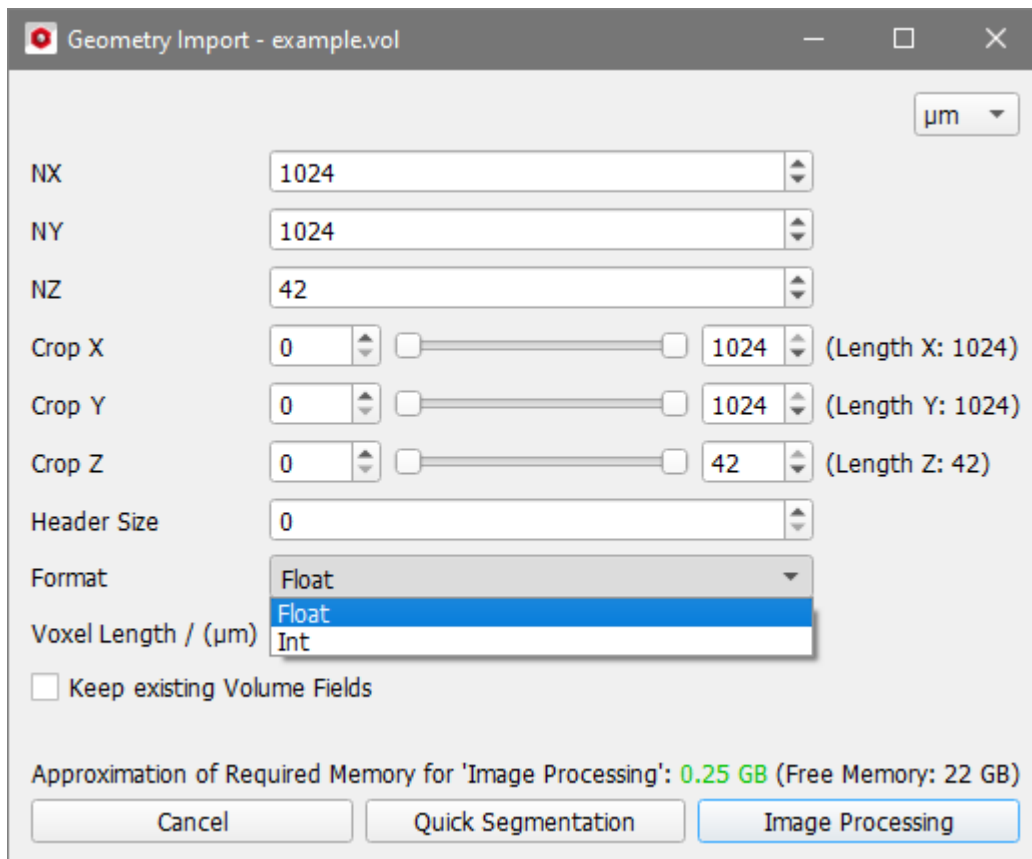
Click [Quick Segmentation](#)¹⁸ to segment the image without image processing or click [Image Processing](#)²³ to open the image in the 3D Image Processing dialog.

1.2.2 4 Byte Float or Int File Formats

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

The order of parameters in the dialog is the same as in the [RAW file format](#)⁹. As in the RAW file format, a file header may be present.

Unlike RAW files, 4 bytes are always used to represent the image, and these 4 bytes can be read as a floating-point number or an integer value. As with RAW files, the **Header Size**, number of voxels (**NX**, **NY**, and **NZ**), and **Voxel Length** are not contained in the file and must be entered in the **Geometry Import** dialog before importing.

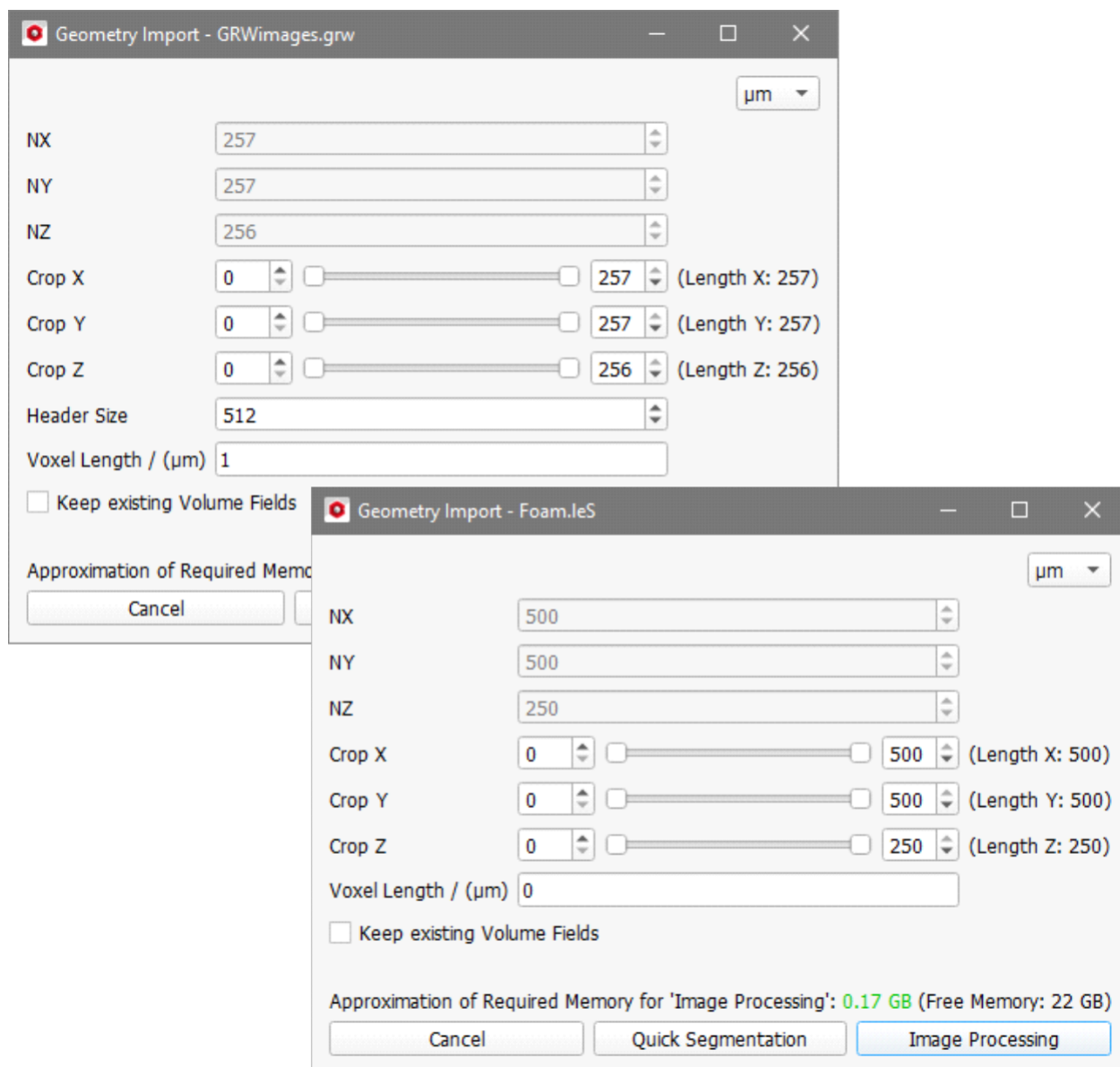


Some other software packages do not follow GeoDict's naming scheme and produce VOL files containing integer values, typically 16-bit. If you have trouble importing VOL files and suspect that they contain integer data rather than floating-point data, try changing the **Format** option to **Int** (see the image above) and then importing the file.

Click [Quick Segmentation](#)^[18] to segment the image without image processing or click [Image Processing](#)^[23] to open the image in the 3D Image Processing dialog.

1.2.3 GeoDict File Formats

For the import of the GeoDict file formats **GRW** (GeoDict Raw), **GDT** (GeoDict Binary), and **G32** (GeoDict 32 bit) the dimension parameters (**NX**, **NY**, **NZ**), **Header Size**, and **Voxel Length** are automatically read from the file. For the import of **LES** files (GeoDict ASCII) the **Voxel Length** must be entered manually.

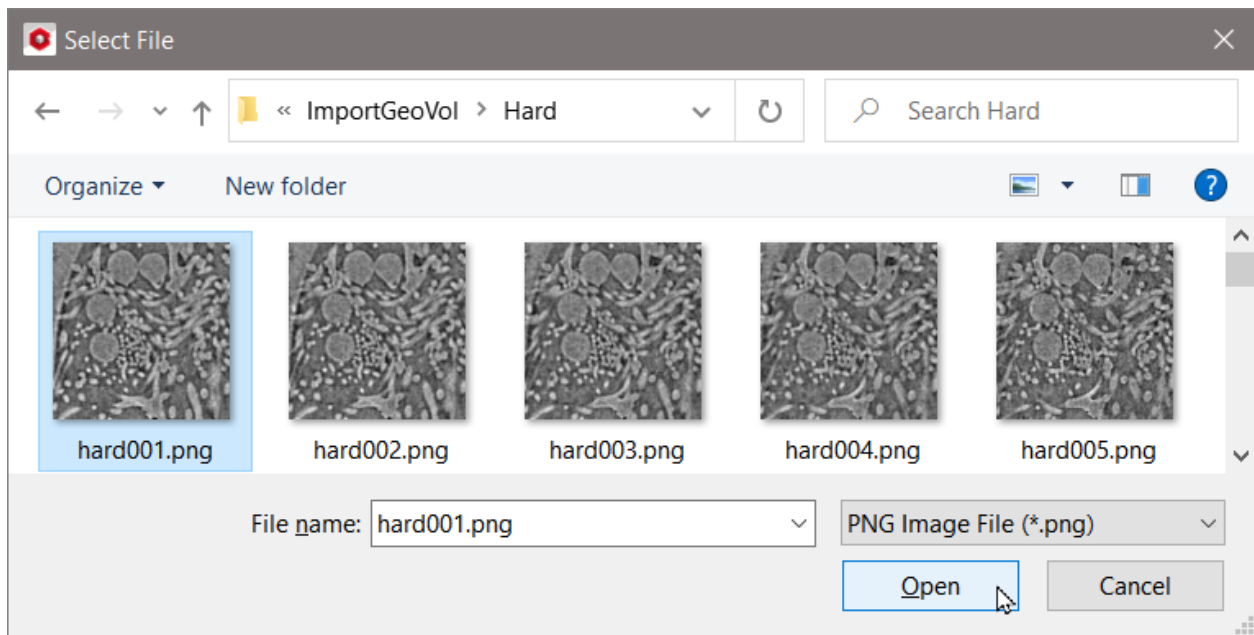


Click [Quick Segmentation](#)¹⁸ to segment the image without image processing or click [Image Processing](#)²³ to open the image in the 3D Image Processing dialog.

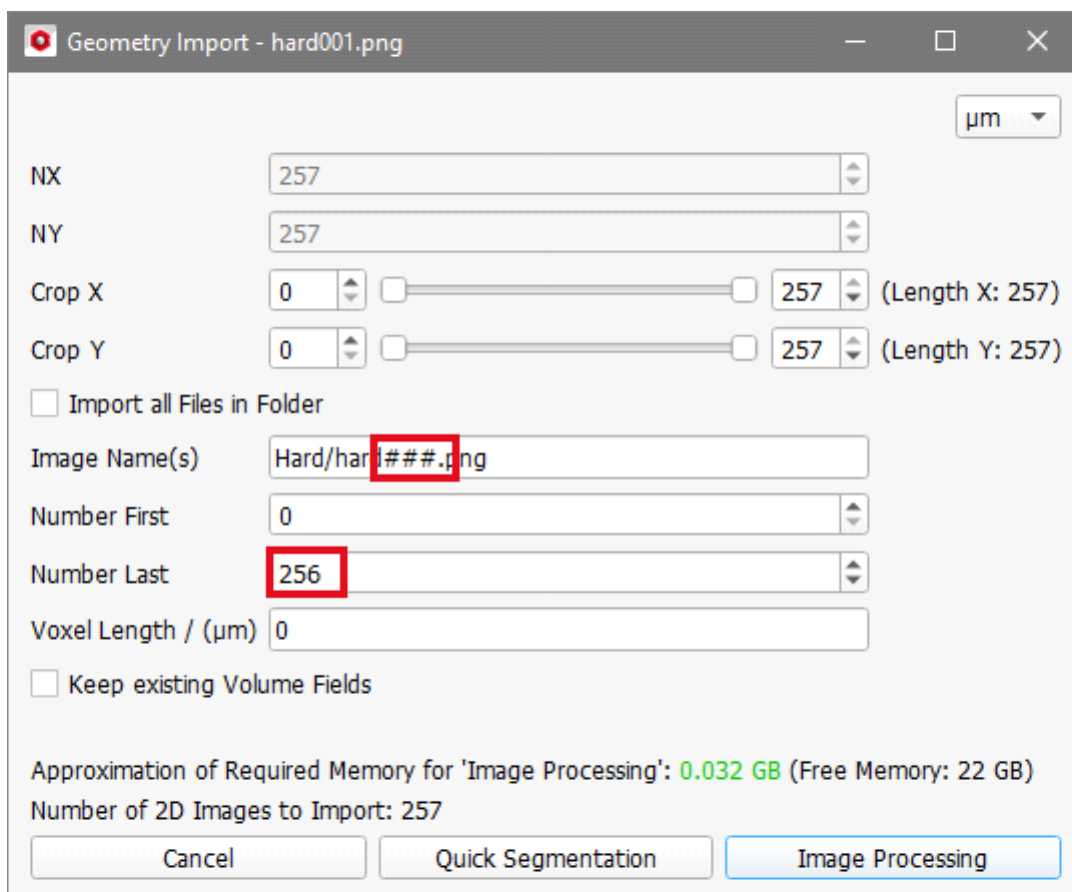
1.2.4 Image File Formats

You can import single 2D images or complete 3D geometry data consisting of a stack of 2D images in any supported image format using ImportGeo-Vol. The images in a stack form layers in the XY plane. Each image is then 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, select the image or one of the image files from the stack. To import a single image or a stack of images, select the desired image or file. You can also use the pull-down menu in the **Select File** dialog to select a specific format and only view images with that format.



After you click **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 adjusted to the resolution provided by the person who created the file (typically the person who performed the tomography). All images in a stack must be imported with the same resolution.

Importing a Selection of Files

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



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

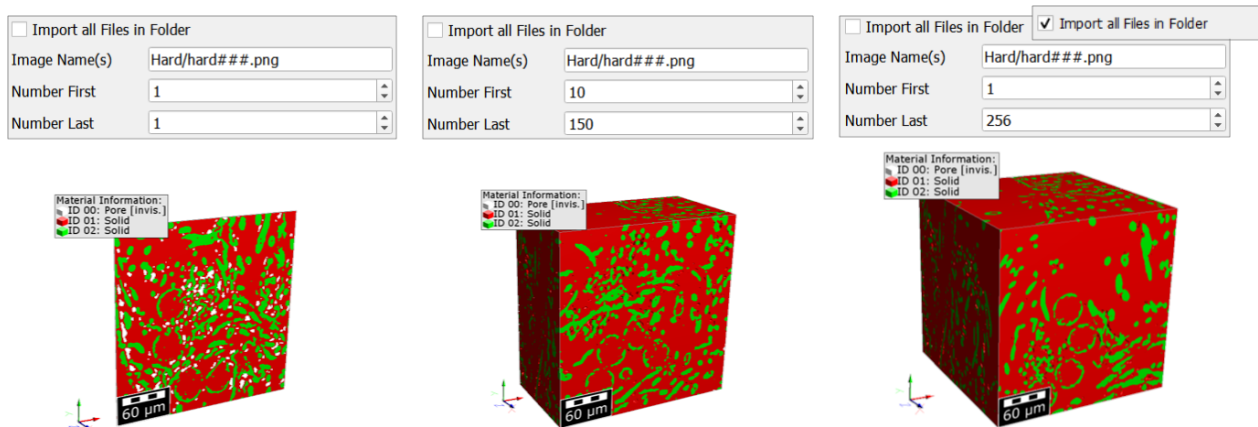
Checking **Import all Files in Folder** has the same effect as:

- changing the numbers in **Image(s) Name** by as many “#”s as the image number (e.g., 001 = ###) and
- entering the first image and last image numbers for the range of images to load.

Below, the number of imported images is changed using 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.

Then the selection is segmented using the [Quick Segmentation](#)²⁰.

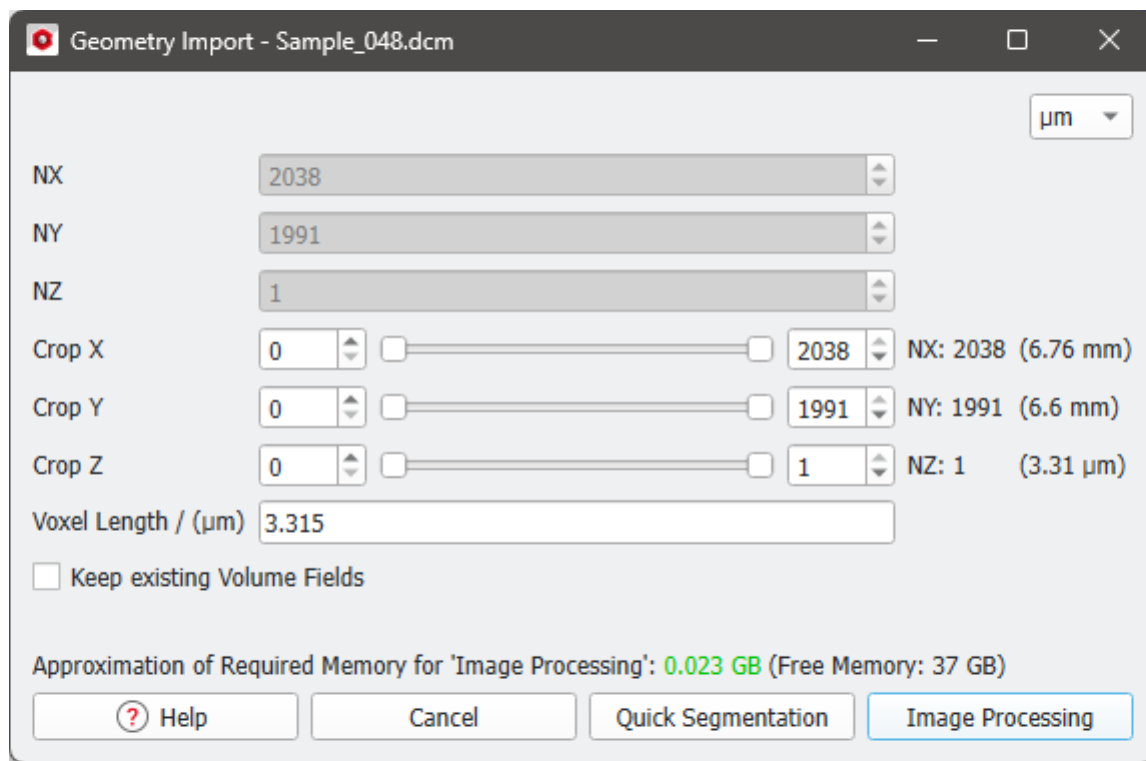


Click [Quick Segmentation](#)¹⁸ to segment the image without image processing or click [Image Processing](#)²³ to open the image in the 3D Image Processing dialog.

1.2.5 DICOM File Formats

A DICOM (Digital Imaging and Communications in Medicine) image is a file that contains a medical image (or a series of images) and a comprehensive set of meta data that describes who, what, how, and when the image was produced.

GeoDict can import DICOM file formats, such as **DCM**, **DMZ**, **IMA**, and **ZIP**, directly. Information such as the dimensions of the file (**NX**, **NY**, **NZ**) and the **Voxel Length** is read automatically from the imported file.



Click [Quick Segmentation](#)^[18] to segment the image without image processing or click [Image Processing](#)^[23] to open the image in the 3D Image Processing dialog.

1.2.6 Other 3D Data File Formats

For the import of **REK** (Fraunhofer), **TXM** (Zeiss), **AM** (Avizo), **VOX** (WiseTex), and **IASS** (Fraunhofer) files, 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).

Geometry Import - example.rek

μm

NX 1024

NY 1024

NZ 42

Crop X 0 1024 (Length X: 1024)

Crop Y 0 1024 (Length Y: 1024)

Crop Z 0 42 (Length Z: 42)

Header Size 2048

Voxel Length / (μm) 0

☐ Keep existing Volume Fields

Approximation of Required Memory for 'Image Processing': 0.25 GB (Free Memory: 22 GB)

Cancel Quick Segmentation Image Processing

Click [Quick Segmentation](#)¹⁸ to segment the image without image processing or click [Image Processing](#)²³ to open the image in the 3D Image Processing dialog.

1.3 Quick Segmentation

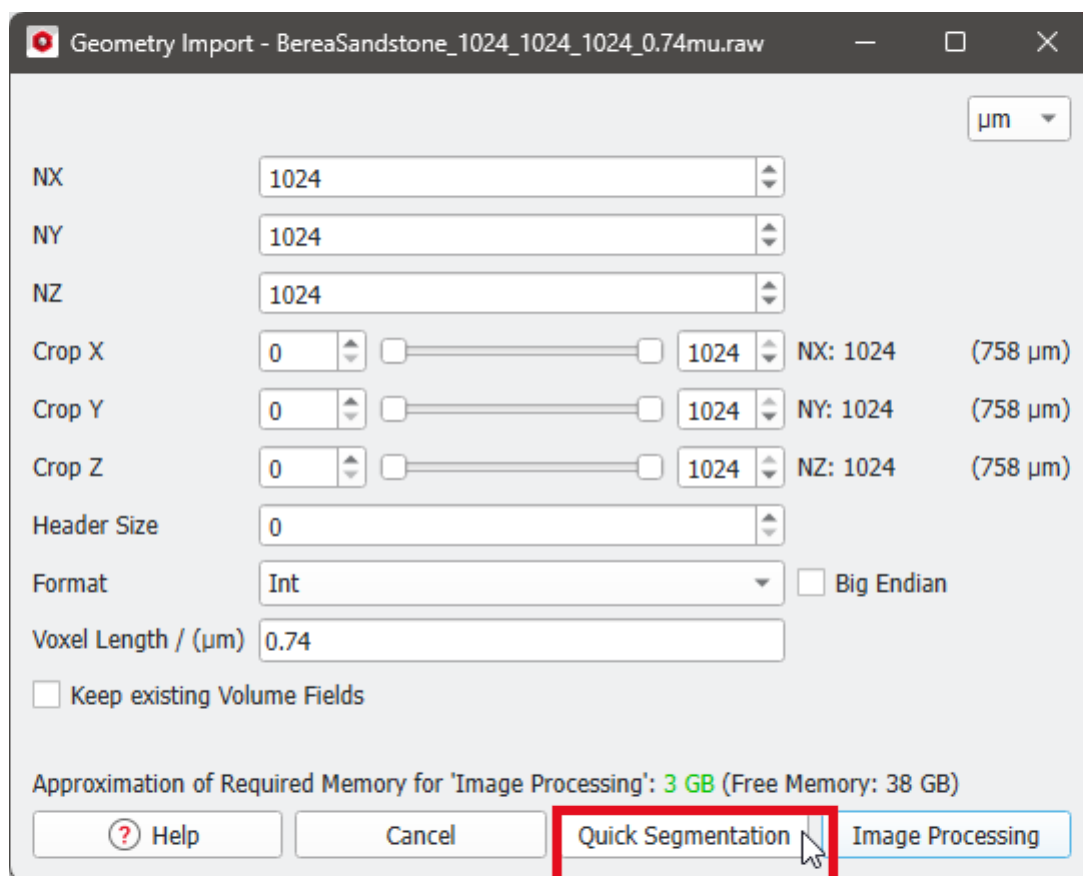
Load image datasets with ImportGeo-Vol by clicking **Quick Segmentation** in the [Geometry Import](#)^[5] dialog. **Quick Segmentation** allows you to segment images based solely on the histogram via [Global Thresholding](#)^[108]. Note that it is not possible to view the image datasets, and there are no options for processing or filtering. Additionally, you will not get a preview of the potential segmentation.



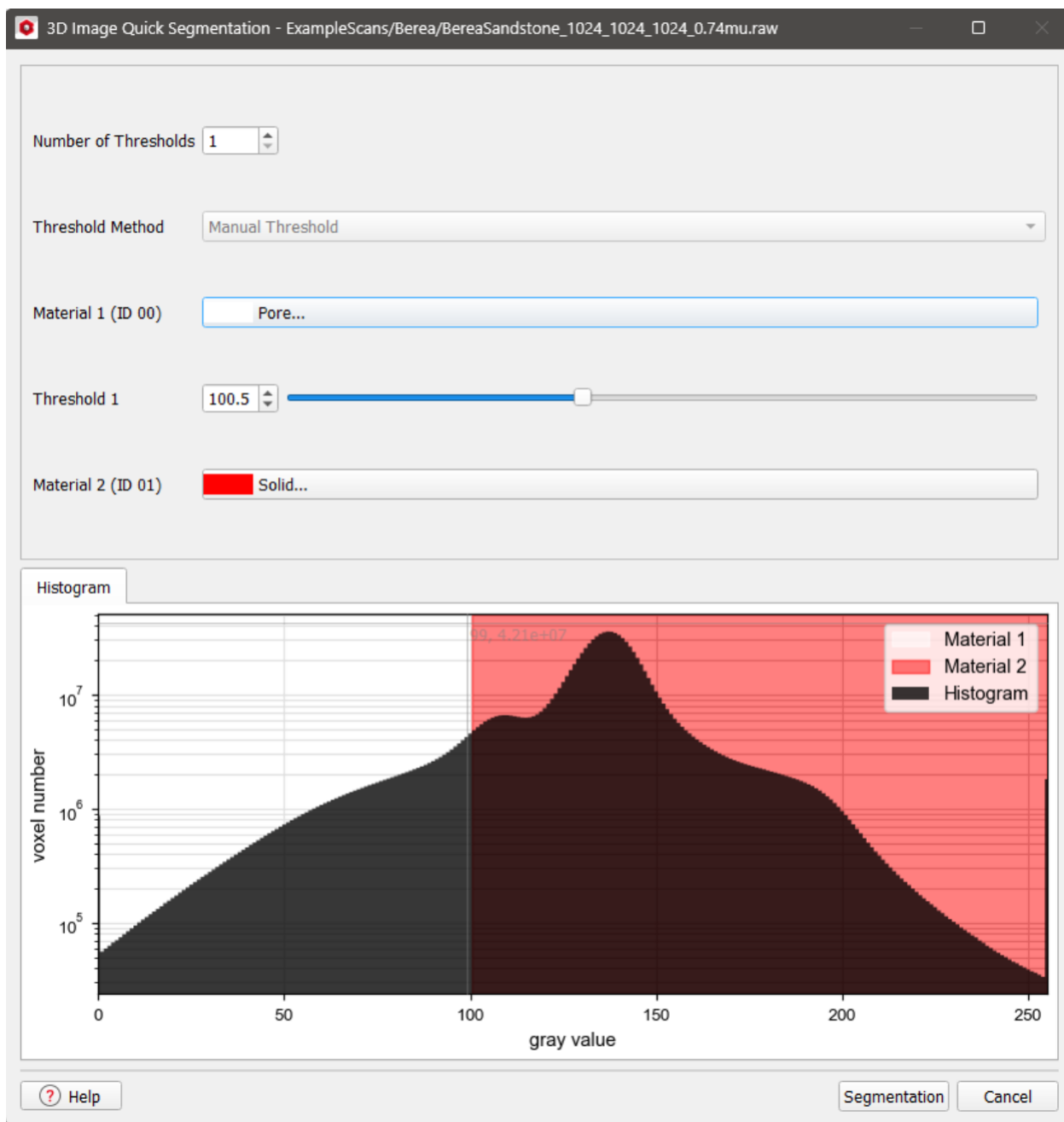
Important! For non-binary 3D image scans, it is highly recommended to continue with [Image Processing](#)^[23], which also allows you to use the entire range of processing and segmentation capabilities in GeoDict.

Exemplary Workflow on a Berea Sandstone

The Berea sandstone of [Andrä et al., 2013](#)^[143] is used here to describe the workflow using the **Quick Segmentation**.



In the **3D Image Quick Segmentation** dialog, you can manually segment the 3D image via global gray value threshold(s) without opening the [3D Image Processing](#)^[23] dialog.



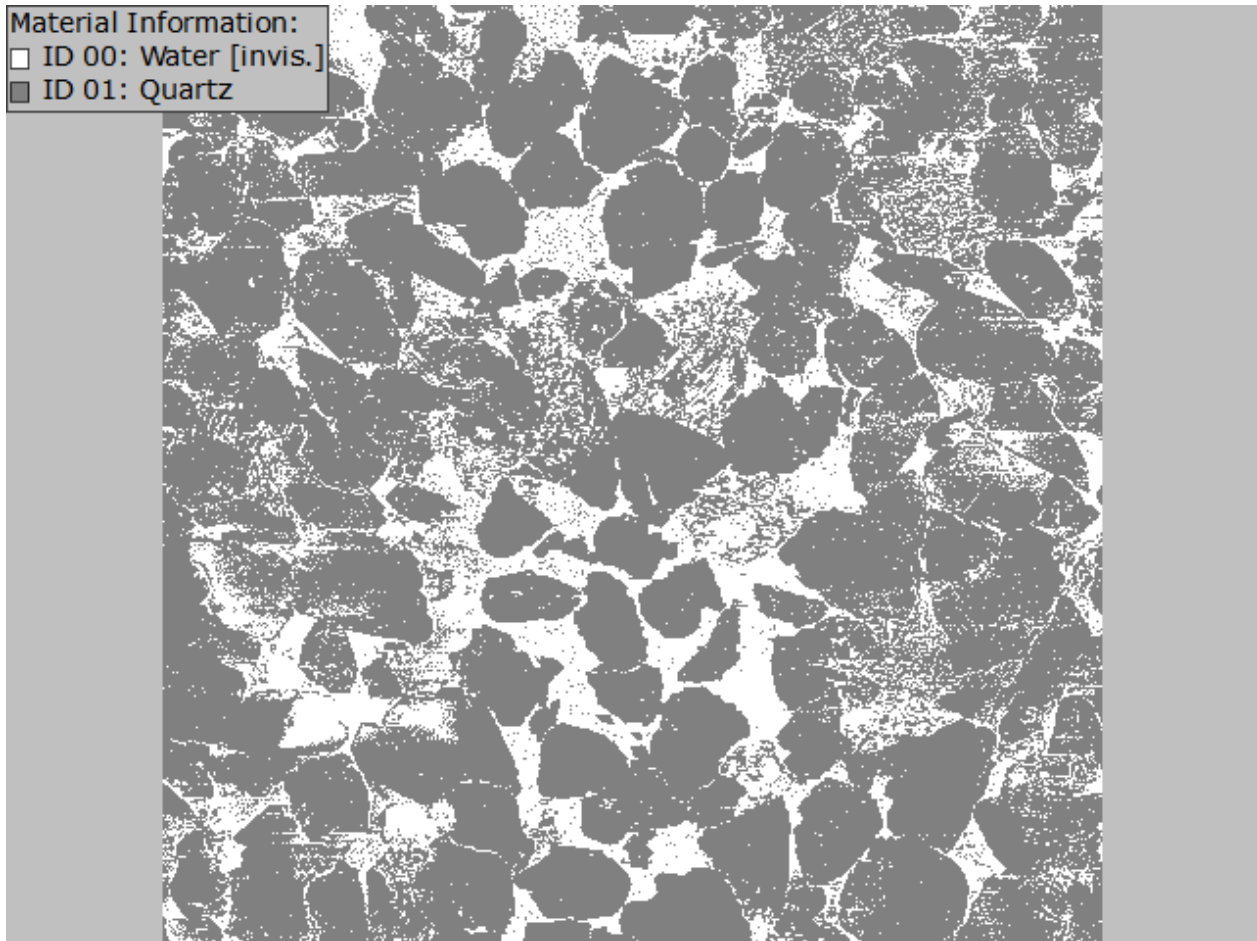
For the segmentation, you first need to define the **Number of Thresholds**. If the information is available, you can also set the constituent materials for the segmented material phases (e.g., Water and Quartz).

Adjust the gray value **Thresholds** between the chosen materials 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](#)^[47] section to learn more about distinguishing materials by filtering 3D images.

In the **3D Image Quick Segmentation** dialog using the example above, pore space and solid fraction can be distinguished with a threshold of 115.5. Then, click **Segmentation** to segment

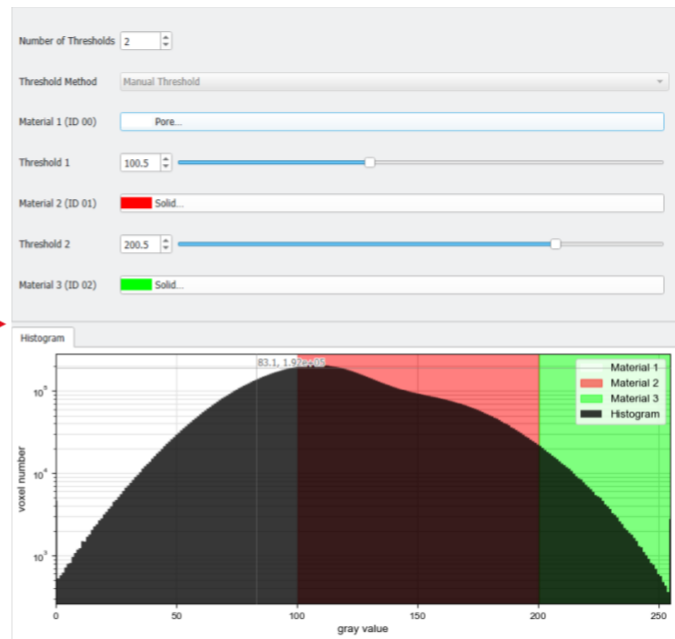
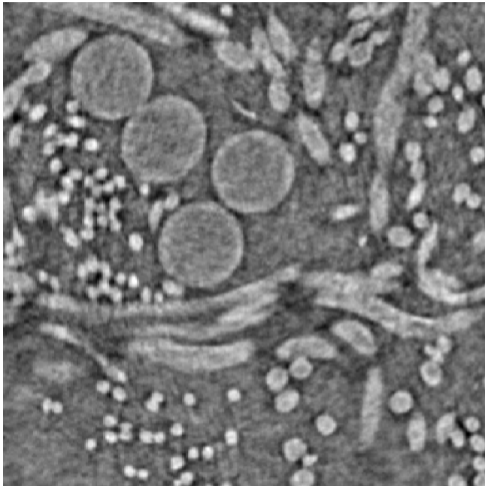
the image. Then the image dataset is segmented and visualized in the visualization area of the GeoDict GUI.

The 2D view 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 visualization highlights the need for a proper [Image Processing](#)^[23]. In general, if threshold values are not known a priori, it is recommended to continue with [Image Processing](#)^[23] instead of clicking **Quick Segmentation**.



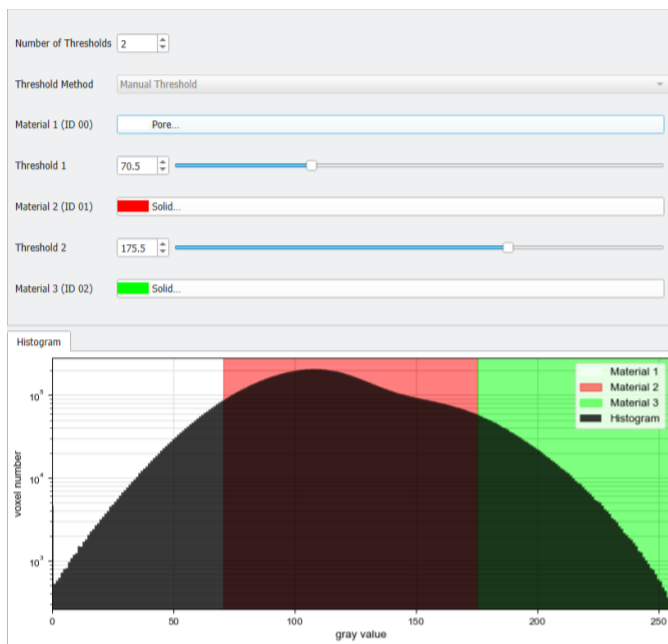
Second Example

In the following, the **Quick Segmentation** feature is explained on another sample (this is the same dataset as used [here](#)^[13]). After clicking **Quick Segmentation**, you can assign the gray values in the image file(s) to Material IDs (and their colors) for visualization in GeoDict. It is possible to set up to 255 thresholds.

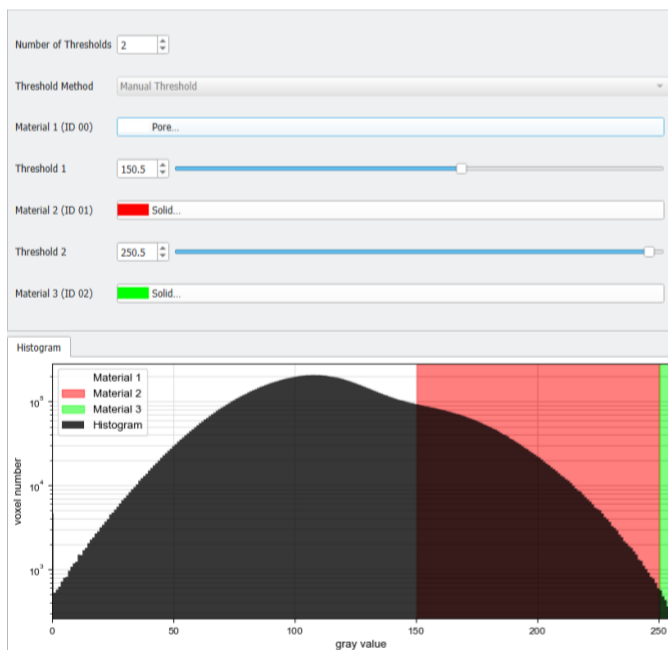
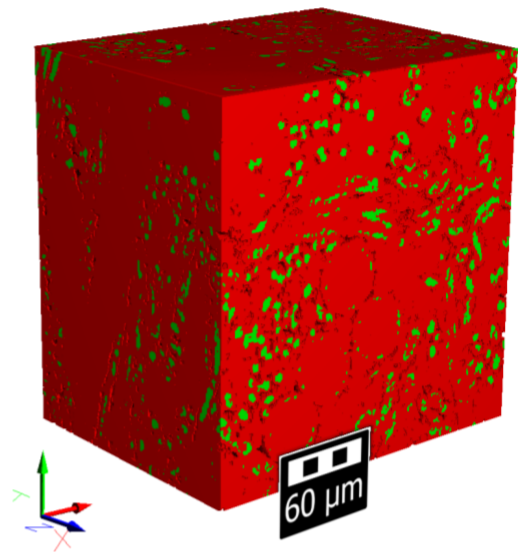


Move the threshold value sliders around before segmenting the stack of images and see the [Image Segmentation](#)^[104] section for more information on thresholding values. After setting the thresholds, click **Segmentation** to load the cutout specified in the **Import Geometry** dialog.

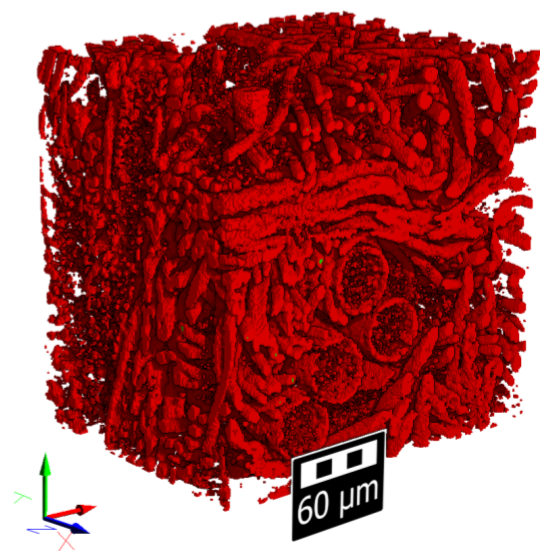
ImportGeo-Vol: Quick Segmentation



Material Information:
ID 00: Pore [invis.]
ID 01: Solid
ID 02: Solid



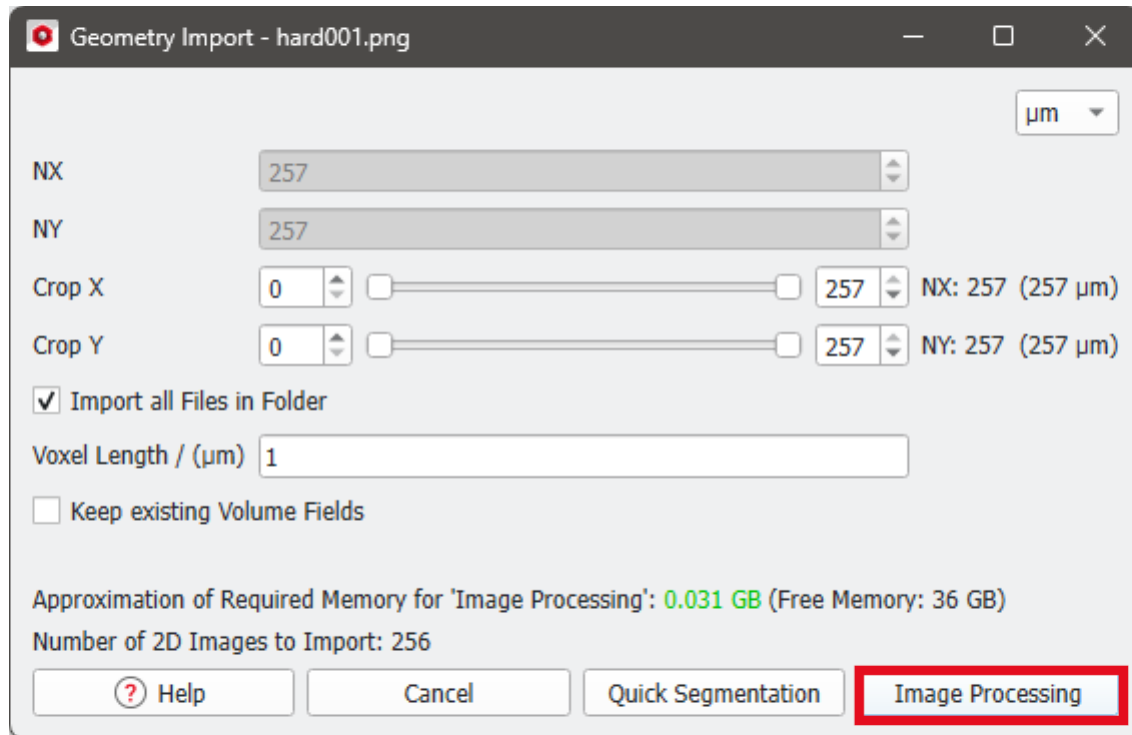
Material Information:
ID 00: Pore [invis.]
ID 01: Solid
ID 02: Solid



1.4 3D Image Processing

Advanced **3D Image Processing** is available for all [file formats](#)^[8] supported by ImportGeo-Vol. Images can be cut, re-sized, rotated, filtered, and segmented using different methods.

To process an image file or a stack of image files for import, click **Browse**, locate them, fill in the needed parameters in the [Geometry Import](#)^[5] dialog, and then click **Image Processing**.



All steps done in the image processing tab are not only visualized in the [2D Slice Visualization](#)^[40] area in the [3D Image Processing](#)^[24] dialog, but also in the main GeoDict GUI, where the view can also be switched to 3D by selecting **View** → **3D Rendering**. You can find a short introduction to visualization in GeoDict [here](#)^[141]. For more detailed information, refer to the Visualization user guide.

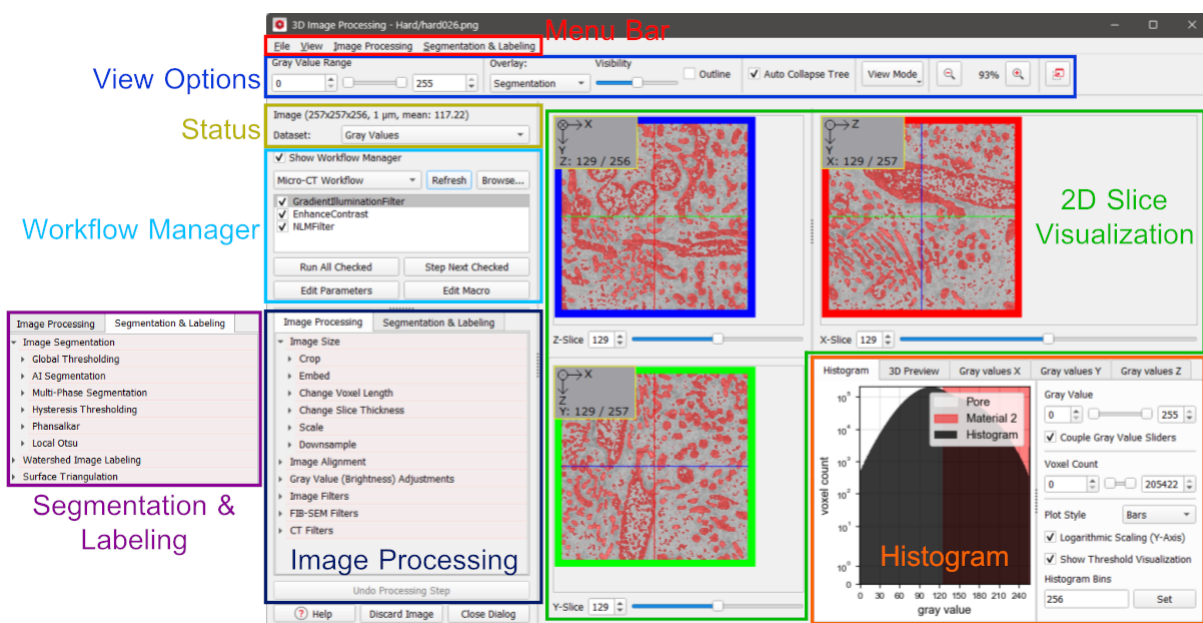
Explore all sections and features of the 3D Image Processing dialog:

- [3D Image Processing Dialog](#)^[24]
Learn to navigate the 3D Image Processing dialog.
- [Image Processing Tools](#)^[47]
Understand how to process and filter your images.
- [Segmentation & Labeling Tools](#)^[104]
Find out how to segment your images using different methods.
- [3D Gray Value Visualization](#)^[141]
Learn how to visualize gray-value images as a volume field in the main GeoDict GUI.

1.4.1 3D Image Processing Dialog

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

- The **Menu Bar**^[25] at the top provides quick access to the **File**, **View**, **Image Processing** and **Segmentation & Labeling** pull-down menus.
- The Quick Access Bar for **View Options**^[36] displays the most frequently used view settings.
- The **2D Slice Visualization**^[40] section displays the image scan in all three directions.
- The **Histogram**^[41] section contains image statistics and related view settings.
- The **Status**^[45] section shows the image's size and resolution, as well as the intermediate results after applying filters.
- The **Workflow Manager**^[46] shows all the performed steps of your Image Processing workflow.
- The **Image Processing and Segmentation** section contains two tabs:
 - The **Image Processing**^[47] tab contains all the tools needed to crop, re-size, rotate, and filter the gray value images.
 - The **Segmentation & Labeling**^[104] tab contains all the tools needed to label and segment gray value images.



Know how! To reverse the last image processing step, click **Undo Processing Step**, located below the **Image Processing and Segmentation** panel.

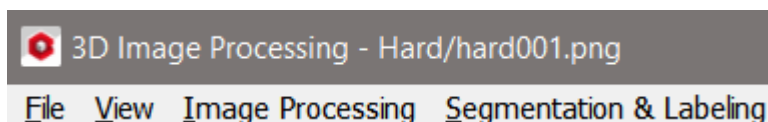
To abort the image processing, click either **Discard Image** or **Close Dialog**. Clicking **Discard Image** closes the dialog and removes the gray value image from memory, thus removing it from the GeoDict visualization area. **Close Dialog** only closes the dialog, while the gray value

image remains in memory and is still shown in the visualization area. Otherwise, the dialog will remain open, even after labeling or segmenting an image.

Processing files for import involves several steps. First, apply different processing tools in the [Image Processing](#)^[47] tab. Then, move to the [Segmentation and Labeling](#)^[104] tab to segment the image with the chosen method or label the image with the watershed algorithm. A result file (*.gdr) for the image processing and segmentation/labeling is then created, and the segmented structure (*.gdt) or labeled image (*.g32) is saved to a new folder according to the given **Result File Name**, as described [here](#)^[133]. You can create new and improved 3D models at any time by using different processing, segmentation, or labeling parameters.

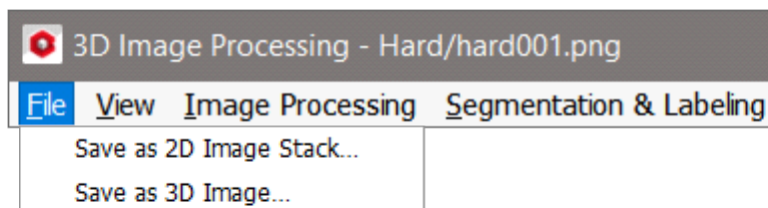
Menu Bar

From the **Menu Bar** in the **3D Image Processing** dialog, you can access **File** options that allow you to save the image as a 2D image slice(s) or as 3D image data. You can also 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 [Image Processing](#)^[47] and [Segmentation & Labeling tools](#)^[104].



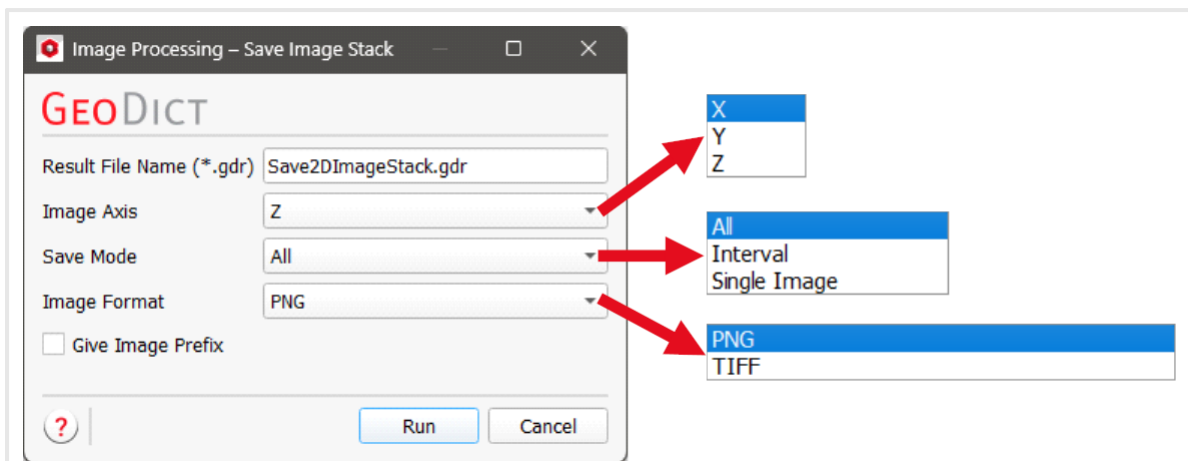
File

From the **File** menu, you can save the image as a **2D Image Stack** or a **3D Image**. This allows you to save the processed images as grayscale data before (or instead of) importing them into GeoDict.

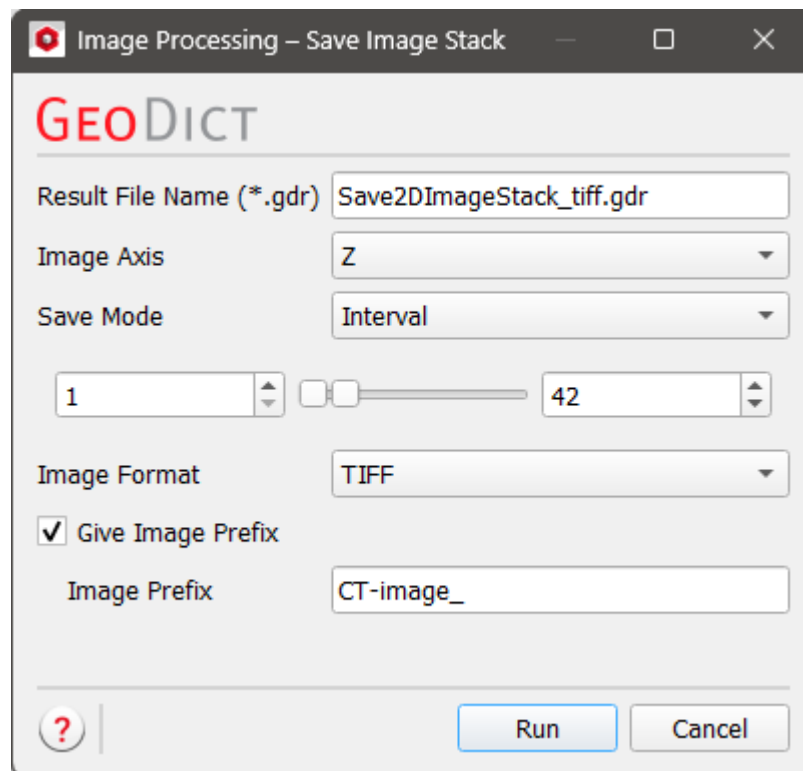


✓ Save as 2D Image Stack

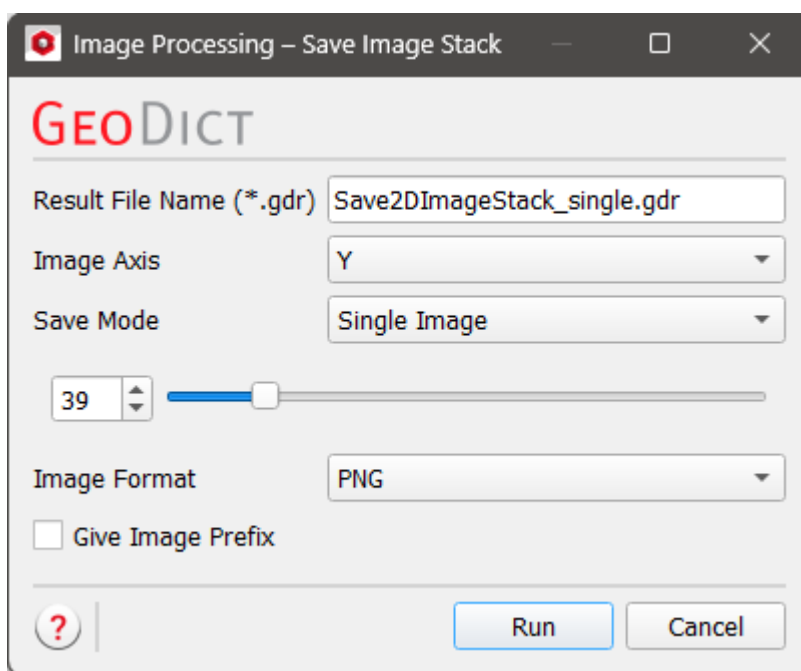
At the top of the dialog, provide a name for the **Result File** and the result folder. The 3D image dataset can be saved as a stack of 2D images in one of the spatial directions (**X**, **Y**, or **Z**). The names of the saved 2D images contains the selected direction and the slice number and start with either the folder name or a prefix if you choose **Give Image Prefix**.



You can select to save the entire stack of 2D images (**All**), a range of them (**Interval**), or just one (**Single Image**). If you select **Interval**, (1 to 42 in the shown example), the images in the Z-direction are saved as 2D TIFF files to the chosen folder. The images are named from *CT-image_Z00001.tif* through *CT-image_Z00042.tif*.



Also, a **Single Image** may be saved as a 2D image. For example, here, slice 39 in the Y-direction would be saved as PNG image.

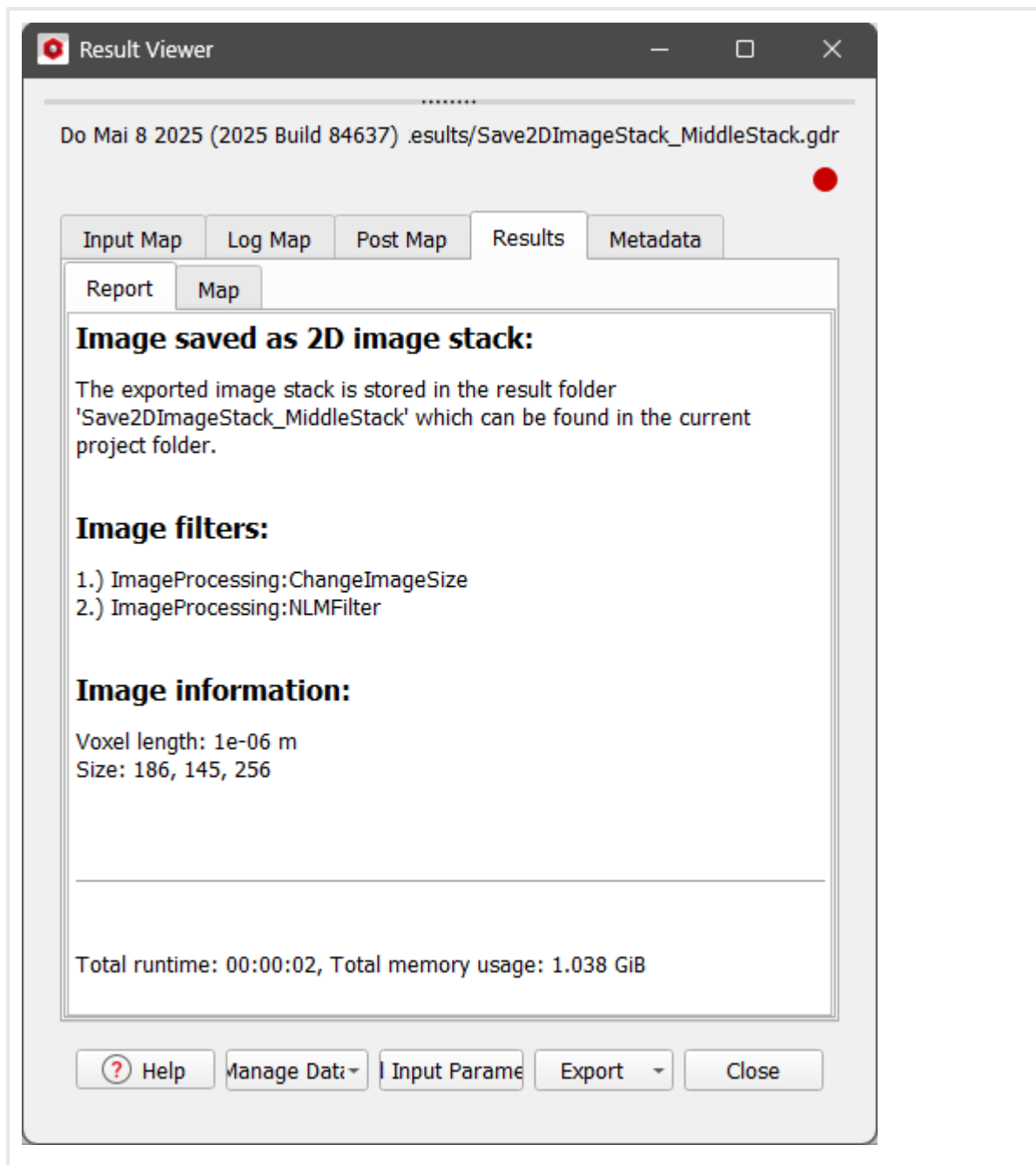


Depending on the data, slices may be saved as 2D images in either the 8-bit **PNG** or as 8-/16-bit **TIFF** file format.



Note! Upon import, 32-bit image data is converted to 16-bit, so it will also be exported as 16-bit TIFF files.

The slice thickness is one voxel length. Additionally, a GeoDict result file (*.gdr) with the given name is saved to the current project folder. This file contains 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.

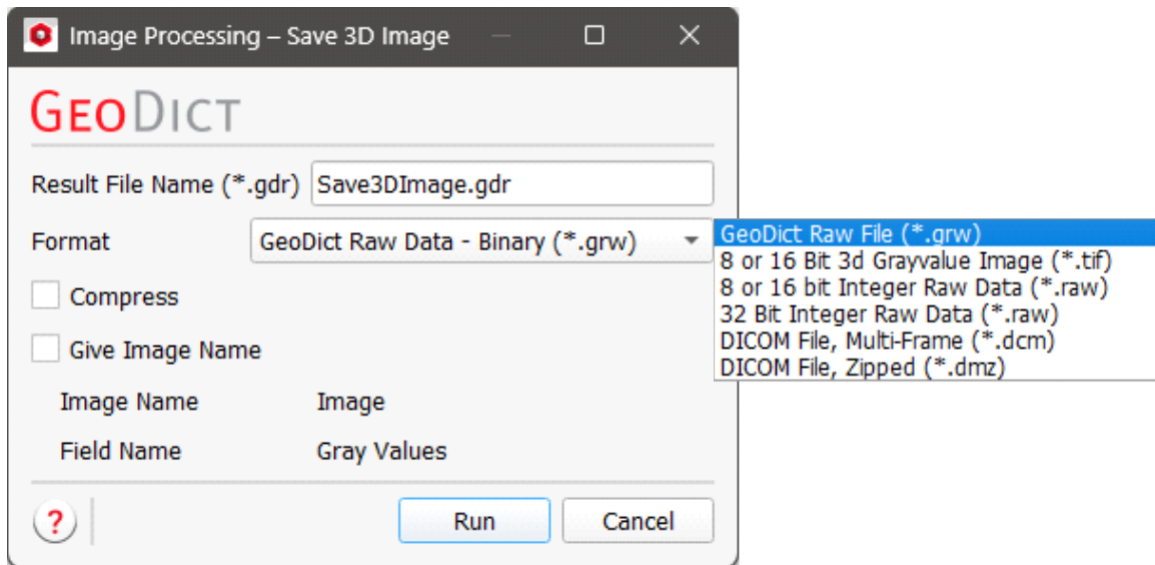


✓ Save as 3D Image

You can save 3D images in a single 3D data file with one of these file formats:

- GeoDict Raw File (*.grw)
- 8 or 16 Bit 3d Grayvalue Image (*.tif)
- 8 or 16 Bit Integer Raw Data (*.raw)
- 32 Bit Integer Raw Data (*.raw)
- DICOM File, Multi-Frame (*.dcm)

- DICOM File, Zipped (*.dmz)

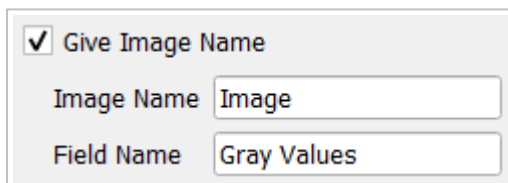


Define a **Result File Name** at the top of the dialog. Click **Run** to store the result file and 3D image file in the current project folder.

More options are available when storing data in the GeoDict *.grw file format. A *.grw file is a **GeoDict Universal File** with a standardized header describing the 3D data format. You can read this header with a text editor such as Notepad++.

Checking the **Compress** box will compress the raw part of the image. Thus, the image data is compressed while the header remains uncompressed.

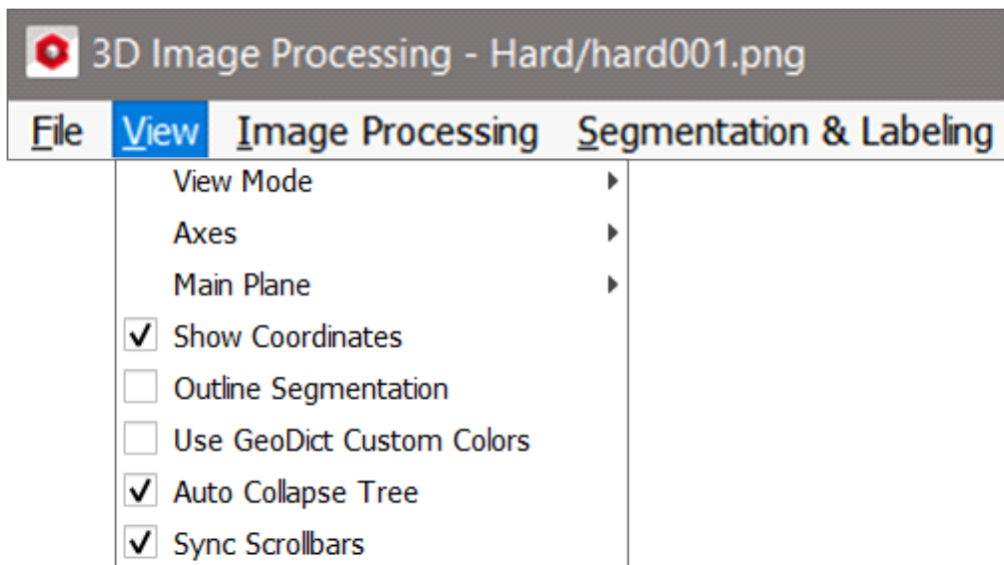
Define the **Image Name** and the **Field Name** by checking **Give Image Name**. These names are visible when loading the gray values into GeoDict as a volume field, for example. The name will then appear in the Project Status section and as the title of the gray value legend. If **Give Image Name** is not selected, the default names *Image* and *Gray Values* are used instead.



Additionally, a GeoDict result file (*.gdr) with the defined **Result File Name** is saved to the current project folder. This file contains 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.

View

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



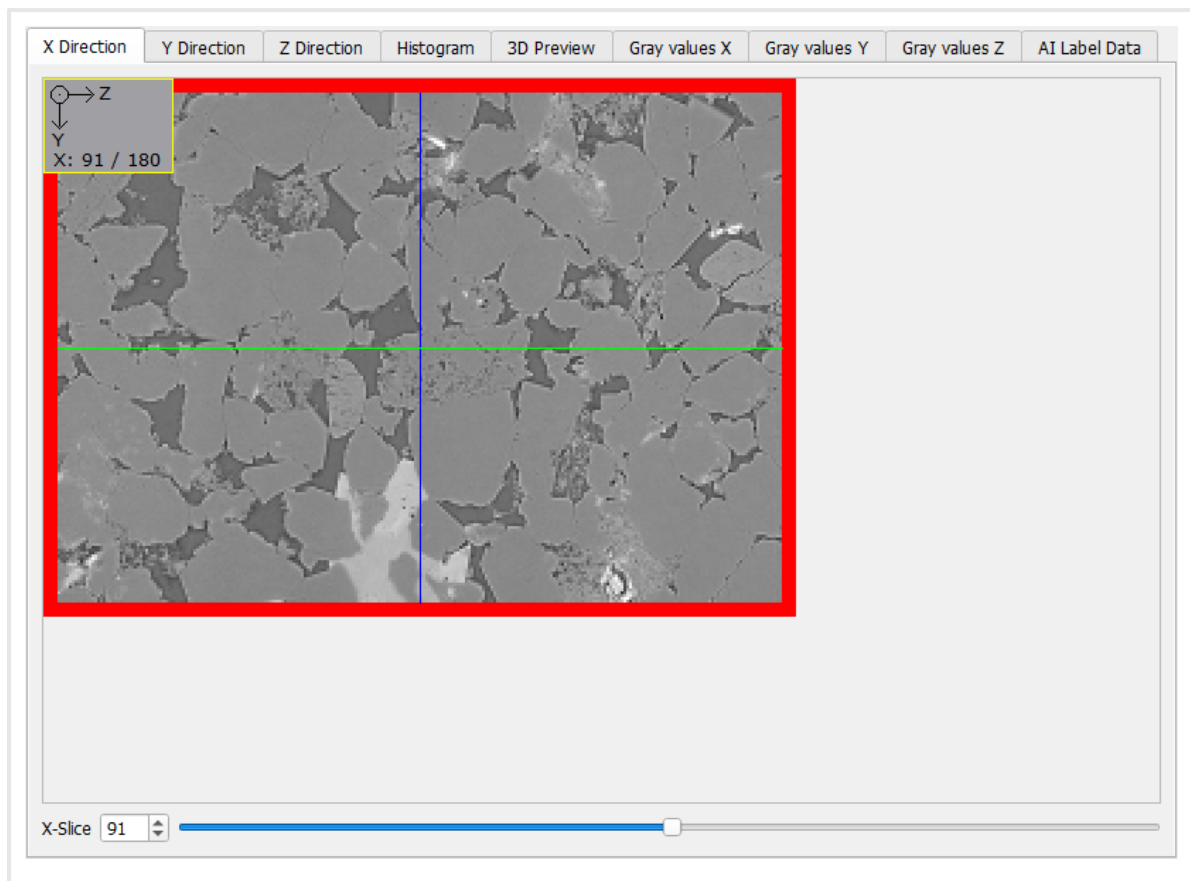
✓ View Mode

The **View Mode** allows you to switch between **Tile View** and **Stacked View**.

- Tile View (2D/Histogram)
- Stacked View

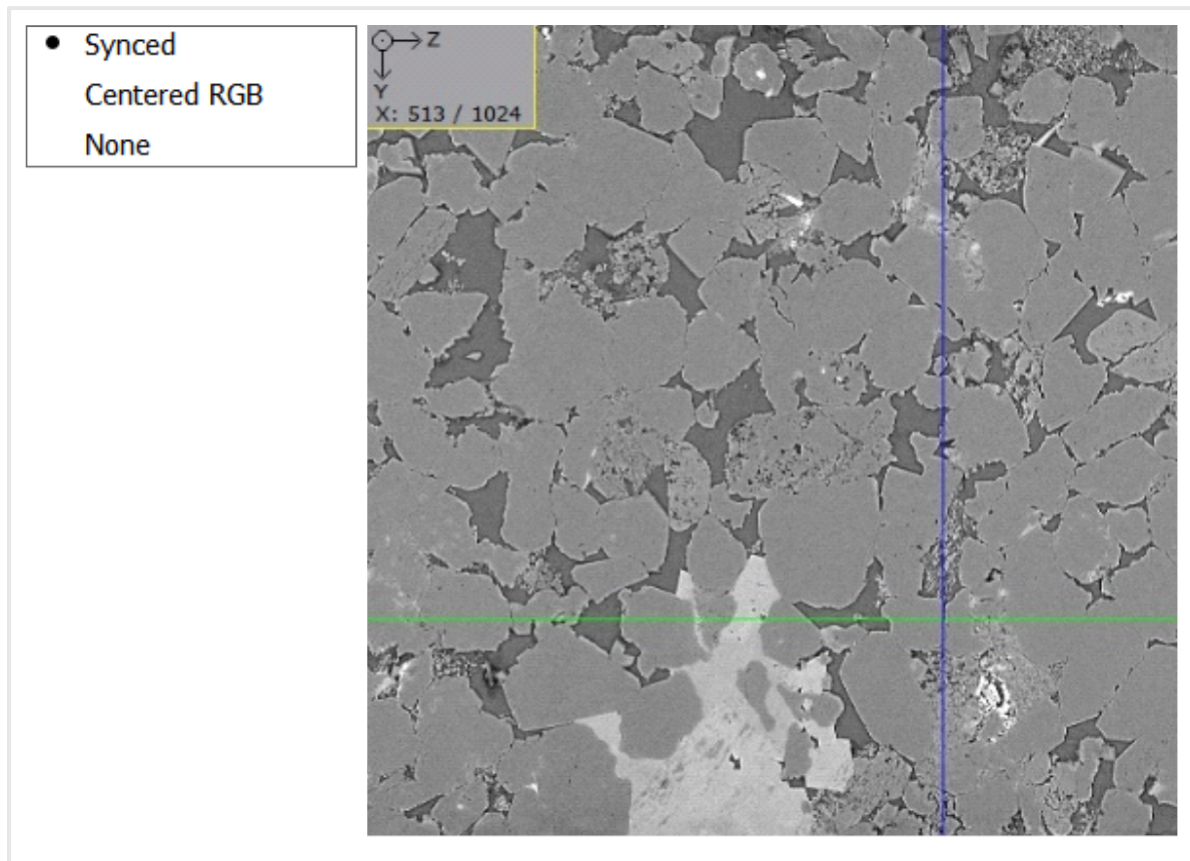
The **Tile View** displays the three 2D slices (for the X-Y, X-Z, and Y-Z planes) and the histogram section, as shown in the screenshot of the 3D Image Processing dialog [here](#)²⁴.

In **Stacked View**, only one 2D slice or tab from the [Histogram](#)⁴¹ section is displayed. You can focus on a specific visualization by selecting it from the available tabs.



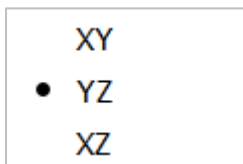
✓ Axes

The **Axes** selection controls the display of lines that provide orientation in the 2D image slices. For **Synced**, the lines show the currently selected slices in the other two planes, as seen in the screenshot below. The colors of the lines correspond to the colors of the boundaries around the slices in the **2D Slice Visualization** section (blue for the X-Y plane, green for the X-Z plane, and red for the Y-Z plane). For **Centered RGB**, the lines are always displayed in the center. For **None**, the lines are invisible.



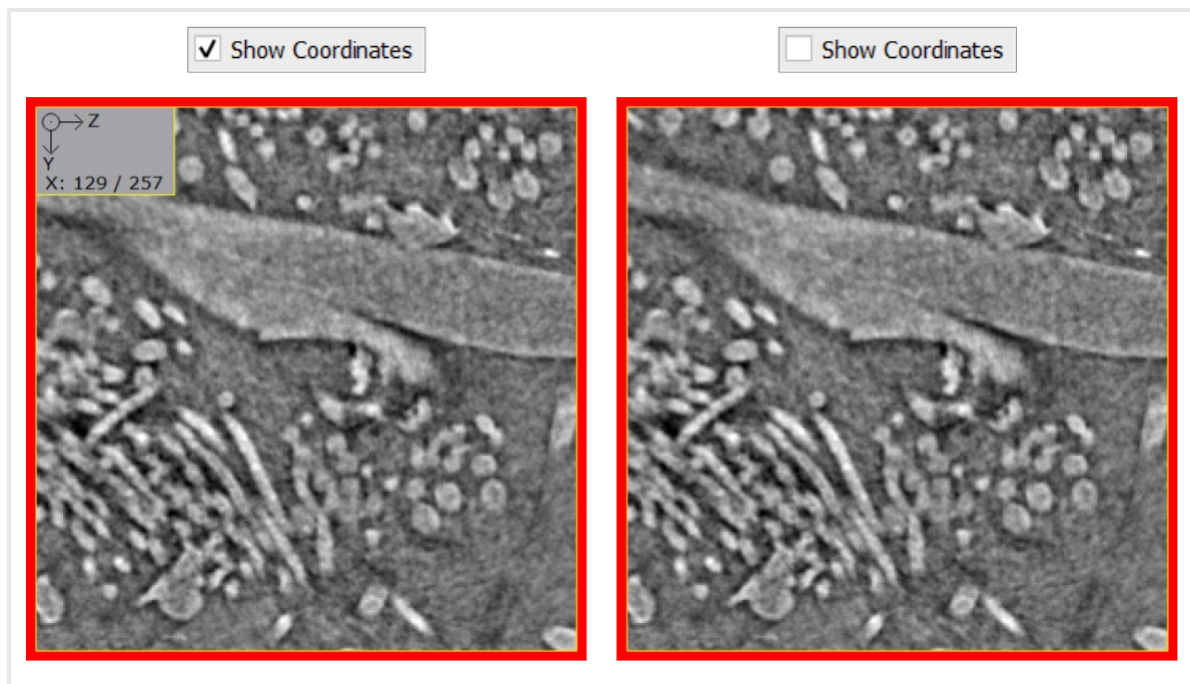
✓ Main Plane

From the **View** menu, you can select the **Main Plane**. This option only affects the visualization in [Tile View](#)³⁰. The selected plane is displayed in the upper left panel (here, YZ), and the order of the panels changes according to the selection.



✓ Show Coordinates

Check or uncheck **Show Coordinates** to control whether the legend in the upper left corner is displayed. The legend contains information about the plane and slice in the preview areas for the three directions.

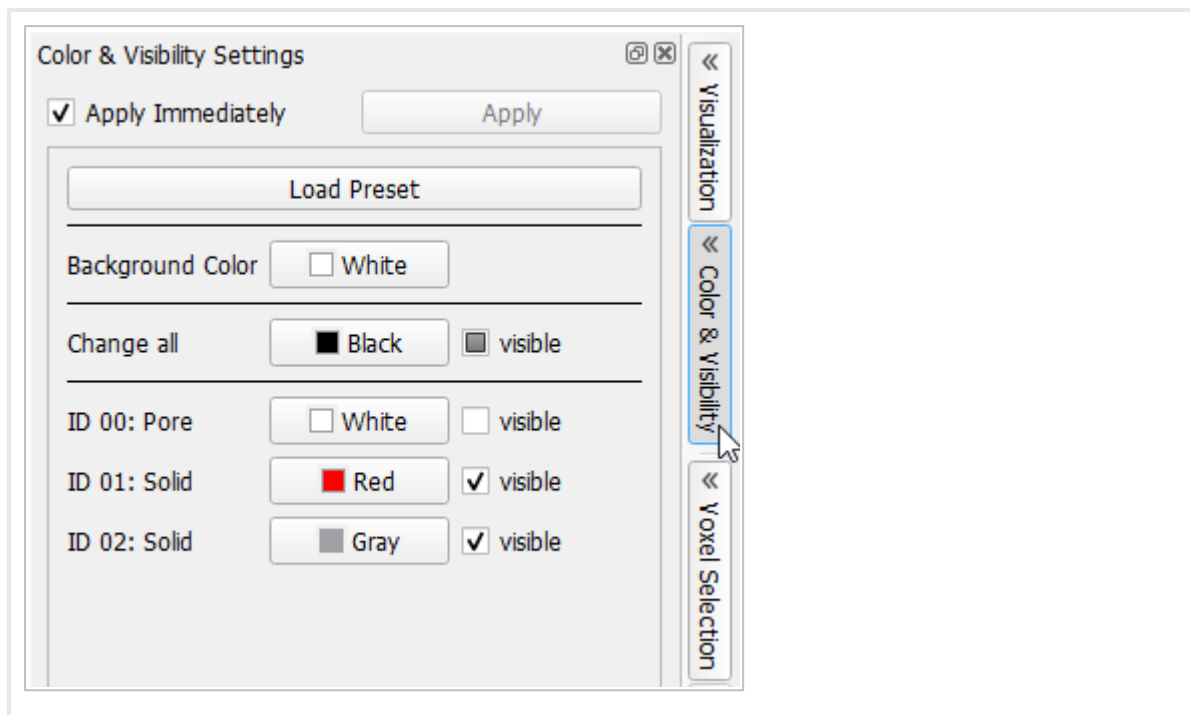


✓ Outline Segmentation

Outline Segmentation refers to the representation of the thresholding settings, which is explained in more detail in the [Image Segmentation](#)³⁸ section.

✓ Use GeoDict Custom Colors

Use GeoDict Custom Colors to change the colors representing the threshold settings for the image segmentation to those currently defined in the main GeoDict GUI. These color settings are accessible via the Color & Visibility tab in the sidebar to the right of the main GeoDict window:



✓ Auto Collapse Tree

When the **Auto Collapse Tree** option is selected, only the currently chosen feature from the **Image Processing** or **Segmentation & Labeling** tab is visible in the **Image Processing and Segmentation** section. For convenience and simplification, all other features are automatically collapsed after selecting another feature in the respective tab.

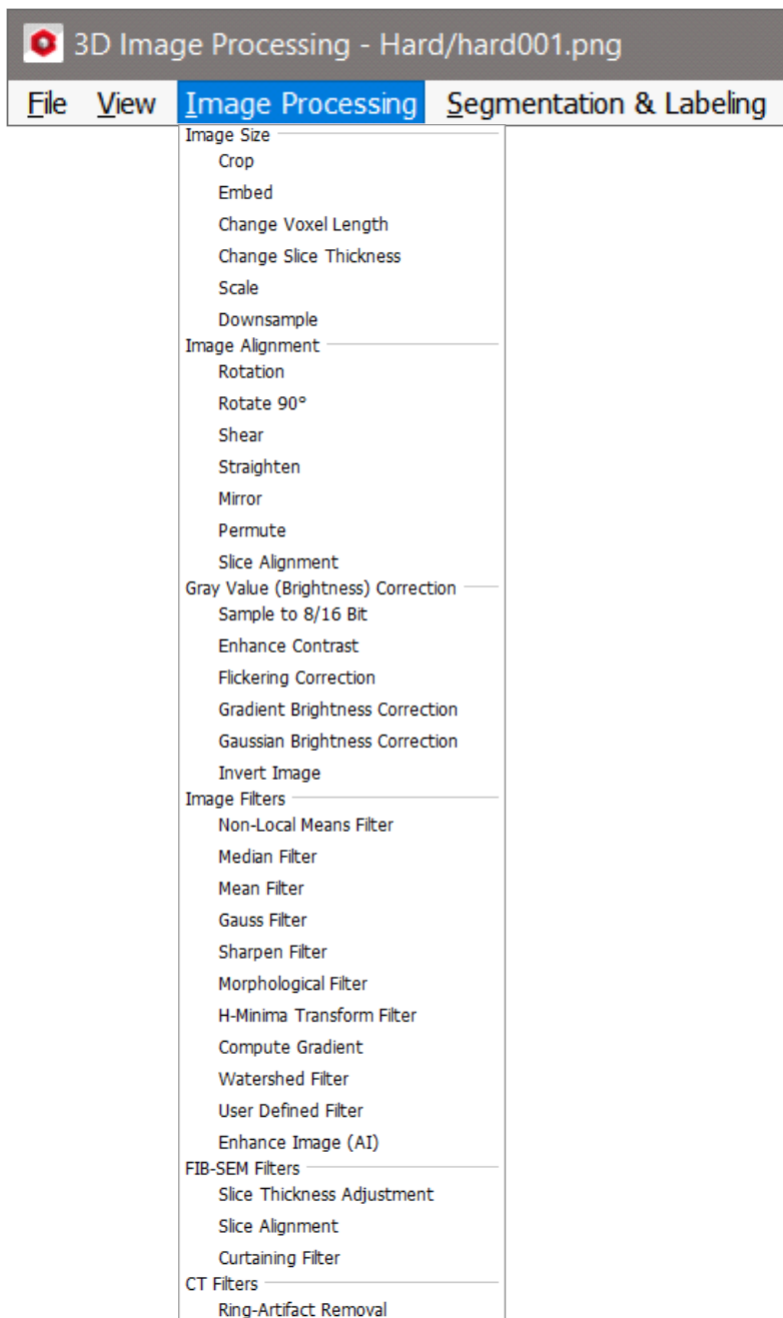
✓ Sync Scrollbars

Select the **Sync Scrollbars** option to synchronize the 2D slices in the **Tile View** when scrolling the excerpt up, down, left, or right.

Image Processing

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

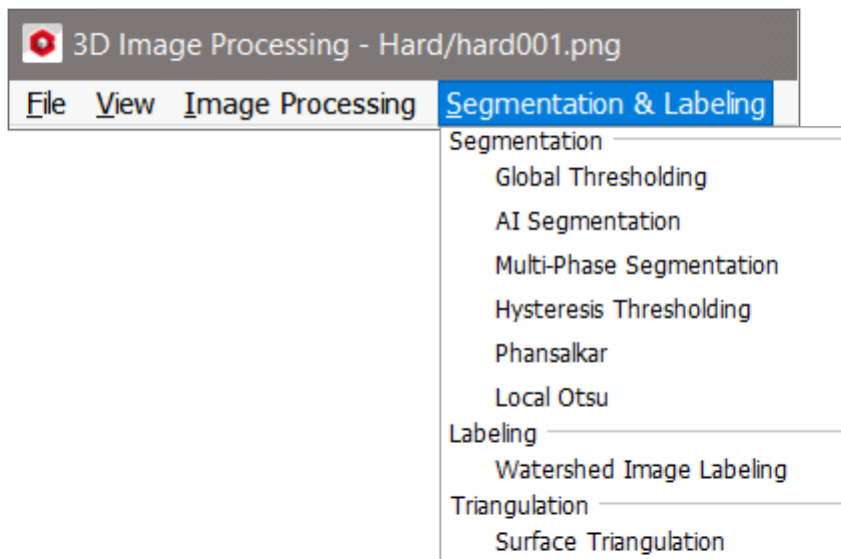
Click on the names of the various features to be forwarded directly to the corresponding functionality in the [Image Processing](#)^[47] tab to the left of the [3D Image Processing dialog](#)^[24].



Segmentation & Labeling

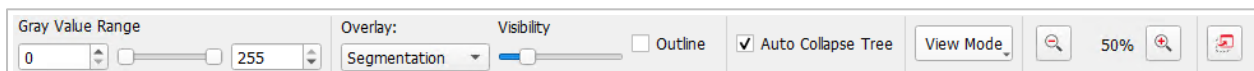
The **Segmentation & Labeling** menu provides an overview of the [3D Image Segmentation and Labeling](#)^[104] tools in GeoDict.

Click on a features's name to be forwarded directly to its corresponding method in the [Segmentation & Labeling](#)^[104] tab to the left of the [3D Image Processing dialog](#)^[24].



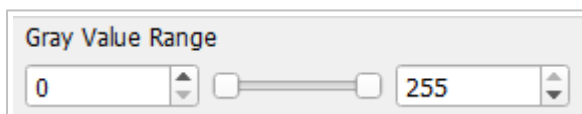
View Options

The **View Options** section provides quick access to the most frequently used visualization settings and is always visible. You can use this section to set the **Gray Value Range** to be viewed, choose between the two **View Modes** (see the [View menu](#)^[29] for more information), or **Zoom** in and out by a factor of two per click.

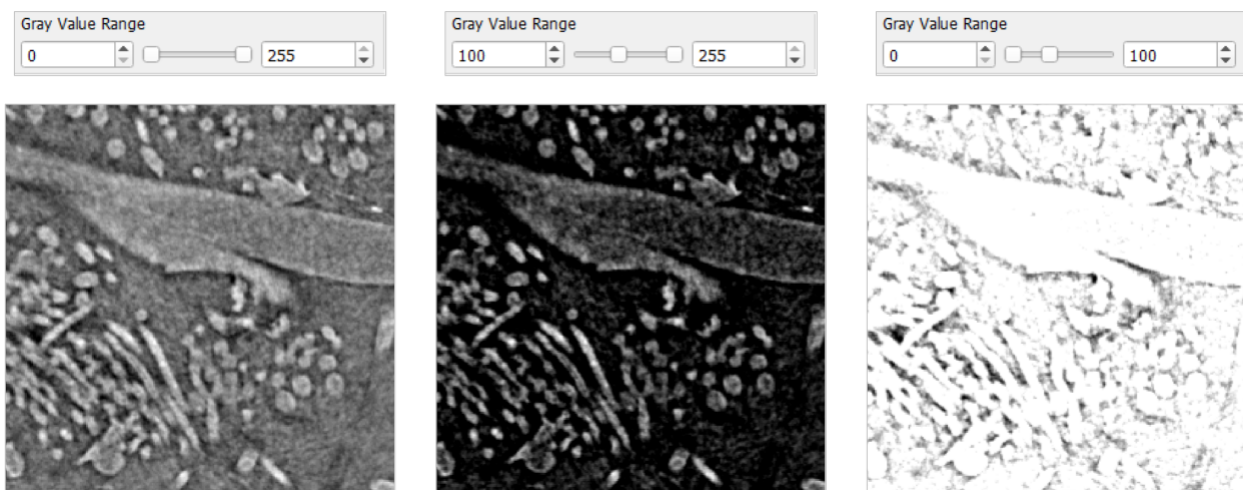


Gray Value Range

Adjust the **Gray Value Range** to narrow or widen the interval, within which the gray values brighten from black to white.



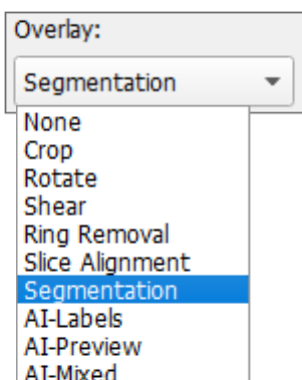
Change the interval by moving the slider or entering specific numbers directly. Observe the difference with varying settings in the images shown below. When the gray value range is set from **0** to **255**, the gray values are displayed for the full data range because this is an 8-bit image. When the gray value range is set to **100** to **255**, the values between 0 and 100 are assigned the color black, and the rest become relatively darker. The higher range of gray values is removed from the image when the gray value range is set from **0** to **100**. Voxels with gray values from 0 to 100 become relatively brighter, while those with values of 101 or higher are assigned the color white.



Overlay

From the **Overlay** pull-down menu select the desired overlay for the [2D Slice Visualization](#)^[40] section. The overlay is updated automatically if one of the corresponding options in the [Image Processing](#)^[47] and [Segmentation](#)^[104] section are edited.

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



Selecting **None** will result in no overlay being displayed in the **2D Slice Visualization** section.

The next five options correspond to functions from the [Image Processing](#)^[47] tab:

- The **Crop** overlay corresponds to the [Image Size – Crop](#)^[48] feature. When selected, a yellow rectangle shows the cutout resulting from the entered values.
- The **Rotate** overlay corresponds to the [Image Alignment – Rotation](#)^[56] feature and displays the new axes after rotation, if the visualization of the axes is turned on, as described [here](#)^[31].
- The **Shear** overlay corresponds to the [Image Alignment – Shear](#)^[60] feature and shows the new resulting center line as a yellow line.
- Selecting **Ring Removal** displays a yellow ring on the images, showing the values entered for the [CT Filters – Ring-Artifact Removal](#)^[102] feature.

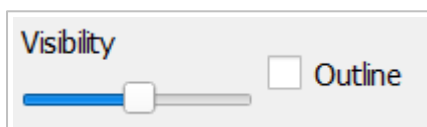
- The **Slice Alignment** overlay corresponds to the [FIB-SEM Filters – Slice Alignment \(Z-Direction\)](#)^[97] feature. When selected, a red rectangle appears in the X-Y-plane that displays the cutout resulting from the entered values.

The last four overlay options correspond to functions from the [Segmentation & Labeling](#)^[104] tab:

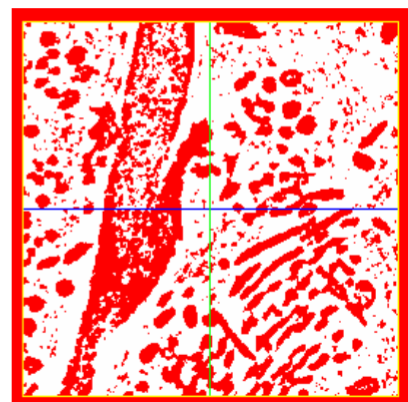
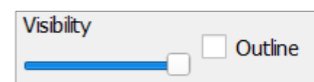
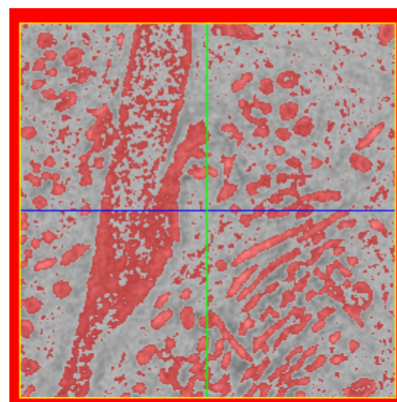
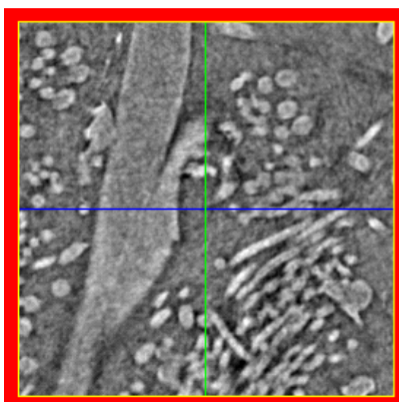
- The **Segmentation** overlay is selected by default and shows the segmentation result if the [Visibility](#)^[38] is turned on. The visualized segmentation corresponds to the values entered for the options in the [Image Segmentation](#)^[104] section.
- The **AI-Labels**, **AI-Preview**, and **AI-Mixed** overlays correspond to the features of the [AI-based Segmentation](#)^[111] method. They are only shown when the [Visibility](#)^[38] is turned on.

Visibility and Outline

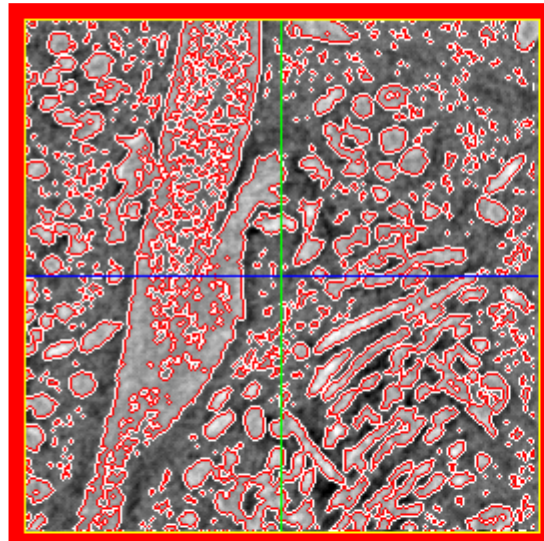
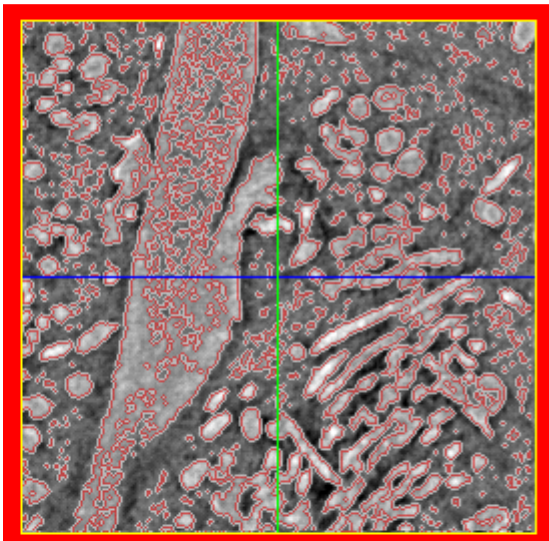
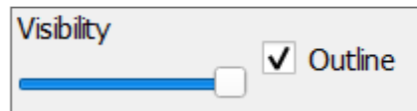
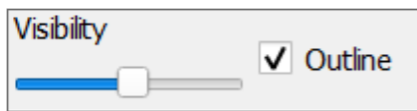
The **Visibility** slider and **Outline** checkbox control the visualization of the threshold(s) used for segmentation as well as the labels and previews for the [AI-based Segmentation](#)^[111]. Moving the **Visibility** slider changes the transparency of the threshold(s) in the [2D Slice Visualization](#)^[40] section.



When the **Outline** option is selected, only the interface between the segmented phases is overlaid with the given thresholding color(s). Observe the difference with varying settings in the following images. When the **Visibility** is set to zero, only the gray values of the image are shown and the thresholded image is not visible. With intermediate **Visibility**, an overlay of the thresholded image and the gray value image is shown. When **Visibility** is at its maximum, only the thresholded image is shown.



When **Outline** is checked and intermediate **Visibility** is selected, the interface between the segmented phases is slightly overlaid with the given thresholding color. When **Outline** is selected and **Visibility** is increased, these interfaces become increasingly highlighted.



Pressing **CTRL + A** toggles between the currently selected visibility value and a visibility value of zero. This allows you to quickly enable or disable an overlay with one shortcut, which can be especially helpful when [labeling](#)^[121] for AI segmentation.

Auto Collapse Tree, View Mode, and Zoom

When you select the **Auto Collapse Tree** option, only the currently chosen feature from the [Image Processing](#)^[47] or [Segmentation & Labeling](#)^[104] tab in the **Image Processing and Segmentation** section is visible. For convenience and simplification, all other features are automatically collapsed after selecting another feature in the respective tab.

Use the **Tile View** and **Stacked View** options in the **View Mode** menu to change the visualization area. This allows you to choose whether to show 2D slices of all three directions and the histogram section or to show only one of the directions or tabs of the histogram section. Refer to the [View menu](#)^[29] for more details.

The **Zoom** buttons on the right of the **View Options** zoom in and out of the 2D slices by a factor of two.

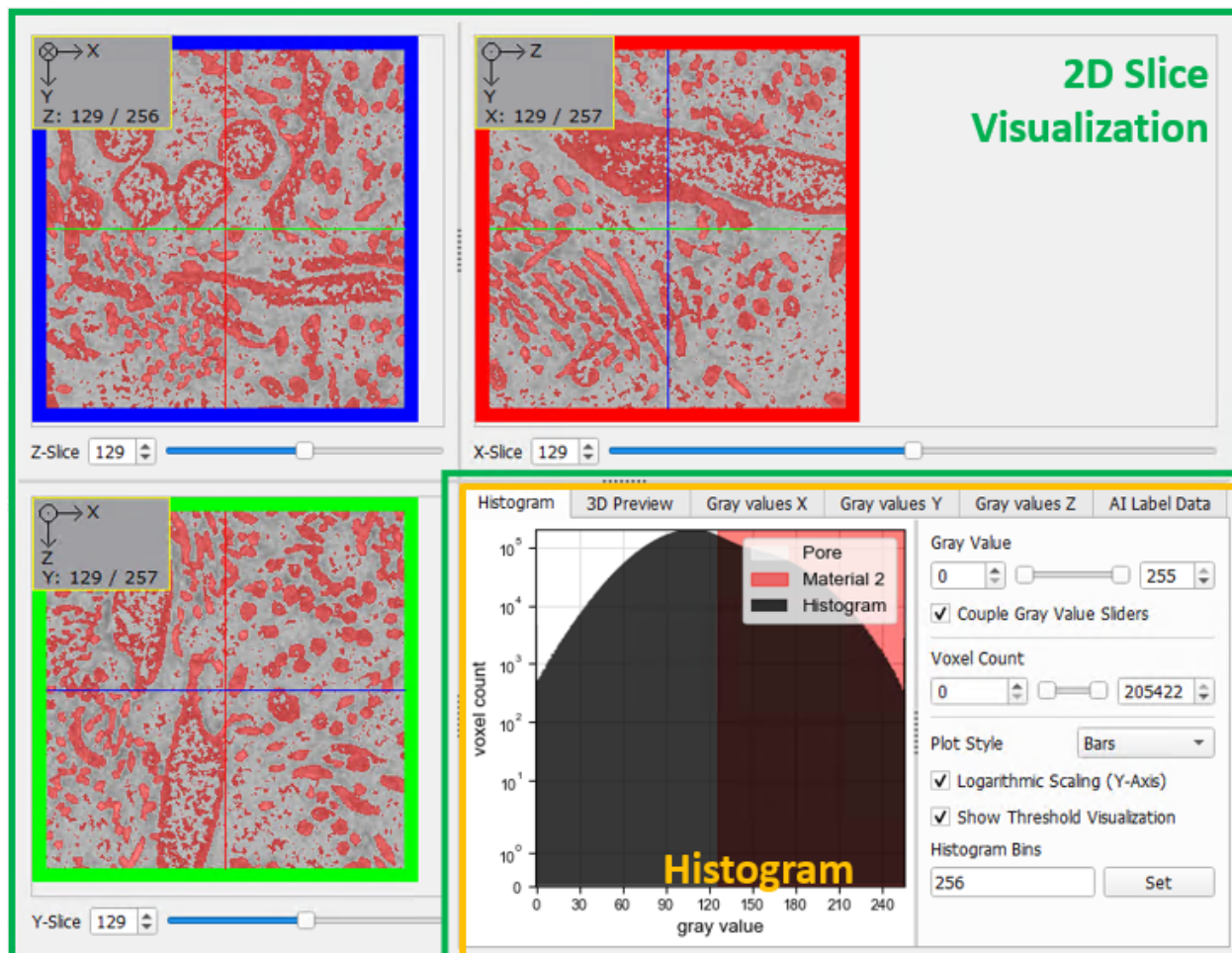


Know how! You can continuously zoom in or out by right-clicking on the image, holding the right mouse button down, and moving the mouse up or down.

Save time searching for the GeoDict **Main Window** in the taskbar by raising it by clicking on the corresponding icon .

2D Slice Visualization

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



The values for **Z-Slice**, **X-Slice**, and **Y-Slice**, located below the 2D images, control which slices are shown in the preview areas above. You can quickly change these values by resting the mouse cursor on the field box or the corresponding image slice and using the mouse wheel. The slice being shown also moves in the three-dimensional representation in the [3D Preview](#)^[43] tab in the histogram section.

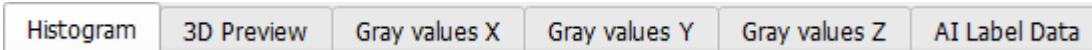
You can zoom in and out using the corresponding buttons in the [View Options](#)^[36] section, or by clicking and holding **CTRL** while scrolling the mouse wheel over a gray value image slice. To zoom continuously, right-click on the 2D image, hold the right mouse button, and move the mouse up and down.

Pan the image by holding down the left mouse button while moving the mouse.

For more information on 2D visualization, please refer to the [View menu](#)^[29] and the [View Options](#)^[36] section. Since the grayscale image is loaded into the GeoDict visualization area as well, consider the advanced 3D visualization options described in the Visualization user guide.

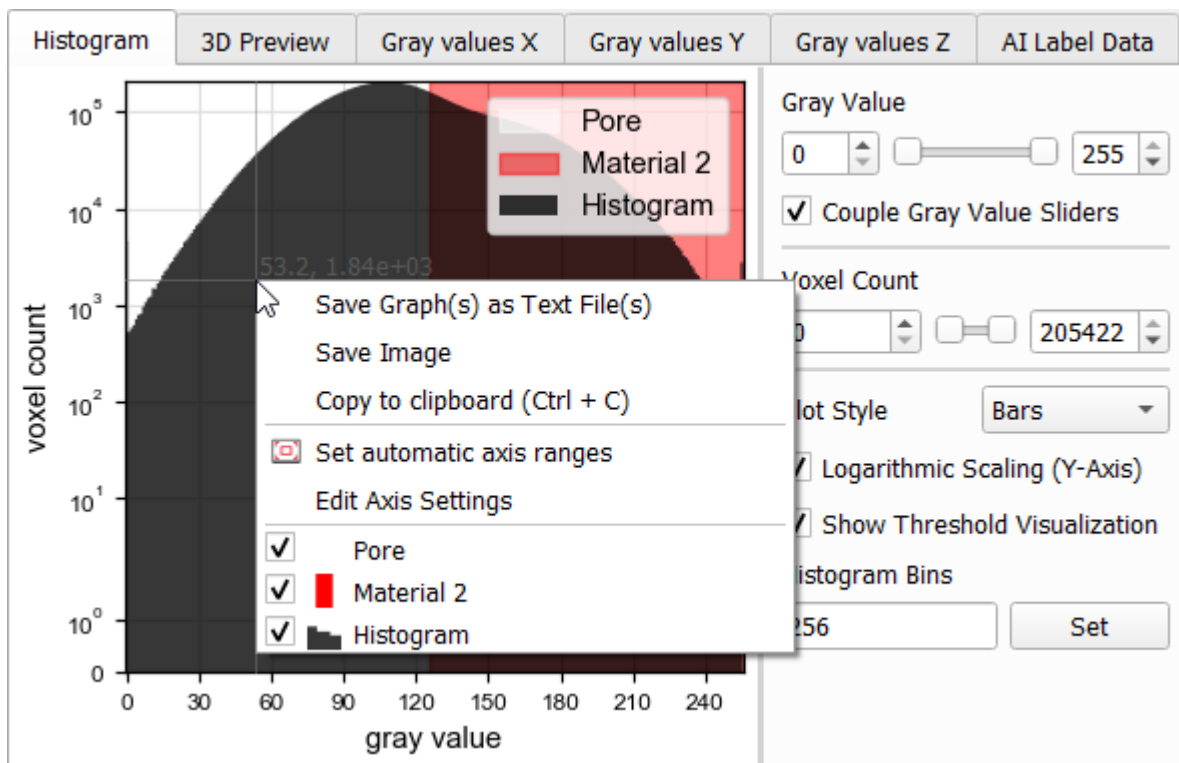
Histogram

The **Histogram** section contains statistical information about the gray value image and is organized into several tabs.



Histogram

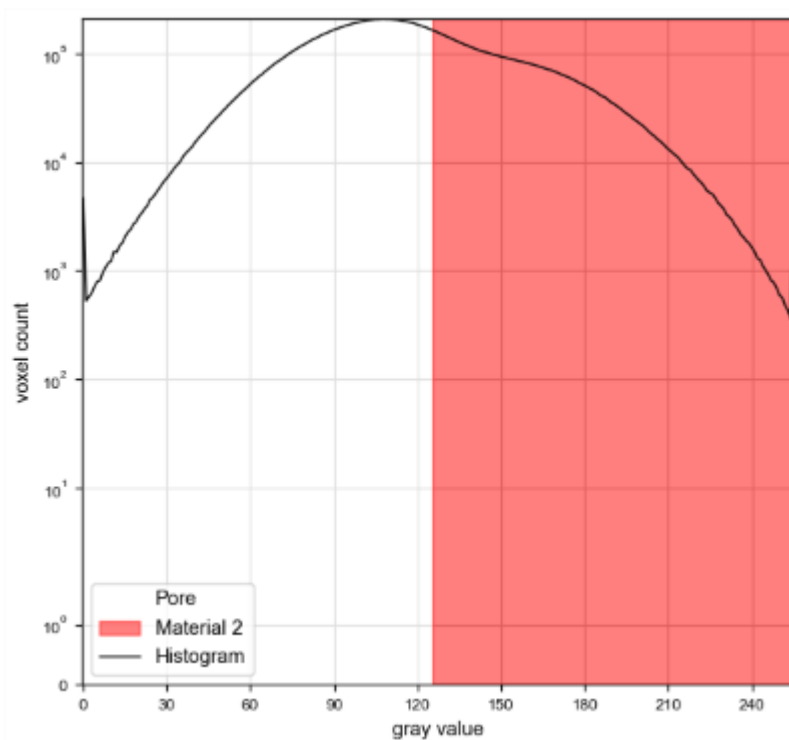
The **Histogram** shows the frequency of all gray values as absolute numbers, providing information on the number of distinguishable material phases. The appearance of the histogram, on the bottom right, is controlled by the options right next to it and by the context menu, which is accessed by right-clicking in the plot. The histogram plots the number of voxels against the gray values (within a given range) and shows how many voxels have a particular gray value.



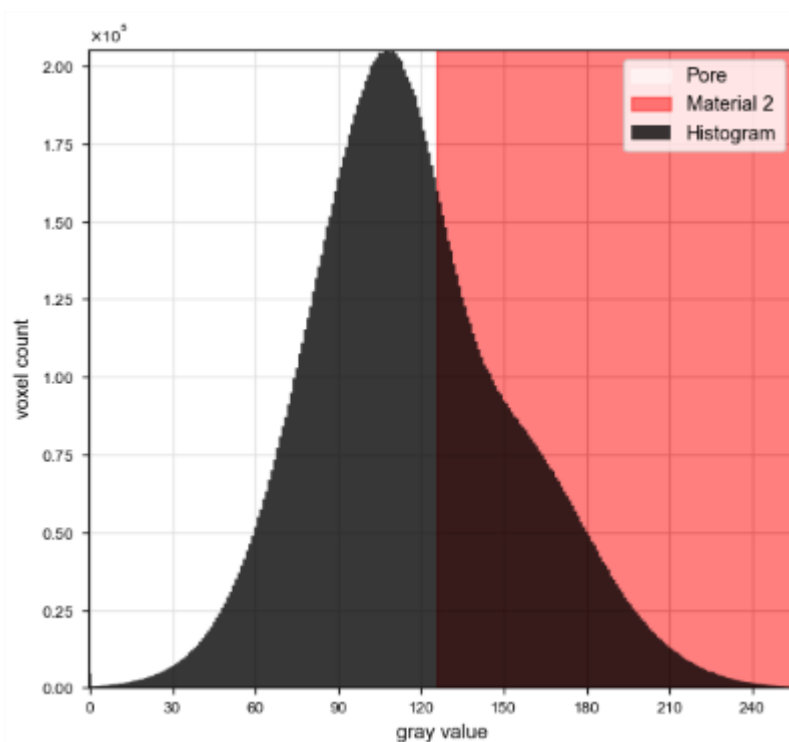
The **Gray Value** and **Voxel Count** ranges control the horizontal and vertical axes of the histogram, respectively. To focus on a specific area of the plot, adjust the voxel count and gray value ranges. The histogram will then change to show the portion of the plot corresponding to the new range of values.

The **Couple Gray Value Sliders** option couples the changes made to the **Gray Value** slider in the histogram with the general **Gray Value Range** in the image preview. This allows you to apply changes made in the histogram to the [2D Slice Visualization](#)^[40] as well.

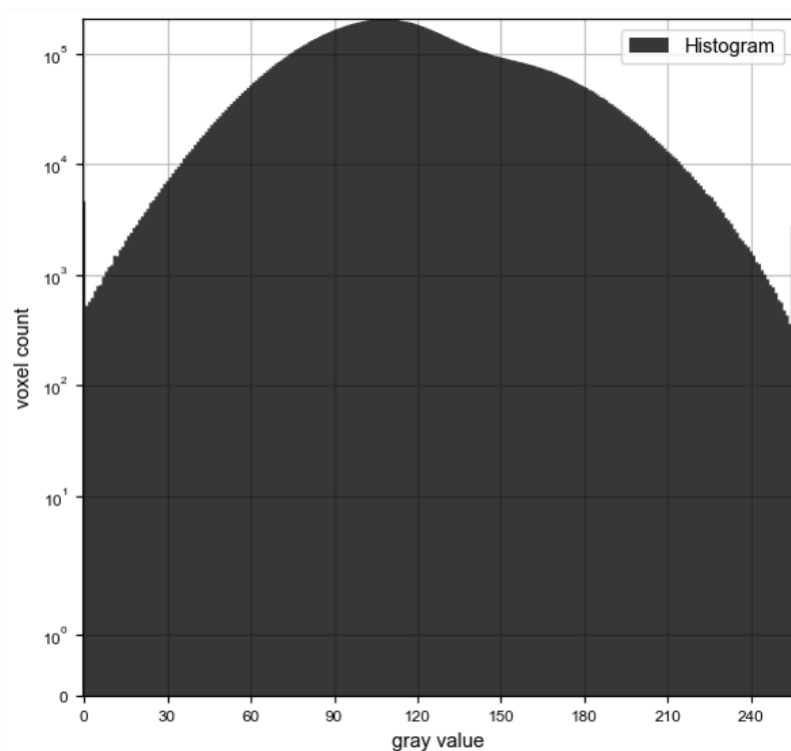
Depending on the preferred visualization, the **Plot Style** can be changed from the default **Bars** to a **Line** plot.



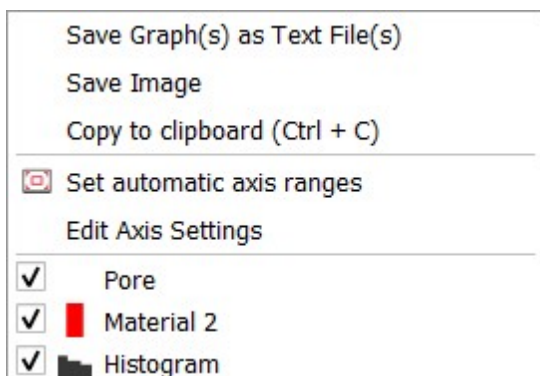
Deactivate **Logarithmic Scaling** of the **Y-Axis** to highlight the gray value ranges of material phases.



To disable the depiction of the segmentation thresholds between the different defined materials, choose not to **Show Threshold Visualization**. Find more information on segmentation thresholds [here](#)¹⁰⁸.

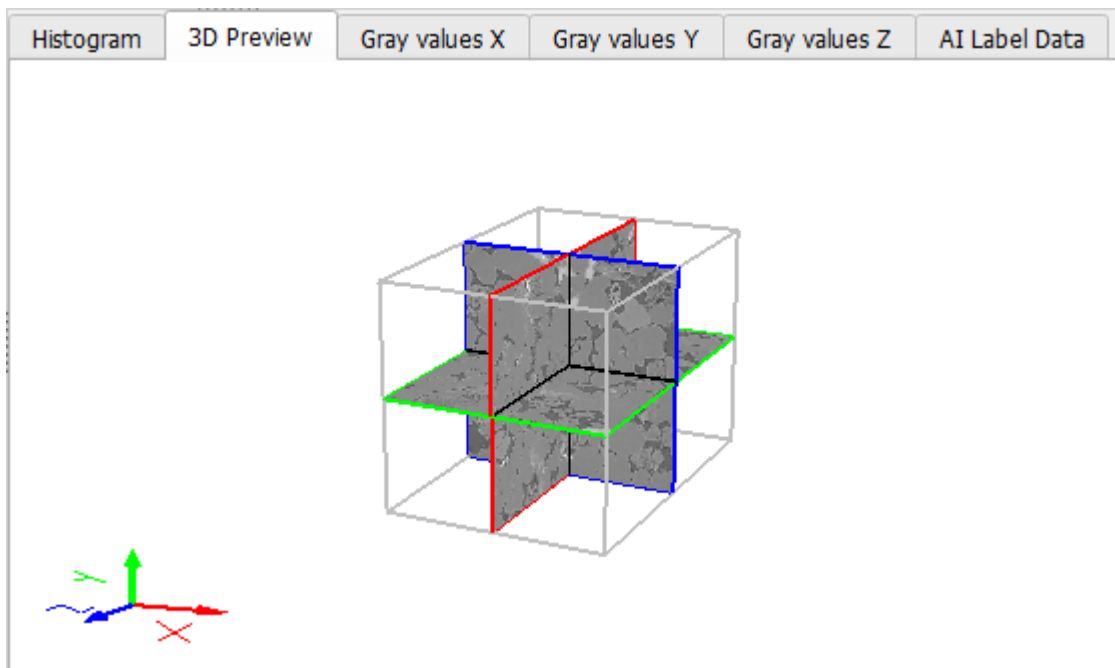


Right-click on the plot area to change its appearance further, save the image as a *.png or *.svg file, copy the image to the clipboard, or store all graph values in a *.txt file. The context menu is the same as that for **Result Viewer** plots and is described in more detail in the Result Viewer User Guide.



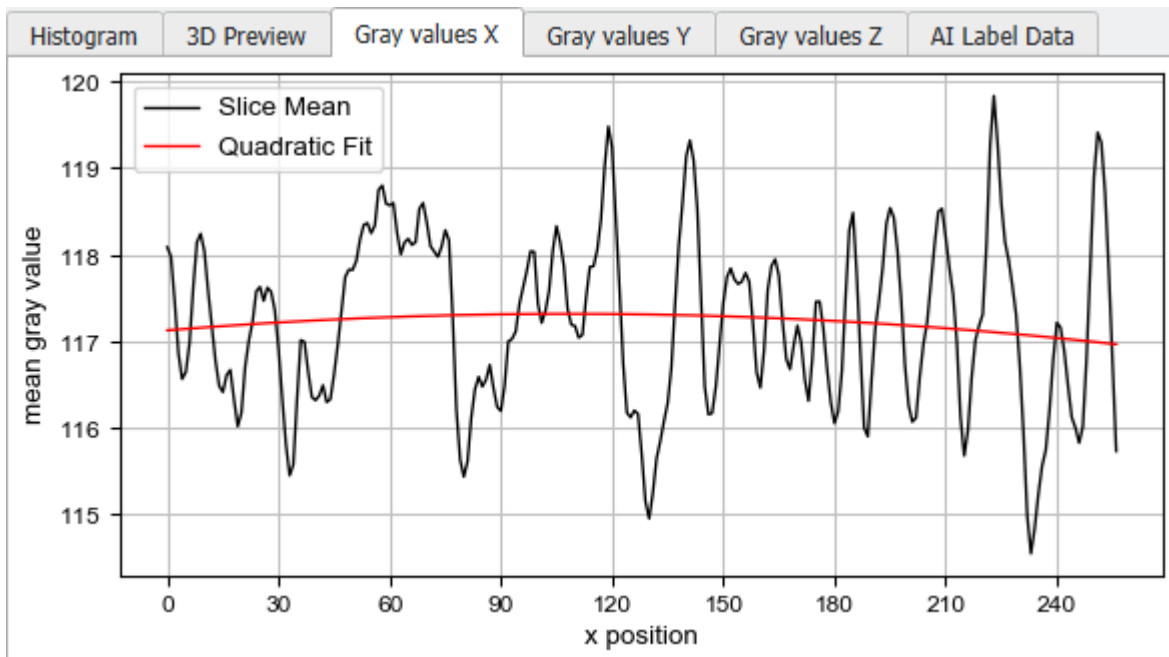
3D Preview

The **3D Preview** shows the X-, Y-, and Z-slices currently selected in the [2D Slice Visualization](#) ⁴⁰ as a 3D representation. This representation updates interactively when the slice selection is changed. Full 3D visualization options are available in the main GeoDict GUI. Please refer to the Visualization User Guide for more information.



Gray Values X, Y, Z

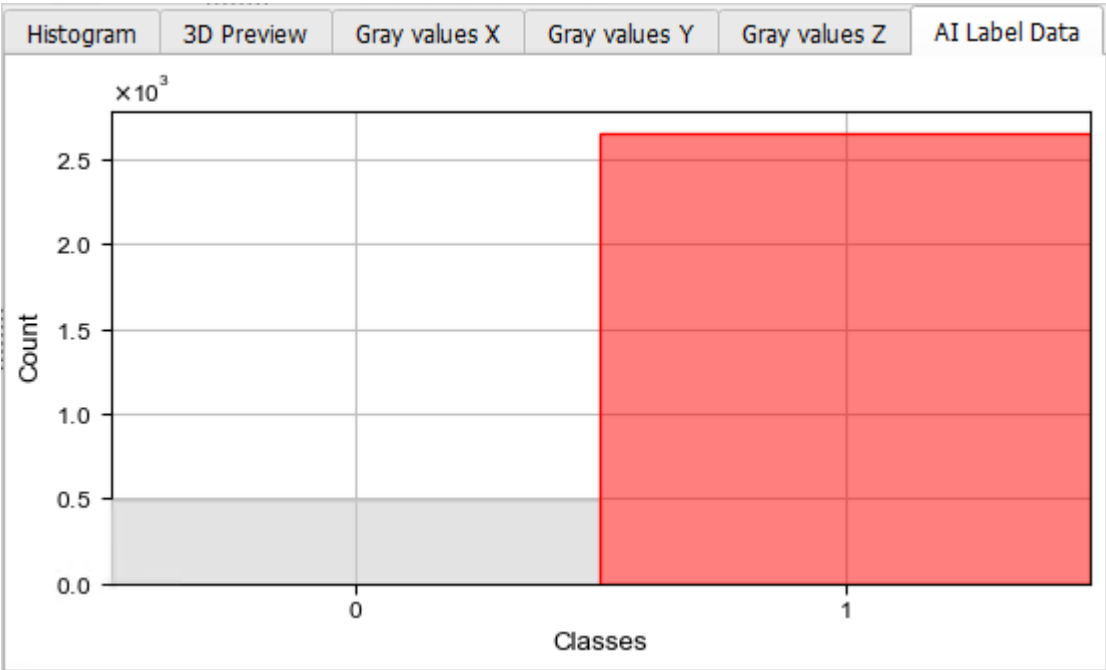
The slice mean of the gray values is plotted in the **X**, **Y**, and **Z** tabs of the **Gray Values** plots. Additionally, a quadratic fit is calculated and plotted. These graphs may reveal brightness gradients in the scans. The [Gradient Brightness Correction](#)^[72] and [Gaussian Brightness Correction](#)^[73] filters can correct such brightness gradients.



AI Label Data

In the **AI Label Data** tab, you find a plot showing the number of voxels per labeled material for the [AI Segmentation](#)^[11]. This tab is only available if the image was labeled as described [here](#)^[12].

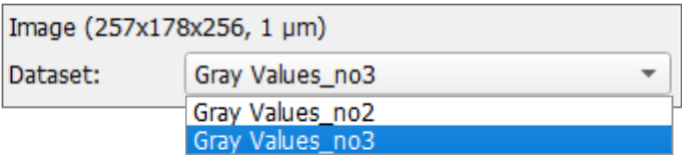
The plot shows the amount of training data for each labeled material **Class**. This helps evaluate whether the **Count** of labeled voxels is similar enough for all materials and allows you to improve the labeling. In the example below, there are many more red (solid material) voxels than white (pore space) voxels.



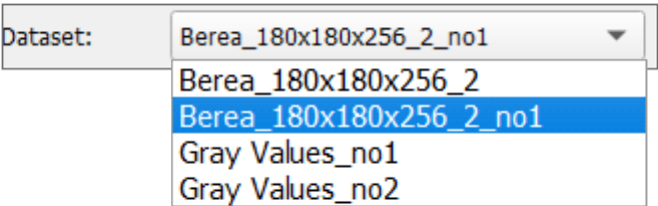
Status

The **Status** section displays the image size, which is the number of voxels in the X-, Y-, and Z- directions, as well as the voxel length.

The **Dataset** pull-down menu contains the current processed image and the previous step. Selecting an image from this menu loads it in the **Image Processing** dialog.

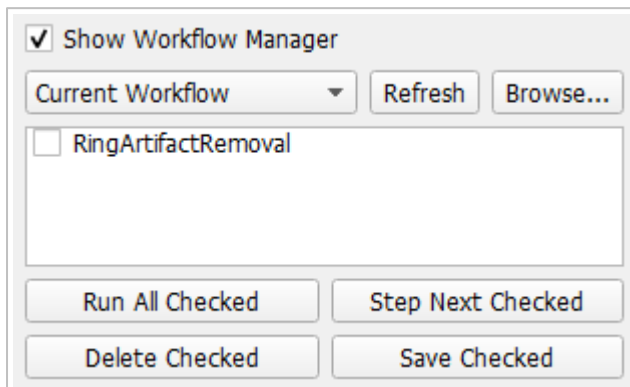


Additionally, you can load different image datasets in the **Image Processing** dialog while keeping the [Keep existing Volume Fields](#)^[6] option selected in the **Import Geometry** dialog. It is easy to switch between several images that are loaded simultaneously.



Workflow Manager

To display the **Workflow Manager**, check **Show Workflow Manager** in the top left of the 3D Image Processing dialog. This section displays either the **Current Workflow** or a chosen predefined workflow. The current workflow contains all the image adjustments and filters applied (e.g., [Ring Artifact Removal](#)^[102]).



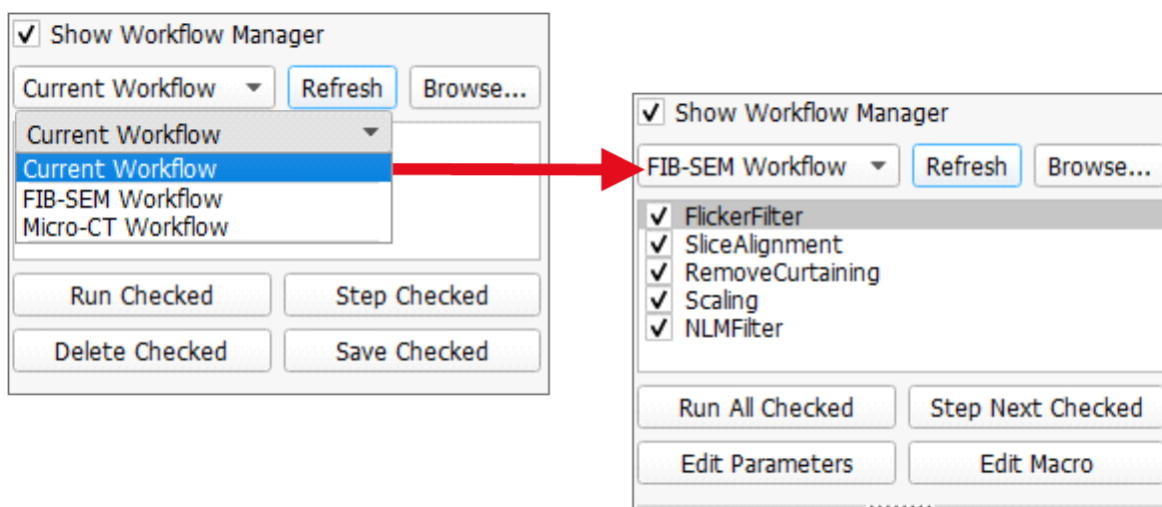
If you added a new workflow to the workflow folder during the current GeoDict session, either by moving a GeoPy (GeoDict Python) file to the GeoDict settings folder or by clicking the **Save Checked** button, click **Refresh** to display the new workflow in the pull-down menu.

Click **Browse** and select a GeoPy macro to add it 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 the [Flickering Correction](#)^[70], [Slice Alignment](#)^[97], [Curtaining Filter](#)^[101], [Scale](#)^[53] of the image, and the [Non-Local Means Filter](#)^[77].
- The **Micro-CT Workflow** combines the [Gradient Brightness Correction](#)^[72], [Enhance Contrast](#)^[69], and [Non-Local Means Filter](#)^[77].

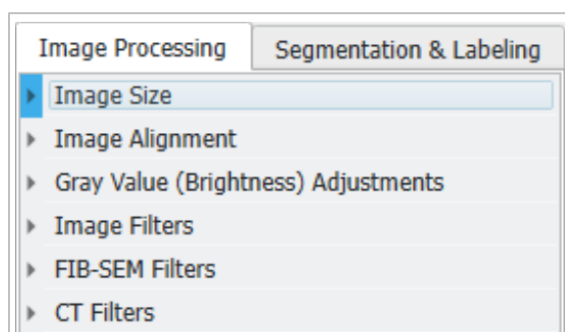


Predefined workflows may be controlled by variables, but they can be edited (**Edit Parameters**) to adjust a workflow to your needs.

With **Edit Macro**, the chosen workflow script is opened for editing. To learn more about GeoPy macros refer to the GeoPy scripting user guide.

1.4.2 Image Processing Tools

The **Image Processing** tools are located in the image processing tab, under the **Image Processing and Segmentation** section of the [3D Image Processing](#)^[24] dialog. They are located directly below the [Workflow Manager](#)^[46] section. The tools are organized into expandable and collapsible trees.



Discover the full range of tools available for Image Processing:

- [Image Size](#)^[47]
Modify the size of your image dataset.
- [Image Alignment](#)^[55]
Correct the alignment of your images.
- [Gray Value \(Brightness\) Adjustments](#)^[67]
Change the gray values in your images.
- [Image Filters](#)^[75]
Apply filters to your images to improve the quality.
- [FIB-SEM Filters](#)^[96]
Explore specific filters for images measured with Focused Ion Beam - Scanning Electron Microscopy.
- [CT Filters](#)^[102]
Find specific filters for images measured with X-ray Microtomography.

Image Size

The **Image Size** tree contains the tools for controlling image size and resolution.



Explore the Image Size Tools:

- [Crop](#)⁴⁸
Cut out a section of the image dataset.
- [Embed](#)⁵⁰
Add empty voxels around the image dataset.
- [Change Voxel Length](#)⁵¹
Adjust the resolution of your image dataset.
- [Change Slice Thickness](#)⁵²
Adjust the Slice Thickness if it differs from the pixel size.
- [Scale](#)⁵³
If the voxel length differs in one or more directions, adjust it accordingly.
- [Downsample](#)⁵⁴
Reduce the image size by combining multiple voxels into one.

Crop

Use the **Crop** tool to select dimensional parameters and cut out a section of the 3D dataset. There are three ways to find the desired cutout:

Cropping Manually

Starting from the leftmost positions of the sliders, a box is cut out to the rightmost positions of the sliders. The numbers **NX**, **NY**, and **NZ** represent the number of voxels in the **X**-, **Y**-, and **Z**-directions, respectively.

Moving the sliders defines a region that appears [highlighted](#)³⁷ in yellow lines forming a rectangle in the 2D preview areas of the three directions. You can also change the size of the yellow rectangles using the left mouse button. Click and drag a line to move it. This is illustrated here for a 3D gray-value image of Berea sandstone. The values of **NX**, **NY**, and **NZ** indicate the size of the domain after cropping. In this case, it is 70 x 70 x 80 voxels.

▼ Crop

NX : 70 (70 µm) 40 ————— 110

NY : 70 (70 µm) 60 ————— 130

NZ : 80 (80 µm) 100 ————— 180

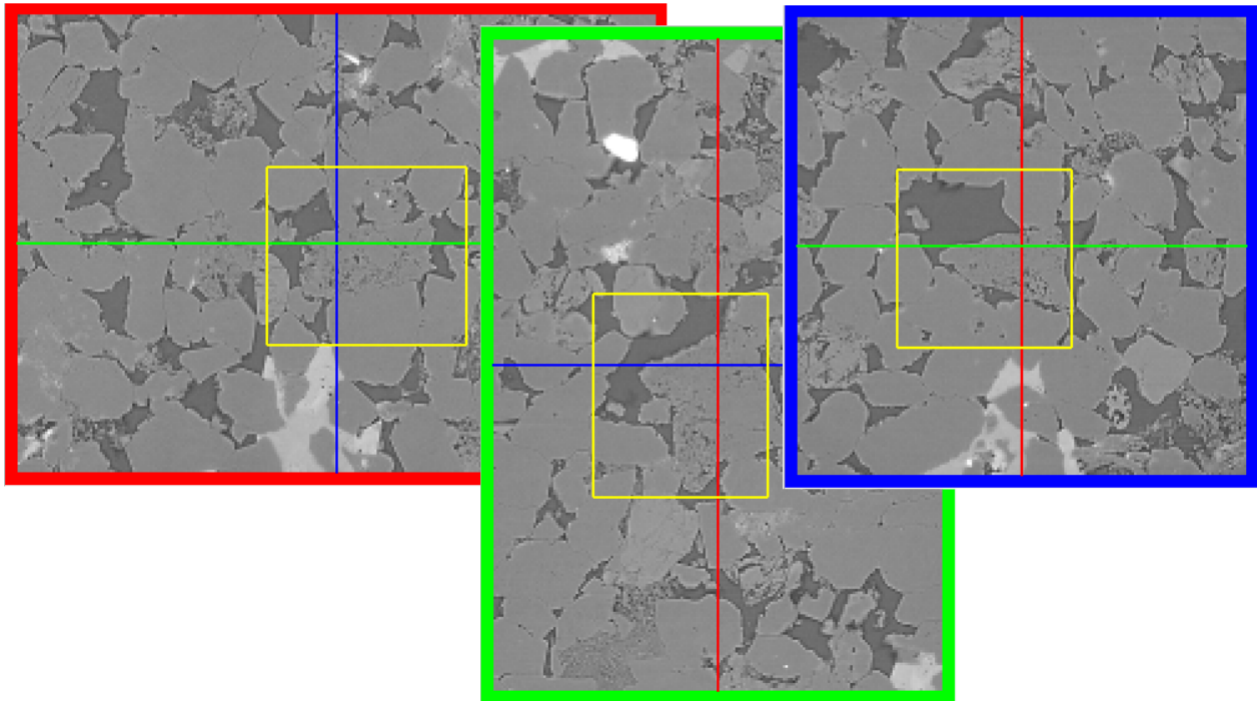
☐ Automatic Crop

☒ Automatic Threshold

Threshold 122.5

Suggest

Apply



Cropping Automatically

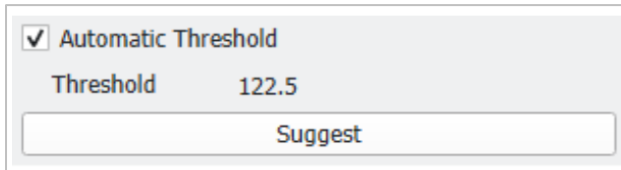
Checking the **Automatic Crop** box renders the cropping parameters inactive. Instead, all regions of pure background around the structure are cropped according to the **Threshold** defined below.

☒ Automatic Crop ☒ Automatic Threshold Threshold 122.5	☒ Automatic Crop ☐ Automatic Threshold Threshold 122.5
--	---

If the **Automatic Threshold** is enabled, the [Otsu](#)^[109] method is used to create the threshold. Otherwise, enter a **Manual Threshold**. Note that this threshold is not used for segmentation; it is only used to determine where the image should be cropped.

Suggesting Cropping Values

Click **Suggest** to preload the sliders with values that will crop away all pure-background regions according to the [Otsu](#)^[109] or manually entered threshold. The cropping values for the three directions can then be changed as needed.



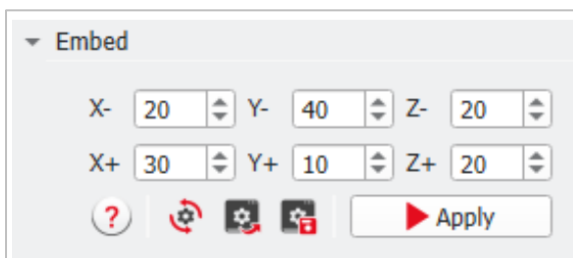
Click **Apply** to crop the structure using the current settings.



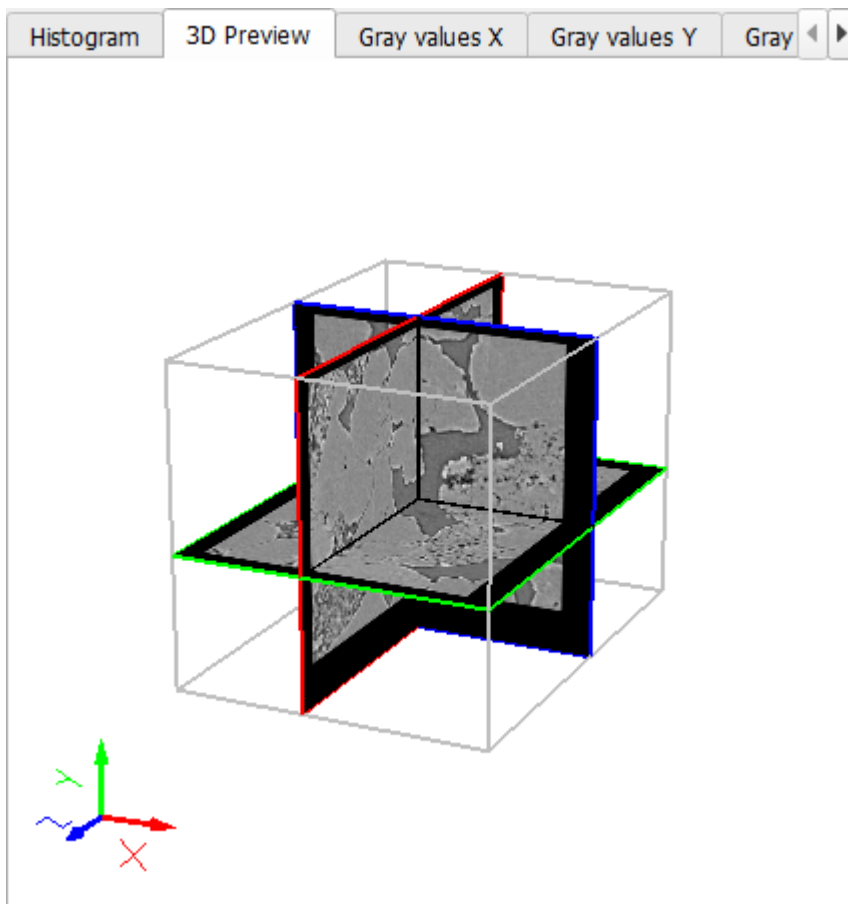
Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Embed

Embedding adds empty voxels (voxels with a gray value of 0) around the current image. Enter the desired number of voxels for directions **X-**, **Y-**, **Z-**, **X+**, **Y+**, and **Z+**. Then, click **Apply** to embed the image. This can be useful for generating enough space to [rotate](#)^[56] the image without losing information, for example.



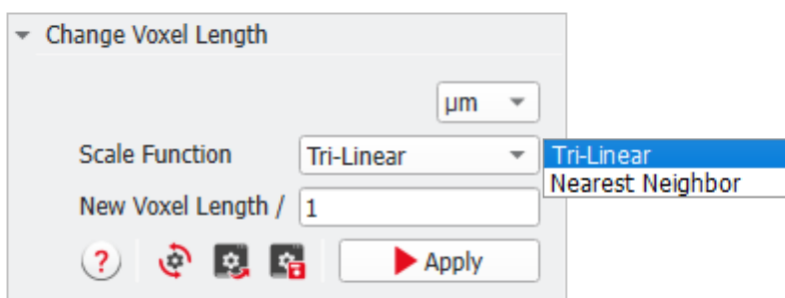
The embedding effect is easily observable in the [3D Preview](#)^[43].



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Change Voxel Length

Use **Change Voxel Length** to adjust the resolution of your image. When you enter a higher voxel length value than the original, the number of voxels in the three dimensions decreases since fewer voxels are needed to build the image.

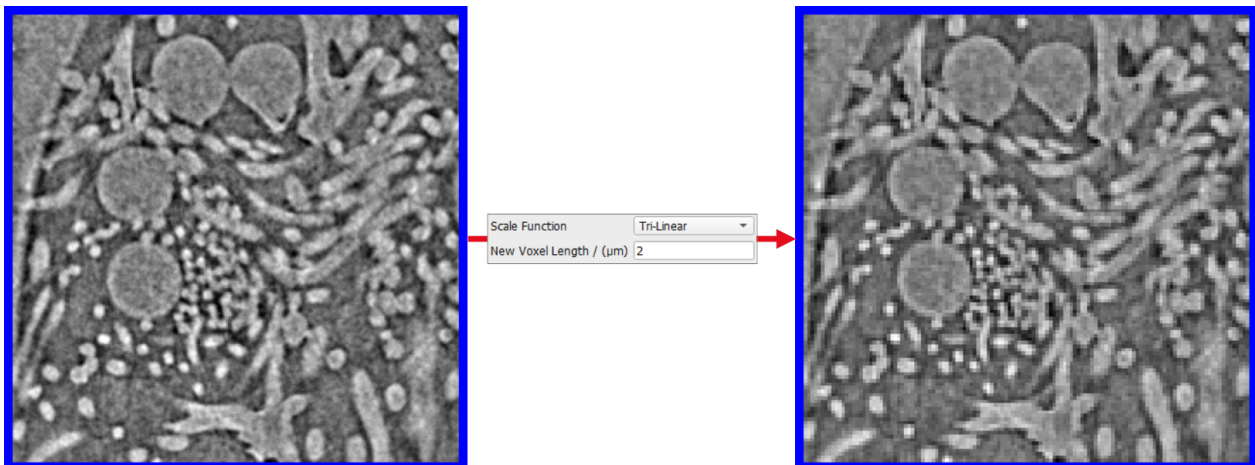


Select the **Unit** for the voxel length from the pull-down menu at the top. The available units are m, cm, mm, μm , nm, and Inch.

For the **Scale Function** the two interpolation methods [Tri-Linear](#) or [Nearest Neighbor](#) are available. See the [Scale](#)⁵³ tool for a visualization of the difference between the two methods.

Enter the desired **New Voxel Length** in the selected unit.

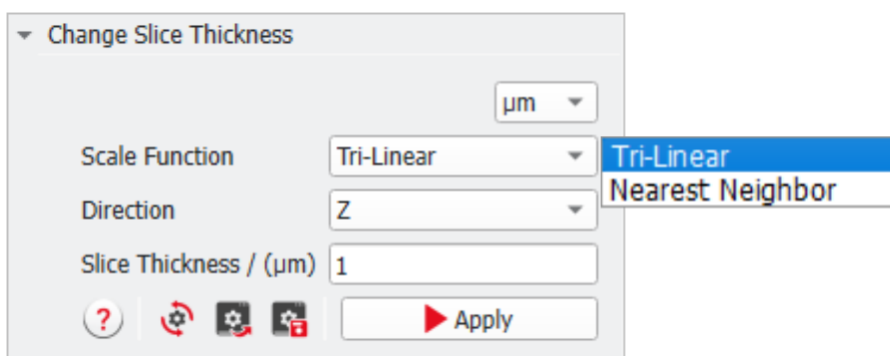
Click **Apply** to scale the image according to the new voxel length.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Change Slice Thickness

Use **Change Slice Thickness** if the thickness of the slices in a scan differs from the pixel size.

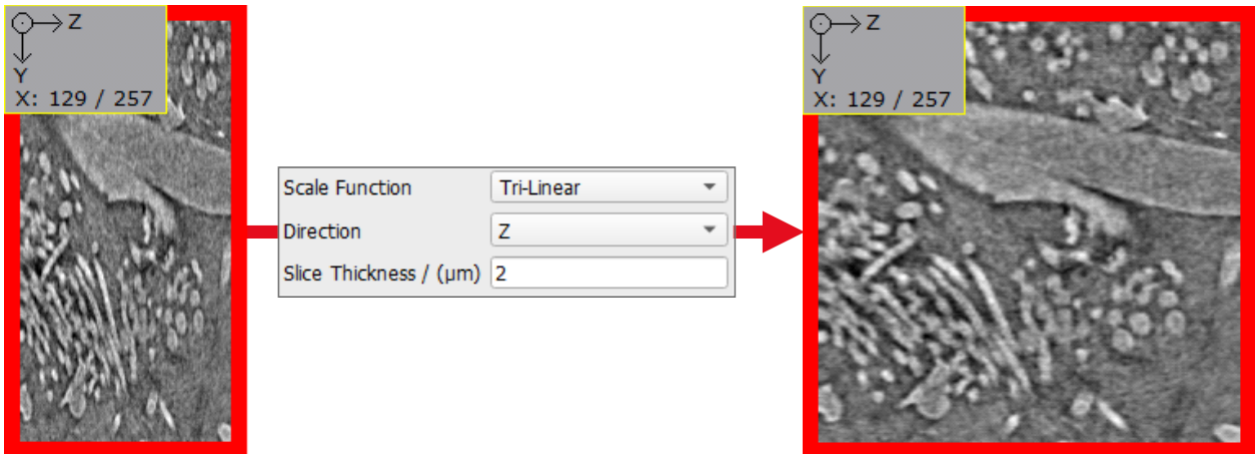


Select the **Unit** for the voxel length from the pull-down menu at the top. The available units are m, cm, mm, μm , nm, and Inch.

For the **Scale Function** the two interpolation methods [Tri-Linear](#) or [Nearest Neighbor](#) are available. See the [Scale](#)⁵³ tool for a visualization of the difference between the two methods.

From the pull-down menu, select the **Direction** in which the slice thickness should be changed. Enter the **Slice Thickness** in the selected unit.

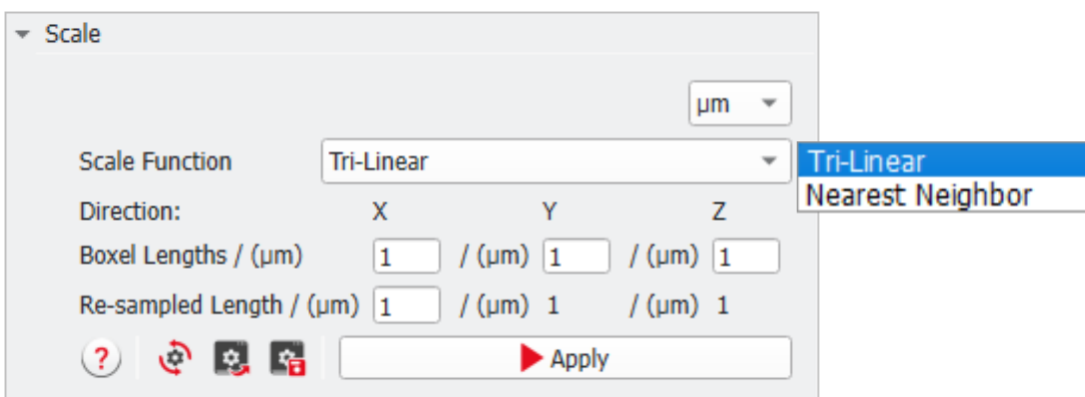
After **Apply** is clicked the selected scale function is applied to add or remove voxels in the given direction to obtain the different slice thickness.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Scale

For the **Scale** tool, you can choose between [Tri-Linear](#) or [Nearest Neighbor](#) interpolation. These are both methods of multivariate interpolation in one or more dimensions.



The **Boxel Lengths** refer to the current lengths in the structure model, in the three directions. These values are automatically entered based on the **Voxel Length** defined by the user at the bottom of the [Import Images](#)  dialog.

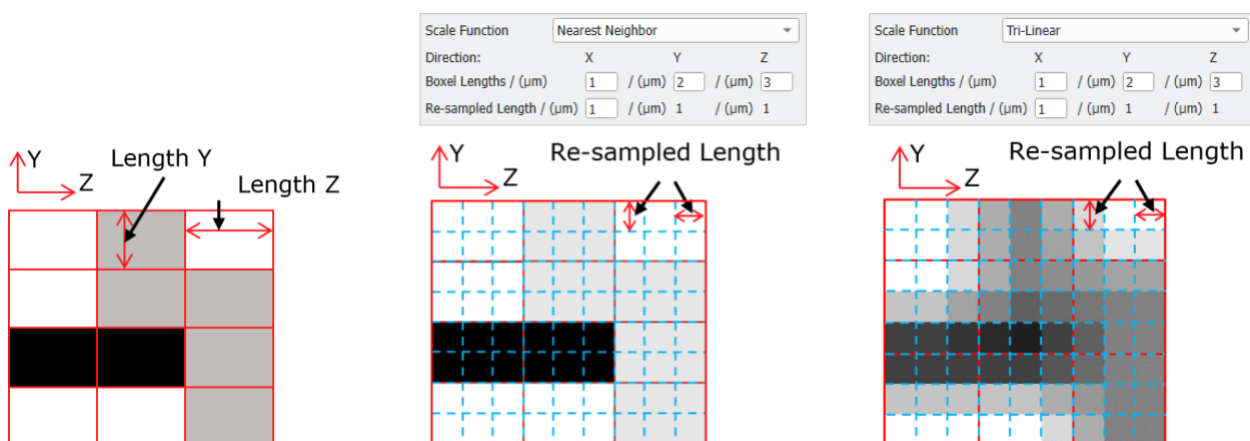
For example, in FIB-SEM scans, the length in the Z-direction typically differs from the other two directions. It corresponds to the spacing between images. This spacing is defined when the

FIB-SEM images are acquired and should be included with the image files as data. Importing the stack directly without accounting for spacing distortion results in a stacked structure that does not replicate the original scan.

To account for this distortion in the Z-direction, enter the length and click **Apply**. GeoDict will then scale the voxels in that direction and complete the missing slices to create a uniform object. The size of the scaled object will change to reflect the fill-in.

The **Re-sampled Length** value is used to uniformly re-sample the physical structure size (voxel length) in all directions with a grid adapted to the re-sampled length value. This process either coarsens or refines the imported structure.

Observe the difference between the two interpolation methods for the **Scale** tool in the following example. Although the number of voxels is the same for both, **Tri-Linear** interpolates gray values for a smoother transition.

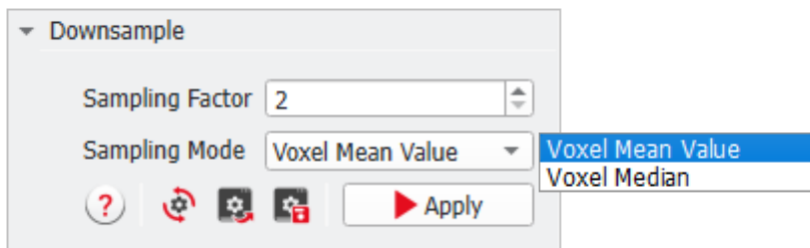


Know how! You can **Save** your current settings for this tool as **Start-Up Settings**. The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings** available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings**.

Downsample

Downsampling is the process of combining multiple voxels to one in order to reduce the structure size. Choose to apply the **Sampling Factor** to the **Voxel Mean Value** or the **Voxel Median** in the **Sampling Mode** pull-down menu. Click **Apply** to sample the structure with the current parameters.

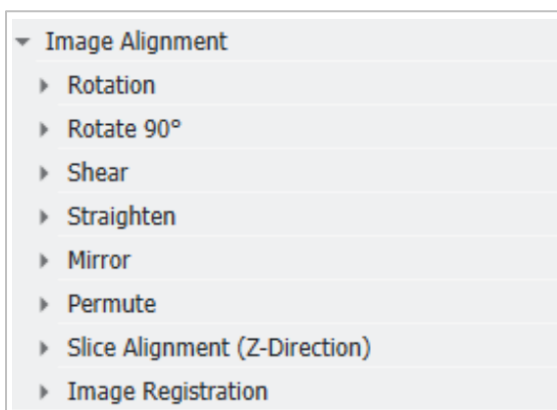
Downsampling involves combining multiple voxels into one to reduce the size of the structure. In the **Sampling Mode** pull-down menu, choose to apply the **Sampling Factor** to the **Sampling Factor** or the **Voxel Median**. Click **Apply** to sample the structure with the current parameters.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Image Alignment

The **Image Alignment** tree contains tools that affect the orientation of a 3D image.



Explore the Image Alignment Tools:

- [Rotation](#) 
Perform a three-dimensional rotation of the image dataset.
- [Rotate 90°](#) 
Turn the image dataset by 90°.
- [Shear](#) 
Adjust image datasets that have been distorted.
- [Straighten](#) 
Straighten bowed or warped image datasets.
- [Mirror](#) 
Mirror the image along the plane perpendicular to a selected Mirror Direction axis.
- [Permute](#) 
Change the allocation of the axes for the image dataset.
- [Slice Alignment \(Z-Direction\)](#) 

Explore the Image Alignment Tools:

Correct the alignment of image slices in the dataset.

- [Image Registration](#)

Align two scans of the same structure that have been shifted or rotated relative to each other.

Rotation

You can perform a three-dimensional rotation of the image using the **Rotation** tool. Enter values for the **Phi**, **Theta**, and **Psi** [Euler rotation angles](#), or enter a single angle to rotate about one axis. This feature is useful when images are not aligned with the structure's inherent axis and empty space is found around them.

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

Rotation

Rotation Mode: Euler Angles

Phi / (°): 0

Theta / (°): 0

Psi / (°): 0

☐ Enlarge Image Automatically

☐ Automatic Rotation

☒ Automatic Threshold

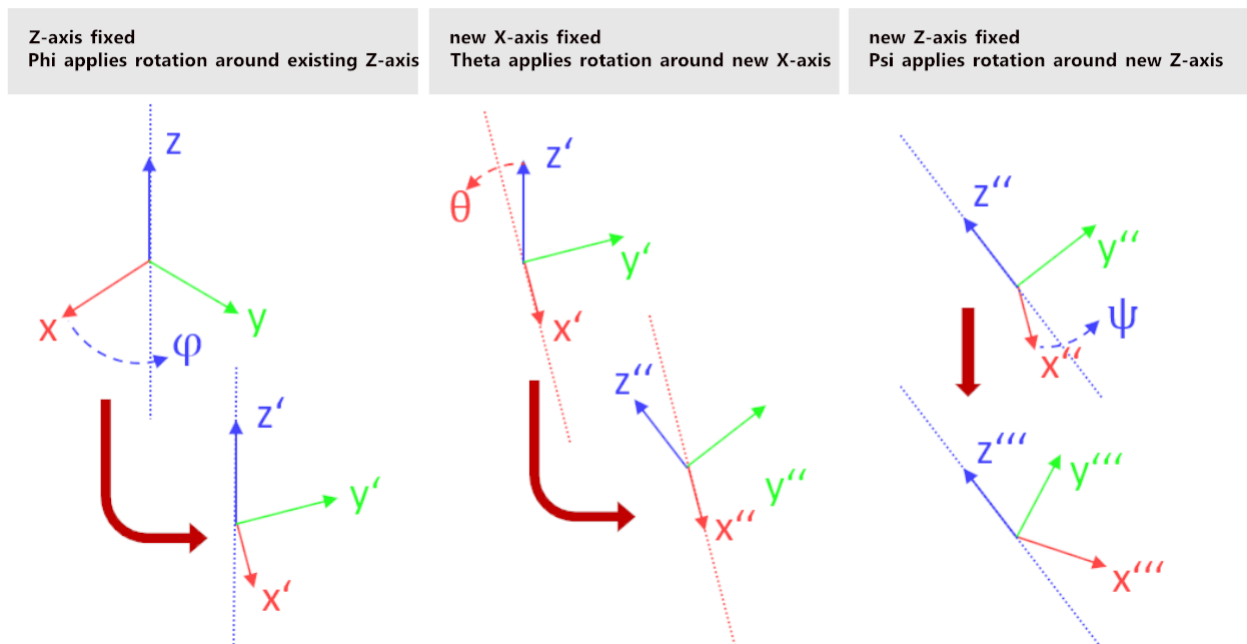
Threshold: 125.5

Suggest - Volume Suggest - Plane

Apply

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

Euler Angles	Phi / (°)	90
	Theta / (°)	30
	Psi / (°)	30



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

Rotation Mode	Rotate around X Axis
Rotate about X / (°)	0

Check the **Enlarge Image Automatically** box to avoid cropping after rotation.

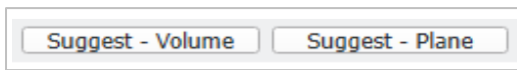
When you check **Automatic Rotation**, the entered parameters for the rotation angles are ignored and become inactive. Instead, the Euler rotation angles are calculated automatically based on principal component analysis for the imported gray value image. From the pull-down menu for **Automation Mode** 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.

Checking **Automatic Rotation** causes the entered parameters for the rotation angles to become inactive and ignored. Instead, the Euler rotation angles are automatically calculated based on principal component analysis of the imported gray value image. From the **Automation Mode** pull-down menu, 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 to only two major axes can minimize unwanted rotations inside a planar structure.

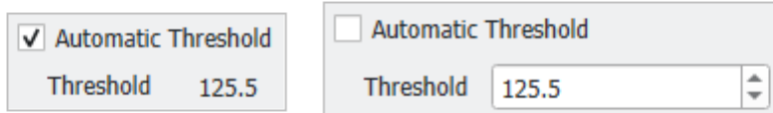
☒ Automatic Rotation
Automation Mode
Volume
Plane

Alternatively, you can use the **Suggest** buttons to suggest values for rotation first. This functionality uses the same calculation as **Automatic Rotation**, and the two modes, **Volume**

and **Plane**, are also available. Click one of these options to obtain suggested values for **Phi**, **Theta**, and **Psi**.

Two buttons are shown side-by-side. The left button is labeled 'Suggest - Volume' and the right button is labeled 'Suggest - Plane'. Both buttons have a light gray background and a thin border.

A structure is required to compute the alignment to either two or all three major axes for the suggestion or automatic rotation. [Global Thresholding](#)^[108] is used to obtain such a structure. If the **Automatic Threshold** is enabled, the [Otsu](#)^[109] method is used to threshold the image. Otherwise, enter a **Manual Threshold**.

Two panels are shown side-by-side. The left panel has a checked checkbox labeled 'Automatic Threshold' and a text field below it showing 'Threshold 125.5'. The right panel has an unchecked checkbox labeled 'Automatic Threshold' and a text field below it showing 'Threshold 125.5' with a small up/down arrow button to its right.

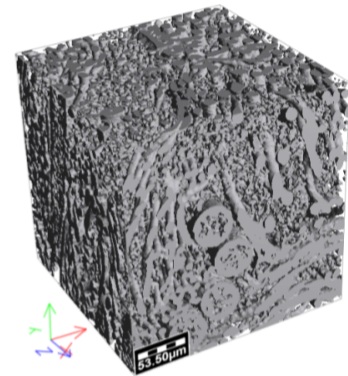
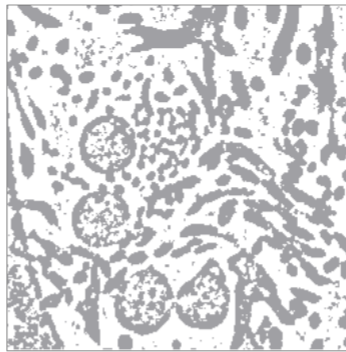
Click **Apply** to rotate the structure with the current settings.

Example

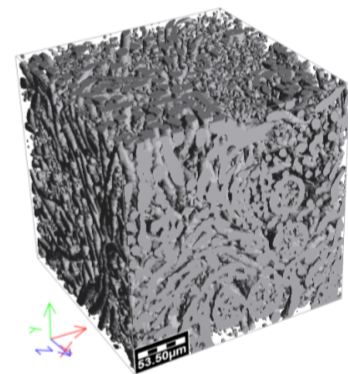
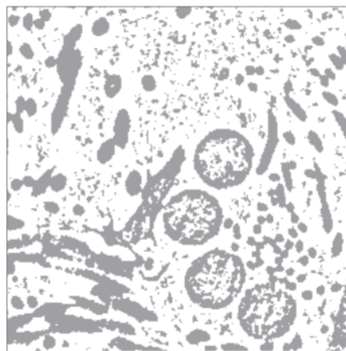
First, a structure model is obtained without rotation. To obtain a structure that has been rotated 90° or 180° about the Y-axis, the following Euler angles are used:

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

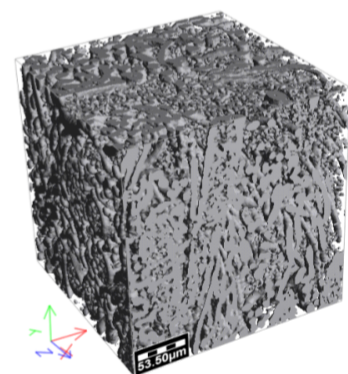
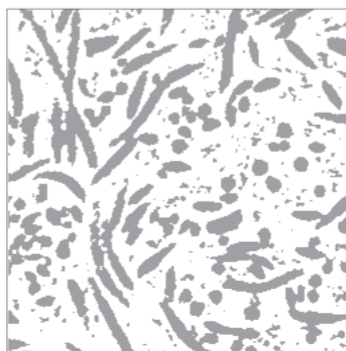
Rotation Mode	Euler Angles
Phi / (°)	0
Theta / (°)	0
Psi / (°)	0



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

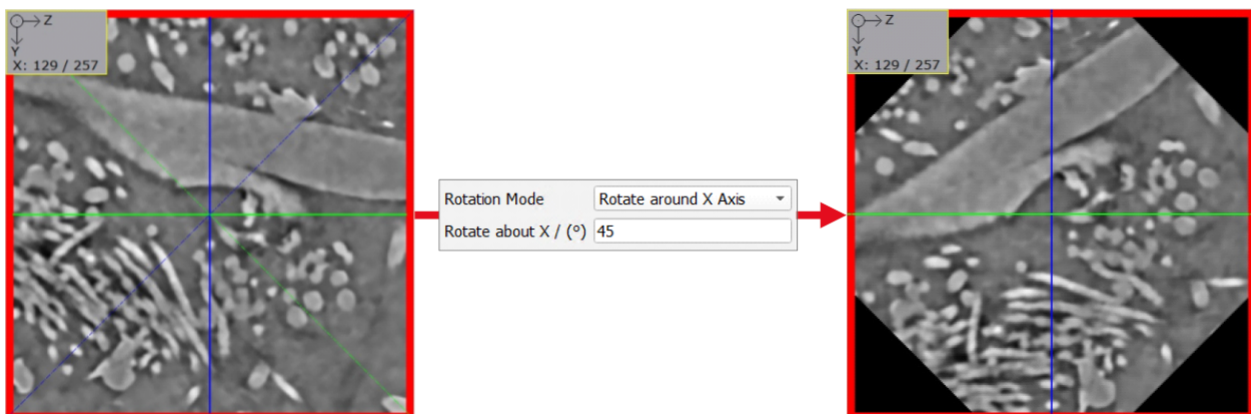


Rotation Mode	Euler Angles
Phi / (°)	90
Theta / (°)	90
Psi / (°)	-90



Of course, these two rotations can be obtained more easily by selecting **Rotate around Y-Axis** for **Rotation Mode**, but the example helps to understand the Euler angles. Since they can rotate the 3D image in any direction, they are more powerful when the image needs to be rotated about more than one axis.

Selecting **Rotate** as the [Overlay](#)³⁷ visualizes the resulting rotation in the [2D Slice Visualization](#)⁴⁰ area. Diagonal red, green, and blue lines show the resulting new center lines. In the following example, the image is rotated about the X-axis. Therefore, in the YZ plane, blue and green diagonals can be seen. These are the new center lines after rotating.

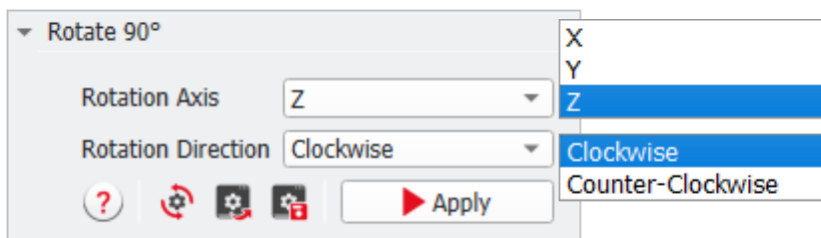


Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Rotate 90°

The **Rotate 90°** tool allows you to simply turn the image by 90°. For more complex rotation options, use the [Rotation](#) ⁵⁶ tool.

Select whether the image should be rotated **Clockwise** or **Counter-Clockwise** around the selected **Rotation Axis**.



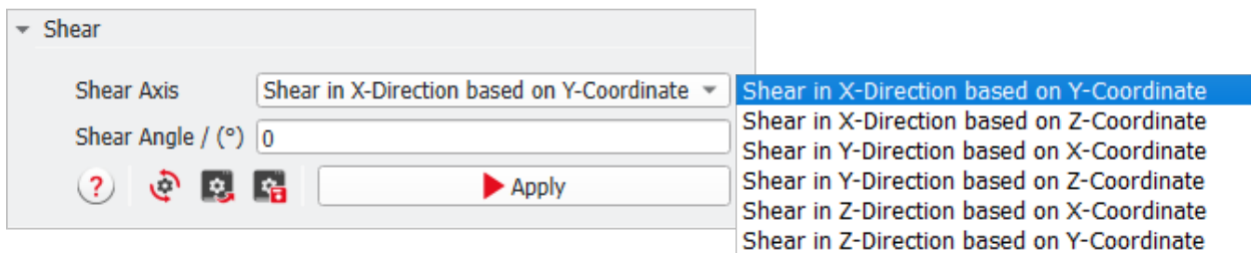
Click **Apply** to rotate the structure as defined.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Shear

The **Shear** tool allows you to adjust volumes that have been distorted, as can happen in FIB-SEM images, for example.

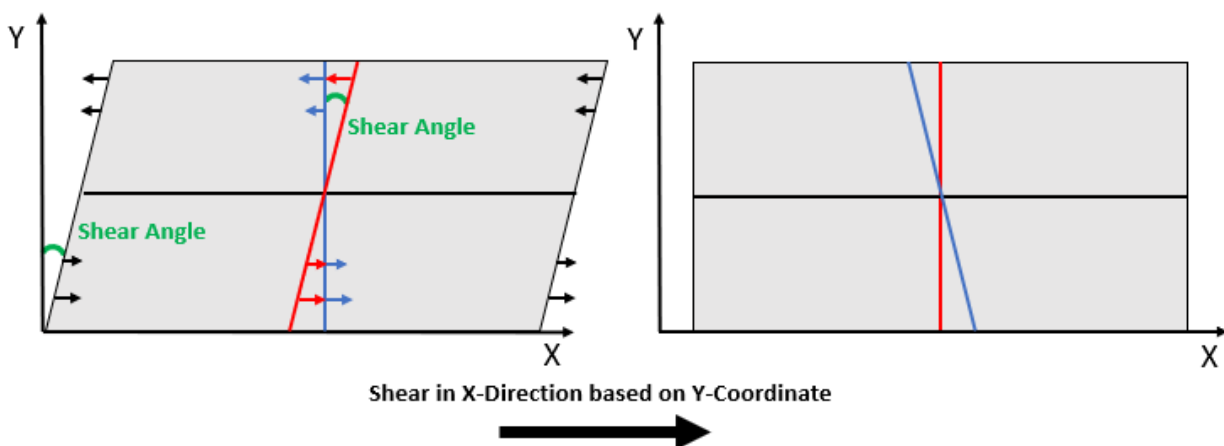


For **Shear Axis** choose the shear direction and the coordinate that the **Shear Angle** is based on.

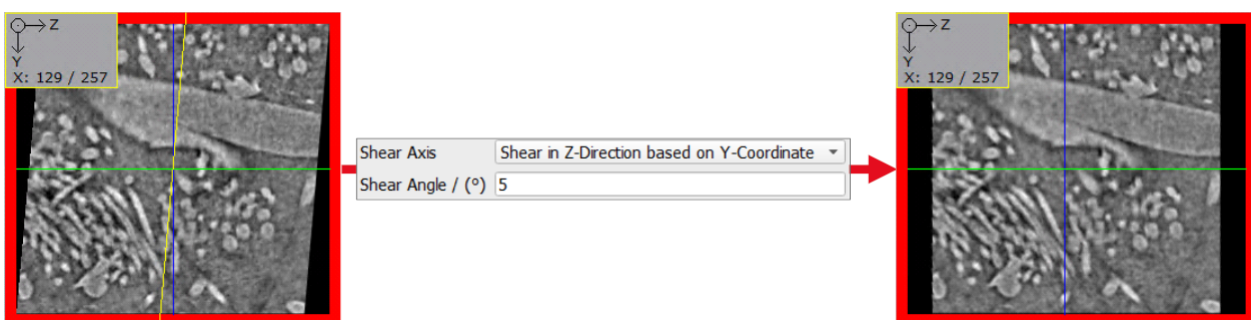
Click **Apply** to shear the structure with the current settings.

Shearing the image displaces each voxel in the shear direction (defined by the **Shear Axis**) upon consideration of the **Shear Angle**.

The figure below illustrates the process of handling a sheared image. In this example, the image is sheared in the X direction, resulting in a parallelogram. To correct the image, the **Shear Axis** must be defined as **Shear in X-Direction based on Y-Coordinate**. Then, the **Shear Angle** must be determined. After entering an angle, a yellow line will appear in the corresponding 2D slice. This line will become the new center line after clicking **Apply**. Gray values move as indicated by the arrow lengths below. For more information about the applied method, refer to [Shear Mapping](#).



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°. Since **Shear** is selected as [Overlay](#)³⁷ the resulting new center line is visualized with a yellow line.

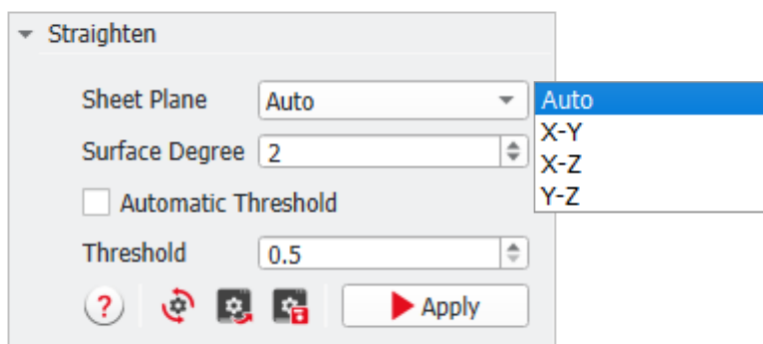




Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Straighten

Images of structures captured in a μ CT scanner may appear slightly bowed or warped. Straightening these images is especially interesting in the case of flat geometries and can be used to make the structure in the image lie flat again. To do so, a surface with a given **Surface Degree** of a polynomial surface used for interpolation is fitted through the structure and aligned to a **Sheet Plane**.



Select the **Sheet Plane** in which the structure lies, either in the **X-Y**, **X-Z**, or **Y-Z** direction, or allow the direction to be estimated **Automatically**. For automatic determination of the plane, a threshold is needed to obtain the structure. This is based on [Global Thresholding](#)^[108]. If you select **Automatic Threshold**, the thresholds is computed based on the [Otsu](#)^[109] algorithm. Otherwise, enter a **Manual Threshold**.

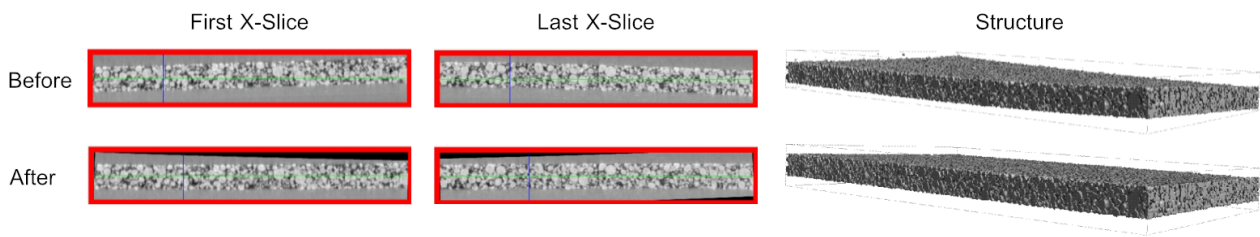
Click **Apply** to straighten the structure with the current settings.



Know how! Straightening can be helpful to improve the [cropping](#)^[48] of empty space without the loss of sample material voxels.

Example

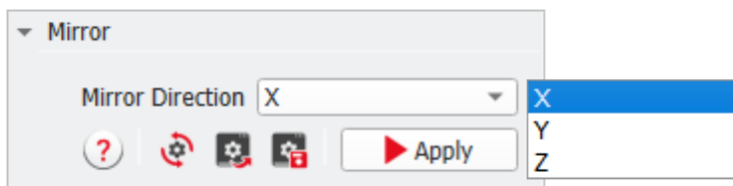
The bow of a granular structure is removed by applying the straightening process here. The bow can be seen in the [2D Slice Visualization](#)^[40] section. The first and last X-slices are shown here. Compare the two slices to observe the bow in both slices and in the X-direction. Applying the **Straighten** tool with the default settings produces a straightened structure, which is shown in both 2D and 3D.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Mirror

Click **Apply** to **Mirror** the image along the plane perpendicular to the selected **Mirror Direction** axis.



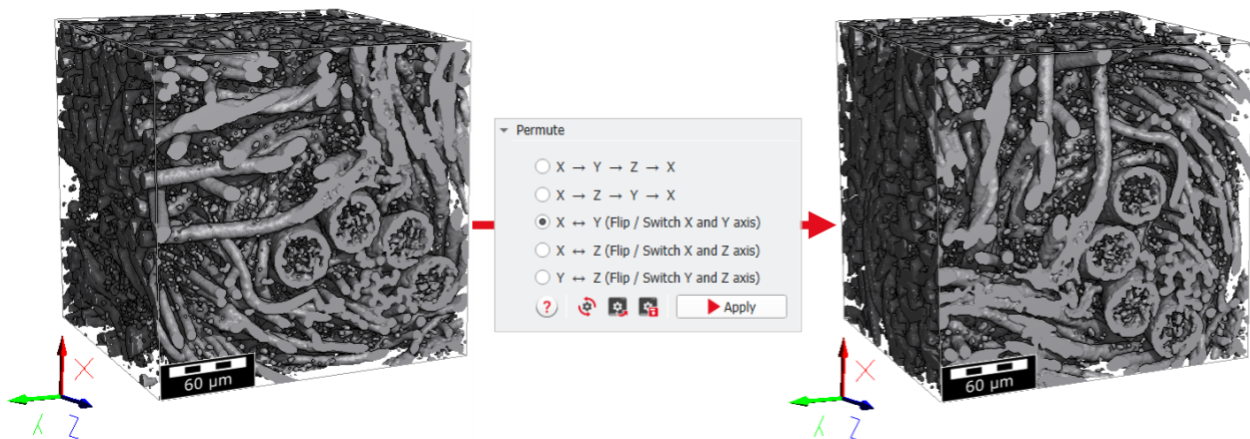
In the example below, **Z** is selected as the **Mirror Direction**. Thus, the image is mirrored along the XY-plane.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Permute

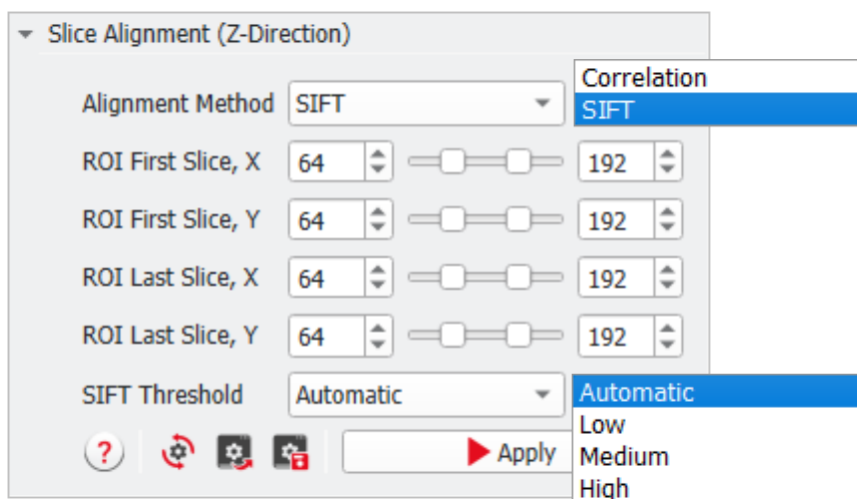
Permute changes the allocation of the axes for the image to be imported. Select the desired permutation of axes and click **Apply**. For example, if the X-axis should be exchanged with the Z-axis, you select **X ↔ Z** and click **Apply**. Now what used to be the X-direction has turned into Z-direction.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings**. The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings** available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings**.

Slice Alignment (Z-Direction)

During FIB-SEM image acquisition, the alignment of the image slices is not maintained due to specimen drift or image distortion, for example. This typically occurs along the Z-axis. Therefore, **Slice Alignment** is necessary.





Note! Before aligning the slices, please ensure that the image is oriented with the misalignments in the Z direction. This can be best observed by sliding through the 2D slices in the Z direction. Offsets are typically visible when looking at images in the X- and Y-directions. If the misalignments occur in a different direction, [rotate](#)^[56] or [permute](#)^[64] the image first.

Two options are available for the **Alignment Method**:

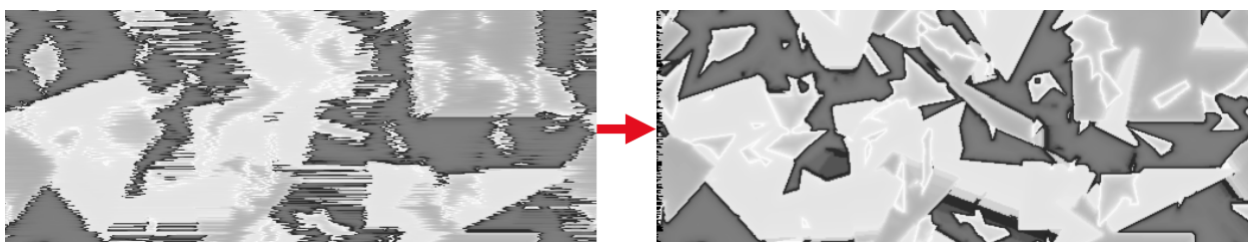
- The **Correlation** algorithm shifts the slices in the X- and Y-directions until the regions within the defined region of interest (**ROI**) are as similar as possible.
- The **SIFT (Scale-Invariant Feature Transform)** algorithm recognizes features and attempts to map them to each other by shifting and rotating the slices. This method works well when the features are similar across the different slices. More detailed information on this method can be found [here](#).

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 performed on the entire image. Please note that this may result in unavoidable boundary effects, which may necessitate [cropping](#)^[48] the image at its boundaries. The rectangle resulting from the **First Slice** and **Last Slice** values is visualized in red in the [2D Slice Visualization](#)^[40] section in the X-Y-plane if **Slice Alignment** is chosen as [Overlay](#)^[37].

In the **Correlation** method, the **Radius** defines the maximum shift between two slices that will be searched. For many FIB-SEM images, the default radius of 10 voxels is sufficient. However, if the slices are shifted by more than 10 voxels, the radius setting needs to be increased.

For the **SIFT** method, the **SIFT Threshold** for the image features can be defined as **Low**, **Medium**, or **High**. A higher threshold uses only the most significant image features, while a lower threshold uses more image features. If the alignment does not modify the image, choose a lower threshold. If, on the other hand, the alignment is incorrect, a higher threshold may be better. When the threshold is set to **Automatic**, it is adjusted automatically.

The example below shows a 2D slice from the X direction of an artificially misaligned gray value image (left). After applying the **Slice Alignment** tool with the default settings, the misalignment is completely corrected. Note the offsets on the left and right boundaries of the aligned image. The image size in the X and Y directions has increased to include all aligned slices in the 3D image without losing information.

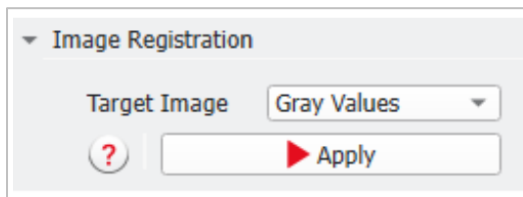


Know how! You can **Save** your current settings for this tool as **Start-Up Settings** .

The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Image Registration

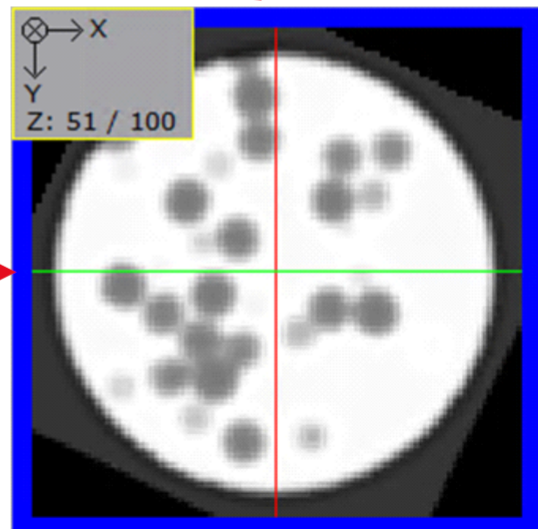
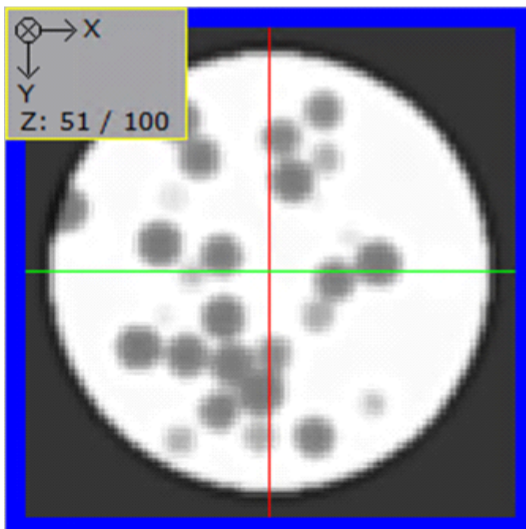
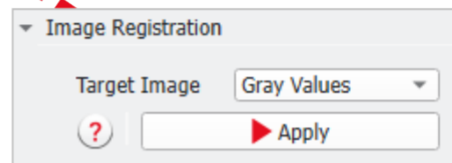
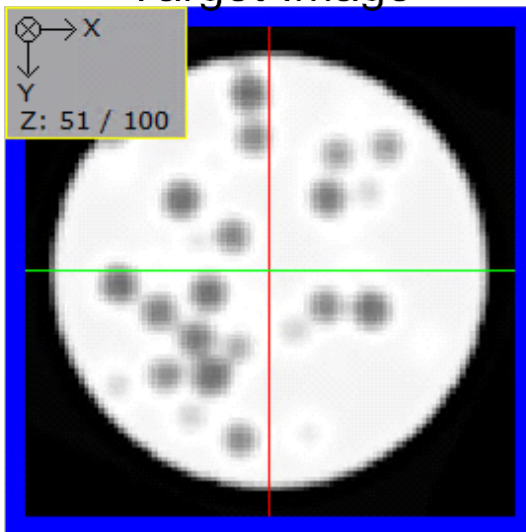
Image Registration is an intensity-based method of aligning images. It is used to align two scans of the same structure that have been shifted or rotated relative to each other.



From the datasets currently loaded to the Image Processing dialog, specify a **Target Image**. Learn how to load multiple datasets into the dialog [here](#) ⁶. Click **Apply** to shift and rotate the entire 3D image to align it with the selected target image.

The following example shows two images of the same structure taken from different angles. In order to use both images for [AI segmentation](#) ¹¹¹, for example, they must be registered.

Target Image

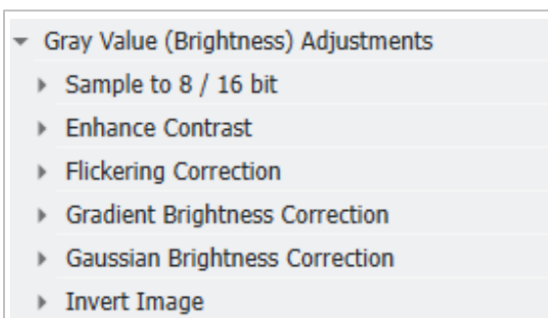


Current Image

Registered Image

Gray Value (Brightness) Adjustments

The **Gray Value (Brightness) Adjustments** tree contains tools for modifying the gray values of an image.



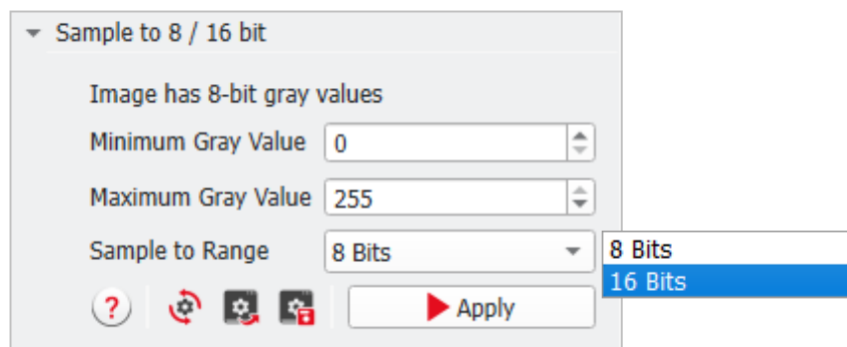
Explore the Gray Value (Brightness) Adjustment Tools:

- [Sample to 8 / 16 Bit](#)⁶⁸
Convert the image dataset to an 8-bit or 16-bit format
- [Enhance Contrast](#)⁶⁹
Increase the contrast of the image dataset.
- [Flickering Correction](#)⁷⁰
Remove flickering variations in gray values between slices.
- [Gradient Brightness Correction](#)⁷²
Correct slow brightening or darkening in one direction in the image dataset.
- [Gaussian Brightness Correction](#)⁷³
Balance the brightness of the image dataset's dark and light regions.
- [Invert Image](#)⁷⁴
Invert all gray values.

Sample to 8 / 16 Bit

Use the **Sample to 8 / 16 Bit** tool to convert the sample image to an 8-bit or 16-bit format. Then, each pixel in the image will be represented by an 8- or 16-bit value, respectively.

The current image format is displayed at the top of the panel. In this example, the **Image has 8-bit gray values**. Therefore, each pixel contains a gray value between **0** and **255**. For a 16-bit image, the values range from **0** to **65,535**, representing 2^{16} distinct values.



Enter the **Minimal Gray Value** and the **Maximal Gray Value** for the image to be sampled. These values adjust the gray value range for the 8- or 16-bit images. From the **Sample to Range** pull-down menu, select either **8 Bits** or **16 Bits**.



Know how! Converting from a 16-bit to an 8-bit format reduces the large data size of 16-bit images. The gray value range shrinks from **0-65,535** to **0-255**.

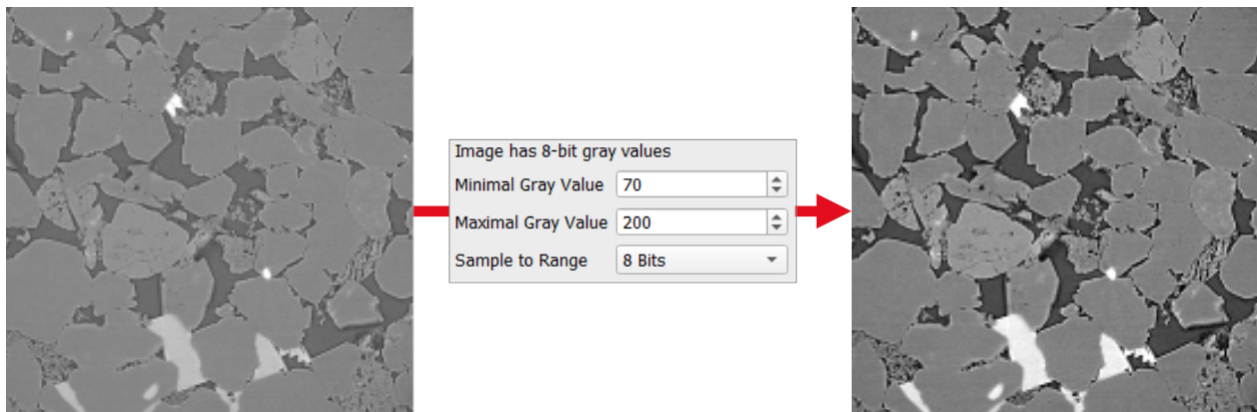
Selecting **16 Bits** increases the bit depth from 8 to 16.

Click **Apply** to sample the image using 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.

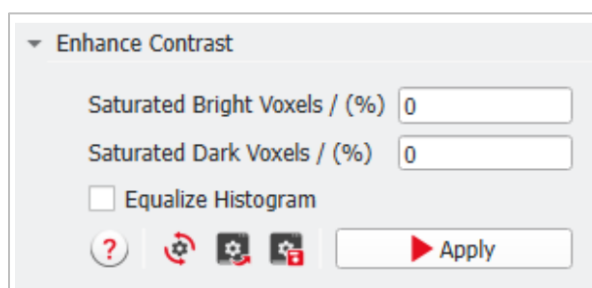
The following images illustrate how to adjust the gray value range in an 8-bit Berea sandstone image. Reducing the original gray value range of 0-255 to 70-200 increases the contrast between solid phases (mid and bright gray values) and pore space (dark gray values).



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Enhance Contrast

The **Enhance Contrast** tool increases the contrast of 3D image data. Observe the changes to the [histogram](#) ^[41] when applying the tool.



Using **Saturated Bright** and **Dark Voxels** changes the gray value distribution in an image. With 0% of each, the gray values are automatically distributed across the entire gray value range. This is also possible in [Sample to 8 / 16 bit](#) ^[68]. Increasing the percentages narrows the range of considered gray values by ignoring a given percentage of bright and/or dark gray values, respectively. Thus, higher values increase contrast. In detail:

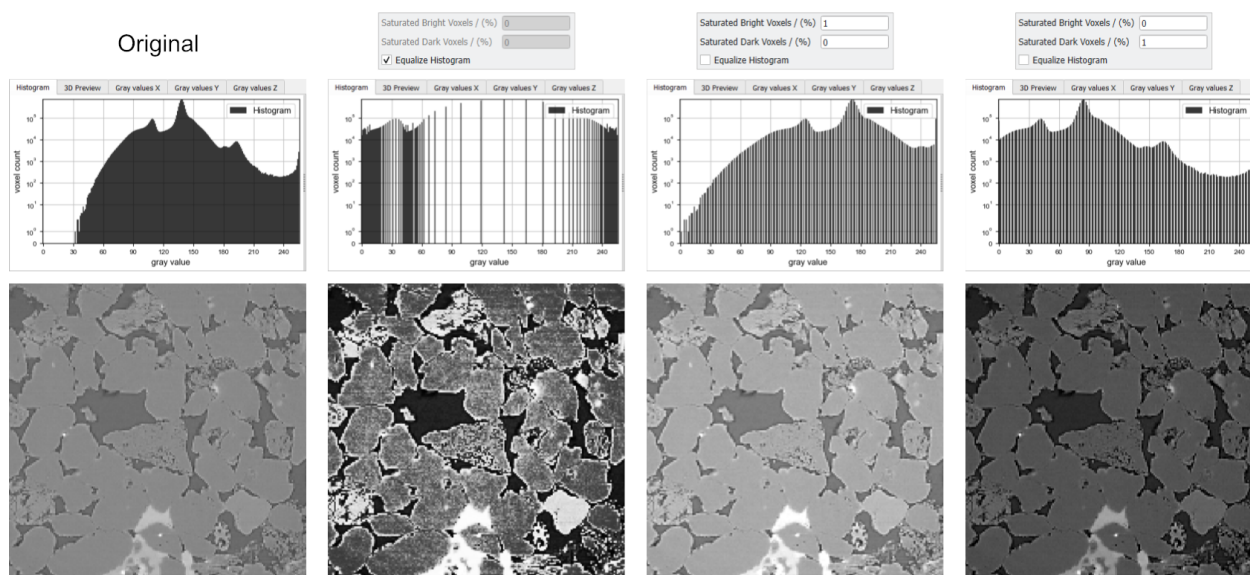
- The gray values are set to the maximum gray value (e.g., 255 for 8-bit images) for the given percentage of **Saturated Bright Voxels**.

- The gray values are set to a minimum of 0 for the given percentage of **Saturated Dark Voxels**.
- The gray values of the intermediate voxels are distributed evenly across the full range of possible gray values.

Checking the **Equalize Histogram** option distributes the most frequent gray values more evenly across the histogram. This balances the original distribution of gray values, ensuring an equal number of occurrences on average for each value. This pulls the most frequent gray values apart, reaching the highest possible contrast.

Click **Apply** to enhance the contrast in the image using the current settings.

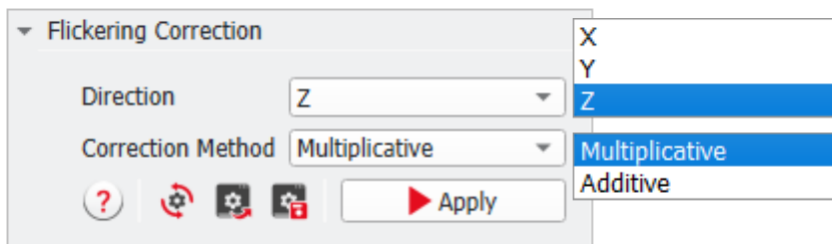
The following examples show the results of the histograms for the different settings. The gray values are separated and distributed in order to utilize the full range of gray values. The resulting gaps between the gray values improve the contrast. Note the contrast changes in the slice visualization as well.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Flickering Correction

When sliding through an image dataset in one direction, some scans display a "flickering" in the 2D slices. This is common in FIB-SEM scans, which then require **Flickering Correction**.

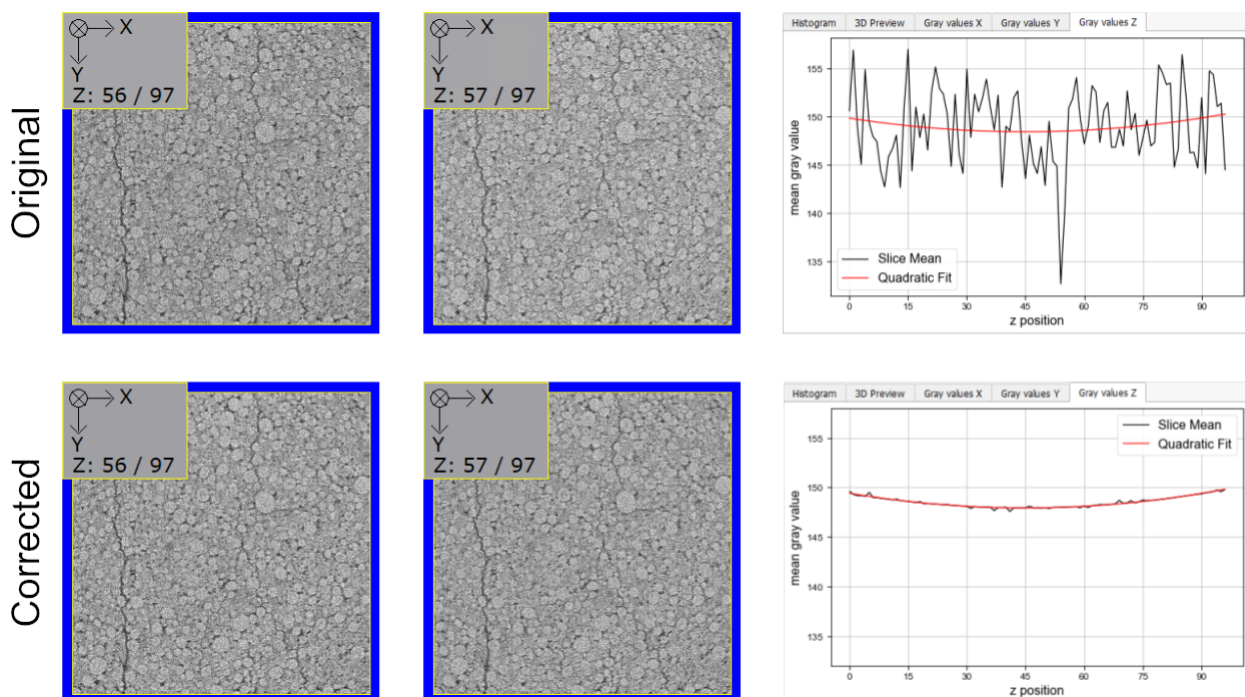


First, choose the **Direction** in which the flickering occurs: **X**, **Y**, or **Z**.

The **Correction Method** provides two options: **Multiplicative** and **Additive**. Which method should be used depends on the processing applied by the image acquisition device. Scanned image data typically indicates whether the device uses linear or logarithmic processing. If the processing is linear, use the **Multiplicative** correction method. If the processing is logarithmic, use the **Additive** correction method.

Click **Apply** to correct the flickering according to the given settings.

The dataset below is an FIB-SEM image of a cathode provided by Zeiss. Flickering can be observed along the Z-axis. Slices 56 and 57 are shown as examples. Slice 56 is slightly darker than slice 57, and the Z-direction [histogram](#)⁴¹ also shows significant variation. After applying **Flickering Correction** in the Z direction, the brightness of the slices is consistent, and the variations in the histogram are much smaller.



To analyze a scan for flickering, either manually scroll through the slices in the Image Processing dialog or create a video that slices through the structure. In the main GeoDict GUI, select **File** → **Save Video as**. Under the 2D tab, find the **Back to Front (All Slices)** and **Front to Back (All Slices)** presets. For more information about creating videos with GeoDict, refer to the Create Videos user guide.



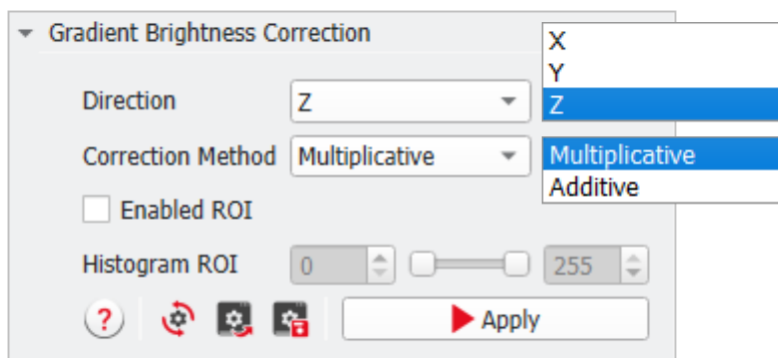
Know how! You can **Save** your current settings for this tool as **Start-Up Settings**.



The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Gradient Brightness Correction

Gradient Brightness Correction is necessary when you notice the image dataset slowly brightening or darkening as you slide through it in one direction



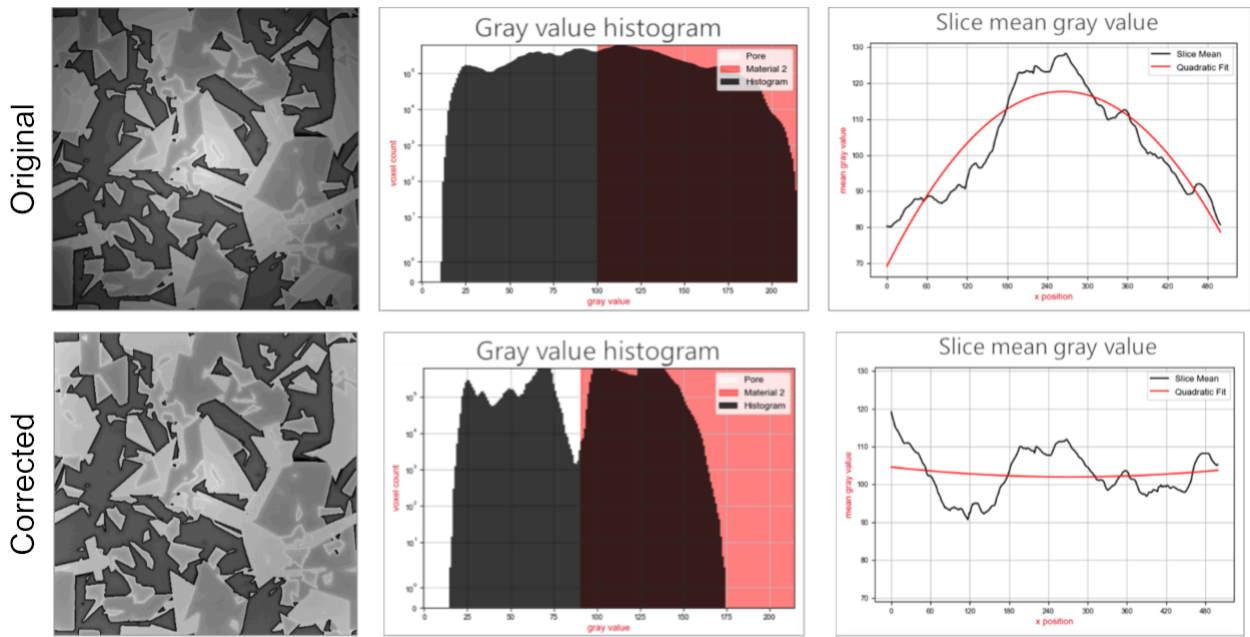
First, choose the **Direction** in which the gradient occurs: **X**, **Y**, or **Z**.

There are two **Correction Methods** available: **Multiplicative** and **Additive**. Which method should be used depends on the processing applied by the image acquisition device. Scanned image data typically indicates whether the device uses linear or logarithmic processing. If the processing is linear, use the **Multiplicative** correction method. If the processing is logarithmic, use the **Additive** correction method.

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

Click **Apply** to correct the **Gradient Brightness** based on the given settings.

The following example illustrates a brightness gradient from the exterior to the interior along the Z-axis. This gradient can also be seen in the **Slice Mean** gray value, as shown in the [Histogram](#)^[41] section and the following diagrams for the X-axis. **Gradient Brightness Correction** is applied to **Direction X** without **Enabled ROI**. This correction significantly improves the gray-value image. Consequently, the gray value histogram shows a significant improvement in differentiation between pore space and solid phases. The slice mean gray values now have a linear trend along the X-axis.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings**. The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings** available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings**.

Gaussian Brightness Correction

The goal of **Gaussian Brightness Correction** is to balance the brightness of the image's dark and light regions.

The screenshot shows the 'Gaussian Brightness Correction' tool interface. It includes a 'Sphere Radius / (Voxel)' input field set to 30, a 'Correction Method' dropdown menu with 'Multiplicative' selected, and an 'Apply' button. A tooltip is visible over the 'Correction Method' dropdown, showing the options 'Multiplicative' and 'Additive'.

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 when the grain diameters (d_{grains}) are small in relation to the **Sphere Radius** (r_{sphere}):

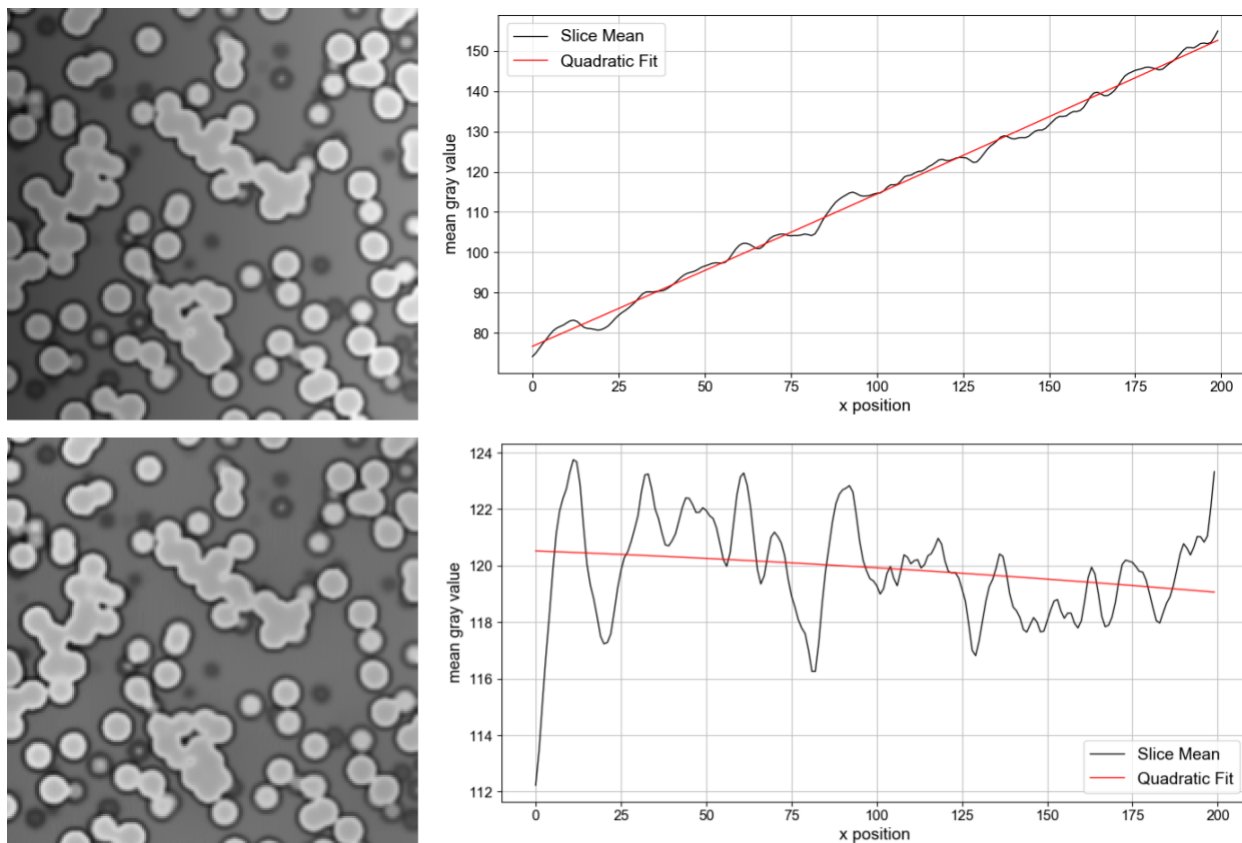
$$3 \times d_{grains} < r_{sphere} \quad (1)$$

There are two **Correction Methods** available: **Multiplicative** and **Additive**. Which method should be used depends on the processing applied by the image acquisition device. Scanned image data typically indicates whether the device uses linear or logarithmic processing. If the

processing is linear, use the **Multiplicative** correction method. If the processing is logarithmic, use the **Additive** correction method.

Click **Apply** to use the **Gaussian Brightness Correction** based on the the given settings.

The example below shows how a brightness gradient in a granular structure was corrected by applying the **Gaussian Brightness Correction**. The structure's average grain diameter is 15 μm , and its voxel length is 1 μm . Therefore, using a **Sphere Radius** of 45 works well for correcting the brightness gradient.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Invert Image

The **Invert Image** tool inverts all gray values, when you click **Apply**.

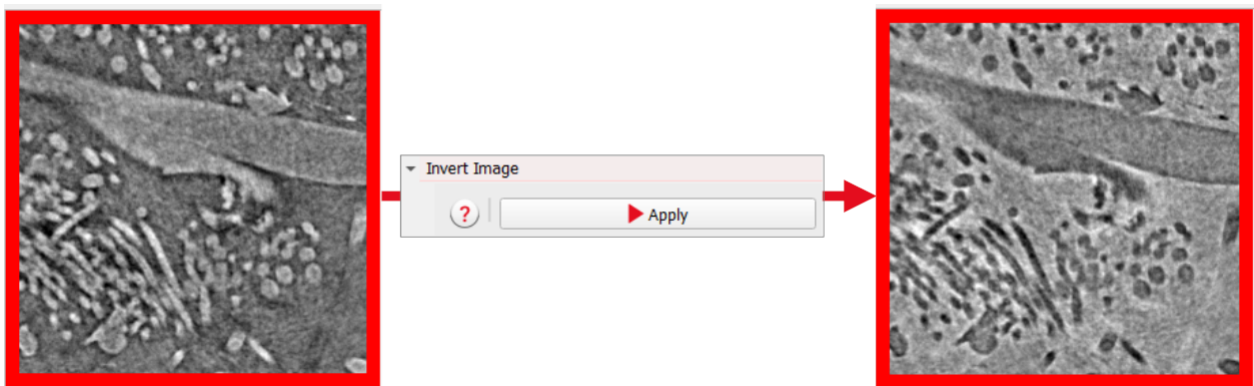
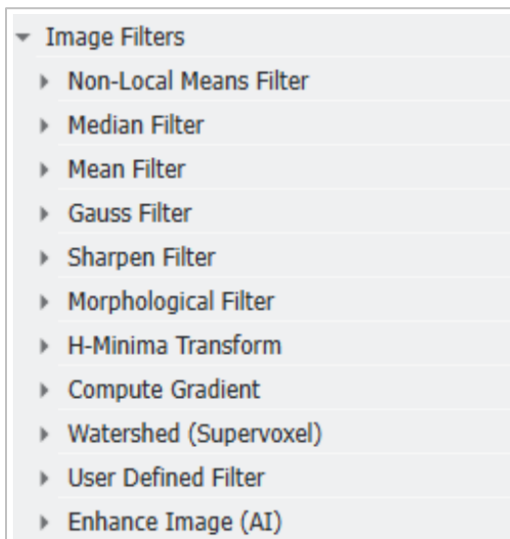


Image Filters

The **Image Filters** tree contains the tools to improve image quality.



Explore the Image Filters:

- [Non-Local Means Filter](#)^[77]
Reduce noise in the image dataset while keeping edges sharp.
- [Median Filter](#)^[79]
Remove noise or smooth the image dataset.
- [Mean Filter](#)^[80]
Remove noise or smooth the image dataset.
- [Gauss Filter](#)^[81]
Remove noise or smooth the image dataset.
- [Sharpen Filter](#)^[82]
Improve low contrast image datasets.
- [Morphological Filter](#)^[82]
Perform morphological operations on the image dataset.
- [H-Minima Transform](#)^[86]
Reduce over-segmentation in watershed algorithms by filtering out noise in the darker

Explore the Image Filters:

regions of image datasets.

- [Compute Gradient](#)^[88]
Calculate the gradient for each voxel in the image dataset.
- [Watershed \(Supervoxel\)](#)^[88]
Detect edges and create a distance map.
- [User Defined Filter](#)^[93]
Create and use your own scripts as image filters for your image dataset.
- [Enhance Image \(AI\)](#)^[94]
Apply a trained neural network to transform low-quality image datasets into high-quality ones.

Preview

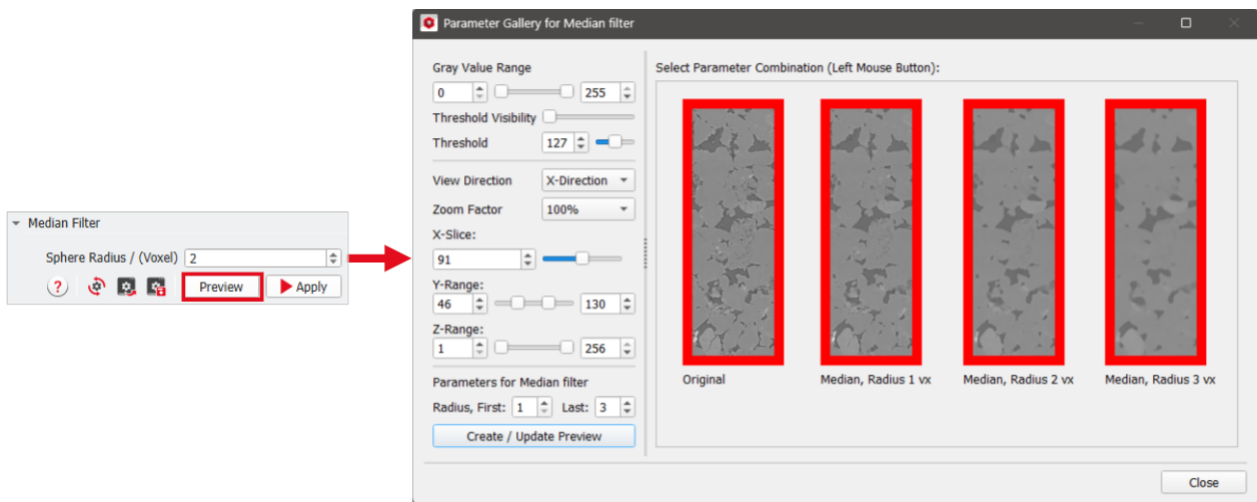
Applying image enhancement filters to complete 3D image data can be very time-consuming. To avoid long processing times, **Preview** the effect of the filter parameters before applying them to the entire dataset. Click **Preview** to open the **Parameter Gallery** dialog, which shows the effect of the entered filter parameters on the image. The **Preview** is available for these filters: [Non-Local Means](#)^[77], [Median](#)^[79], [Mean](#)^[80], [Gauss](#)^[81], [Sharpen](#)^[82], [Morphological](#)^[82], and [H-Minima Transform](#)^[86].

On the left side of the dialog, you can adjust the [Gray Value Range](#)^[36], [Threshold Visibility](#)^[38], **Threshold**. You can also adjust the viewing parameters, such as the **View Direction**, **Zoom Factor**, and the selected **Slice**, as well as the **Range** of the window on this slice to which the filter is applied.

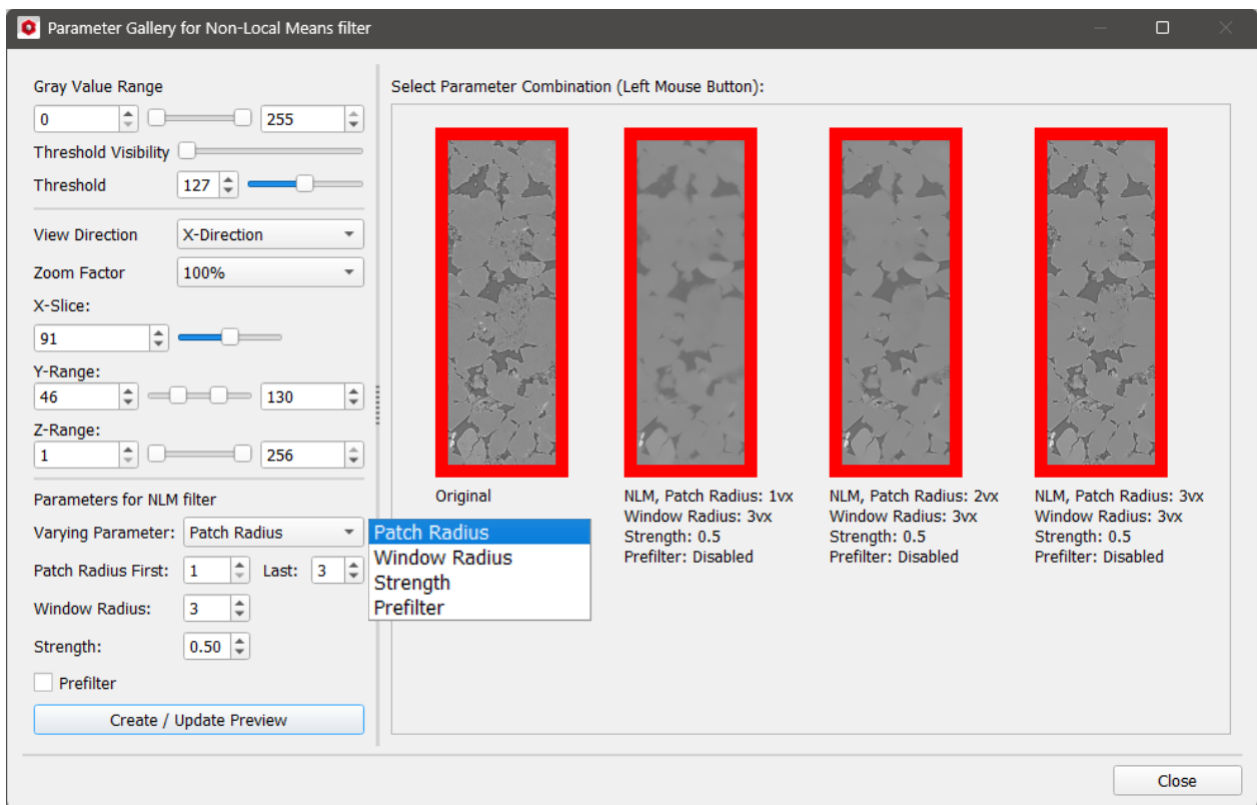
Click **Create / Update Preview** to generate a set of images that can be used to identify the desired filter effect.

Depending on the filter, different preview **Parameters** can be set.

For the [Median Filter](#)^[79], the [Mean Filter](#)^[80], and the [Morphological Filter](#)^[82], a range of Radii (here 1 to 3 voxels) can be chosen.



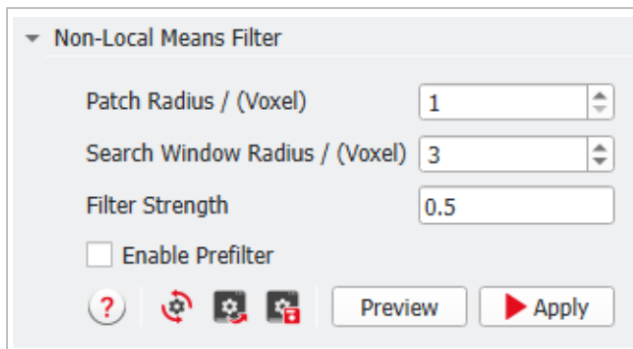
For the [Gauss Filter](#)^[81], [Sharpen Filter](#)^[82], and the [Non-Local Means Filter](#)^[77], one parameter can be chosen as **Varying Parameter**, while a fixed values are entered for all other parameters. For example, in the [Non-Local Means Filter](#)^[77], the **Patch Radius** can be set to be the **Varying Parameter**, while the **Window Radius**, the **Strength**, and **Prefilter** have fixed values.



Simply click on the desired image on the right to select the optimal parameter combination. After you close the dialog, these parameters will be transferred automatically to the corresponding filter's parameter fields.

Non-Local Means Filter

The **Non-Local Means Filter** is a very powerful tool for reducing noise while keeping edges sharp. Click [here](#) to learn more about the underlying theory.



Patch Radius controls the size of the image regions (patches) that are compared during filtering. Larger patches capture more structural information but may smooth fine details.

Search Window Radius defines the neighborhood around each voxel in which similar patches are searched. Increasing this value allows the filter to consider more candidate regions, which can improve denoising at the cost of longer processing times.

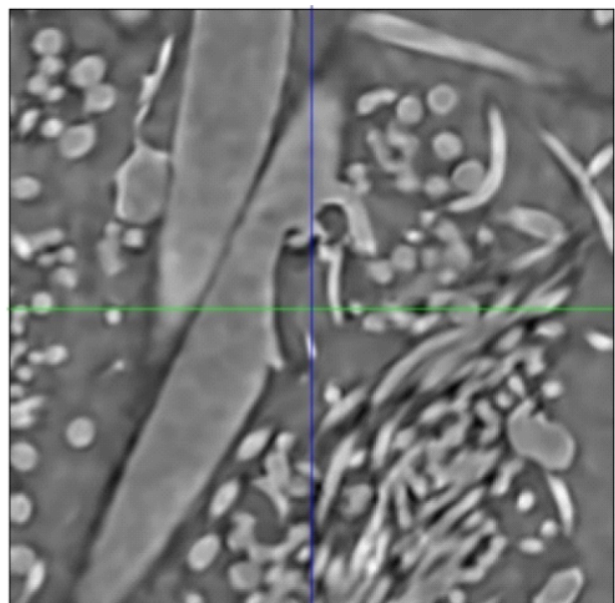
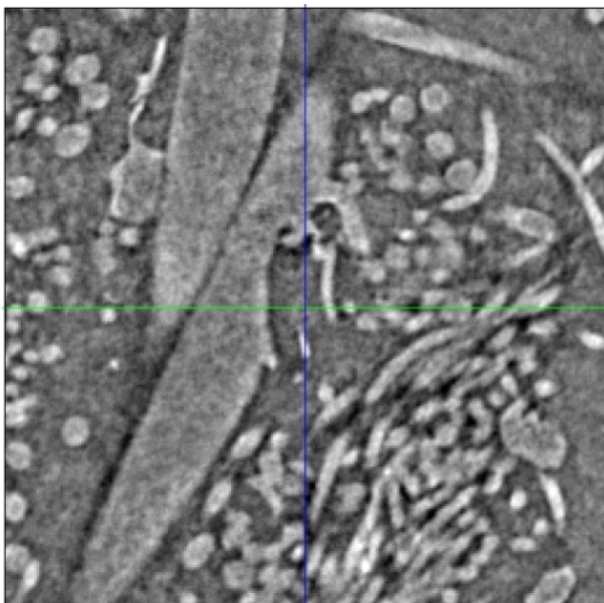
Filter Strength determines the amount of smoothing applied. Higher values produce stronger noise reduction but may also blur image details.

For highly noisy images, **Enable Prefilter** can improve the quality of the patch comparison. In this mode, a [Gaussian filter](#)^[81] is first applied to reduce noise before the **Non-Local Means Filter** is executed. This often leads to more reliable similarity estimates and improved denoising performance.



Know how! The **Non-Local Means Filter** can significantly improve the quality of segmentations. However, applying it to a complete dataset may take longer than the application of other filters. Therefore, we recommend to always use the [Preview](#)^[76] function before to identify the ideal settings.

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** using default settings.



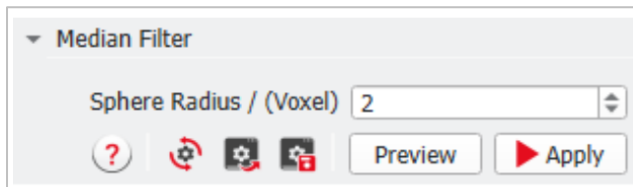


Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

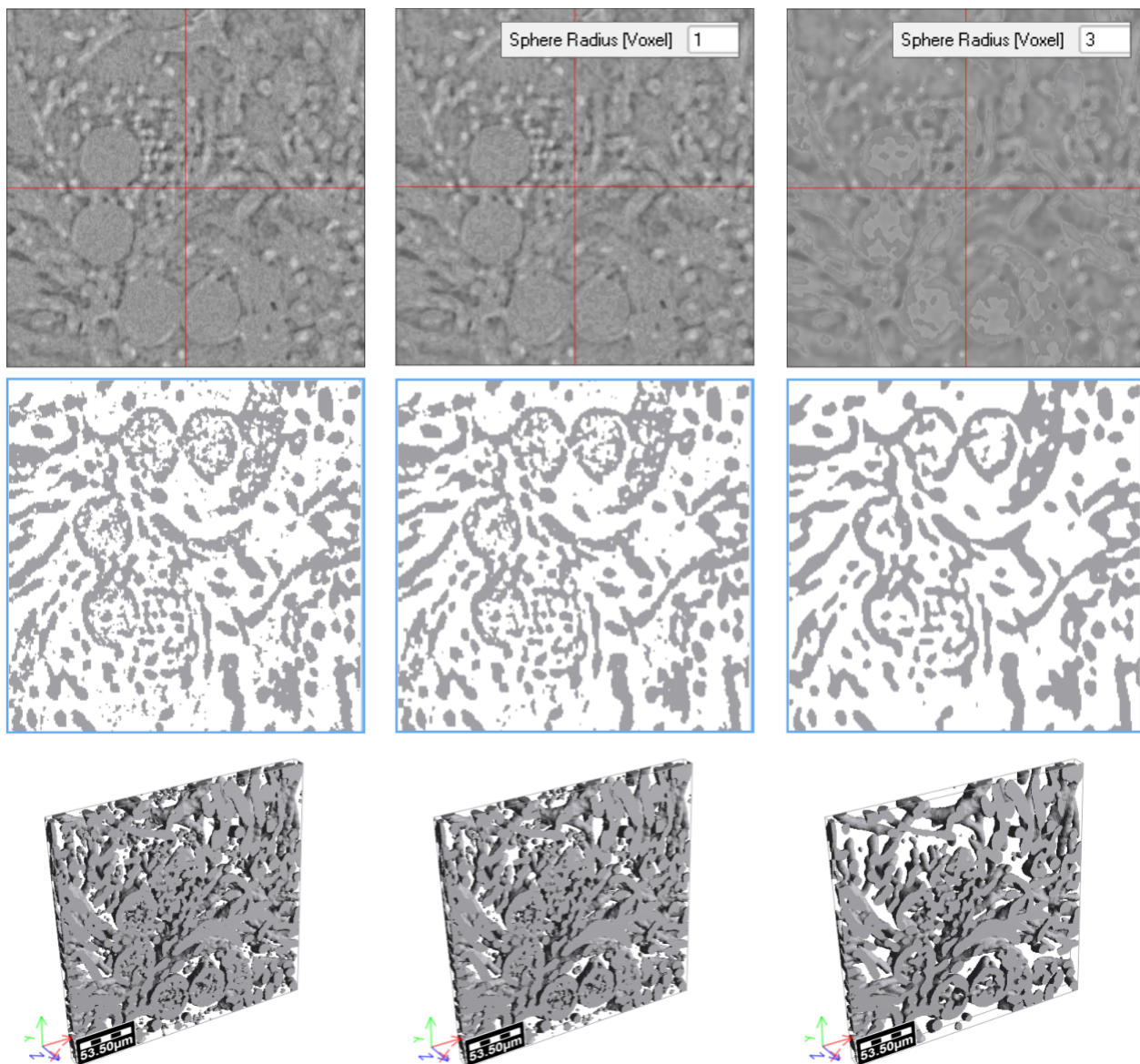
Median Filter

The [Median Filter](#) can be applied to the 3D image to remove noise or to smooth the image.

Sphere Radius defines the size of the spherical neighborhood used for filtering the 3D image. The radius is specified in voxels and determines how many neighboring voxels are included in the filtering operation. Larger radii produce stronger smoothing effects but may reduce fine structural details. After setting the desired radius, click **Apply** to execute the filter.



Notice the cleansing effect of applying the **Median Filter** after setting the **Sphere Radius** in the original image to one and then three voxels. 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.

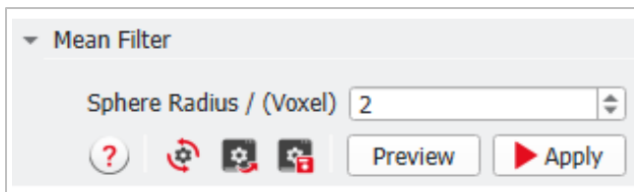


Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Mean Filter

The [Mean Filter](#) can be applied to the 3D image to remove noise or to smooth the image.

Sphere Radius defines the size of the spherical neighborhood used for filtering the 3D image. The radius is specified in voxels and determines how many neighboring voxels are included in the filtering operation. Larger radii produce stronger smoothing effects but may reduce fine structural details. After setting the desired radius, click **Apply** to execute the filter.



Please refer to the [Median Filter](#)⁷⁹ page for an example. Similar results to the example shown there can also be achieved using the **Mean Filter** using the same sphere radius value.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

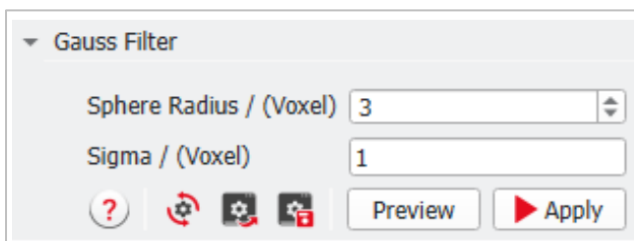
Gauss Filter

The [Gauss Filter](#) can be applied to the 3D image to remove noise or to smooth the image.

Sphere Radius defines the size of the neighborhood used for filtering the 3D image. The radius is specified in voxels and determines the extent of the Gaussian kernel applied to the image.

Sigma specifies the standard deviation of the Gaussian filter in voxels and controls the amount of smoothing. Larger sigma values result in stronger smoothing and noise reduction, while smaller values preserve more image detail.

After adjusting the parameters, click **Apply** to filter the image using the current settings.



Please refer to the [Median Filter](#)⁷⁹ page for an example. You can achieve similar results using the **Gauss Filter** with the same sphere radius value.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

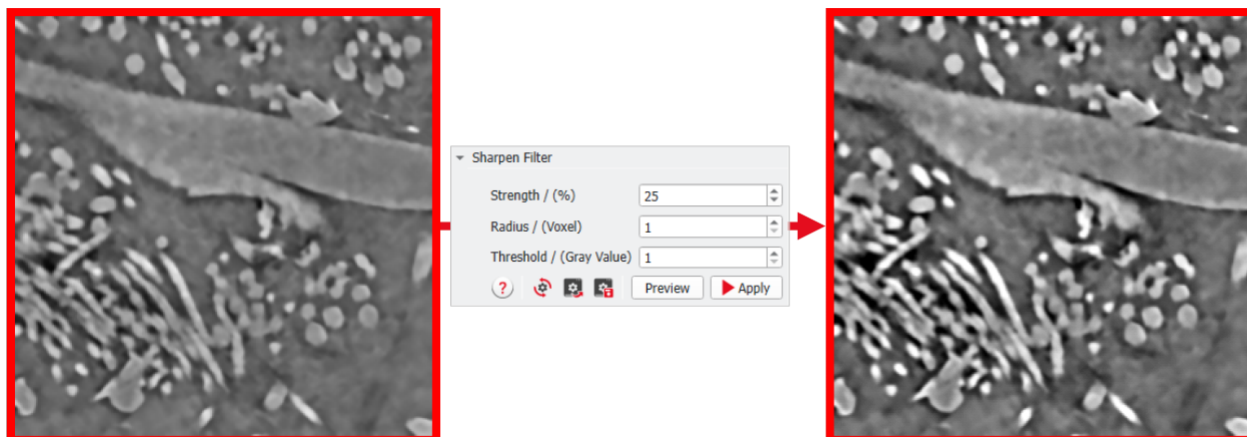
Sharpen Filter

The [Sharpen Filter](#) can be applied to improve low contrast 3D images.

The **Strength** parameter controls the amount of sharpening.

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

The **Threshold / (Gray Value)** describes the minimum difference regions must have before being sharpened. This parameter allows you to preserve smooth areas in the image.

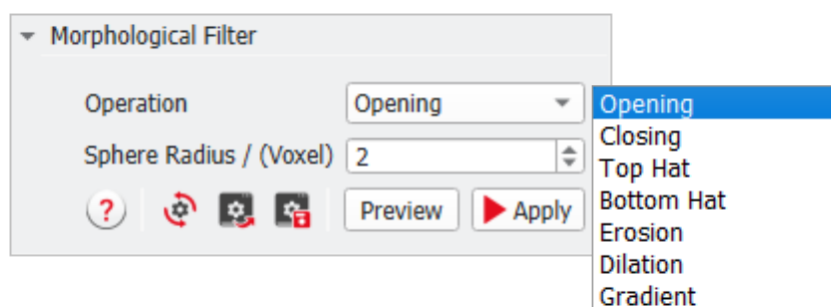


Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Morphological Filter

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

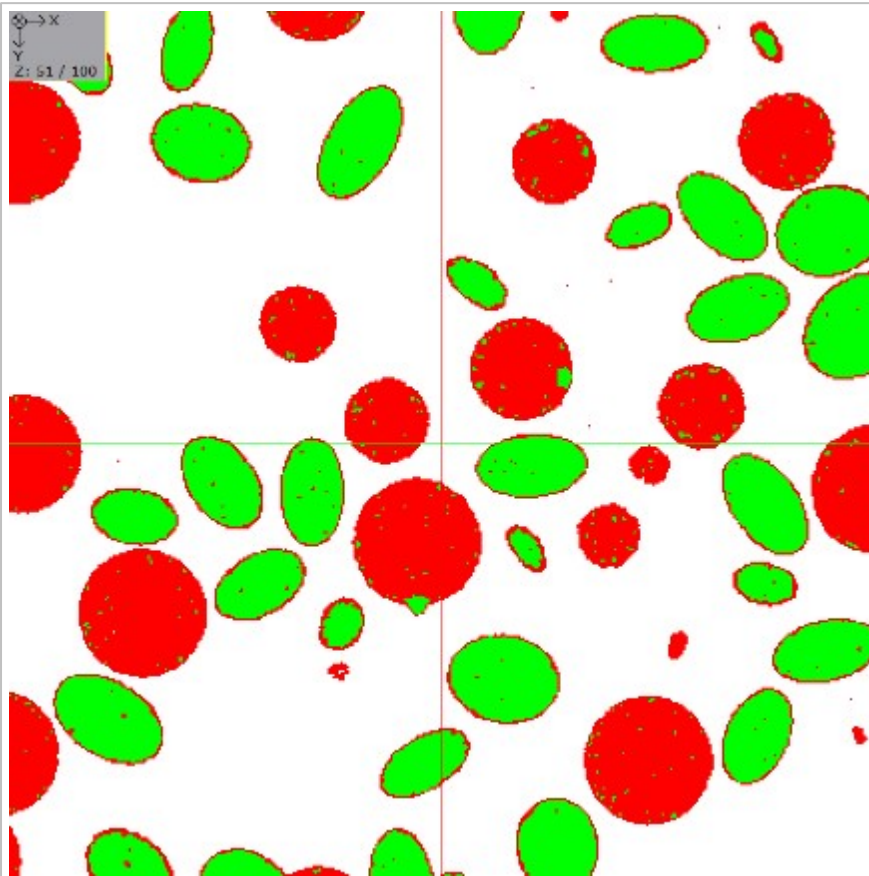
Each **Operation** requires the input of a **Sphere Radius**, which controls the size of the region in which the filter is applied. Click **Apply** to use the selected **Operation**.



Some of the **Operations** are illustrated with an example based on an artificial gray value image consisting of a few grains at high porosity. The 2D slice images show a preview of the multiple threshold segmentation as described [here](#) ¹¹⁰.

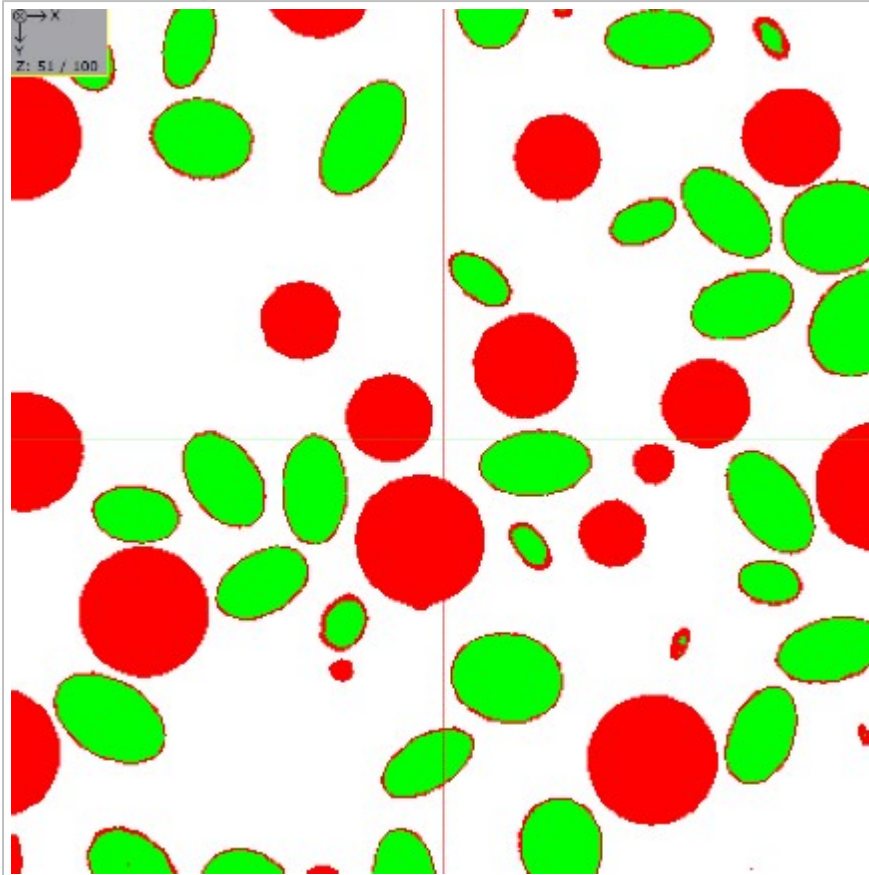


Know how! The effects of the **Operations** in the **Morphological Filter** are best seen in the **Segmentation Overlay**³⁷. Here, you can directly observe the impact on the resulting structure. The following images show the image data with this overlay activated.



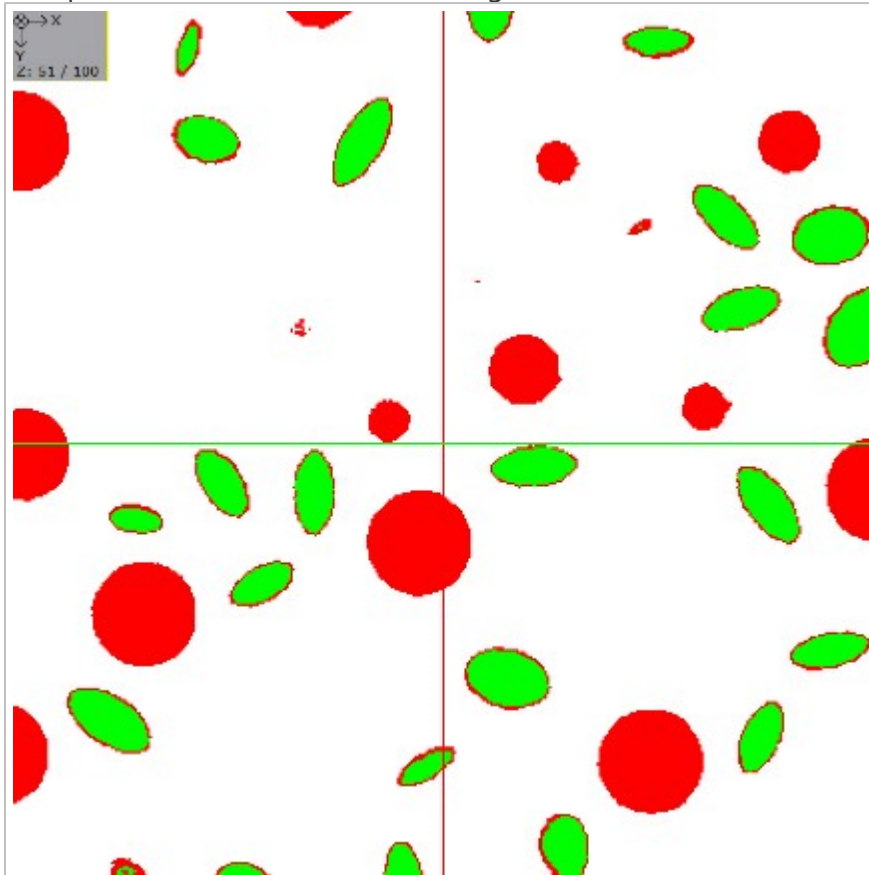
- **Opening:** Removes bright structures smaller than the specified spheres. Please note that the Cleanse tool in **ProcessGeo** can remove these *island artifacts* from segmented structures as

post-processing.

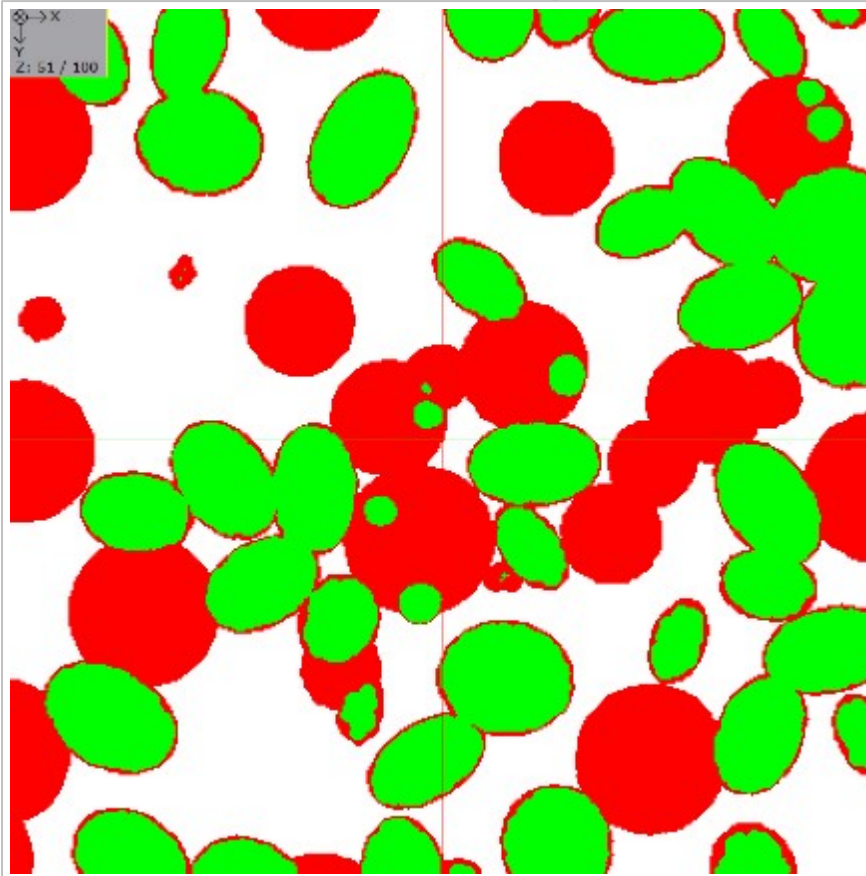


- **Closing:** Removes dark structures smaller than the given spheres. Please note that the Cleanse tool in **ProcessGeo** can remove these *island artifacts* from segmented structures as post-processing.
- **Top Hat:** Removes bright regions larger than the specified sphere.
- **Bottom Hat:** Removes dark regions larger than the specified sphere.

- **Erosion:** Grows dark regions in the image. It assigns the darkest gray value to spheres with the specified radius in the entire image.



- **Dilation:** Grows bright regions in the image. It assigns the brightest gray value to spheres with the specified radius in the entire image.



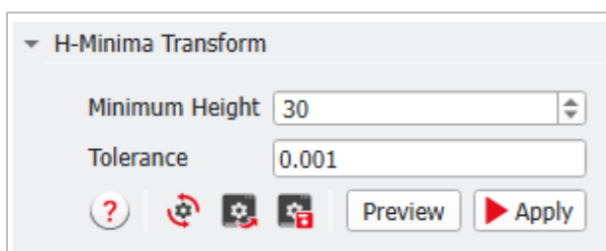
- **Gradient:** Both **Erosion** and **Dilation** are applied to the image. Then, the eroded image is subtracted from the dilated image to highlight the gradients and borders.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

H-Minima Transform

The **H-Minima Transform** was invented to reduce the over-segmentation in watershed algorithms by filtering out noise in the darker regions of gray value images.



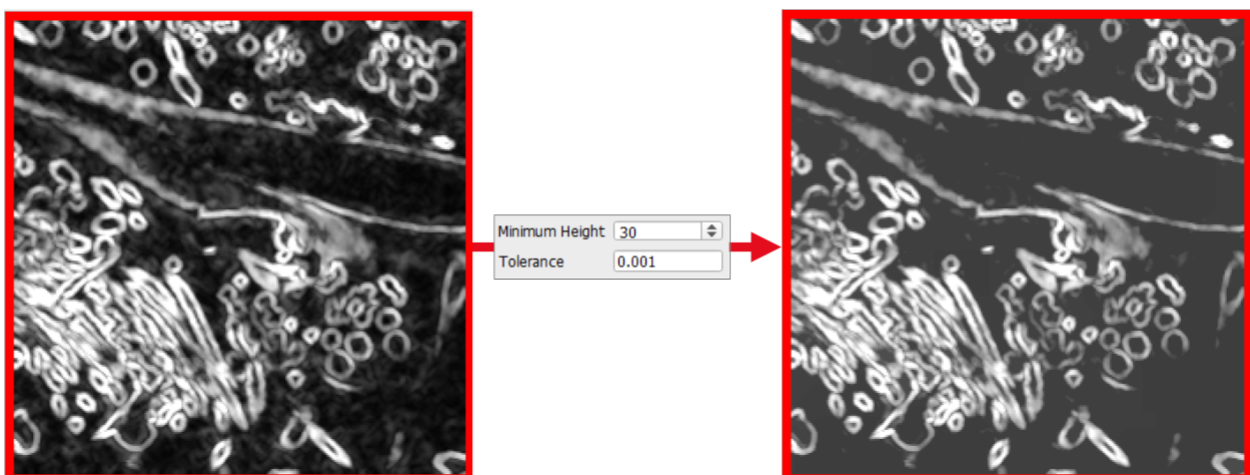
The method searches for local minima in the gray value image and suppresses them if their depth is less than or equal to the **Minimum Height**. The depth of a local minimum is defined as the difference between the gray value of the local minimum and the next local maximum gray value.

The simplified 2D example below shows neighboring gray values in gray bars. The corresponding depth of each local minimum is visualized in blue. For comparison, the given **Minimum Height** is visualized as a red rectangle. Note that the depth of the two minima in the center is shallower than the **Minimum Height**, while the depth of the other two is deeper than the **Minimum Height**. Thus, as shown below, the two in the middle will be suppressed, while the other two will not.



Tolerance represents the relative change in image mean gray values. If 0 is entered for **Tolerance**, the runtime may be very long as it tries to find a perfectly stable solution. However, in most cases, a slightly higher tolerance, the default of 0.001 for example, already leads to good results.

Click **Apply** to apply the filter on the gray value image. The following example has already been filtered with the [Non-Local Means Filter](#)^[77] and a [Morphological Gradient](#)^[86]. Then, the **H-Minima Transform** was applied with a minimum height of 30.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and

filled into the parameter fields. You can also load the **Built-In Default Settings** available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings**.

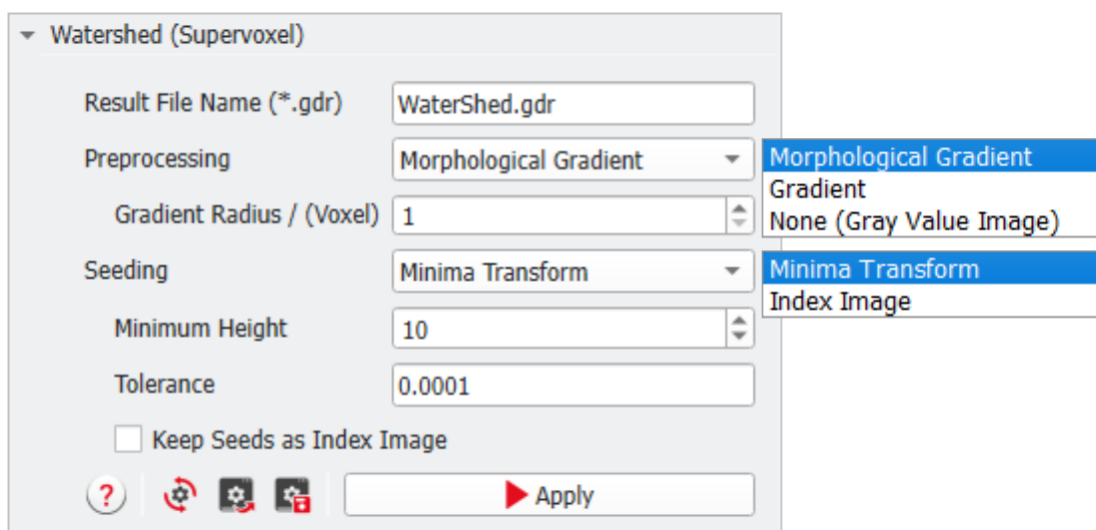
Compute Gradient

When you click **Apply**, the **Compute Gradient** tool calculates the gradient for each voxel in the gray value image. This results in an image where the gray values are brighter near the borders between different materials.

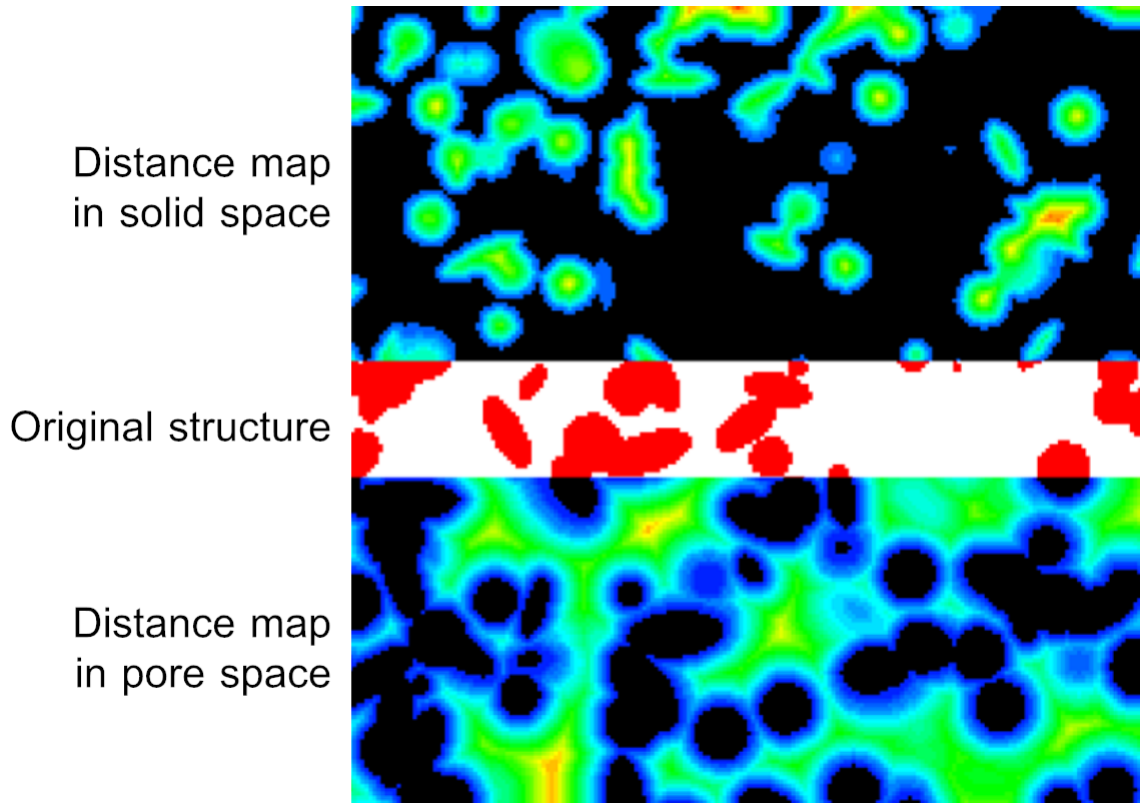


Watershed (Supervoxel)

The [Watershed](#) Transformation treats the image it operates on as if it were a topographic map. In this model, the brightness of each pixel represents its elevation. The computation then finds lines running along ridge lines. The **Watershed (Supervoxel)** is based on the **Euclidean Distance Transform** (EDT). Seeds for the Watershed component are placed at the local maxima of the EDT. In these seeds, components begin to *grow*. During this growth process, component boundaries form as soon as components touch.

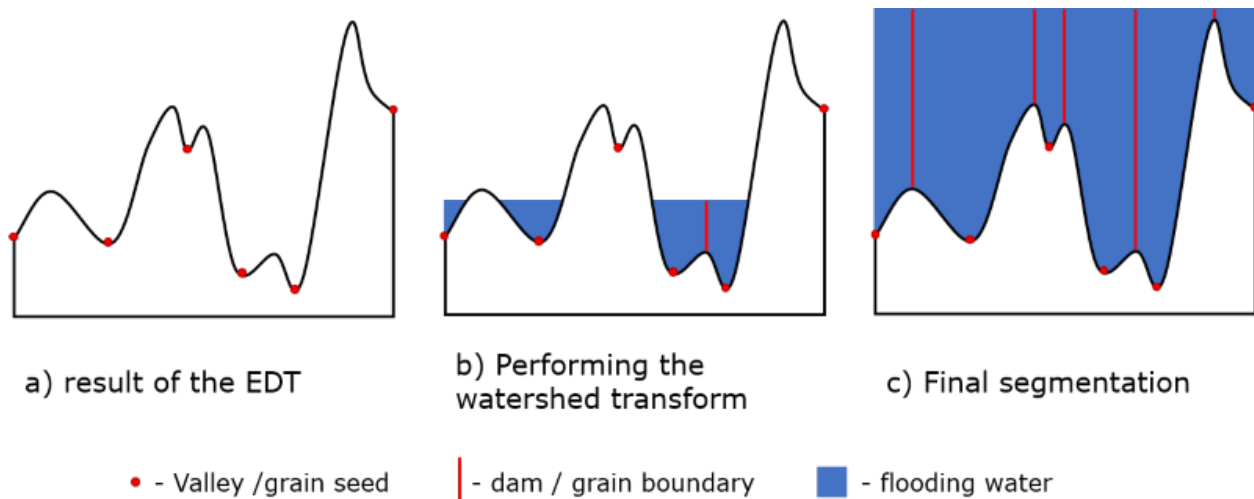


The implemented algorithm detects edges in the imported image based on the gray value or morphological gradient (see [Preprocessing](#)^[90]). Then, a distance map is created based on the edge distances. The maxima in the distance map (see the image below) are used as seeds for the watershed algorithm, which is then performed on the distance map.



The concept of a watershed is easier to understand with a 2D example. In this representation, the EDT is a topographical relief where high values represent valleys and low values represent peaks. This topography is continuously *flooded with water*, beginning with the deepest valleys. As soon as water from a neighboring valley begins to mix in, a dam is created, corresponding to a material boundary. The result is a topography with water-filled valleys separated by dams. The identified valleys represent watershed components, and the dams separating them denote component boundaries.

The figure below illustrates the progression of the watershed algorithm. On the left, the topographical relief corresponding to the EDT is shown, with the component seeds (valley bottoms) marked in red. This topography is successively flooded with water, forming dams between adjacent valleys. Information about the component space, such as the minimum component diameter, can be used to adjust the **Watershed (Supervoxel)** results. Each watershed component is assigned the mean gray value of that component. This is the supervoxel. The result is a gray value image that is much easier to segment.



If there are artifacts in the initial image, it is recommended to apply other image filters, such as the [Non-Local Means Filter](#)^[77], before running the **Watershed (Supervoxel)** algorithm. This will lead 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.

✓ Preprocessing

Three options are available for **Preprocessing** in the pull-down menu:

- **Morphological Gradient:** A [morphological gradient](#)^[86] is computed from the gray value image. Then the watershed algorithm is applied to the gradient. If this option is selected, a **Gradient Radius** must be specified. This radius controls the size of the region in which the morphological filter is applied.
- **Gradient:** A [gradient](#)^[88] is computed from the gray value image. Then, the watershed algorithm is applied to the gradient.
- **None (Gray Value Image):** The watershed algorithm is applied directly to the gray value image. This is not recommended in most cases.

✓ Seeding

For **Seeding**, select how the seeds should be specified:

- **Minima Transform:** The seeds are specified by an H-Minima Transform. The **Minima Transform** is controlled by the parameters **Minimum Height** and **Tolerance**. A detailed description can be found [here](#)^[86]. Seeds found by the **Minima Transform** can be saved in an index image (*.g32) by selection the **Keep Seeds as Index Image** option.

Seeding	Minima Transform
Minimum Height	10
Tolerance	0.0001
☐ Keep Seeds as Index Image	

- **Index Image:** A corresponding index image (*.g32) must be loaded in GeoDict. To do so, select **File** → **Load Volume Field** from the menu bar, then browse for the corresponding *.g32. This file specifies the seeds. If you have loaded more than one *.g32 file, select the desired image from the **Index Image** pull-down menu. This option is useful if you have already run **Watershed** on the image and you want to try different [Preprocessing](#) options. This reduces the runtime by skipping the image seeding.

Seeding	Index Image
Index Image (*.g32)	WaterShedSeeds.g32

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



Know how! You can **Save** your current settings for this tool as **Start-Up Settings**. The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings** available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings**.

Results

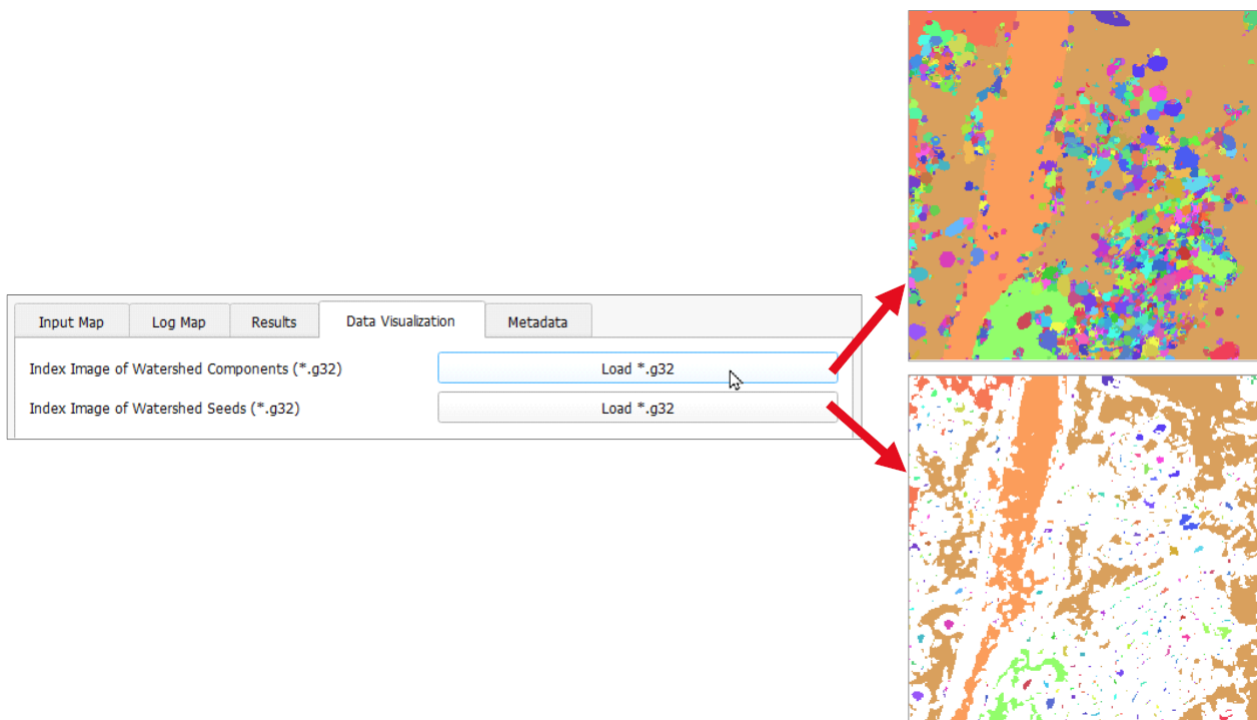
The result file with the specified **Result File Name** is opens automatically in the **Result Viewer**. The number of watershed components and their minimum, maximum, and mean sizes can be found under the **Results – Report** sub-tab.

Input Map	Log Map	Post Map	Results	Data Visualization	Metadata				
<table border="1"> <tr> <td>Report</td> <td>Map</td> </tr> <tr> <td colspan="2"> Number of watershed components: 70290 Minimal size of component: 1 voxel Maximal size of component: 6082655 voxel Mean size of component: 240.554 voxel </td> </tr> </table>						Report	Map	Number of watershed components: 70290 Minimal size of component: 1 voxel Maximal size of component: 6082655 voxel Mean size of component: 240.554 voxel	
Report	Map								
Number of watershed components: 70290 Minimal size of component: 1 voxel Maximal size of component: 6082655 voxel Mean size of component: 240.554 voxel									

Go to the **Data Visualization** tab and click **Load *.g32** to visualize the **Index Image of Watershed Components** in the GeoDict visualization area. This image shows the individual regions identified by the watershed. For the filtered image visualized in the Image Processing dialog, the resulting gray value is the mean gray value of the corresponding region. If the

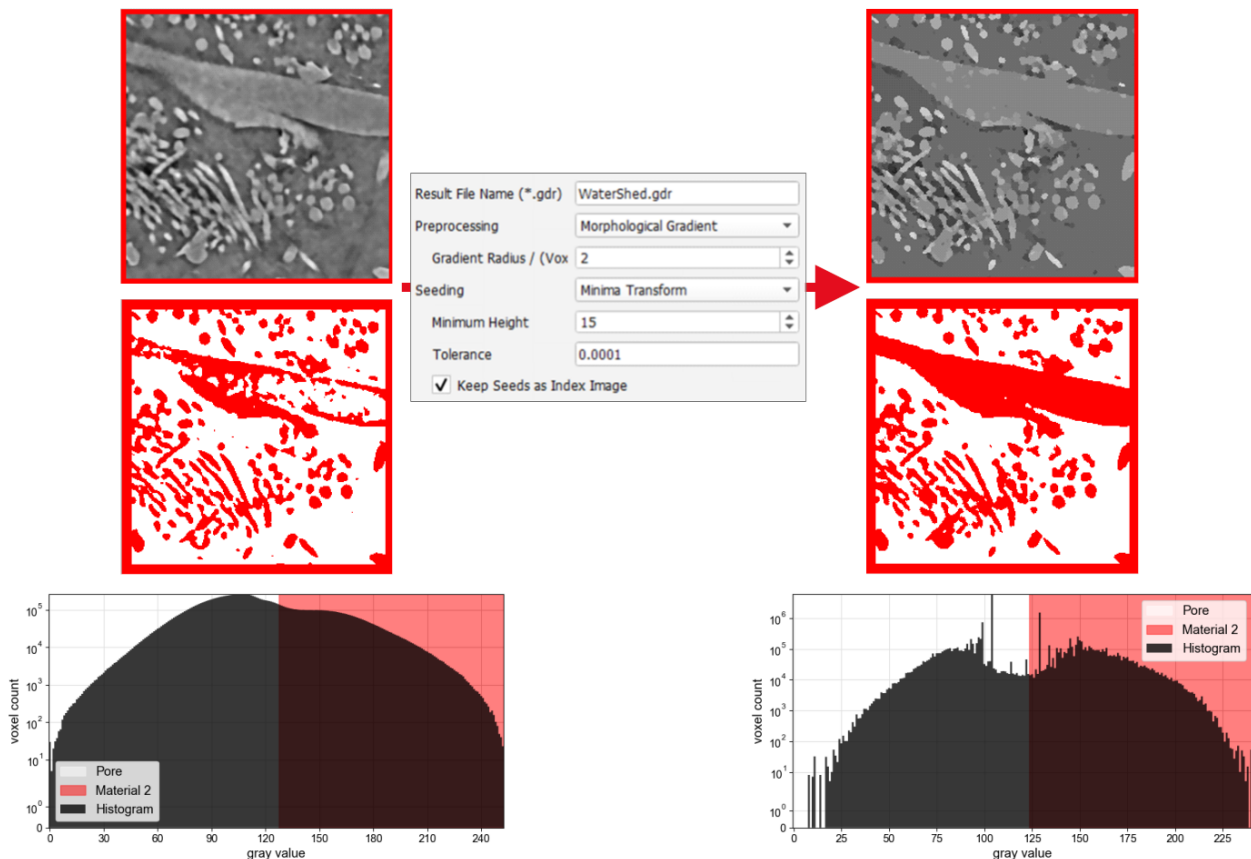
watershed identifies individual objects, the components file can be used as input for GrainFind Identify Grains, for example. However, for many scans, the individual objects cannot be recognized from the gray value image.

If the **Keep Seeds as Index Image** box is checked, the watershed seeds can be visualized by clicking the lower **Load *.g32** button. Otherwise, the button is grayed out. This image shows the seeds specified by the H-Minima Transform algorithm. Use it to rerun the watershed with different preprocessing parameters, as explained above. In the opening dialog, click **OK** to load the index image in GeoDict. For more information about GeoDict result files, refer to the Result Viewer user guide.



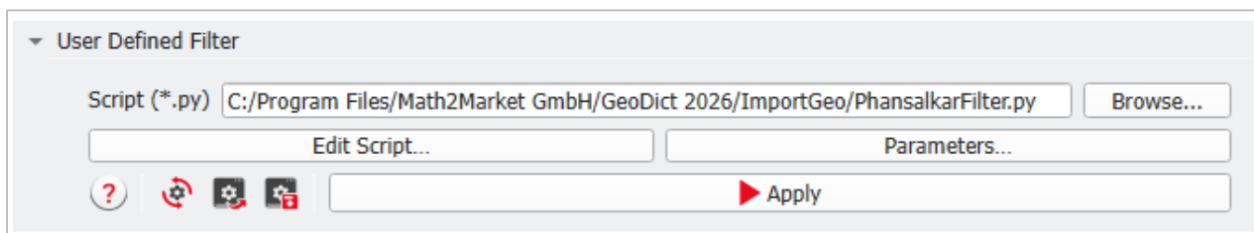
Example

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. Note the difference in the resulting [Histogram](#)^[41], which makes it possible to simply apply the automatic [Otsu](#)^[109] threshold.



User Defined Filter

You can use your own scripts as image filters for your data. Examples of these user-defined scripts can be found in the **ImportGeo** folder within the GeoDict installation folder, as well as in the GeoDict settings folder.



The `PhansalkarFilter.py` script can be used to learn how to obtain and modify the image data that is shown in the **ImportGeo-Vol** box. Click **Browse** to navigate to the GeoPy macro. Then, 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

filteredImage = gd.ImportGeoVol.getNewImage()
to create a new image.
```

You can then extract the dimensions with the `shape` command:

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

The Phansalkar script uses loops over each image voxel to determine whether the corresponding voxel should be set to white [255] or black [0]. It is sufficient to change the new image (`filteredImage`). For more details on this topic, please refer to the [Phansalkar](#)^[130] section and the GeoPy scripting user guide.

For scripts containing parameters that can be varied as inputs, click **Parameters** to edit them.

Click **Apply** to run a selected script.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Enhance Image (AI)

Use the GeoDict-AI module to train a neural network to transform low-quality images into high-quality ones. For example, scans taken from fewer angles or with reduced exposure time can be improved by a trained network. The GeoDict-AI user guide explains how to train a neural network to enhance gray value images.

If a suitable graphics card is detected, the GPU mode is used to run **Enhance Image (AI)**. Otherwise, it runs in CPU mode. If multiple GPUs are available, select the one on which it should run. Image enhancement can also run on multiple GPUs. If you select more GPUs than are licensed, an error message will appear when you click **Apply**.

Browse for the neural network model trained with GeoDict-AI and best suitable for the loaded image dataset.

The **Description** lists the current constraints for applying the neural network, as entered in the GeoDict-AI module for training neural networks. For example, it specifies the type of images that the neural network was trained with.

The **Batch Size** selection is related to the available memory on the graphics card (GPU). Conceptually, GeoDict loads the GPU with portions of work called *batches*. Currently, this selection must be made manually, and the parameter is set according to the value entered in **Batch Size**. The larger the **Batch Size**, the better the performance. Therefore, set the **Batch Size** as high as possible, depending on your GPU and the neural network settings. If multiple GPUs are selected, the batches are distributed equally among them. If a GPU is not detected, image enhancement runs on the CPU, which takes much longer.

If the **Batch Size** exceeds the graphics card's capabilities, an error message appears and the image enhancement process is aborted.

Click **Apply** to start the image enhancement.

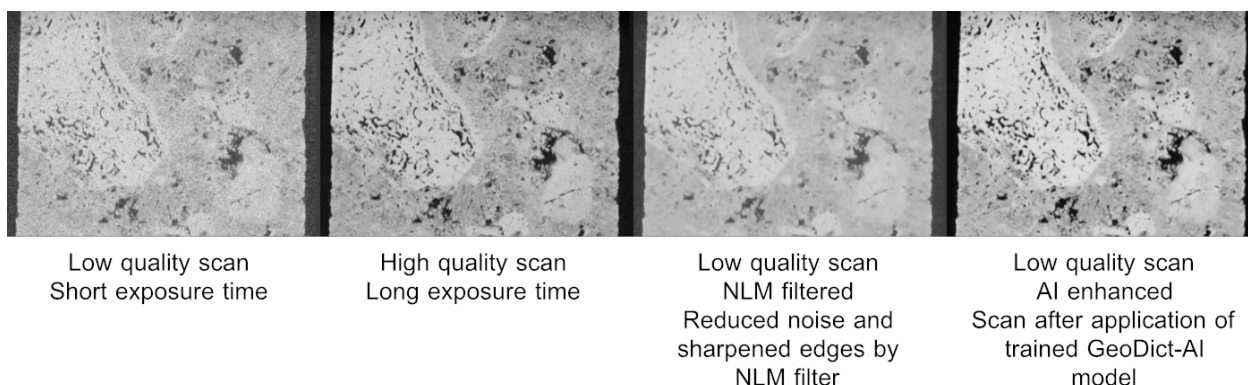


Know how! You can **Save** your current settings for this tool as **Start-Up Settings**

The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Example

A carbonate sample was scanned twice, once with a short exposure time and once with a long exposure time. The sample data was provided by [Chandra and Al-Naimi](#)^[143]. A neural network was trained using GeoDict-AI to transform the low-quality scan into a high-quality scan. Below is a comparison of applying the [NLM Filter](#)^[77] and the trained AI model to the low-quality scan. While the NLM filter reduces noise, the contrast is worse compared to the scan with a long exposure time. However, the AI model produces a scan with a comparable contrast to the high-quality scan and has less noise. Once a model is trained with GeoDict-AI, short exposure times are sufficient to obtain high-quality images using the **Enhance Image (AI)** tool.



FIB-SEM Filters

The **FIB-SEM Filters** section contains tools designed specifically for filtering and adjusting images captured using **Focused Ion Beam Scanning Electron Microscopy**.



Explore the FIB-SEM Filters:

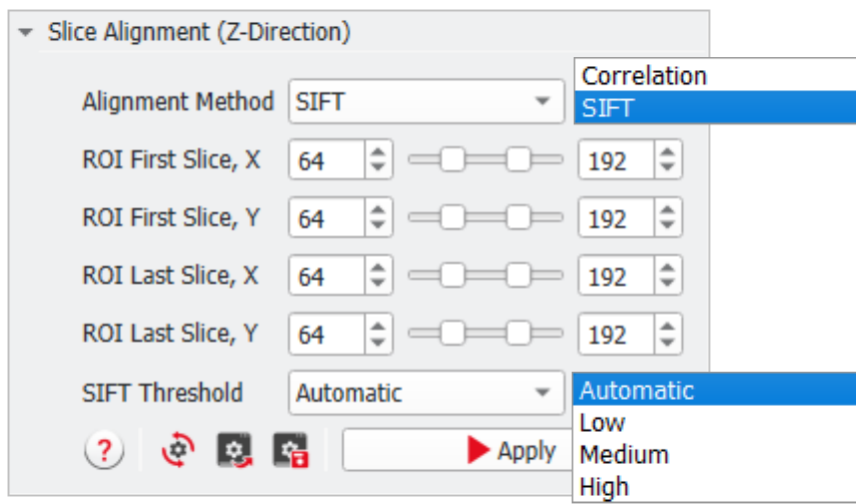
- [Slice Alignment \(Z-Direction\)](#)^[97]
Correct the alignment of image slices in the dataset.
- [Slice Thickness Adjustment](#)^[98]
Adjust slice thickness based on information contained in the image file names.

Explore the FIB-SEM Filters:

- [Curtaining Filter](#)^[101]
Remove the curtaining effect from FIB-SEM image datasets.

Slice Alignment (Z-Direction)

During FIB-SEM image acquisition, the alignment of the image slices is not maintained due to specimen drift or image distortion, for example. This typically occurs along the Z-axis. Therefore, **Slice Alignment** is necessary.



Note! Before aligning the slices, please ensure that the image is oriented with the misalignments in the Z direction. This can be best observed by sliding through the 2D slices in the Z direction. Offsets are typically visible when looking at images in the X- and Y-directions. If the misalignments occur in a different direction, [rotate](#)^[56] or [permute](#)^[64] the image first.

Two options are available for the **Alignment Method**:

- The **Correlation** algorithm shifts the slices in the X- and Y-directions until the regions within the defined region of interest (**ROI**) are as similar as possible.
- The **SIFT** (**S**cale-**I**nvariant **F**eature **T**ransform) algorithm recognizes features and attempts to map them to each other by shifting and rotating the slices. This method works well when the features are similar across the different slices. More detailed information on this method can be found [here](#).

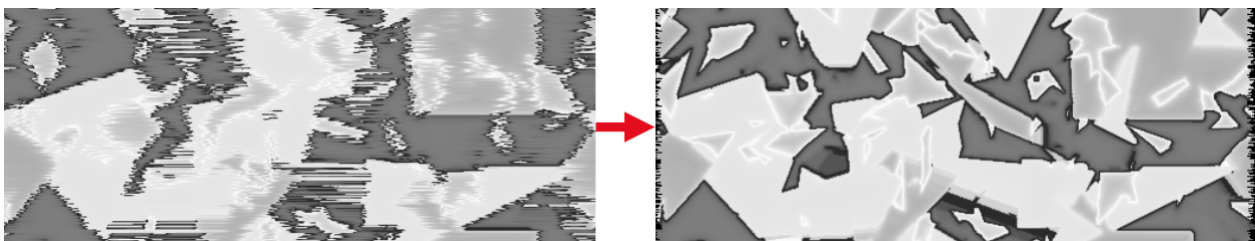
The choices for **ROI First Slice** and **ROI Last Slice** for **X** and **Y** define the region, in which the alignment is examined. Based on the findings for that region, the slice alignment is performed on the entire image. Please note that this may result in unavoidable boundary effects, which may necessitate [cropping](#)^[48] the image at its boundaries. The rectangle resulting from the **First Slice** and **Last Slice** values is visualized in red in the [2D Slice Visualization](#)^[40] section in the X-Y-plane if **Slice Alignment** is chosen as [Overlay](#)^[37].

In the **Correlation** method, the **Radius** defines the maximum shift between two slices that will

be searched. For many FIB-SEM images, the default radius of 10 voxels is sufficient. However, if the slices are shifted by more than 10 voxels, the radius setting needs to be increased.

For the **SIFT** method, the **SIFT Threshold** for the image features can be defined as **Low**, **Medium**, or **High**. A higher threshold uses only the most significant image features, while a lower threshold uses more image features. If the alignment does not modify the image, choose a lower threshold. If, on the other hand, the alignment is incorrect, a higher threshold may be better. When the threshold is set to **Automatic**, it is adjusted automatically.

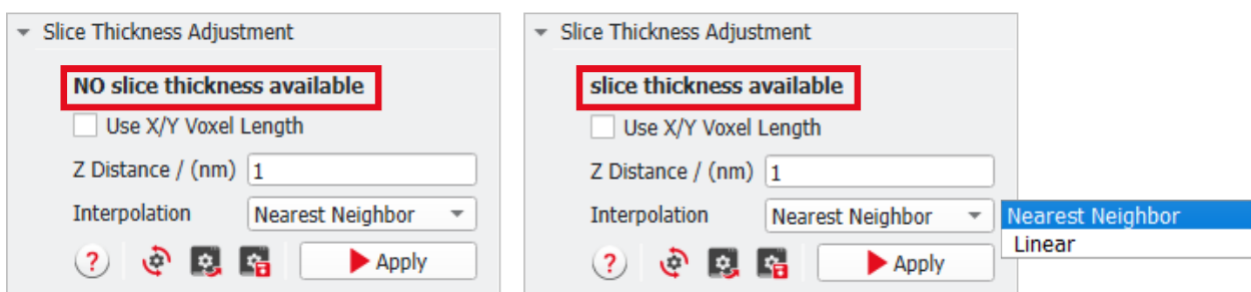
The example below shows a 2D slice from the X direction of an artificially misaligned gray value image (left). After applying the **Slice Alignment** tool with the default settings, the misalignment is completely corrected. Note the offsets on the left and right boundaries of the aligned image. The image size in the X and Y directions has increased to include all aligned slices in the 3D image without losing information.



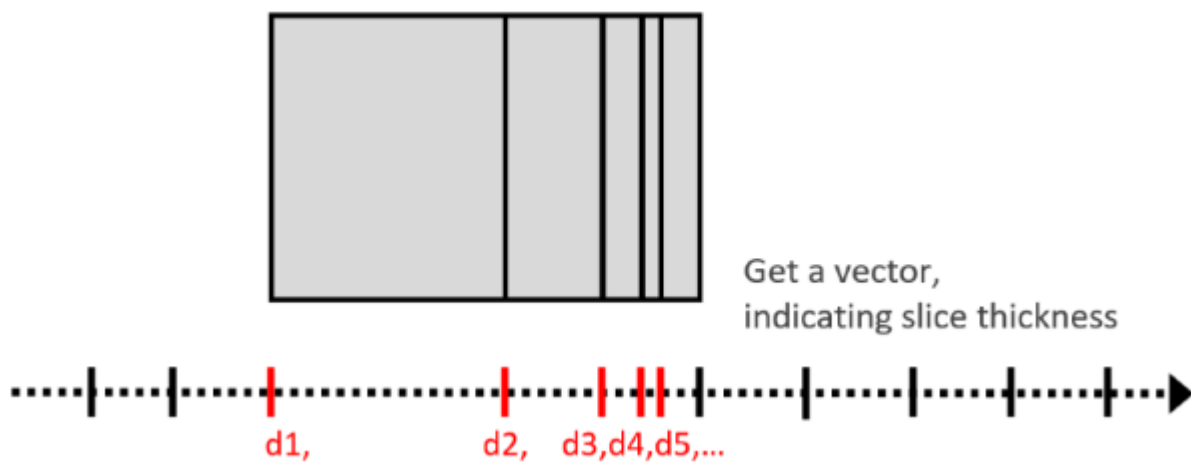
Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

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 at the top of the section.



Observe how the different slice thicknesses are assigned to coordinates, forming a vector that indicates the slice thickness, in the following figure.



These vector entries must be provided for the image stack under consideration. Therefore, the ending of each image in the stack must be **_z=...um** (the unit must be given in microns), where the ... must be replaced by the corresponding coordinate. For example, the names could be **image_001_z=1.0um.tif**, **image_002_z=2.1um.tif**, **image_003_z=3.3um.tif**, and so on. FIB-SEM image stacks from Zeiss machines follow this naming scheme.

The slice thickness is adjusted by using interpolation to fit the given distance between the given Z-slices.

If the **Use X/Y Voxel Length** box is checked, the distance between the resulting Z-slices will be equal to the voxel length in the X- and Y-directions. Otherwise, enter the desired **Z-Distance** in nanometers.

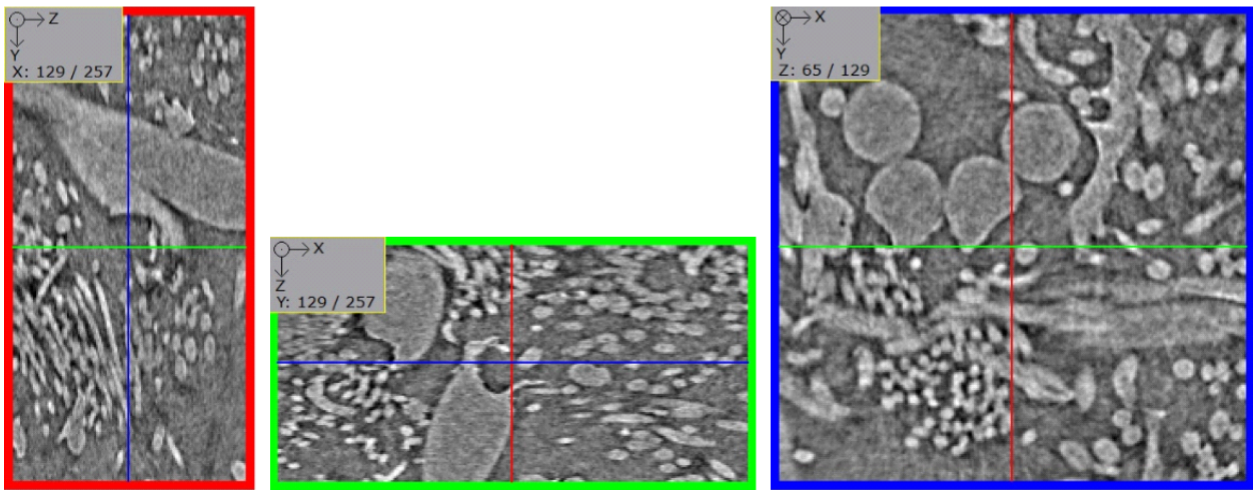
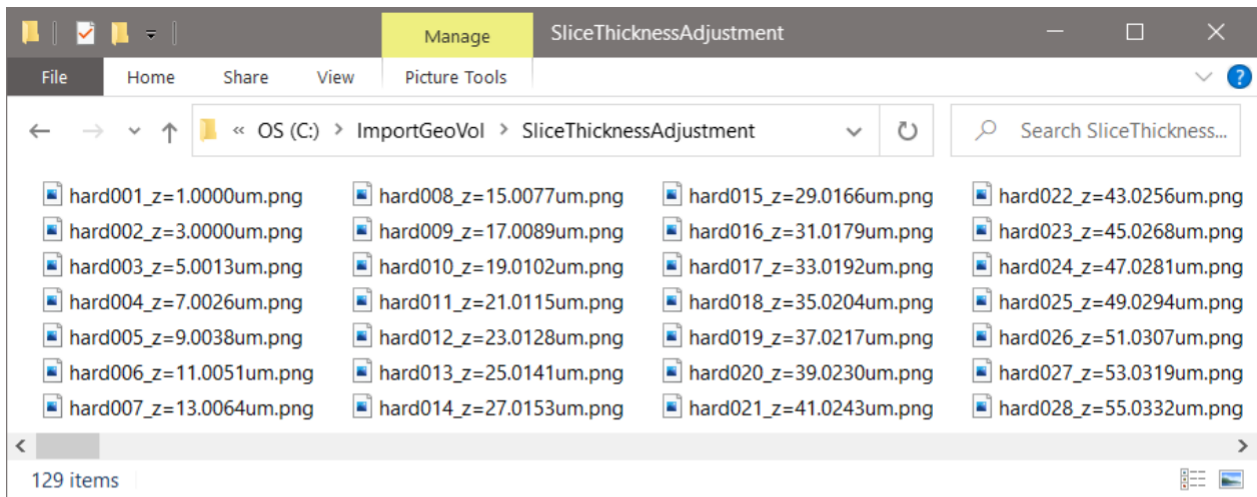
For gray value **Interpolation**, choose between **Linear** and [Nearest Neighbor](#).

Click **Apply** to adjust the **Slice Thickness Adjustment**.

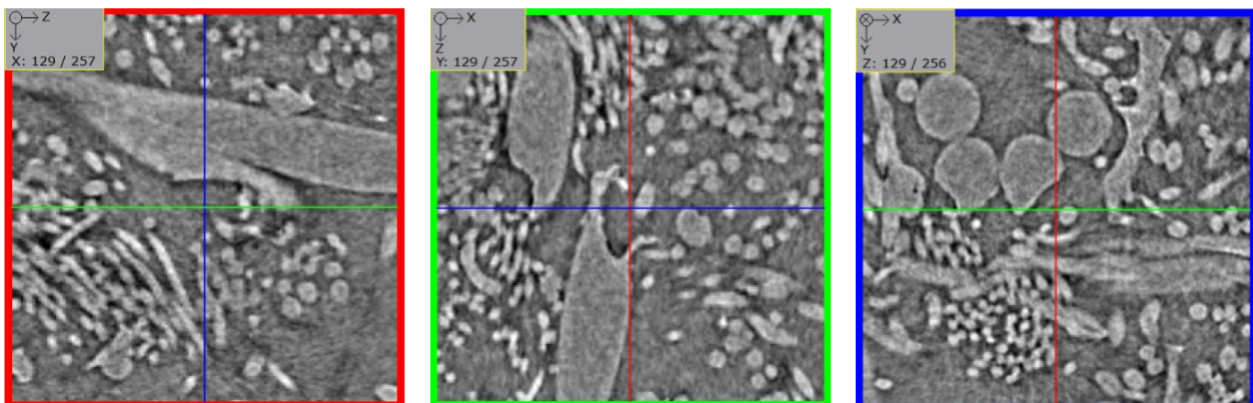
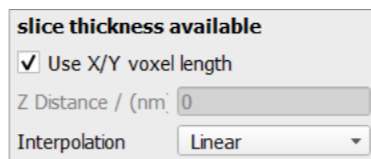


Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

In the following example, the slice thickness between the individual images is approximately 2 μm , while the voxel length in the X- and Y-directions is 1 μm .

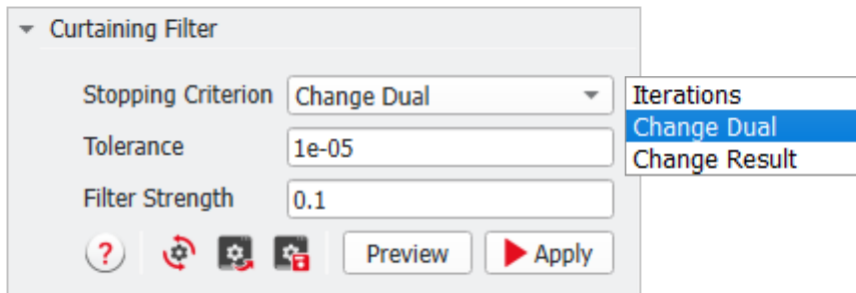


Thus, selecting **Use X/Y Voxel Length** and clicking **Apply** results in 256 slices instead of 129, stretching the image in the Z-direction.



Curtaining Filter

The **Curtaining Filter** removes the curtaining effect, which is common in FIB-SEM image scans. The filter generally applies deconvolution to produce two 3D images: one containing only the stripes of the curtaining effect and the other containing the filtered image. For more information about this filter, refer to [Fitschen et al., 2017](#)¹⁴³.



The filter includes three **Stopping Criteria** and the corresponding **Tolerance** or **Iterations** values, which control the computational time and quality of the filter results:

- In the **Iterations** mode, the filter stops after the specified number of **Iterations**.
- With **Change Dual**, an internal tolerance value is determined. The filter stops iterating once the given **Tolerance** is reached.
- In **Change Result** mode, differences in gray values between iterations are examined to define the **Tolerance** value. This mode requires approximately twice the amount of working memory.



Know how! We recommend to use the default settings for most cases.

The given **Tolerances** are independent of image size.

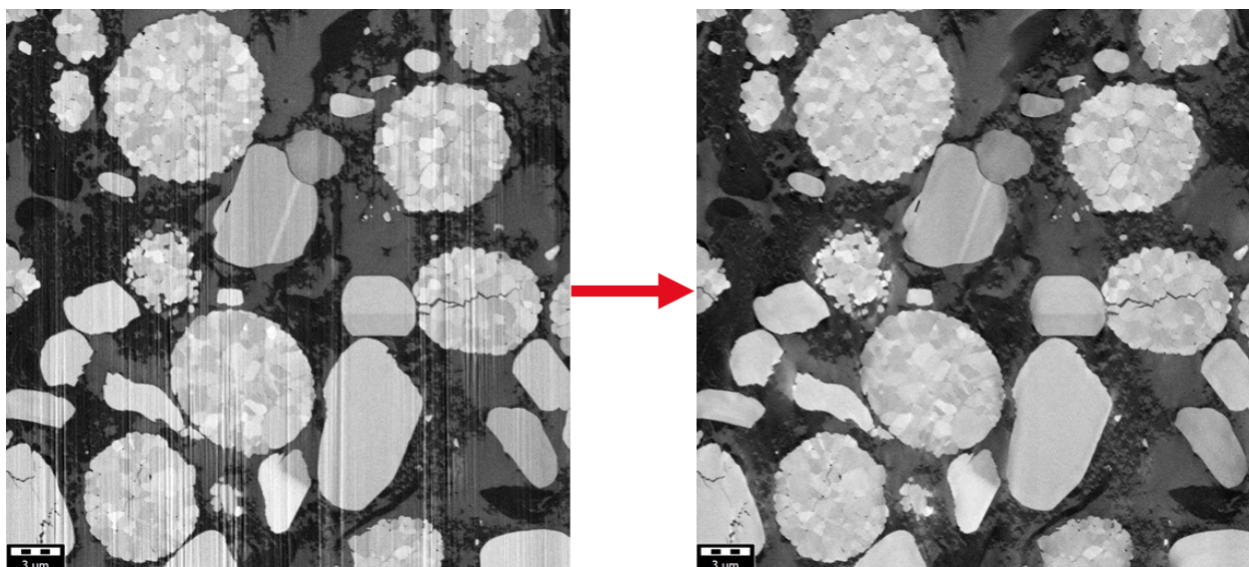
Increasing the **Filter Strength** can remove heavy stripes. Decreasing the strength reduces the effect of the curtaining filter.

Click **Apply** to remove the **Curtaining** according to the defined settings.



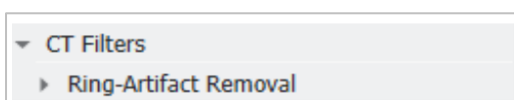
Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

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



CT Filters

The **CT Filters** section contains tools designed specifically for filtering and adjusting images measured with **Computed Tomography**.



Explore the CT Filters:

- [Ring-Artifact Removal](#)^[102]
Remove ring artifacts from CT image datasets.

Ring-Artifact Removal

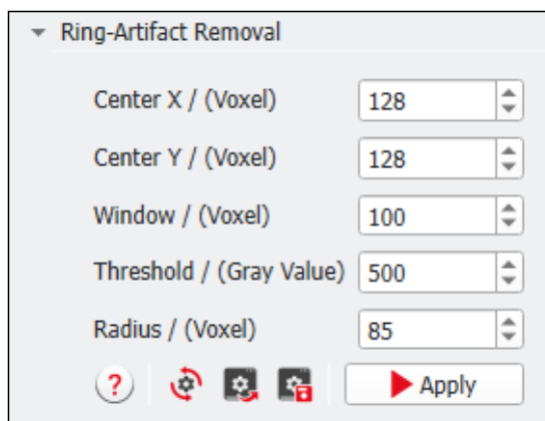
Ring-Artifact Removal removes ring artifacts from CT scans. Ring artifacts in CT images appear as concentric circular patterns centered on the rotation axis and are typically caused by defective, unstable, or improperly calibrated detector elements during scanning. In CT scans these artifacts can obscure internal features and interfere with accurate microstructural analysis. The applied algorithm is based on the work of [Sijbers and Postnov, 2004](#)^[143].



Important! For the filter to work properly, the Z-axis must be the rotation axis, the standard for CT scans. If that is not the case, however, you can [rotate](#)^[56] or [permute](#)^[64] the image before applying **Ring-Artifact Removal**.

The first step in the filtering process is defining the midpoint of the rotation axis and the extent of the artifacts. Based on this midpoint, the filter searches for artifacts at every possible **Radius**. At each radius, the extent examined is given by the **Window** size (see the **Red Ring** in the image below). The effect of the ring artifacts on the gray values is examined within these extents.

However, the algorithm requires correction wherever multiple phases are affected. Therefore, a **Threshold** value must be provided to define the maximum gray value range. This value varies depending on the material and scan. The threshold value must be smaller than the variance between the ring artifacts and the average gray value inside a window around the ring artifact. Note that there is a significant difference in gray values between 8-bit and 16-bit images, for example.



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

Click **Apply** to remove the ring artifacts according to the defined settings.

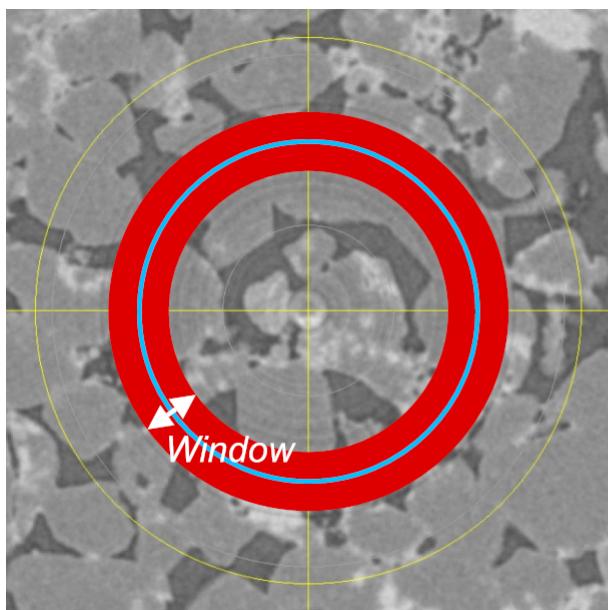


Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

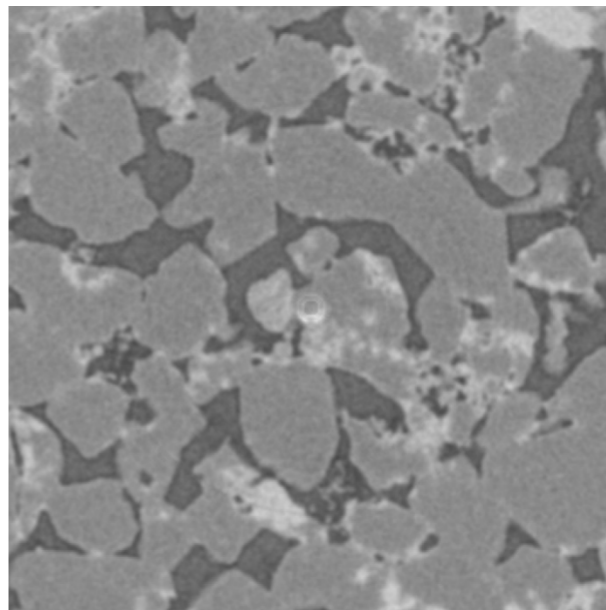
In the example below, **Ring-Artifact Removal** has been selected as the [Overlay](#)³⁷. The **Ring-Artifact Removal** overlay is displayed with yellow lines. The intersection of the straight yellow lines indicates the specified **Center**. The yellow circle indicates the specified **Radius**. You can also change both directly via the overlay. Click on the center of the circle to move the center point, and click on the outer circle to change the radius.

Below, red and blue circles are added to illustrate how the **Ring-Artifact Removal** considers each blue ring within the yellow circle. These rings then form a center line for a new red **Window**. The **Ring-Artifact Removal** filter only examines values within the red area for this single blue ring. However, the filter checks for all possible rings within the yellow circle. The filter calculates the variance of gray values within the blue ring compared to the average gray value inside the red window. If the variance is higher than the given threshold, a ring is

assumed to be present. Then, the gray values of the identified ring voxels are adjusted to match the average gray value in the red window.



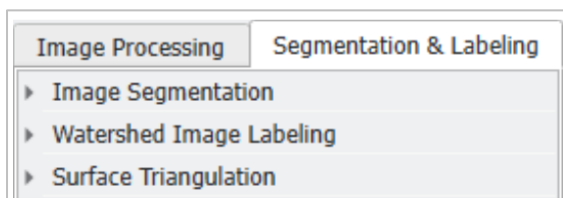
Original



Filtered

1.4.3 Segmentation & Labeling Tools

The **Segmentation & Labeling** tools are located in the **Segmentation & Labeling** tab in the **Image Processing and Segmentation** section of the [3D Image Processing](#)^[24] dialog. The tools are organized in expandable and collapsible trees.



Learn how to use all of the Labeling and Segmentation tools:

- [Image Segmentation](#)^[104]
Segment your images using various methods.
- [Watershed Image Labeling](#)^[135]
Label your images using a Watershed algorithm.
- [Surface Triangulation](#)^[140]
Create a surface mesh directly from your images.

Image Segmentation

The **Image Segmentation** panel provides several methods for segmenting your image dataset. **Image segmentation** is the process of transforming your image data into a 3D digital model of your sample. In GeoDict, this digital model is called a *structure*.



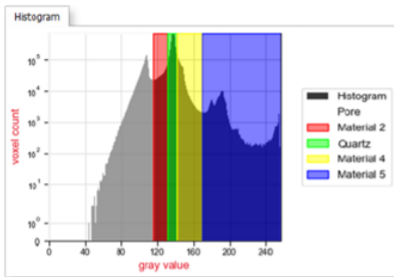
Learn how to use all the tools available to you to segment your image:

- [Global Thresholding](#)^[108]
Segment the image by setting a single or multiple gray value thresholds. This method is the fastest and simplest.
- [AI Segmentation](#)^[111]
Train a custom AI model by labeling images. This is a very powerful tool for images that are difficult to segment.
- [Multi-Phase Segmentation](#)^[129]
Define confidence areas with gray value ranges. Then, compute the areas in between with the watershed algorithm.
- [Hysteresis Thresholding](#)^[130]
Use two thresholds to accomplish edge detection.
- [Phansalkar](#)^[130]
Use this local thresholding method to deal with low-contrast images.
- [Local Otsu](#)^[132]
Use this local thresholding method to automatically perform clustering-based image thresholding.
- [Results](#)^[133]
View the segmentation results.

Comparison of different Segmentation Methods

To compare different segmentation methods, a Berea sandstone sample (Andrä et al. [1-2013](#)^[143], [2-2013](#)^[143]) was segmented using [Global Thresholding](#)^[108], [Multi-Phase Segmentation](#)^[129], and [AI Segmentation](#)^[111]. See the figure below for a comparison of these methods.

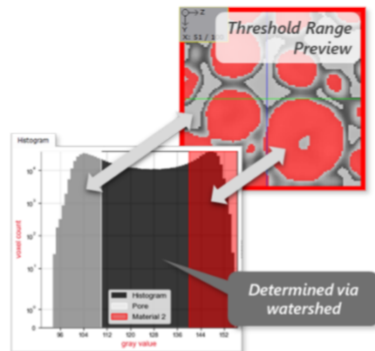
Global Thresholding



Single or multiple gray value thresholds

Automatic thresholding based on gray value histogram (e.g., Otsu)

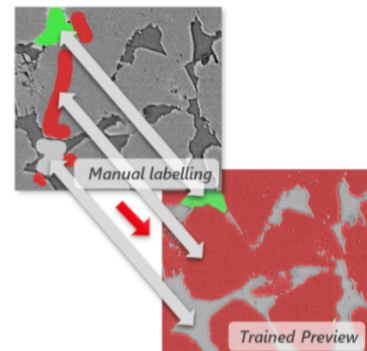
Multi-Phase Segmentation



Define gray value ranges for phases

Any remaining "uncertain" areas are automatically segmented via Watershed

AI Segmentation

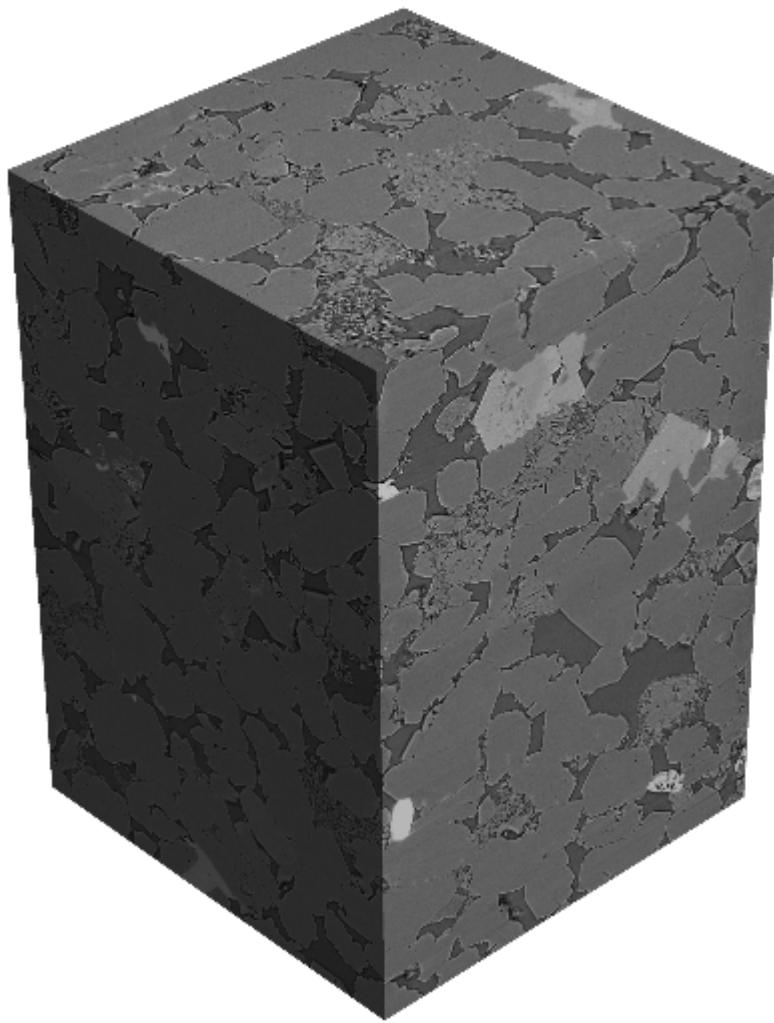


Label multiple materials manually

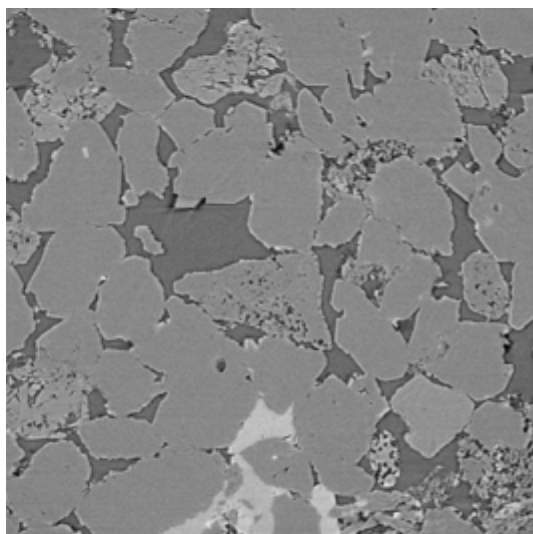
Fast machine learning-based training algorithms

Deep learning-based training algorithms (Unet2D, Unet3D)

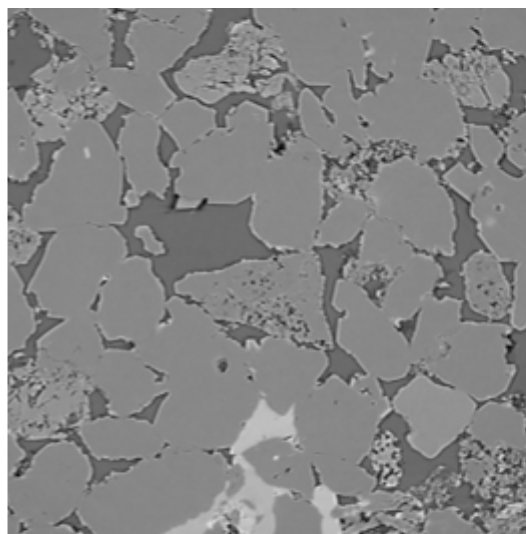
This dataset has dimensions of 720x720x1024 voxels and a resolution of 0.74 μm . Its material components are quartz, feldspar, calcite, and zircon.



A parameter study was conducted that compared published experimental data with GeoDict results. Segmented porosity and computed absolute permeability were determined for the different segmentation methods. The results showed that the [Non-Local Means Filter](#)^[77] was not necessary for the AI segmentation but was necessary for the other two methods. After segmentation, any remaining small-scale features were reassigned using the ProcessGeo Cleanse feature.

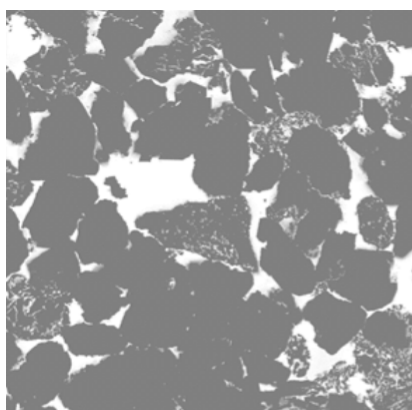
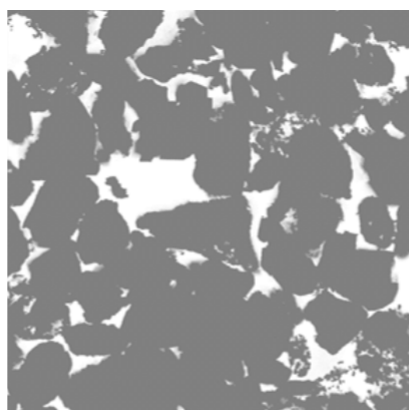
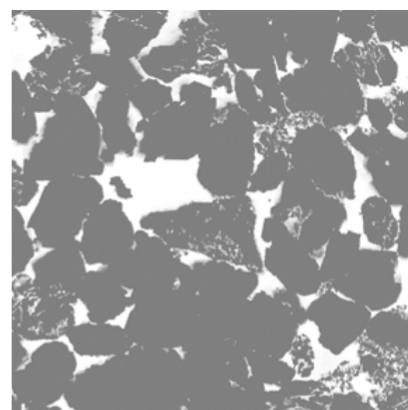


Original gray values



Non-Local Means Filter

The figure below shows the segmentation results for the different methods applied to the Berea sandstone. A visual comparison shows that the [Global Thresholding](#)^[108] result is very similar to the [AI Segmentation](#)^[111] result. [Multi-Phase Segmentation](#)^[129] removes most of the small-scale features. Thus, reduced porosity is expected for this result.

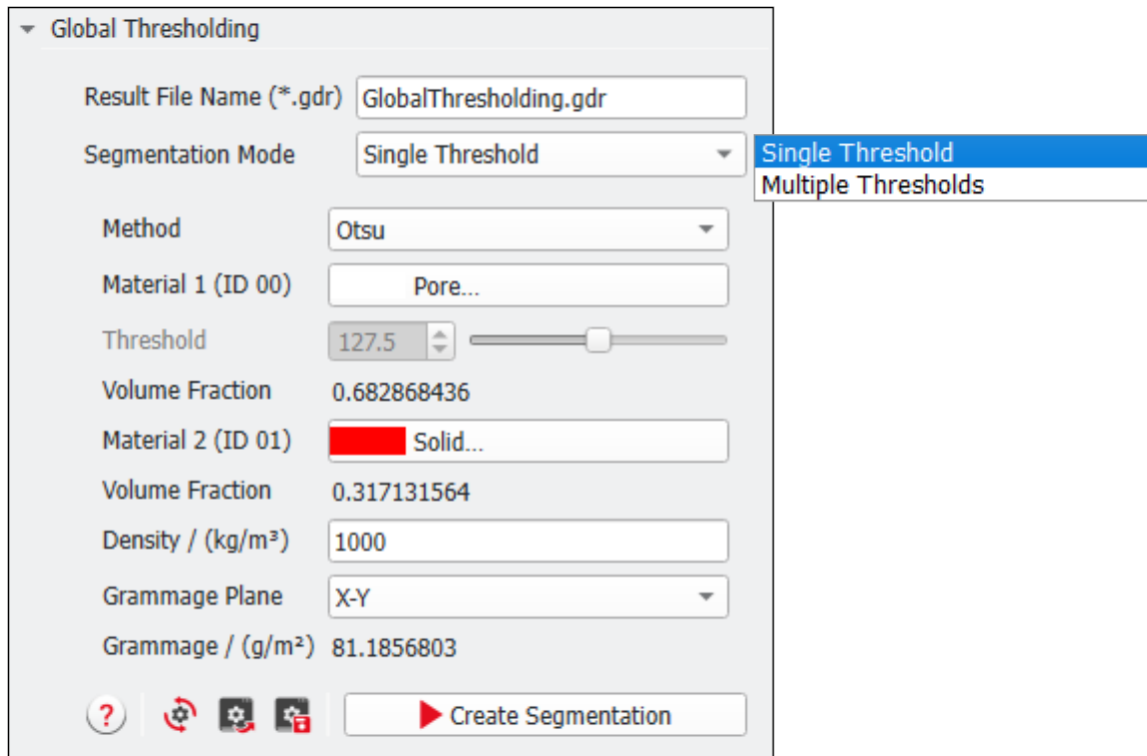

NLM +
Single Threshold (Otsu)

NLM +
Multi-Phase Segmentation

AI-based Segmentation +
ProcessGeo - Cleanse

The comparison study shows that all of the above segmentation results fall within the range of the experimentally obtained data. Flow computations performed via the FlowDict module result in absolute permeability values that fall within the range of published laboratory data by [Andrä et al., 2013](#)^[143]. The entire study, *Impact of different segmentation methods on Digital Rock Analysis results*, was presented at the 2020 **iRIS** (International Rock Imaging Summit) conference and is available on the [GeoDict website](#).

Global Thresholding

Various options are available for **Image Segmentation** via **Global Thresholding** of gray values. Up to 255 thresholds can be used to define gray value ranges and assign material IDs

to respective voxels. Enter the name of the file and folder that will contain the results in the **Result File Name (*.gdr)** field. Choose a name that fits the current project. Two **Segmentation Modes** are available: [Single Threshold](#)^[109] and [Multiple Thresholds](#)^[110]. The choice depends on the number of different materials in your dataset.



Global Thresholding

Result File Name (*.gdr) GlobalThresholding.gdr

Segmentation Mode **Single Threshold**

Method Otsu

Material 1 (ID 00) Pore...

Threshold 127.5

Volume Fraction 0.682868436

Material 2 (ID 01) Solid...

Volume Fraction 0.317131564

Density / (kg/m³) 1000

Grammage Plane X-Y

Grammage / (g/m²) 81.1856803

Buttons: ? (Help), Refresh, Save, Load, Create Segmentation



Know how! You can **Save** your current settings for this tool as **Start-Up Settings**. The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings** available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings**.

Single Threshold

In **Single Threshold** mode, you can use a **Manual Threshold** as well as one of the automatic thresholding methods: **Otsu** or **KMeans**. For more information about the theory behind these two methods, refer to the Wikipedia pages on [Otsu's method](#) and [KMeans clustering](#).

Segmentation Mode: Single Threshold

Method: Otsu (dropdown menu open showing: Manual Threshold, Otsu, KMeans)

Material 1 (ID 00): Pore... (dropdown menu open showing: X-Y, X-Z, Y-Z)

Threshold: 127.5 (slider)

Volume Fraction: 0.682868436

Material 2 (ID 01): Solid... (dropdown menu open showing: X-Y, X-Z, Y-Z)

Volume Fraction: 0.317131564

Density / (kg/m³): 1000

Grammage Plane: X-Y (dropdown menu open showing: X-Y, X-Z, Y-Z)

Grammage / (g/m²): 81.1856803

The value of the single **Threshold** separates the gray value range into two constituent materials. **Material 1 (ID 00)** is set to **Pore** by default, and **Material 2 (ID 01)** is set to a generic **Solid**. The overlay color and material selection are shown for each material. You can assign the desired material phase to each material ID by clicking the available button and following the dialog. Please refer to the Material Database User Guide for more details. You can change the overlay color through **Use GeoDict Custom Colors**, as explained [here](#)^[33].



Note! Note that the **Visibility** and **Outline** options, located in the [View Options](#)^[36] section, control the threshold visualization settings. See [here](#)^[38] for more details. You can also visualize a single threshold in 3D, as described [here](#)^[141].

The **Volume Fraction** indicates the computed volume fraction corresponding to the current **Threshold** value and updates automatically whenever threshold values change. For example, a **Volume Fraction** of 0.32 at a **Threshold** of 127.5 means that 32% of the image voxels have gray values above 127.5 and are assigned to **Material 2**.

The **Density** (kg/m³) of **Material 2** and the selected **Grammage Plane** (**X-Y**, **X-Z**, or **Y-Z**) are used to calculate the material's **Grammage**. If the density of **Material 2** is known, it can be entered, and GeoDict will automatically calculate the area density for the selected plane. Only **Material 2**'s density can be set. **Material 1**'s density is assumed to be zero. This option is useful for materials like paper, which consist of one solid material and pore space. If you have **Grammage** measurements available, you can use it to choose the threshold accordingly.

Multiple Thresholds

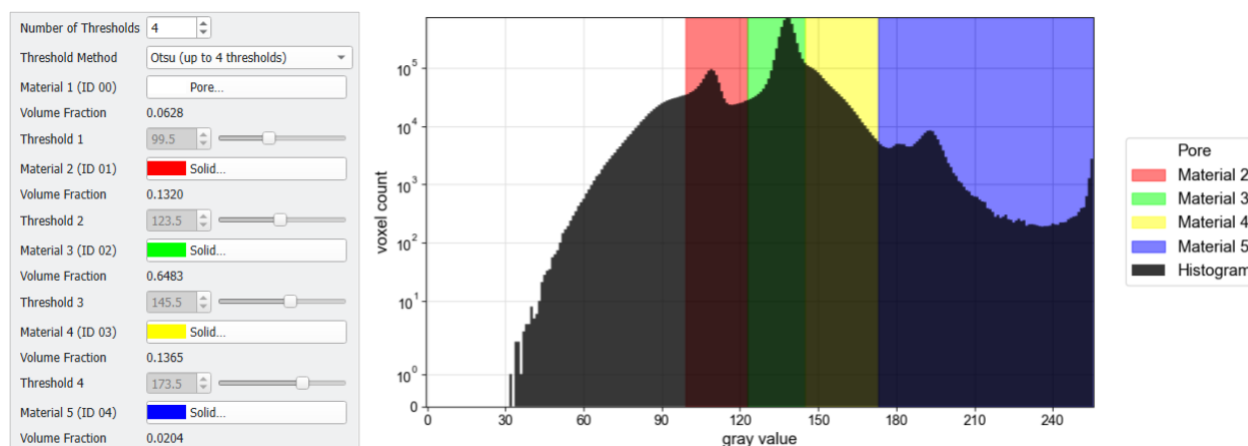
Use **Multiple Thresholds** when defining more than one threshold for more than two different materials. The available **Threshold Methods** are: **Manual Threshold**, the **Otsu** method, and **KMeans** clustering.

The **Otsu** method is an automatic segmentation algorithm. It can be used for up to four thresholds for 8-bit images and up to two thresholds for 16-bit images. Up to 255 thresholds

are available for **Manual** or **KMeans** thresholding. For more information about the underlying theory, refer to the Wikipedia pages on [Otsu's method](#) and [KMeans clustering](#).

The automatic thresholding methods (**Otsu** and **KMeans**) use only the histogram for segmentation. **Manual** thresholds are selected by moving the sliders or entering values.

Enter the **Number of Thresholds** to be applied. If you select multiple thresholds, they will be shown in the histogram plot at the bottom right of the dialog. For an 8-bit excerpt of a Berea sandstone, four thresholds are set. The five corresponding materials are shown in the histogram plot as determined by the **Otsu** method.



Click **Create Segmentation** to create a structure based on your image dataset and the current settings. You can find a description of the results [here](#) ¹³³.

AI Segmentation

AI Segmentation allows you to train machine learning algorithms to segment complete gray value images based on user-defined labels. To do so, manually label the image and train a machine learning model to segment the image based on the provided labels.

Enter the name of the file and folder containing the results in the **Result File Name (*.gdr)** field. Choose a name that fits the current project.

Click **Create Segmentation** to create a structure based on your image dataset and the current settings. You can find a description of the results [here](#)^[133].



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Topics of this section

- [AI Models](#)^[113]
Understand the four available AI models
- [Labeling](#)^[121]
Learn how to create training data
- [Train and Apply AI Models](#)^[127]

Topics of this section

Explore how to train and apply segmentation models

AI Models

There are four different **AI Models** available: **Boosted Tree**, **Random Forest**, **Unet2D**, and **Unet3D**. The following table compares the learning methods directly.

Boosted Tree & Random Forest	Unet2D & 3D
Fast training	Computationally expensive and require a GPU for interactive work
Work with very little training data	More manual labels are required
Limited when the scale of the relevant features becomes large	Learn more and deal with highly complex datasets

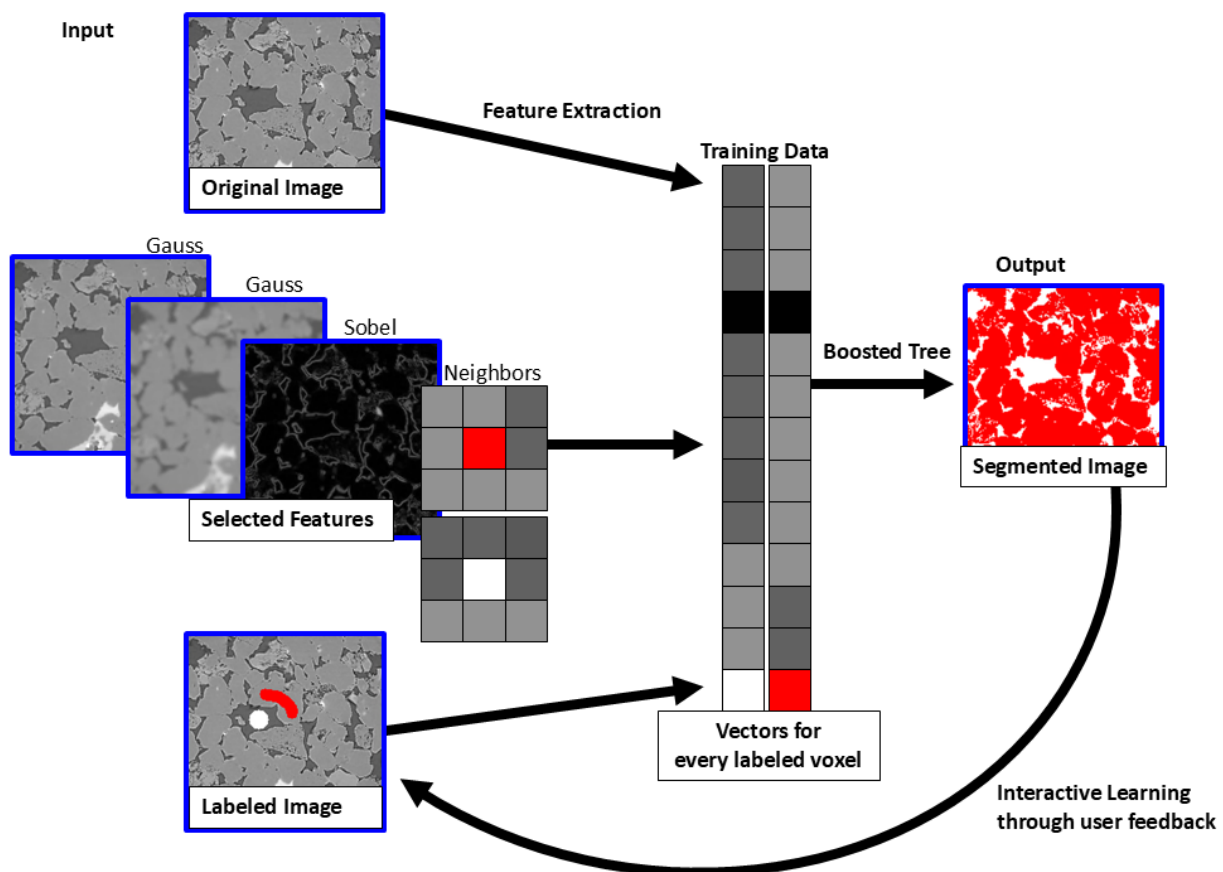
Random Forest and Boosted Tree

Random Forest and a **Boosted Tree** are machine learning models that use many decision trees to make predictions. The two methods are very similar, but the **Boosted Tree** model is usually faster since it is an advanced version of the **Random Forest** model.

Both models perform well in many cases and are very fast. For training data, information about neighboring voxel data is used, and different filters are applied to the input image:

- **Gauss** filter for blurring the image
- **Sobel** filter for emphasizing the edges

The figure below shows three filtered images: one with a small sigma for the Gaussian filter, one with a larger sigma, and one filtered with the Sobel filter. Then, a vector containing the corresponding data from the original image, each of the filtered images, neighboring voxels, and the labeled image is built for each voxel. The diagram below illustrates this process for two voxels. The **Random Forest/Boosted Tree** algorithm learns from these vectors and segments the image.



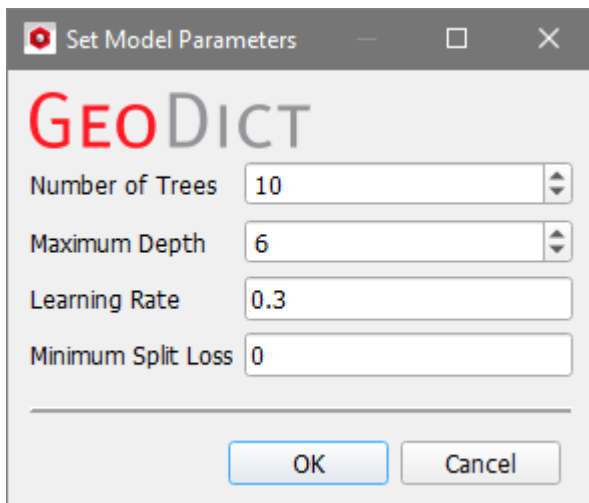
Note! For more information on training data extraction, refer to [Arganda-Carreras et al., 2017](#)^[143]. For more information on **Random Forest**, see the [Wikipedia](#) page. For a detailed explanation of the **Boosted Tree** model, see [Drucker and Cortes, 1995](#)^[143] and [Chen and Guestrin, 2016](#)^[143]. Also refer to the [Introduction to Boosted Trees](#)^[143] and the [Python API Reference](#)^[143].

The **Random Forest** and **Boosted Tree** methods may be limited in the case of large-scale relevant features. This is because the decision for each pixel depends on its surroundings, particularly the fixed-size Gauss kernel. For example, if an image contains pores of different materials with similar gray values and the only difference is the border with the solid material, the **Boosted Tree** method could make the wrong decision for large pores. In such cases, [Unet](#)^[117] methods are recommended. Additionally, if there are more than two materials in the structure, the methods may be limited, and the [Unet](#)^[117] method is preferable.

✓ Model Parameters

Click on the gear wheel icon  to access to the parameters that define the model setup. The **Set Model Parameters** dialog opens. The following parameters can be set for the **Boosted Tree** model:

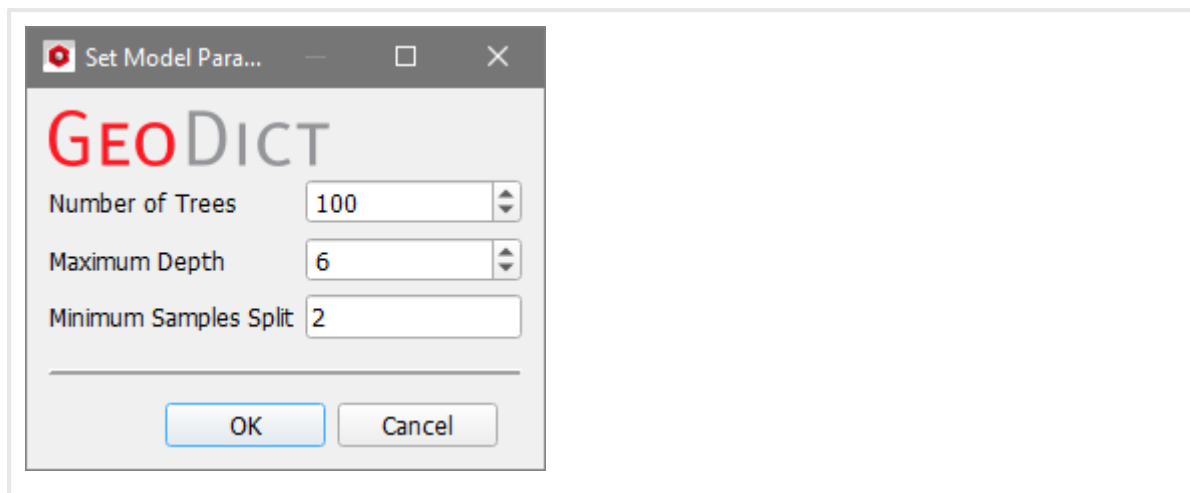
- **Number of Trees:** This defines the number of parallel trees constructed during each iteration. While more trees result in a higher learning ability, they can also lead to overfitting. A model that is overfit does not generalize well.
- **Maximum Depth:** The maximum depth of a tree. Increasing this value makes the model more complex and more likely to overfit.
- **Learning Rate:** The learning rate is the amount by which the step size shrinks with each update, preventing overfitting. It must be >0 and ≤ 1 . A lower learning rate results in a longer runtime, but a higher generalization ability of the final model.
- **Minimum Split Loss:** The minimum amount of loss reduction required to create an additional partition of a leaf node in the tree. The larger the minimum split loss, the more conservative the algorithm.



The screenshot shows a window titled "Set Model Parameters" with the "GEO Dict" logo. It contains four input fields: "Number of Trees" with a value of 10, "Maximum Depth" with a value of 6, "Learning Rate" with a value of 0.3, and "Minimum Split Loss" with a value of 0. At the bottom, there are "OK" and "Cancel" buttons.

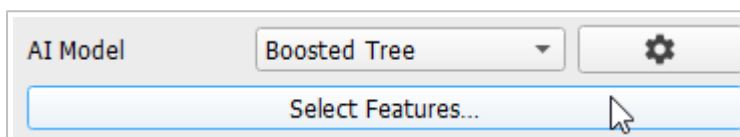
The following parameters can be configured for the **Random Forest** model:

- **Number of Trees:** This defines the number of parallel trees constructed during each iteration. While more trees result in a higher learning ability, they can also lead to overfitting. A model that is overfit does not generalize well.
- **Maximum Depth:** The maximum depth of a tree. Increasing this value makes the model more complex and more likely to overfit.
- **Minimum Samples Split:** The minimum number of samples required to split an internal node. The larger the value of the minimum sample split, the more conservative the algorithm will be.



✓ Select Features

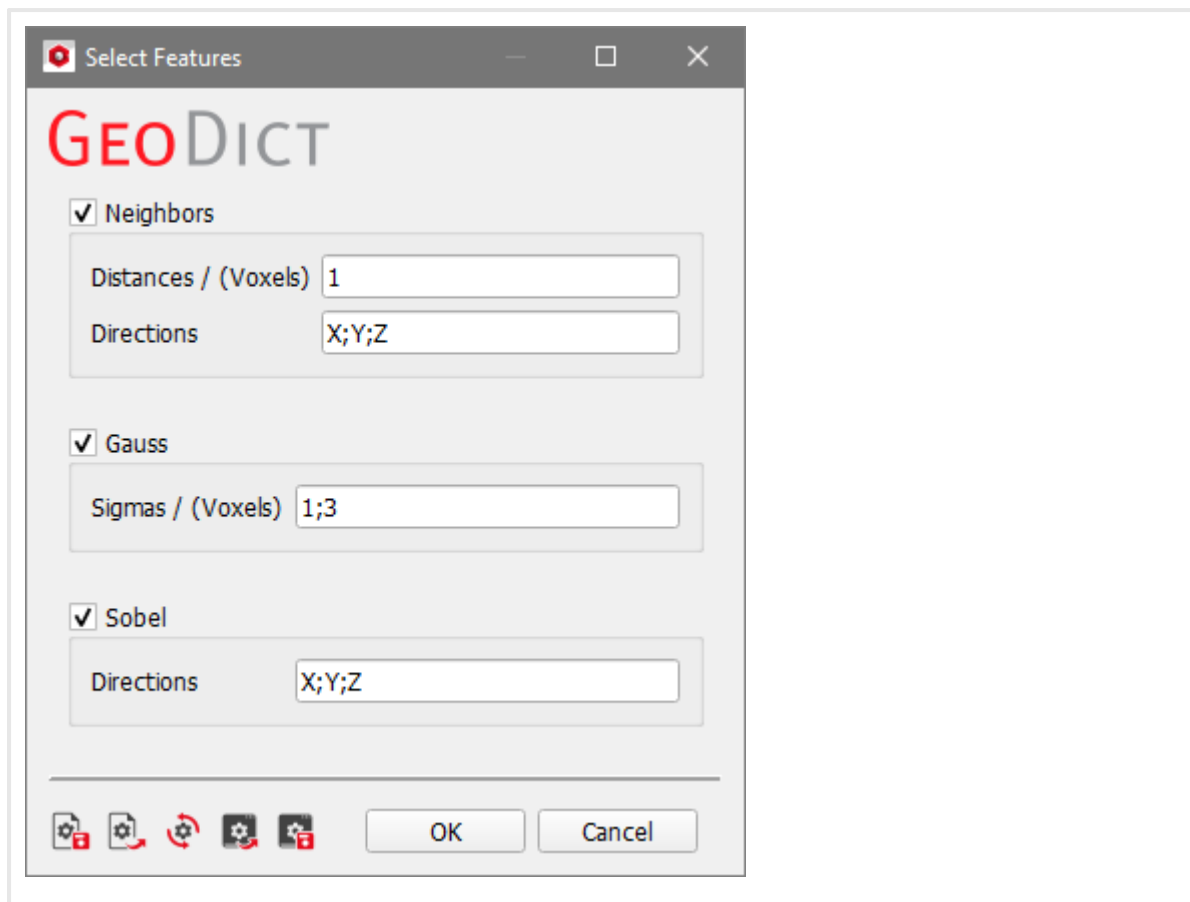
The **Select Features** dialog allows you to adjust the parameters of the filters applied to the Boosted Tree and the Random Forest methods.



These filtered images are considered in the training of the model as shown in the figure above to gain more information for each voxel. They are used also in the segmentation, but only as a reference for the model, since they can help to identify which label is correct for which voxel in the original image. Check the features that should be used and enter a list of parameters for the feature runs, separated by ";":

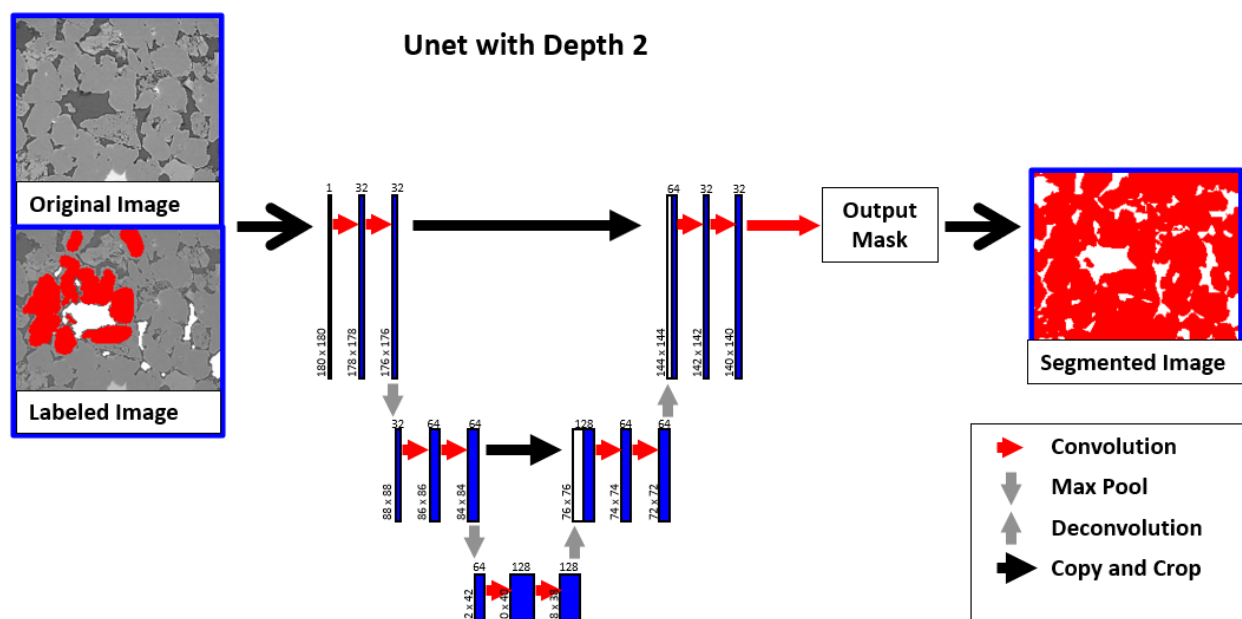
As shown in the figure above, these filtered images are considered during model training to gain more information about each voxel. They are also used in segmentation, but only as a reference for the model since they help identify the correct label for each voxel in the original image. Check the features to be used, then enter a list of parameters for the feature runs, separated by semicolons:

- The **Neighbors** method has two parameters: **Distances** and **Directions**. With the default settings, the neighborhood is examined three times, once for each direction, with a distance of one voxel. Voxels within the given distance are considered when determining how the current voxel should be labeled.
- The **Gauss** filter has a parameter called **Sigmas**. **Sigma** is the standard deviation of the Gaussian function used by this filter. With the default settings, the filter runs twice: once with a sigma of 1 and again with a sigma of 3. The higher the standard deviation, the more blurred the image becomes. This filter is also described [here](#)⁸¹.
- The **Sobel** filter has a parameter called **Directions**. In the default settings, the filter is applied in all three directions. This filter emphasizes edges. It is similar to the [Compute Gradient](#)⁸⁸ filter.



Unet

The deep learning methods **Unet2D** and **Unet3D** require more training data. Therefore, more labels must be provided manually. However, they can analyze scans more accurately and achieve better results. The name **Unet** refers to the U-shape of the neural network diagram, which consists of a constricting branch on the left and an expanding branch on the right. The number of layers in each branch determines the depth of the **Unet**. **Unet3D** considers the complete image, while **Unet2D** learns from a single slice in the specified direction. The default is the Z-direction.



Note! For a more detailed explanation of the **Unet** models and their underlying architecture, see [Ronneberger et al., 2015](#) or the GeoDict-AI user guide.

Using the Unet models require a good GPU. For up-to-date recommendations visit our [website](#).

✓ Model Parameters

Click on the gearwheel icon  to access the parameters that define the model setup. The **Set Model Parameters** dialog opens. The following parameters can be set for the **Unet** models:

- **Window Size X, Y, and Z:** For AI model training, the **Unet** algorithm divides the gray value image into windows of a specified voxel size. A larger window size requires more training data and time, but increases the learning potential. 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. The learning time grows linearly with more epochs, but the learning potential increases as well. However, too many epochs can lead to overfitting.
- **Depth of the Unet:** The number of levels in a **Unet**. A higher depth requires more training data, increases runtime, and increases GPU memory usage, but also increases learning potential.
- **Number of Features in First Layer:** This is the number of features that the model can learn in the first layer. More features require more training data and time, but increase the model's learning potential.
- **Kernel Size:** Control the size of the convolutional kernel. A kernel is a feature detector, i.e., an $n \times n \times n$ voxels box (or an $n \times n$ square for **Unet2D**), with a defined

pattern. The size n is the number of voxels in one direction and must be an odd number. Common values are 3 or 5.

- **Use Strides:** Define a window stride using the values **Stride X, Y, and Z**, which determine how many voxels the window moves for each new training sample starting in the upper left corner. Then, only windows containing labeled voxels are considered. If this option is not checked, all windows around labeled voxels are used for training.
- **Normalize:** Use the minimum and maximum gray values in the image to normalize the input images. If this option is unchecked, the values of 0 and the maximum are used.

Set Model Parameters

GEOdict

Window Size X: 52

Window Size Y: 52

Window Size Z: 52

Number of Epochs: 3

Depth of the Unet: 2

Number of Features in First Layer: 16

Kernel Size: 3

☐ Use Strides

Stride X: 4

Stride Y: 4

Stride Z: 1

☒ Normalize

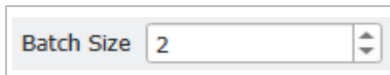
OK Cancel

For a more detailed explanation of the **Unet** parameters refer to the GeoDict-AI user guide.

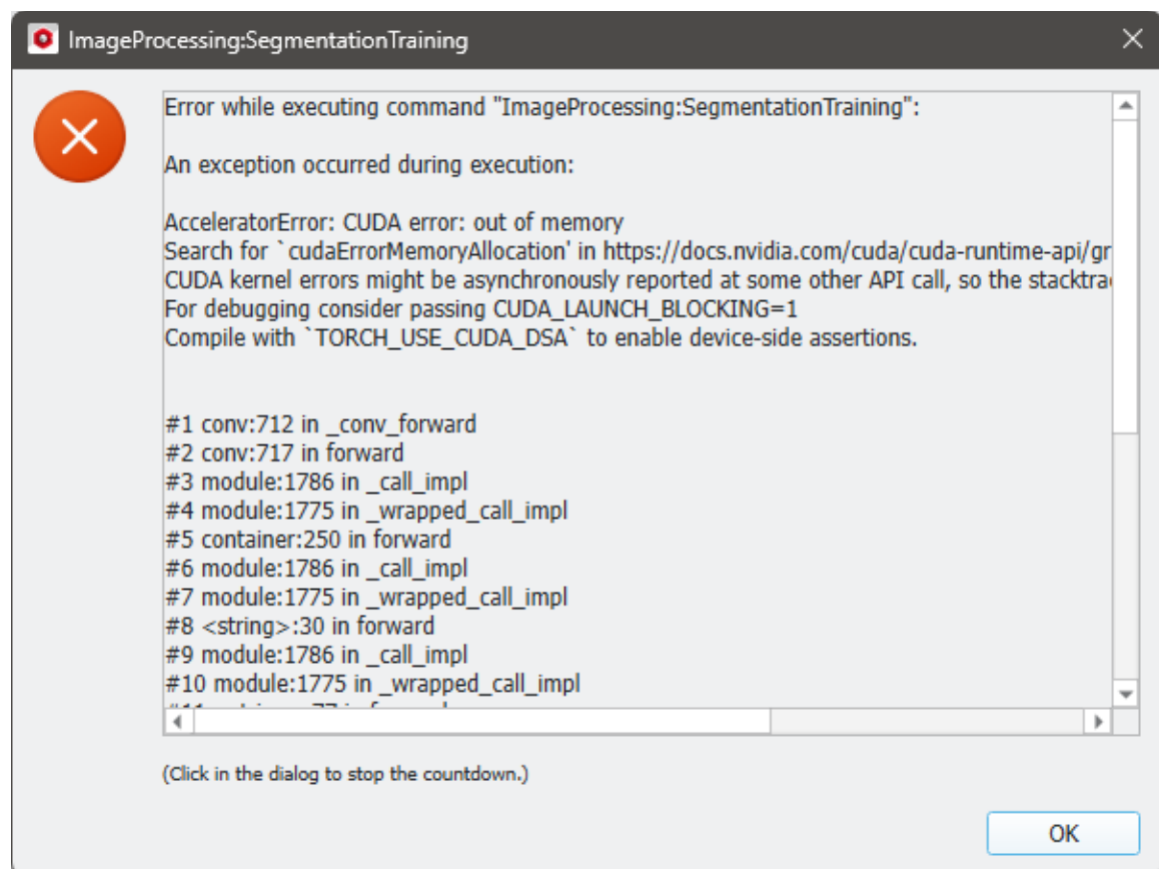
In **Unet2D**, the windows determined by the **Window Size** parameter are 2D slices, meaning one of the three parameters is set to 1. The default setting of **Z = 1** usually leads to good results. If all three size parameters are greater than one, the **Unet3D** model is applied automatically.

✓ Batch Size

The **Batch Size** option is only available for **Unet** models and refers to the number of samples used for training simultaneously. For example, with a **Batch Size** of 4, the error is computed and the network is updated for one window at a time before moving on to the next four windows.



In literature there is usually a warning about too large values for batch size due to the potential of overfitting. However, in 3D image analysis the batch size is limited by the available GPU memory. If the value is chosen too high, an error occurs shortly after starting the training. Reduce the batch size and try starting the training again.

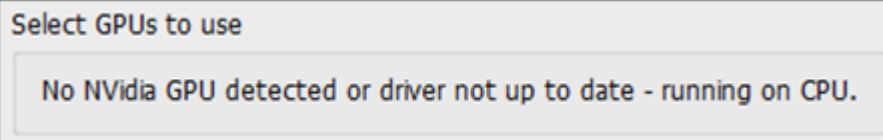


The literature usually warns against setting the batch size too large due to the potential for overfitting. However, in 3D image analysis, the available GPU memory limits the batch size. If the value is set too high, an error will occur shortly after training begins. Reduce the batch size and try starting the training again. It is recommended that you set the value to the maximum available GPU memory. This value is often between 1 and 8, depending on the GPU hardware. Modern GPUs allow for even higher batch sizes.

✓ Using Multiple GPUs

If multiple GPUs are available, select the one on which it should run by checking the corresponding box. If licensed, you can use multiple GPUs for training and segmentation. The batches will then be distributed equally among the different GPUs.

If no GPU is detected, the training and AI segmentation will run on the CPU. This process usually takes much more time and is therefore not recommended.



✓ Using Multiple Images for Training

Click **Select Additional Images** to choose which loaded images should be used for training, in addition to the current image. You can load multiple images into the **Image Processing** dialog by selecting [Keep existing Volume Fields](#) in the [Import Geometry](#) dialog. This allows you to take multiple images of the same structure's cutout into account for training. For this, the images must be the same size and fit to the labels. If the network was trained on several images, those images are also needed for segmentation.



Different scanning settings can produce different types of images. For example, it can sometimes be difficult to achieve good contrast for all material phases in an image at the same time. In this case, it is better to take two images: one with good background separation and one with good contrast between the solid materials. When training the neural network, both data sets are considered, resulting in better outcomes compared to considering only one image.



Labeling

Labeling is the process of annotating images datasets so that an AI model can identify and separate different materials in your geometry. Labeling is necessary because segmentation models rely on accurately labeled training data to learn how to detect boundaries and shapes.

For all models, select the **Number of Materials** to be labeled in the image dataset. If you know how many materials are present in your sample, enter that number here. Otherwise, observe the different gray levels in your images and select the appropriate number.

Number of Materials	3	↑	↓
Material 1 (ID 00)	Pore...	☐	
Material 2 (ID 01)	Solid...	☒	
Material 3 (ID 02)	Solid...	☐	

Use the Material Database to select different materials. Click on the button next to the material you want to use, e.g., Pore. The checkbox to the right of each material determines which material will be used to paint the labels.

✓ Labeling Modes

In **Navigation Mode** , you can 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 **Painting Mode**  to start painting in the **2D Slice Visualization** area. Make sure that **Visibility**  is turned on and that AI-Labels is selected for **Overlay** .

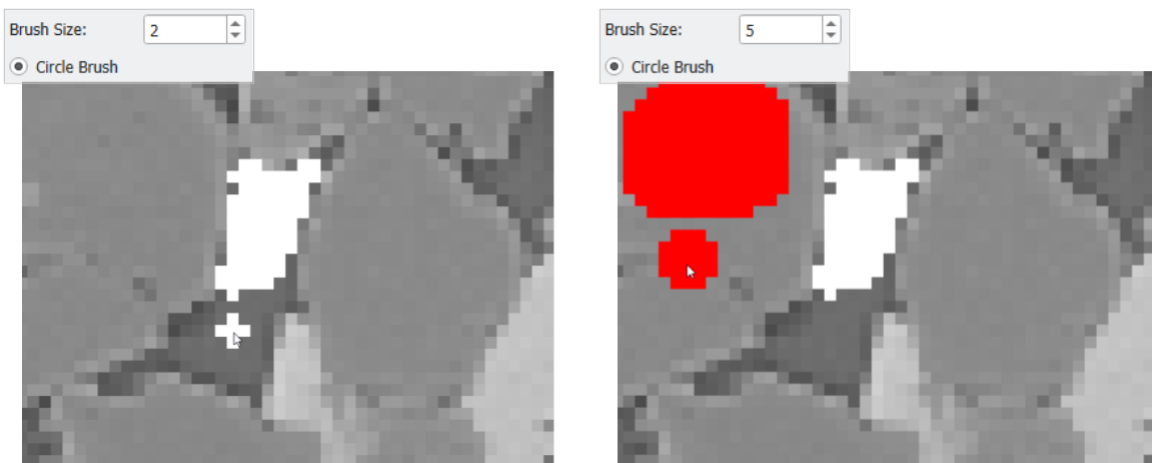
Painting Mode allows you to add labels to the scan using the left mouse button. Use the right mouse button to erase labels. Switch between materials by selecting the corresponding checkboxes. When you press and hold Shift, navigating in the 2D Slice Visualization section works the same way as in **Navigation Mode**.

If a label was not painted correctly, switch to **Erasing Mode**  and erase the label by clicking and holding the left mouse button while moving the mouse over the label. Press and hold Shift to navigate the 2D Slice Visualization section in the same way as in **Navigation Mode**. Alternatively, you can erase labels in **Painting Mode** by pressing the right mouse button.

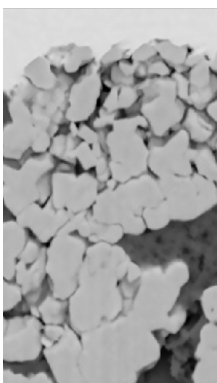
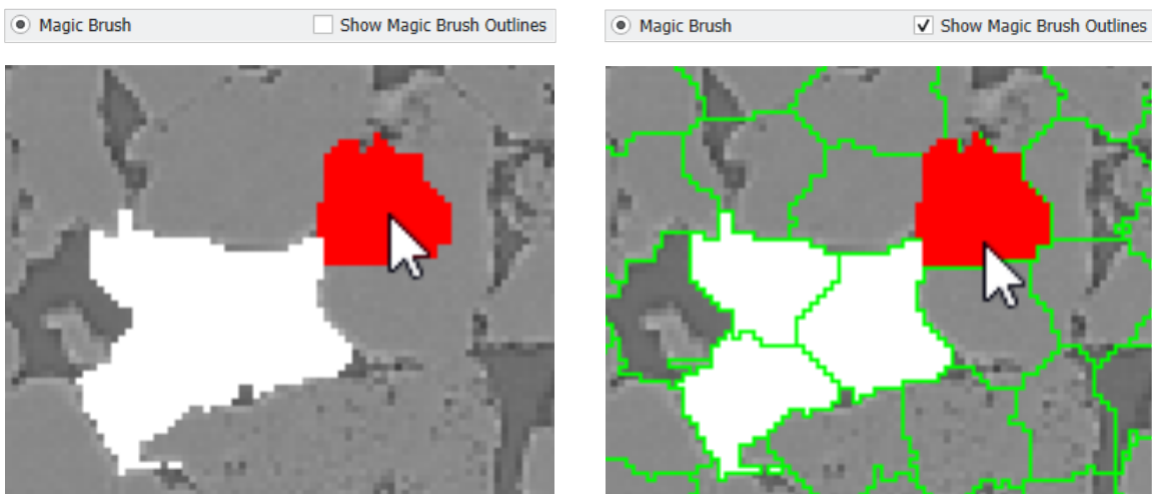
Use the **Undo**  and **Redo**  buttons to remove or restore previous label paint strokes. This allows you to easily remove labels that were painted in error or restore previous labels.

✓ Brush Modes

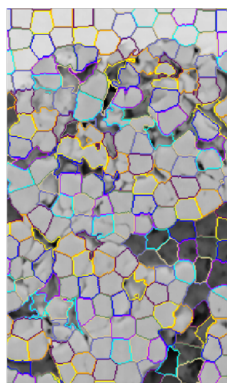
The default **Circle Brush** allows you to label a circular area around your mouse pointer with the currently selected material. Hold down the left mouse button to paint continuous strokes. Adjust the **Brush Size** to fit the size of the area being labeled. Reduce the size to capture fine components and increase it to quickly label larger sections of materials.



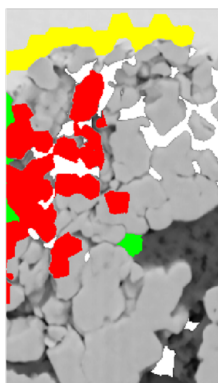
When you enable the **Magic Brush**, the images are analyzed and clustered based on edge recognition. These clusters are computed using the **SLIC** (Simple Linear Iterative Clustering) algorithm, which generates clusters based on gray value similarity and proximity in the image plane. Then, you can create labels by left-clicking on these clusters in **Painting Mode**. To show the clusters, enable **Show Magic Brush Outlines**. You can adjust the size of the clusters by changing the **Brush Size**. This mode makes labeling much easier for many image datasets.



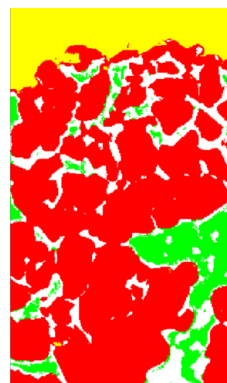
FIB-SEM scan of a
NMC532 cathode



Clustering computed by
GeoDict magic brush

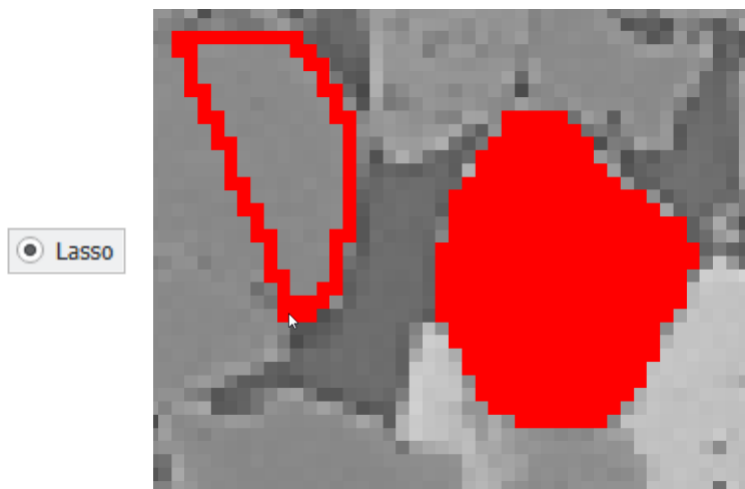


Labels created by
selecting clusters



Segmentation with
Boosted Tree model

Use the **Lasso** mode to label areas by tracing their outlines with your mouse. First, select this brush mode. Then, select the material that you want to label. Finally, change to **Painting Mode**. Your mouse pointer will indicate that you are labeling a single voxel. Click and hold the left mouse button, then trace the outline of an area (e.g., a single grain, fiber, or pore). A line connecting the start point of the label tracing and the current position of your mouse is always displayed in the overlay. Once you release the left mouse button, the area contained by your painted outline will be filled automatically. This allows you to precisely trace boundaries between different materials, where high precision is required, while automatically filling larger areas, which would otherwise be tedious to label manually.

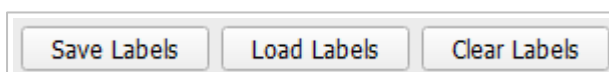


✓ Save and Load Labels

Save the painted labels as a ***.gld** file by clicking **Save Labels**. We recommend saving labels regularly to avoid losing any progress, since labeling can take a lot of time depending on the complexity of the image dataset.

Click **Load Labels** to reload the training data whenever needed. Note that the label data must have the same dimensions as the currently loaded image.

Click **Clear Labels** to delete all labels.

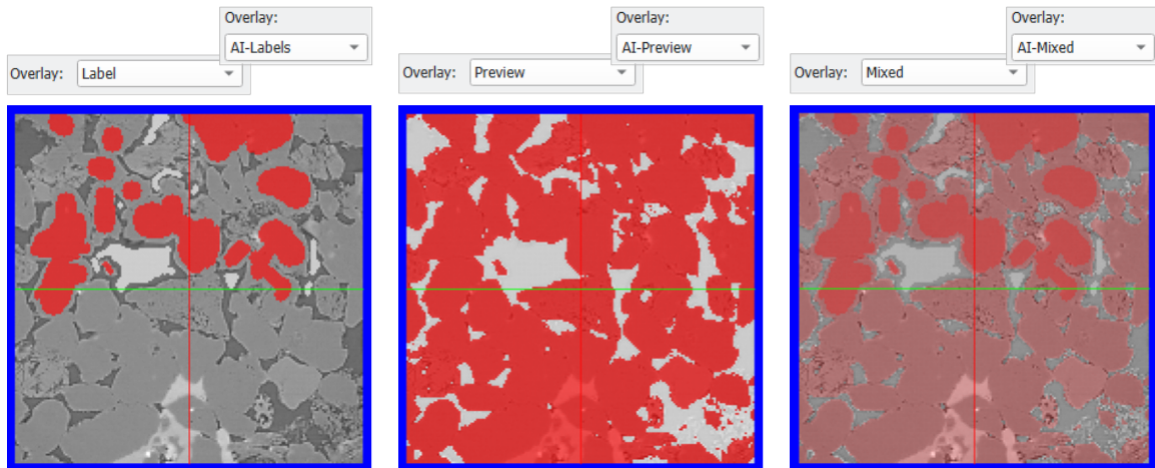


✓ Overlays

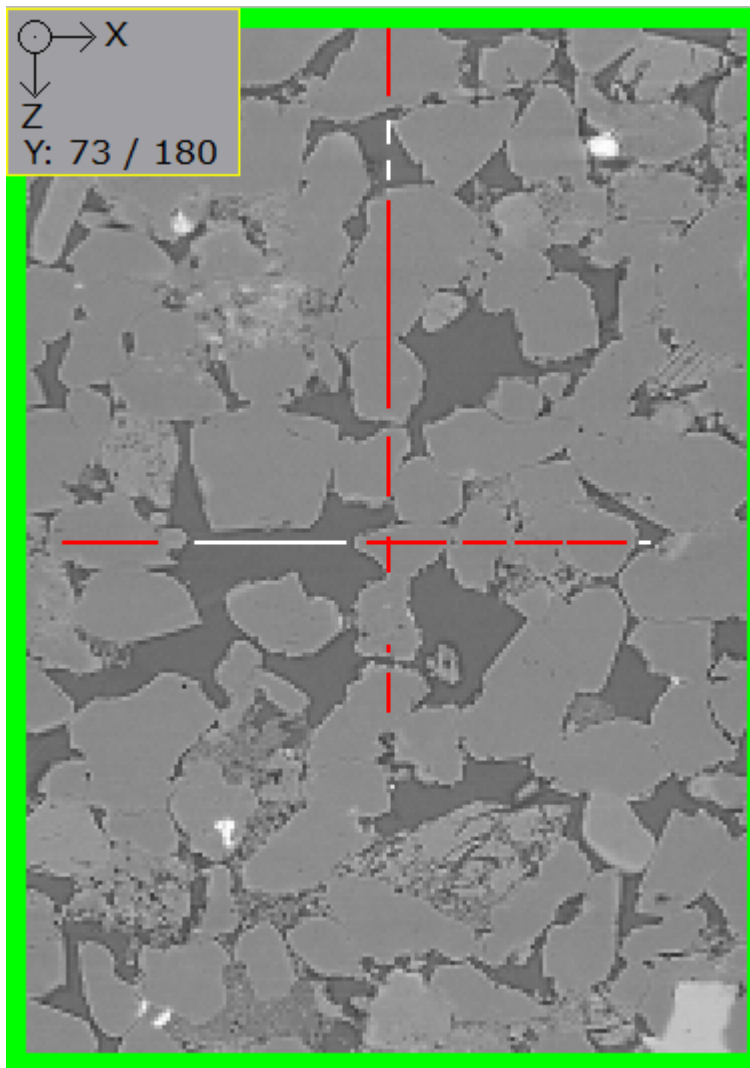
The **AI-Labels Overlay**^[37] will automatically activate when you select the AI segmentation. This overlay shows the current labels and allows you to add more labels when in **Painting Mode**.

If a **trained model**^[127] is loaded, you can also set the **Overlay**^[37] to **Preview** to view the segmentation results for the current slices.

When you change the [Overlay](#)³⁷ to **Mixed**, you can view both the current **Labels** and the **Preview** of the current trained AI model. The labels are shown with less transparency than the preview. If the preview shows that the model needs more training, the **Mixed** view helps you concentrate further labeling on areas where the model did not classify the voxels correctly.



By using the different view directions, you can observe the labels on the slices that were labeled in the other two directions. In the example below, the center slices in the X- and Z-directions are labeled. Thus, when viewed in the Y-direction, two thin lines with white (material 1) and red (material 2) sections are labeled. If labels are erased on these lines, thin lines are erased in the respective slices in the other directions.



✓ Labeling Recommendations

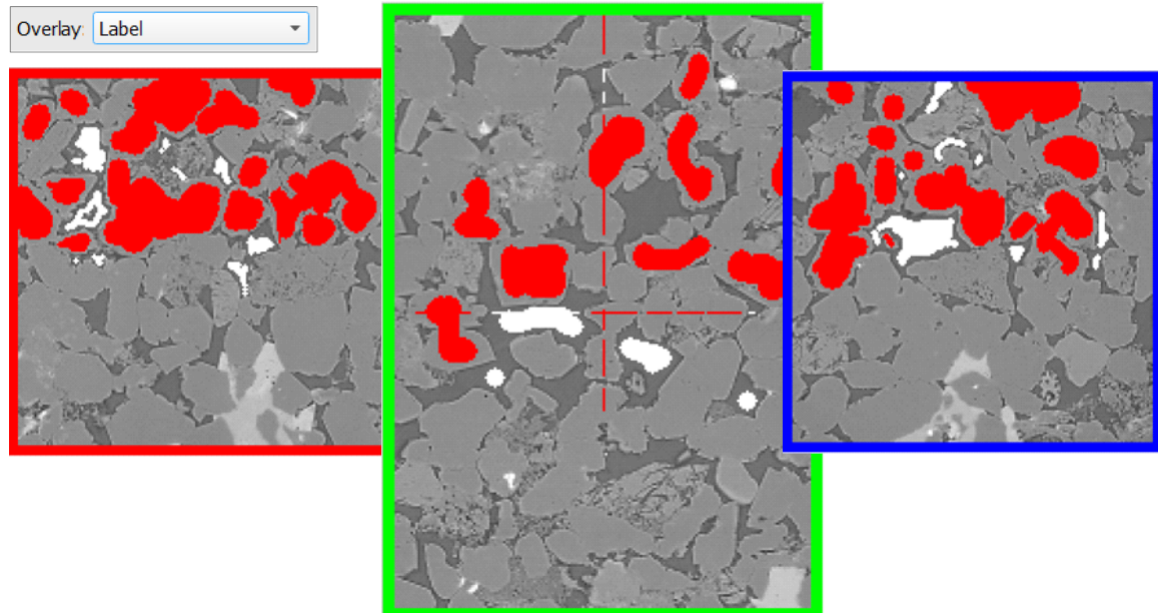
It is crucial to label the boundaries between different materials so that the model can learn to differentiate between them. If there are more than two materials, it is crucial to label all possible boundary combinations. While labeling boundaries is important, only label as close to the boundary as necessary to ensure that you are labeling the correct boundary. Otherwise, incorrect training data will be generated.

It is not necessary to label an entire slice. Be sure to label sections of each material, as well as the boundaries. Also, label entire structures, such as grains or fibers, so that the AI model can recognize the shapes present in your structure. You can also label multiple materials with different gray values as one (e.g., small pores contained in grains). The **Unet** models are powerful and can learn to combine these gray values into one material based on the shapes and geometries.

Clustering labels close together produces better results. For each labeled area, paint as many labels as possible to fully fill the output window.

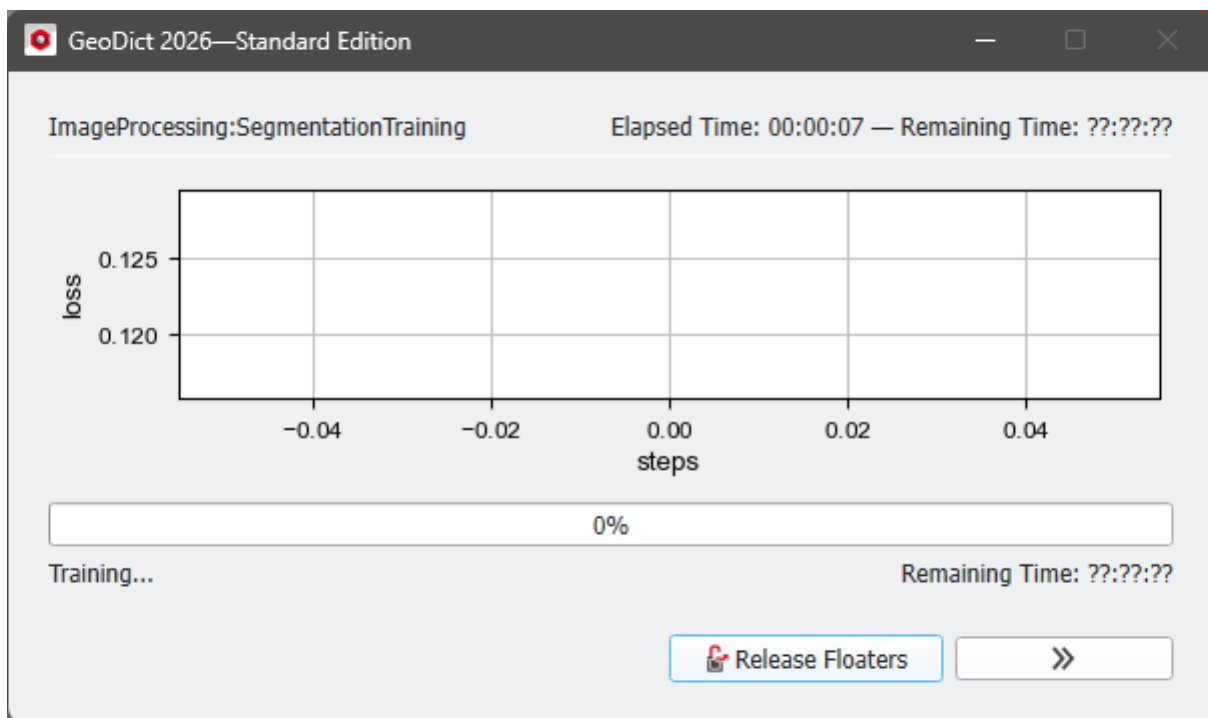
Paint slices in all three directions, especially if the gray values differ significantly.

For the **Unet3D** method, be sure to label consecutive slices from the same area. This allows the model to learn 3D shapes within your structure.



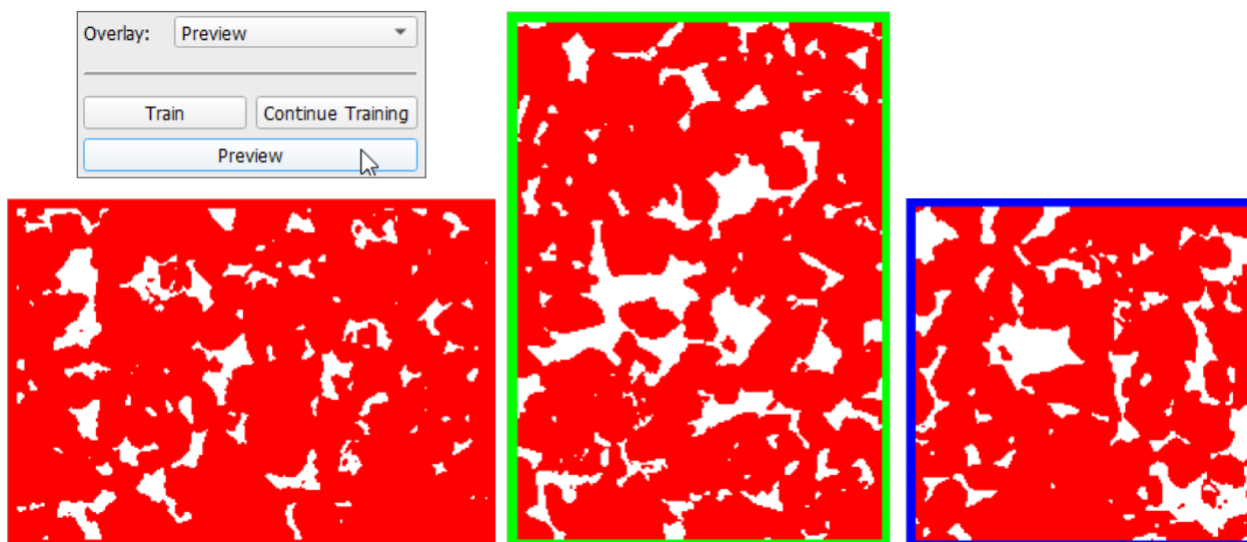
Train and Apply AI Models

Once you have painted enough [labels](#)^[121], click **Train** to train an AI model for segmentation. The progress of the training is shown in a separate dialog.



Note! The loss reported for the **Unet** models during training refers to the training loss because there is currently no separation between training and test data. All available data is used for training.

After completing the training, select the **Preview Overlay**^[37] to see what a segmentation using the trained model would look like. In the example below, the **Boosted Tree**^[113] model was used. Therefore, only a few labels were needed for this gray value image of a Berea sandstone.



You can improve a previously trained and currently loaded model by clicking **Continue Training**. A model can be loaded by training it in the current **Image Processing** session or by clicking **Load Model** to load a previously trained model. For example, **Continue Training** can improve the model when you have added more **labels**^[121]. Note that not only are the new labels considered, but also the labels used for the loaded model, so that all available information is used for training. Additionally, a model can be improved by loading and labeling another similar image, as explained [here](#)^[6], to provide more training data.

Note! If you click **Train** while a trained model is already loaded, the current model will be discarded and a new one will be trained from scratch. This can be helpful when a model does not improve with **Continue Training**.

Click **Save Model** to save a trained machine learning model. You can load this model again by clicking **Load Model** whenever you need to segment similar scans.



The file formats for the different AI models are as follows:

- *.XGBM for **Boosted Tree**
- *.FOREST for **Random Forest**
- *.UNET2D for **Unet 2D**
- *.UNET3D for **Unet 3D**

The final step is to click **Create Segmentation** to apply the trained AI model to the entire image dataset.

Multi-Phase Segmentation

For more than two materials, **Multi-Phase Segmentation** often yields better results than the [Multiple Thresholds](#)^[110] method. If there are bright artifacts at the borders of different materials or if the contrast is low, **Multi-Phase Segmentation** can be used to fill in these uncertain regions based on the [watershed algorithm](#)^[88]. This makes it very useful for avoiding partial volume effects.

Enter the name of the file or folder containing the results in the **Result File Name (*.gdr)** box. Choose a name that fits the current project.

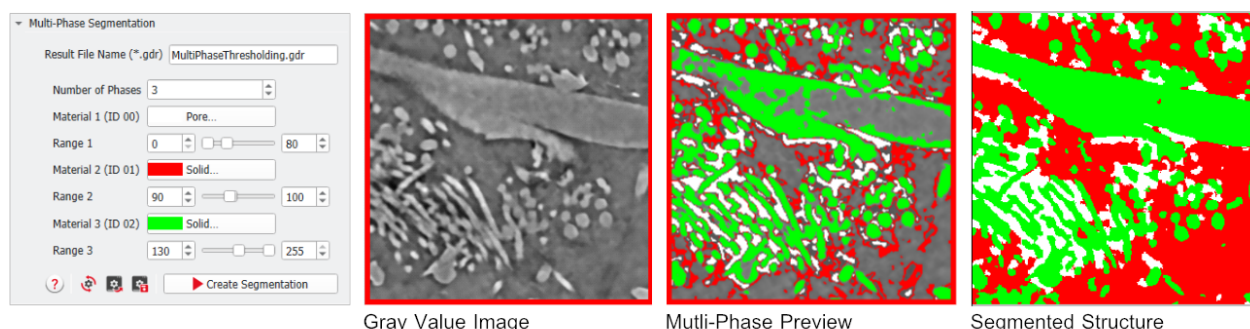
Select the **Number of Phases** in your dataset. This can be any value between 2 and 255. Choose the **Materials** for each phase from the Material Database.

Define the gray value **Ranges** assigned to each phase by adjusting the sliders. The upper limit of each range must be smaller than the lower limit of the next range. If they are equal, the gray value is assigned to the next phase. For example, if **Range 1** is defined as **20-50** and **Range 2** is defined as **50-70**, then the gray value of 50 is assigned to **Material 2**.

The [watershed algorithm](#)^[88] is used to fill all remaining uncertain areas, i.e., gray values not contained within a defined range.

Click **Create Segmentation** to apply the multi-phase segmentation to the image dataset. You can find a description of the results [here](#)^[133].

In the following example, the gray values are divided into three phases. **Material 1** is assigned as pore space with a gray value range of 0 to 80. **Material 2** is defined as solid, with a range set to 90–100. The second solid material is defined in **Material 3**, with its range set to 130–255. Thus, the gray values 81–89 and 101–129 are not assigned to any phase. This can be observed in the **2D Slice Visualization** section when **Visibility** is turned on. Gray values in **Range 1** are marked in white, those in **Range 2** in red, and those in **Range 3** in green. All other gray values are unmarked. After creating the segmentation, the watershed algorithm fills these.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings**^[134]. The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**^[135].

available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

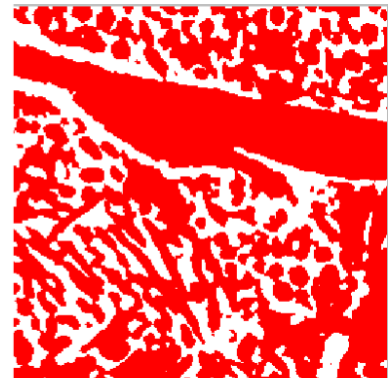
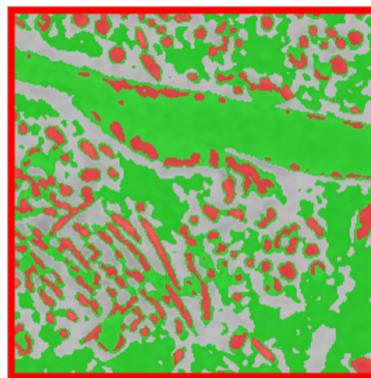
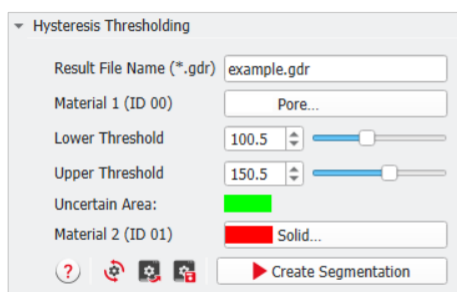
Hysteresis Thresholding

Hysteresis Thresholding is a method of edge detection between two materials (e.g., a solid and the pore space) that uses two thresholds. This method suppresses weak edges that are not connected to strong edges, thereby detecting edges. Edges with a low threshold that are connected to edges with a high threshold are retained. Low-thresholded edges that are not connected to high-thresholded edges are removed. This process creates three classes:

- Below the **Lower Threshold** → removed
- Above the **Upper Threshold** → retained
- Between **Lower** and **Upper Thresholds** → retained only if connected to an edge above the **Upper Threshold**

Define the **Materials** for the removed and retained sections of the image. Enter a name for the file and folder containing the results in the **Result File Name (*.gdr)** box at the top of the dialog. Choose a name that fits the current project.

Finally, click **Create Segmentation** to apply the **Hysteresis Thresholding** to the image dataset. You can find a description of the results [here](#) ¹³³.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Phansalkar

The **Phansalkar** filter, based on the work of [Sauvola and Pietikäinen, 2000](#) ¹⁴³, deals with low-contrast images. For more information about the theory, see [Phansalkar et al., 2011](#) ¹⁴³.

The **Sphere Radius** setting controls the radius of the mask used for the mean filter.

The local threshold T is determined by the mean m and standard deviation s of the pixel intensities:

$$T = m \left[1 + p e^{-qm} + K \left(\frac{s}{R} - 1 \right) \right] \quad (2)$$

p defines the strictness of noise removal in low-contrast, dark regions, and q specifies those regions.

K defines the strictness of noise removal in low-contrast bright regions. It takes values between 0.2 and 0.5.

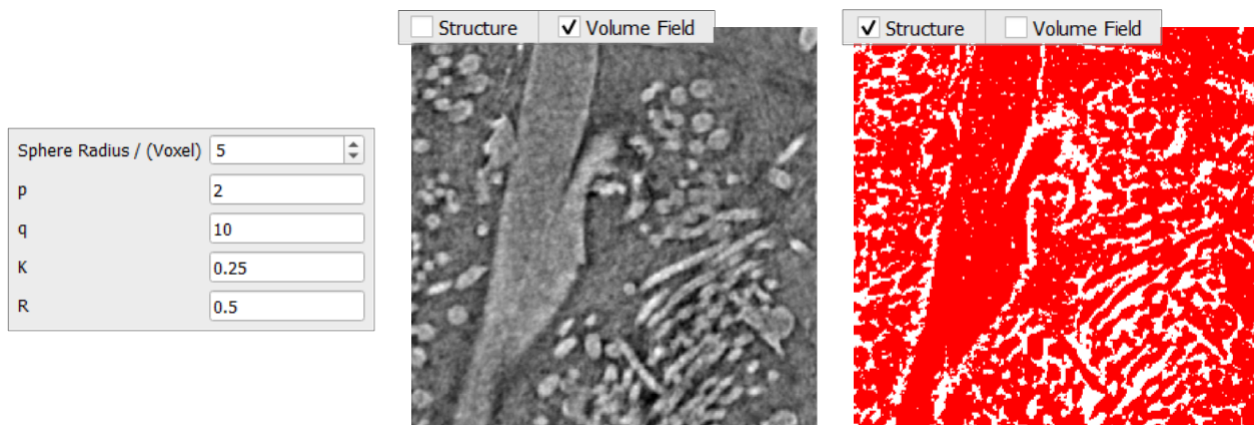
R specifies the noise regions and has a value range of 0.2 to 0.8. It is the dynamic range of the standard deviation and is equal to 0.5 for a normalized image.

The local mean and standard deviation adjust the local threshold value.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

Click **Create Segmentation** to use the **Phansalkar** method to segment the gray value image. This thresholding method does not generate a GeoDict result file. The resulting structure is displayed in the GeoDict visualization area. The gray value image remains in memory and can be compared to the structure. In the visualization panel above the visualization area, check **Structure** and uncheck **Volume Field** to only visualize the structure. To save the structure as a *.gdt file, select **File** → **Save Structure as** from the menu bar in the main GeoDict GUI.



Local Otsu

In image processing, the **Local Otsu** method is used to automatically perform clustering-based image thresholding. It converts a gray value image into a binary image. Global [Otsu](#)¹⁰⁹ thresholding is also available and explained in the **Image Segmentation** section.

Note! There is no segmentation preview available for the **Local Otsu** method.

The **Local Otsu** method avoids potential irregularities in the full 3D image by focusing on smaller cubes with voxel edge lengths according to the assigned **Window Size**.

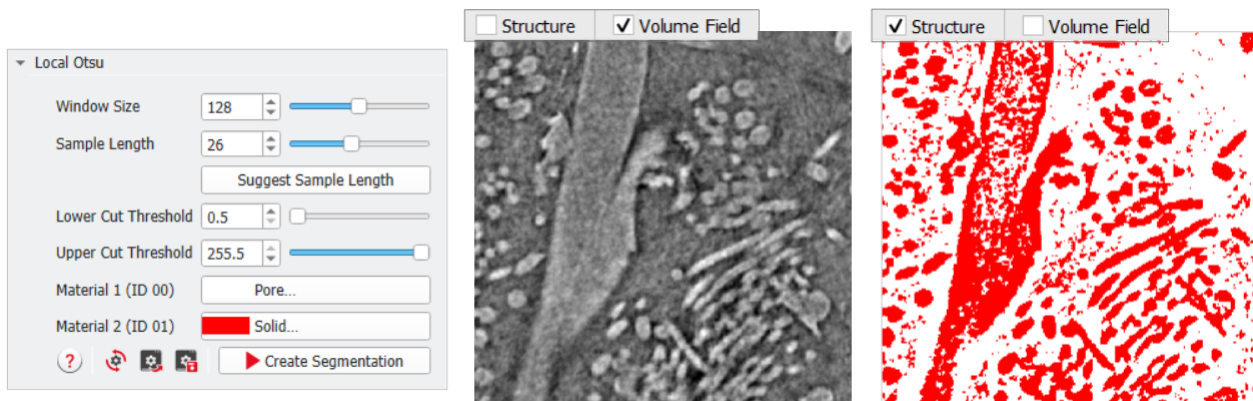
The **Sample Length** parameter defines the distance between these regions. You can set it automatically by clicking **Suggest Sample Length**.

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



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load the Start-Up Settings** .

Click **Create Segmentation** to use the **Local Otsu** method to segment the gray value image. This thresholding method does not generate a GeoDict result file. The resulting structure will be displayed in the GeoDict visualization area. The gray value image remains in memory and can be compared to the structure. In the view control panel above the visualization area, check **Structure** and uncheck **Volume Field** to only visualize the structure. To save the structure as a *.gdt file select **File** → **Save Structure as** from the menu bar in the main GeoDict GUI.



Results

After selecting one of the segmentation methods and clicking **Create Segmentation**, the segmentation is applied to the entire gray value image. A result file (*.gdr) is generated and saved automatically to the project folder. The result file with the name entered in the **Result File Name** field opens automatically in the **Result Viewer**.

The **Report** tab of the result file contains the following information:

- The applied **Segmentation** method
- The applied **Image Processing** and **Filtering** steps
- **Structure Information**, such as voxel length, size of the dataset, contained materials and their volume percentages

In addition to the result file, a result folder with the same name is saved in the current project folder. This folder contains the segmented structure file (*.gdt). For AI segmentation, it also contains the used labels (*.gld), and the trained AI model (*.FOREST, *.XGBM, *.UNET2D, or *.UNET3D).

Refer to the Result Viewer user guide for a more detailed description of the **Result Viewer** options.

Segmentation:

Method: AISegmentation

Image filters:

1.) ImageProcessing:SegmentationTraining

Structure information:

Voxel length: 2.96e-06 m
Size: 180, 180, 256

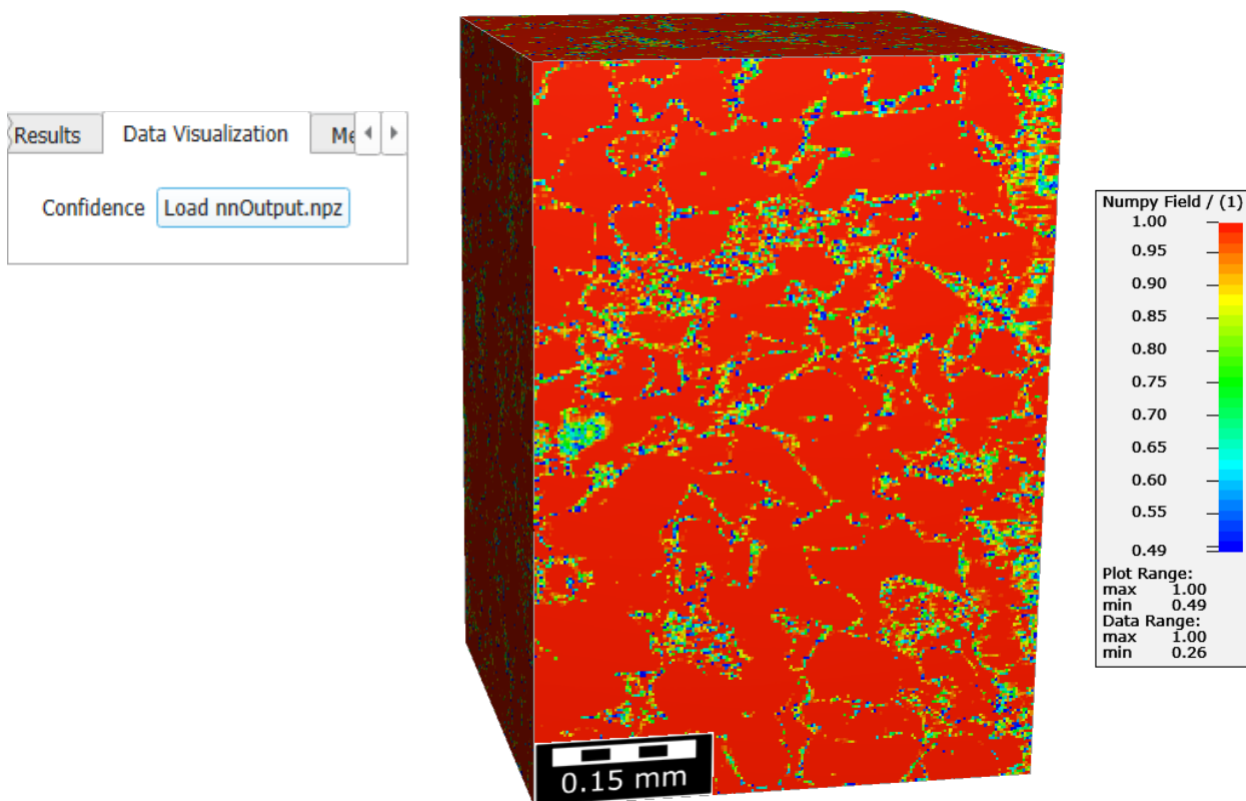
Porosity: 0.256883
Solid volume fraction: 0.743117

Constituent materials:
Pore, Manual 1, Manual 2, Manual 3

Volume fraction:
Material Pore: 0.256883
Material Manual 1: 0.689723
Material Manual 2: 0.0518157
Material Manual 3: 0.00157817
MaterialID 0: 0.256883
MaterialID 1: 0.689723
MaterialID 2: 0.0518157
MaterialID 3: 0.00157817

Total runtime: 00:00:14, Total memory usage: 2.556 GiB

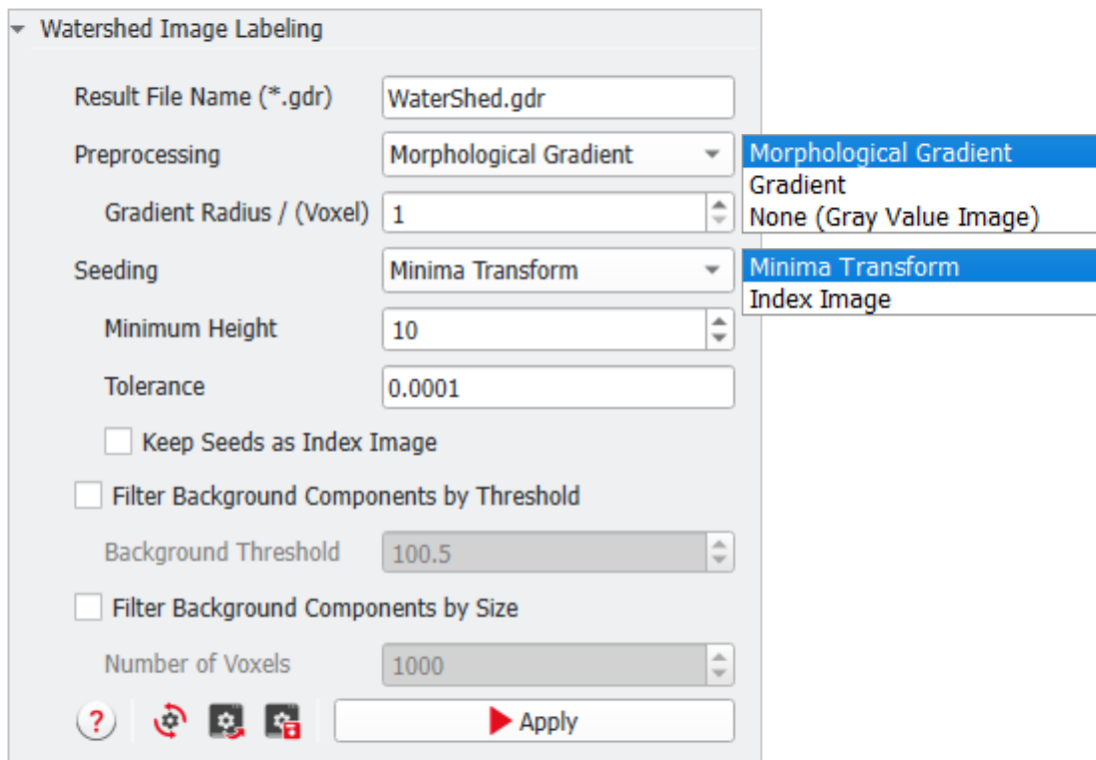
If you trained your model using one of the [Unet^{\[117\]}](#) models, you can load the model's confidence field under the **Data Visualization** in the **Result Viewer**. The confidence field represents the model's estimated certainty for each pixel belonging to a specific material. These values can help you to identify regions in the image that are uncertain or ambiguous, which can be improved by adding more [labels^{\[121\]}](#) and [continuing to train^{\[128\]}](#) the model.



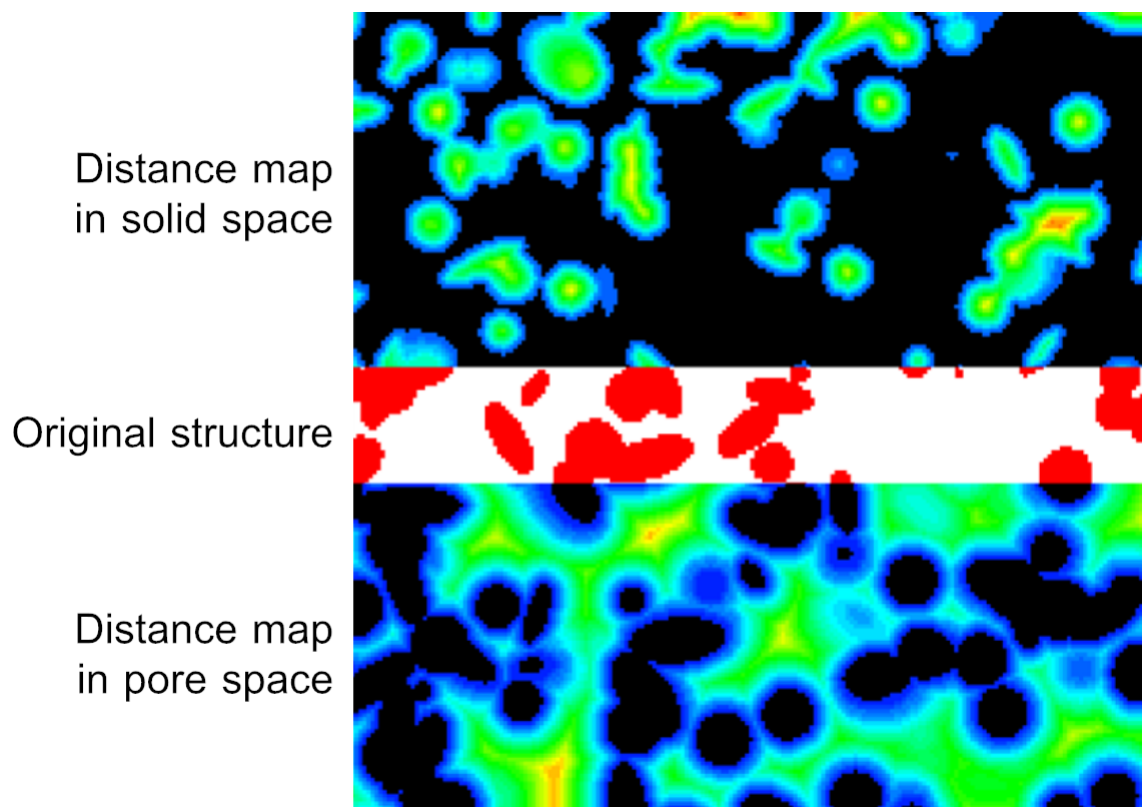
Watershed Image Labeling

The [Watershed Image Labeling](#) treats the image it operates on as if it were a topographic map. In this model, the brightness of each pixel represents its elevation. The computation then finds lines running along ridge lines. The **Watershed Image Labeling** is based on the **Euclidean Distance Transform** (EDT). Seeds for the watershed component are placed at the local maxima of the EDT. In these seeds, components begin to *grow*. During this growth process, component boundaries form as soon as components touch.

Watershed Image Labeling creates a *.g32 index image from the gray value image. This index image can then be used in GrainFind, for example, to reconnect over-segmented objects and obtain grain statistics.



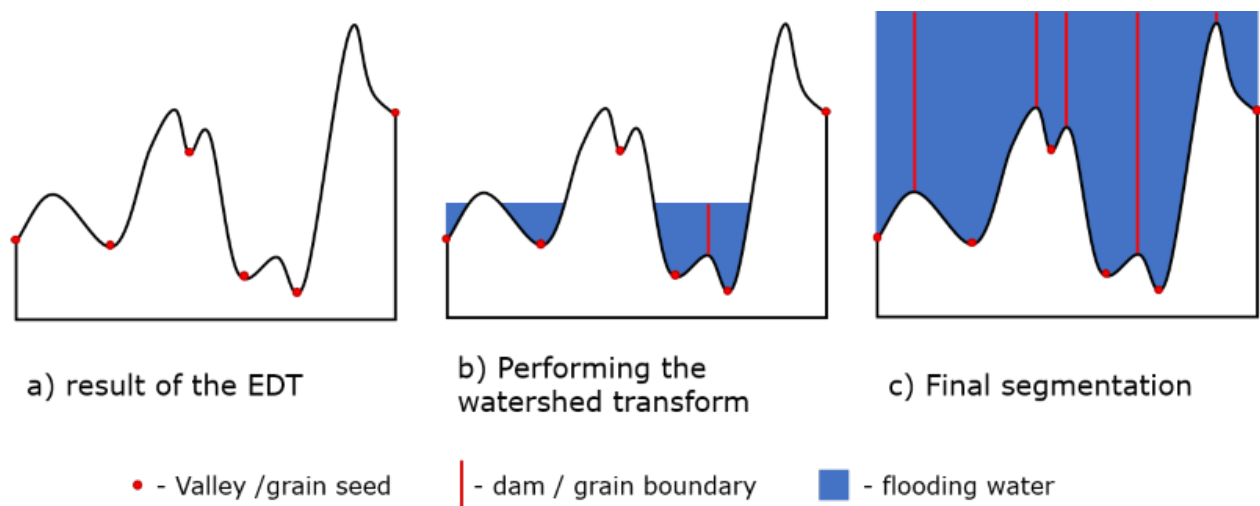
The implemented algorithm detects edges in the imported image based on the gray value or morphological gradient (see [Preprocessing](#)^[137]). Then, a distance map is created based on the edge distances. The maxima in the distance map (see the image below) are used as seeds for the watershed algorithm, which is then performed on the distance map.



The concept of a watershed is easier to understand with a 2D example. In this representation,

the EDT is a topographical relief where high values represent valleys and low values represent peaks. This topography is continuously *flooded with water*, beginning with the deepest valleys. As soon as water from a neighboring valley begins to mix in, a dam is created, corresponding to a material boundary. The result is a topography with water-filled valleys separated by dams. The identified valleys represent watershed components, and the dams separating them denote component boundaries.

The figure below illustrates the progression of the watershed algorithm. On the left, the topographical relief corresponding to the EDT is shown, with the component seeds (valley bottoms) marked in red. This topography is successively flooded with water, forming dams between adjacent valleys. Information about the component space, such as the minimum component diameter, can be used to adjust the **Watershed (Supervoxel)** results. Each watershed component is assigned the mean gray value of that component. This is the supervoxel. The result is a gray value image that is much easier to segment.



If there are artifacts in the initial image, it is recommended to apply other image filters, such as the [Non-Local Means Filter](#)^[77], before running the **Watershed (Supervoxel)** algorithm. This will lead 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.

✓Preprocessing

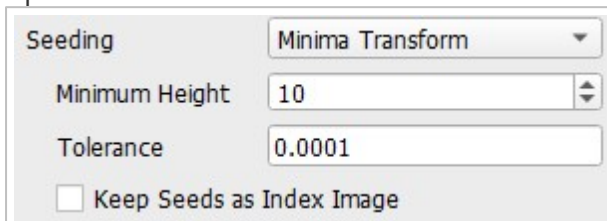
Three options are available for **Preprocessing** in the pull-down menu:

- **Morphological Gradient:** A [morphological gradient](#)^[86] is computed from the gray value image. Then the watershed algorithm is applied to the gradient. If this option is selected, a **Gradient Radius** must be specified. This radius controls the size of the region in which the morphological filter is applied.
- **Gradient:** A [gradient](#)^[88] is computed from the gray value image. Then, the watershed algorithm is applied to the gradient.
- **None (Gray Value Image):** The watershed algorithm is applied directly to the gray value image. This is not recommended in most cases.

✓ Seeding

For **Seeding**, select how the seeds should be specified:

- **Minima Transform:** The seeds are specified by an H-Minima Transform. The **Minima Transform** is controlled by the parameters **Minimum Height** and **Tolerance**. A detailed description can be found [here](#)^[86]. Seeds found by the **Minima Transform** can be saved in an index image (*.g32) by selection the **Keep Seeds as Index Image** option.

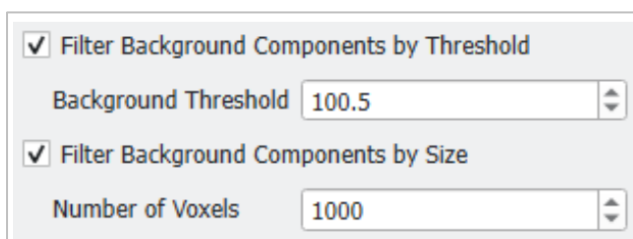


- **Index Image:** A corresponding index image (*.g32) must be loaded in GeoDict. To do so, select **File** → **Load Volume Field** from the menu bar, then browse for the corresponding *.g32. This file specifies the seeds. If you have loaded more than one *.g32 file, select the desired image from the **Index Image** pull-down menu. This option is useful if you have already run **Watershed** on the image and you want to try different [Preprocessing](#)^[137] options. This reduces the runtime by skipping the image seeding.



✓ Filter Background Components

Additionally, components can be labeled as background. Background components are labeled with an index of 0.



When **Filter Background Components by Threshold** is selected, watershed components with a mean gray value lower than the specified **Background Threshold** are considered background.

When **Filter Background Components by Size** is selected, watershed components consisting of fewer voxels than the given **Number of Voxels** are considered background.

Check both background component filters to label components with a mean gray value lower than the given threshold and consisting of fewer voxels than the given number.

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

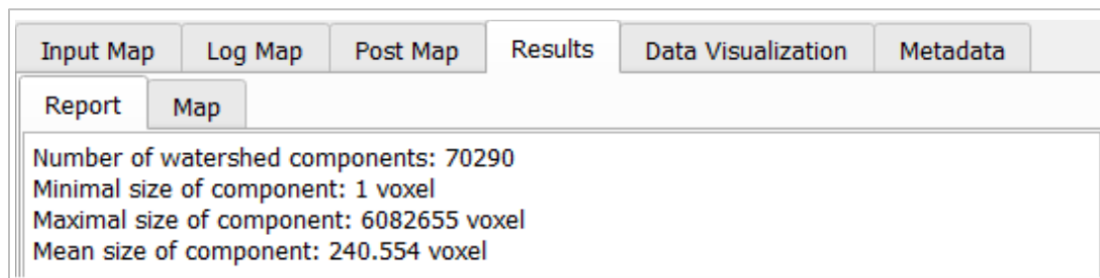


Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

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 below.

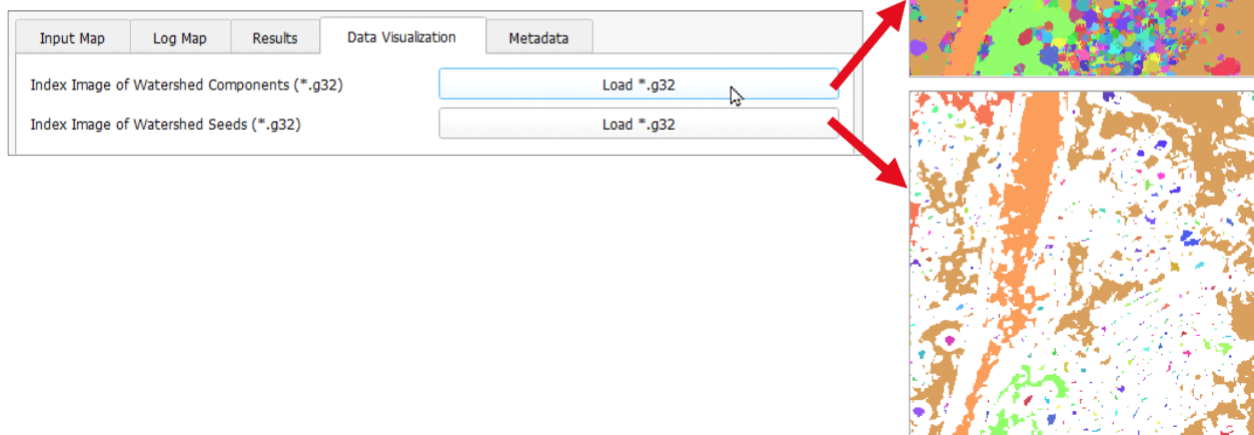
Results

The result file with the specified **Result File Name** is opens automatically in the **Result Viewer**. The number of watershed components and their minimum, maximum, and mean sizes can be found under the **Results – Report** sub-tab.



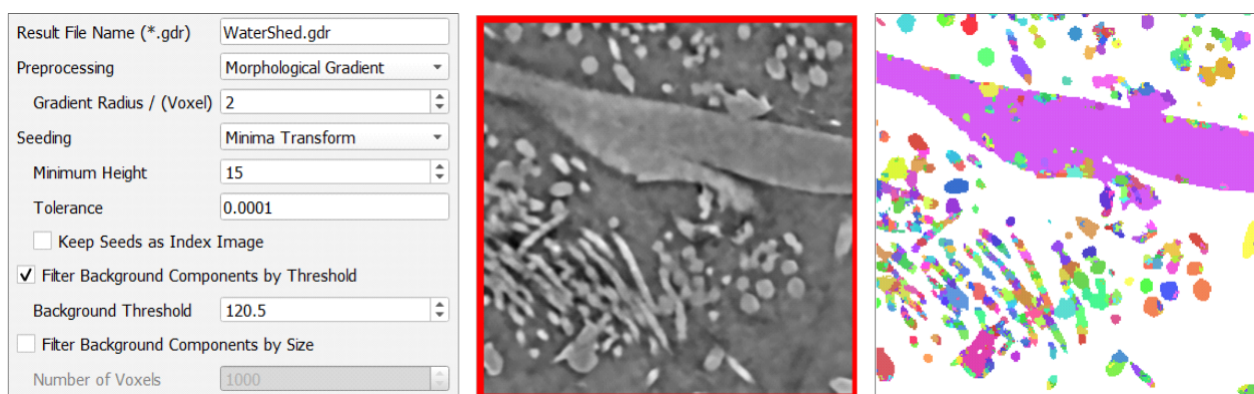
Go to the **Data Visualization** tab and click **Load *.g32** to visualize the **Index Image of Watershed Components** in the GeoDict visualization area. This image shows the individual regions identified by the watershed. For the filtered image visualized in the Image Processing dialog, the resulting gray value is the mean gray value of the corresponding region. If the watershed identifies individual objects, the components file can be used as input for GrainFind Identify Grains, for example. However, for many scans, the individual objects cannot be recognized from the gray value image.

If the **Keep Seeds as Index Image** box is checked, the watershed seeds can be visualized by clicking the lower **Load *.g32** button. Otherwise, the button is grayed out. This image shows the seeds specified by the H-Minima Transform algorithm. Use it to rerun the watershed with different preprocessing parameters, as explained above. In the opening dialog, click **OK** to load the index image in GeoDict. For more information about GeoDict result files, refer to the Result Viewer user guide.



Example

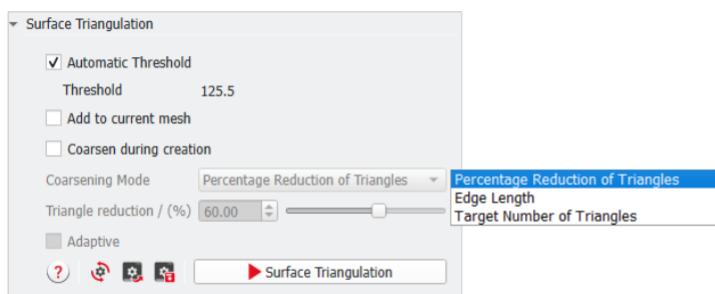
The following example uses the same image as the [Watershed \(Supervoxel\)](#) filter. The same parameters are used for **Watershed Image Labeling**. Additionally, the **Filter Background Components by Threshold** option is selected, and a **Background Threshold** of 120.5 is entered. Thus, all components with a gray value lower than 120.5 were assigned to index 0 and colored white.



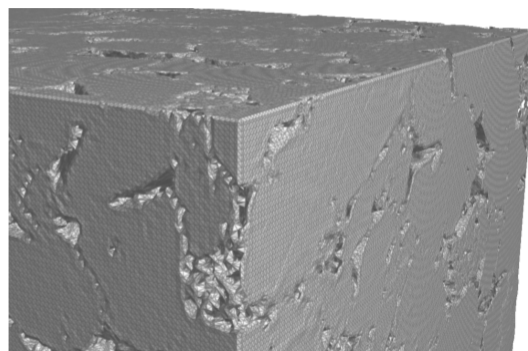
Surface Triangulation

Create a **Surface Triangulation** for the resulting structure by creating a **Surface Mesh**. This feature is only available if you have a MeshGeo license, either leased or purchased.

The structure is segmented into two phases, and the isosurface wraps around the high gray values, which are assigned to Material ID 01. The isosurface normal points into the pore space, which is assigned to Material ID 00.



Example: Surface Triangulation of a Berea sandstone



Segment the gray value image using either an **Automatic Threshold** or a manually entered **Threshold**. If the **Automatic Threshold** is enabled, the [Otsu](#)¹⁰⁹ method is used to threshold the image.

If a mesh is already in memory when **Add to current mesh** is selected, the new mesh is added to it. Then, multiple meshes can be edited together and saved to a single file.

Checking the **Coarsen during creation** box reduces the number of triangles in the generated surface mesh.

Three different **Coarsening Modes** are provided coarsening algorithm's stopping criteria:

- by **Percentage Reduction of Triangles**
- by **Edge Length**
- by **Target Number of Triangles**

The coarsening algorithm reduces the number of triangles in the generated mesh by merging short edges into longer edges. Select the **Adaptive** box to use error quadrics based on the adaptive coarsening mode.

See the MeshGeo user guide for a detailed description and examples of the triangulation parameters.

Click **Surface Triangulation** to start the process. Once the triangulation is complete, the resulting mesh will be displayed in the GUI visualization area.



Know how! You can **Save** your current settings for this tool as **Start-Up Settings** . The next time you process an image, these settings will be automatically loaded and filled into the parameter fields. You can also load the **Built-In Default Settings**  available in GeoDict. If you change any settings and want to revert to your saved start-up settings, click the corresponding button to **Load** the **Start-Up Settings** .

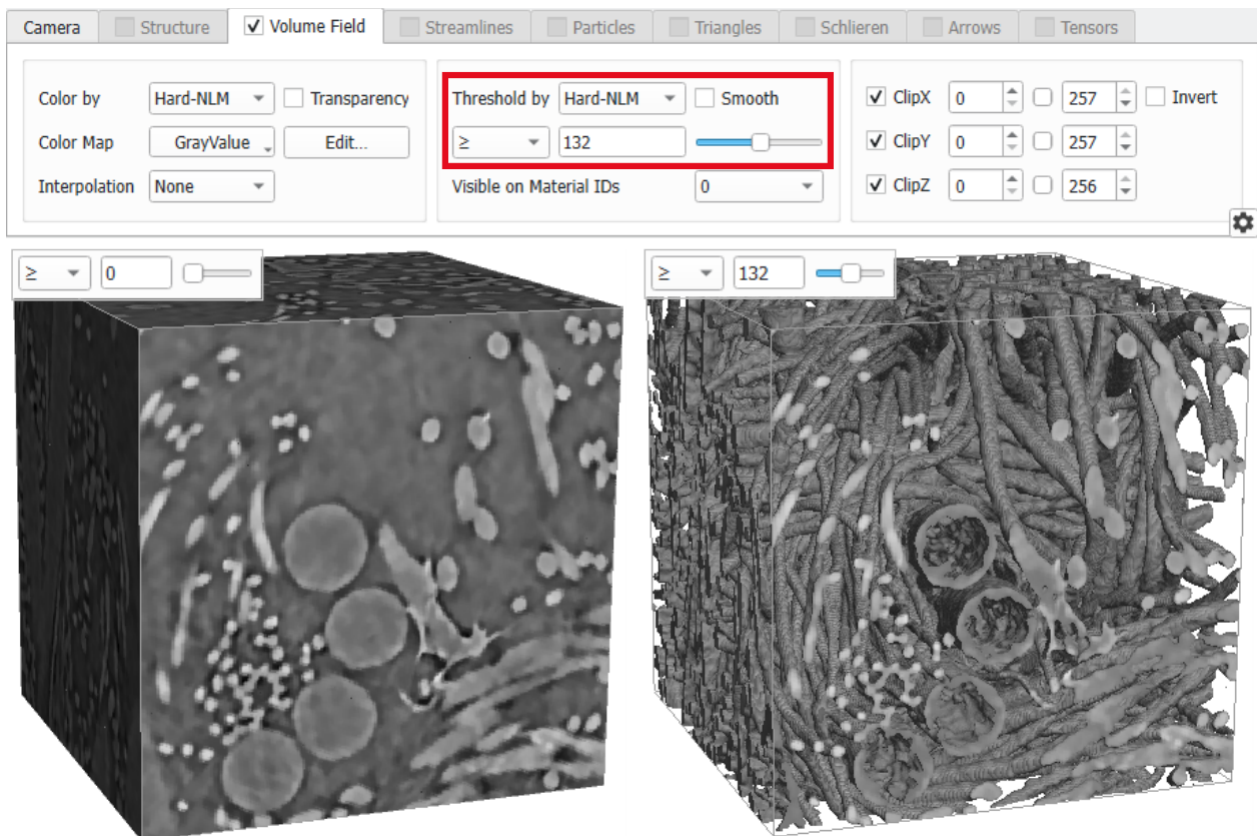
1.4.4 3D Gray Value Visualization

Since the 3D gray-value image is visualized as a **Volume Field** in the main GeoDict GUI, it can be rendered in 3D. To do so, leave the **Image Processing** dialog and return to the main user interface.

All gray value images that are currently loaded can be viewed in 2D in the **Visualization** area.

To view the image in 3D, switch to 3D view by clicking the  icon in the toolbar or selecting **View** → **3D Rendering** from the menu bar.

In $\geq$ threshold mode, dark gray values are rendered invisible in the visualization when the threshold slider is moved or a gray value is entered. In this example, a threshold of 122.5 is entered, which is the Otsu threshold for this image. For gray value images, it is recommended to uncheck **Smooth** as this feature interpolates values between the voxels to show a smooth surface, which can lead to artifacts. Detailed information on visualization in GeoDict can be found in the Visualization user guide.



1.5 References

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