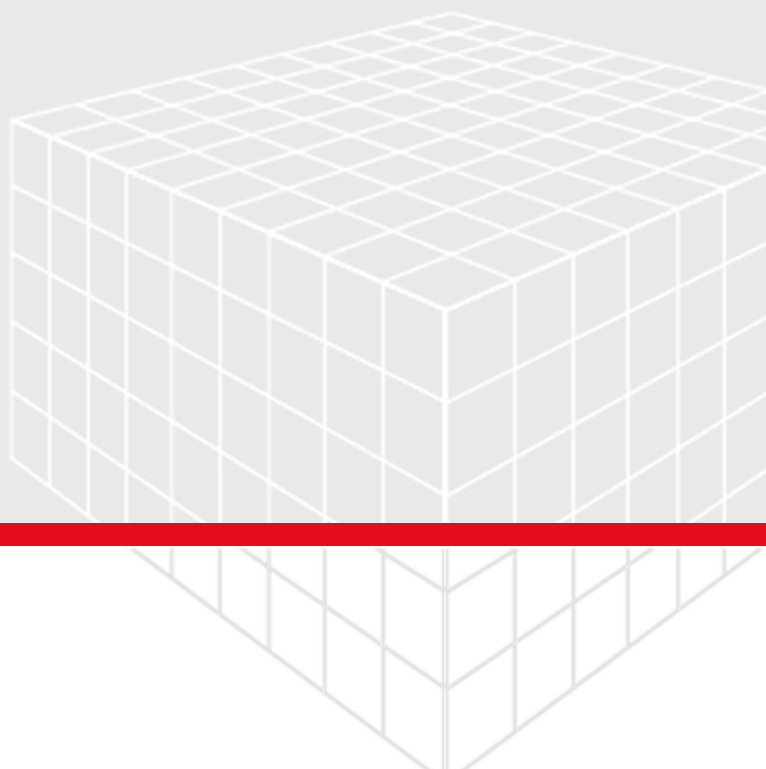


PoroDict

User Guide

GEODICT Release 2026

Published: July 2026



GEODICT

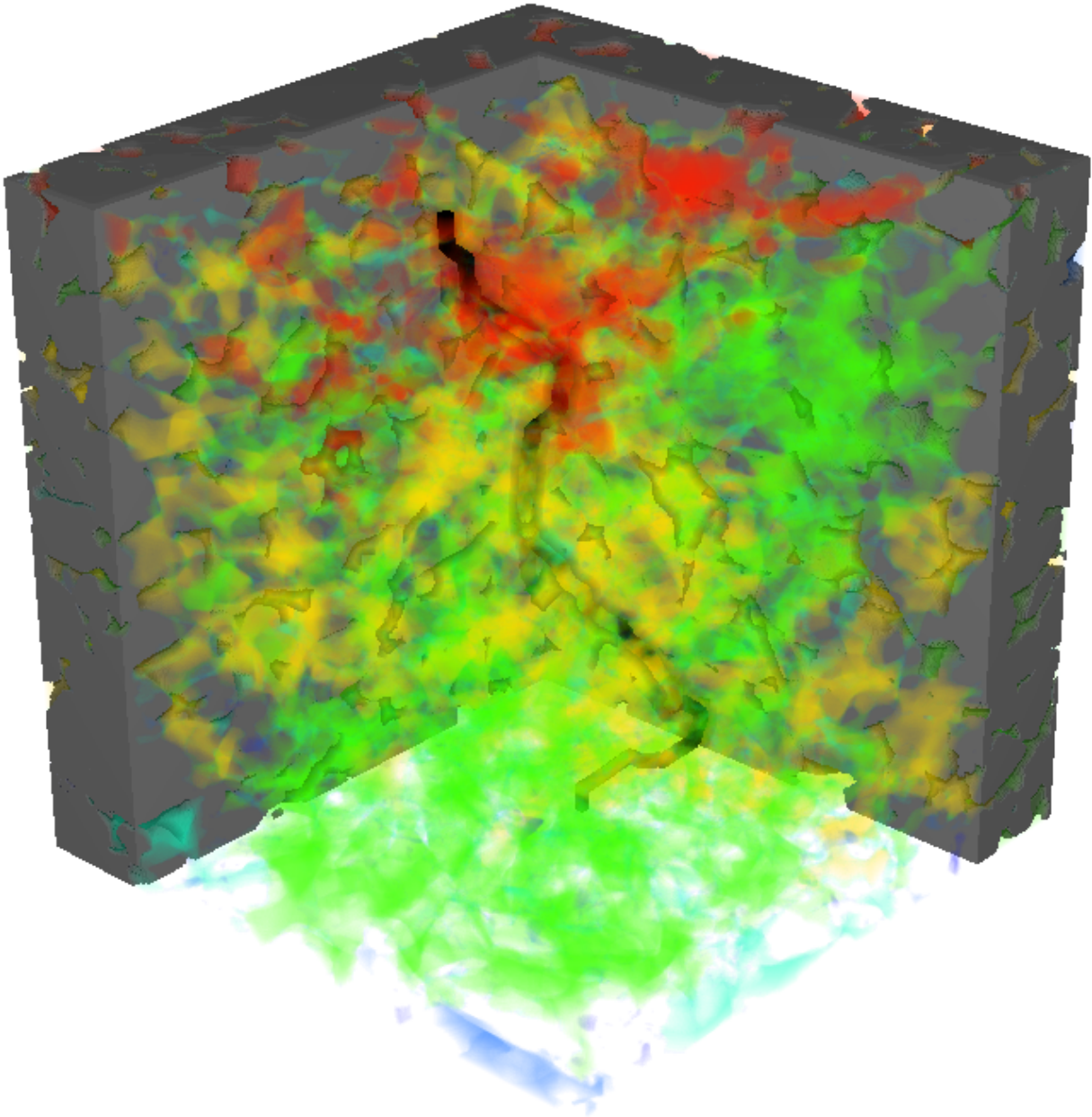
<https://doi.org/10.30423/userguide.geodict>

PoroDict

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1 PoroDict

PoroDict estimates the pore structure characteristics of three-dimensional models of porous media obtained from a μ CT or FIB/SEM image or from a 3D model generated with GeoDict.



New in GeoDict 2026

- New output option [Save Pore-Network Model as *.gad](#) in Identify Pores.

Learn to use PoroDict

- [Theoretical Background](#)^[5]
Learn how pore size can be measured using the different commands of PoroDict.
- [Pore Size Distribution \(Granulometry\)](#)^[23]
Determine the pore radius by fitting spheres into the pore volume.
- [Pore Size Distribution \(Porosimetry\)](#)^[37]
Porosimetry measures the pore sizes by pressing a non-wetting fluid into the medium. The pressure applied is related to the radius of the pores.
- [Identify Pores](#)^[50]
This method introduces a segmentation of the pores, based on a distance transform, which allows a detailed pore-size characterization.
- [Open and Closed Porosity](#)^[95]
Determination of Open Porosity (pores connected to a domain boundary) and Closed Porosity (pores not connected to a domain boundary).
- [Bubble Point](#)^[106]
Compute the Bubble point pressure, which is a direct measure of the effective pore diameter.
- [Percolation Path](#)^[119]
Check if there is a percolation path for a specified material in the structure and determine its length and minimal diameter.
- [Chord Length Distribution](#)^[130]
Determine the distribution of the length of a typical chord (number of connected voxels along the computational direction) of a structure.
- [Geodesic Tortuosity](#)^[138]
Find the shortest paths crossing the material, either through pore space or through solid materials.
- [Pore Analysis GeoApps](#)^[143]
The Pore Analysis GeoApps section contains additional Python macros deployed with GeoDict for specific applications.
- [References](#)^[151]
Publications cited in this chapter.



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 Theoretical Background

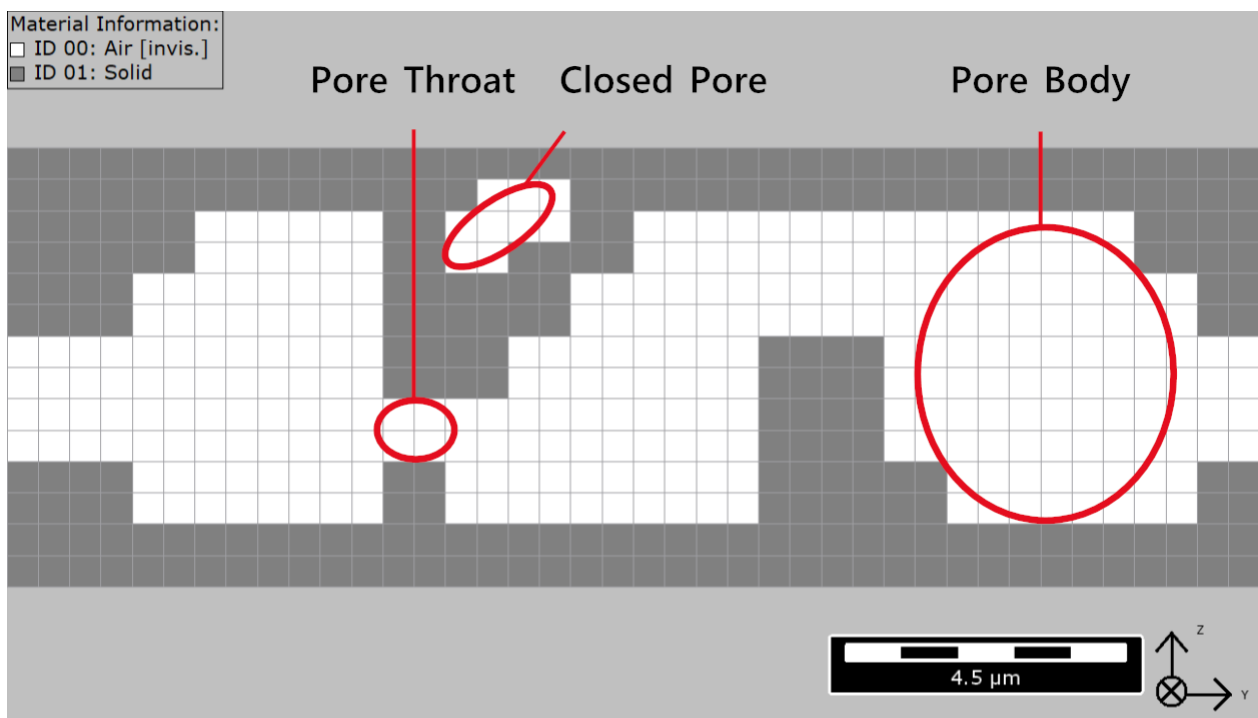
In GeoDict, different methods are available to determine the size of a pore. Before describing them in more detail we answer the following questions:

- What is a pore?
- What is a pore body and what is a pore throat (or pore neck)?

Structures in GeoDict may consist of solid voxels and non-solid voxels. The non-solid parts are also called pore space. The pore space may be empty or filled with a fluid material.

The transition from the term pore space to the term pore is not that trivial. For a pore space that is convex, e.g., it has the shape of a sphere, the whole pore space can be called a pore. But for more arbitrary shaped geometries, we need two other definitions.

A **Pore Body** is a relatively large part of the pore space while a narrower part is called a **Pore Throat**. To get an idea, imagine the pore space to be a network of channels, where pore throats divide larger parts of the pore space but still connect those parts. When talking about the term pore, often the pore body is meant. However, there can also be pore space which is not connected to any other pore space. This pore space is called **Closed Pores**.



Now, we can go into more detail about how the three methods ([Granulometry](#)^[6], [Porosimetry](#)^[8] and [Identify Pores](#)^[10]) for determining the pore body sizes in GeoDict work. We will look at the structure shown above, which is periodic in the y-direction and has a voxel length of 0.5 μm and visualize the results for each method. By pure visual investigation we can observe three pore bodies that are connected via pore throats.

Afterwards, we explain how the two methods to [determine pore throat sizes](#)^[12] (Percolation Path and Bubble Point) work.

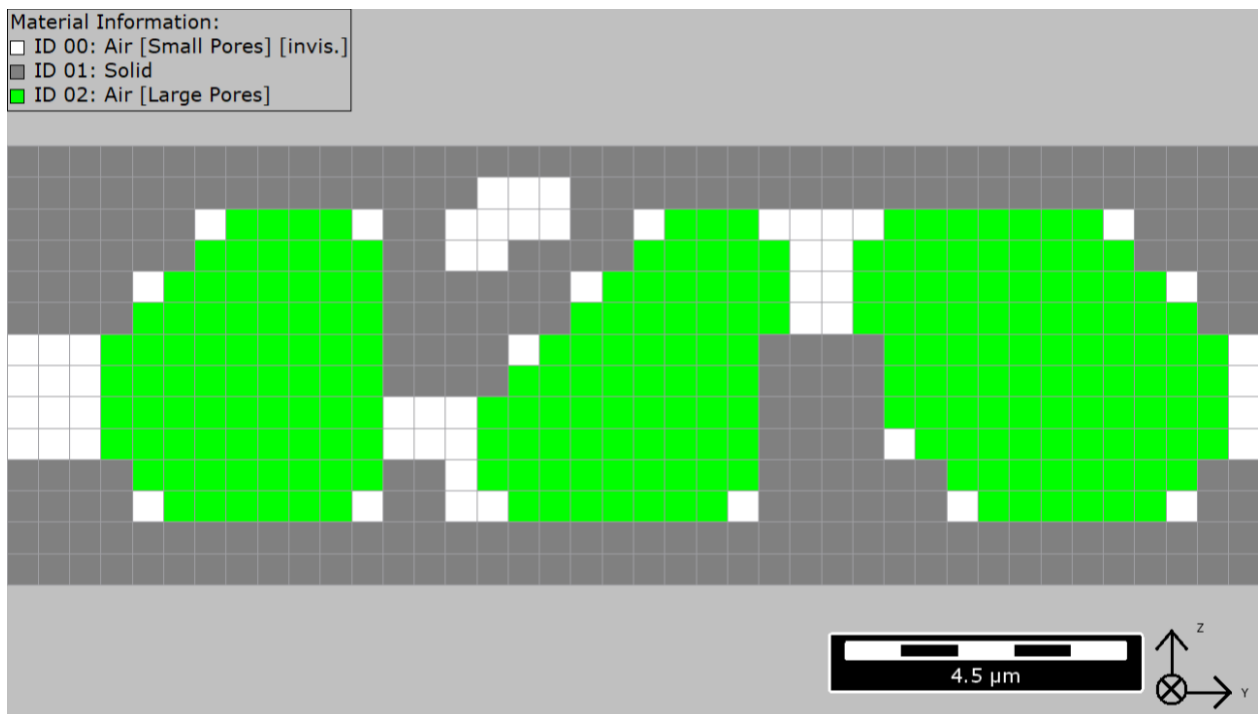
1.1.1 Granulometry

First, we compute pore sizes using granulometry, a purely geometrical algorithm. PoroDict Granulometry uses the following assertion when defining a pore diameter:

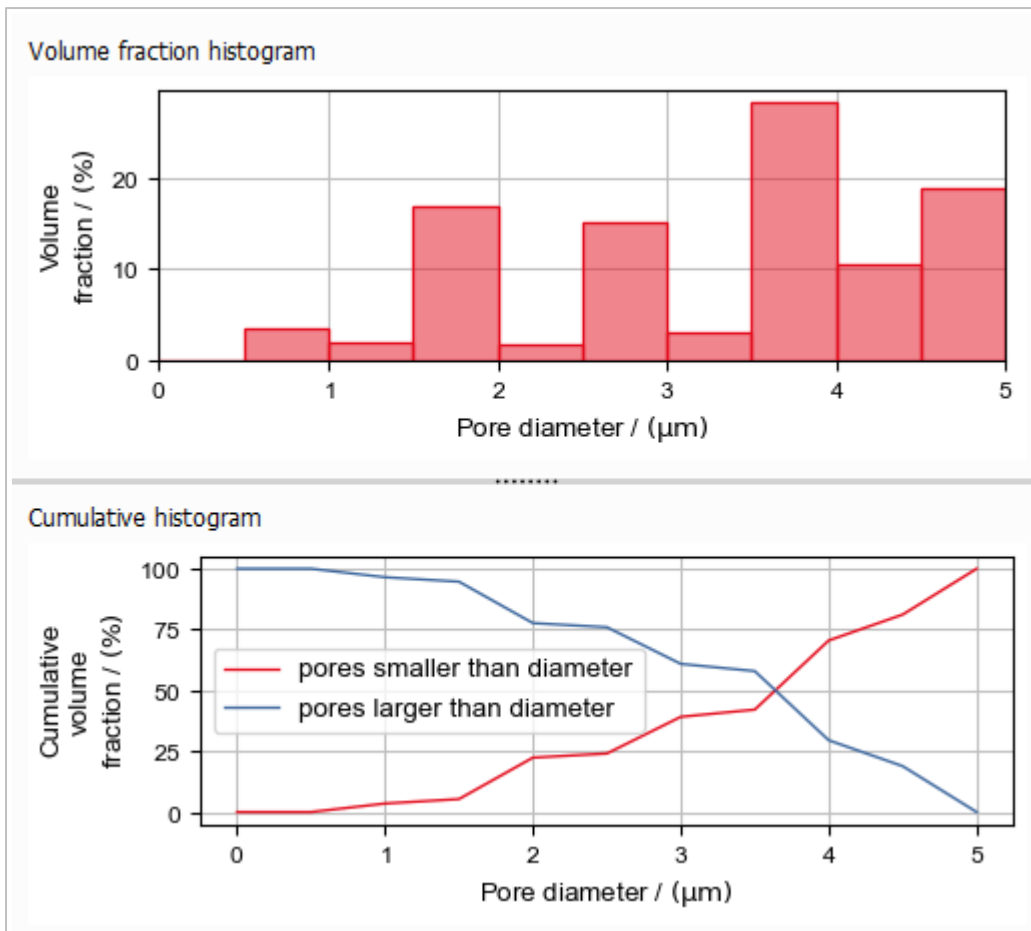
A voxel is part of a pore with a diameter equal or larger than D , if it is included in a sphere of diameter D , which is completely included in the pore space.

So, for the example above with a voxel length of $0.5\ \mu\text{m}$, if a sphere of diameter $1\ \mu\text{m}$ can be found that contains a certain voxel, but no sphere of diameter $1.5\ \mu\text{m}$ can be found that contains the voxel, this voxel is assigned a pore diameter of $1\ \mu\text{m}$. This means, that each voxel is linked to the diameter of the largest sphere that fits inside the pore and contains this voxel.

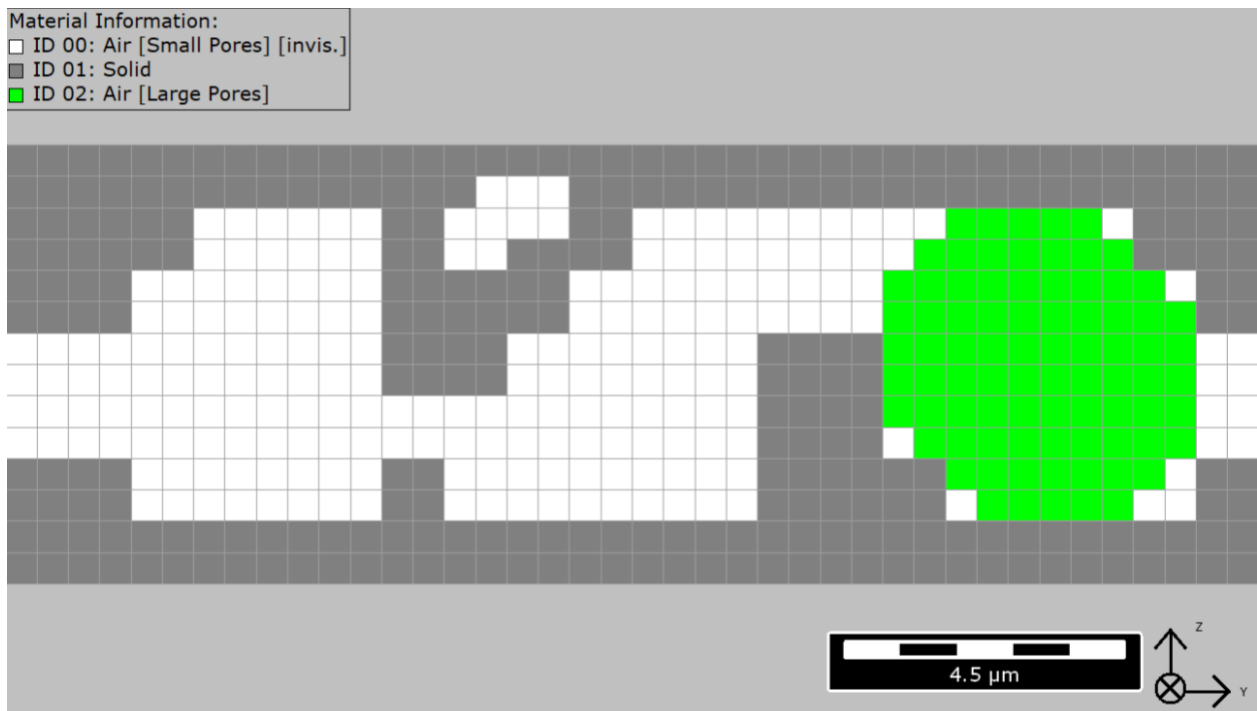
Granulometry seems to find three large pore bodies (green), but these belong to pores with a diameter larger or equal than $2\ \mu\text{m}$.



In the cumulative volume fraction histogram, observe that nearly 80% of the pore space is associated to a diameter larger than $2\ \mu\text{m}$. The small closed pore at the top has a diameter smaller than $2\ \mu\text{m}$.



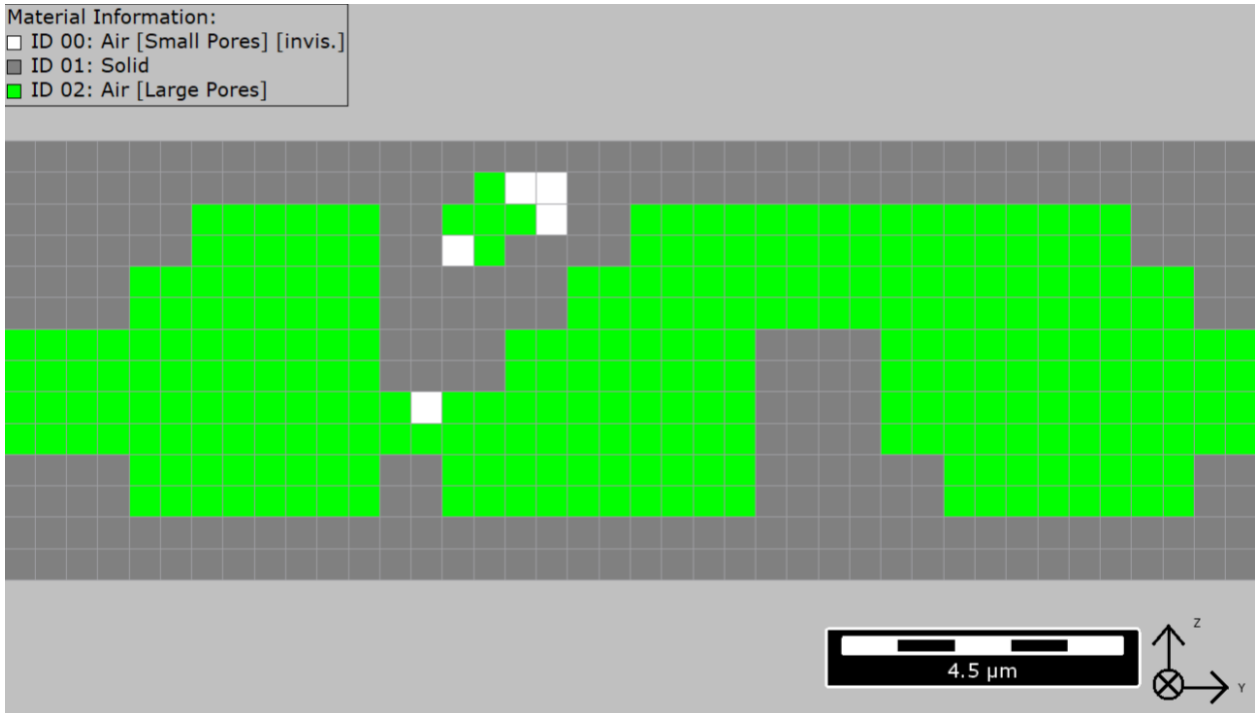
When looking at the pores with a diameter larger or equal than 4.5 μm , only one of the large pore bodies is detected. This causes the increase in the volume fraction at the far right of the graph. The two other large pore bodies add up to the peak, at just below 4 μm .





Note! Granulometry assigns small spheres even into pore space that human observers consider as pore throats. But these small spheres fit, of course, also in the pore bodies. Thus, Granulometry is useful to detect the larger **pore bodies**. Even closed pores can be identified with this method.

In the image below, the pore space with a diameter larger than 1 μm has green color. A part of the closed pore is colored white, which means these voxels have a diameter smaller than 1 μm .



1.1.2 Porosimetry

In contrast to the Granulometry method, Porosimetry is an experimental physical method to determine the size of the pore space.

When measured by *porosimetry* in laboratory tests (e.g., mercury intrusion porosimetry or liquid extrusion porosimetry), a non-wetting fluid is pressed through the pore space into the structure. Non-wetting means that the invading fluid and the solid materials have a contact angle larger than 90° . The smaller the pore space - that is, the pore throats - the more pressure is needed to pass through them. The pore space behind, the pore body, is flooded instantly until smaller passages are reached. There, a higher pressure is needed to permeate the pore throat. Via the Young-Laplace / Washburn equation

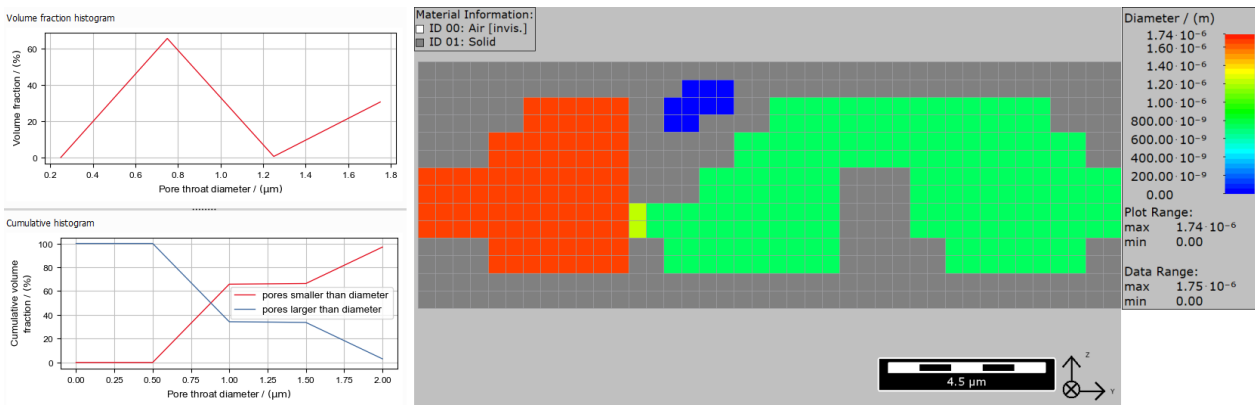
$$P_c = \frac{2\sigma}{r} \cos(\theta)$$

(1) Young-Laplace / Washburn equation

the applied pressure P_c is related to the size of the pore throat, where r is the radius of the pore throat, σ is the surface tension and θ is the contact angle.

In the example used in the [Theoretical Background](#) section, we let a fluid intrude the structure first from left to right (Y- is the intrusion side) and then from right to left (Y+ as intrusion side).

Looking at the results, we can observe that at a lower pressure the red area gets filled. In the volume fraction histogram, this corresponds to the peak at the right with a pore diameter of 1.75 μm . At a larger pressure the yellow throat is passed, and the green area gets filled. The associated diameter (0.75 μm) of the green area is nearly the same as the diameter of the yellow throat and causes the peak at the left side of the histogram.



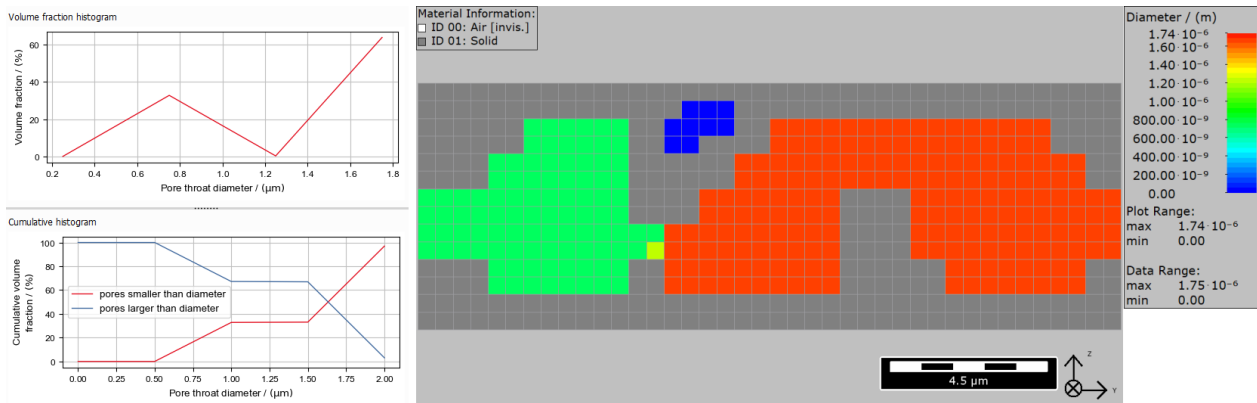
Thus, the pore bodies are not measured as large pores, because they are hidden behind smaller pore throats. Therefore, the pore bodies are only measured as having the diameter of the smallest pore throat between the intrusion side of the fluid and the corresponding pore body. Furthermore, closed pores are not recognized as they have no connection to the intrusion side of the fluid. Thus, the closed pore at the top has a diameter of 0 μm and is colored blue.

Consequently, the computed pore size distribution *by porosimetry* takes the connectivity of the pores into account. In this case, the definition of what is a pore diameter changes slightly because in fact pore throat diameters are measured:

*A voxel is part of a pore with a diameter equal or larger than D , if it is included in a sphere of diameter D , which is completely included in the pore space **and can be moved in through the pores connected with the intrusion side(s) of the fluid.***

This definition does not lead to unique pore diameters for the same pore space! The pore diameters are dependent on the chosen intrusion sides.

Looking at the example, where the fluid enters the structure on the right side of the structure, we can see that the histogram and the pore size distribution is mirrored compared to the first porosimetry run. As before, first the red volume is filled with the fluid, but now a bigger fraction of the pore space is occupied. The associated diameter of this red volume is the same as for the red volume in the example before. This is because the structure is periodic in y-direction and the pore throats on both sides of the structure have the same diameter.



The red volume is represented by the peak at the right of the volume fraction histogram. At a higher pressure first the yellow pore throat is passed and then the green volume is filled with the fluid.

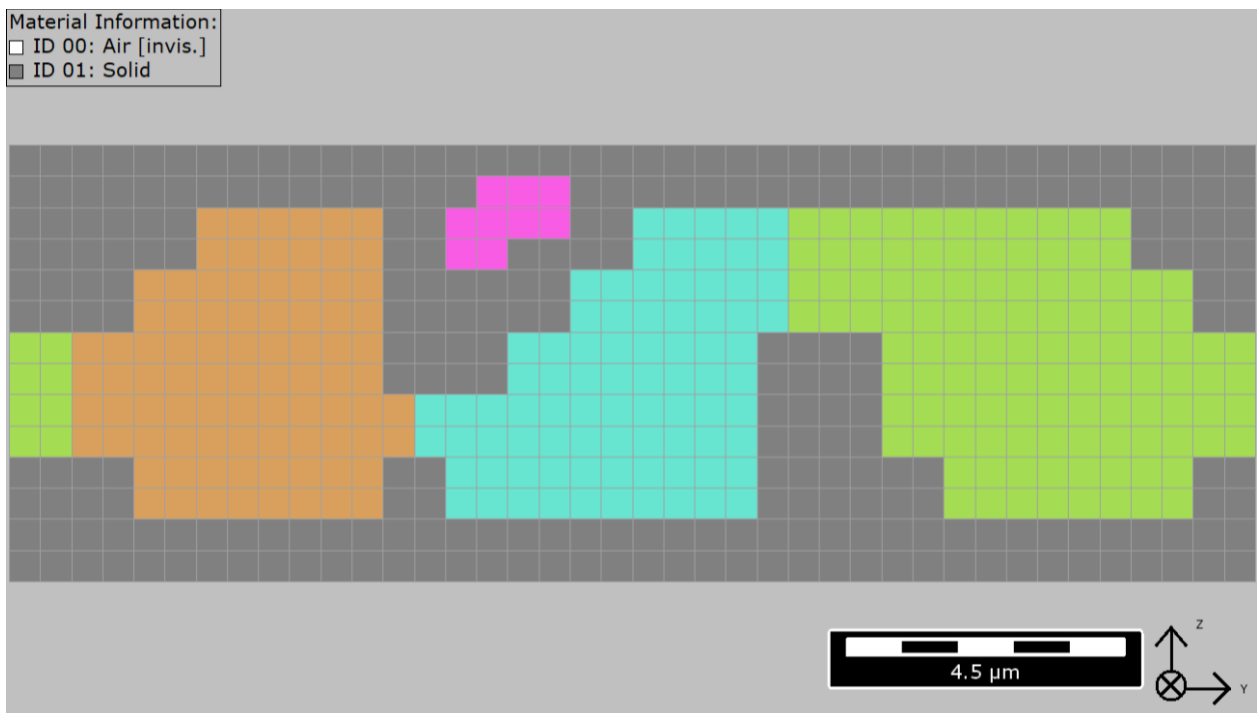
We can observe that the pore body on the left side of the structure is assigned to a smaller diameter if the fluid enters from the right side of the structure, compared to the case where the fluid enters from the left. The reason is, that in the case where it comes from the right side the fluid has to pass the narrowest point first before entering the left pore body. The diameter of the pore body is then assigned to the diameter of the pore throat.



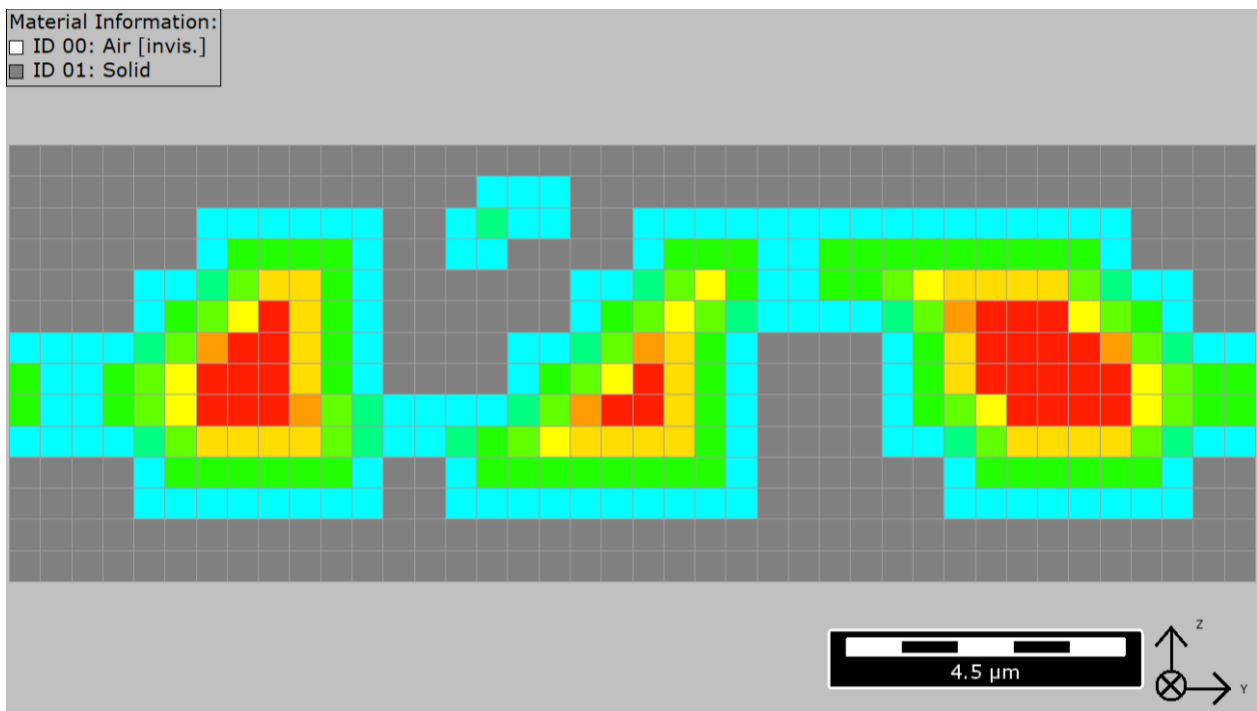
Note! Porosimetry is good in detecting narrow pore throats, but does not take into account closed pores.

1.1.3 Identify Pores

In the example structure Identify Pores finds four individual pores, which might be the same that a human eye would identify. The boundary conditions were set to be periodic in Y-direction, thus, the pore at the right side of the structure enters again on the left side.



When using Identify Pores, first a Euclidean distance transformation and then a Watershed transformation are performed. The minima of the negative distance transform define the seeds for the following watershed transformation (in the example in the middle of the three red zones and the green voxel of the closed pore). Here, as seen in the next figure, starting from the seeds, the algorithm proceeds to higher and higher values of the distance transform, and labels those voxels with the index of the seed they are connected with. This is done until all voxels have been reached.



If two voxel of different seeds touch during this process, they mark the boundary between two neighboring pores. If selected, fragmented pores can be reconnected, i.e., a smaller pore is

associated to a bigger neighbor. After the Watershed transformation is done, an ellipsoid is fitted into each of the identified pores. In the report, the orientation of the three axes, the length of the three axes, and more parameters are given to describe the pore sizes. See [Results of Identify Pores](#)¹⁶ for a description of all computed parameters.



Note! Currently, Identify Pores can describe the sizes of the pore bodies quite well, while the pore throats are only identified and not measured.

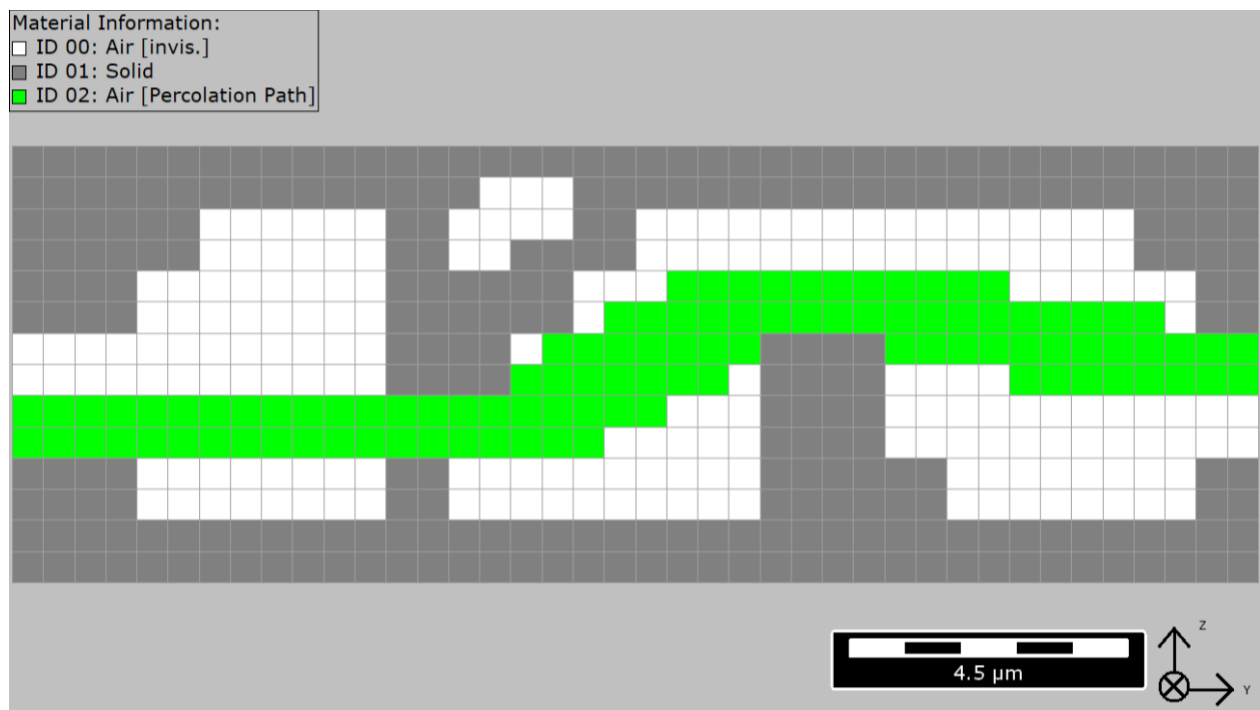
1.1.4 Pore Throat Size Distribution

GeoDict offers two methods to determine a pore throat size distribution:

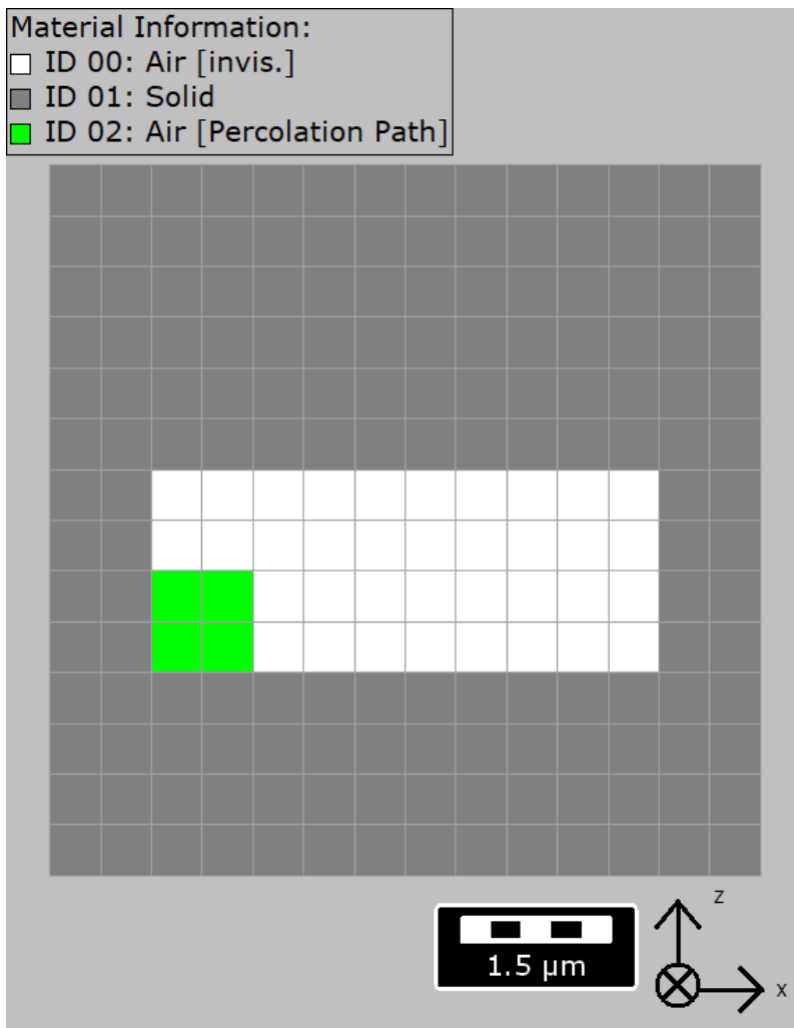
- Percolation Path
- Bubble Point

Percolation Path

If only a single maximal path is computed, the **Percolation Path** gives the diameter of the largest spherical glass bead that can pass the structure. If more paths should be found, the already found paths reduce the pore space. This means the same bottleneck cannot be used a second time. Repeatedly applied this results in a size distribution.



The found percolation path has a spherical cross section, but in this example the resolution is very coarse, so the cross section is cubic. This can be observed when looking at the percolation path from the Y-direction, which is the flow direction to determine the path. In our example the largest percolation path has a diameter of two voxels. This is the smallest diameter of the second to left pore throat.



When searching more paths, their diameters would be the diameters of the next smaller pore throats. One disadvantage of the percolation path is, that it will find the shortest diameter of a pore throat. But there might be pores that have a large expansion in one direction and in another direction they have only a few voxels diameter. Percolation path only sees the smaller diameter while the other is omitted. This is the case for the shown example.

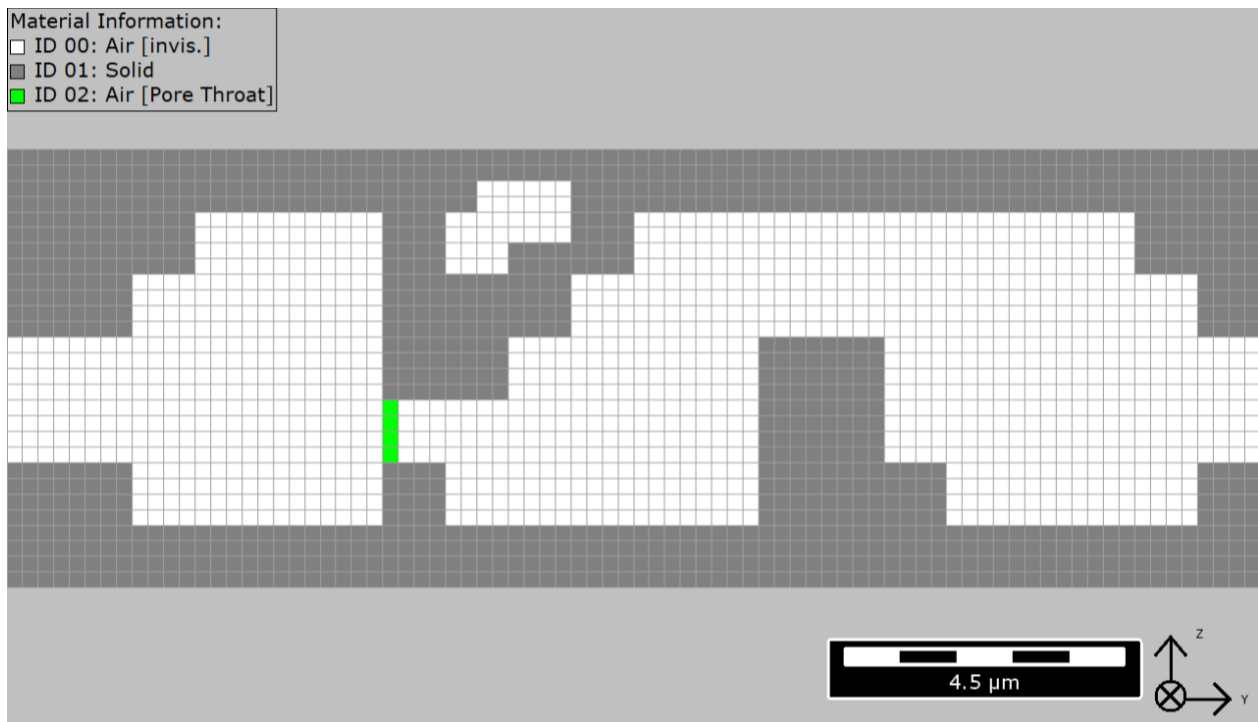
Bubble Point

For pore throats with a non-spherical cross-section in the flow direction, the **Bubble Point** method is more suitable. The bubble point method is often used for filters or metal wire meshes. It is based on a real physical experiment, where the observed media is placed in a liquid. Underneath, a gas under pressure is placed and the pressure rises during the experiment. The non-wetting gas will at some point break through the pore with the largest diameter and rise through the structure until it exits. Thus, it detects the largest pore throat in a structure. The pressure point is then converted into a pore diameter using the Young-Laplace or Washburn equation. However, it is assumed that the pore throat has a cylindrical shape, which might not be the case in reality. Moreover, a gas bubble is quite flexible and can fill the whole cross-sectional area of an arbitrarily shaped pore throat.

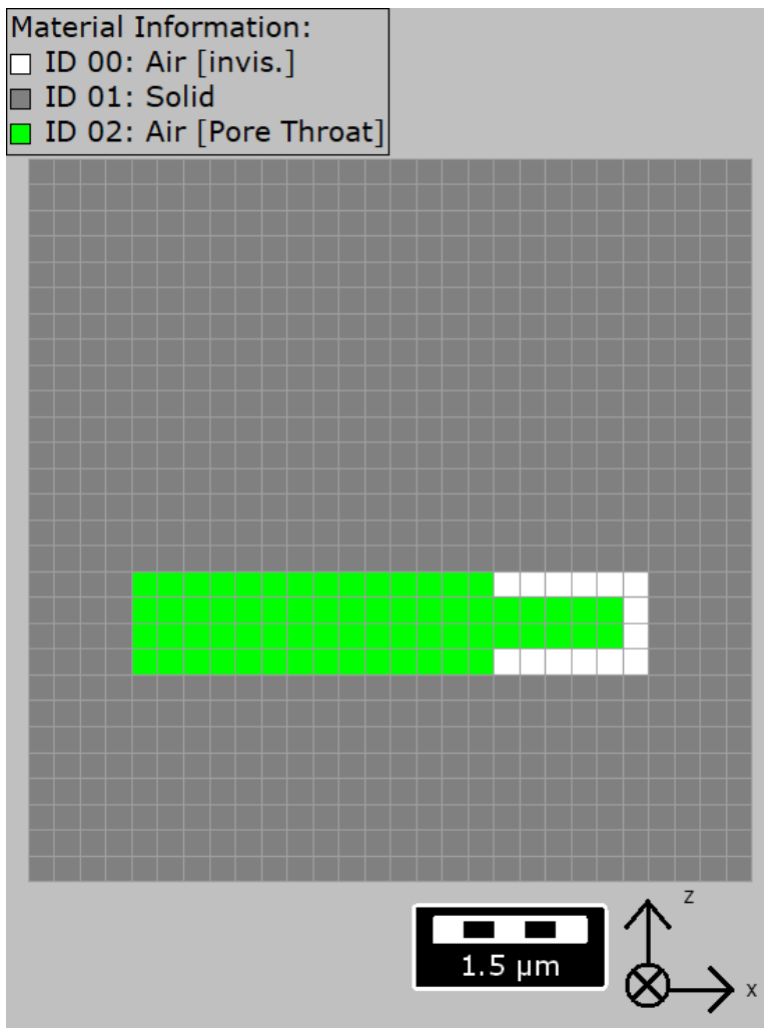
For metal weaves, GeoDict offers the GeoApp [ASTM Calculation Factor](#)¹⁴⁹, which determines a calculation factor to convert the pressure into a pore diameter, following the standards provided in the ASTM E3278-21 norm.

To use the bubble point method, the smallest pores in the structure need to have a resolution of at least 5 voxel. As this is not the case for our example, we use the [Rescale](#) command from ProcessGeo with strictly rescaling. Here, the number of voxels in each direction is doubled and all corners remain.

We apply **Bubble Point** with flow in Y-direction. The second to left pore throat is again identified as smallest pore throat.



The view from the Y-direction in the image on the left shows that now nearly the whole cross section of the pore throat belongs to the bubble point.

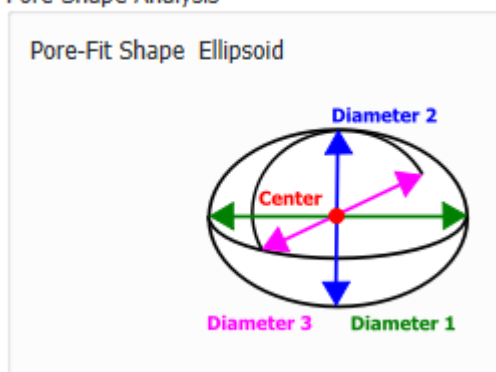


1.1.5 Results of Identify Pores

Fit Shapes

In **Identify Pores**, an ellipsoid is fitted into each identified pore.

Pore-Shape Analysis



To define such an ellipsoid, a center point and three diameters are needed.

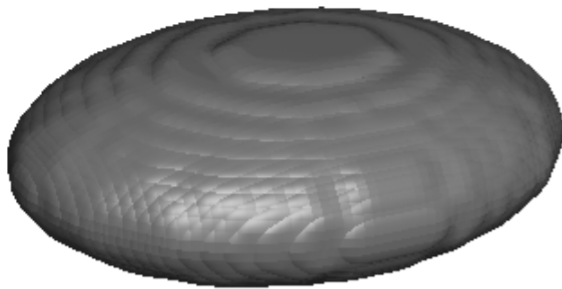
In the following, we set

- a to be the length of the longest of the three diameters,
- b to be the length of the medium diameter,
- c to be the length of the shortest diameter.

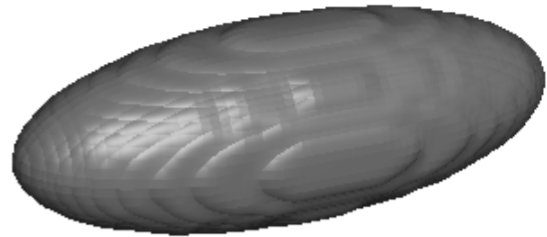
A pair of diameters is similar if its size ratio (the smaller diameter is divided by the larger diameter) is larger than 0.875. Two diameters differ, if their ratio is smaller than 0.875.

Four shapes for the ellipsoids can be fitted into the pore:

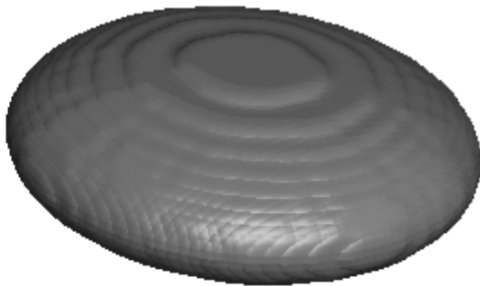
- An ellipsoid is formed as a **Flat Bar**, if all three diameters a , b , and c differ much from each other.
- A **Prolate Spheroid** has one bigger diameter, a , and the two smaller diameters, b and c , are similar to each other. Its shape is similar to a cigar.
- The two bigger diameters (a and b) of an **Oblate Spheroid** are similar. Thus, it can be compared to a disk.
- For a **Sphere** all three diameters a , b , and c are similar.



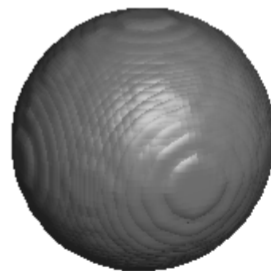
Flat Bar



Prolate Spheroid



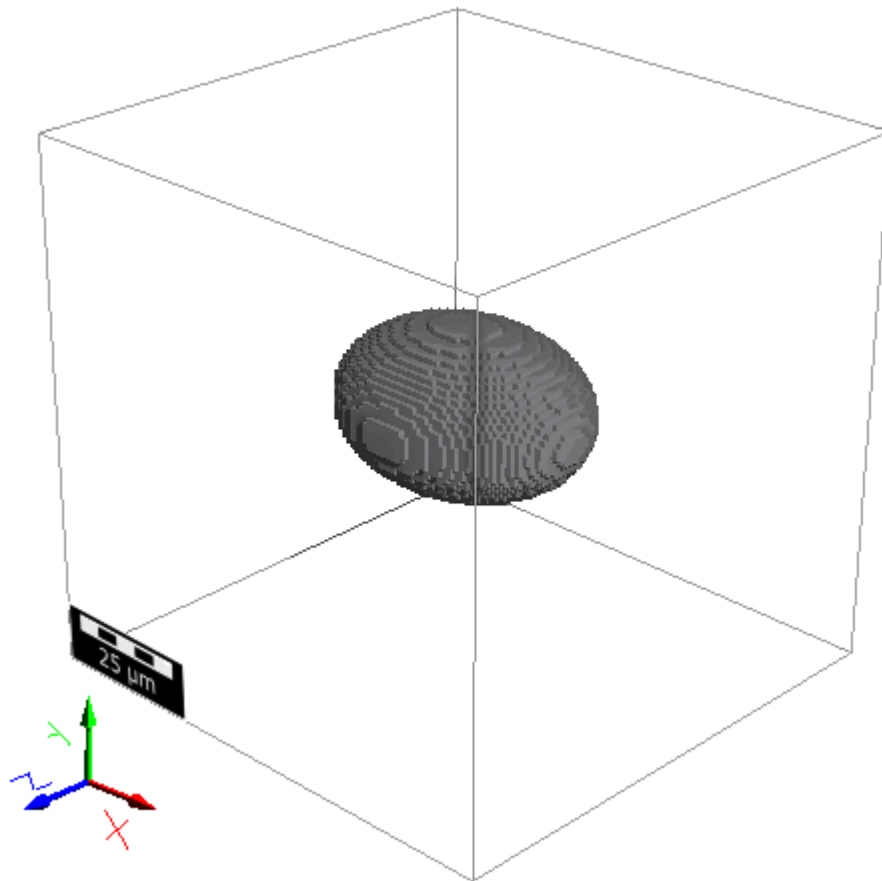
Oblate Spheroid



Sphere

Computed Scalar Values

The parameters of these ellipsoids are used to compute further scalar values of the pores. We show the parameters graphically with the help of a simple structure, that contains one ellipsoidal pore in the center of the structure. It was created by placing an ellipsoid with dimensions $50\text{ }\mu\text{m} \times 30\text{ }\mu\text{m} \times 40\text{ }\mu\text{m}$ in the center of an empty domain with voxel length $1\text{ }\mu\text{m}$ and then inverting the structure.



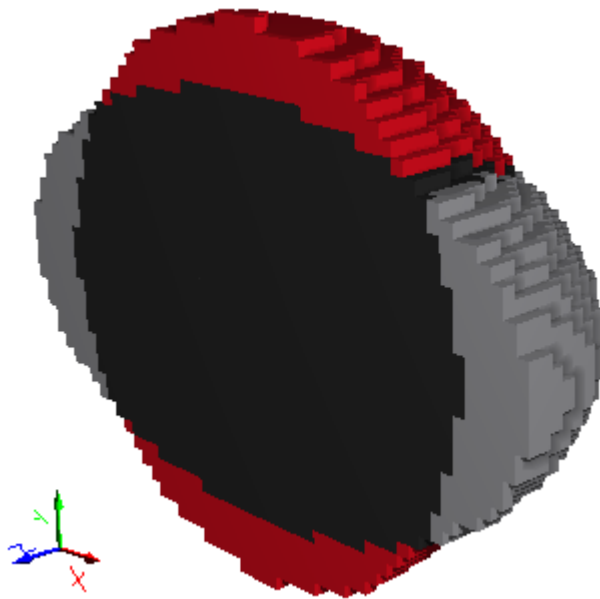
- **Volume:** The volume of the pore is simply determined by the number of voxels the pore contains. To get a volume in metrical units, it is multiplied by the cubed voxel length:

$$V = \#(\text{pore voxels}) * (\text{voxel length})^3$$

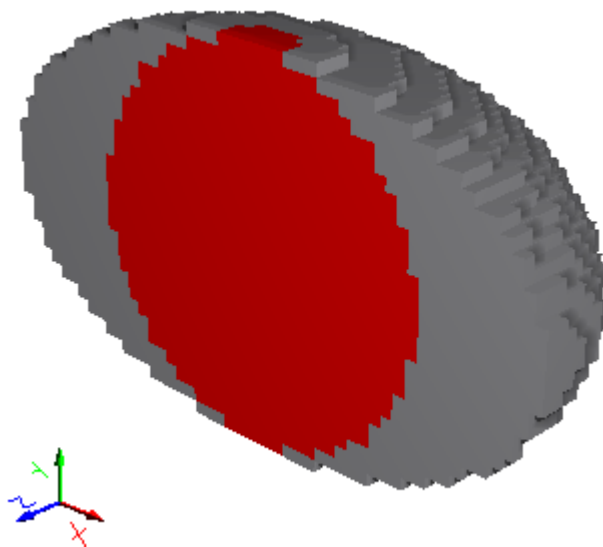
(2) Volume

In the example, the pore consists of 31384 voxels, so that the pore volume is $31384\text{ }\mu\text{m}^3$.

- **Equivalent Diameter:** The equivalent diameter is the diameter of the sphere which has the same volume as the pore. Below, the volume equivalent sphere for the example (which has a diameter of $39\text{ }\mu\text{m}$) is shown in red and was added to the initial ellipsoid using the Add command of LayerGeo. The black part represents the overlap.



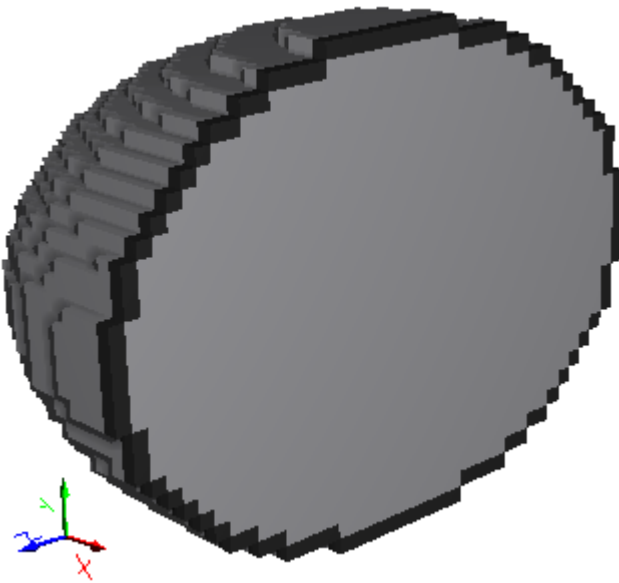
- **Inner Diameter:** The inner diameter is the diameter of the largest sphere that can be inscribed into the pore. Below, the inscribed sphere for the example, which has a diameter of 30 μm , is shown in red and was added to the ellipsoid structure with LayerGeo.



Important! Note that the Inner Diameter is only calculated if the option **Save Inscribed-Sphere Diameters and Sheppard Sphericities** was checked in the [Output Options](#) of the pore-identification options.

- **Shortest Fit Diameter:** This is the shortest diameter (c) of the ellipsoid fitted into the pore. For the example, the shortest diameter is 30 μm .
- **Intermediate Fit Diameter:** This is the intermediate diameter (b) of the ellipsoid fitted into the pore. For the example, the intermediate diameter is 40 μm .

- **Longest Fit Diameter:** This is the longest diameter (a) of the ellipsoid fitted into the pore. For the example, the longest diameter is 50 μm .
- **Perimeter:** The computed perimeter is the shortest perimeter around the ellipsoid fitted into the pore. As an ellipsoid is defined by three diameters, the perimeter is computed as the perimeter of the ellipse formed from the two smallest of those three diameters. For the example structure the perimeter would be the length of the black line, which is 110 μm .



- **Krumbein Sphericity:** The Krumbein Sphericity is a measure for the sphericity of the pore, based on the three principal axes (a, b, c) of the fitted ellipsoid. If the Krumbein Sphericity is close to 1, the ellipsoid is nearly a sphere. In the example above, the Krumbein Sphericity is 0.78, which means that the diameters differ much.

$$P_K = \sqrt[3]{\frac{bc}{a^2}}$$

(3) Krumbein
Sphericity

- **Sheppard Sphericity:** The Sheppard Sphericity is defined as the diameter of the inscribed sphere divided by the diameter of the volume-equivalent sphere. For the example, the Sheppard Sphericity of the pore is 0.76.



Important! Note that the Sheppard Sphericity is only calculated if the option **Save Inscribed-Sphere Diameters and Sheppard Sphericities** was checked in the [Output Options](#) of the pore-identification options.

- **Aspect Ratio:** The ellipsoid fitted into the pore is defined by three diameters. The aspect ratio is computed as

$$\text{aspect ratio} = \frac{c}{a}$$

(4) Aspect
Ratio

where the shortest diameter c is divided by the largest diameter a , which is 0.6 for the example.

- **Surface Area:** The surface of the pores is estimated by an algorithm based on MatDict's **Estimate Surface Area** command (see also J. Ohser, F. Mücklich). The Area (or Surface) Probability is defined by computing the surface area of each segmented pore (using the same algorithm as in MatDict's Estimate Surface Area command) and then weighting the pores by that value. The computed surface area does also include the surface between different pores, not only the area between pore and solid material. For the example, the surface is 4985 μm^2 .
- **Surface-to-Volume Ratio:** The estimated surface area of the pore is divided by the volume of the pore. For the example a value of 0.159 is obtained.
- **Surface Smoothness:** This is the surface of the fitted ellipsoid divided by the estimated surface of the pore. Usually, the estimated pore surface is larger than the surface of the fitted ellipsoid. Hence, the surface smoothness is usually below 1. Only if the shape of the pore is very similar to the fitted shape, then the surface estimation might be a little smaller than the surface of the fitted ellipsoid. The latter is the case in the example, where the surface smoothness is 1.002.
- **Cut-Surface Ratio:** The Cut-Surface Ratio measures how much of the pore surface is part of the domain boundary. The interface of the pore with the domain boundary is the **Cut Surface**, which is then divided by the remaining surface of the pore. Thus, it is a measure for the quality of boundary pores. For example, a Cut-Surface Ratio of 1 means that the interface of the pore with the domain boundary is as large as the remaining surface of the pore. In the example, the pore has no boundary contacts and thus the cut surface area and the cut-surface ratio are both 0.

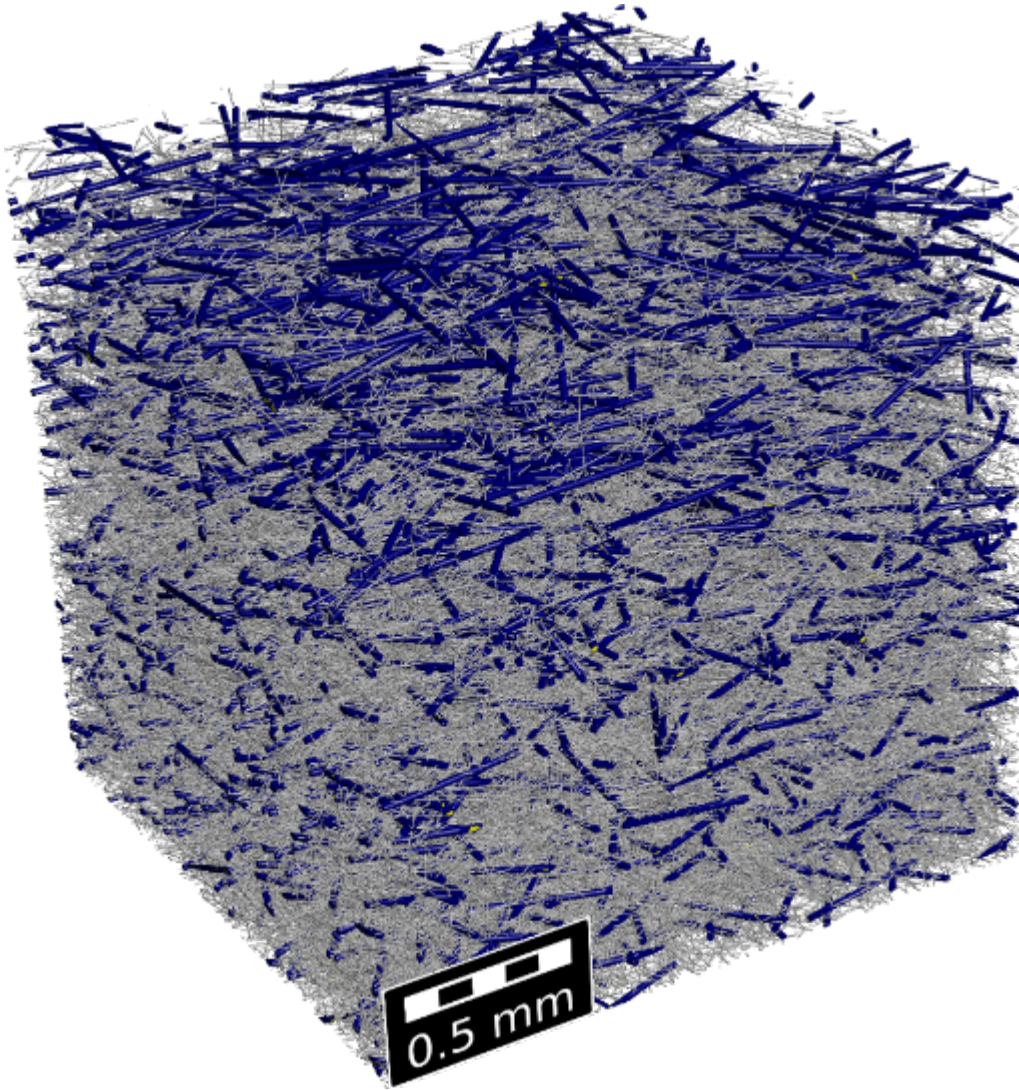


Important! Note that the domain boundaries, that were set to be periodic, do not contribute to the interface of the pore with the domain boundary. Particularly, if all domain boundaries are set to be periodic, the cut-surface ratio will always be zero. Also, if [Remove Pore Fragments at Domain Boundary](#) was activated, then the cut surface ratio is zero, too, because there will be no pores left that have an interface with the domain boundaries.

- **Mass:** If a density is assigned to the [analyzed material](#), each pore has a mass which can be calculated from its volume.
- **Moment of Inertia:** It depends on the mass distribution of the pores and is only computed if a density is assigned.
- **Coordination Number:** This is the number of contacts of a pore to other pores. In the example the coordination number is 0 as only one pore exists.

1.1.6 Speed-up through parallelization

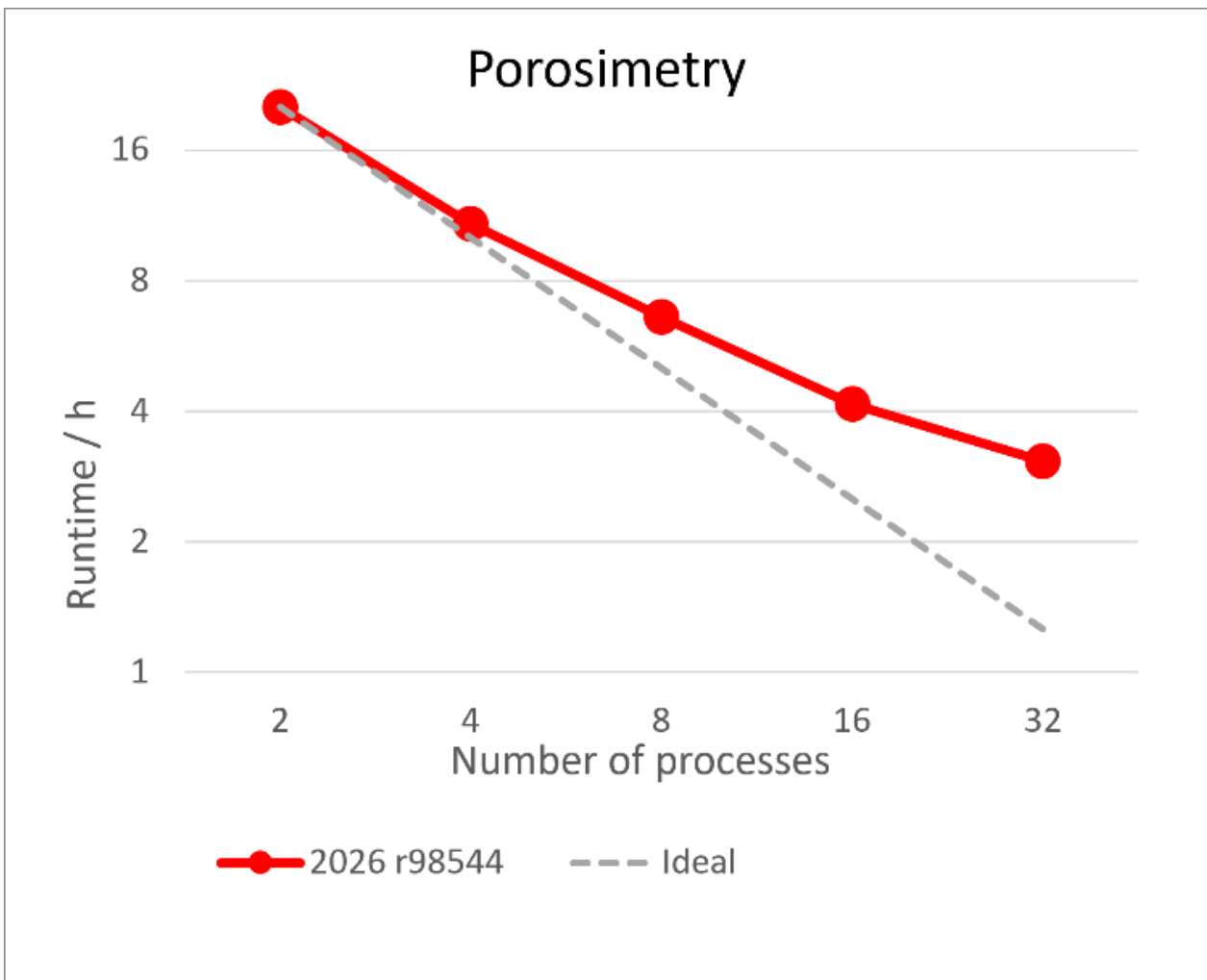
The pore size distribution analyses **Granulometry** and **Porosimetry** can be parallelized with several processes to speed-up the simulation runtime. An example of a parallelization benchmark for PoroDict **Porosimetry** is shown here.



The computation was run on a server with 2xIntel E5-2697A v4 processors with 16 cores each, running with a maximum of 3.60GHz.

The input structure is a filter structure with linearly increasing density of size 2048x2048x2032 voxels. A **Pore Size Distribution (Porosimetry)** analysis was run on this structure.

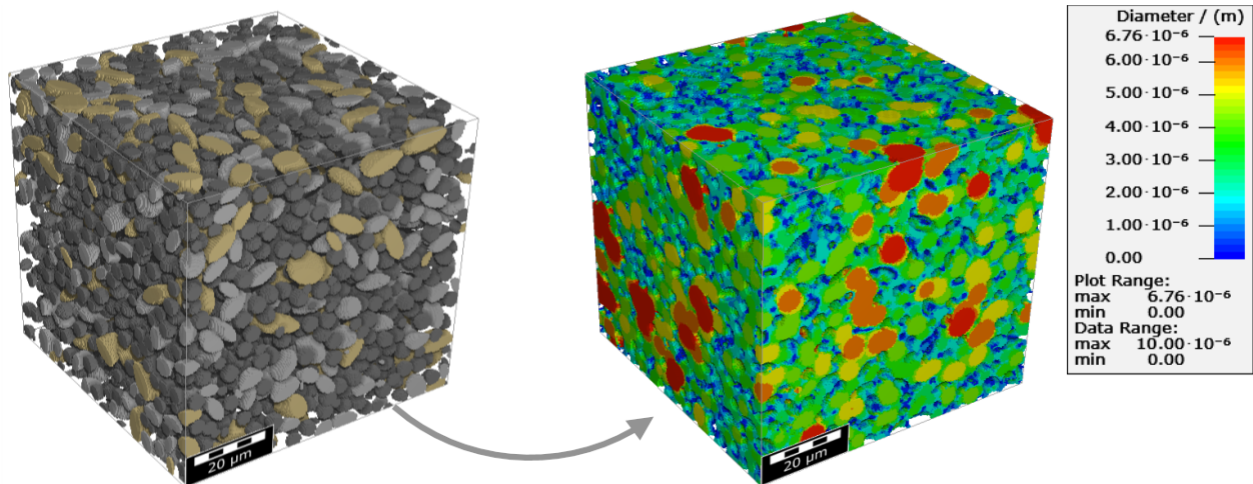
The following figure shows the runtime for a different number of processes for the whole simulation. The ideal speedup, i.e., getting half the runtime for twice the number of processes, is also shown as a gray dashed line.



1.2 Pore Size Distribution (Granulometry)

In the calculation of the **Pore Size Distribution (Granulometry)**, the algorithm used to determine the size of a pore is purely geometrical. A pore radius is determined by fitting spheres into the pore volume. To be more precise, a point belongs to a pore of radius r , if it is inside a sphere of radius r , which can be fitted into the pore space. Find more details about the theory behind the **Granulometry** in the [Theoretical Basics](#)^[6] section.

The **Pore Size Distribution (Granulometry)** dialog opens when clicking the **Edit...** button.



On the right, the volume field (.gsd) showing the diameter for each pore voxel is visualized.*

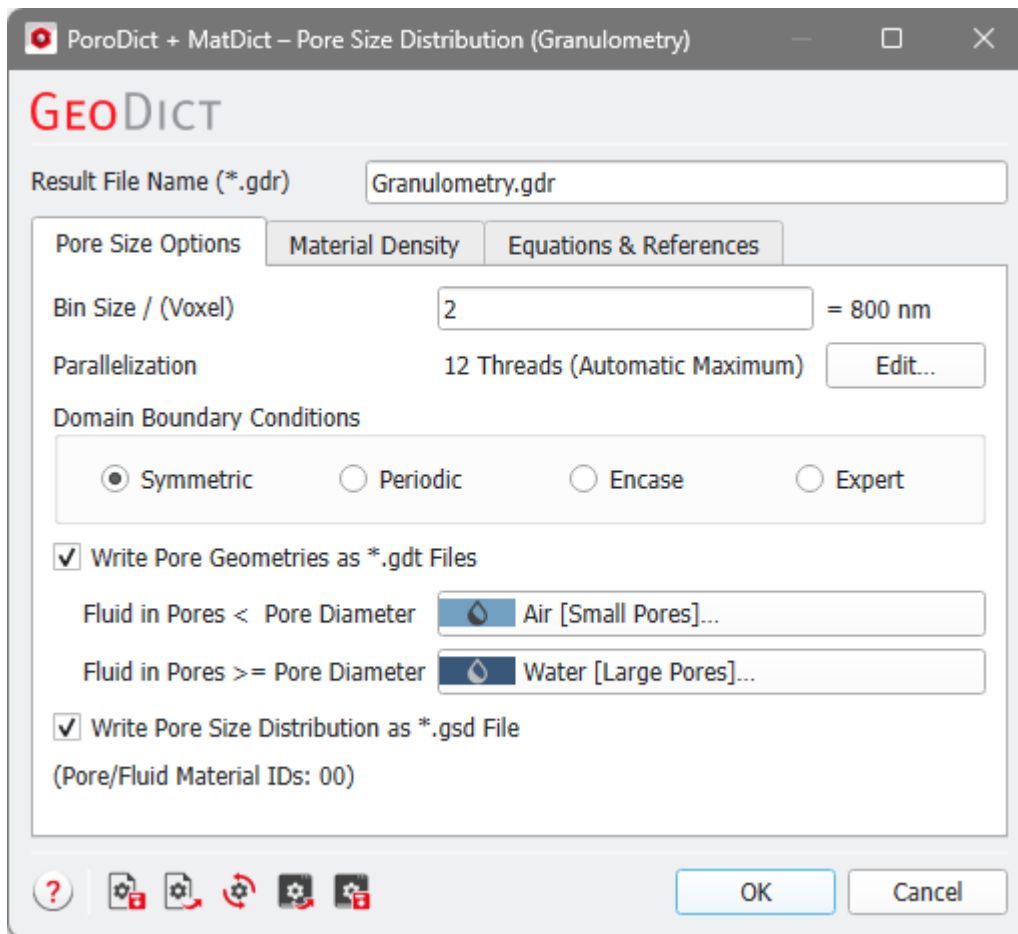
The Pore Size Distribution (Granulometry) command:

- [Options](#)^[23]
Set the parameters for the analysis.
- [Results](#)^[31]
View the computed results.

1.2.1 Options

The parameters are organized into the **Pore Size Options** tab, the **Material Density** tab, and the **Equations & References** tab, which cites several [references](#)^[151].

At the top of the dialog, enter the **Result File Name**. The result file is saved in the chosen project folder (**File** → **Choose Project Folder** in the menu bar).



Pore Size Options

✓ Bin Size

Enter the **Bin Size** in units of voxels. The equivalent in metric length units is shown on the right. The bin size determines the range of diameters that belong to one class of solid sizes.

All bins have equal bin size. Beginning with the largest possible diameter that is divisible by the bin size, the diameter is reduced by the bin size in each step. Every voxel is then assigned the diameter of the largest possible sphere that can be fitted in the solid and contains this voxel. Thus, each bin contains solid voxels with an assigned diameter in the range comprised between $[(i - 1) * \text{bin size}]$ and $[i * \text{bin size}]$, where i is the bin number.

For example, when analyzing a porous structure with a voxel size of 1 μm , you can set the bin size to 2 or to 4 (voxels) which would come to classify the solid by their diameter in ranges of 2 μm or 4 μm , and would result in the following bins:

Bin number (<i>i</i>)	Pore diameter between $[(i - 1) \cdot \text{bin size}] - [i \cdot \text{bin size}]$	
	Bin Size 2 μm	Bin Size 4 μm
1	0 μm - 2 μm	0 μm - 4 μm
2	2 μm - 4 μm	4 μm - 8 μm
3	4 μm - 6 μm	8 μm - 12 μm
..	...	...

When choosing the bin size, be aware that the underlying algorithm to compute the Euclidean distance operates directly on the voxel grid. Thus, the smallest possible distance between two grid points is 1 voxel, which corresponds to a radius of 1 voxel. This means the smallest diameter that the algorithm will find is 2 voxels. In general, the error made when computing the solid size distribution is of the same order of magnitude as the discretization error of the structure, i.e., 1 voxel.

In the result viewer, for each bin the **Minimal Diameter**, which is the diameter of the smaller sphere, and the **Maximal Diameter**, which is the diameter of the larger sphere, are given. This means all solid voxels in that bin have a diameter that is larger than the minimal diameter and smaller or equal than the maximal diameter.

✓ Parallelization

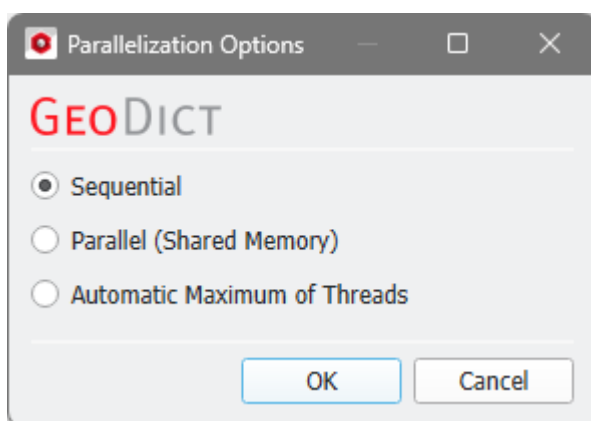
Control how many threads are used for the computation. Parallelization is possible if your license and hardware allow it.

The **Parallelization Options** dialog opens when clicking the **Edit** button and you can choose between **Sequential**, **Parallel (Shared Memory)**, or **Automatic Maximum of Threads**.

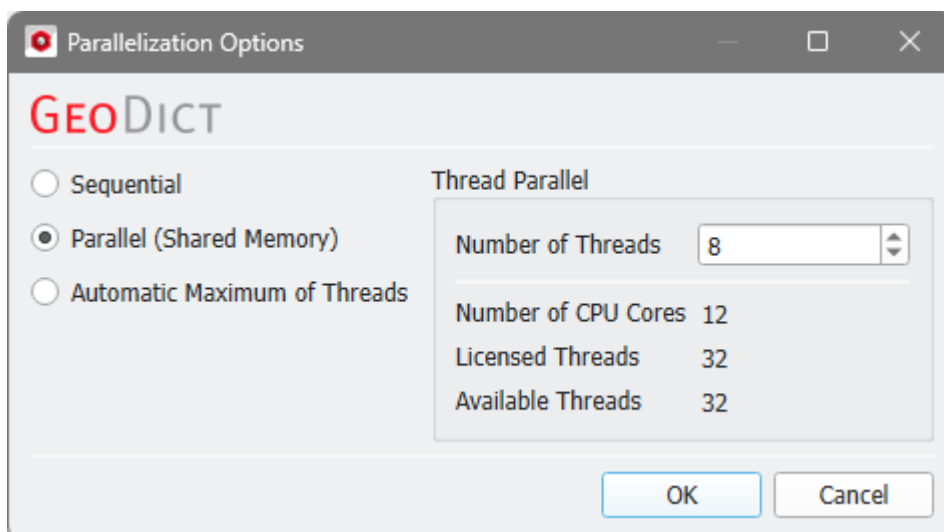
Parallelization 12 Threads (Automatic Maximum)

Edit...

Selecting **Sequential** will not apply parallelization and only one thread is used for the computation.



When **Parallel (Shared Memory)** is selected, the **Number of Threads** can be entered. Below, the **Number of CPU Cores** that the current machine has, the maximum number of **Licensed Threads** and the number of those licensed threads that are available (**Available Threads**) are shown in the dialog. Of course, the maximal number of parallel processes you can use, is the smallest of those three numbers.



If **Automatic Maximum of Threads** is selected, the number of parallel processes is automatically selected for optimal speed, based on the CPU cores and licensed parallel processes.

Parallelization Options

GEO

DICT

☐ Sequential
 ☐ Parallel (Shared Memory)
 ☒ Automatic Maximum of Threads

Automatic Local Maximum

Automatic Number of Threads	12
Number of CPU Cores	12
Licensed Threads	32
Available Threads	32

OK

Cancel

The **Automatic Local Maximum** of processes is automatically selected, which is the minimum of **Number of CPU Cores**, **Licensed Threads**, and **Available Threads**.

Domain Boundary Conditions

The **Domain Boundary Conditions** can be chosen to be **Symmetric**, **Periodic**, **Encase**, or any combinations of those boundary conditions in all three directions with the choice of **Expert**.

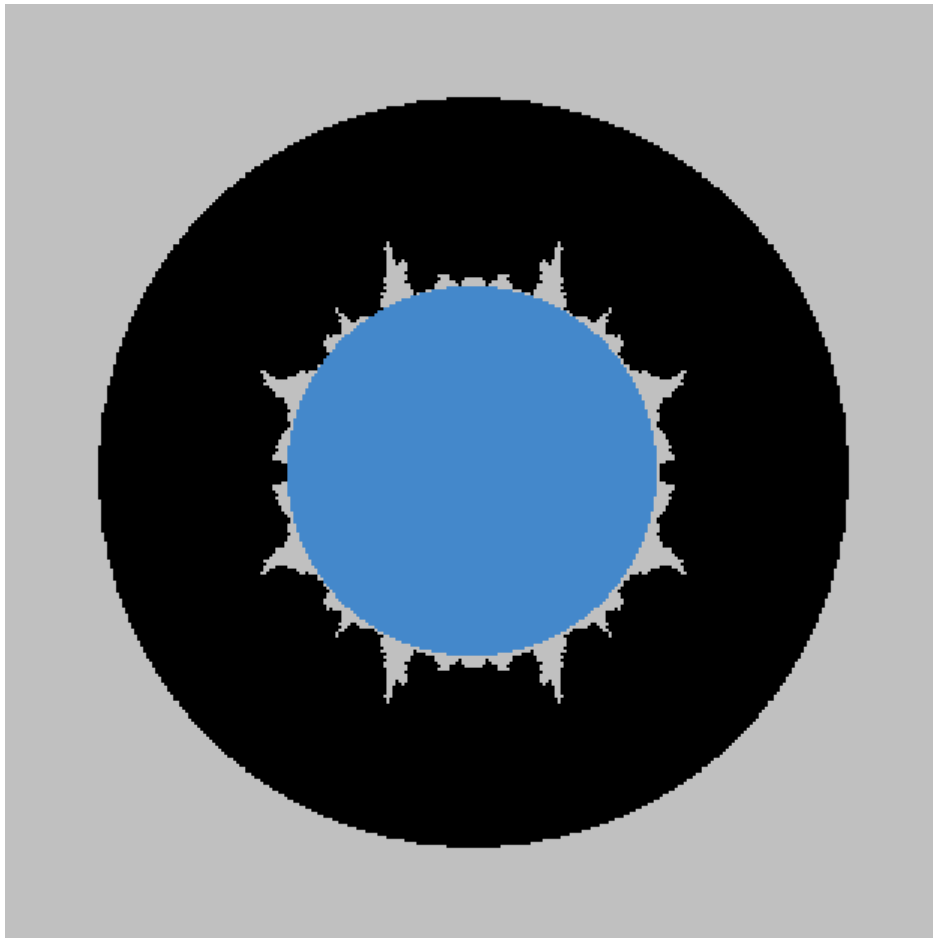
Choosing the appropriate boundary condition depends on the structure's design.

For example, imagine a structure with a cross-section as shown below.

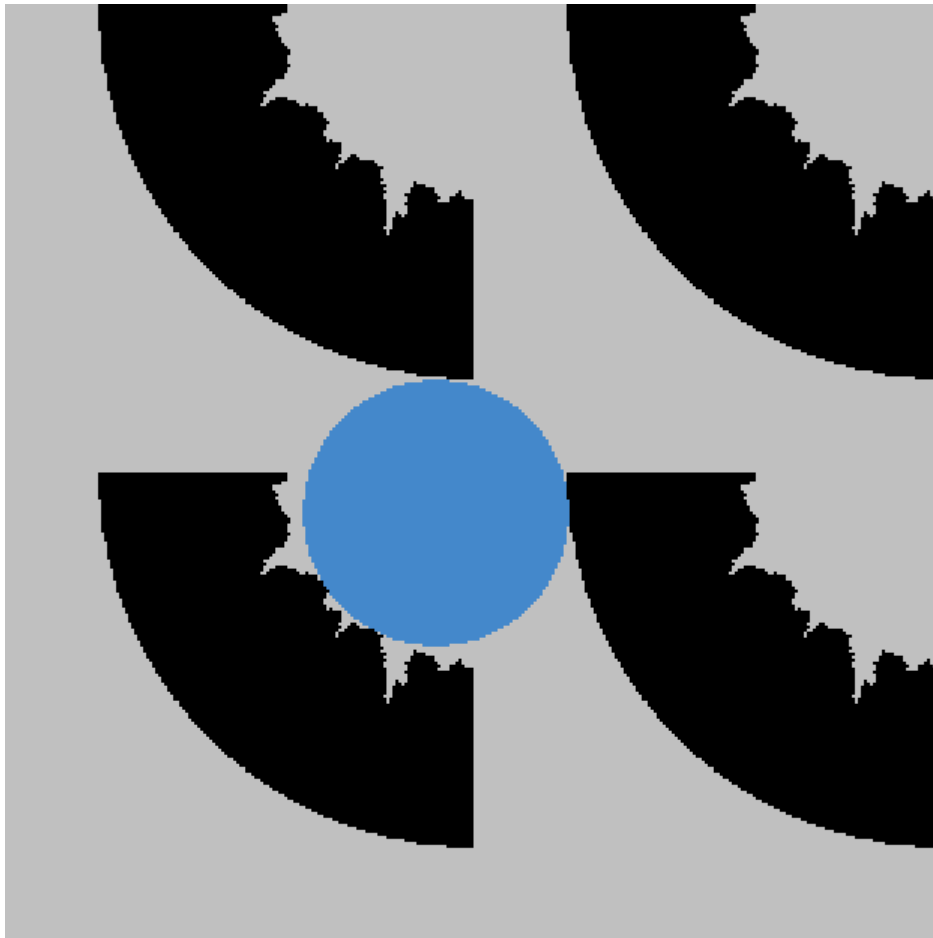


For the three boundary condition options the resulting solid size is visualized in blue.

- If **Symmetric** boundary conditions are taken, the geometry is mirrored at the domain boundary.



- If instead the expected pattern of the geometry is repeated in all directions, **Periodic** boundary conditions should be selected. That has the effect that the objects and pores of the structure that end on one side of the structure reappear on the opposite side.



- If the structure should be encased with a closed wall, the **Encase** boundary conditions are used.



Check **Expert** to apply different boundary conditions for each direction. You can combine the three above mentioned boundary conditions independently for the directions. For example, the boundary conditions could be chosen to be Encase in X-direction, Symmetric in the Y-direction and Periodic in Z-direction.

Domain Boundary Conditions

☐ Symmetric
☐ Periodic
☐ Encase
☒ Expert

Expert Settings

X
Encase
Y
Symmetric
Z
Periodic

✓ Write Pore Geometries as *.gdt Files

When **Write Pore Geometries as *.gdt Files** is checked, files in *.gdt format are saved in the automatically created results folder inside the project folder. The amount of these *.gdt files reflects the number of pore size steps and depends on the entered **Bin Size**. A large bin size results in fewer size steps, and thus, fewer *.gdt files are saved for the visualization. For each bin, a separate *.gdt file is written, where every voxel of the pore space is assigned to one of the specified materials.

☒ Write Pore Geometries as *.gdt Files

Fluid in Pores < Pore Diameter
Air [Small Pores]...

Fluid in Pores >= Pore Diameter
Water [Large Pores]...

In the *.gdt file of a certain bin, a voxel is assigned to the first material if it belongs to a lower bin number, i.e., the corresponding pore diameter is smaller. Consequently, all voxels from a bin with the same or higher number are assigned to the second material. This results in two different Material IDs for the voxels in the pore space. The materials written into these *.gdt files can be specified after checking **Write Pore Geometries as *.gdt Files**. For example, predefined materials of the **Material Database**, such as Air or Water can be chosen by clicking on the buttons. The current Material IDs for the fluids in the pores are shown at the bottom.

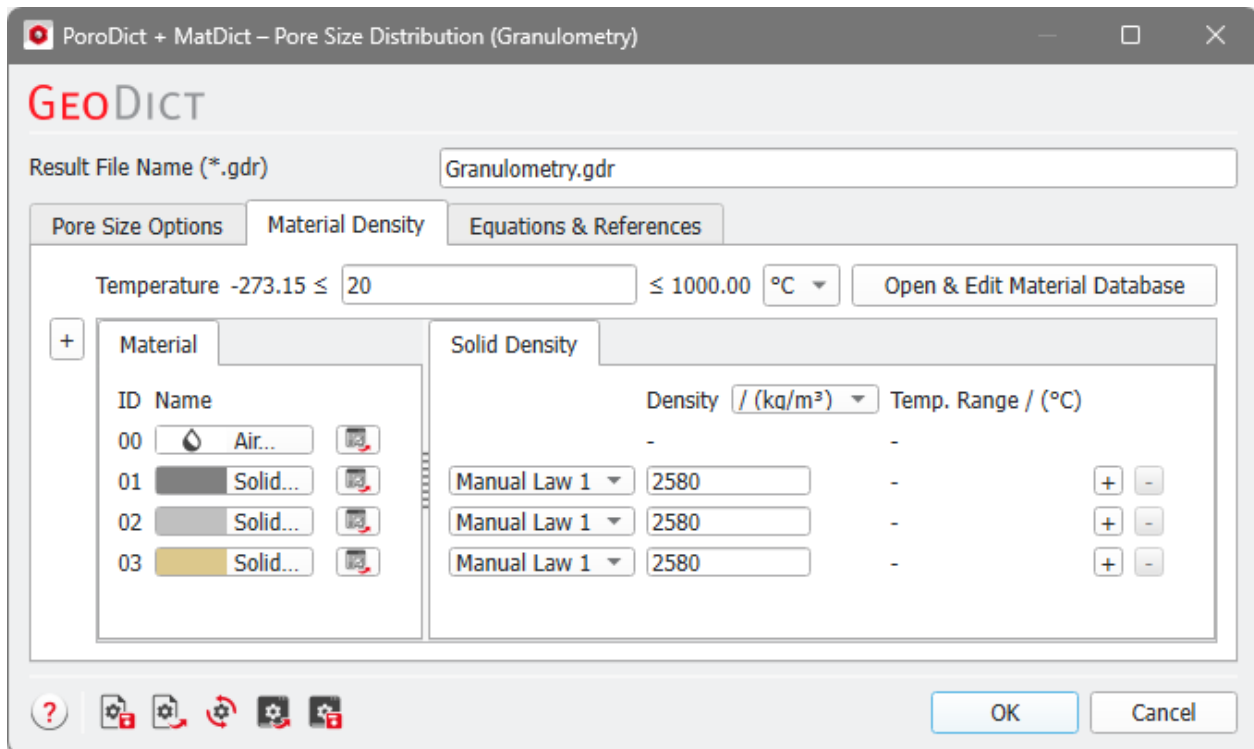
You can load these structure files into GeoDict from the [Pore Size Visualization](#)³⁴ tab in the Result Viewer.

✓ Write Pore Size Distribution as *.gsd File

Additionally, when **Write Pore Size Distribution as *.gsd File** is checked, a file with the default name PoreSizeDistribution.gsd, in *.gsd (**GeoDict Size Distribution**) format, is saved in the results folder inside the project folder. The file contains the pore size (diameter of sphere) of each voxel written into a volume field that can be loaded from the [Pore Size Visualization](#)³⁵ tab of the Result Viewer.

Material Density

Under the **Material Density** tab, the temperature can be edited if the density of a material is temperature dependent. Additionally, the density of every solid material in the structure must be specified in this tab. The density can be given in kg/m³ or g/cm³. For materials from the GeoDict Material Database, the density value is entered automatically. If a material is set to **Manual**, the Material Law changes to **Manual Law** and more laws can be added or deleted by clicking the "+" or "-" button on the right of the corresponding row. You can enter the density for manual materials directly in this tab.



1.2.2 Results

After the **Pore Size Distribution (Granulometry)** calculation is finished, the resulting files are saved in the project folder and a Result Viewer with the GeoDict result file opens automatically. The created GeoDict result file (*.gdr) contains six tabs. The computational results are shown under the **Results** tab, and can be loaded for visualization via the **Pore Size Visualization** tab. The other four tabs (**Input Map**, **Log Map**, **Post Map**, and **Metadata**) display additional information about the computation.

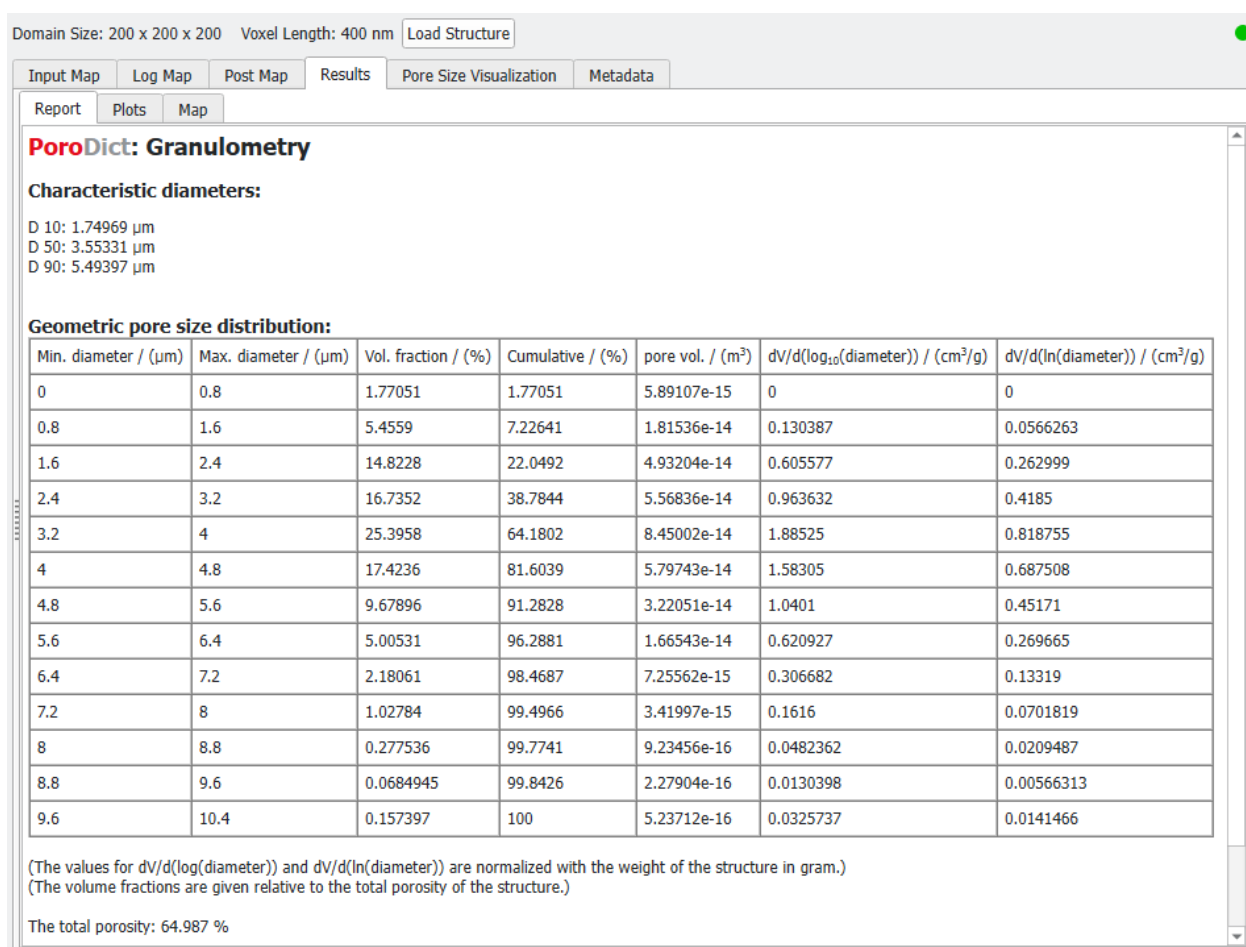
Find more details on the general functionalities in the Result Viewer user guide.

Pore Size Distribution (Granulometry) Results:

- [Report](#)^[32]
See the computed results.
- [Plots](#)^[33]
View result plots.
- [Pore Size Visualization](#)^[34]
Load results for a graphical visualization.

Report

Under the **Report** tab, first the **Characteristic diameters** D10, D50, and D90 are shown. These three numbers are the most common “summary” points of a pore-size distribution as they provide a quick, intuitive snapshot of the pore-size distribution. They originate from the [cumulative pore-size histogram](#)^[34]. These are the diameters such that 10%, 50%, or 90% of the pore volume has a smaller diameter than the corresponding value, respectively. In this example, the D10 value of 1.75 μm means that 10% of all pores have a diameter smaller than 1.75 μm . The D50 value means that 50% of all pores have a diameter smaller than 3.55 μm . The D90 value means that 90% of all pores have a diameter smaller than 5.49 μm . The discretization error is less than 1 voxel, which means for the presented example, that the D10 is 1.75 $\mu\text{m} \pm 0.4 \mu\text{m}$.



Below the characteristic diameters, the **Geometric pore size distribution** table contains **Minimum** and **Maximum Diameters**, **Volume Fraction**, **Cumulative Volume Fraction**, **Pore Volume**, and the **Differential Pore Volume Distribution** for every bin. Also, at the bottom, the total porosity of the structure is shown.

The **Volume Fraction** of the pore voxels in each bin and the **Cumulative Volume Fraction** (starting with the smallest pore diameters) based on the total pore volume of the structure are shown. For each bin, the **Pore Volume** in m^3 is computed as the summarized volume of the voxels that belong to this bin.

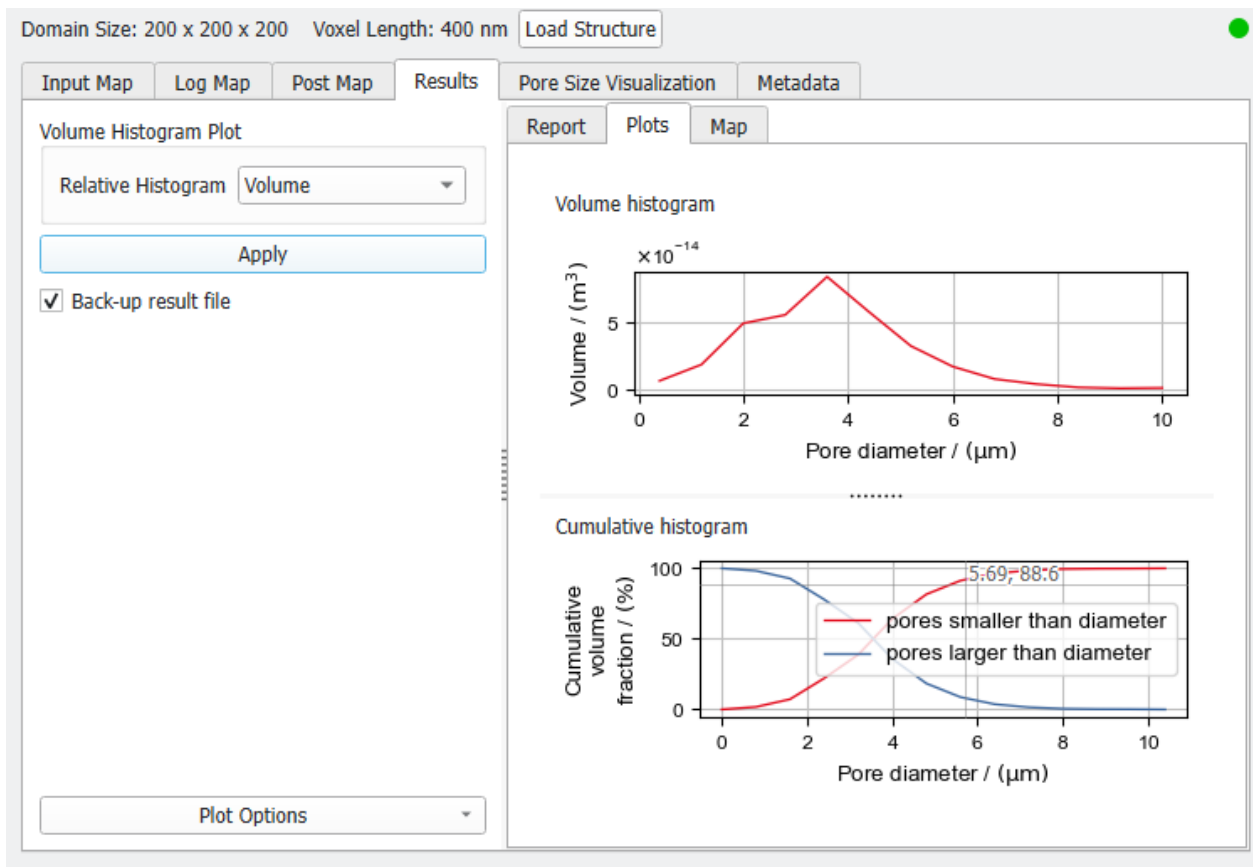
The **Differential Pore Volume** $dV/d(\log(\text{Diameter}))$ for each bin is computed, where both the common logarithm ($\log_{10}$) and the natural logarithm ($\ln$) are shown. The differential pore volume distribution is then computed as:

$$\frac{dV}{d(\log(\text{Diameter}))} = \frac{V_{cum}(d_{i+1}) - V_{cum}(d_i)}{(\log(d_{i+1}) - \log(d_i)) \cdot m} \quad (5) \text{ Differential Pore Volume}$$

with d_i the pore diameter of the i -th bin, V_{cum} the cumulative volume fractions, and m the mass of the pores. The latter is computed using the densities of the constituent materials of the sample entered in the Material Density tab. This normalization ensures that the value of the differential pore volume is independent of the domain size.

Plots

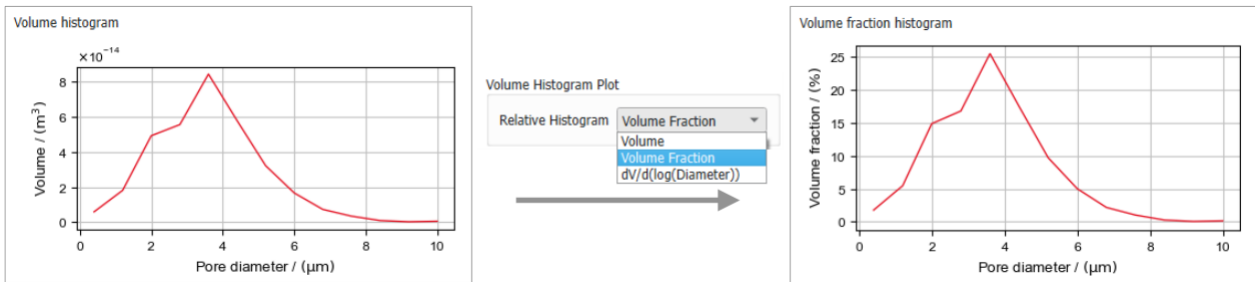
Under the **Results – Plots** subtab, a relative and a cumulative histogram is plotted.



Relative Pore Size Histogram

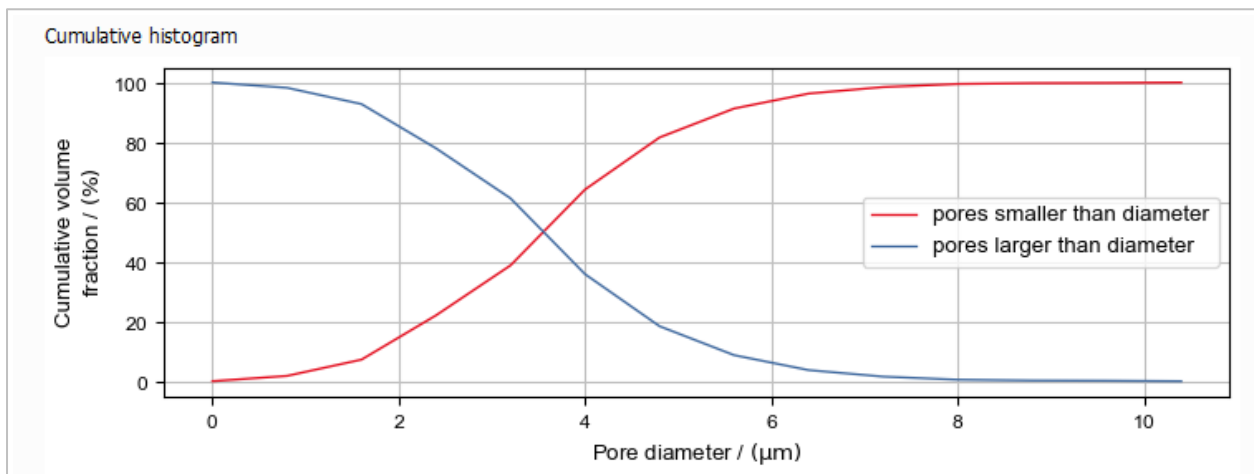
The content of the relative histogram is defined by the selection in the **Volume Histogram Plot** section of the Post-Processing panel on the left of the Result Viewer. The pore diameter is plotted either against the Volume, Volume Fraction, or the differential pore volume (

$dV/d(\log(\text{Diameter}))$). After choosing the histogram and clicking **Apply...**, the plots change accordingly.



Cumulative Pore Size Histogram

In the **Cumulative Histogram** plot, the red curve shows the volume fraction of pores smaller than a given diameter and the blue curve shows the volume fraction of pores larger than or equal to a given diameter. Both curves sum up to 100% for any given diameter.

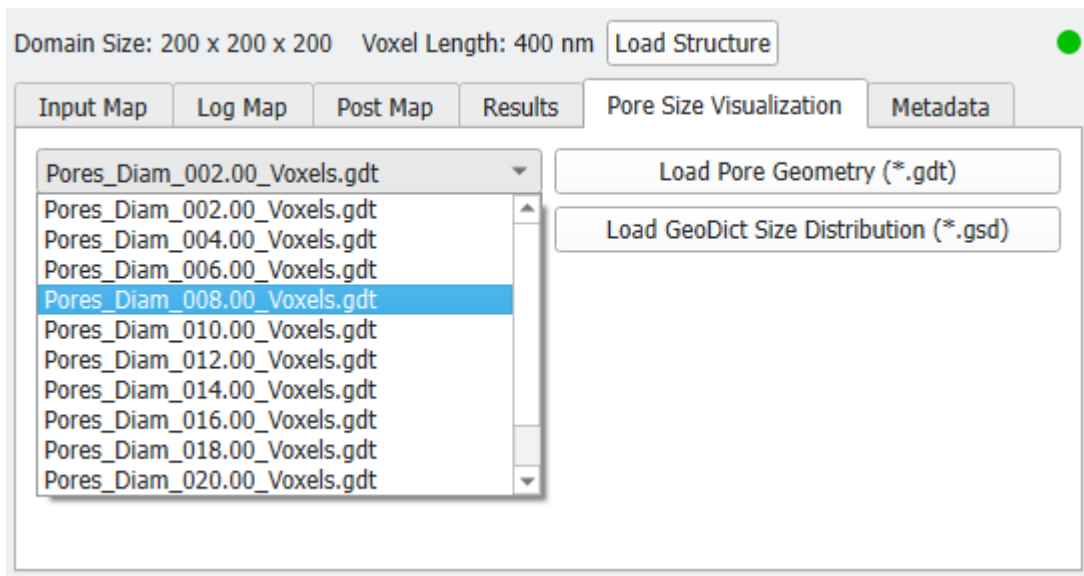


Pore Size Visualization

Depending on the choices in the settings dialog the size distribution of pores can also be visualized through the **Pore Size Visualization** tab.

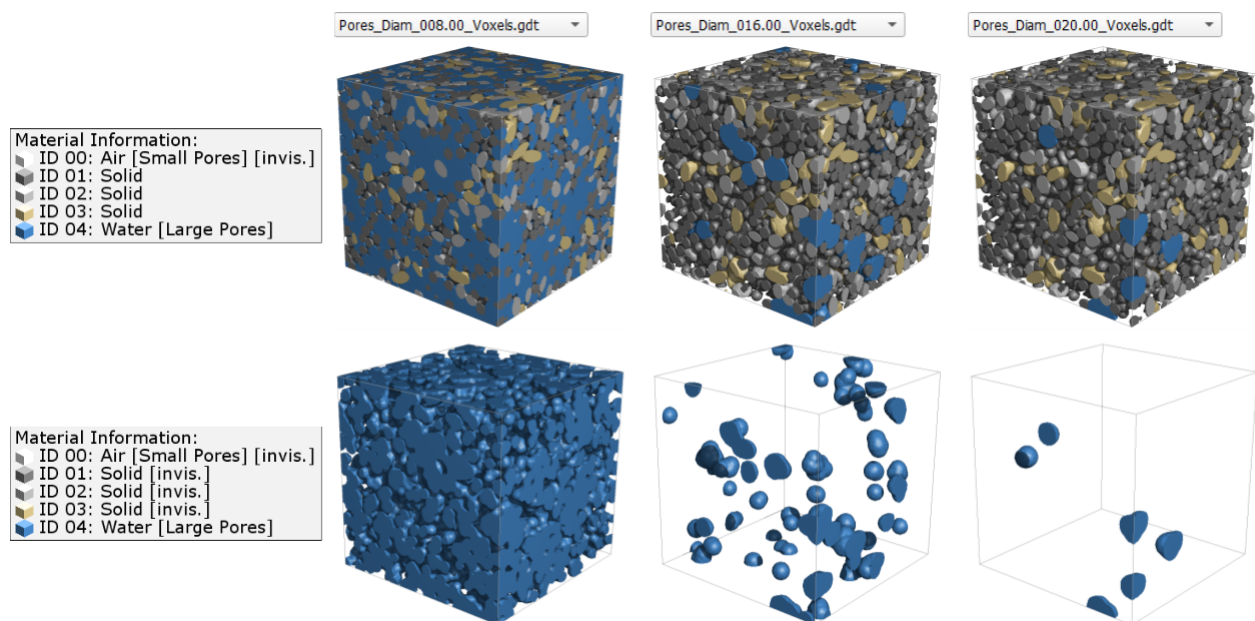
Pore Geometries as *.gdt Files

If [Write Pore Geometries as *.gdt Files](#)  was checked, you can load a structure for each bin into the visualization area. Select the *.gdt file corresponding to a particular pore diameter from the drop down menu and then click **Load Pore Geometry (*.gdt)**.



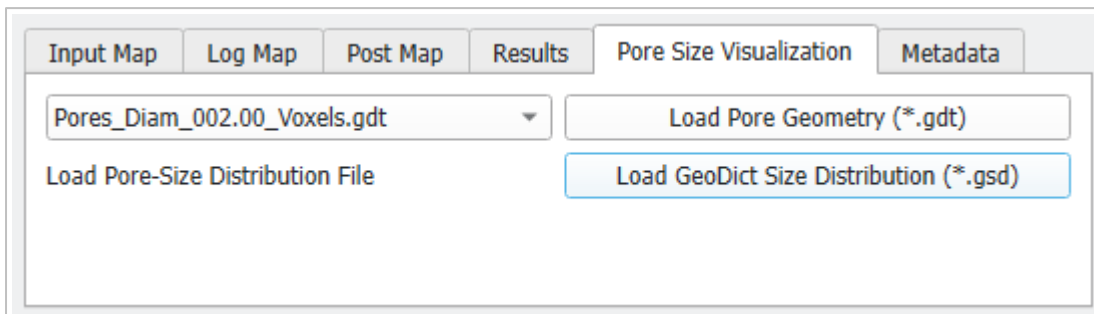
In this example, a bin size of 2 voxels (800 nm) was chosen. The **Pores_Diam_008.00_Voxels.gdt** file shows the pore space separated into two Material IDs. Pore voxels which belong to pores with a diameter of 8 voxels (or more) are assigned to Material ID 04 (blue), while the pore voxels of smaller pores are assigned to ID 00 (invisible). The **Pores_Diam_016.00_Voxels.gdt** file shows the more limited pore space in which spheres with a (larger) diameter of at least 16 voxels would fit. The **Pores_Diam_020.00_Voxels.gdt** file shows that in this structure, the pore space in which spheres with diameter over 20 voxels can fit is very small.

Check or un-check **visible** in **Settings** → **Color & Visibility Settings**, to turn off the visibility of the solid materials in the structure (Material ID 01, Material ID 02, and Material ID 03) and see only the pore space filled with water (Material ID 04).

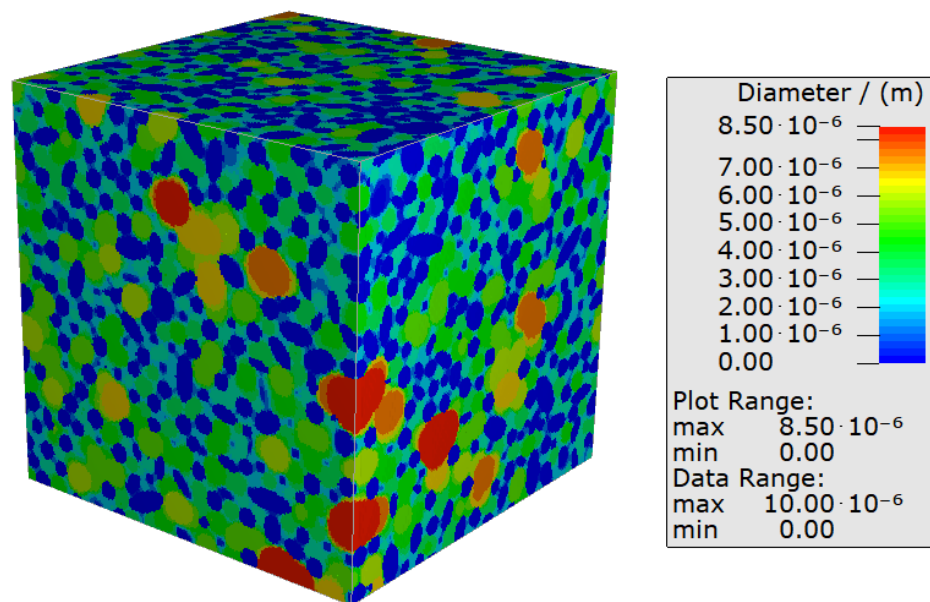


Pore Size Distribution

If [Write Pore Size Distribution as *.gsd File](#)  was checked, you can click on **Load GeoDict Size Distribution (*.gsd)** to load a volume field containing the pore diameters.



The value at each voxel is the diameter of the largest sphere, that contains this voxel and fits inside the pore space. Thus, the diameter for the solid materials is zero (dark blue in the picture below). Comparing the volume field shown below with the pores, that have a diameter of 20 voxels or more, you can see that these pores have a red color in the volume field plot.

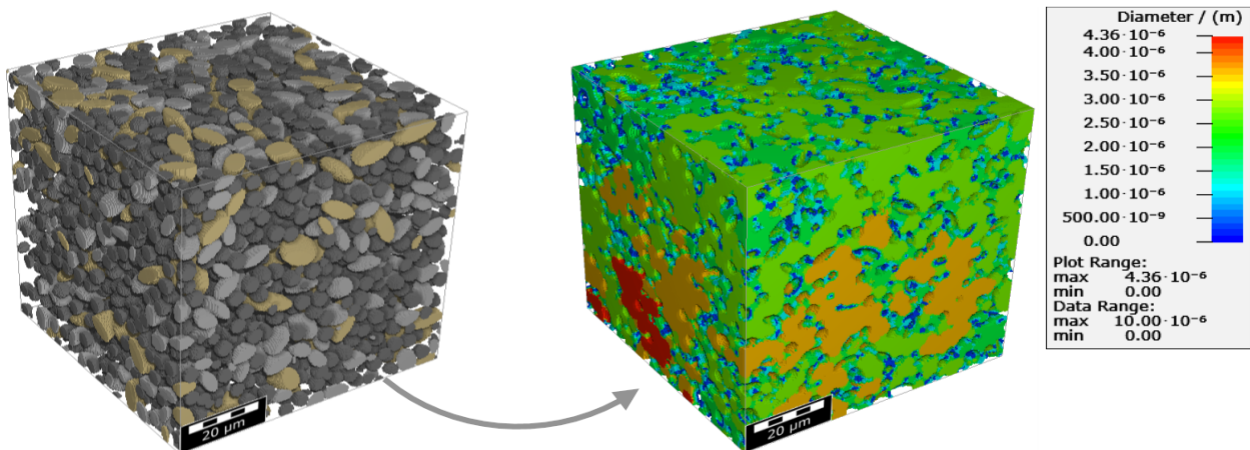


1.3 Pore Size Distribution (Porosimetry)

In **Pore Size Distribution (Porosimetry)** measurements, such as Mercury Intrusion Porosimetry (MIP) or Liquid Extrusion Porosimetry (LEP), the pore sizes of a medium are measured by pressing a non-wetting liquid or gas into it and registering the applied pressure and absorbed volume. The pressure applied is related to the radius of the pores accessible to the non-wetting liquid, which gives a size distribution of the pores. Closed pores do not contribute to the pore volume at all, while other pores only contribute to the pore volume fraction if they are connected to the non-wetting phase reservoir (e.g., the mercury reservoir). Find more details about the theory behind the **Porosimetry** in the [Theoretical Basics](#)^[8] section.

The parameters of Porosimetry are similar to those of [Pore Size Distribution \(Granulometry\)](#)^[23] but fewer large pores are found by Porosimetry than by Granulometry. The reason for this is that a big pore in the interior of the volume must be reached from the intrusion sides, usually through a small diameter pore-throat. The big pore is counted as pore volume of a certain diameter only if a sphere with this diameter can be pushed from the intrusion side through the pore-throat to reach the big pore. In other words, porosimetry provides a measure of the pore-throat size distribution.

The **Pore Size Distribution (Porosimetry)** dialog opens when clicking the **Edit...** button.



On the right, the volume field (*.gsd) showing the diameter for each pore voxel is visualized. The non-wetting fluid is injected from the bottom.

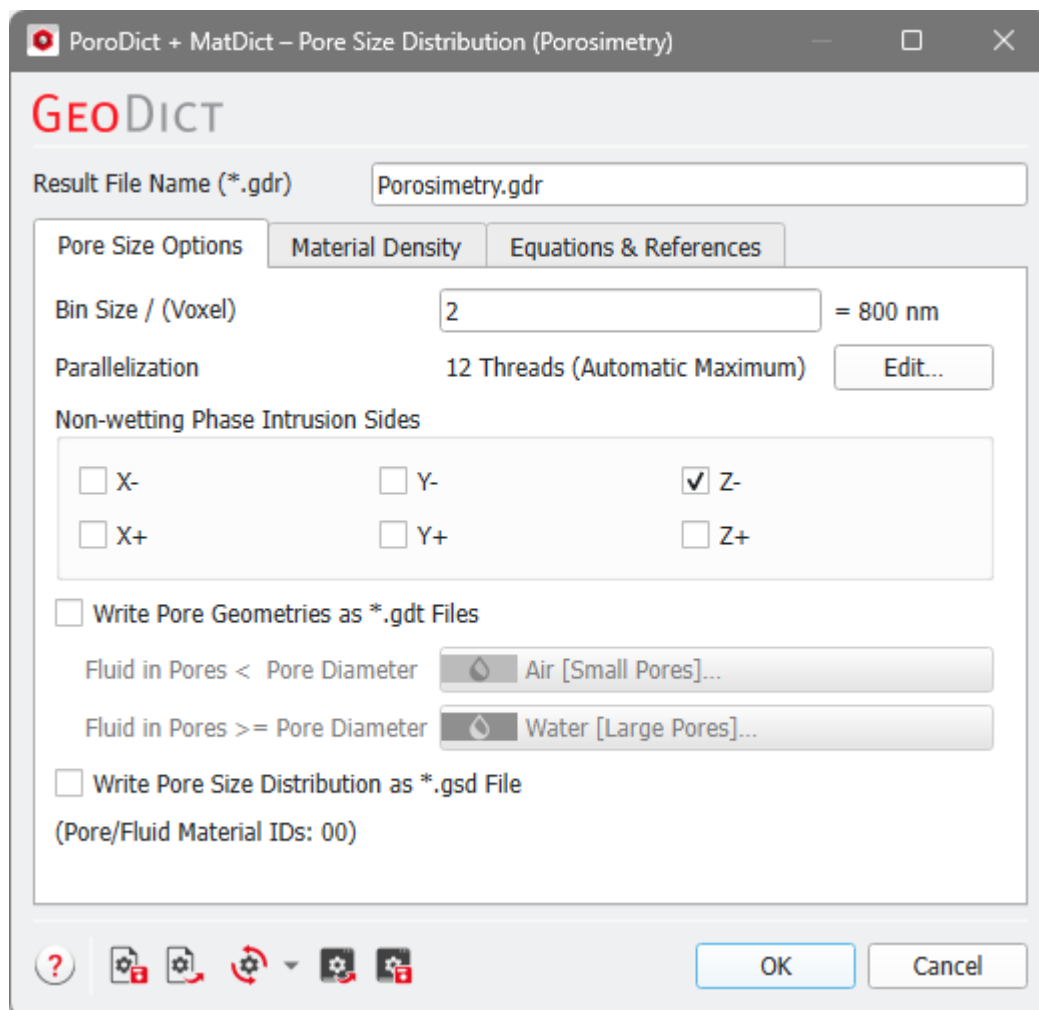
The Pore Size Distribution (Porosimetry) command:

- [Options](#)^[37]
Set the parameters for the analysis.
- [Results](#)^[43]
View the computed results.

1.3.1 Options

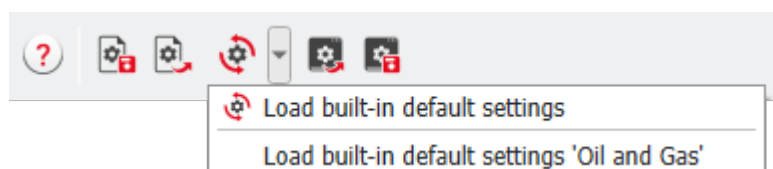
The parameters are organized into the **Pore Size Options** tab, the **Material Density** tab, and the **Equations & References** tab, which cites several [references](#)^[151].

At the top of the dialog, enter the **Result File Name**. The result file is saved in the chosen project folder (**File** → **Choose Project Folder** in the menu bar).



The built-in default icon comes with a selection of different presets. Clicking on the little arrow shows several additional preset options.

The usual built-in default settings will load the settings according to the current GeoDict edition. You can change the current GeoDict edition from the **Settings menu** as described in the Graphical User Interface chapter.



In **Porodict - Porosimetry** find edition-specific presets for the **Standard Edition** and the **Oil and Gas Edition**.

In the Oil and Gas edition, all domain sides are set as **Intrusion Side** and the default material to fill the large pores (done if [Write Pore Geometries as *.gdt Files](#)⁴² is checked) is set to **Mercury**.

Non-wetting Phase Intrusion Sides

☒ X-
☒ Y-
☒ Z-

☒ X+
☒ Y+
☒ Z+

☐ Write Pore Geometries as *.gdt Files

Fluid in Pores < Pore Diameter

 Air [Small Pores]...

Fluid in Pores >= Pore Diameter

 Mercury [Large Pores]...

Pore Size Options

Bin Size

Enter the **Bin Size** in units of voxels. The equivalent in metric length units is shown on the right. The bin size determines the range of diameters that belong to one class of solid sizes.

All bins have equal bin size. Beginning with the largest possible diameter that is divisible by the bin size, the diameter is reduced by the bin size in each step. Every voxel is then assigned the diameter of the largest possible sphere that can be fitted in the solid and contains this voxel. Thus, each bin contains solid voxels with an assigned diameter in the range comprised between $[(i - 1) \cdot \text{bin size}]$ and $[i \cdot \text{bin size}]$, where i is the bin number.

For example, when analyzing a porous structure with a voxel size of 1 μm , you can set the bin size to 2 or to 4 (voxels) which would come to classify the solid by their diameter in ranges of 2 μm or 4 μm , and would result in the following bins:

Bin number (i)	Pore diameter between $[(i - 1) \cdot \text{bin size}] - [i \cdot \text{bin size}]$	
	Bin Size 2 μm	Bin Size 4 μm
1	0 μm - 2 μm	0 μm - 4 μm
2	2 μm - 4 μm	4 μm - 8 μm
3	4 μm - 6 μm	8 μm - 12 μm
..	...	...

When choosing the bin size, be aware that the underlying algorithm to compute the Euclidean distance operates directly on the voxel grid. Thus, the smallest possible distance between two grid points is 1 voxel, which corresponds to a radius of 1 voxel.

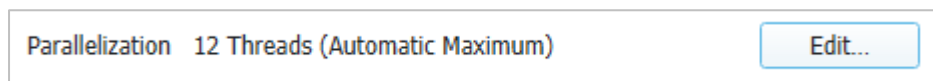
This means the smallest diameter that the algorithm will find is 2 voxels. In general, the error made when computing the solid size distribution is of the same order of magnitude as the discretization error of the structure, i.e., 1 voxel.

In the result viewer, for each bin the **Minimal Diameter**, which is the diameter of the smaller sphere, and the **Maximal Diameter**, which is the diameter of the larger sphere, are given. This means all solid voxels in that bin have a diameter that is larger than the minimal diameter and smaller or equal than the maximal diameter.

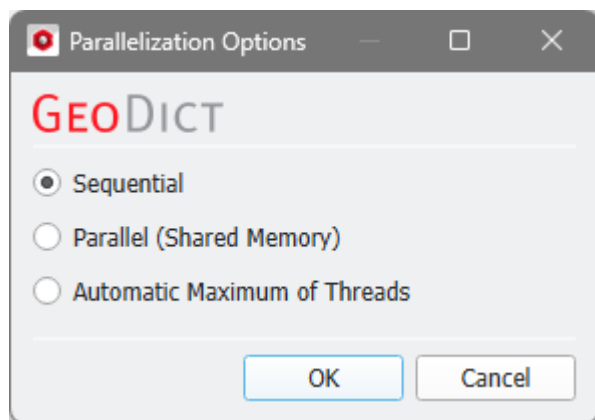
✓ Parallelization

Control how many threads are used for the computation. Parallelization is possible if your license and hardware allow it.

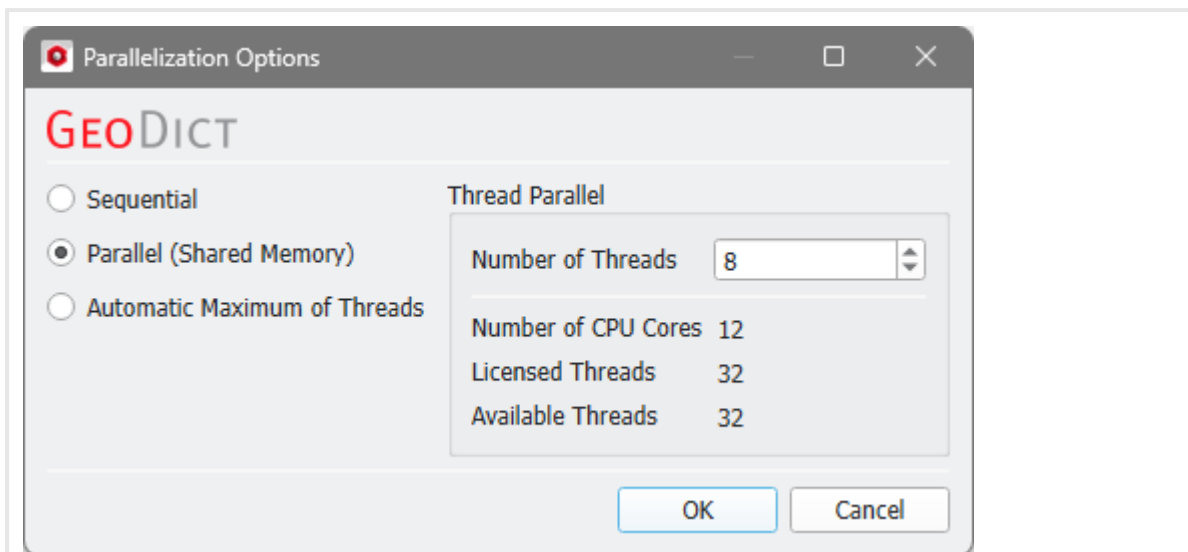
The **Parallelization Options** dialog opens when clicking the **Edit** button and you can choose between **Sequential**, **Parallel (Shared Memory)**, or **Automatic Maximum of Threads**.



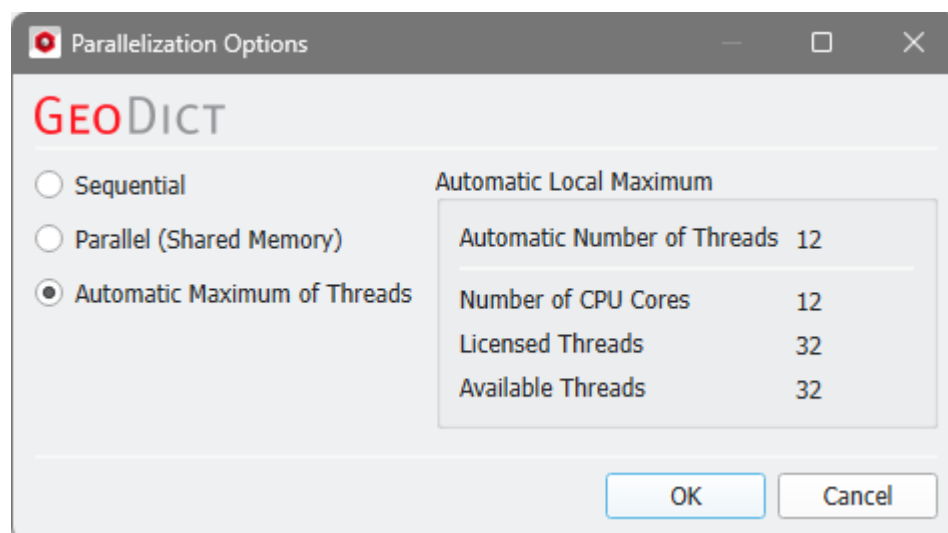
Selecting **Sequential** will not apply parallelization and only one thread is used for the computation.



When **Parallel (Shared Memory)** is selected, the **Number of Threads** can be entered. Below, the **Number of CPU Cores** that the current machine has, the maximum number of **Licensed Threads** and the number of those licensed threads that are available (**Available Threads**) are shown in the dialog. Of course, the maximal number of parallel processes you can use, is the smallest of those three numbers.



If **Automatic Maximum of Threads** is selected, the number of parallel processes is automatically selected for optimal speed, based on the CPU cores and licensed parallel processes.



The **Automatic Local Maximum** of processes is automatically selected, which is the minimum of **Number of CPU Cores**, **Licensed Threads**, and **Available Threads**.

Have a look into our [benchmark case](#)^[21] where we show how the computation speeds-up with an increasing number of parallel processes.

✓ Non-wetting Phase Intrusion Sides

Choose the direction (or multiple directions) from which the fluid intrudes the structure during the simulation.

Non-wetting Phase Intrusion Sides

☐ X- ☐ Y- ☒ Z-

☐ X+ ☐ Y+ ☐ Z+

✓ Write Pore Geometries as *.gdt Files

When **Write Pore Geometries as *.gdt Files** is checked, files in *.gdt format are saved in the automatically created results folder inside the project folder. The amount of these *.gdt files reflects the number of pore size steps and depends on the entered **Bin Size**. A large bin size results in fewer size steps, and thus, fewer *.gdt files are saved for the visualization. For each bin, a separate *.gdt file is written, where every voxel of the pore space is assigned to one of the specified materials.

☒ Write Pore Geometries as *.gdt Files

Fluid in Pores < Pore Diameter  Air [Small Pores]...

Fluid in Pores >= Pore Diameter  Water [Large Pores]...

In the *.gdt file of a certain bin, a voxel is assigned to the first material if it belongs to a lower bin number, i.e., the corresponding pore diameter is smaller. Consequently, all voxels from a bin with the same or higher number are assigned to the second material. This results in two different Material IDs for the voxels in the pore space. The materials written into these *.gdt files can be specified after checking **Write Pore Geometries as *.gdt Files**. For example, predefined materials of the **Material Database**, such as Air or Water can be chosen by clicking on the buttons. The current Material IDs for the fluids in the pores are shown at the bottom.

You can load these structure files into GeoDict from the [Pore Size Visualization](#)⁴⁷ tab in the Result Viewer.

✓ Write Pore Size Distribution as *.gsd File

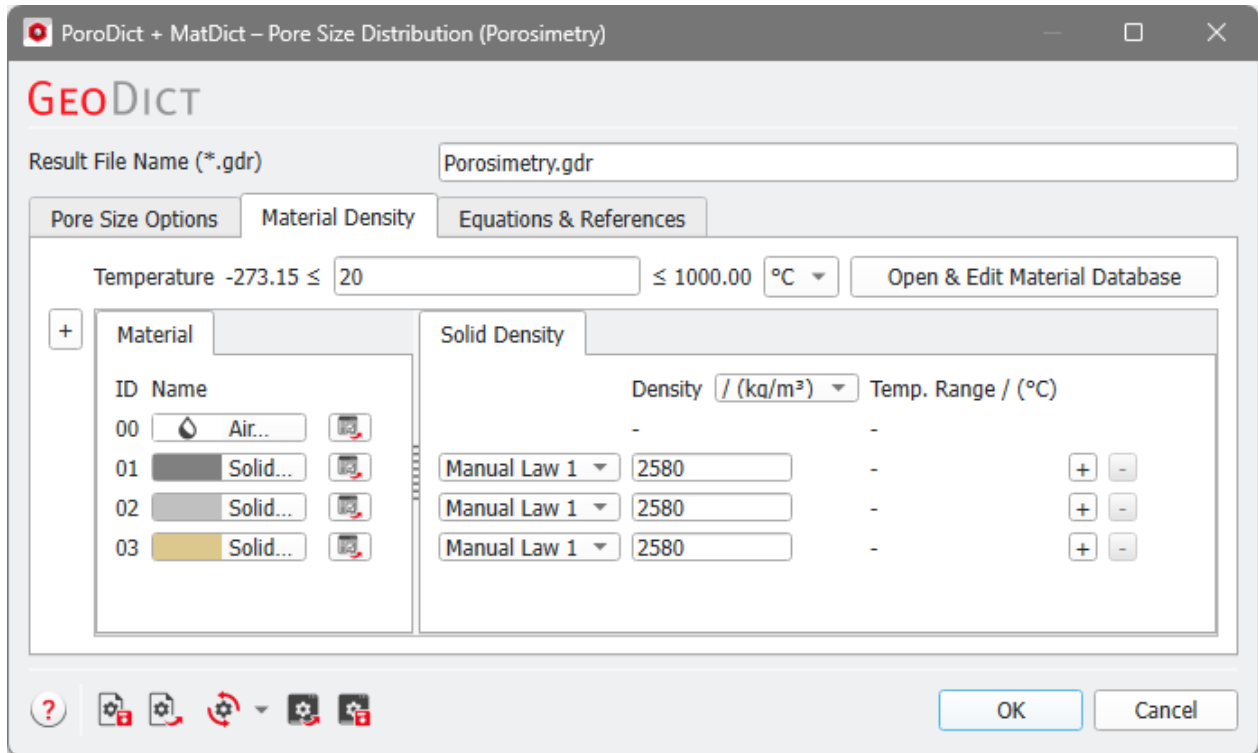
Additionally, when **Write Pore Size Distribution as *.gsd File** is checked, a file with the default name PoreSizeDistribution.gsd, in *.gsd (**GeoDict Size Distribution**) format, is saved in the results folder inside the project folder. The file contains the pore size (diameter of sphere) of each voxel written into a volume field that can be loaded from the [Pore Size Visualization](#)⁴⁸ tab of the Result Viewer.

Material Density

Under the **Material Density** tab, the temperature can be edited if the density of a material is temperature dependent. Additionally, the density of every solid material in the structure must

be specified in this tab. The density can be given in kg/m^3 or g/cm^3 . For materials from the GeoDict Material Database, the density value is entered automatically. If a material is set to **Manual**, the Material Law changes to **Manual Law** and more laws can be added or deleted by clicking the "+" or "-" button on the right of the corresponding row. You can enter the density for manual materials directly in this tab.

The densities are needed to determine the mass of the structure for the computation of the [Differential Pore Volume Distribution](#)^[44].



1.3.2 Results

After the **Pore Size Distribution (Porosimetry)** calculation is finished, the resulting files are saved in the project folder and a Result Viewer with the GeoDict result file opens automatically. The created GeoDict result file (*.gdr) contains six tabs. The computational results are shown under the **Results** tab, and can be loaded for visualization via the **Pore Size Visualization** tab. The other four tabs (**Input Map**, **Log Map**, **Post Map**, and **Metadata**) display additional information about the computation.

Find more details on the general functionalities in the Result Viewer user guide.

The result file contains the same information and options as the [Pore Size Distribution \(Granulometry\) result file](#)^[31], except for the additional **Contact Angle** option in the [Volume Histogram Plot](#)^[46] panel. When the porosimetry is performed, a contact angle of 0° for the invading fluid is assumed for the computations. To meet the results of a real-life experiment, the contact angle can be adapted. If, e. g., a mercury intrusion should be simulated, a contact angle of 140° is typically chosen. If the contact angle was changed, the minimum and maximum pore diameters for both 0° contact angle and the chosen contact angle are shown in the table in the Report tab.

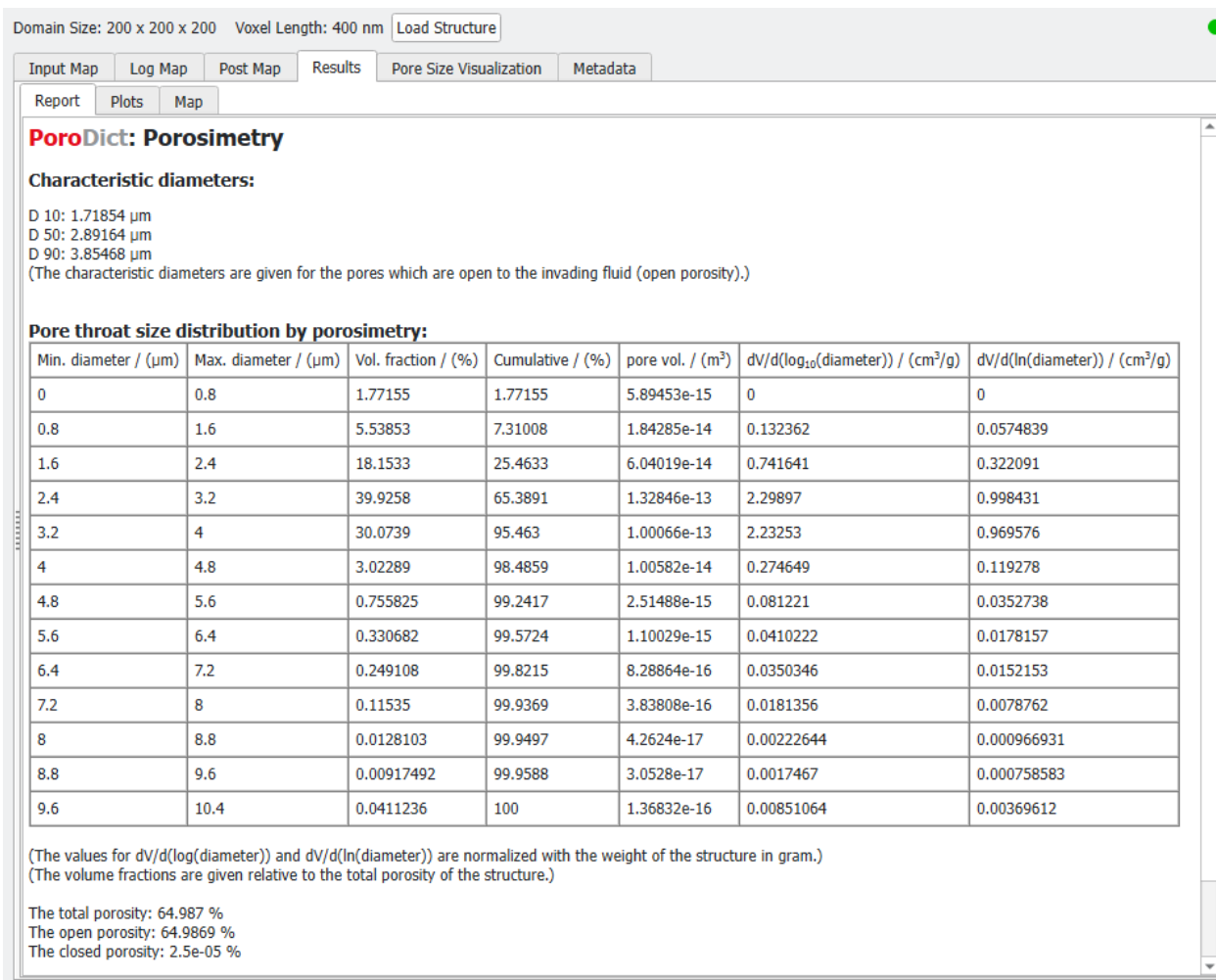
Pore Size Distribution (Porosimetry) Results:

- [Report](#)⁴⁴
See the computed results.
- [Plots](#)⁴⁶
View result plots.
- [Pore Size Visualization](#)⁴⁷
Load results for a graphical visualization.

Report

Under the **Report** tab, the **Characteristic diameters** D10, D50, and D90 are shown. These are the diameters such that 10%, 50%, or 90% of all pore throats have a smaller diameter than the corresponding value. See the explanations in the [Report](#)³² topic of Granulometry for more information.

In this example, the D10 value of 1.72 μm means that 10% of all pores have a diameter smaller than 1.72 μm . The D50 value means that 50% of all pores have a diameter smaller than 2.89 μm . The D90 value means that 90% of all pores have a diameter smaller than 3.85 μm . The discretization error is less than 1 voxel, which means for the presented example, that the D10 is 1.72 $\mu\text{m} \pm 0.4 \mu\text{m}$.



Underneath, a detailed table lists **Minimum** and **Maximum Diameters**, **Volume Fraction**, **Cumulative Volume Fraction**, **Pore Volume**, and the **Differential Pore Volume Distribution** for every bin. Also, at the bottom, the total porosity, the open porosity and the closed porosity of the structure is shown. The open porosity includes all pores that can be reached by the invading fluid, while the closed porosity denotes the non-reachable pores.

The **Volume Fraction** of the pore voxels in each bin and the **Cumulative Volume Fraction** (starting with the smallest pore diameters) based on the total pore volume of the structure are shown. For each bin, the **Pore Volume** in m^3 is computed as the summarized volume of the voxels that belong to this bin.

The **Differential Pore Volume** $dV/d(\log(\text{Diameter}))$ for each bin is computed, where both the common logarithm ($\log_{10}$) and the natural logarithm ($\ln$) are shown. The differential pore volume distribution is then computed as:

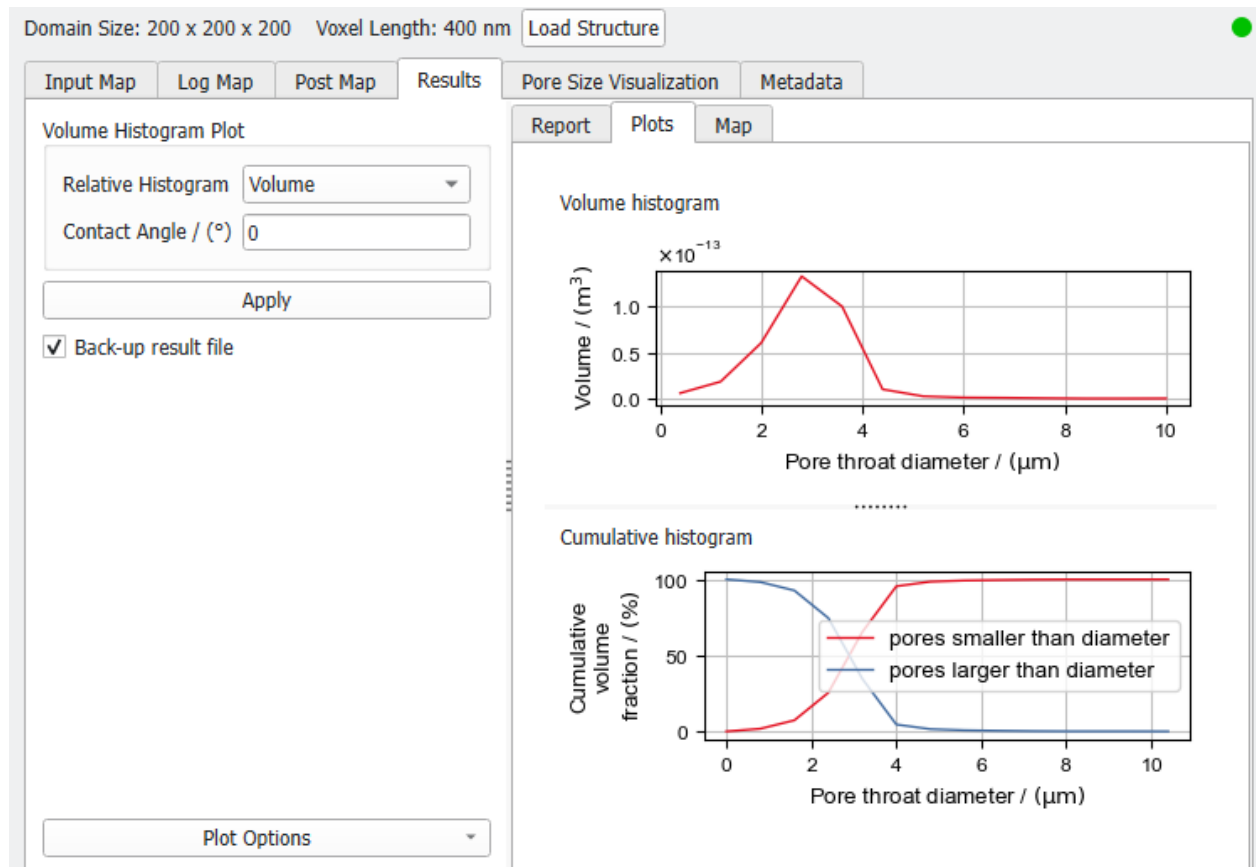
$$\frac{dV}{d(\log(\text{Diameter}))} = \frac{V_{cum}(d_{i+1}) - V_{cum}(d_i)}{(\log(d_{i+1}) - \log(d_i)) \cdot m} \quad (6) \text{ Differential Pore Volume}$$

with d_i the pore diameter of the i -th bin, V_{cum} the cumulative volume fractions, and m the mass of the pores. The latter is computed using the densities of the constituent materials of the

sample entered in the Material Density tab. This normalization ensures that the value of the differential pore volume is independent of the domain size.

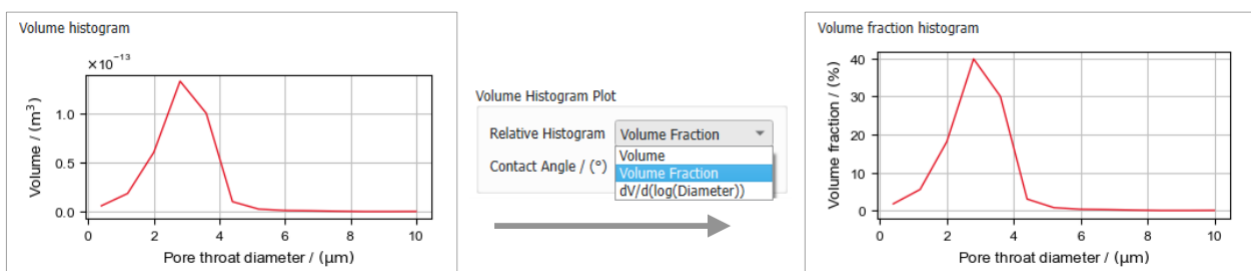
Plots

Under the **Results – Plots** subtab, a relative and a cumulative histogram is plotted.

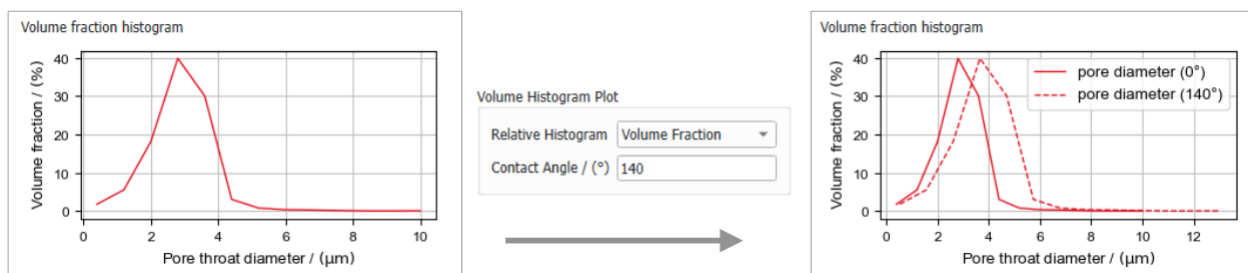


Relative Pore Size Histogram

The content of the relative histogram is defined by the selection in the **Volume Histogram Plot** section of the Post-Processing panel on the left of the Result Viewer. The pore diameter is plotted either against the Volume, Volume Fraction, or the differential pore volume ($dV/d(\log(\text{Diameter}))$). After choosing the histogram and clicking **Apply...**, the plots change accordingly.

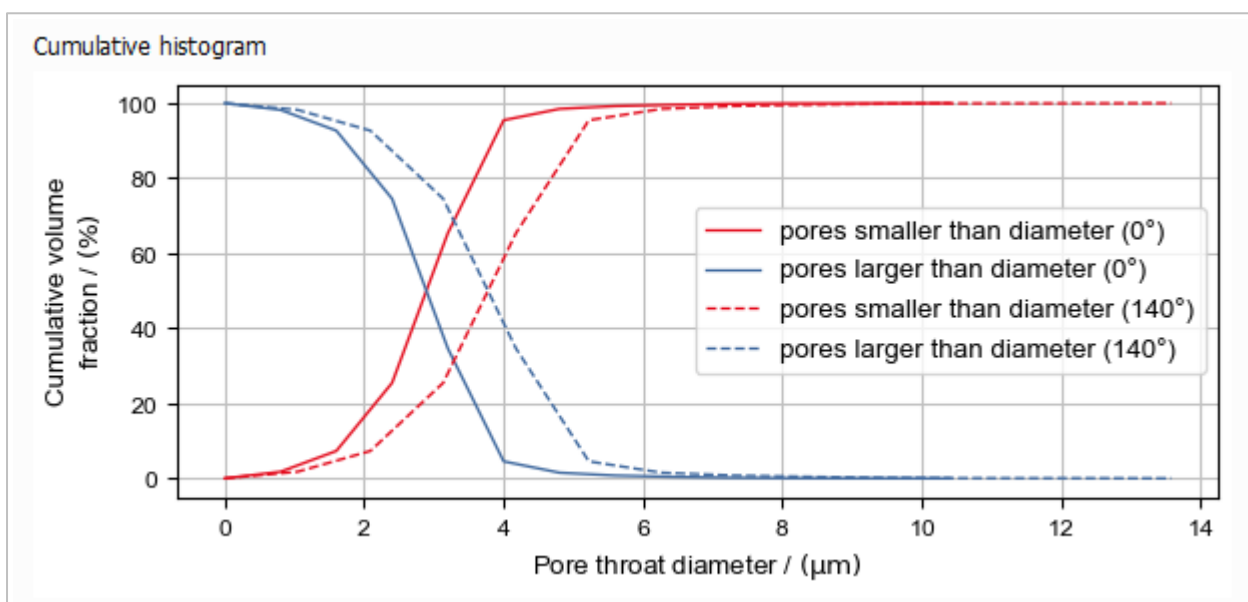


When changing the Contact Angle, the original values are scaled with $\cos(\text{Contact Angle})$ and the original graph is plotted along with the shifted graph.



Cumulative Pore Size Histogram

In the **Cumulative Histogram** plot, the red curve shows the volume fraction of pores smaller than a given diameter and the blue curve shows the volume fraction of pores larger than or equal to a given diameter. Both curves sum up to 100% for any given diameter. This curve is also updated when the contact angle is changed.

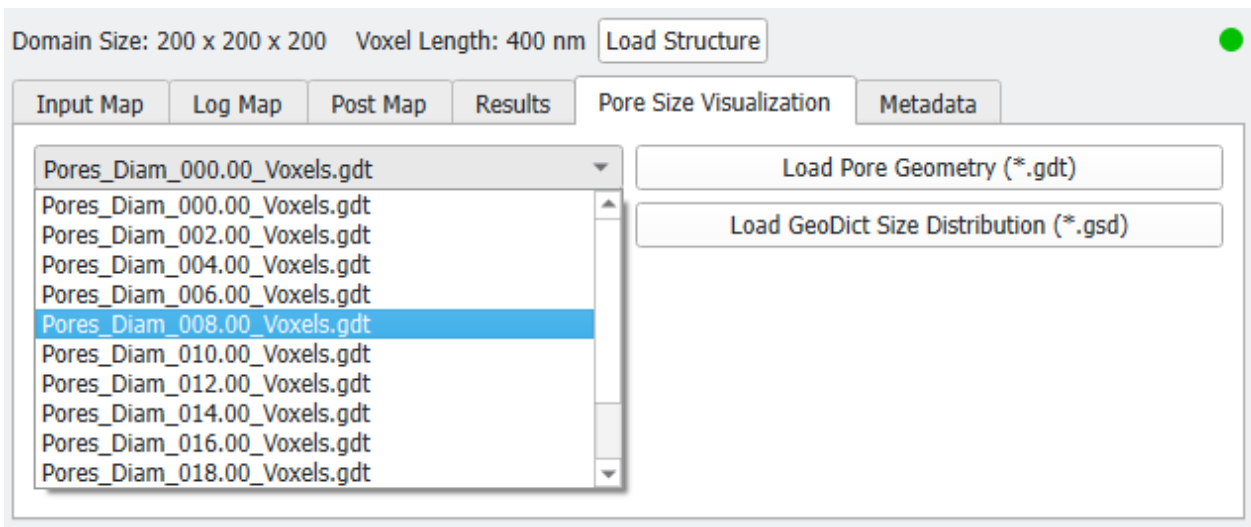


Pore Size Visualization

Depending on the choices in the settings dialog the size distribution of pores can also be visualized through the **Pore Size Visualization** tab.

Pore Geometries as *.gdt Files

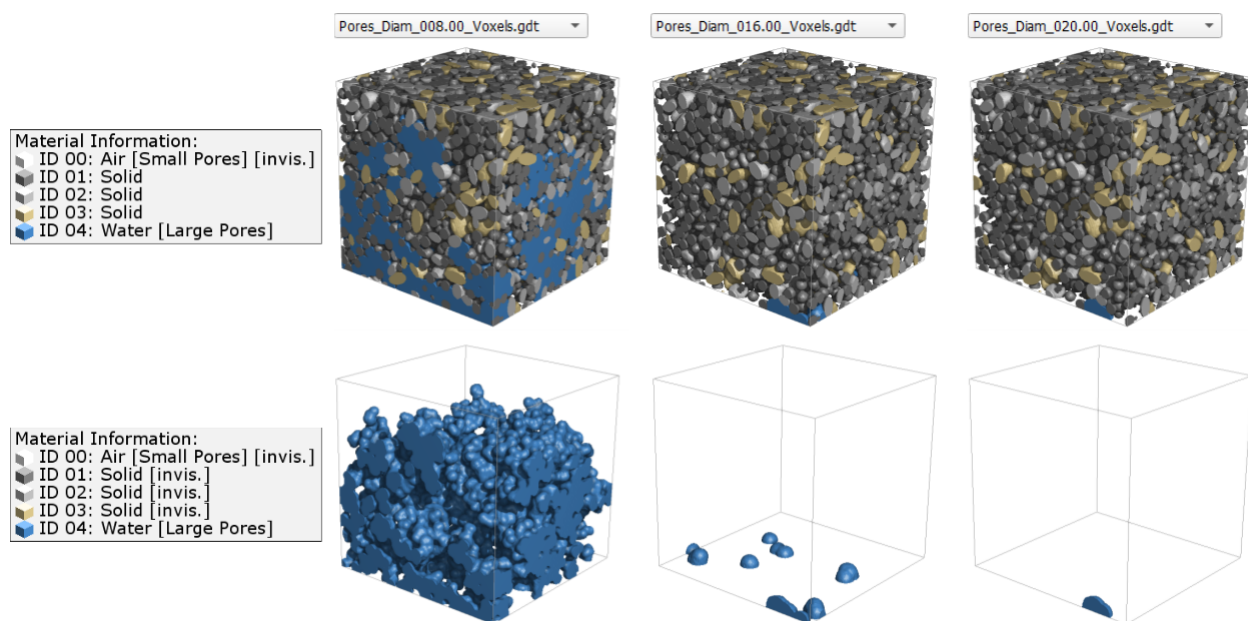
If [Write Pore Geometries as *.gdt Files](#)⁴² was checked, you can load a structure for each bin into the visualization area. Select the *.gdt file corresponding to a particular pore diameter from the drop down menu and then click **Load Pore Geometry (*.gdt)**.



In this example, a bin size of 2 voxels (800 nm) was chosen and the non-wetting fluid invades the structure from the bottom. The **Pores_Diam_008.00_Voxels.gdt** file shows the pore space separated into two Material IDs. Pore voxels which belong to pores with a diameter of 8 voxels (or more) and are reached by the invading fluid are assigned to Material ID 04 (blue), while the pore voxels of smaller pores are assigned to ID 00 (invisible). The

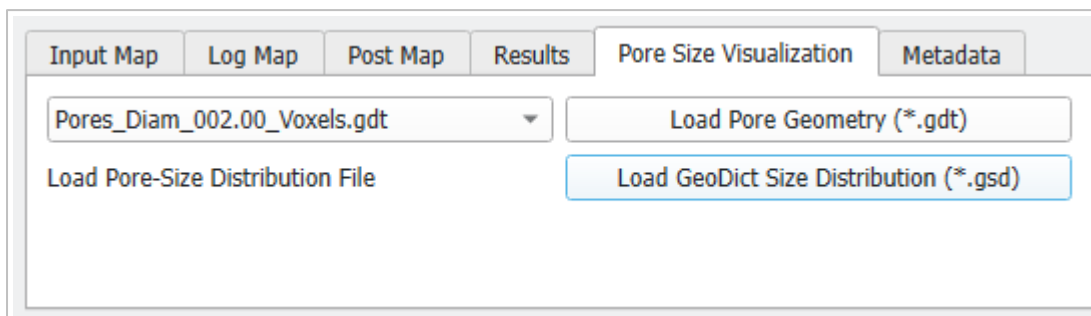
Pores_Diam_016.00_Voxels.gdt file shows the more limited pore space in which spheres with a (larger) diameter of at least 16 voxels would fit. The **Pores_Diam_020.00_Voxels.gdt** file shows that in this structure, the pore space which could be reached by spheres with diameter over 20 voxels is very small.

Check or un-check **visible** in **Settings** → **Color & Visibility Settings**, to turn off the visibility of the solid materials in the structure (Material ID 01, Material ID 02, and Material ID 03) and see only the pore space filled with water (Material ID 04).

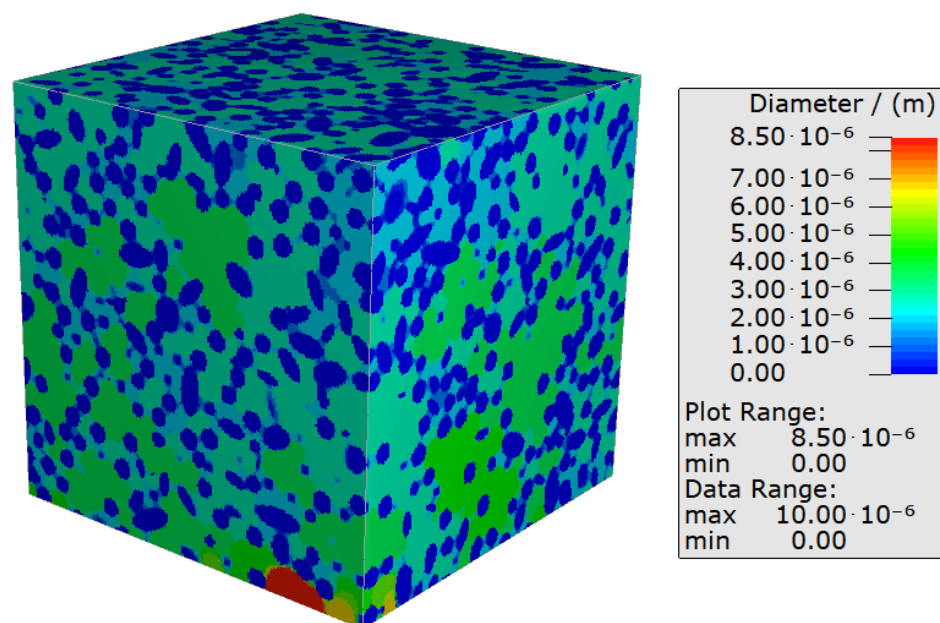


Pore Size Distribution

If [Write Pore Size Distribution as *.gsd File](#)⁴² was checked, you can click on **Load GeoDict Size Distribution (*.gsd)** to load a volume field containing the pore diameters.

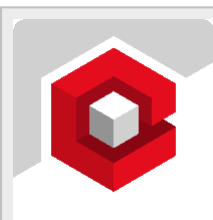
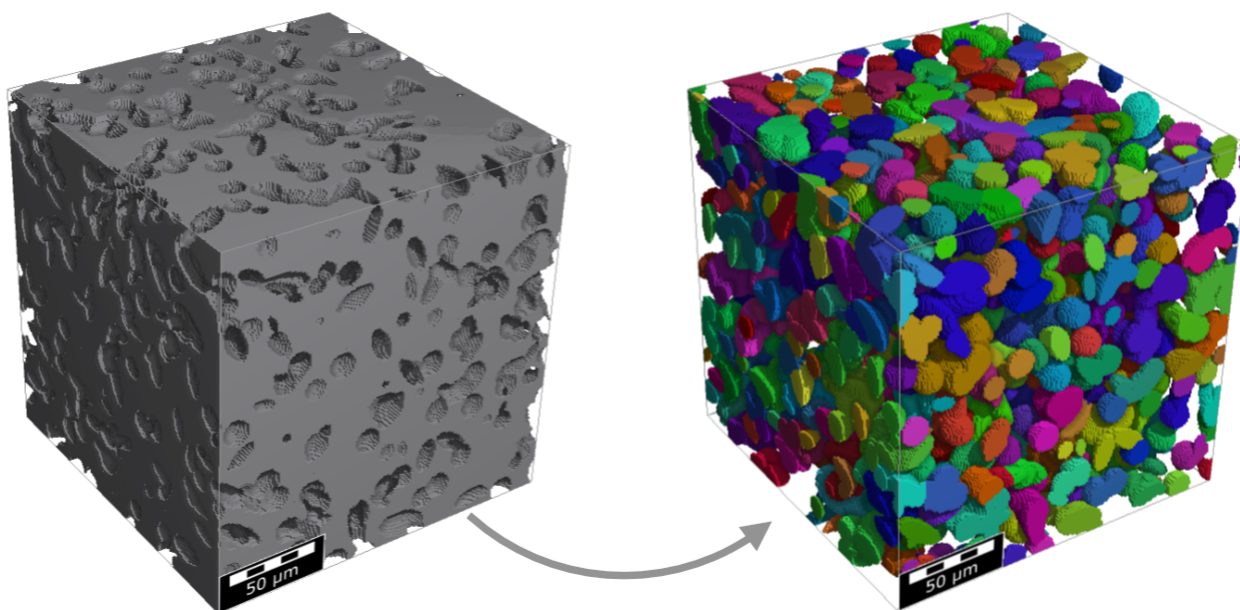


The value at each voxel is the diameter of the largest sphere, that contains this voxel and can be moved from the intrusion side(s) through the pore space to this voxel. Thus, the diameter for the solid materials is zero (dark blue in the picture below). Comparing the volume field shown below with the pores, that have a diameter of 20 voxels or more, you can see that these pores have a red color in the volume field plot.



1.4 Identify Pores

The Watershed algorithm is used to **Identify Pores**, which is especially useful to analyze mechanical and transport properties of foams and other structures with interconnected pores. The method introduces a segmentation of the pores, based on a distance transform, which identifies the number of pores, as well as the pore volume. This analysis is also very important to study the complex interconnected pore space in μ CT scans of rocks. Find more details about the theory behind **Identify Pores** in the [Theoretical Background](#)^[10] section.



New in GeoDict 2026

- New output option [Save Pore-Network Model as *.gad](#)^[63].

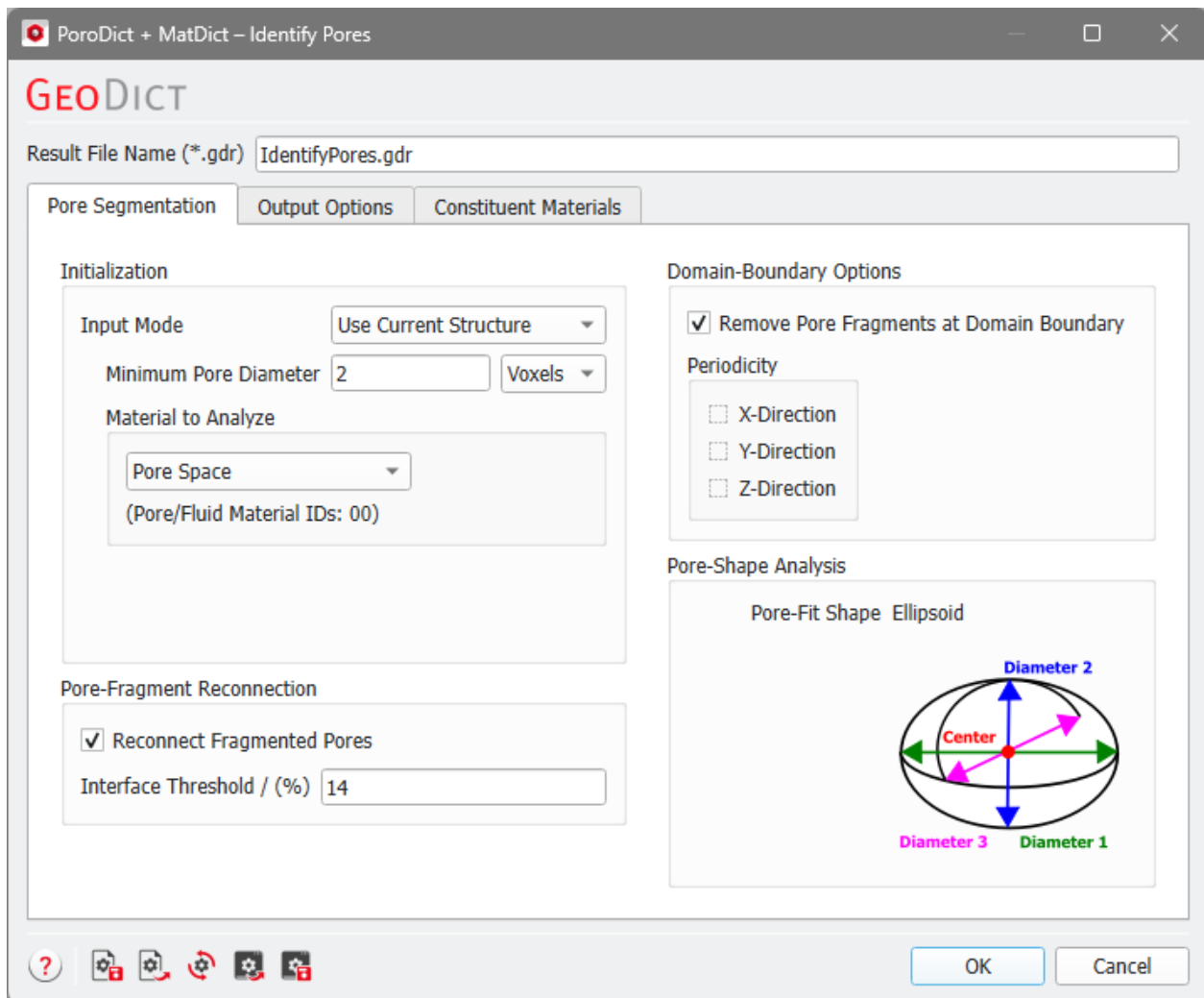
The **Identify Pores** command:

- [Options](#)^[50]
Set the parameters for the identification.
- [Results](#)^[66]
View the computed results.

1.4.1 Options

The **Identify Pores** dialog opens when clicking the **Edit...** button and includes the **Pore Segmentation** tab, the **Output Options** tab, and the **Constituent Materials** tab.

At the top of the dialog, enter the **Result File Name**. The result file is saved in the chosen project folder (**File** → **Choose Project Folder** in the menu bar).

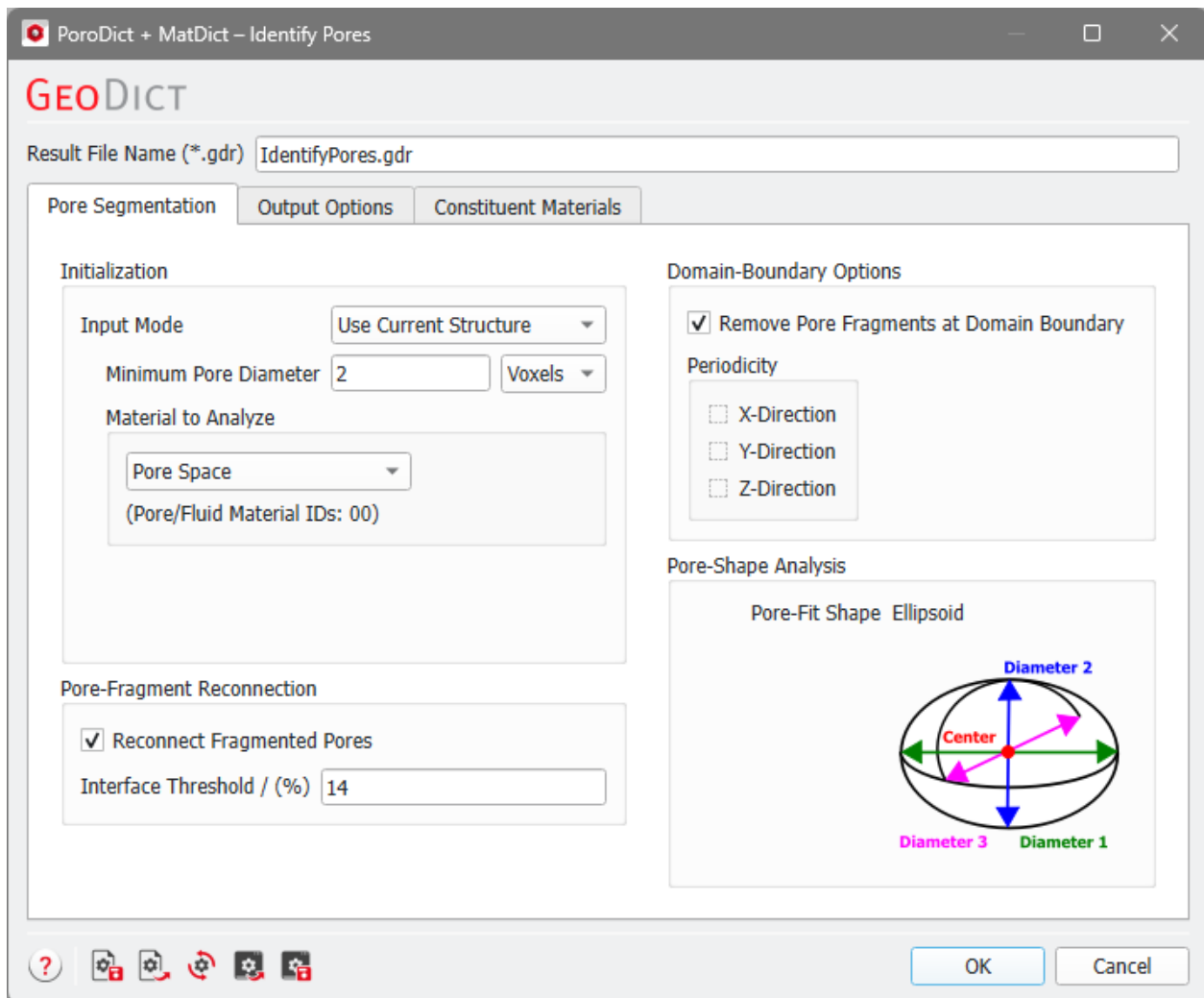


Identify Pores Options:

- [Pore Segmentation](#)⁵¹
Set the parameters for the identification.
- [Output Options](#)⁶³
Select which additional files should be saved.
- [Constituent Materials](#)⁶⁵
Enter the density of the materials in the structure.

Pore Segmentation

The parameters in the **Pore Segmentation** tab are separated in four panels: **Initialization**, **Pore-Fragment Reconnection**, **Domain-Boundary Options**, and **Pore-Shape Analysis**.



The Pore Segmentation tab:

- [Initialization](#)⁵²
Select the Input for the analysis.
- [Pore-Fragment Reconnection](#)⁵⁶
Select whether pore fragments should be merged before analyzing them.
- [Domain-Boundary Options](#)⁵⁹
Choose if pores touching the boundary should be removed before the analysis.
- [Pore Shape Analysis](#)⁶⁰
Find information on the different types of ellipsoids that are fitted in the structure.

Initialization

From the pull-down menu, select what should be the basis for the analysis.

Input Mode	Use Current Structure ▼
	Use Current Structure
	Load Presegmented Data
	Use Loaded Index Image

Use Current Structure

Select **Use Current Structure** to use the structure currently in memory. Below, enter the **Minimum Pore Diameter**, which defines the minimum size an individual, unconnected pore must have for the analysis. The unit of **Minimum Pore Diameter** can be selected as **Voxels** or **m**.

Input Mode	Use Current Structure ▼
Minimum Pore Diameter	2 Voxels ▼
Material to Analyze	
Pore Space ▼	
(Pore/Fluid Material IDs: 00)	

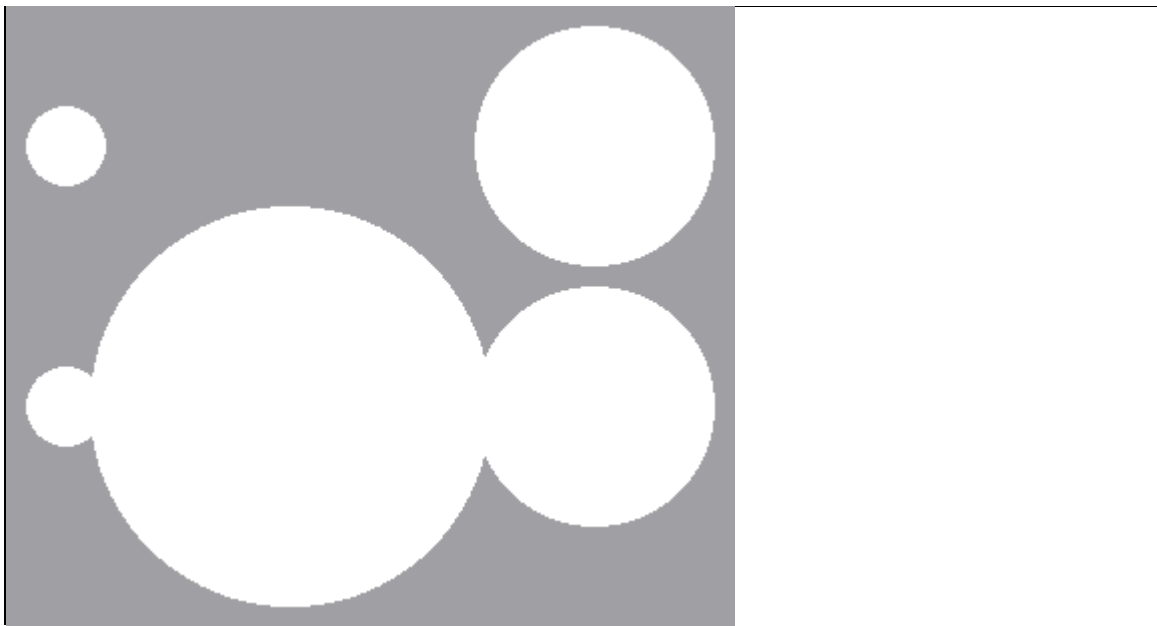


Note! The initialization of the pore segmentation (the watershed algorithm) might be time consuming for large structures. Thus, the options **Load Presegmented Data** or **Use Loaded Index Image** are useful when performing parameter studies with PoroDict – Identify Pores, where the initialization is kept unchanged while other parameters are varied.

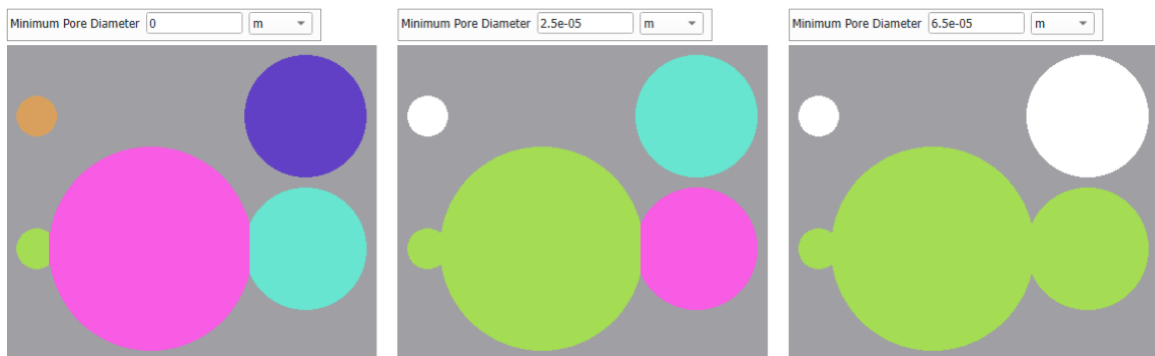
✓ Minimum Pore Diameter

This parameter determines which pores to keep and which pores to neglect or combine with others. If smaller pores exist which are connected to larger pores, the pores are combined and count as one pore. Single pores with a diameter smaller than the **Minimum Pore Diameter** are neglected.

In the next figure, the effect of the choice for **Minimum Pore Diameter** in the initialization step (of the watershed algorithm) is illustrated using the visualization of *.g32 files. The original structure contains spherical pores with diameters 100 μm , 60 μm , and 20 μm . Some of the pores are touching and therefore sharing an interface.

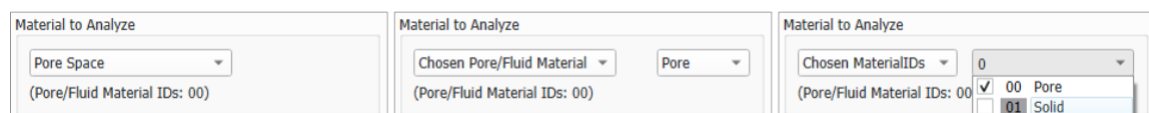


With **Minimum Pore Diameter** set to zero, all five pores are identified as single pores. When setting the **Minimum Pore Diameter** to 25 μm , the single 20 μm pore is neglected (shown in white), while the 20 μm pore connected to the larger pore is merged and so only three pores are identified. Analogously, for a choice of 65 μm , only one single merged pore is detected while the smaller pores are neglected.



✓ Material to Analyze

Under **Material to Analyze**, define the part of the structure to be considered in the analysis. Either the complete structure can be analyzed (**Pore Space**), an individual material in the pore space can be selected (**Chosen Pore/Fluid Material**) or a choice of Material IDs in the pore space can be made (**Chosen MaterialIDs**).



With **Chosen Material IDs**, one or multiple IDs can be chosen, which are then combined and analyzed as one single material. For example, when the pore space is occupied by brine and oil during the simulation of drainage or imbibition, choosing

the material to analyze allows computing the amount of the pore space occupied by each of the two fluids.

The specific materials can be selected in the [Constituent Materials](#)  tab. The material info is used to compute the pore mass and the moment of inertia and is contained in the Map tab of the Result Viewer.

Load Presegmented Data

If you want to import already segmented data from an index-image file (*.g32 or *.leS) select **Load Presegmented Data**. In this case **Browse** for the file you want to load below.

Input Mode	Load Presegmented Data ▾	
Pore-Index Image (*.g32; *.leS)	Pores.g32	Browse...
Pore Material	 Air...	
Solid Material	 Calcite (Solid)...	



Know how! For **Load Presegmented Data**, the difference between the *.g32 and *.leS formats is that *.g32 is a binary format, which produces comparatively smaller files but is not human readable, and *.leS is an ASCII-format which is human readable, but produces larger files. Furthermore, loading a *.g32 file into GeoDict is much faster than loading a *.leS file. Therefore, we recommend to use the *.g32 option.

For the presegmented data you have to define the **Pore Material** and the surrounding **Solid Material** by clicking on the corresponding buttons and choosing the material. For this Input Mode the Constituent Materials tab is not available and thus grayed-out.

Use Loaded Index Image

Alternatively, you can use the currently loaded *.g32 file by selecting **Use Loaded Index Image**. Then, the name of the *.g32 file will be displayed below or it is shown that no Index Image is loaded.

Input Mode	Use Loaded Index Image ▾	
Pore-Index Image (*.g32)	<No Index Image Loaded>	
Pore Material	 Air...	
Solid Material	 Calcite (Solid)...	



Know how! Check **Use Loaded Index Image** if the presegmented data is already loaded into GeoDict. In that case, it can be used directly and it is not necessary to load it again.

When choosing the loaded index image as input you have to define the **Pore Material** and the surrounding **Solid Material** by clicking on the corresponding buttons. For this Input Mode the Constituent Materials tab is not available and thus grayed-out.

Pore-Fragment Reconnection

In some cases (e.g., for complex pore shapes), the watershed algorithm in step 1 tends to over-segment the pore space. This means, that sometimes pores are identified as multiple pores (**Fragmented Pores**) when, in fact, they may be a single pore with a complex shape. Activate the checkbox **Reconnect Fragmented Pores** to merge connected pores depending on the value chosen for **Interface Threshold**.

The probability that two pore fragments belong to the same pore is measured with the interface ratio. This interface ratio compares the interface area of two touching pore fragments with the surface area of the pore fragment with the smaller surface.

$$\text{interface ratio} = \frac{\text{interface of touching fragments}}{\min(\text{surface of object 1, surface of object 2})} \quad \begin{matrix} (7) \text{ Interface} \\ \text{Threshold} \end{matrix}$$

For the computation of the interface ratio, the pore surfaces and interfaces need to be computed. The surface area estimation is based on Estimate Surface Area from MatDict (see also [J. Ohser, F. Mücklich^{\[151\]}](#)).

If the *interface ratio* is larger than the percentage chosen for the **Interface Threshold**, the two pore fragments are merged and only one pore is reported as identified.

For example, if the **Interface Threshold** is set to the default **14**, the shared interface of two pores must be larger than 14% of the total surface of the smaller pore for the two pores to be merged. The next example shows two structures in which a big pore and a small pore touch with different interface surface between them. Depending on the surface of the interface, the value of **Interface Threshold** at which the two pores stop being reconnected and are detected as two (instead of only one) is very different.

When the two pores share a small interface, a low value of **Interface Threshold** (7) is enough to separate the two pores. When the two pores instead share a large interface, a higher value of **Interface Threshold** (15) is needed to separate the two pores. The default value of

Interface Threshold (14) would be appropriate to separate the two pores sharing a small interface, but not the pores sharing a large interface.

Small Interface

Interface Threshold / (%)

Interface Threshold / (%)



Large Interface

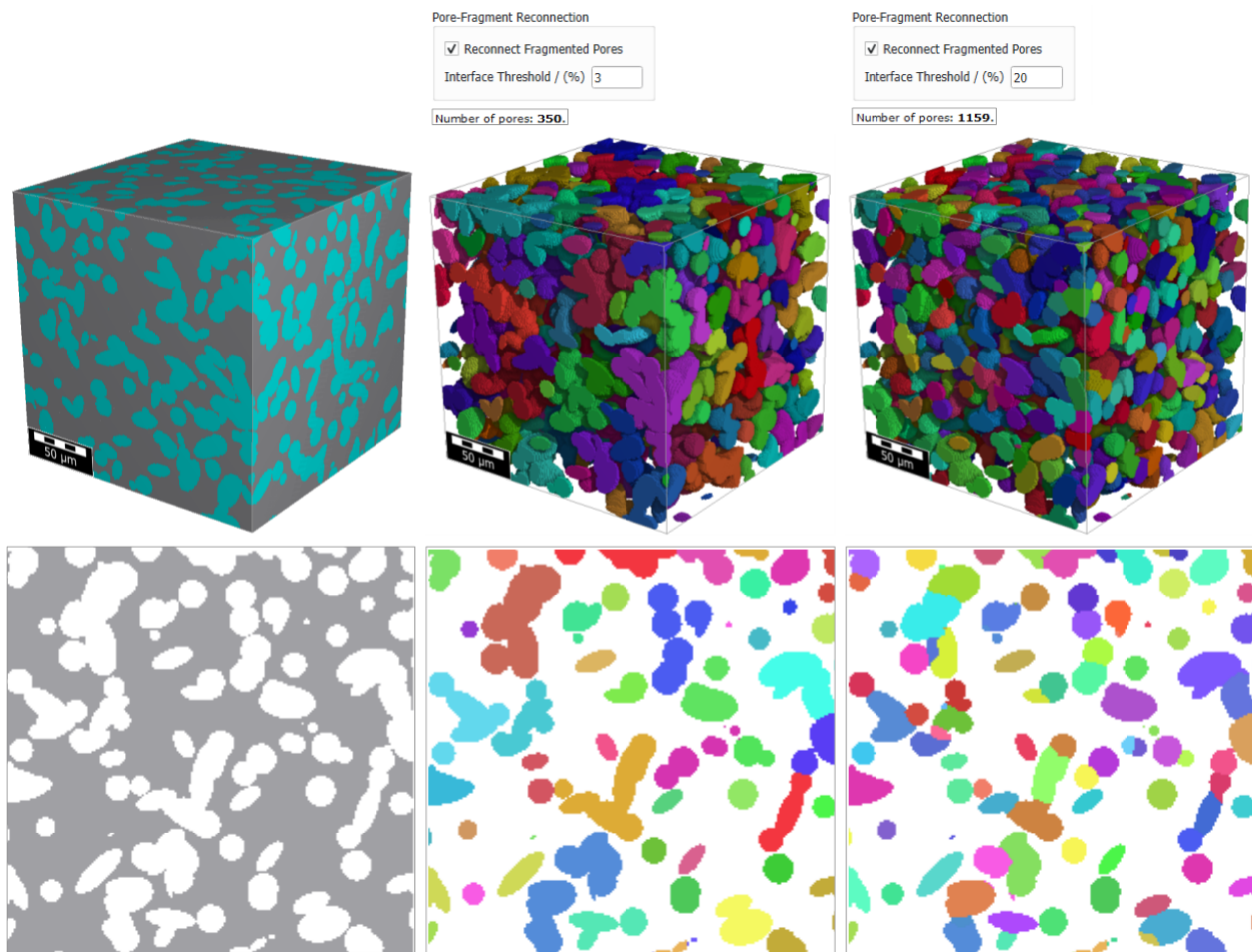
Interface Threshold / (%)

Interface Threshold / (%)



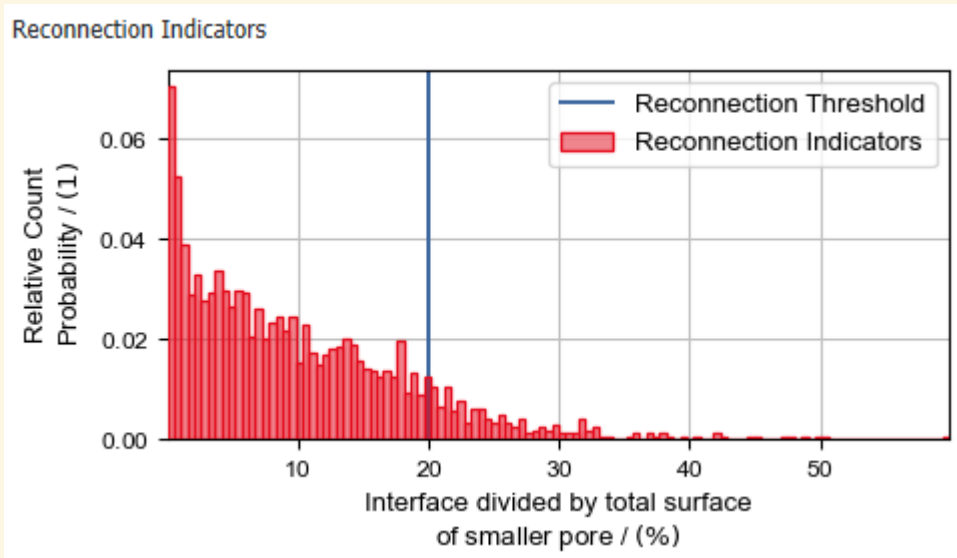
The value for the **Interface Threshold** must be chosen carefully depending on the size of pores in the structure. With a low threshold, more pores are merged (and less pores are identified).

In the figures below (using the visualization of *.g32 files), observe the effect of different choices for the **Interface Threshold**. For this example, the **Minimal Pore Diameter** is always 2 μm . With a very low **Interface Threshold** value of 3%, several large and complex pores are identified in the structure that may not correspond to single pores. With a value of 20%, the pore space may be over-segmented with many small pores being detected.



Know how! Use the **Reconnection Indicators** histogram under the **Results** → **Plots** subtab in the Result Viewer to find an appropriate **Interface Threshold** for the structure. As described above, the ratio of the interface area between two pores and the total surface of the smaller pore is computed. This ratio of all pore interfaces and the selected **Interface Threshold** are plotted in the **Reconnection Indicator** histogram.

The following ratio histogram belongs to the example structure and the interface threshold of 20% is marked in blue. Observe that many pore interfaces have a ratio smaller than 20%, thus only few pores are merged together.



Domain-Boundary Options

In the **Domain-Boundary Options** panel, the handling of boundary pores is defined.

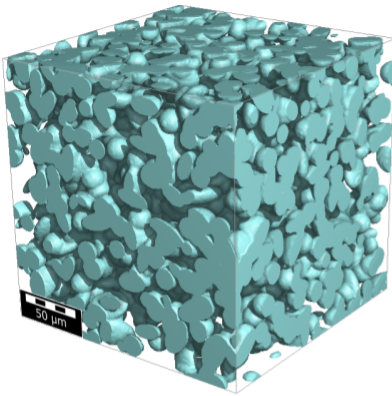
Domain-Boundary Options

☒ Remove Pore Fragments at Domain Boundary

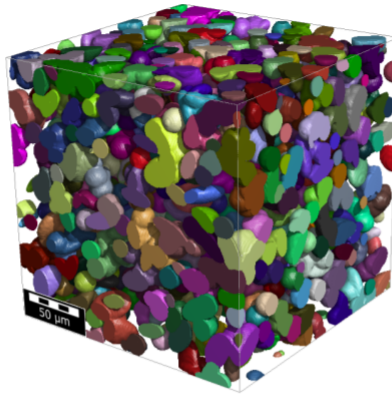
Periodicity

☐ X-Direction
☐ Y-Direction
☐ Z-Direction

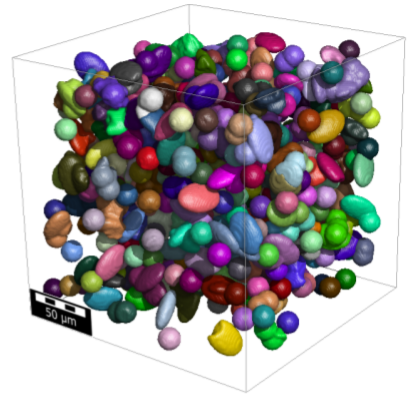
When **Remove Pore Fragments at Domain Boundary** is checked, all pores touching the domain boundary, after the initialization and the pore-fragment reconnection are done, are removed. This might improve the results, since boundary pores which do not lie entirely within the domain might lead to incorrect pore shape estimates. The visualizations below are loaded from the Result Viewer of the *.gdr result file (under the [Pore Visualization tab](#)⁹⁰).



Pore space to analyze



Pore space after Pore Reconnection



Pore space after pore fragment removal at domain boundaries

When **Remove Pore Fragments at Domain Boundary** is unchecked, the **Periodicity** options become available. By checking the X-, Y-, or Z-Direction checkboxes, the pore space is treated as periodic in the chosen direction(s) before the pore segmentation. Otherwise, when **Periodicity** is not chosen in a direction, the structure is assumed to end at the domain boundary.

Domain-Boundary Options

☐ Remove Pore Fragments at Domain Boundary

Periodicity

☒ X-Direction
☒ Y-Direction
☒ Z-Direction



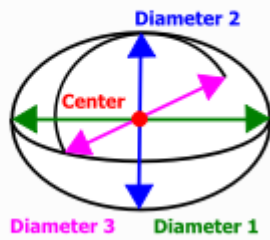
Important! Periodicity should only be chosen for real periodic structures, otherwise it might lead to strange results (with pores which are treated as connected but are distant from each other in reality).

Pore Shape Analysis

After the pore identification step (defined by the parameters under **Initialization**, **Pore-Fragment Reconnection**, and **Domain-Boundary Options**), the shape of the pores is analyzed. This analysis is done by fitting ellipsoids into the identified pores.

Pore-Shape Analysis

Pore-Fit Shape Ellipsoid



To define such an ellipsoid, a center point and three diameters are needed.

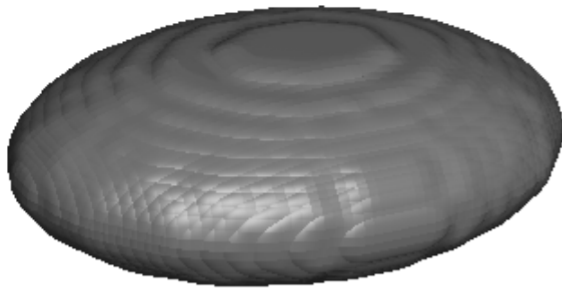
In the following, we set

- a to be the length of the longest of the three diameters,
- b to be the length of the medium diameter,
- c to be the length of the shortest diameter.

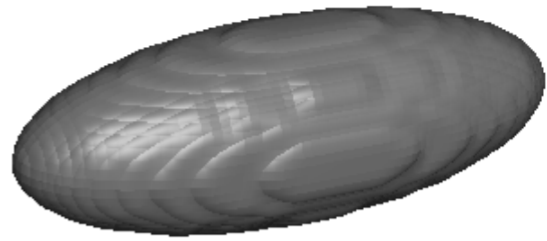
A pair of diameters is similar if its size ratio (the smaller diameter is divided by the larger diameter) is larger than 0.875. Two diameters differ, if their ratio is smaller than 0.875.

Four shapes for the ellipsoids can be fitted into the pore:

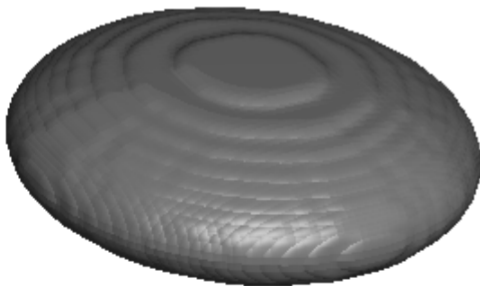
- An ellipsoid is formed as a **Flat Bar**, if all three diameters a , b , and c differ much from each other.
- A **Prolate Spheroid** has one bigger diameter, a , and the two smaller diameters, b and c , are similar to each other. Its shape is similar to a cigar.
- The two bigger diameters (a and b) of an **Oblate Spheroid** are similar. Thus, it can be compared to a disk.
- For a **Sphere** all three diameters a , b , and c are similar.



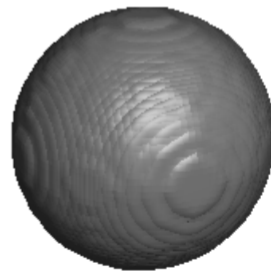
Flat Bar



Prolate Spheroid



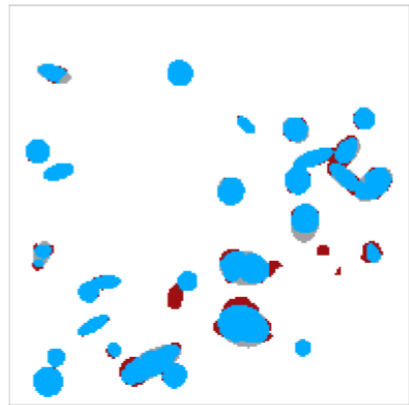
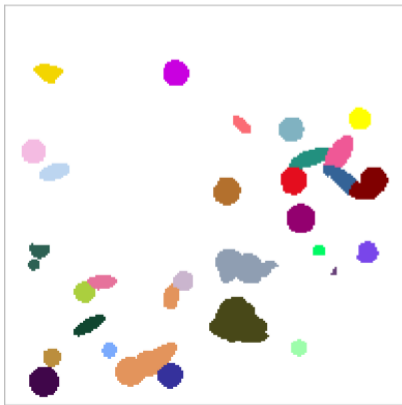
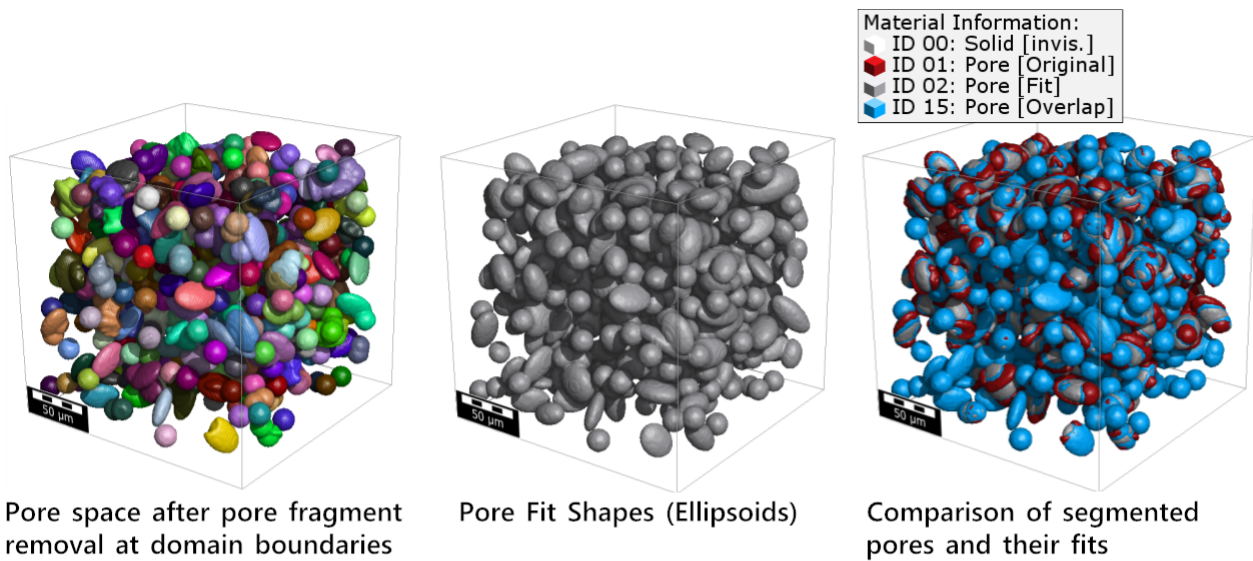
Oblate Spheroid



Sphere

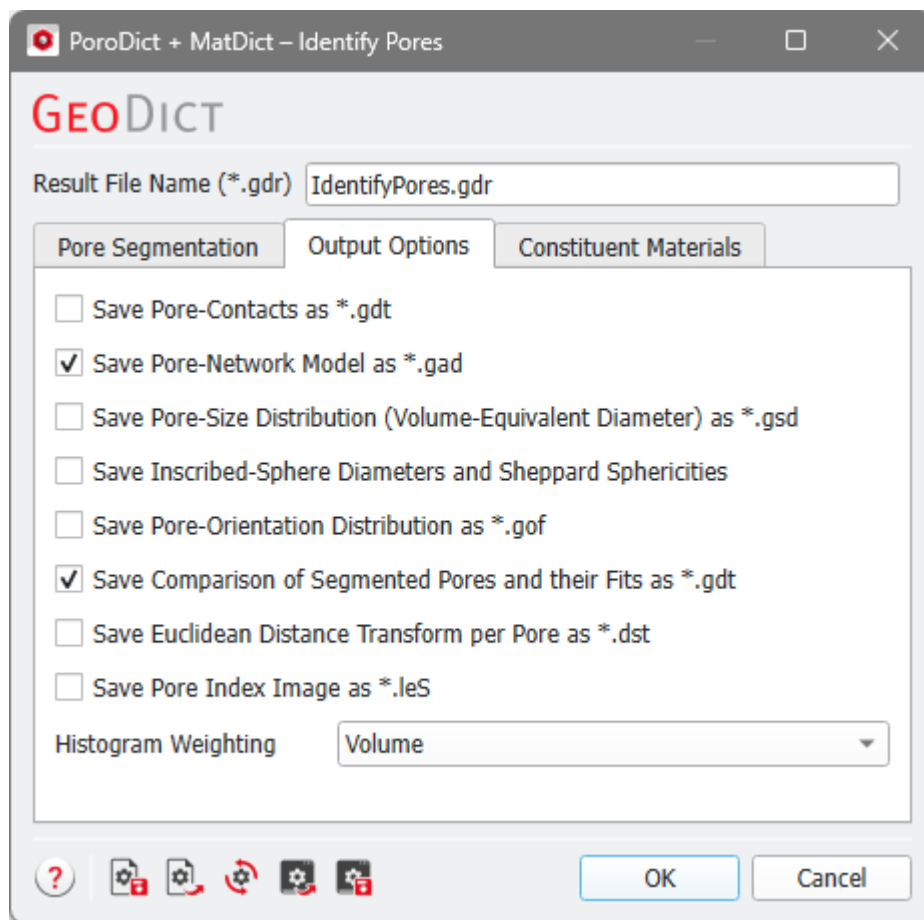
The following figure shows the results of **Pore-Shape Analysis** on a porous structure. These visualizations are loaded from the Result Viewer of the *.gdr result file (under the [Pore Visualization tab](#) ).

On the **left**, the structure is shown after pores are identified, and the pore fragments are removed at the domain boundary. The **middle** image shows the shapes of ellipsoids fitted to the pores. The **right** image shows a comparison between the identified pores (red) and the ellipsoid shapes fitted to them (gray). The matching voxels are shown in blue. This visualization provides a validation of the fitting to the ellipsoid shapes. A fitting is considered very good when a high percentage of overlap is observed, meaning the fitted ellipsoids accurately cover the pores.



Output Options

Under the **Output Options** tab, choose which additional results should be computed and saved. Load the files for visualization in the Result Viewer under the [Pore Visualization](#)⁸² tab. Some of these options need an additional computing effort and are unchecked by default. Shown below is the default selection of the output options.



Note! The following files are always saved as Output, independent of the selection in this tab:

- A Pore Index Image as *.g32 file
- The Pore Fit Shapes as *.gad file
- Intermediate Result of Watershed Transformation as *.gdt file

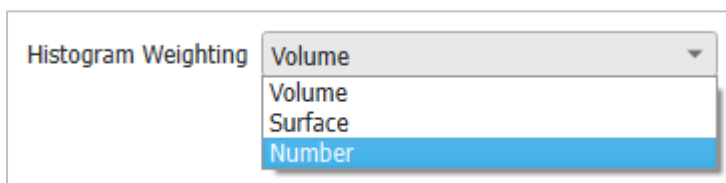
- Check **Save Pore-Contacts as *.gdt** to save a structure file, where the pores have Material ID 01 and the contact areas have Material ID 02.
- The option **Save Pore-Network Model as *.gad** is selected by default and creates a file containing analytic objects to represent the network. The pores are represented by spheres (Material ID 01) and the connections between them are modeled by cylinders (Material ID 02).
- Check **Save Pore-Size Distribution (Volume-Equivalent Diameter) as *.gsd** to save the computed pore size distribution as a volume field. This information can be used, e.g., for visualization of the volume field of the Volume-Equivalent Diameter or for further analysis with Python.



Know how! You can modify the fields of the volume file after the computation in the [post-processing widget](#)^[68] in the Result Viewer.

- When **Save Inscribed-Sphere Diameters and Sheppard Sphericities** is checked, the diameter of the inscribed sphere for every pore is calculated as volume field and saved. Both options need additional computing effort and are unchecked by default.
- Check **Save Pore-Orientation Distribution as *.gof** to save the orientation of the pores in a volume field and use the orientation information in simulations or for later analysis.
- By default selected is to **Save Comparison of Segmented Pores and their Fits as *.gdt**, which is useful to evaluate the quality of the fitted GAD-objects (Ellipsoids). A good accordance of the pore fit shapes and the identified pores is important as a basis for generating good digital twins.
- After checking **Save Euclidean Distance Transform per Pore as *.dst**, the EDT for every pore is calculated individually and the result is saved in one single file (*.dst format). This option needs additional computing effort and is unchecked by default.
- The resulting pore index image is saved by default in the binary *.g32 format. With the last option, **Save Pore Index Image as *.leS**, it can be additionally saved as an ASCII file. This format takes more space and needs longer to write and load into GeoDict, but it is human-readable and can easily be imported into other software.

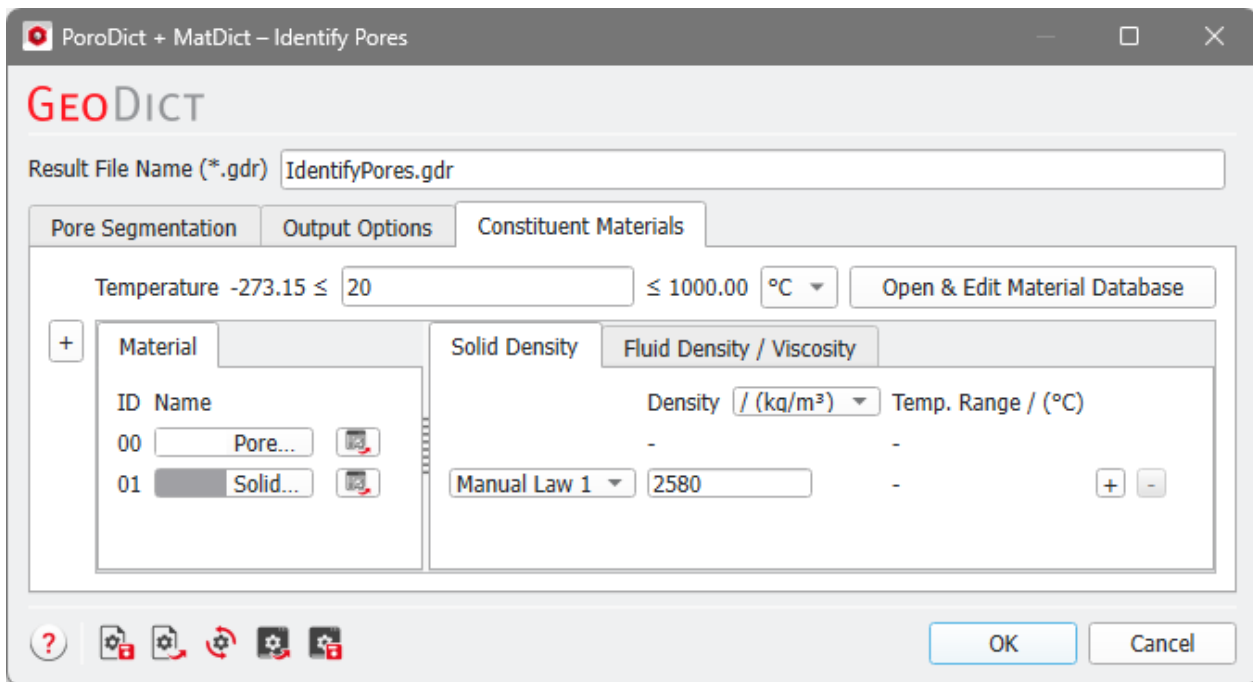
Choosing **Histogram Weighting** as **Volume**, **Surface**, or **Number** changes the values on the Y-axis of the resulting histogram plots. Then, either the pore volume probability, the pore surface area probability, or the pore count probability is shown. The histogram weighting can also be changed in the [Histogram Plot Options](#)^[80] in the Result Viewer after the analysis has been run.



Constituent Materials

This tab is only available if **Use Current Structure** is chosen as [Input Mode](#)^[52] in the **Pore Segmentation** tab.

Under the **Constituent Materials** tab, the temperature can be edited if the density of a material is temperature dependent. Additionally, the density of every fluid and solid material in the structure must be specified in this tab. The density can be given in kg/m³ or g/cm³. For materials from the GeoDict Material Database, the density value is entered automatically. If a material is set to **Manual**, the Material Law changes to **Manual Law** and more laws can be added or deleted by clicking the "+" or "-" button on the right of the corresponding row. You can enter the density for manual materials directly in this tab.

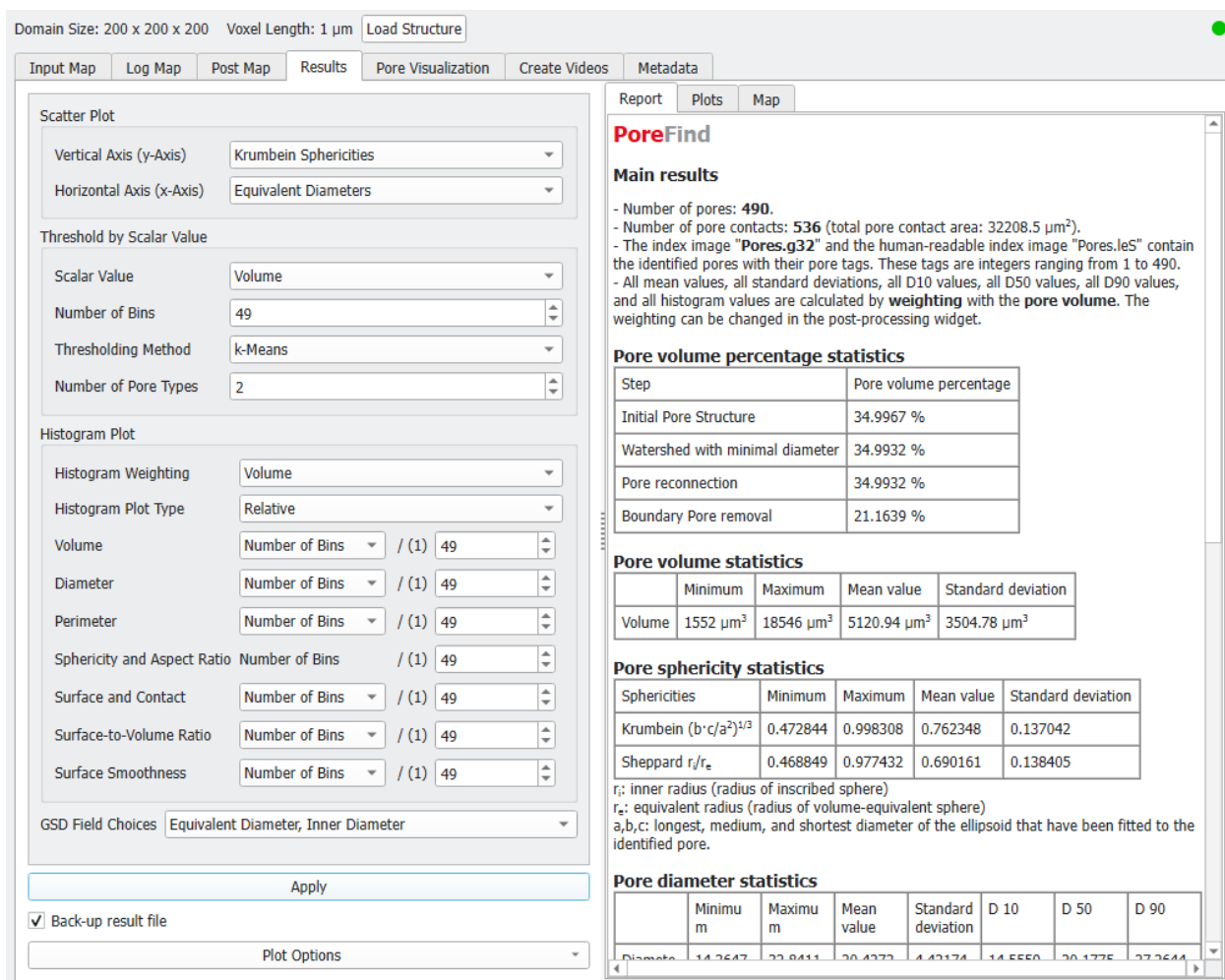


1.4.2 Results

After the **Identify Pores** calculation is finished, the resulting files are saved in the project folder and a Result Viewer with the GeoDict result file opens automatically. The created GeoDict result file (*.gdr) contains six tabs. The computational results are shown under the **Results** tab, and can be loaded for visualization via the **Pore Visualization** tab. The other four tabs (**Input Map**, **Log Map**, **Post Map**, and **Metadata**) display additional information about the computation.

Find more details on the general functionalities in the Result Viewer user guide.

The **Results** tab is the central point for the analysis of the identified pores. It is grouped in three subtabs: **Report**, **Plots**, and **Map**. The **Report** tab shows statistics about the identified pores and the **Plots** tab contains plot options for the analysis of the results. The **Map** tab contains all resulting data from the **Identify Pores** run. This data is the basis for the tables in the **Report** tab and for the plots in the **Plots** tab. On the left, the **Post-Processing Widget** allows you to fine-tune many graphs of the **Plots** tab. Collapse the **Post-Processing Widget** by pulling it to the left.



Post-Processing Widget

Scatter Plot

In the **Scatter Plot** panel, you can choose two scalar values to be plotted against each other. By default, the Krumbein Sphericity is plotted against the Equivalent Diameters.

Find out more about the **Scatter Plot** in the [Plots](#)⁷² topic.

Threshold by Scalar Value

In the **Threshold by Scalar Value** panel you can choose a scalar value and a thresholding method to classify the pores into a selected number of types.

Find out more about the **Threshold by scalar value** plot in the [Plots](#)⁷³ topic.

Histogram Plot

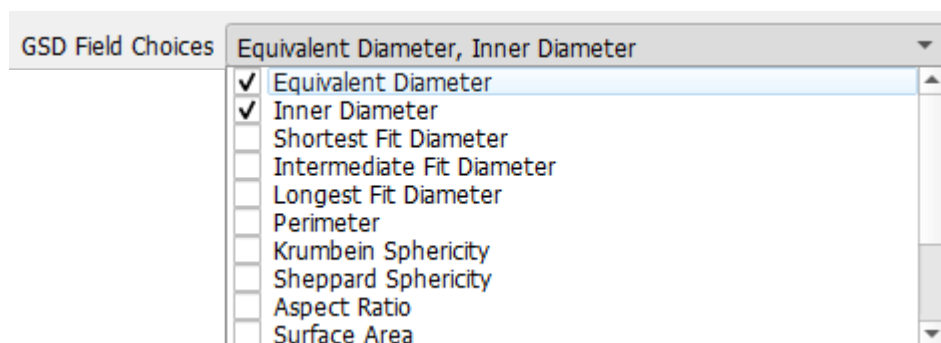
Define the options for the histograms in the Plot tab in the **Histogram Plot** panel. The **Weighting** and **Plot Type** are equal for all histograms, while the bin number can be set individually.

Find more about the Histogram Plot Options in the [Plots](#)^[80] topic.

GSD Field Choices

From the drop-down menu choose the [scalar pore properties](#)^[16] that you want to visualize. For every chosen pore property, a volume field is created containing the 3D distribution of this property. These volume fields are saved together in a *.gsd file (**GeoDict size distribution**). Load this file in the **Pore Visualization** tab under [Load Pore-Size Distribution](#)^[84].

In the example below, where **Equivalent Diameter** and **Inner Diameter** were chosen, the *.gsd file will contain two volume fields: one with the size distribution of the diameters of volume-equivalent spheres, and one with the inner diameter.



Identify Pores Results:

- [Report](#)^[68]
See the computed results.
- [Plots](#)^[71]
View result plots.
- [Pore Visualization](#)^[82]
Load results for a graphical visualization.
- [Create Videos](#)^[92]
Use a predefined macro to create a video.

Report

The **Report** tab shows the **Main results** at the top, and below, in several tables, more detailed statistics. For an explanation of the different computed properties see [Results of Identify Pores](#)^[16].

✓ Main results

In the **Main results** section, the number of identified pores and the number and total area of pore contacts is given. For the *.g32 file (and for the *.leS file if **Save Pore Index Image as *.leS** was checked in the [Output Options](#)^[63] tab) the range of the index numbers is stated. Below, for the mentioned statistical values, the weighting property is given. This is the same as entered for **Histogram Weighting** in the [Output Options](#)^[63] tab, but you can also change it later in the Post-Processing Widget under the [Histogram Plot Options](#)^[80].

Main results

- Number of pores: **490**.
- Number of pore contacts: **536** (total pore contact area: 32208.5 μm^2).
- The index image "**Pores.g32**" and the human-readable index image "Pores.leS" contain the identified pores with their pore tags. These tags are integers ranging from 1 to 490.
- All mean values, all standard deviations, all D10 values, all D50 values, all D90 values, and all histogram values are calculated by **weighting** with the **pore volume**. The weighting can be changed in the post-processing widget.

✓ Pore volume percentage statistics

In this table, the pore volume during the different steps of the identification is displayed. The pore volume percentage after the Watershed transformation is only shown if [Current Structure](#)^[52] was chosen as Input Mode. Then, only pores larger than the minimal pore diameter count for the statistics. The volume percentage after [Pore-Fragment Reconnection](#)^[56] and [Boundary Pore removal](#)^[59] are only shown if the corresponding options were selected in the options dialog.

Pore volume percentage statistics

Step	Pore volume percentage
Initial Pore Structure	34.9967 %
Watershed with minimal diameter	34.9932 %
Pore reconnection	34.9932 %
Boundary Pore removal	21.1639 %

✓ Pore volume statistics

For the identified pores, the minimum, maximum, and mean volume and the standard deviation are shown. The mean value and standard deviation are weighted with the chosen **Histogram Weighting** (changeable in the [Post-Processing Widget](#))^[80].

Pore volume statistics

	Minimum	Maximum	Mean value	Standard deviation
Volume	1552 μm^3	18546 μm^3	5120.94 μm^3	3504.78 μm^3

✓ Pore sphericity statistics

The statistics for the Krumbein sphericity and the Sheppard sphericity (only if **Save Inscribed-Sphere Diameters and Sheppard Sphericities** was checked in the [Output Options](#)^[63] tab) are shown. The mean value and standard deviation are weighted with the chosen **Histogram Weighting** (changeable in the [Post-Processing Widget](#))^[80].

Pore sphericity statistics

Sphericities	Minimum	Maximum	Mean value	Standard deviation
Krumbein $(b \cdot c / a^2)^{1/3}$	0.472844	0.998308	0.762348	0.137042
Sheppard r_i / r_e	0.468849	0.977432	0.690161	0.138405

r_i : inner radius (radius of inscribed sphere)

r_e : equivalent radius (radius of volume-equivalent sphere)

a, b, c : longest, medium, and shortest diameter of the ellipsoid that have been fitted to the identified pore.

✓ Pore diameter statistics

For different pore diameters the minimum, maximum, and mean value and the standard deviation are shown. The mean value and standard deviation are weighted with the chosen **Histogram Weighting** (changeable in the [Post-Processing Widget](#))^[80]. Additionally, the [characteristic diameters](#)^[32] D10, D50, and D90 are shown. These are the diameters such that 10%, 50%, or 90% of all pores have smaller diameter than the corresponding value. The **Diameter of inscribed sphere** is only computed if **Save Inscribed-Sphere Diameters and Sheppard Sphericities** was checked in the [Output Options](#)^[63] tab.

Pore diameter statistics

	Minimum	Maximum	Mean value	Standard deviation	D 10	D 50	D 90
Diameter of volume-equivalent sphere	14.3647 μm	32.8411 μm	20.4273 μm	4.43174 μm	14.5559 μm	20.1775 μm	27.2644 μm
Diameter of inscribed sphere	9.38083 μm	16.2481 μm	13.6018 μm	1.44368 μm	11.0993 μm	14.1949 μm	15.084 μm
Shortest Diameters	9.70215 μm	29.4897 μm	15.4757 μm	3.29183 μm	11.3692 μm	14.8354 μm	19.9884 μm
Intermediate Diameters	14.2925 μm	34.1763 μm	20.2288 μm	4.55559 μm	14.4864 μm	19.7581 μm	26.5472 μm
Longest Diameters	14.9758 μm	62.0524 μm	28.132 μm	9.07 μm	14.7219 μm	28.6775 μm	39.7913 μm

✓ Coordination number statistics

For the coordination number (number of contacts a pore has to other pores) the minimum, maximum, and mean value and the standard deviation are shown. The mean value and standard deviation are weighted with the chosen **Histogram Weighting** (changeable in the [Post-Processing Widget](#))^[80].

Coordination number statistics

	Minimum	Maximum	Mean value	Standard deviation
Coordination number	0	8	2.72281	1.75495

✓ Pore Orientation

At the bottom, the orientation tensor of all pores is shown.

Pore Orientation

Direction tensor:

0.3275	0.0064	0.0011
-	0.3479	-0.0027
-	-	0.3246

In detail, let

$$d_k = \begin{pmatrix} x_k \\ y_k \\ z_k \end{pmatrix}$$

be the unit vector describing the direction of the k-th object and **n** the number of objects. Then the orientation tensor **T** is the sum over the dyadic products of the **d_k** from all **n** objects, divided by **n**:

$$T = \frac{1}{n} \left(\sum_{k=1}^n d_k d_k^T \right) = \frac{1}{n} \sum_{k=1}^n \begin{pmatrix} x_k x_k & x_k y_k & x_k z_k \\ y_k x_k & y_k y_k & y_k z_k \\ z_k x_k & z_k y_k & z_k z_k \end{pmatrix} = \begin{pmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \end{pmatrix} \quad (8) \text{ Orientation Tensor}$$

The diagonal elements define the orientation strength for the corresponding directions and sum up to 1. Thus, if for example **t₁₁=1** (and **t₂₂=t₃₃=0**), all objects are oriented in the X-direction. For **t₁₁=0** all objects are oriented normally to the X-direction and same values for all diagonal elements (**t₁₁=t₂₂=t₃₃=1/3**) result in a uniform distribution for the object orientation.

Plots

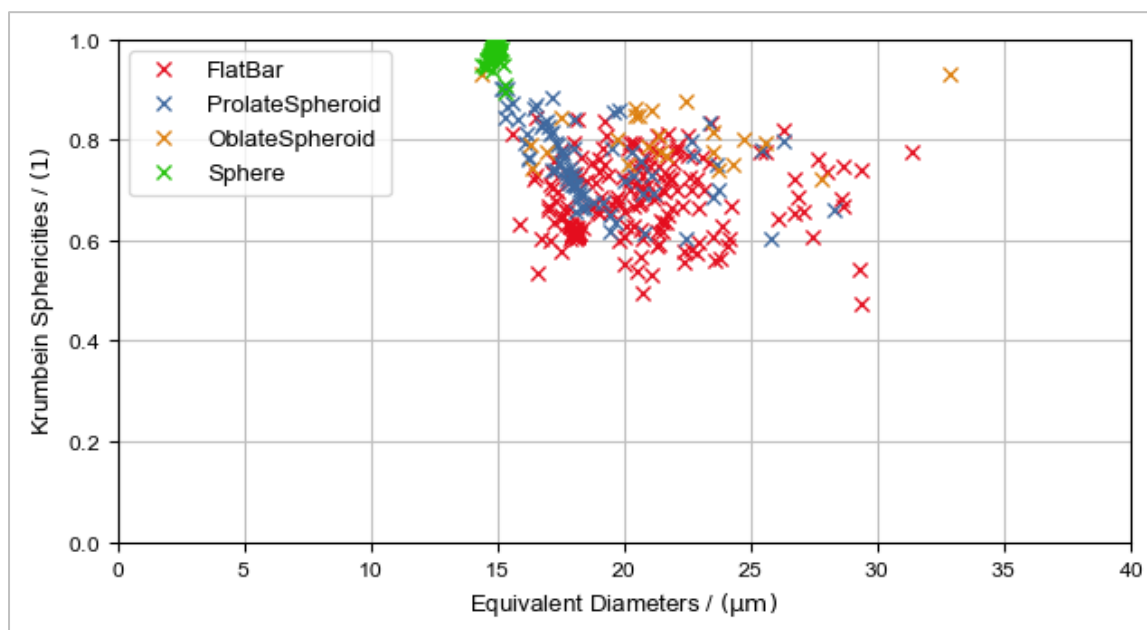
The **Plots** tab offers several plots to show the relationship between pore parameters: **Scatter Plot**, **Threshold by scalar value** histogram, **Volume** histogram, **Diameters** histogram, **Perimeter** histogram, **Sphericities** histogram, **Aspect ratio** histogram, **Surfaces And Contacts**

histogram, **Coordination Number** histogram, the **Orientation** polar plot, and the **Reconnection Indicators** histogram.

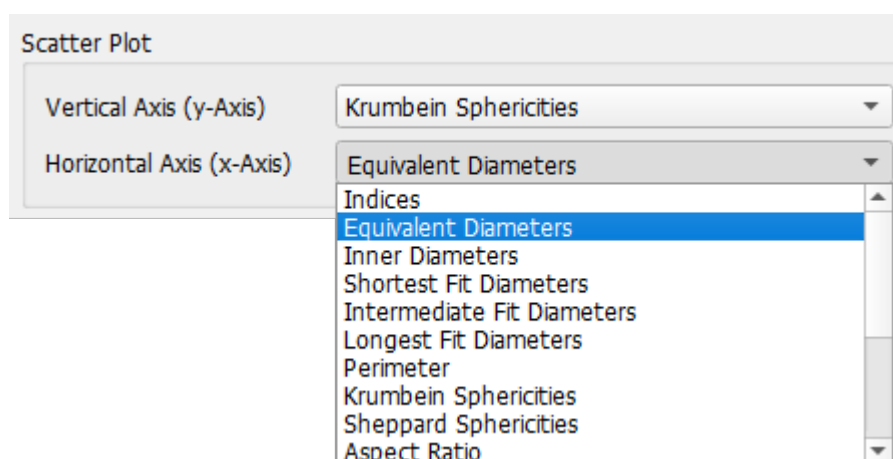
Change the plot options in the post-processing widget at the left side of the **Plots** tab. After changes are made, click **Apply...** to use the new values. The changes are also applied to the tables under the **Report**  subtab.

✓ Scatter Plot

In the **Scatter Plot** panel, you can choose two scalar values to be plotted against each other. By default, the Krumbein Sphericity is plotted against the Equivalent Diameters.



You can change the scalar values in the post-processing widget. The different scalar values are explained in [Results of Identify Pores](#) .



The Scatter Plot distinguishes between the four shapes Flat Bar, Prolate Spheroid, Oblate Spheroid, and Sphere. These are the four possible shapes for the ellipsoids that are fitted into the pores (see also [Results of Identify Pores](#)  for more information). In the example above, observe in the **Scatter Plot** that the found spherical pores have an

equivalent diameter of 15 μm , while the other found ellipsoids have equivalent diameters between 15 and 32 μm .

✓ Threshold by scalar value

You can classify the pores in the structure into different types based on a chosen scalar value. Define the parameters in the Post-Processing Widget and control the performance in the **Threshold by scalar value** plot.

The screenshot shows a widget titled "Threshold by Scalar Value" with four input fields: "Scalar Value" set to "Volume", "Number of Bins" set to 49, "Thresholding Method" set to "k-Means", and "Number of Pore Types" set to 2.

First, select the **Scalar Value** from the drop-down list to determine a threshold for. The default scalar value is **Volume**. All scalar values are described under [Results of Identify Pores](#)¹⁶.

The **Number of Bins** defines how many bins the histogram **Threshold by scalar value** has. With more bins, a more precise threshold value can be found.

To determine the threshold value, three **Thresholding Methods** are available:

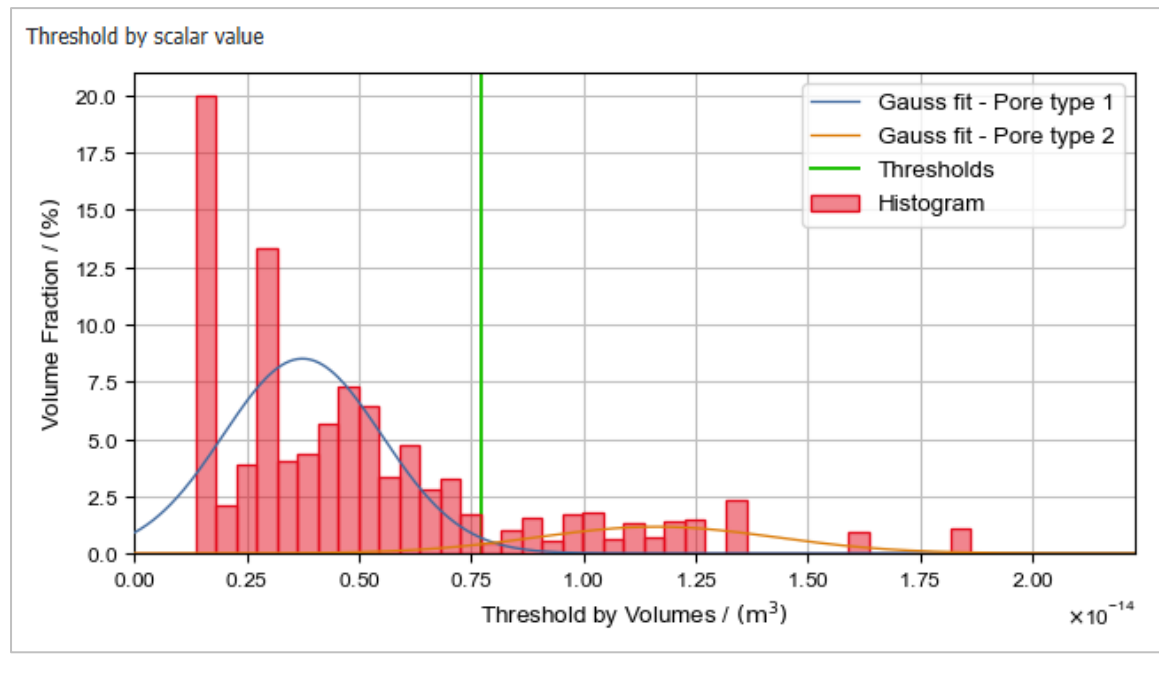
The screenshot shows the "Thresholding Method" dropdown menu with three options: "k-Means" (selected), "Otsu", and "Manual".

- **k-Means:** uses the k-Means algorithm to find thresholds for the chosen **Number of Pore Types**.
- **Otsu:** uses the Otsu algorithm to find thresholds for the chosen **Number of Pore Types**.
- **Manual:** define your own thresholds by writing a comma-separated list of thresholds into **Threshold(s)**. You implicitly define the number of pore types by the number of thresholds you enter, e.g, if you enter two threshold values this will result in three pore types.

The screenshot shows the "Manual" thresholding method interface with a dropdown menu set to "Manual" and an empty text input field labeled "Threshold(s) / (m^3)".

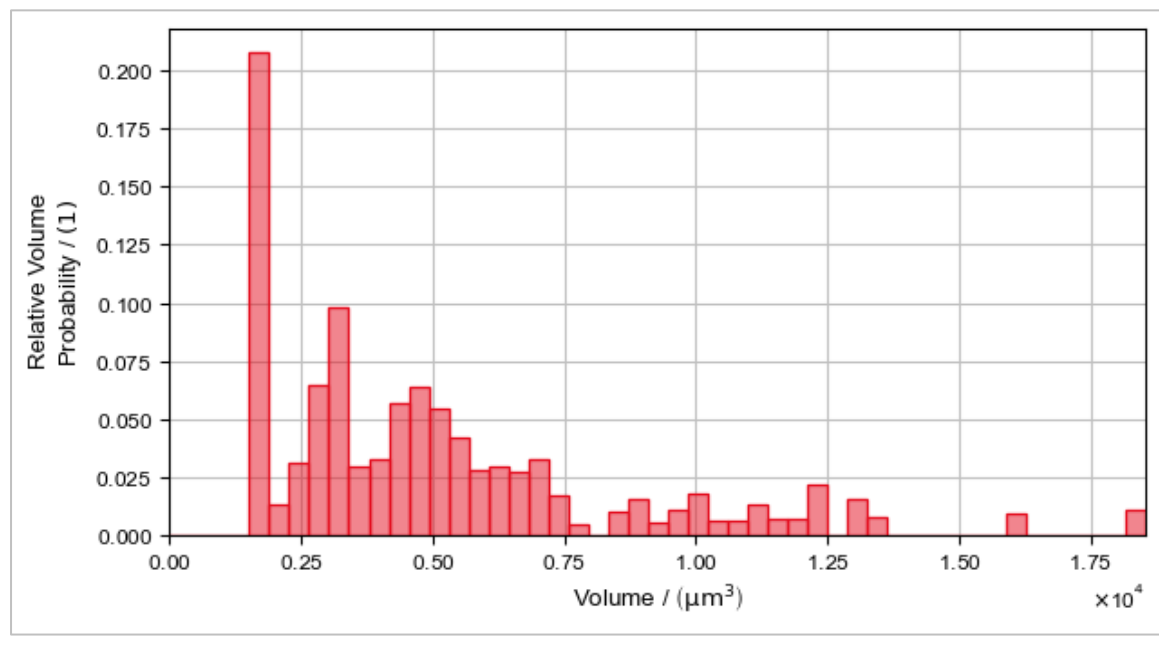
After the settings are applied, the **Threshold by scalar value** plot visualizes the effects. The histogram of the chosen **Scalar Value** is plotted with the entered **Number of Bins**. The computed or entered **Thresholds** are marked as well as the Gauss fit of the pore

types. Additionally, a structure containing the different pore types will be created, that can be loaded into GeoDict from the [Pore Visualization tab](#)^[87].



✓ Volume histogram

In this tab, the **Volume** of the identified pores is plotted. The [Histogram Plot Options](#)^[80] are explained below.



✓ Diameters histogram

In the **Diameters** panel you can switch between different plots.

Diameter of Volume-Equivalent Spheres ▾

Diameter of Volume-Equivalent Spheres

Diameter of Inscribed Spheres

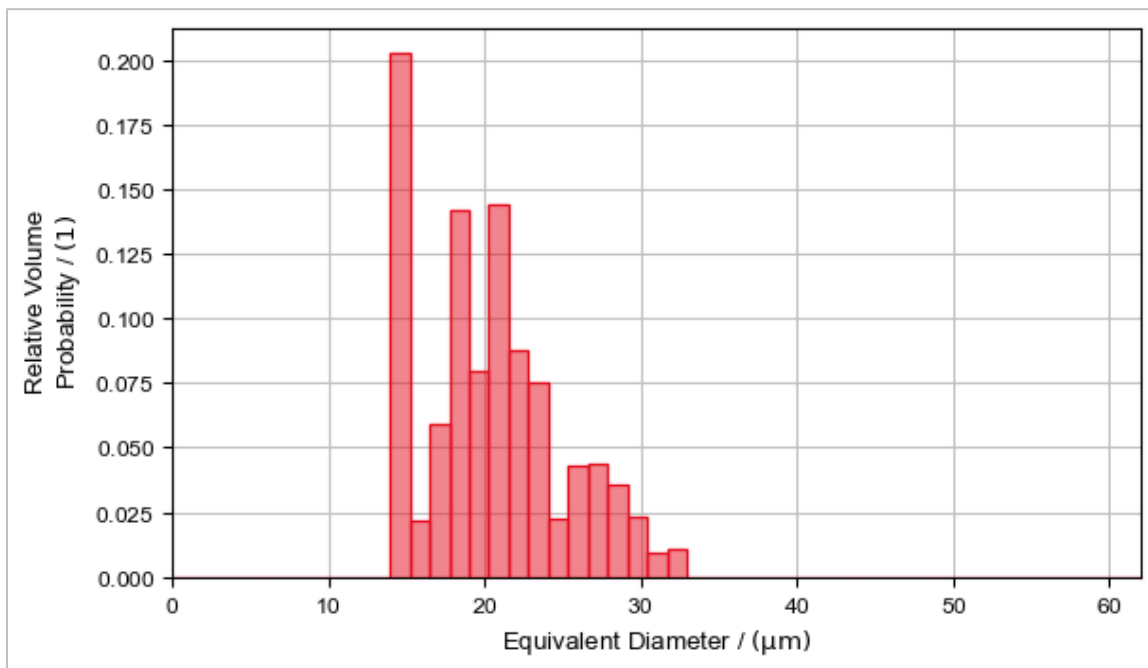
Shortest Fit Diameters

Intermediate Fit Diameters

Longest Fit Diameters

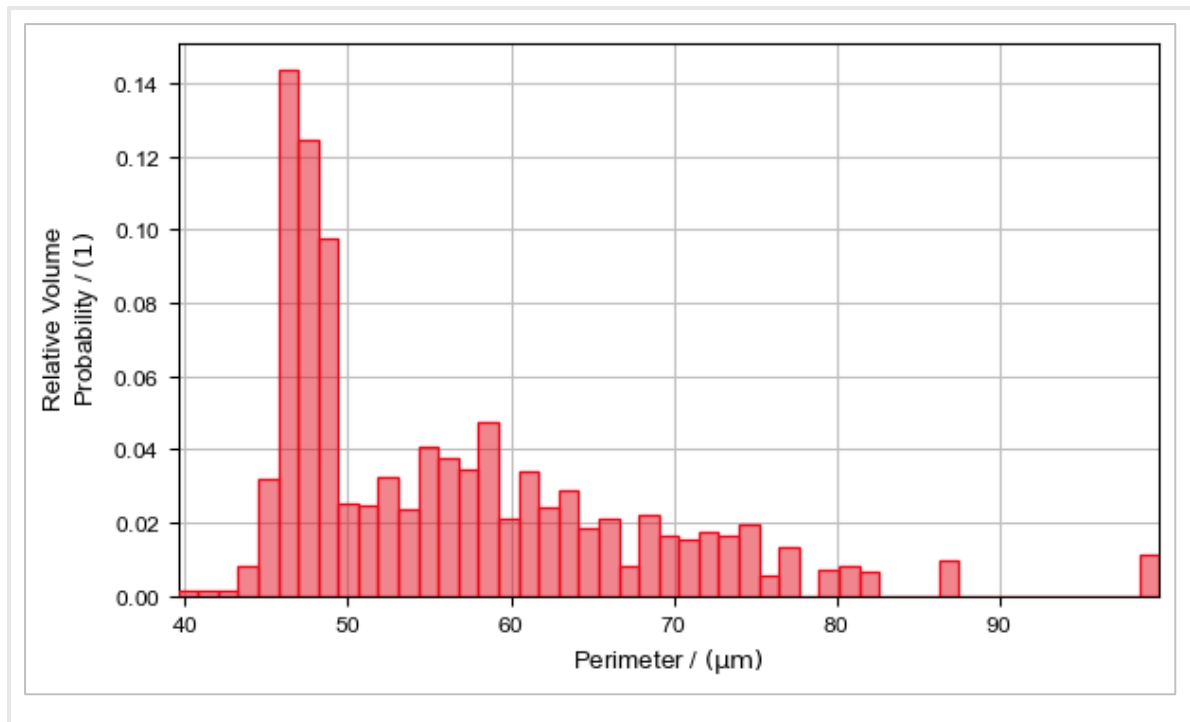
The Diameter of Inscribed Spheres histogram is only available if **Save Inscribed-Sphere Diameters and Sheppard Sphericities** was checked in the [Output Options](#)⁶³ tab.

The [Histogram Plot Options](#)⁸⁰ are explained below.



✓ Perimeter histogram

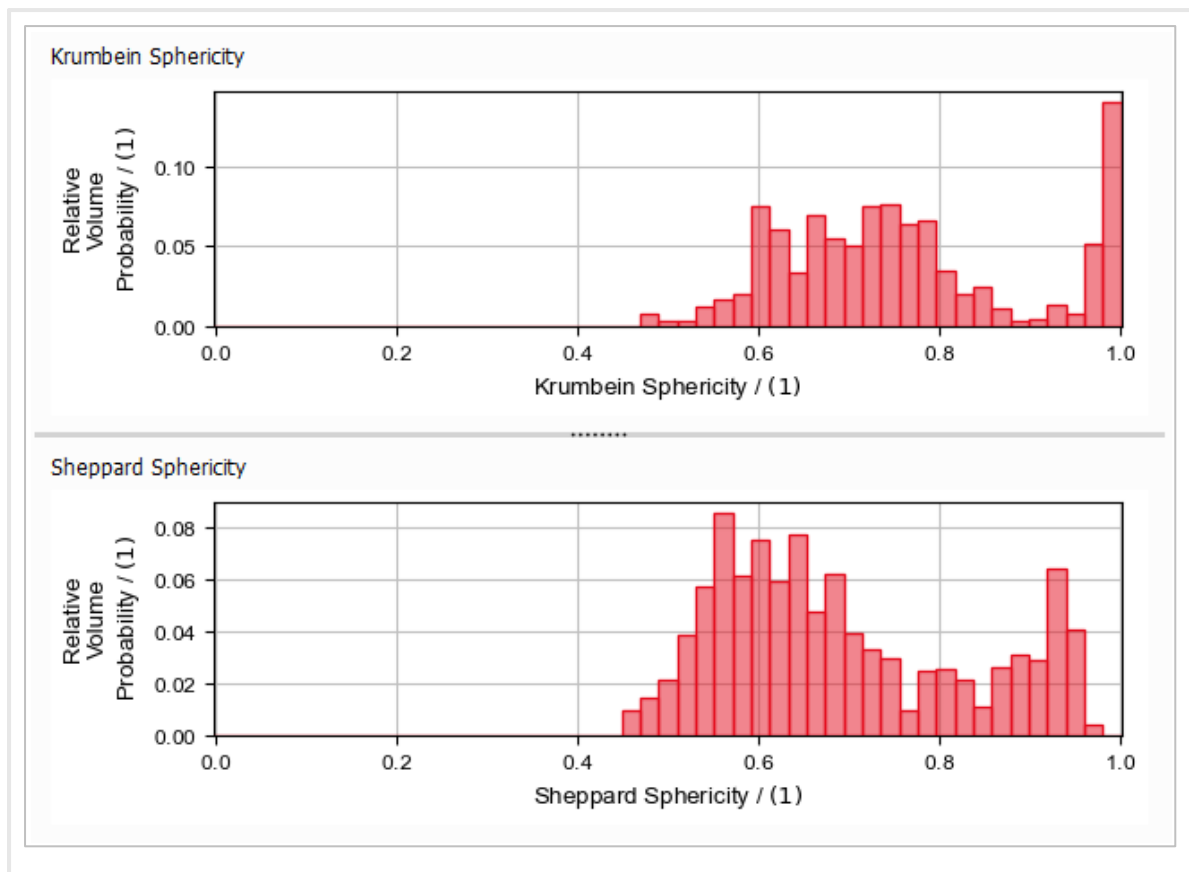
In this tab, the **Perimeter** of the identified pores is plotted. The [Histogram Plot Options](#)⁸⁰ are explained below.



✓ Sphericities histogram

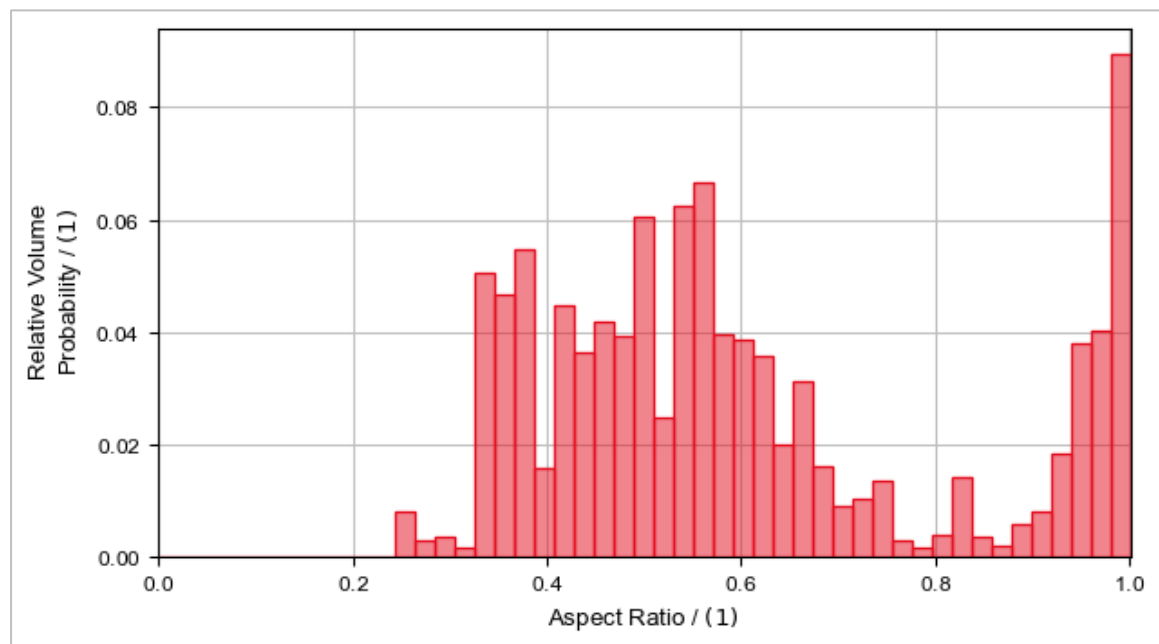
The Krumbein Sphericity and the Sheppard Sphericity (only if **Save Inscribed-Sphere Diameters and Sheppard Sphericities** was checked in the [Output Options](#)⁶³ tab) are shown in this tab.

The [Histogram Plot Options](#)⁸⁰ are explained below.



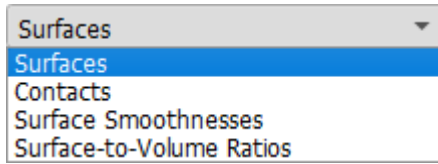
✓ Aspect Ratio histogram

In this tab, the **Aspect Ratio** of the identified pores is plotted. The [Histogram Plot Options](#)⁸⁰ are explained below.

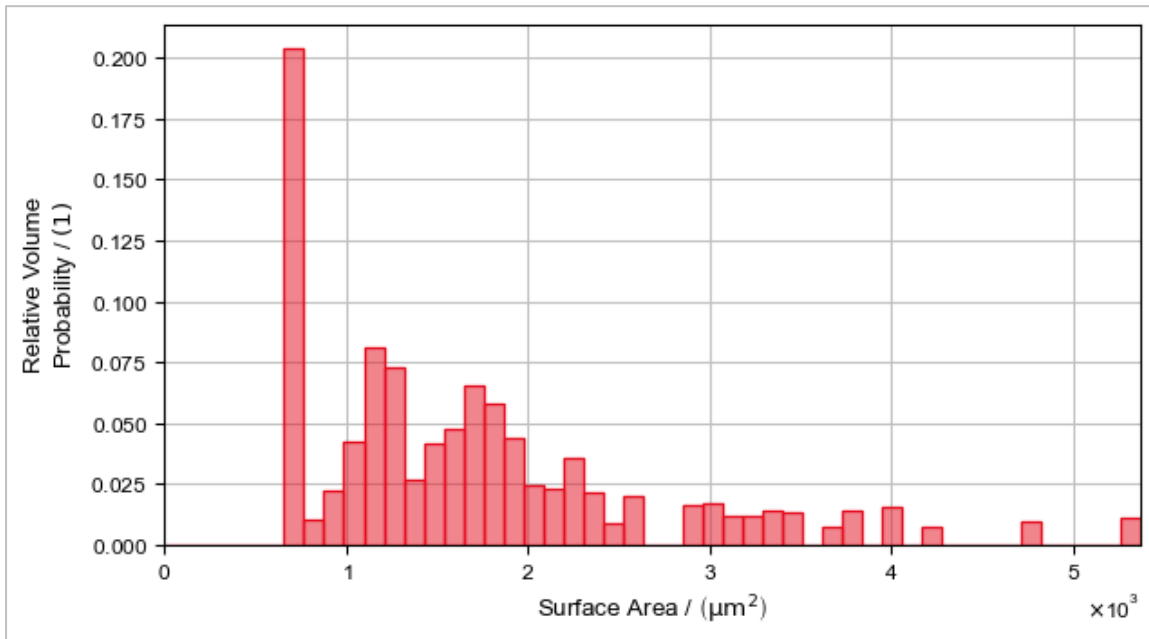


✓ Surfaces And Contacts histogram

In the **Surfaces and Contacts** panel you can switch between different plots.

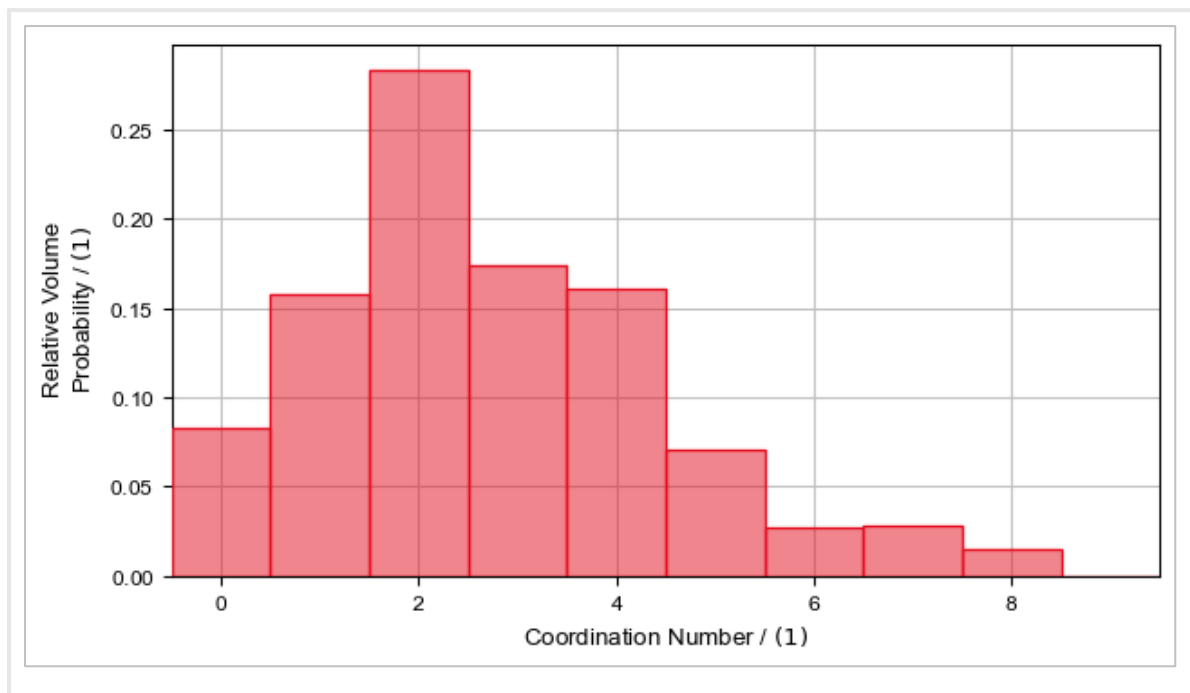


The [Histogram Plot Options](#)^[80] are explained below.



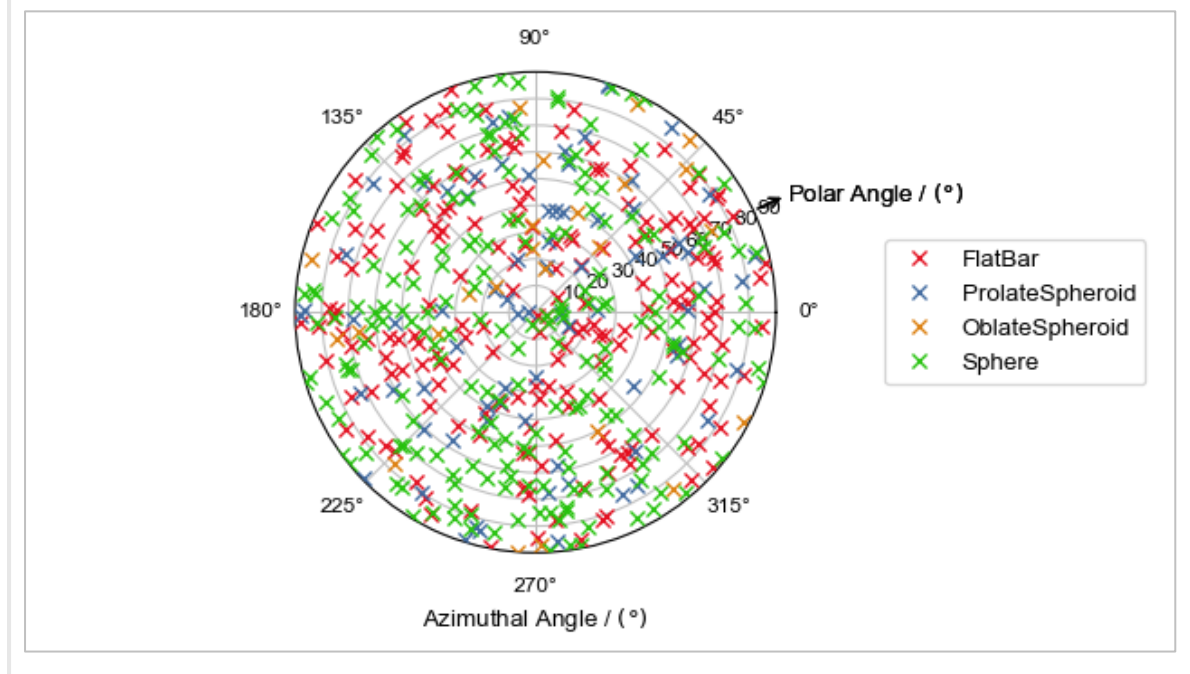
✓ Coordination Number histogram

In this tab, the **Coordination Number** (number of contacts a pore has to other pores) of the identified pores is plotted. The [Histogram Plot Options](#)^[80] are explained below.



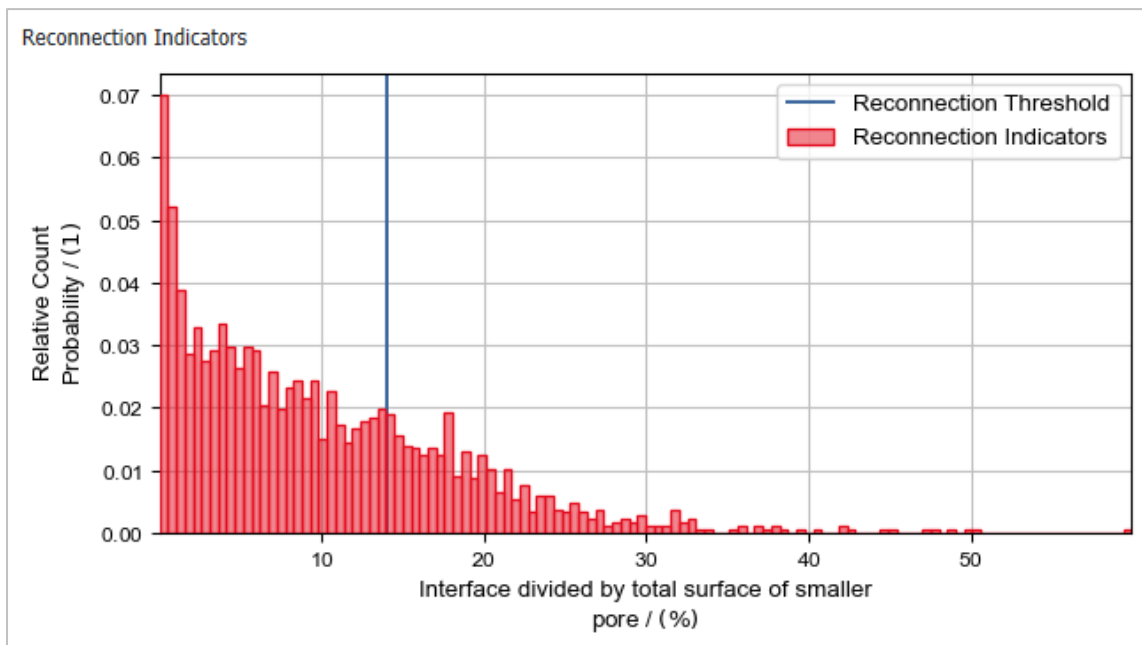
✓ Orientation polar plot

In this tab, the orientation of the fitted pore shapes is plotted as polar plot. This plot distinguishes between the four shapes Flat Bar, Prolate Spheroid, Oblate Spheroid, and Sphere. These are the four possible shapes for the ellipsoids that are fitted into the pores (see also [Results of Identify Pores](#) ¹⁵ for more information).



✓ Reconnection Indicators

Use the **Reconnection Indicators** histogram to find an appropriate **Reconnection Threshold** if you want to use [Pore-Fragment Reconnection](#)⁵⁶ (find more information in this topic).



✓ Histogram Plot Options

You can modify the histogram plots with the **Histogram Plot** options in the post-processing widget.

Histogram Plot

Histogram Weighting	Volume	
Histogram Plot Type	Relative	
Volume	Number of Bins	/ (1) 49
Diameter	Number of Bins	/ (1) 49
Perimeter	Number of Bins	/ (1) 49
Sphericity and Aspect Ratio	Number of Bins	/ (1) 49
Surface and Contact	Number of Bins	/ (1) 49
Surface-to-Volume Ratio	Number of Bins	/ (1) 49
Surface Smoothness	Number of Bins	/ (1) 49

The values on the Y-axes of the histograms in all plots can show **Count Probability** (weighting by **Number**), **Area Probability** (weighting by **Surface**), or **Volume Probability** (weighting by **Volume**), depending on the **Histogram Weighting** you

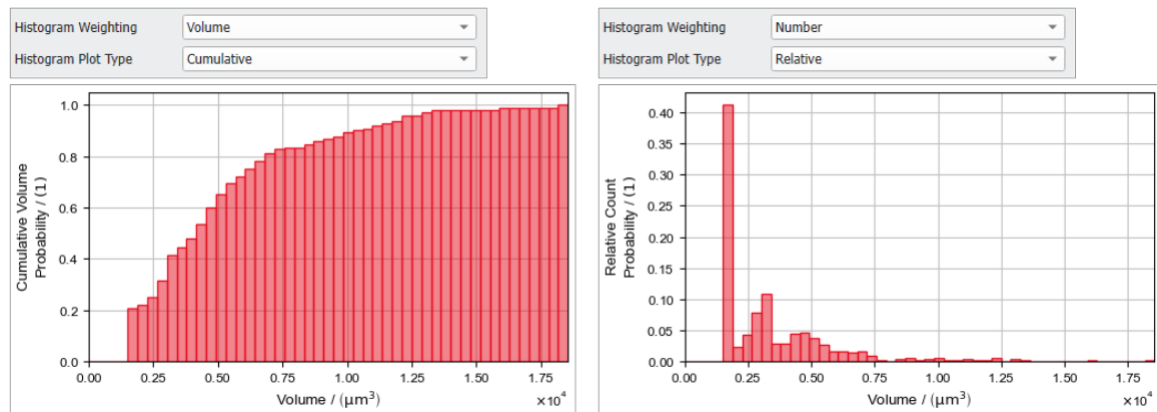
choose. For the Area Probability (weighting by Surface) the surface area of each segmented pore is computed using the same algorithm as in Estimate Surface Area (MatDict) command and then weighting the pores by that value. The computed surface area does also include the surface between different pores, not only the area between pore and solid material.

Histogram Weighting	Volume
	Volume
	Surface
	Number

Set the **Histogram Plot Type** to **Relative** to compare the individual proportions, or to **Cumulative** to show the accumulation over the data range.

Histogram Plot Type	Relative
	Relative
	Cumulative

The example on the left-hand side shows, that the smallest pores make up around 20% of the total pore volume. Compared to the weighting with numbers, 42% of the pores belong to the smallest pores in the structure.



You can customize the bin size for different histogram plots individually. In general, you can choose between:

- **Number of Bins:** choose how many bins the histogram should have.
- **Bin Size in Units:** choose the bin size for the histogram using the value in the displayed unit (e.g., μm , μm^3 , etc.).
- **Bin Size in Voxels:** choose the bin size for the histogram using the value measure in voxel lengths.

As the different histogram plots show different results, only those choices are available which make sense for the corresponding plot.

Volume	Bin Size in Units ▾	/ (μm^3)	300.0
Diameter	Number of Bins ▾	/ (1)	49
Perimeter	Bin Size in Voxels ▾	/ (Voxels)	2
Sphericity and Aspect Ratio	Number of Bins	/ (1)	49
Surface and Contact	Bin Size in Units ▾	/ (μm^2)	110
Surface-to-Volume Ratio	Bin Size in Units ▾	/ ($1/\mu\text{m}$)	0.0095
Surface Smoothness	Bin Size in Units ▾	/ (1)	0.021

The bin size can correspond to one single plot or multiple plots are changed at once:

- The selection made under **Volume** changes the bin size for the plot under the **Volume** tab.
- The selection made under **Diameter** changes the bin size for all plots under the **Diameters** tab.
- The selection made under **Perimeter** changes the bin size for the plot under the **Perimeter** tab.
- The selection under **Sphericity and Aspect Ratio** cannot be changed, this affects the bin size for the plots under the **Sphericities** tab and the plot under the **Aspect Ratio** tab.
- The selection made under **Surface and Contact** changes the bin size for the Surfaces and Contacts plots under the **Surfaces And Contacts** tab.
- The selection made under **Surface-to-Volume Ratio** changes the bin size for the **Surface-to-Volume Ratios plot** under the **Surfaces And Contacts** tab.
- The selection made under **Surface Smoothness** changes the bin size for the **Surface Smoothnesses plot** under the **Surfaces And Contacts** tab.

Pore Visualization

In the **Pore Visualization** tab you can load saved structures and computed volume fields which illustrate the pore identification process and its results.

Domain Size: 200 x 200 x 200 Voxel Length: 1 μm Load Structure

Input Map Log Map Post Map Results Pore Visualization Create Videos Metadata

Pore-Segmentation Result

Load Pores as Index Image	Load *.g32
Load Pore-Size Distribution	Load *.gsd
Load Pore-Orientation Distribution	Load *.gof
Load Pore-Contacts Structure	Load *.gdt
Load Pore-Network Structure	Load *.gad

Thresholding Result

Load Pore-Type Structure	Load *.gdt
Load Pore-Type Structure	Load *.gad

Shape-Analysis Result

Load Pore Fit Shapes	Load *.gad
Load Comparison of Segmented Pores and their Fits	Load *.gdt
Load Euclidean Distance Transform per Pore	Load *.dst

Intermediate Results

Load Pores from Step 1 (Result of Watershed)	Load *.gdt
Load Pores from Step 2 (Result of Pore Reconnection)	Load *.gdt
Load Pores from Step 3 (Result of Boundary-Pore Removal)	Load *.gdt

Several options are available for the visualization of the different steps of **Identify Pores** and for the evaluation of the quality of the results. Some options might be unavailable, depending on the previously chosen parameters in the **Identify Pores** dialog ([Output Options tab](#)⁶³). The visualization options are grouped into panels.



Note! For the 3D visualization of the volume fields, reduce the visibility (in the View Controls) to the pore space of the structure because most values in the solid parts are zero.

Visible on Material IDs

0

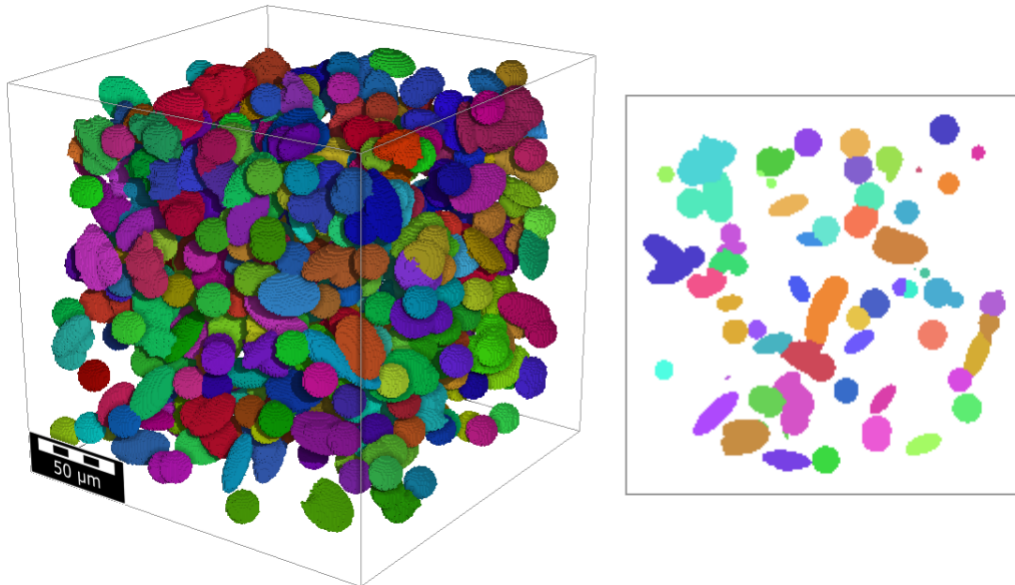
☒	00	Pore
☐	01	Solid

Pore-Segmentation Result

In the first panel, several options for the analysis of the identified pore shapes are available.

✓ Load Pores as Index Image

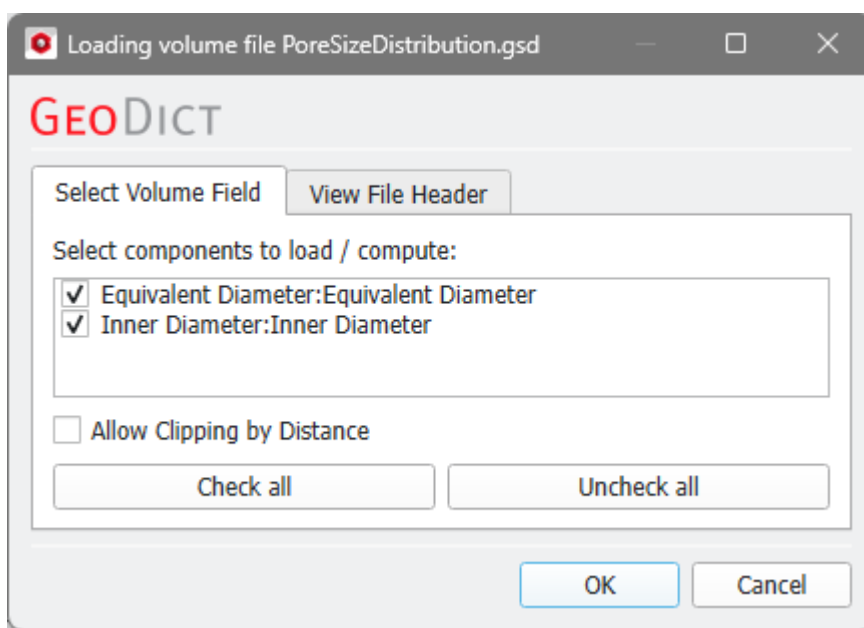
With **Load Pores as Index Image**, all identified pores are assigned to a unique 32-bit color and can be investigated in the Visualization area. The 2D-view of *.g32 files is particularly suited for visual analysis of the correct segmentation.



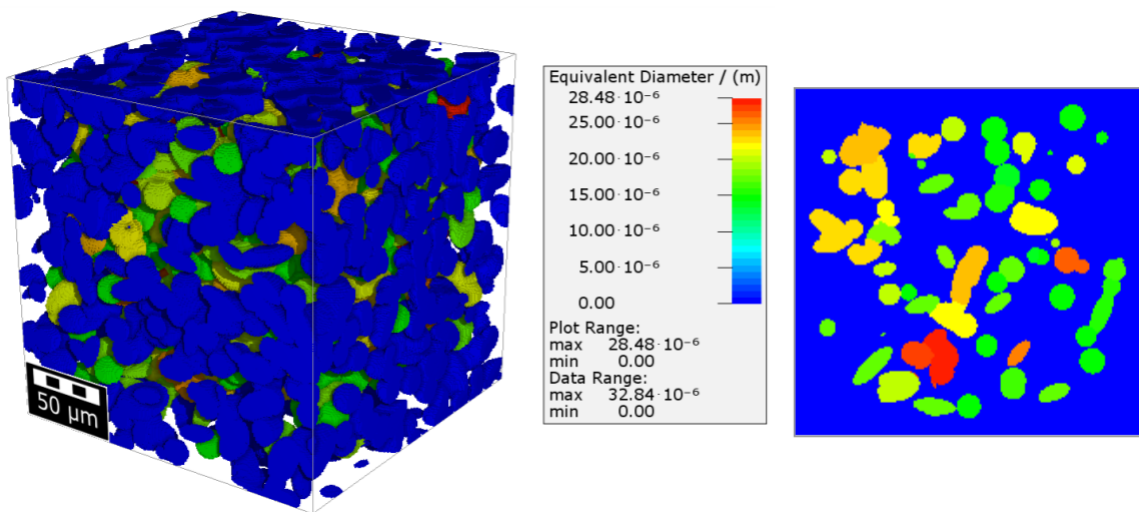
✓ Load Pore-Size Distribution

This file is only available if **Save Pore-Size Distribution (Volume-Equivalent Diameter)** as *.gsd has been checked in the [Output Options](#) ⁶³ tab and contains by default the **Equivalent Diameter** field, which is the diameter of a sphere with the same volume as the pore.

If **Save Inscribed-Sphere Diameters and Sheppard Sphericities** was checked, the *.gsd file additionally contains the fields of the **Inner Diameter**, which is the diameter of the largest sphere that can be fitted inside the pore.



In the example below, the [Boundary-Pore Removal](#)^[59] was activated, thus the pores touching the domain boundary have diameter zero as they are excluded from the analysis.

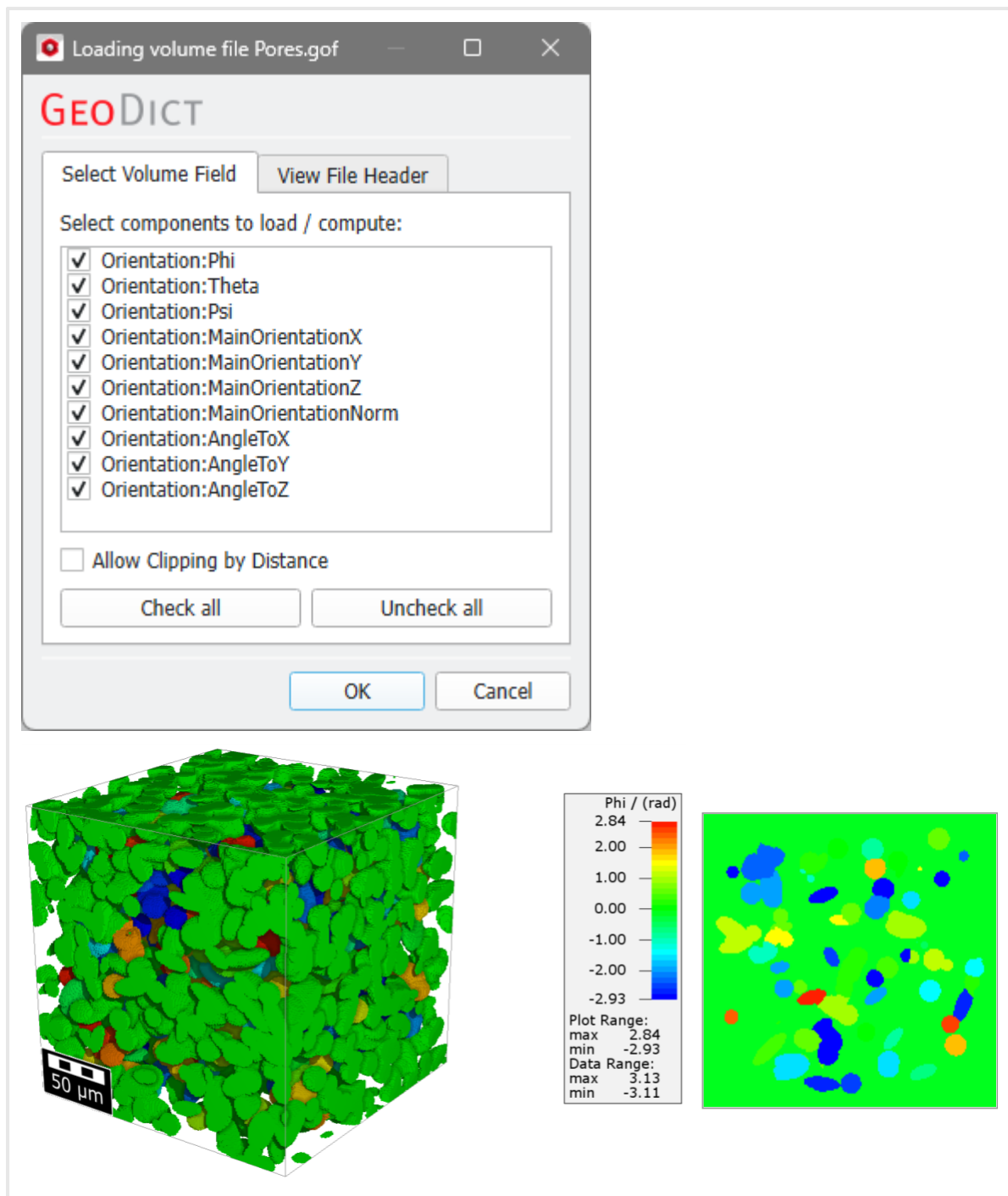


Note! When you selected scalar values under [GSD Field Choices](#)^[68] in the post-processing widget, you can load the created *.gsd file here. Depending on the choices, the file might contain additional or other fields.

✓ Load Pore-Orientation Distribution

This file is only available if **Save Pore-Orientation Distribution as *.gof** has been checked in the [Output Options](#)^[63] tab.

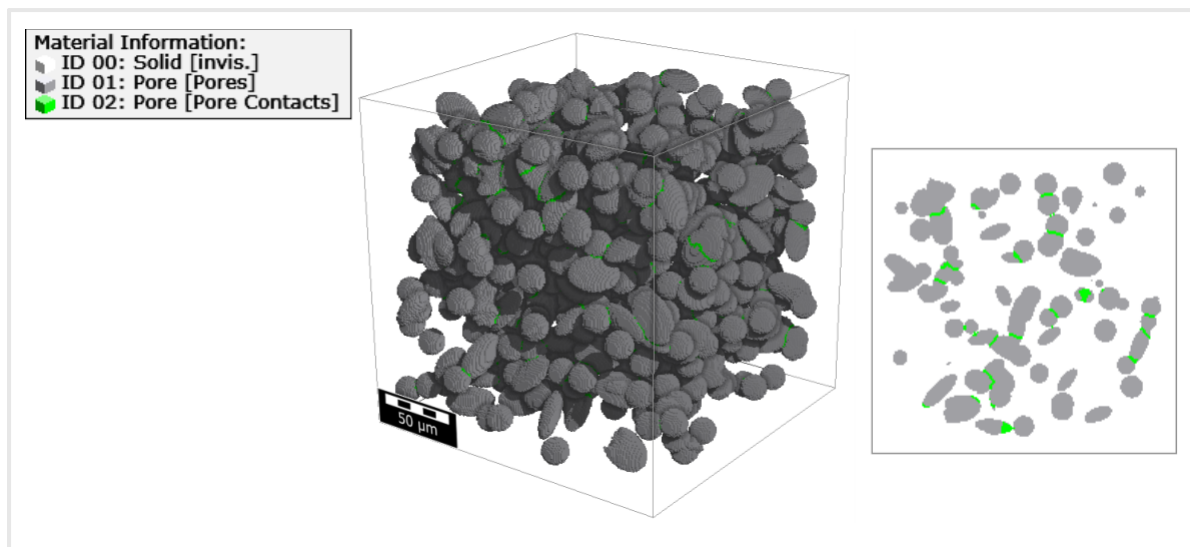
Several fields are saved in this file, e.g., the [Euler Angles](#) are available.



✓ Load Pore-Contacts Structure

This file is only available if **Save Pore-Contacts as *.gdt** has been checked in the [Output Options](#) ⁶³ tab.

The pores have Material ID 01, while the contacts have Material ID 02.

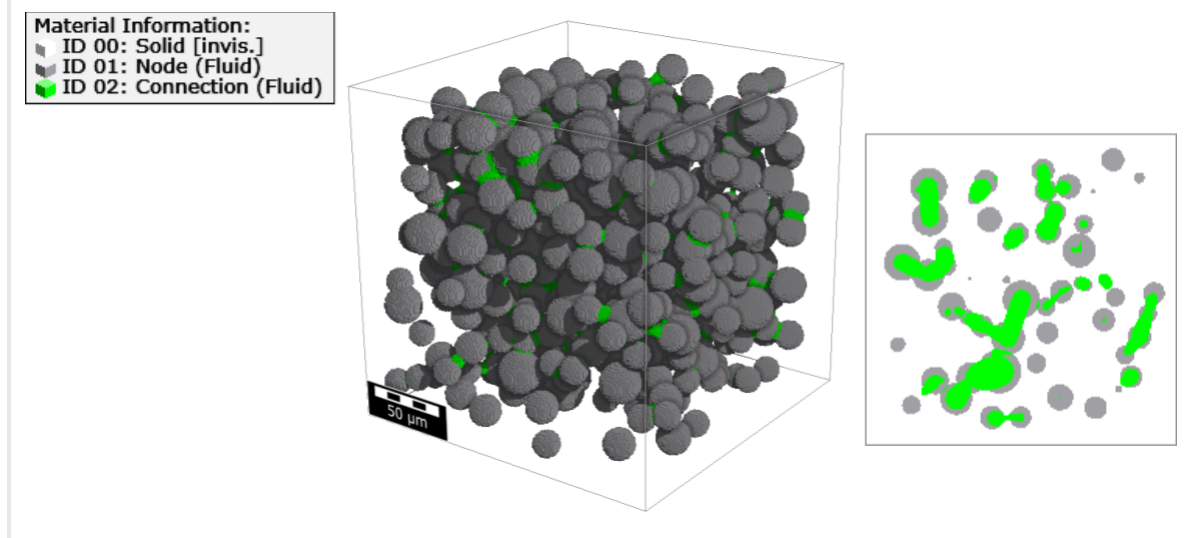


✓ Load Pore-Network Structure

This file is only available if **Save Pore-Network Model as *.gad** has been checked in the [Output Options](#) ⁶³ tab.

The pores (nodes) have Material ID 01, while the connections between them have Material ID 02.

The *.gad file is generated from the fitted ellipsoids. Pores are represented by spheres. The sphere centers are equal to the centers of the fit objects and their diameter equals the **Equivalent Diameter** (diameter of volume-equivalent sphere). The pore contacts are represented by short cylindrical fibers between the center points of the spheres. The cross-sectional area of the cylinders equals the contact area between the corresponding pores.



Thresholding Result

As explained in the previous topic, you can classify the pores by [Thresholding](#) ⁷³ a scalar value. For this example the default Threshold settings were used, where the pores are divided into two types based on the volume.

Threshold by Scalar Value

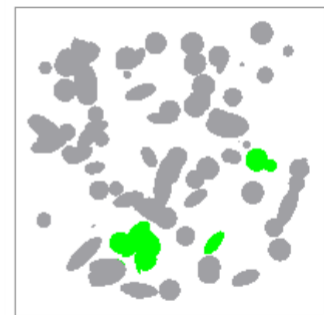
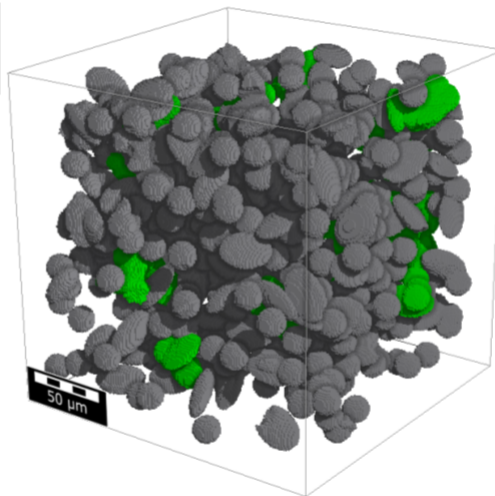
Scalar Value	Volume
Number of Bins	49
Thresholding Method	k-Means
Number of Pore Types	2

If you change the threshold settings, the pore-type structure will be recomputed.

✓ Load Pore-Type Structure as *.gdt

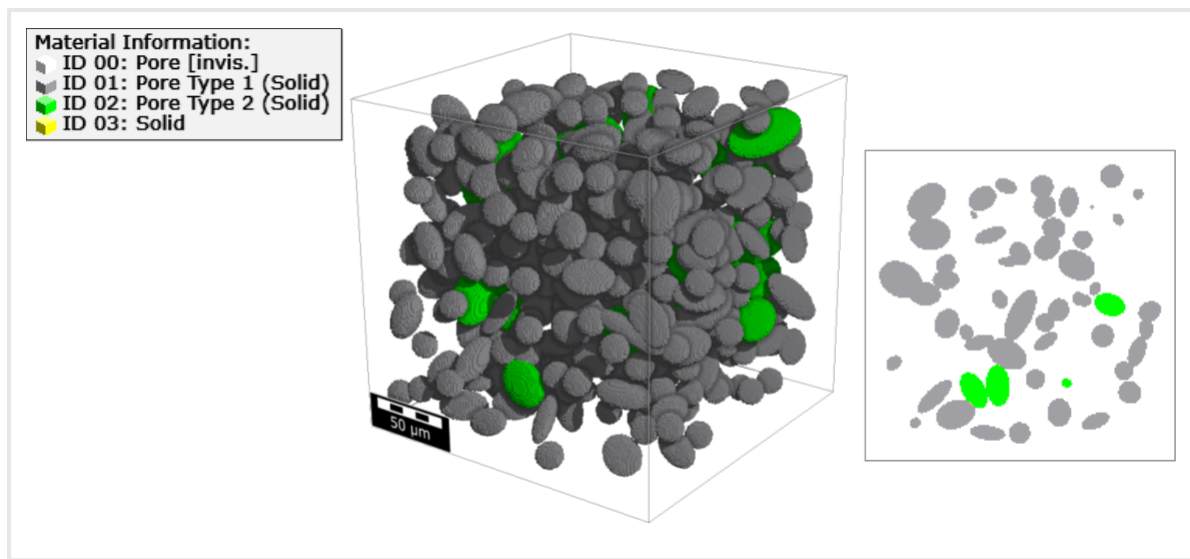
The pore-type structure saved in *.gdt format contains the identified pores with different Material IDs for the different pore types. The pores with a scalar value below the threshold (small pores) are assigned to Material ID 01 and the pores with a larger scalar value (large pores) are assigned to Material ID 02.

Material Information:
ID 00: Pore [invis.]
ID 01: Pore Type 1 (Solid)
ID 02: Pore Type 2 (Solid)



✓ Load Pore-Type Structure as *.gad

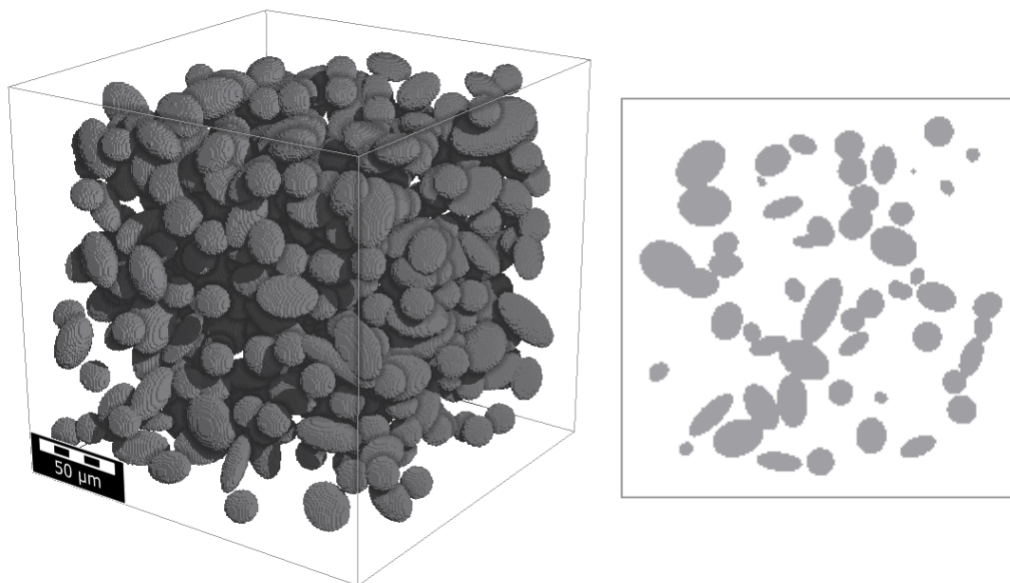
The pore-type structure saved in *.gad format contains the fitted ellipsoids with different Material IDs for the different pore types. Again, the pores with a scalar value below the threshold (small pores) are assigned to Material ID 01 and the pores with a larger scalar value (large pores) are assigned to Material ID 02.



Shape-Analysis Result

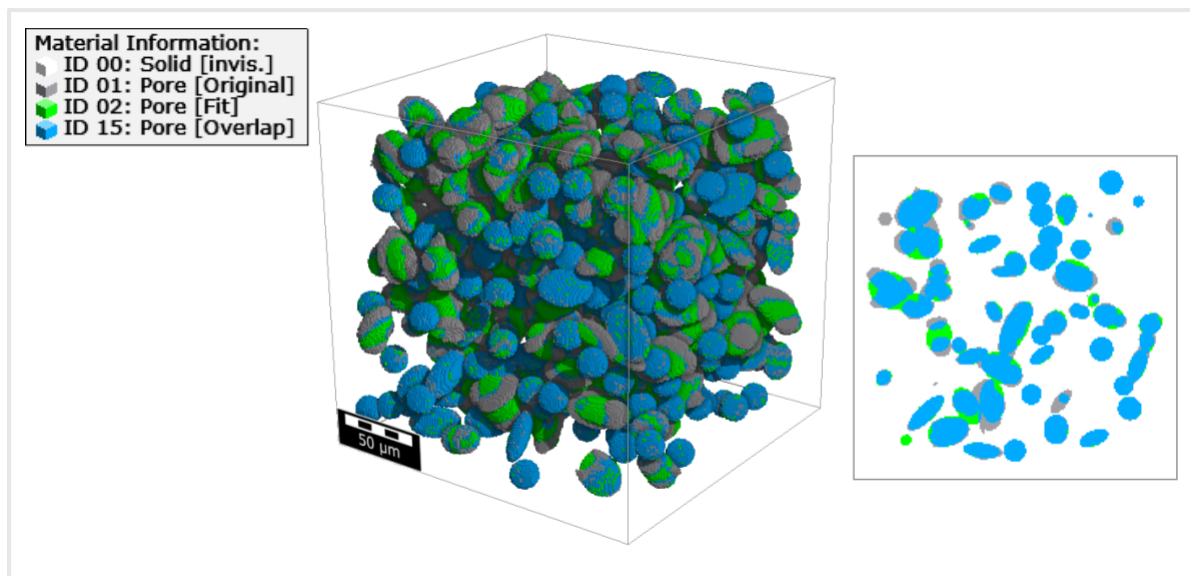
✓ Load Pore Fit Shapes

With **Load Pore Fit Shapes**, load the *.gad file of the fitted ellipsoids for the individual pores.



✓ Load Comparison of Segmented Pores and their Fits

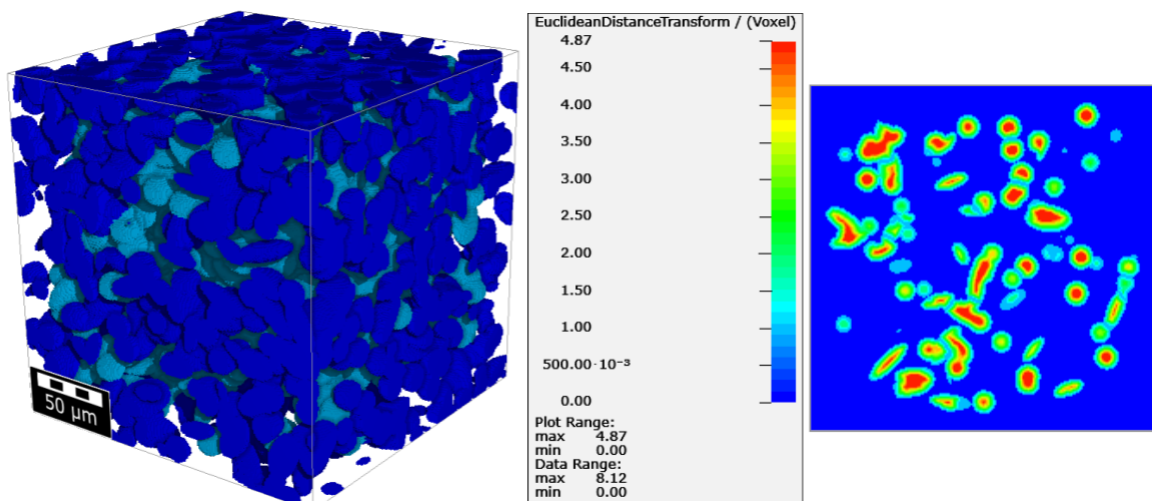
To evaluate the performance of the pore identification with the chosen options use **Load Comparison of Segmented Pores and their Fits**. The identified pores, their best-fit shapes, and their overlap are shown as different Material IDs (**Original**, **Fit**, and **Overlap**). Also have a look at the example in the topic [Pore-Shape Analysis](#).



✓ Load Euclidean Distance Transform per Pore

This file is only available if **Save Euclidean Distance Transform per Pore as *.dst** has been checked in the [Output Options](#) ⁶³ tab.

During the Identify Pores algorithm, first a Euclidean Distance Transform (EDT) and based on the results of a Watershed transformation are performed. You can load the result of the EDT as volume file by clicking **Load *.dst**.

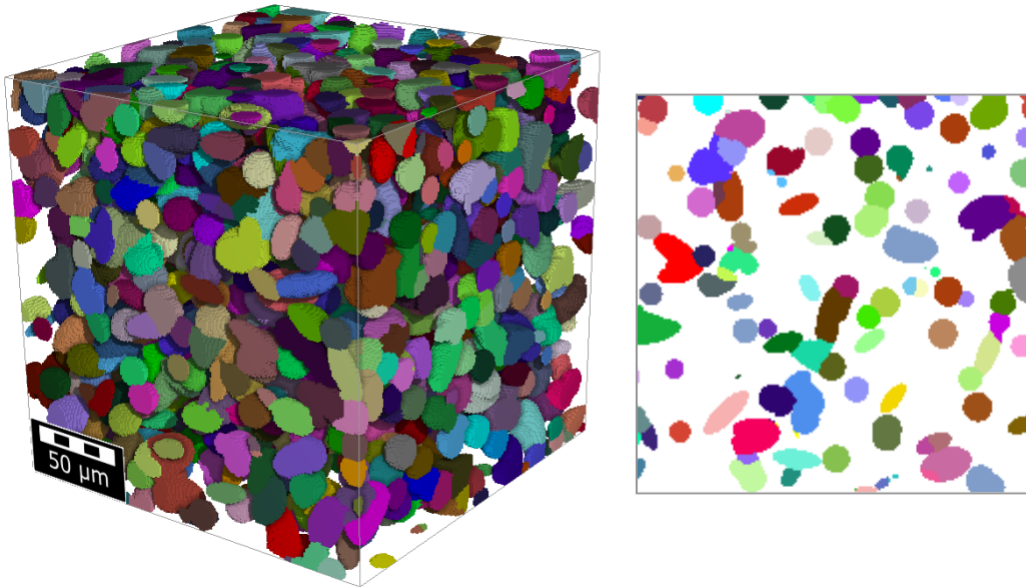


Intermediate Results

Results from the identification steps are loaded in the **Intermediate Results** panel.

✓ Load Pores from Step 1 (Result of Watershed)

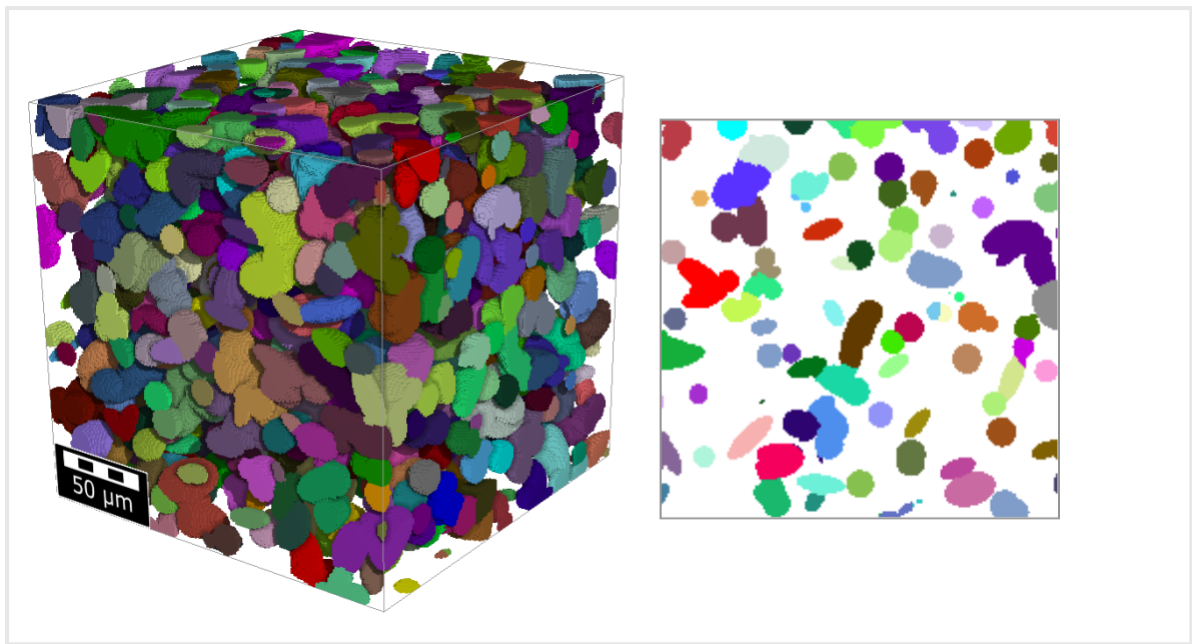
With **Load Pores from Step 1 (Result of Watershed)**, the segmented pores after the Watershed transform are shown without any post-processing. Depending on the structure and the chosen [Minimum Pore Diameter](#)^[52], this step might already be good enough to identify the pores. Otherwise, this option is useful to check the initialization options – mainly if the **Minimum Pore Diameter** was chosen correctly for the analyzed pore space.



✓ Load Pores from Step 2 (Result of Pore Reconnection)

This file is only available if [Reconnect Fragmented Pores](#)^[56] has been checked in the **Pore Segmentation** tab.

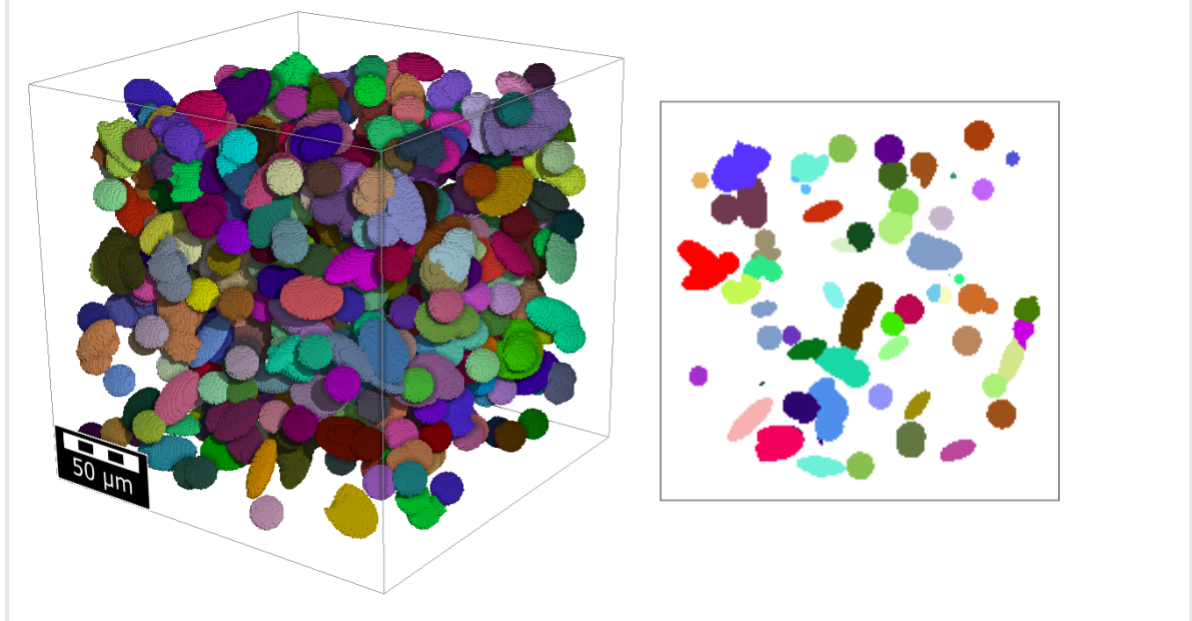
By clicking **Load Pores from Step 2 (Result of Pore Reconnection)**, the pores after the Pore-Fragment Reconnection are loaded in GeoDict. This way it can be assessed whether the chosen value for **Interface Threshold** suits the analyzed pore space.



✓ Load Pores from Step 3 (Result of Boundary-Pore Removal)

This file is only available if [Remove Pore Fragments at Domain Boundary](#)^[59] has been checked in the **Pore Segmentation** tab.

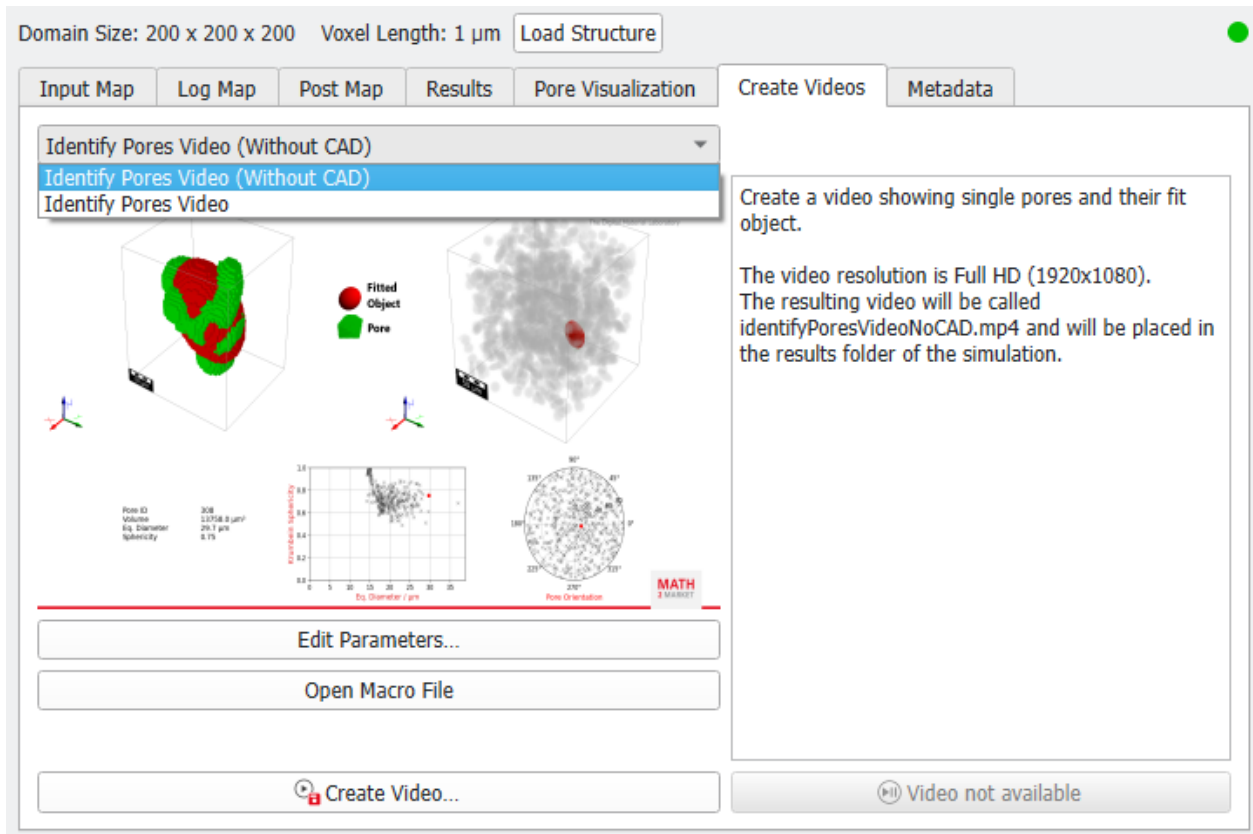
Click **Load Pores from Step 3 (Result of Boundary-Pore Removal)** to import the identified pores resulting from the removal of pore fragments at the domain boundary. This will be the basis structure for the fitting of the ellipsoids.



Create Videos

Generate a video showing the largest identified pores compared to their fit shapes from the **Create Videos** tab. The exemplary video shows which information will be visible in the video. At the top right, the current pore and its fit in the whole structure is highlighted. At the top left,

a crop to the single pore overlaid with its fit is shown. At the bottom left, the **Pore ID**, **Volume**, **Equivalent Diameter**, and **Sphericity** are displayed. In the bottom middle, the corresponding marker in the Equivalent Diameter - Krumbein Sphericity Scatter Plot is highlighted. At the bottom right, you can find the pore orientation highlighted in the orientation polar plot.

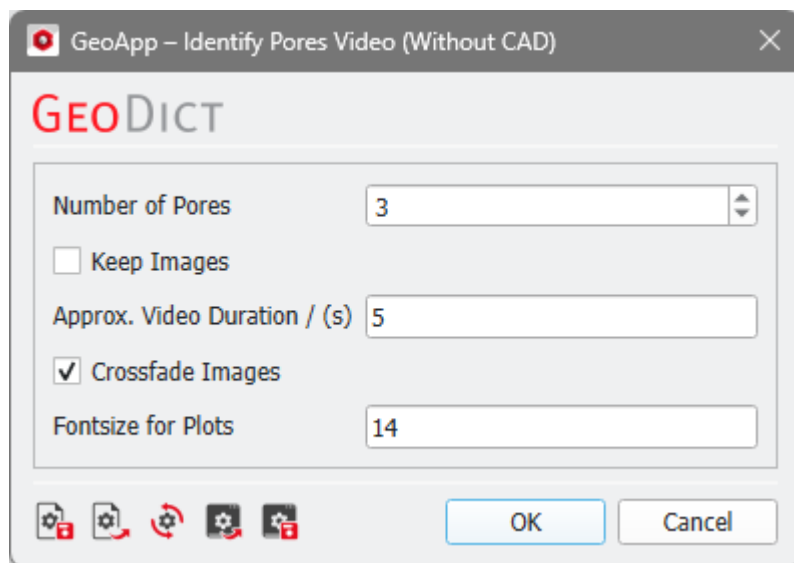


Above the exemplary video, choose from the drop-down menu if you want to create the video with or without CAD.

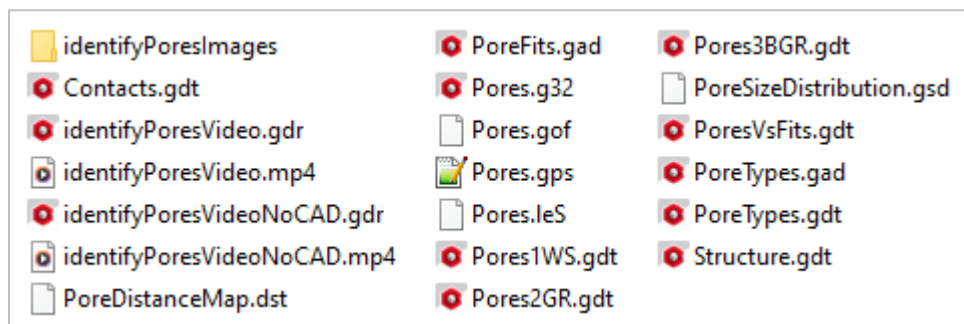


Important! You need an ExportGeo-CAD license to create the video with CAD! The version without CAD works in any case.

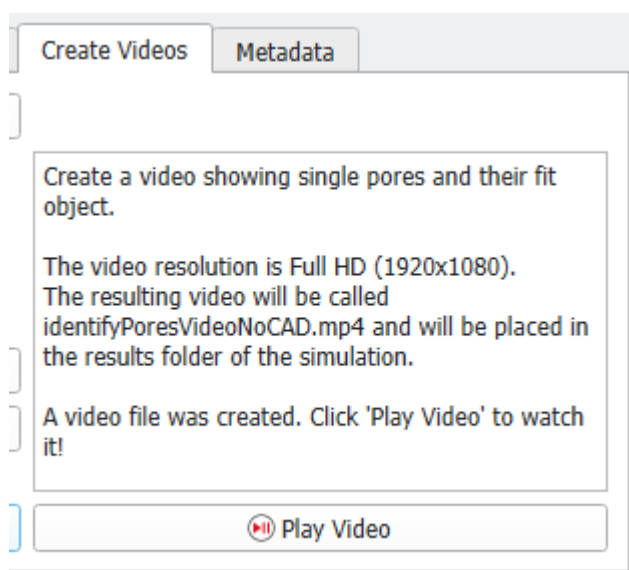
Click **Edit Parameters...** to choose the **Number of Pores** that should appear in the video. Additionally, you can edit the **Approx. Video Duration** and the **Fontsize for Plots** and their labels. Check **Keep Images** if you want to save the single images of the video. In the upper right corner of the video, the position of the currently shown pore and its fit in the whole structure is shown. If you want a smooth transition from pore to its fit, you can check **Crossfade Images**. Click OK to save the parameters and close the dialog.



To start the creation of the video click the **Create Video...** button. The video and the additional files are saved in the results folder belonging to the loaded *.gdr file. Open the result folder by right-clicking on the file name or file path in the Result Viewer Header section and choose **Open Result Folder**.



Click **Play Video** on the bottom right opens the video file in the default video player.



1.5 Open and Closed Porosity

Use **Open and Closed Porosity** to determine the connectivity of the pores to one or more domain boundaries. In the study of mechanical properties and structural integrity of porous materials, it is important to establish the pore morphology of the porous material. Morphological factors to be determined are the amount and percentage of open and closed pores, and the total pore volume percentage. Open pores are extensive networks of interconnected pores, leading from the surface to the core in any of the Cartesian directions. In contrast, isolated pores which do not open to the surface in any direction are referred to as closed pores.

The **Open & Closed Porosity** dialog opens when clicking the **Edit...** button.

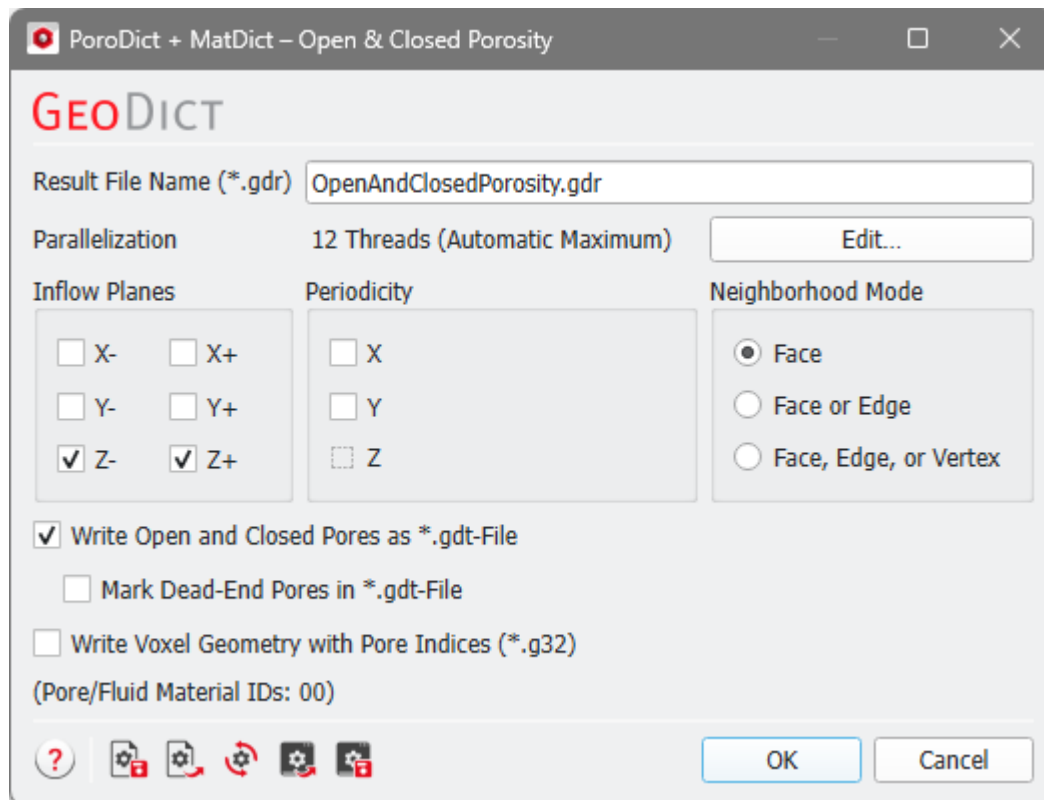


The Open and Closed Porosity command:

- [Options](#)⁹⁵
Set the parameters for the analysis.
- [Results](#)¹⁰²
View the computed results.

1.5.1 Options

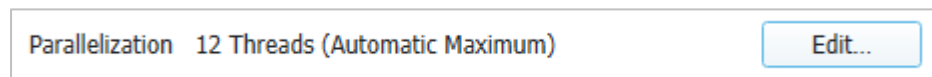
At the top of the dialog, enter the **Result File Name**. The result file is saved in the chosen project folder (**File** → **Choose Project Folder** in the menu bar).



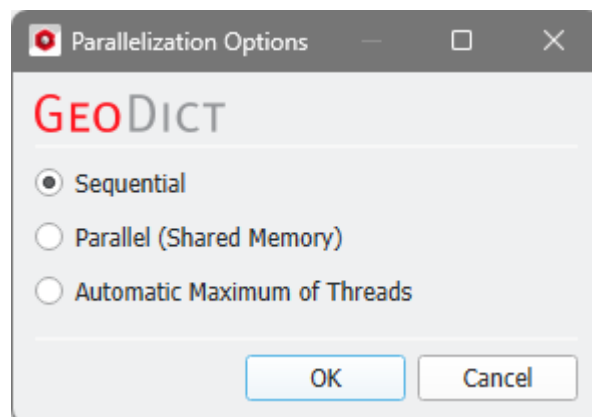
✓ Parallelization

Control how many threads are used for the computation. Parallelization is possible if your license and hardware allow it.

The **Parallelization Options** dialog opens when clicking the **Edit** button and you can choose between **Sequential**, **Parallel (Shared Memory)**, or **Automatic Maximum of Threads**.

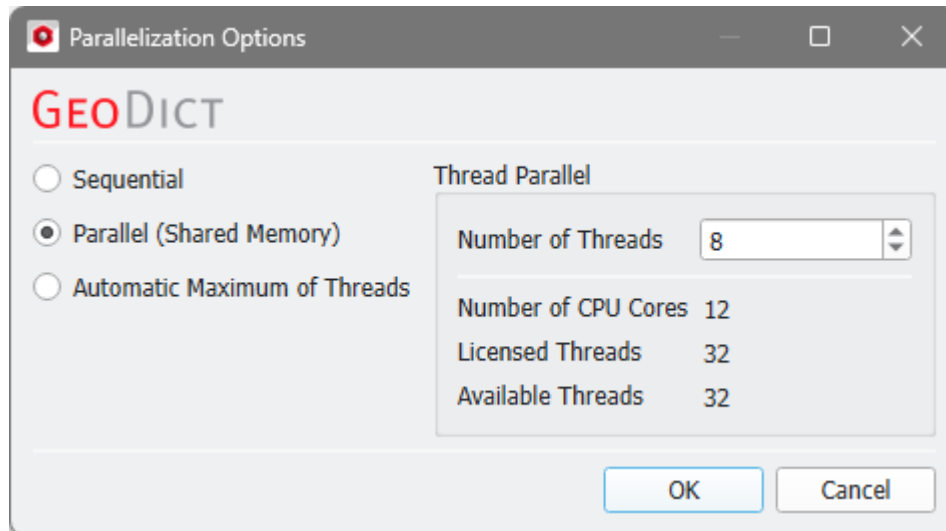


Selecting **Sequential** will not apply parallelization and only one thread is used for the computation.

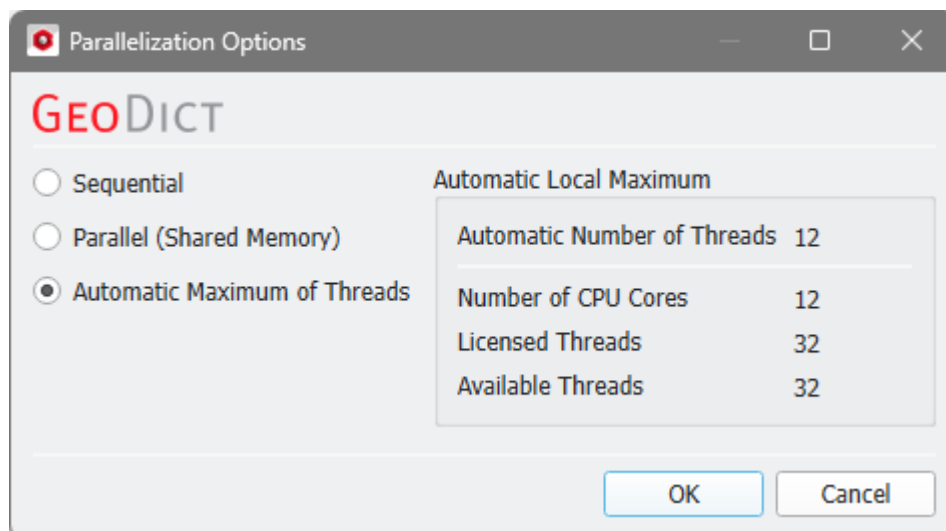


When **Parallel (Shared Memory)** is selected, the **Number of Threads** can be entered.

Below, the **Number of CPU Cores** that the current machine has, the maximum number of **Licensed Threads** and the number of those licensed threads that are available (**Available Threads**) are shown in the dialog. Of course, the maximal number of parallel processes you can use, is the smallest of those three numbers.



If **Automatic Maximum of Threads** is selected, the number of parallel processes is automatically selected for optimal speed, based on the CPU cores and licensed parallel processes.

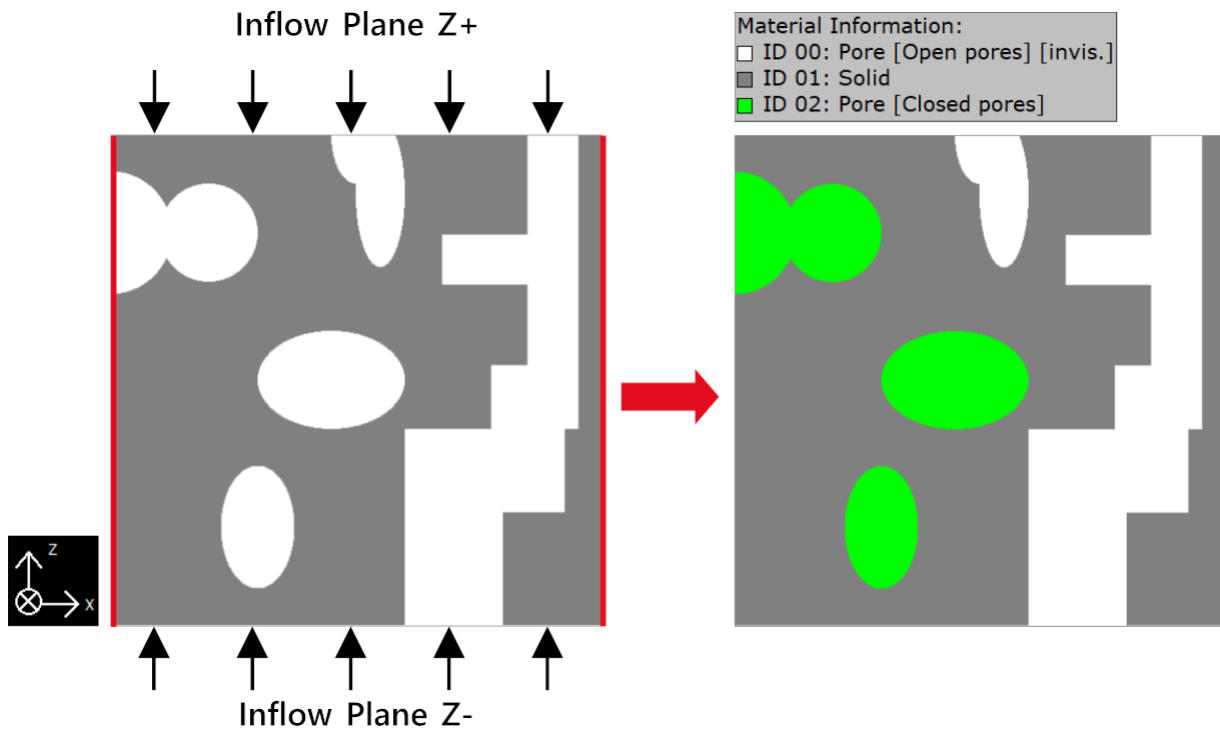


The **Automatic Local Maximum** of processes is automatically selected, which is the minimum of **Number of CPU Cores**, **Licensed Threads**, and **Available Threads**.

✓ Inflow Planes

Select one or more **Inflow Planes** to which the pores are open and considered as part of the open pore network. You can imagine that a fluid invades the structure from the inflow plane and all pores that are reached by the fluid are considered as open pores.

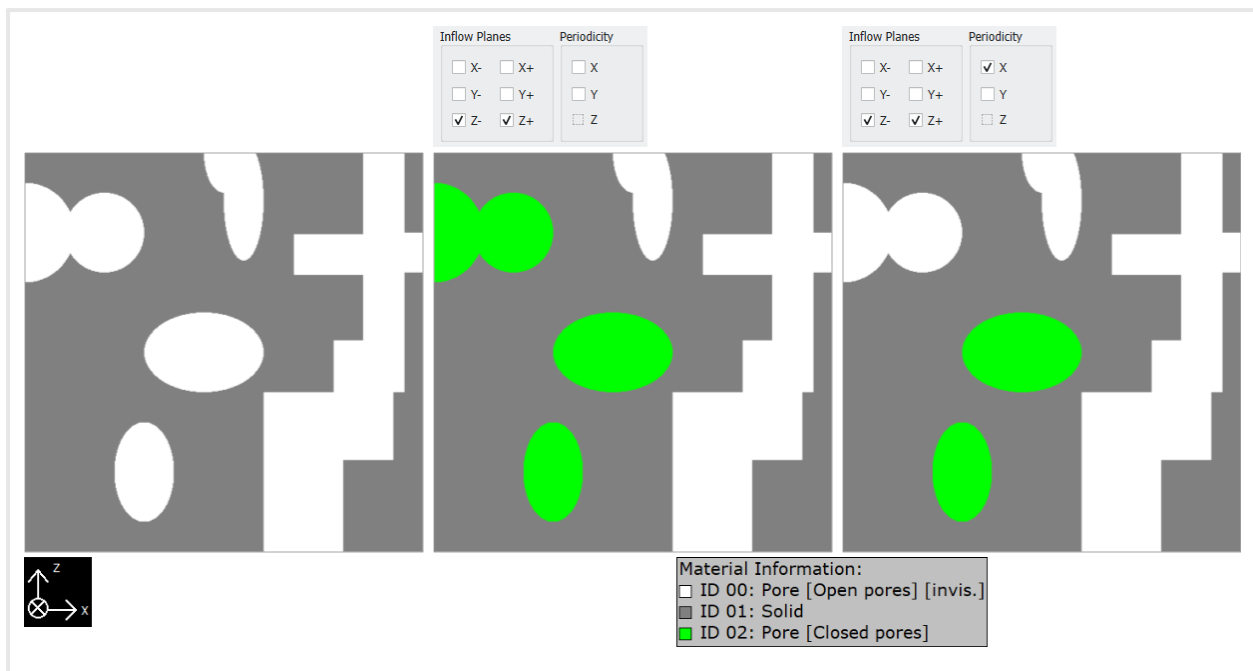
For example, here with the default Z- (x-y-plane through $z=1$) and Z+ (x-y-plane through $z=NZ$) checked, the inflow planes are located at the top and at the bottom of the structure. Then, pores that are connected to the inflow planes are marked as open pores (white), and pores that do not open to the inflow planes are considered as closed pores (marked in green).



✓ Periodicity

When you select **Periodicity**, the boundary pores in that direction will be periodically connected to the opposite domain side. Directions which you choose as **Inflow Plane** cannot be selected for Periodicity.

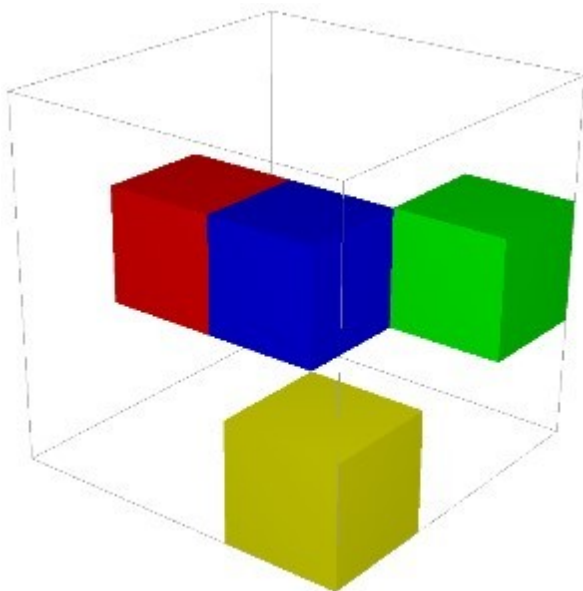
In the example below, Z- and Z+ were chosen as inflow planes. In the middle, the resulting open (white) and closed (green) pores when no **Periodicity** was chosen are shown. Only pores with a direct connection to the **Inflow Plane** are classified as open pores. On the right, Periodicity in X direction was selected. Now, the pore at the top left (touching X-boundary) is periodically connected to the X+ boundary to which the large pore has also a connection. Thus, the pore at the top left is also connected to the inflow planes and treated as open pore.



✓ Neighborhood Mode

With the **Neighborhood Mode** choose how the voxels from the pore space material in the structure are allowed to be connected to each other.

The different **Neighborhood Modes** are explained using this example.



Two voxels can be connected through faces, edges, and vertices (corners). Voxels that share a face, do also share edges and corners, as you can observe for the **red** and the **blue** voxel. The **blue** and the **green** voxel share an edge and the corner points of this edge. Finally, the **blue** and the **yellow** voxel share only one vertex (corner point).

Thus, checking **Face** is more restrictive than choosing **Face or Edge**, and this is more

limiting than selecting **Face, Edge, or Vertex**.

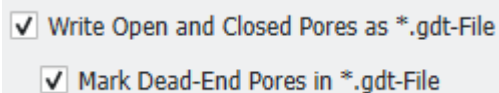
When choosing the Neighborhood Mode **Face** only the red and the blue voxel are connected.

When choosing **Face or Edge** the red and the blue voxel and the blue and the green voxel are connected.

Finally, if **Face, Edge, or Vertex** is chosen, the red and the blue voxel, the blue and the green voxel and the blue and the yellow voxel are connected.

✓ Write Open and Closed Pores as *.gdt-File

Check **Write Open and Closed Pores as *.gdt-File** to save a structure file, where the closed pores get another Material ID than the open pores. The resulting structure files of the examples for the parameters Inflow plane and Periodicity are those *.gdt files. You can load this structure file into GeoDict from the [Data Visualization](#)¹⁰⁴ tab in the Result Viewer.



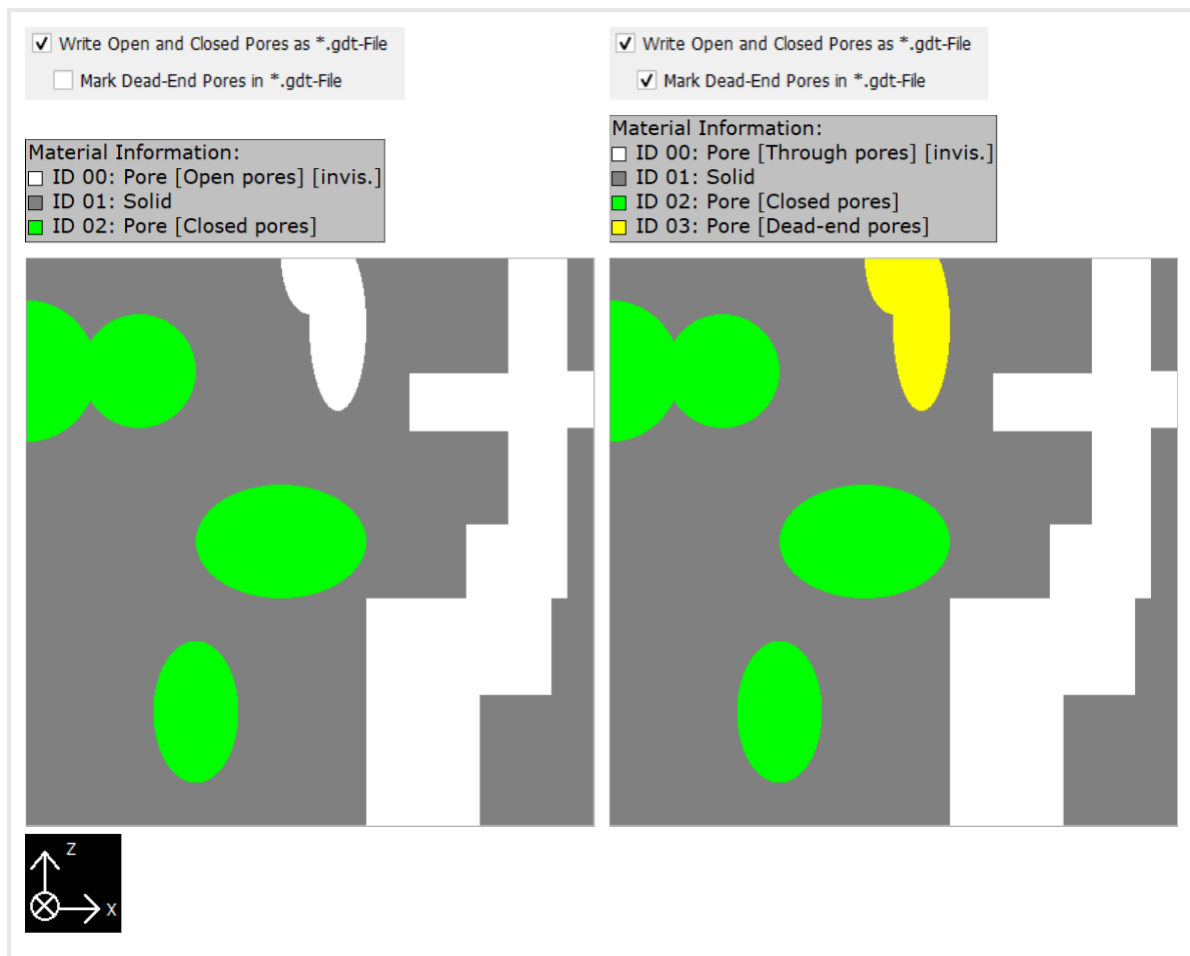
If you choose to save open and closed pores as *.gdt file, you have the option to **Mark Dead-End Pores in *.gdt-File**. This saves a further classification (as different Material IDs) of the open pores into the file:

- **Dead-end pores** are open pores which have contact with only one of the specified inflow planes.
- **Through pores** are open pores which connect multiple specified inflow planes.



Note! This classification only makes sense if multiple inflow planes are chosen.

In the example below, Z- and Z+ were chosen as inflow planes and no periodicity is applied. When **Mark Dead-End Pores in *.gdt-File** was checked, the open pore at the top will be marked as dead-end pore, because it only has connection to the Z+ inflow plane. The large pore at the right goes from top to bottom and is connected to both inflow planes. Thus, it is marked as through pore.



✓ Write Voxel Geometry with Pore Indices (*.g32)

Check **Write Voxel Geometry with Pore Indices (*.g32)** to save an index image as *.g32 file, where each pore is assigned an individual index number. You can load this file into GeoDict from the [Data Visualization](#)¹⁰⁴ tab in the Result Viewer.

In the example below, Z- and Z+ were chosen as inflow planes. When no periodicity is checked, the pore at the top left is not connected to the large pore on the right, so they have different index numbers (resulting in different colors). If periodicity is applied in X-direction, the two pores are connected and have the same index number in the g32 file.



1.5.2 Results

After the **Open and Closed Porosity** calculation is finished, the resulting files are saved in the project folder and a Result Viewer with the GeoDict result file opens automatically. The created GeoDict result file (*.gdr) contains five tabs. The computational results are shown under the **Results** tab, and can be loaded for visualization via the **Data Visualization** tab. The other three tabs (**Input Map**, **Log Map**, and **Metadata**) display additional information about the computation.

Find more details on the general functionalities in the Result Viewer user guide.

Under the **Results - Report** subtab, the **Open and closed porosities** table shows the **Overall porosity** and its decomposition into **Open porosity** and **Closed porosity**. Also, the total **Number of pores** which is the sum of **Number of open pores** and **Number of closed pores** is given.

Below, if more than one inflow plane was selected, a second table shows the **Dead-end porosity** and the **Through porosity**, as well as the **Number of dead-end pores** and the **Number of through pores**.



Note! All porosities are in volume percent and base on the total volume of the structure.

Input Map
Log Map
Post Map
Results
Data Visualization
Metadata

Report
Map

Open and closed porosities

Overall porosity / (%)	34.8904
Open porosity / (%)	21.82
Closed porosity / (%)	13.0704
Number of pores	5
Number of open pores	2
Number of closed pores	3

Dead-end and through pores

The open pores can be sub-classified in:

- dead-end pores, which have only contact with one of the specified inflow planes.
- through pores, which connect multiple specified inflow planes.

Dead-end porosity / (%)	2.7012
Through porosity / (%)	19.1188
Number of dead-end pores	1
Number of through pores	1

Remark: Porosities are in volume percent of the total volume of the sample.

Open and Closed Porosity Results:

- [Data Visualization](#)¹⁰³
Load results for a graphical visualization.

Data Visualization

Depending on the choices in the settings dialog the distribution of the open and closed pores can also be visualized through the **Data Visualization** tab.

Input Map
Log Map
Post Map
Results
Data Visualization
Metadata

Index Image of Pores (*.g32)
Load *.g32
Pores as Structure(*.gdt)
Load *.gdt

Index Image of Pores

If [Write Voxel Geometry with Pore Indices \(*.g32\)](#)^[101] was checked, you can click the **Load *.g32** button to load an index image of the pores, where each pore has an individual index number.

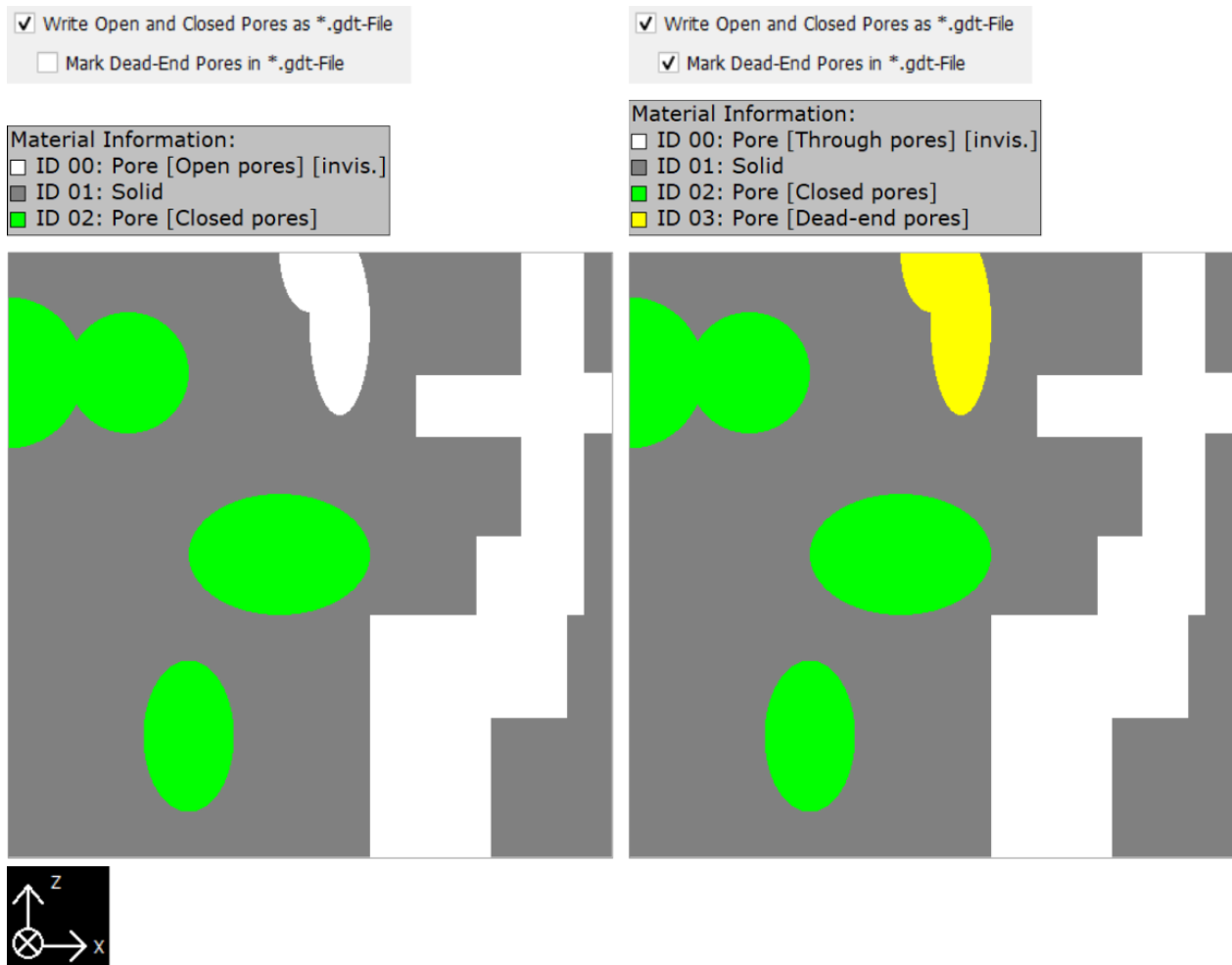


Pores as Structure

The **Load *.gdt** button is active if you chose [Write Open and Closed Pores as *.gdt-File](#)^[100] in the options dialog.

In this file, the open pores are assigned to the initial pore Material ID. The next free Material ID is assigned to the closed pores.

If **Mark Dead-End Pores in *.gdt-File** was additionally checked, the first Pore Material ID represents the **Through Pores** and the **Dead-end Pores** are assigned the next free Material ID after the closed pores, here ID 03 in yellow.



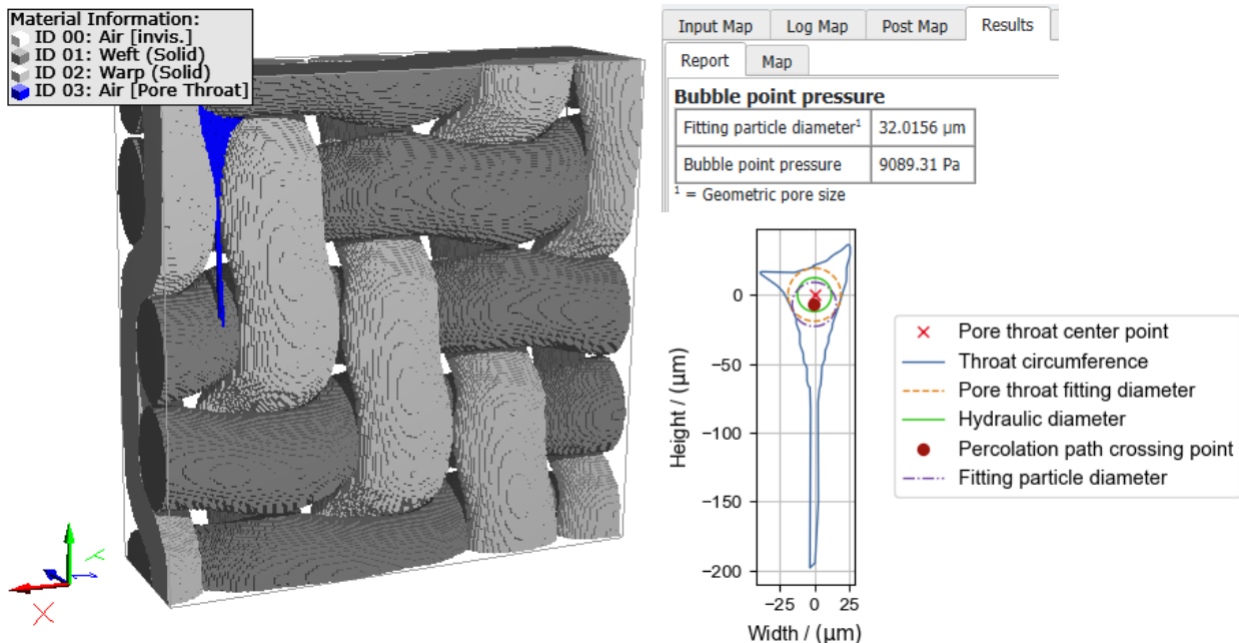
1.6 Bubble Point

The **Bubble Point** test is done to determine the Bubble point pressure. The Bubble point pressure is defined as the pressure at which the first bubble of gas appears while increasing pressure on a sample filled with a fluid. It must be sufficient to overcome the surface tension of the fluid and it is a direct measure of the effective pore diameter. Find more details about the theory behind the **Bubble Point** algorithm in the [Theoretical Basics](#)^[12] section.



Important! The structure resolution has to be high enough so that the smallest pore throat has at least a resolution of 5 voxels. Otherwise the detected bubble point may not be at the correct location.

The **Bubble Point** dialog opens when clicking the **Edit...** button.



The Bubble Point command:

- [Options](#)^[106]
Set the parameters for the analysis.
- [Results](#)^[112]
View the computed results.

1.6.1 Options

At the top of the dialog, enter the **Result File Name**. The result file is saved in the chosen project folder (**File** → **Choose Project Folder** in the menu bar).

✓ Wetting Parameters

Enter the **Wetting Phase Contact Angle** and the **Non-Wetting Phase Contact Angle**, which add up to 180°. They are adjusted automatically when changing one of the two values. For a solid material phase, the fluid with a contact angle smaller than 90° is **wetting** and the other fluid (with contact angle larger than 90°) is **non-wetting**. Thus, for the **Wetting Phase Contact Angle** only values between 0° and 90° are allowed.

For bubble point experiments, usually the water is the wetting fluid, while the injected gas is non-wetting.

Specify the **Surface Tension** of the fluids or use the default value of 0.07275 N/m corresponding to the surface tension between water and air at 20°C.

✓ Flow Direction

Choose the direction (**X**, **Y**, or **Z**) in which the pressure will be applied.

✓ Domain Boundary Conditions

The **Domain Boundary Condition** in the chosen flow direction is always set to symmetric, for the tangential boundaries you are free to choose other boundary conditions.

The **Domain Boundary Conditions** can be chosen to be **Symmetric**, **Periodic**, **Encase**, or any combinations of those boundary conditions in all three directions with the choice of **Expert**.

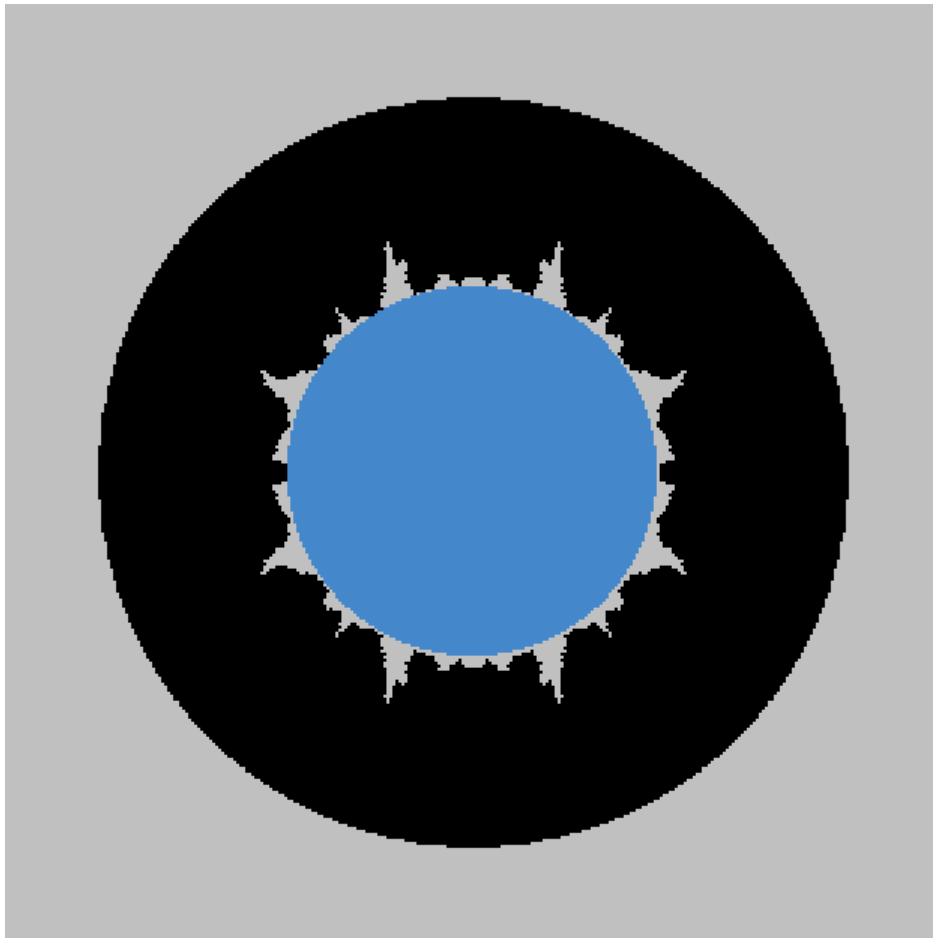
Choosing the appropriate boundary condition depends on the structure's design.

For example, imagine a structure with a cross-section as shown below.

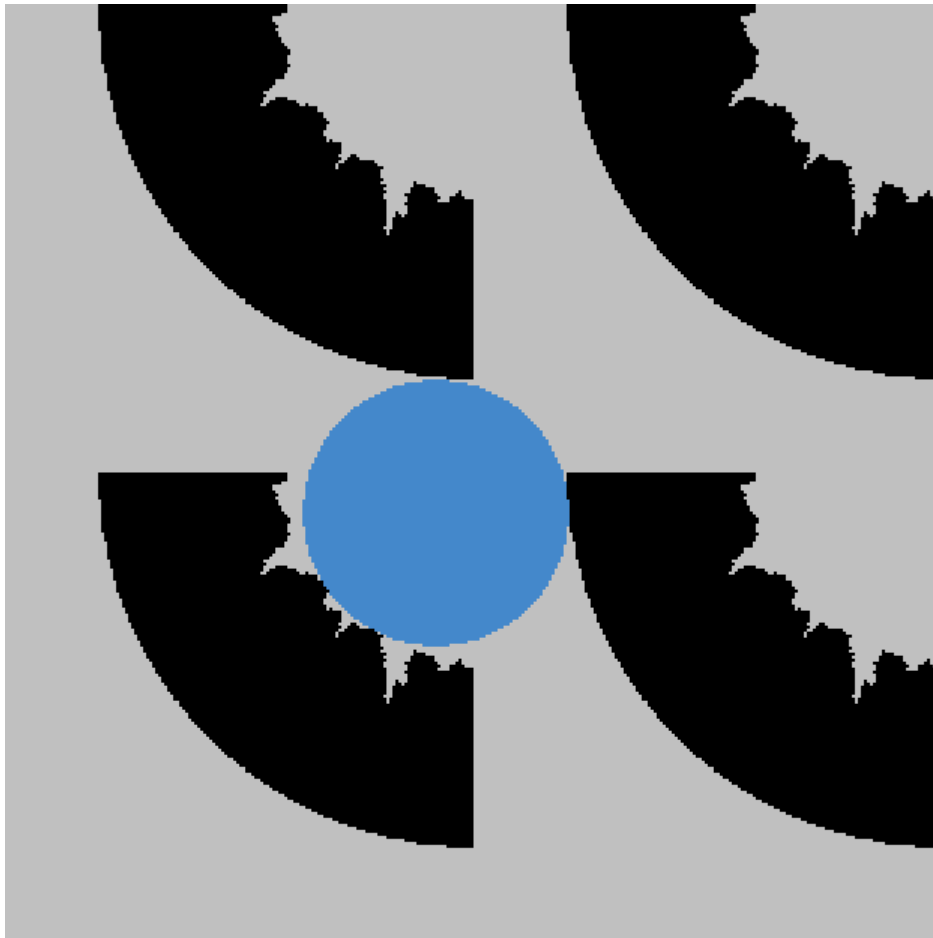


For the three boundary condition options the resulting pore size is visualized in blue.

- If **Symmetric** boundary conditions are taken, the geometry is mirrored at the domain boundary.



- If instead the expected pattern of the geometry is repeated in all directions, **Periodic** boundary conditions should be selected. That has the effect that the objects and pores of the structure that end on one side of the structure reappear on the opposite side.



- If the structure should be encased with a closed wall, the **Encase** boundary conditions are used.



Check **Expert** to apply different boundary conditions for each direction. You can combine the three above mentioned boundary conditions independently for the directions. For example, the boundary conditions could be chosen to be Encase in X-direction, Symmetric in the Y-direction and Periodic in Z-direction.

Domain Boundary Conditions

☐ Symmetric
☐ Periodic
☐ Encase
☒ Expert

Expert Settings

X
Encase
Y
Symmetric
Z
Periodic

High Resolution

To run the calculations in **High Resolution** might be useful when the path space is expected to be narrow. The standard algorithm computes distances directly on the voxel grid, i.e., when determining a pore size, only the distances from the center of a pore voxel to the center of a solid voxel are taken into account. High Resolution also takes the voxel surfaces and edges into account, so the computed distances correspond to the distance to the next surface or edge. The disadvantage of the **High Resolution** mode is that the calculation runtime and memory usage may increase by a factor of eight.

Domain Size: 216 x 216 x 63	Voxel Length: 2.5 μm	Load Structure		Domain Size: 216 x 216 x 63	Voxel Length: 2.5 μm	Load Structure	
Input Map	Log Map	Post Map	Results	Input Map	Log Map	Post Map	Results
Report	Map			Report	Map		
Bubble point pressure Fitting particle diameter ² 30.4138 μm Bubble point pressure 9568.02 Pa ¹ = Geometric pore size				Bubble point pressure Fitting particle diameter ² 32.0156 μm Bubble point pressure 9089.31 Pa ¹ = Geometric pore size			
Total runtime: 00:00:03, Total memory usage: 835.000 MiB				Total runtime: 00:00:00, Total memory usage: 686.000 MiB			

Detailed Pore Throat Analysis

Check **Detailed Pore Throat Analysis** to enable further geometric analysis of the smallest pore throat, including the location and the size. Multiple candidate throat planes along the percolation path will be tested by constructing planar ray-traced planes with varying tilt angles. The plane with the smallest area will be used for further analysis. This includes calculation of the hydraulic diameter, a detailed [plot of the pore throat](#)^[113] and enables [loading the voxelized pore throat](#)^[116] into GeoDict.

Remove Spikes

This option is only available if **Detailed Pore Throat Analysis** is checked.

The circumference of the smallest pore throat may exhibit spike-like extrusions, which have a strong influence on the geometrical analysis run. With the **Remove Spikes** option, those are removed before running the geometrical analysis. We advise to always have a look at the [pore throat plot](#)^[113], to identify spikes in the pore

circumference. If this is the case, re-run the command with **Remove Spikes** checked to achieve [better results](#)^[116].



Note! Either **High Resolution** or **Detailed Pore Throat Analysis** can be chosen, not both at the same time.

1.6.2 Results

After the **Bubble Point** calculation is finished, the resulting files are saved in the project folder and a Result Viewer with the GeoDict result file opens automatically. The created GeoDict result file (*.gdr) contains six tabs. The computational results are shown under the **Results** tab, and can be loaded for visualization via the **Data Visualization** tab. The other four tabs (**Input Map**, **Log Map**, **Post Map**, and **Metadata**) display additional information about the computation.

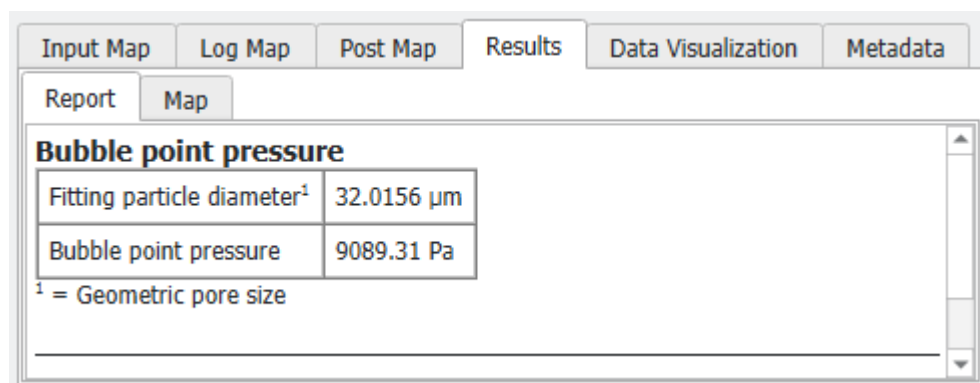
Find more details on the general functionalities in the Result Viewer user guide.

Bubble Point Results:

- [Results Tab](#)^[112]
Observe the computed results and plots.
- [Data Visualization](#)^[116]
Load results for a graphical visualization.

Results Tab

Report



Always reported are the **Fitting particle diameter**, which is the diameter of the largest sphere that fits in the pore throat (computed with the [Percolation Path](#)^[119] command), and the **Bubble point pressure**. The bubble point pressure P_B is computed from the determined through pore diameter d (which is the fitting particle diameter) using the Young-Laplace equation:

$$P_B = \frac{4\sigma}{d} \cos(\theta)$$

(9) Young-Laplace equation

where σ is the entered surface tension and θ is the entered wetting phase contact angle.

If a **Detailed Pore Throat Analysis** is run, additionally, the smallest pore throat is found and analyzed.

Detailed pore throat analysis

and hydraulic diameter estimation

Analyzed geometry of pore throat:

Smallest pore throat pos.	472.67, 479.49, 43.16 μm
Throat plane normal	0.30, -0.10, 1.02
Pore throat area	3306.85 μm^2
Pore throat circumference	536.387 μm
Hydraulic diameter ²	24.6602 μm
Hydraulic bubble point pressure ³	11800.4 Pa

²Hydraulic diameter: $4 \cdot \text{area} / \text{circumference}$

³Pressure calculated based on the hydraulic diameter

The position of the pore throat center point is given as **Smallest pore throat pos.** in metrical units. The normal vector of the pore throat plane (**Throat plane normal**) gives information about the orientation of the pore throat. The **Pore throat area** and the **Pore throat circumference** are used to calculate the **Hydraulic diameter** as:

$$D_H = \frac{4 \cdot \text{pore throat area}}{\text{pore throat circumference}}$$

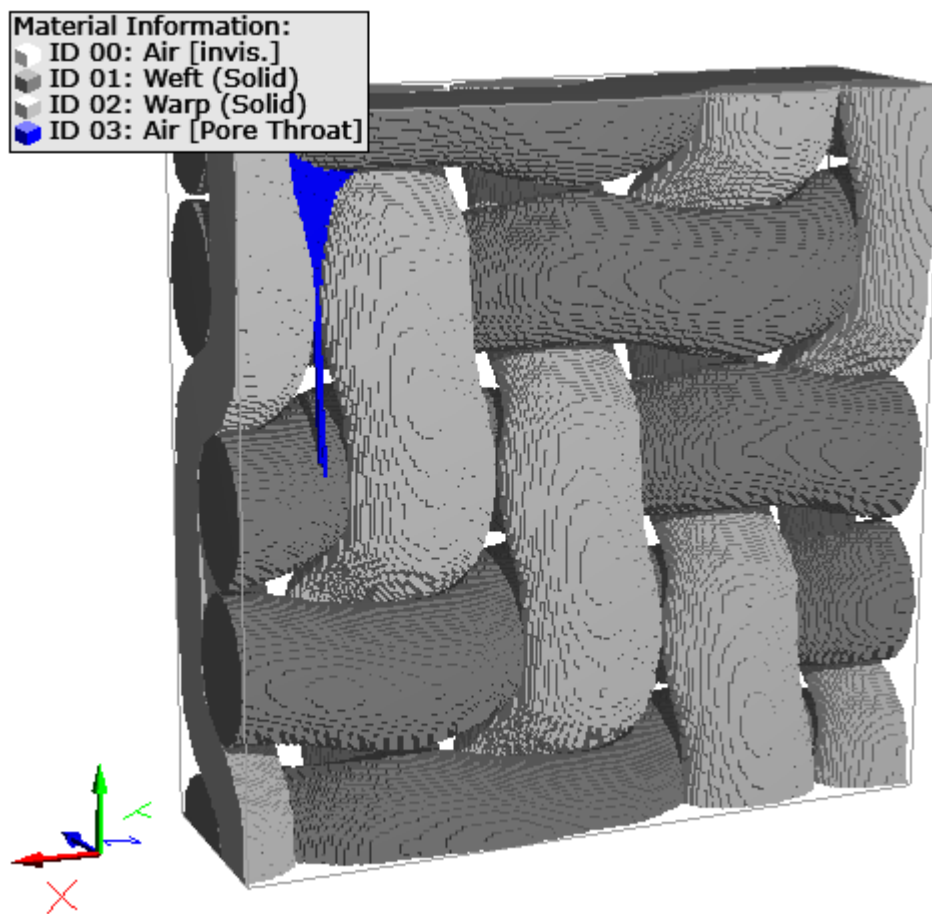
(10) Hydraulic diameter

The **Hydraulic bubble point pressure** uses the [Young-Laplace equation](#)^[113] with the hydraulic diameter for d , which yields a more precise bubble point pressure.

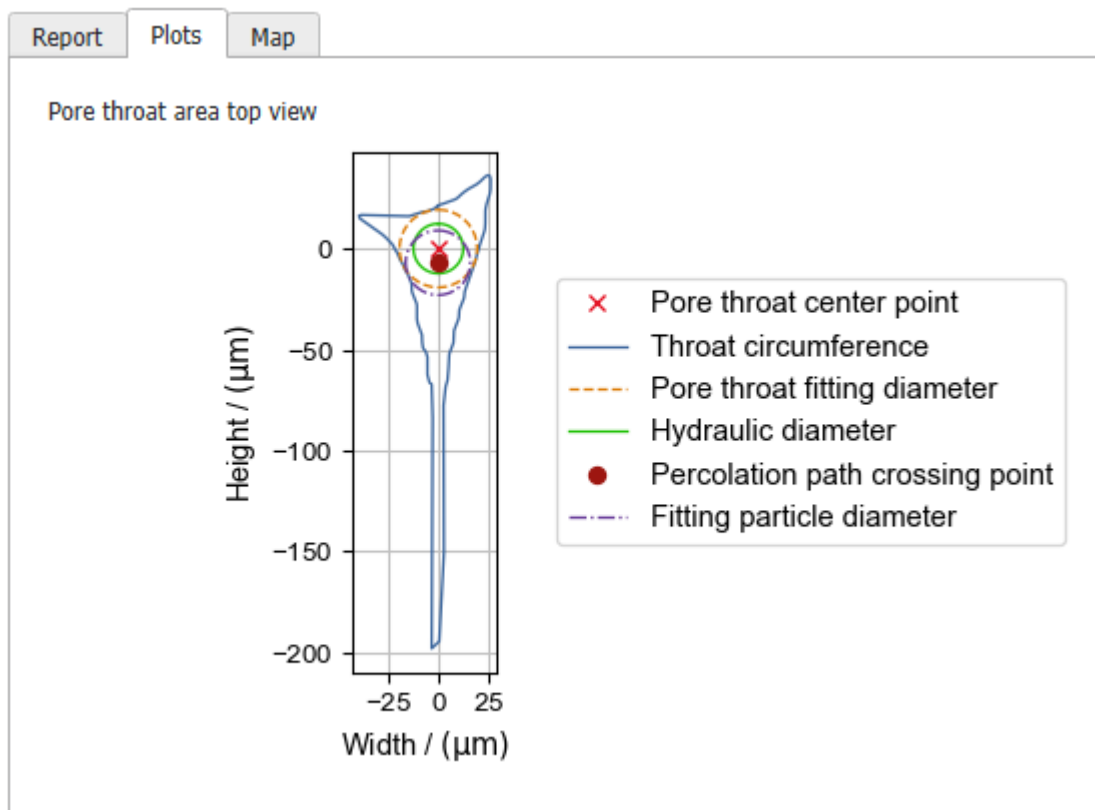
Plots

Plots are only available if a **Detailed Pore Throat Analysis** was conducted.

For better understanding, we show the example structure where the found pore throat (viewed from negative Z-direction) is marked in blue. You can load this kind of visualization from the [Data Visualization](#)^[116] tab.



The only plot shown in the Plots tab is the **pore throat area top view**. The area surrounded by the blue **Throat circumference** line corresponds to the blue area in the example above and is the outline of the pore throat.



Up to five other types of data can be plotted:

- The **Pore throat center point** is the center of the pore throat calculated as center point of the pore throat fitting diameter circle.
- The **Pore throat fitting diameter** describes the maximal circle around the pore throat center point. This parameter considers only the two dimensions of the cross section. Thus, it is only used for visualization and not for the bubble point computation. The corresponding plot is disabled by default. It can be enabled by right-clicking in the plot and checking the corresponding box.
- The **Hydraulic diameter**^[113] is calculated as shown above and shown is the circle with the same diameter around the Pore throat center point. It can be quite different from the Fitting particle diameter, especially for pore throats with sharp angles.
- The **Percolation path crossing point** is the point, where the percolation path crosses the pore throat. As the percolation path considers all three dimensions, the percolation path crossing point and the pore throat center point can be different.
- The **Fitting particle diameter** is the diameter of the spherical particle fitted into the pore throat when computing the percolation path. The percolation path crossing point is the center point of the circle described by this parameter.

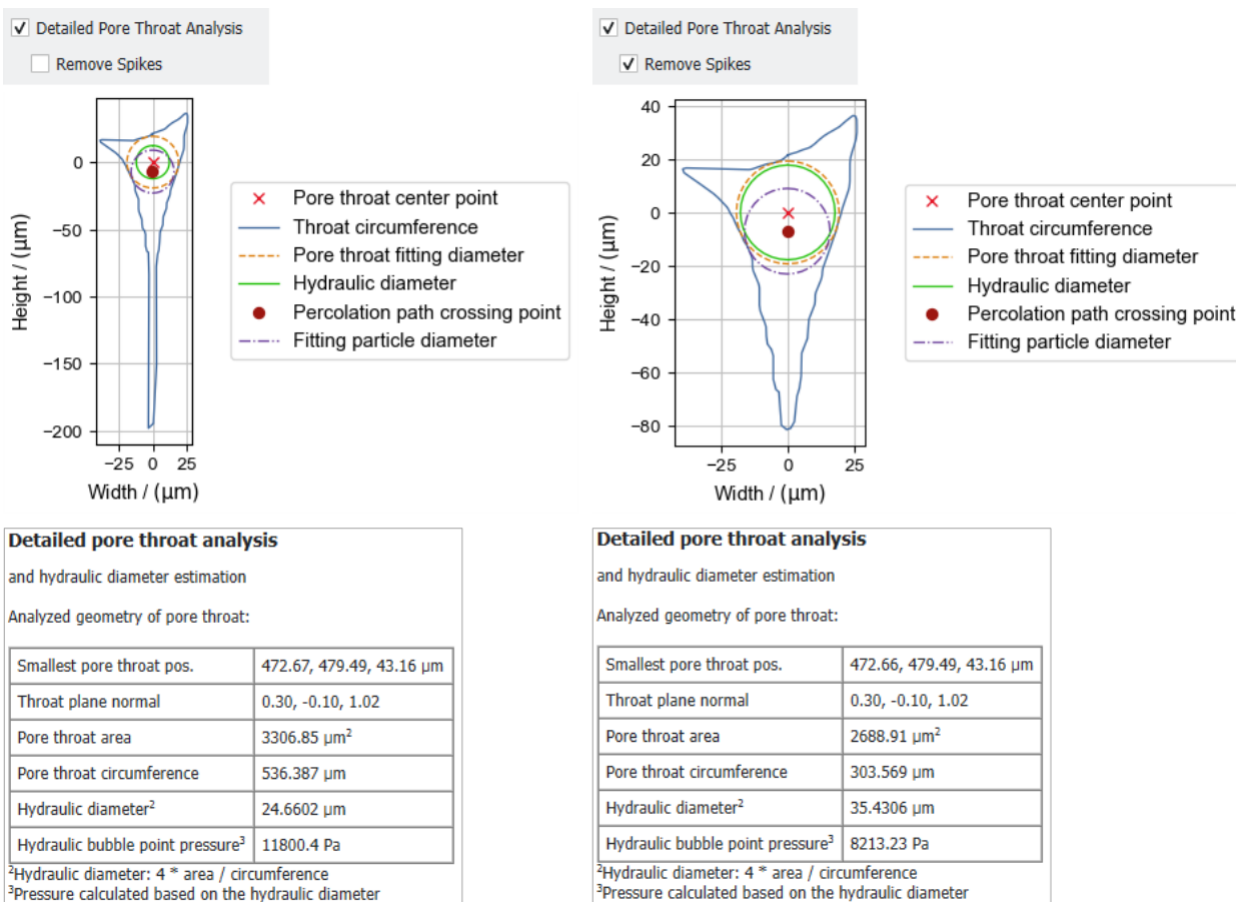


Know how! If the pore throat circumference has spikes like the one shown above, we recommend to enable the **Remove Spikes**^[111] option.

Effects of Remove Spikes

When **Remove Spikes** is used, the spikes seen in the circumference are removed before analyzing the pore throat geometry.

Therefore, the results for the **Detailed Pore Throat Analysis** in the Report tab and the **pore throat area top view** plot may vary. Below, observe that the spike causing a large height of the pore throat is removed when activating the **Remove Spikes** option. The results without this option are shown on the left and the results with this option are on the right.



Data Visualization

If you checked **Detailed Pore Throat Analysis**, you can load two additional files in the **Data Visualization** tab to visualize the bubble point pore throat.

Input Map
Log Map
Post Map
Results
Data Visualization
Metadata

Load Structure with Pore Throat (*.gdt)

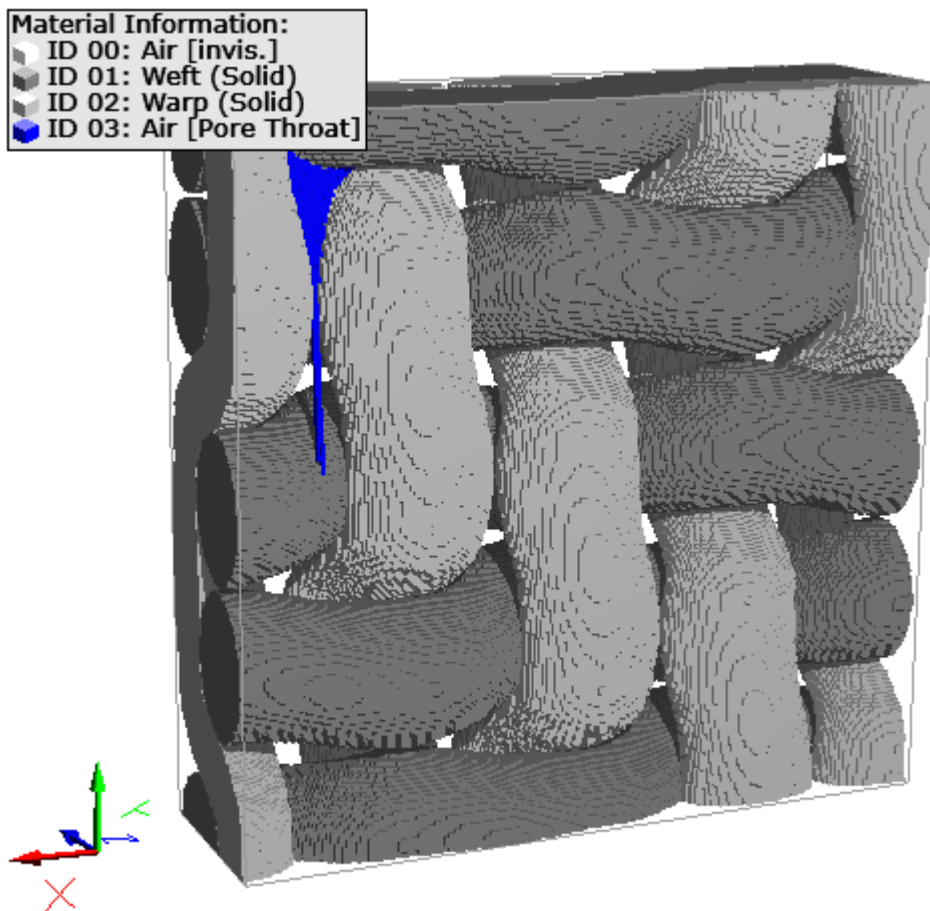
Load Pore Throat Geometry (*.stl)

Load *.gdt

Load *.stl

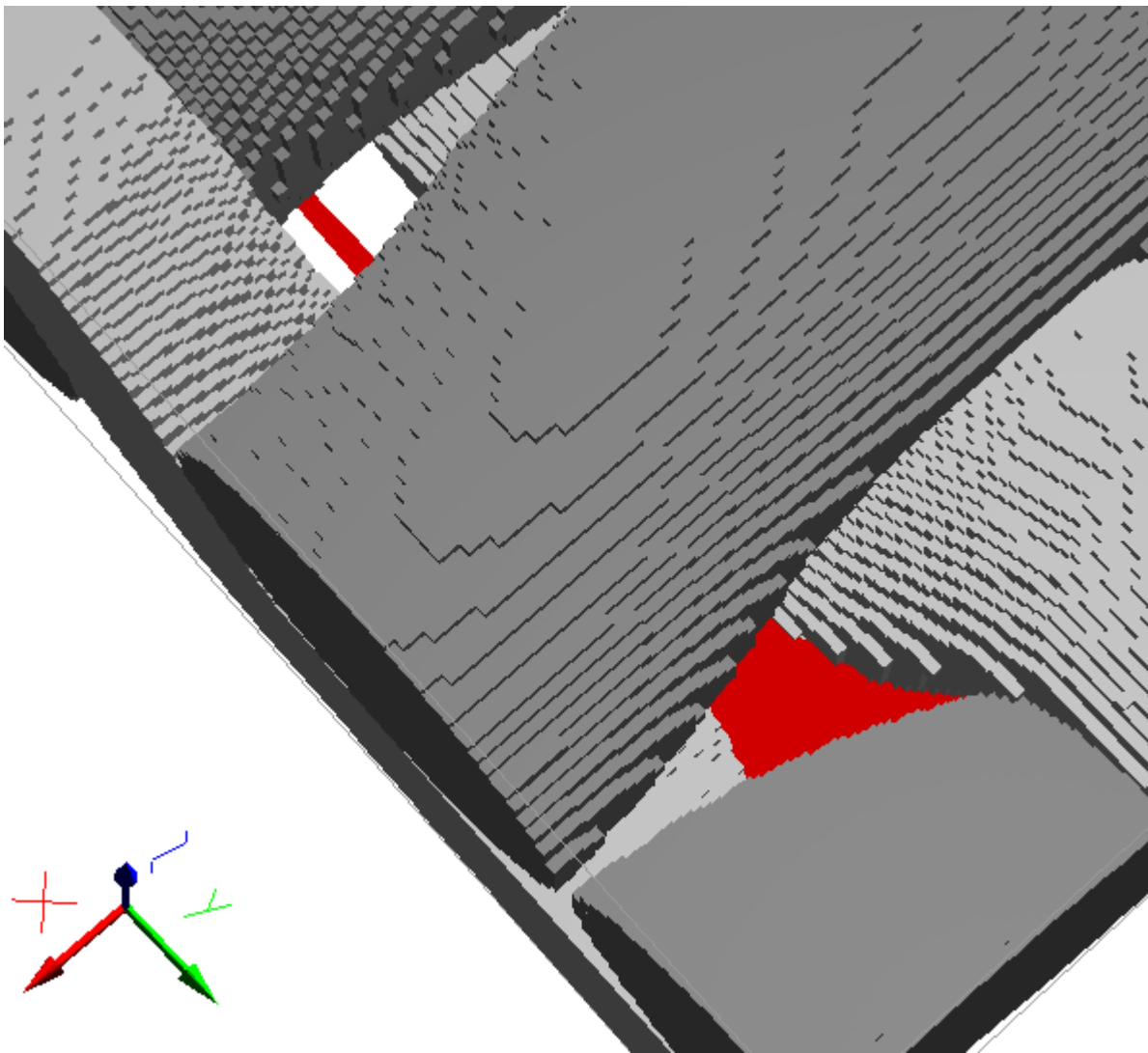
Load Structure with Pore Throat

Click on **Load *.gdt** to open a GDT file with the original structure and the pore throat voxels marked with another Material ID, in this example ID 03. Here, you can easily locate the pore throat in the structure.



Load Pore Throat Geometry

Click on **Load*.stl** to load a surface triangulation of the same pore throat. You can then save this triangulation as mesh to use it in other software.

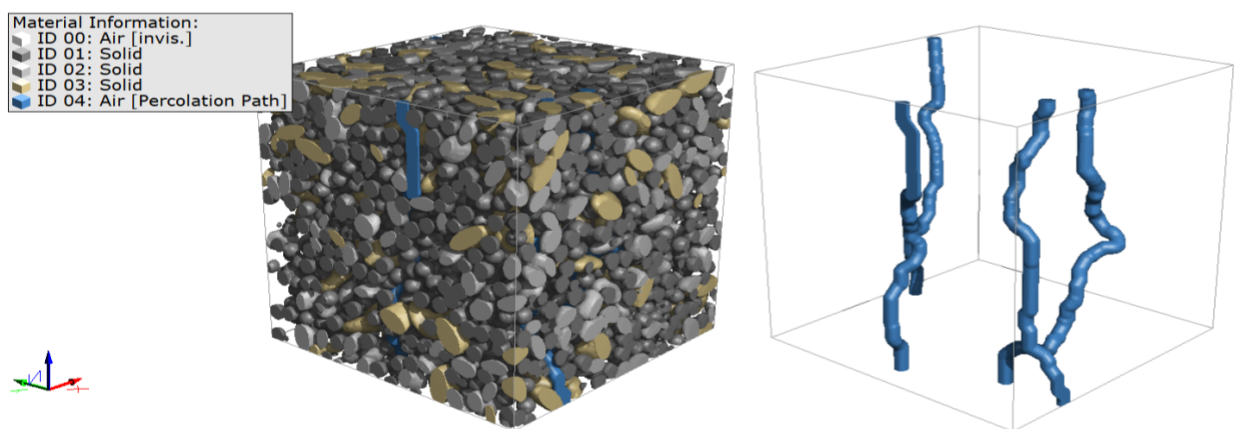


1.7 Percolation Path

The **Percolation Path** command is accessible from MatDict and PoroDict.

It determines the maximal diameters of spherical particles that can move through the medium. Two voxels of a percolation path are connected if they share a common face. In addition, the shortest paths of the largest particles are calculated and displayed. Also, the shortest path of a given sphere size through the medium can be computed when changing the Diameter Mode. Find more details about the theory behind the **Percolation Path** algorithm in the [Theoretical Basics](#) ¹²¹ section of the PoroDict user guide.

The **Percolation Path** dialog opens when clicking the **Edit...** button.



On the left, the four largest percolation paths found in a grainy structure are shown. The analytic geometries of the paths are shown on the right.

The Percolation Path command:

- [Options](#) ¹¹⁹
Set the parameters for the analysis.
- [Results](#) ¹²⁶
View the computed results.

1.7.1 Options

At the top of the dialog, enter the **Result File Name**. The result files are saved in the chosen project folder (**File** → **Choose Project Folder** in the menu bar).

MatDict – Percolation Path

GEO DICT

μm

Result File Name (*.gdr) PercolationPath.gdr

Computational Direction Z-direction

Material to Analyze

Pore Space

Number of Paths 1

Domain Boundary Conditions

☒ Symmetric ☐ Periodic ☐ Encase ☐ Expert

☐ Search Periodic Path

Diameter Mode Maximum Diameter

Maximum Diameter / (μm) 0

☐ High Resolution

☐ Save Center-Line

☐ Optimize Path

(Pore/Fluid Material IDs: 00)

? [Icons] OK Cancel

✓ Computational Direction

Set the direction of the paths by selecting the **Computational Direction**.

Computational Direction

Z-direction

X-direction

Y-direction

Z-direction

✓ Material to Analyze

The algorithm searches for paths in the selected **Material to Analyze**, either **Pore Space**, **All Solid Materials**, **Chosen Material**, or a list of **Chosen Material IDs**.

Material to Analyze

Pore Space
Pore Space
All Solid Materials
Chosen Material
Chosen Material IDs

Material to Analyze

Chosen Material IDs

1

	00	Air
☒	01	Solid

For your convenience, all Material IDs which denote pore space are shown at the bottom of the dialog.

✓ Number of Paths

The number of percolation paths to be detected is set with the **Number of Paths** parameter. Then, the algorithm computes the n best percolation paths.

✓ Domain Boundary Conditions

The diameters of pores and solids near the domain boundary are strongly influenced by the selected **Domain Boundary Conditions**. The boundary condition in the chosen computational direction is always set to symmetric, for the tangential boundaries you are free to choose other boundary conditions.

The **Domain Boundary Conditions** can be chosen to be **Symmetric**, **Periodic**, **Encase**, or any combinations of those boundary conditions in all three directions with the choice of **Expert**.

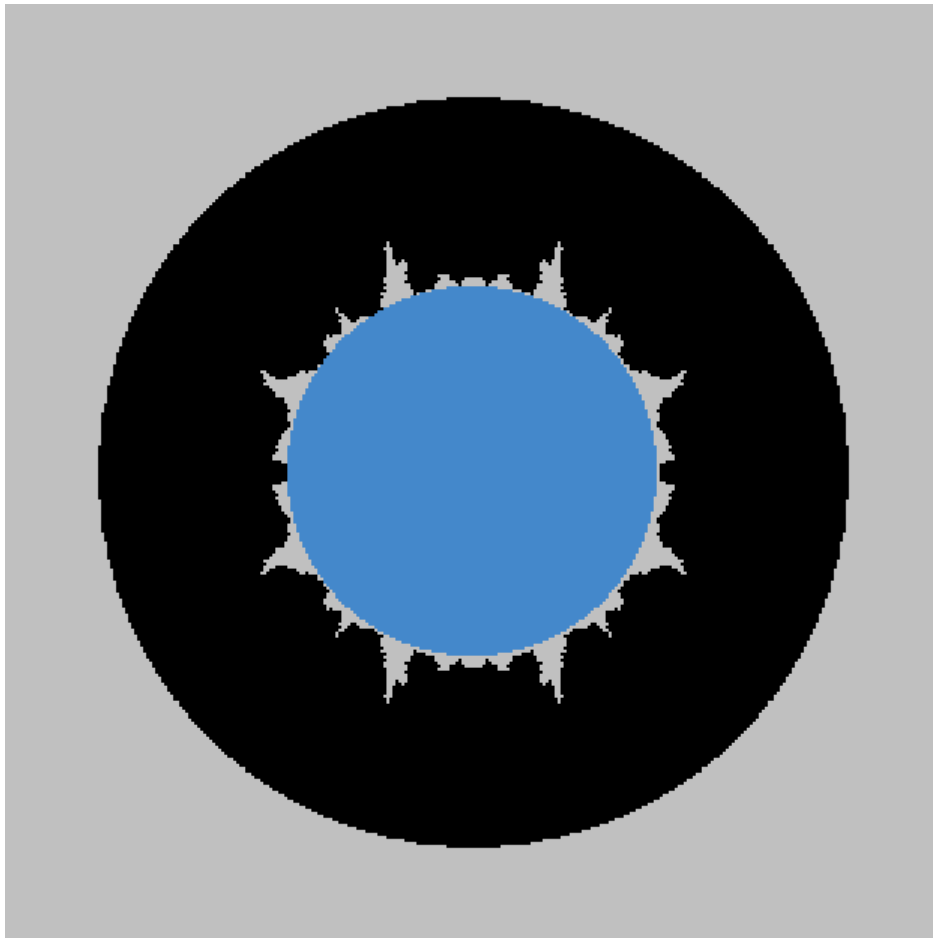
Choosing the appropriate boundary condition depends on the structure's design.

For example, imagine a structure with a cross-section as shown below.

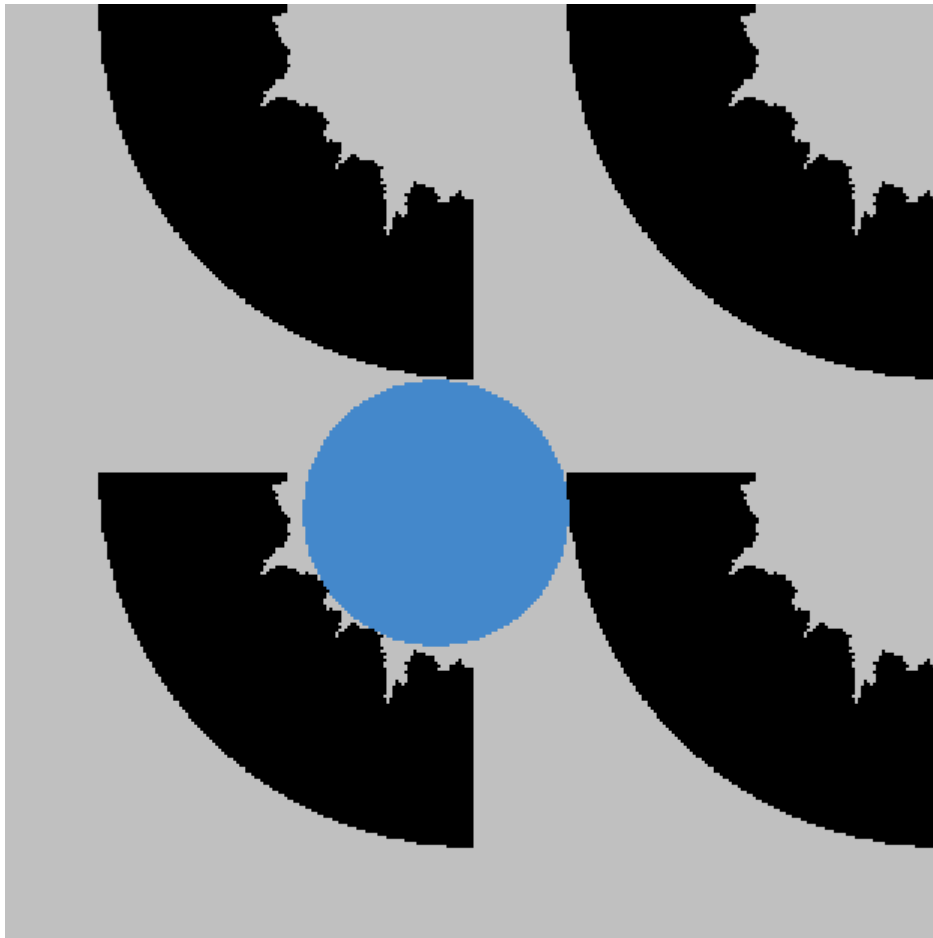


For the three boundary condition options the resulting pore size is visualized in blue.

- If **Symmetric** boundary conditions are taken, the geometry is mirrored at the domain boundary.



- If instead the expected pattern of the geometry is repeated in all directions, **Periodic** boundary conditions should be selected. That has the effect that the objects and pores of the structure that end on one side of the structure reappear on the opposite side.



- If the structure should be encased with a closed wall, the **Encase** boundary conditions are used.



Check **Expert** to apply different boundary conditions for each direction. You can combine the three above mentioned boundary conditions independently for the directions. For example, the boundary conditions could be chosen to be Encase in X-direction, Symmetric in the Y-direction and Periodic in Z-direction.

Domain Boundary Conditions

☐ Symmetric
☐ Periodic
☐ Encase
☒ Expert

Expert Settings

X Y Z

✓ Search Periodic Path

Search Periodic Path is only available for periodic boundary conditions. If checked, the Percolation Path is allowed to cross lateral periodic boundaries. Using this option increases the computation time. A periodic percolation path is not necessarily periodic in the computation direction.

✓ Diameter Mode

From the **Diameter Mode** pull-down menu, choose to detect percolation paths with the **Maximum Diameter** possible or **Specify Maximum Diameter** and enter a **Maximum Diameter** value below.

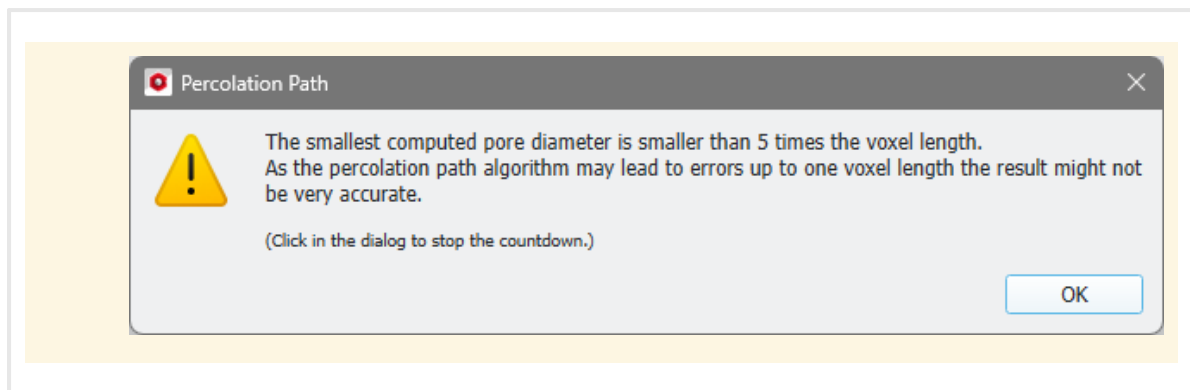
Diameter Mode	Maximum Diameter	Diameter Mode	Specify Maximum Diameter
Maximum Diameter / (μm)	0	Maximum Diameter / (μm)	5

✓ High Resolution

To run the calculations in **High Resolution** might be useful when the path space is expected to be narrow. The standard algorithm computes distances directly on the voxel grid, i.e., when determining a pore size, only the distances from the center of a pore voxel to the center of a solid voxel are taken into account. High Resolution also takes the voxel surfaces and edges into account, so the computed distances correspond to the distance to the next surface or edge. The disadvantage of the **High Resolution** mode is that the calculation runtime and memory usage may increase by a factor of eight.



Know how! If the largest computed path is smaller than five times the voxel length, and the simulation was run in the standard mode, a warning message is shown. In this case, it is recommended to re-run the simulation in **High Resolution** mode.



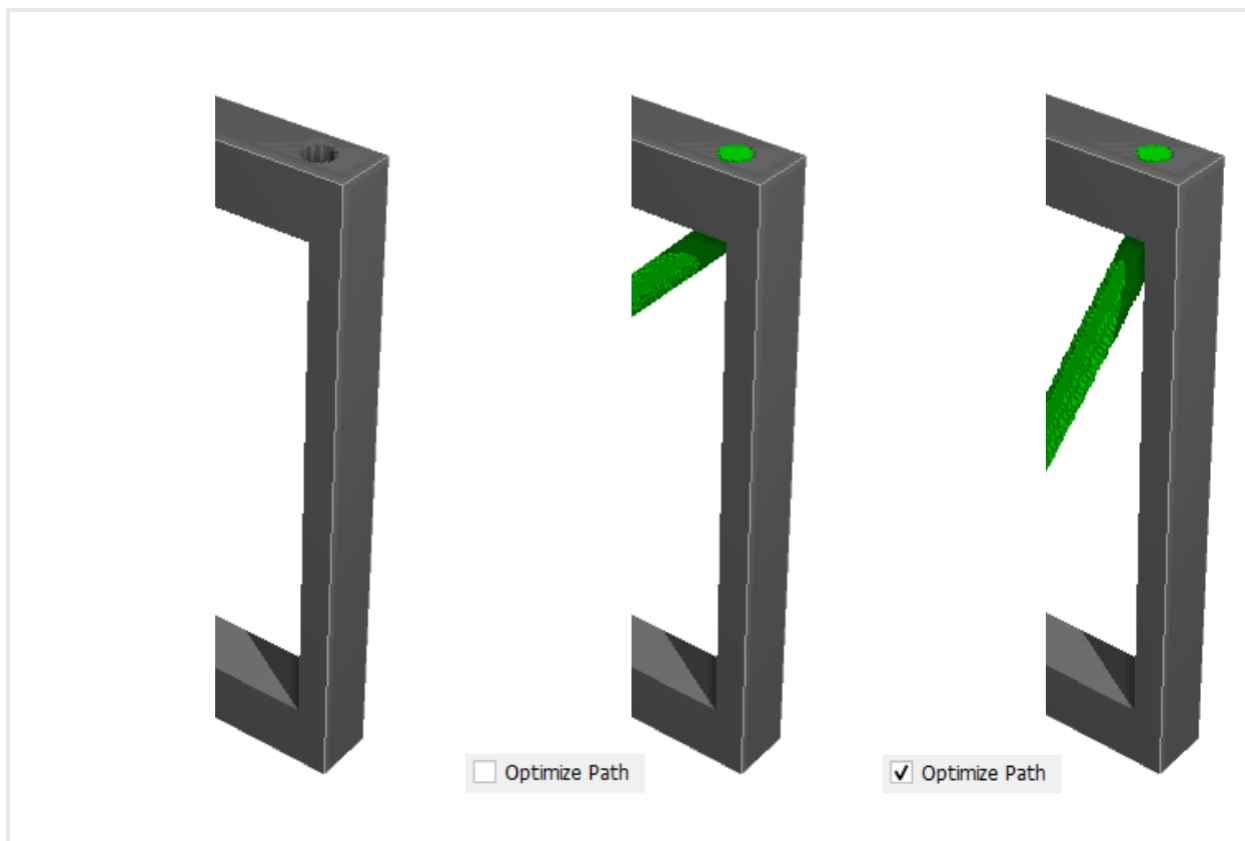
✓ Save Center-Line

When **Save Center-Line** is checked, the results folder additionally contains *.gdt files with the centerline of each computed percolation path.

- CenterlineParticle1.gdt
- CenterlineParticle2.gdt
- CenterlineParticle3.gdt
- CenterlineParticle4.gdt

✓ Optimize Path

With Optimize Path, the length of the path is optimized after the calculation. This shortens the calculated path by removing voxel staircase artifacts: The algorithm works on the voxel structure and can therefore only find paths which run directly through connected voxels. Therefore, the default method might not always find the best path in structures with large open pores. In these cases, it is recommended to select Optimize Path (see the examples below).



1.7.2 Results

After the **Percolation Path** calculation is finished, the resulting files are saved in the project folder and a Result Viewer with the GeoDict result file opens automatically. The created GeoDict result file (*.gdr) contains five tabs. The computational results are shown under the **Results** tab, and can be loaded for visualization via the **Data Visualization** tab. The other three tabs (**Input Map**, **Log Map**, and **Metadata**) display additional information about the computation.

Find more details on the general functionalities in the Result Viewer user guide.

The **Results - Report** subtab shows for all found paths the **Maximum particle diameter** (in **µm** and **Voxel**) of spherical particles which may pass through the medium, as well as the **Path length** (in **µm** and **Voxel**) of the detected percolation path(s).

Input Map	Log Map	Results	Data Visualization	Metadata
Report Map				
Particle paths				
Path no	Maximum particle diameter / (µm)	Maximum particle diameter / (Voxel)	Path length / (µm)	Path length / (Voxel)
1	3.2	8	117.067	292.667
2	2.88444	7.2111	95.7205	239.301
3	2.88444	7.2111	96.6421	241.605
4	2.88444	7.2111	97.4232	243.558

Percolation Path Results:

- [Data Visualization](#)¹²⁷
Load results for a graphical visualization.

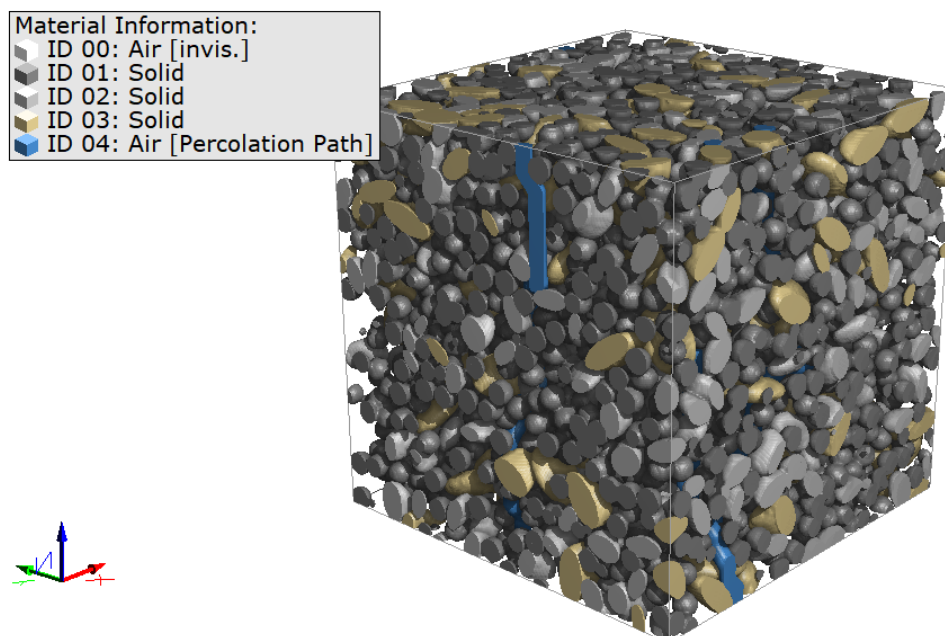
Data Visualization

Under the **Data Visualization** tab up to four result files can be loaded for visualization.

Input Map	Log Map	Results	Data Visualization	Metadata
Voxel Geometry with Percolation Path(s)			Load *.gdt	
Analytic Percolation Path(s) Geometry			Load *.gad	
Center Line Geometry			Load *.gdt	
Percolation Path(s) Trajectories			Load Particles	

✓ Percolation Path with Structure

To show the **Voxel Geometry with Percolation Path(s)** click the corresponding **Load *.gdt** button. Only the voxel geometry is saved in this file, i.e., any analytic information that was present in the original structure is lost in this representation.

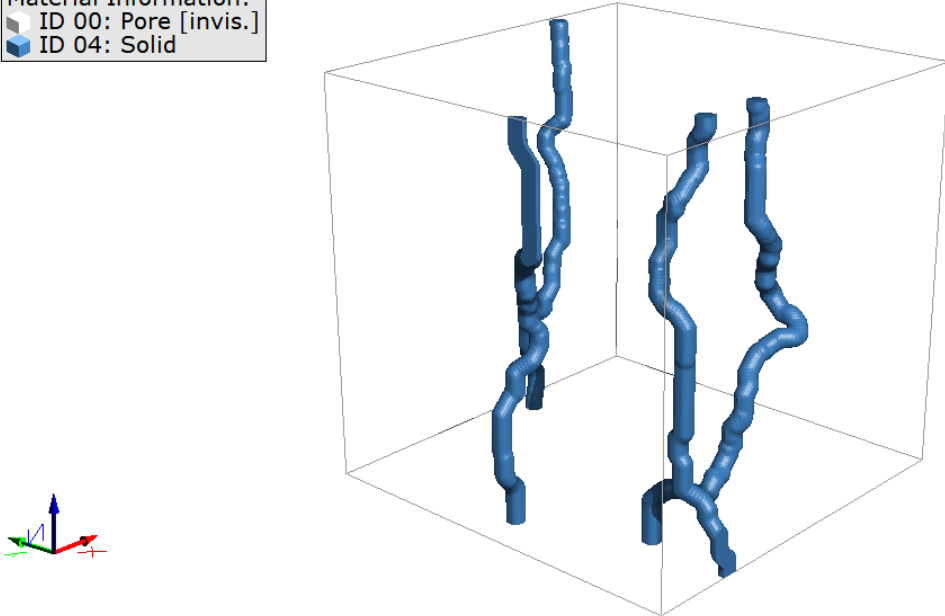


✓ Percolation Path without Structure

The **Analytic Percolation Path(s) Geometry** can be loaded by clicking the **Load *.gad** button and shows only the percolation path(s) without the structure. Each path is saved

as GAD object and is represented by a curved circular fiber.

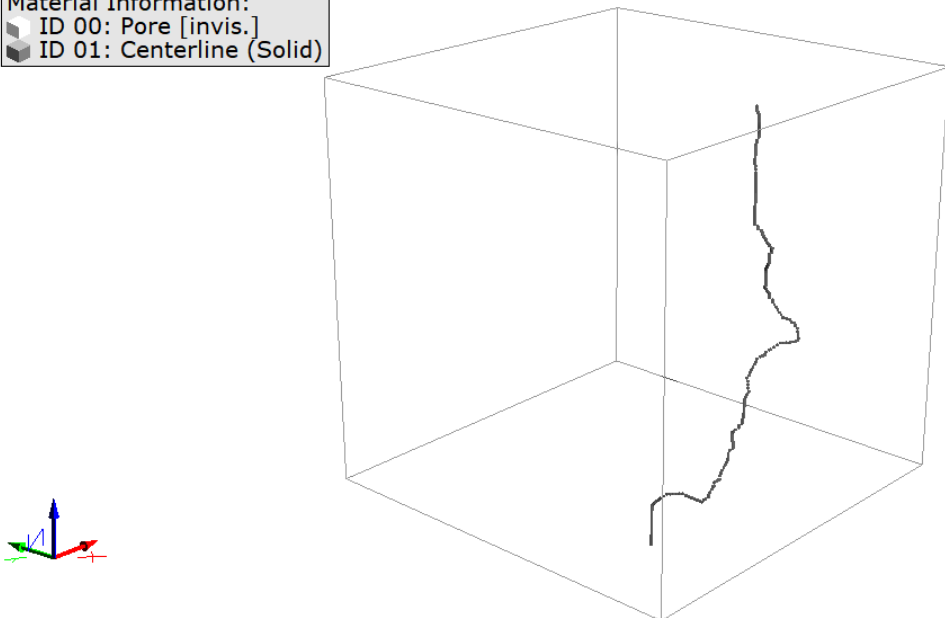
Material Information:
 ID 00: Pore [invis.]
 ID 04: Solid



✓ Center Line Geometry

The option **Center Line Geometry** is only available if **Save Center-Line** was selected before running the computation. It loads a structure file that contains the center line of the path with the largest diameter.

Material Information:
 ID 00: Pore [invis.]
 ID 01: Centerline (Solid)



✓ Particles and Trajectories

The **Percolation Path(s) Trajectories** can also be visualized with animated spheres

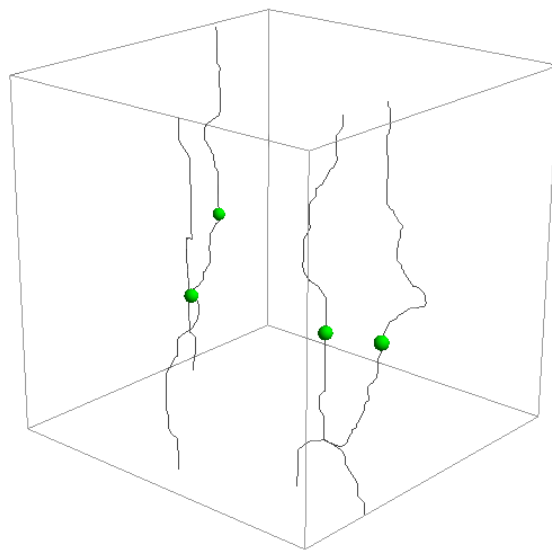
moving through the structure. For this, click **Load Particles**. Deactivate the structure visualization by unchecking the **Structure** tab in the Visualization panel, above the Visualization area, or set all Material IDs to **invisible**.



Note! Check the Visualization user guide for options to best visualize particles and their trajectories.

In this example, you can observe four spheres (here green) and their trajectories, corresponding to the four percolation paths, along which they move through the volume.

Material Information:	
	ID 00: Air [invis.]
	ID 01: Solid [invis.]
	ID 02: Solid [invis.]
	ID 03: Solid [invis.]



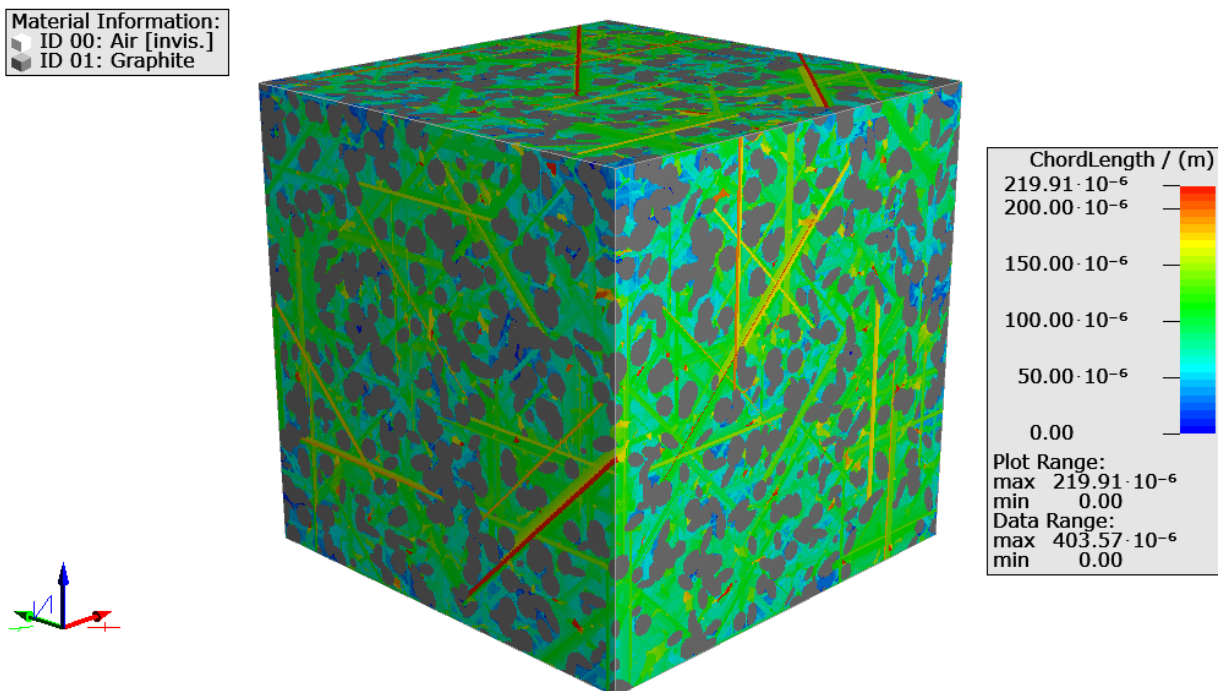
1.8 Chord Length Distribution

The **Chord Length Distribution** command is accessible from MatDict and PoroDict.

A **Chord Length Distribution** (CLD) is the distribution of the length of a typical chord of a structure. By being characteristic for any given geometry class, it is a highly precise and sensitive measure to compare the geometries of porous media. The calculation of CLD is particularly useful in 2D tomographic cross-sections, for which the pore size distribution cannot be determined by [granulometry](#)^[23] or by [porosimetry](#)^[37].

The **Chord Length** is defined as the number of connected voxels along the computational direction. Pseudo-code of the algorithm used for the computation can be found in J. Ohser, F. Mücklich.

The **Chord Length Distribution** dialog opens when clicking the **Edit...** button.



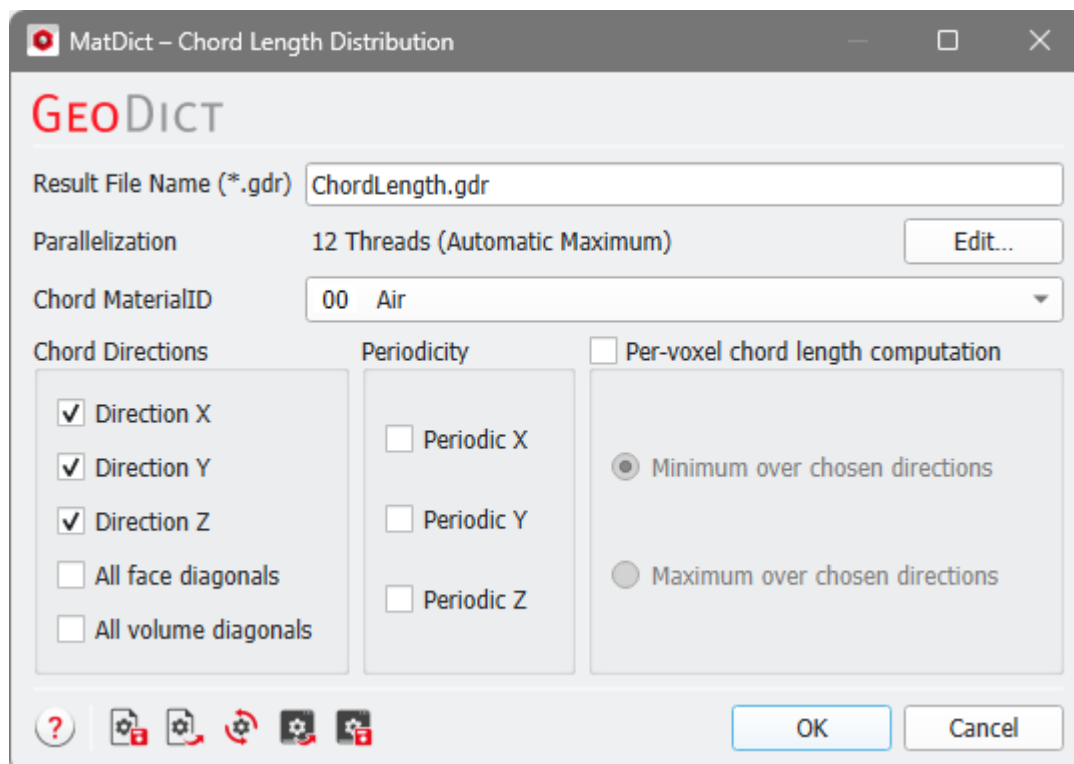
The Chord Length was computed in the pore space for all directions.

The Chord Length Distribution command:

- [Options](#)^[130]
Set the parameters for the analysis.
- [Results](#)^[134]
View the computed results.

1.8.1 Options

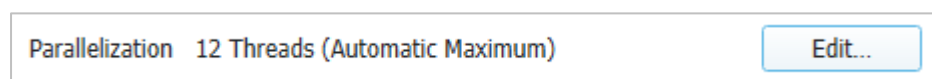
At the top of the dialog, enter the **Result File Name**. The result file is saved in the chosen project folder (**File** → **Choose Project Folder** in the menu bar).



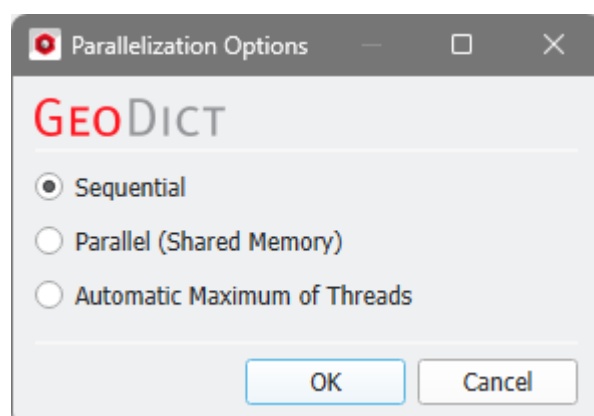
✓ Parallelization

Control how many threads are used for the computation. Parallelization is possible if your license and hardware allow it.

The **Parallelization Options** dialog opens when clicking the **Edit** button and you can choose between **Sequential**, **Parallel (Shared Memory)**, or **Automatic Maximum of Threads**.

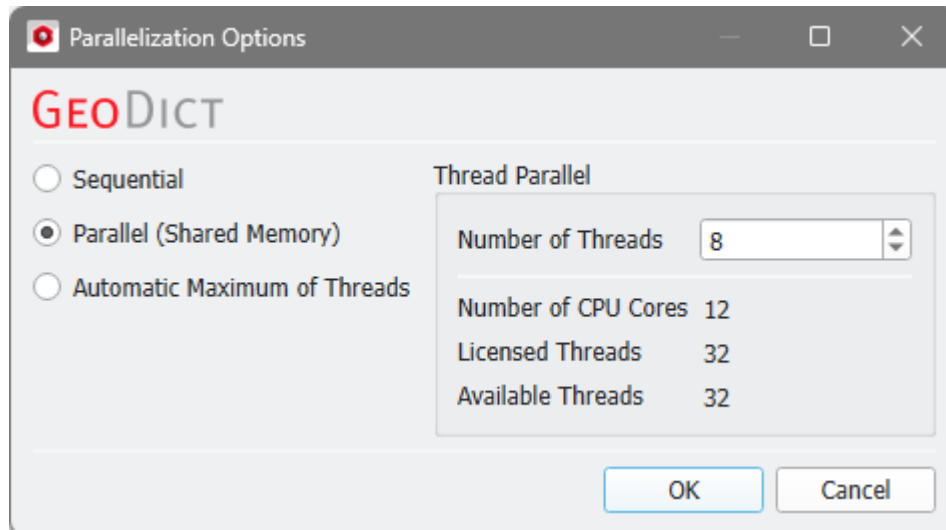


Selecting **Sequential** will not apply parallelization and only one thread is used for the computation.

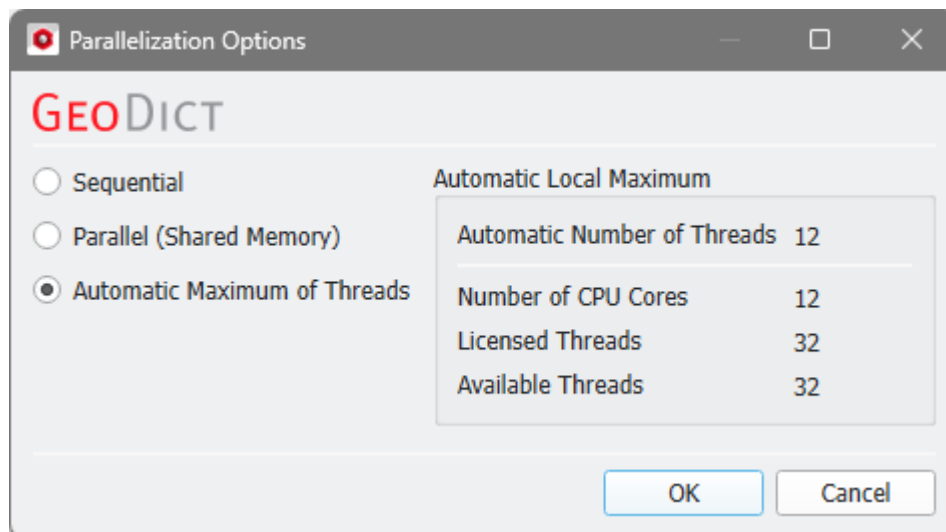


When **Parallel (Shared Memory)** is selected, the **Number of Threads** can be entered. Below, the **Number of CPU Cores** that the current machine has, the maximum number

of **Licensed Threads** and the number of those licensed threads that are available (**Available Threads**) are shown in the dialog. Of course, the maximal number of parallel processes you can use, is the smallest of those three numbers.



If **Automatic Maximum of Threads** is selected, the number of parallel processes is automatically selected for optimal speed, based on the CPU cores and licensed parallel processes.



The **Automatic Local Maximum** of processes is automatically selected, which is the minimum of **Number of CPU Cores**, **Licensed Threads**, and **Available Threads**.

✓ Chord Material ID

Select the **Chord MaterialID** for which the chord length distribution is calculated. This can be done for pore or solid materials alike.

Chord MaterialID	
00	Air
00	Air
01	Graphite
02	Graphite
03	Undefined
04	Undefined
05	Undefined
06	Undefined
07	Undefined
08	Undefined
09	Undefined

✓ Chord Directions

In the **Chord Directions** section, select the direction(s) in which the chord lengths are determined.

Chord Directions

☒ Direction X
☒ Direction Y
☒ Direction Z
☒ All face diagonals
☒ All volume diagonals

This can be done along the main axes (**Direction X**, **Direction Y**, or **Direction Z**), along the two-dimensional diagonals of the domain (**All face diagonals**), or along the three-dimensional diagonals of the domain (**All volume diagonals**).

✓ Periodicity

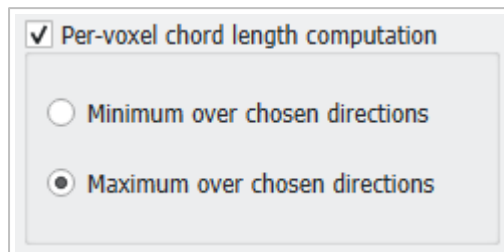
Periodicity can be applied in the X-, Y-, and/or Z-direction for the calculation. Periodicity means, that chords continue on the opposite side of the domain. This can lead to infinitely long chord lengths, if a complete ray along the chosen direction is inside of the selected **Chord MaterialID**. Such chords are neglected when computing the distribution results, and a warning is plotted on top of the resulting report if this occurs:

Report
Plots
Map

Warning: 50 chords of infinite length did not count for mean chord length and L10/L50/L90 in Z-direction

✓ Per-voxel chord length computation

Check **Per-voxel chord length computation** to include a scalar field for the output in which, for each voxel, the length of the minimum or maximum chord through that voxel over all chosen directions is stored. For this, choose between **Minimum over chosen directions** or **Maximum over chosen directions**.



1.8.2 Results

After the **Chord Length Distribution** calculation is finished, the resulting files are saved in the project folder and a Result Viewer with the GeoDict result file opens automatically. The created GeoDict result file (*.gdr) contains six tabs. The computational results are shown under the **Results** tab, and can be loaded for visualization via the **Data Visualization** tab. The other four tabs (**Input Map**, **Log Map**, **Post Map**, and **Metadata**) display additional information about the computation.

Find more details on the general functionalities in the Result Viewer user guide.

Chord Length Distribution Results:

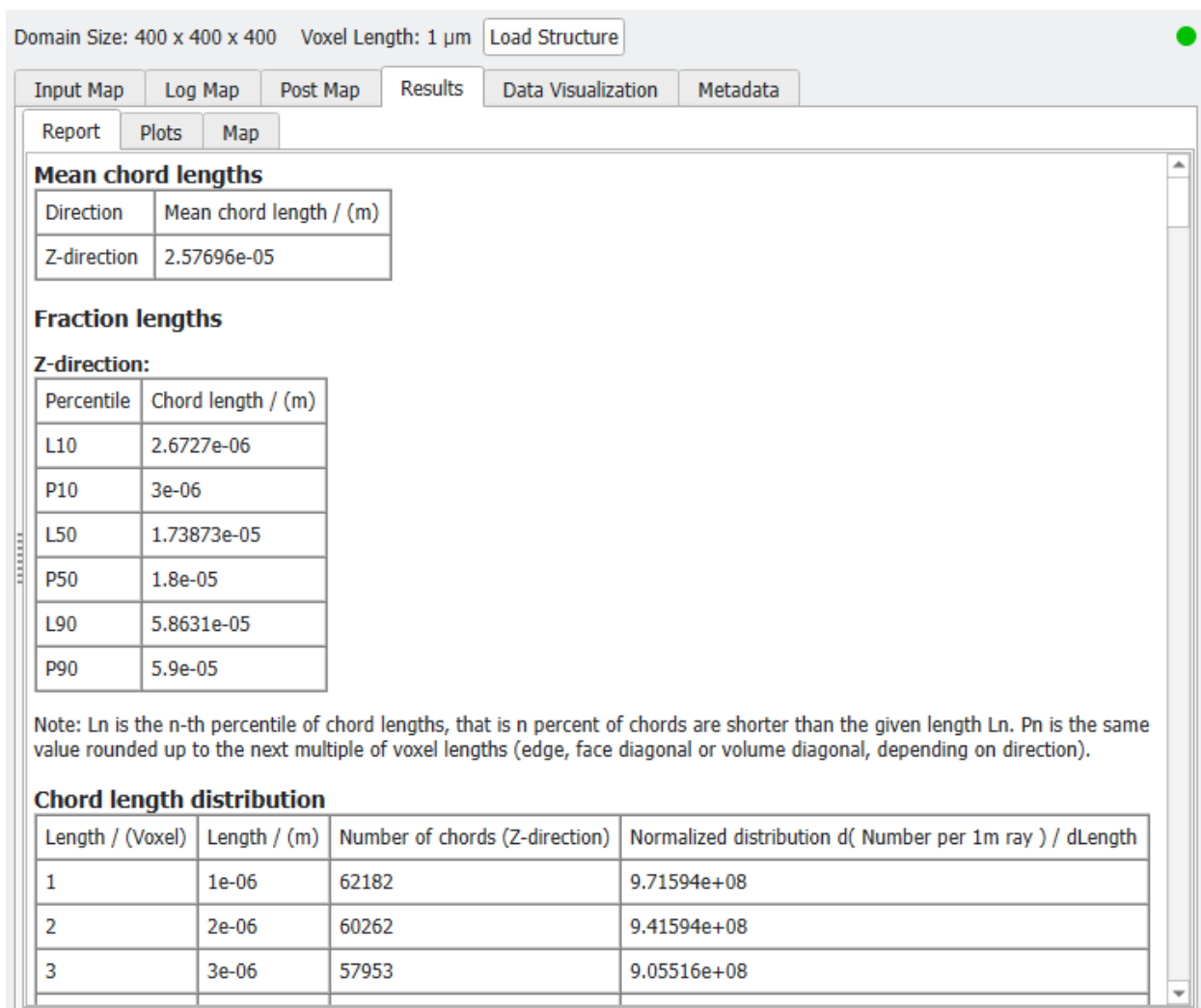
- [Results Tab](#)¹³⁴
Observe the computed results and plots.
- [Data Visualization](#)¹³⁷
Load results for a graphical visualization.

Results Tab

Due to the voxelization, the chord length can only be measured in multiples of the voxel length. A chord length of d meters includes all chord lengths with a distance of half the voxel length around d . For example, a chord length of 2 μm with voxel length 1 μm actually means all chords between 1.5 μm and 2.5 μm .

Report Tab

Under the **Report** tab, the **Mean chord lengths**, the **Fraction lengths** L10, L50, L90 and P10, P50, P90, and the complete **Chord length distribution** in the selected chord direction(s) are shown.



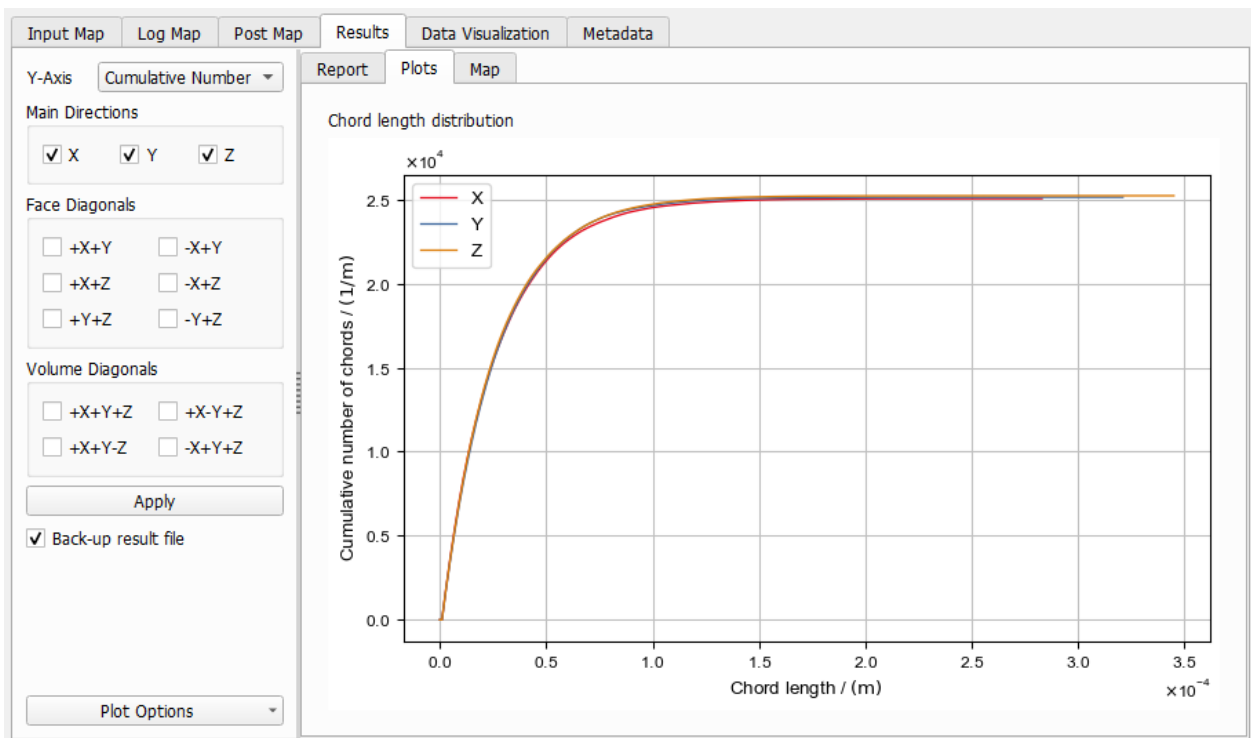
The fraction lengths table reports the chord lengths smaller than 10%, 50%, 90% of all chord lengths (L10, L50, L90). The P-values (P10, P50, P90) are the same, but rounded up to the next largest multiple of the voxel length.

For example, a L10 of 2.6 μm means that 10% of all chords are smaller than this length. A L50 of 17.4 μm means that 50% of all chords are smaller than this length. A L90 of 58.6 μm means that 90% of all chords are smaller than this length.

For P10 the L10 value of 2.6 is rounded up to 3e-6, because the voxel length is 1 μm , and it means that this length (3 μm) is larger than or equal to the length of 10% of all chords. A P50 of 1.8e-5 means that this length (18 μm) is larger than or equal to the length of 50% of all chords. A P90 of 5.9e-5 means that this length (59 μm) is larger than or equal to the length of 90% of all chords.

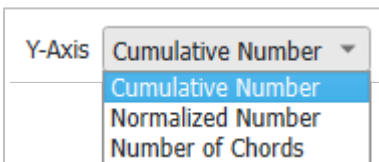
Plots Tab

The plot of the complete chord length distribution is shown in the **Results-Plots** subtab.



Post-processing options

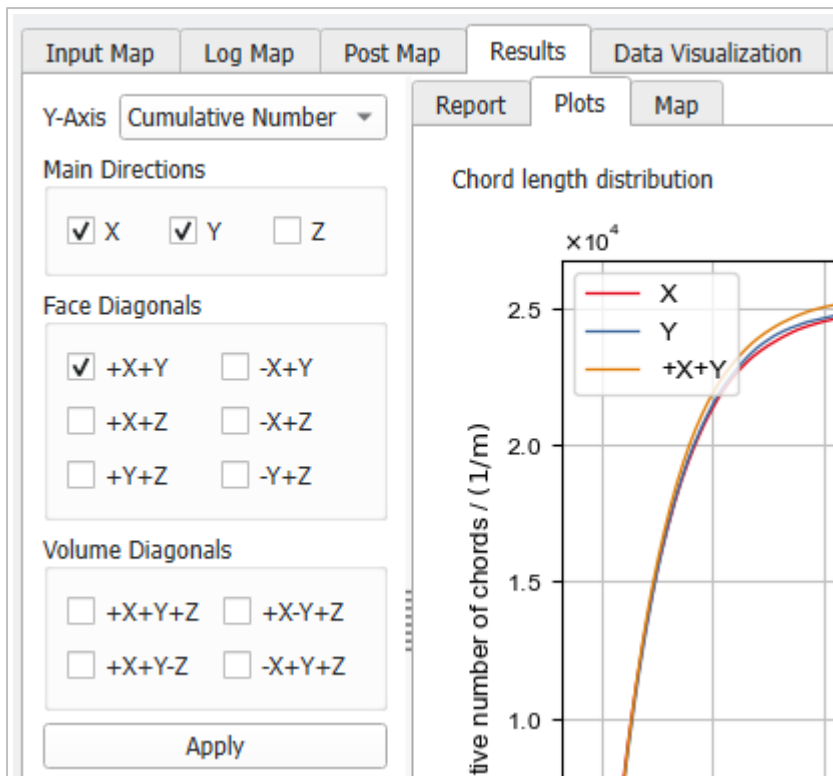
In the context menu on the left, the chord length distribution plot can be customized. For the **Y-Axis**, the **Cumulative Number**, the **Normalized Number**, or the **Number of Chords** can be selected.



The normalized number of chords is the difference quotient of the cumulative chord length distribution, where the step size is the current voxel length.

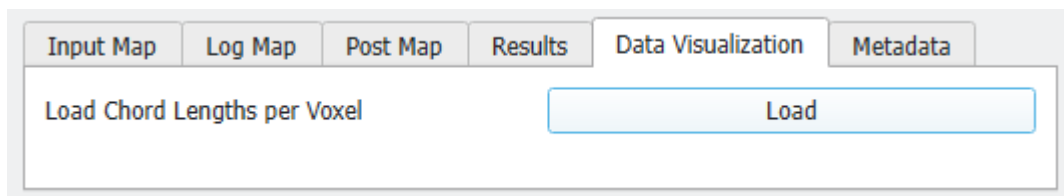
The normalized number of chords can be obtained from the number of chords histogram. For example, in X-direction it can be computed as follows: First, the number of chords is divided by $N_Y \cdot N_Z$, which equals the total number of rays, to obtain the number of chords per ray. Then, this number is normalized by $N_X \cdot \text{voxel length}$ to obtain the number of chords per meter. As the accuracy of the measurement of the chord length is restricted by the voxel length, the histogram bin size is also given in voxels. To reflect this, the number of chords per meter must again be divided by the voxel length (which equals the bin size) in the last step. This allows to compare results for structures with different voxel lengths.

In addition, if more than one direction was chosen for the computations, it can be chosen for which of these directions the distribution should be shown (**Main Directions**, **Face Diagonals**, **Volume Diagonals**). Click **Apply...** to update the displayed plot.

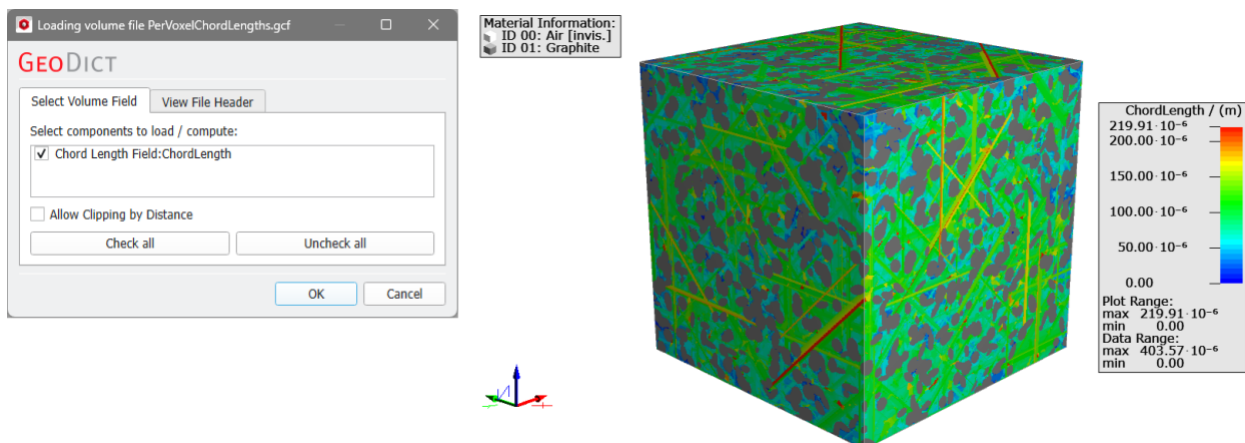


Data Visualization

If **Per-voxel chord length computation** was previously checked, you can click the **Load** button in the **Data Visualization** tab.



This loads a volume field, where for every voxel the minimal or maximal (depending on the selection in the options dialog) chord length over all chosen directions is saved.

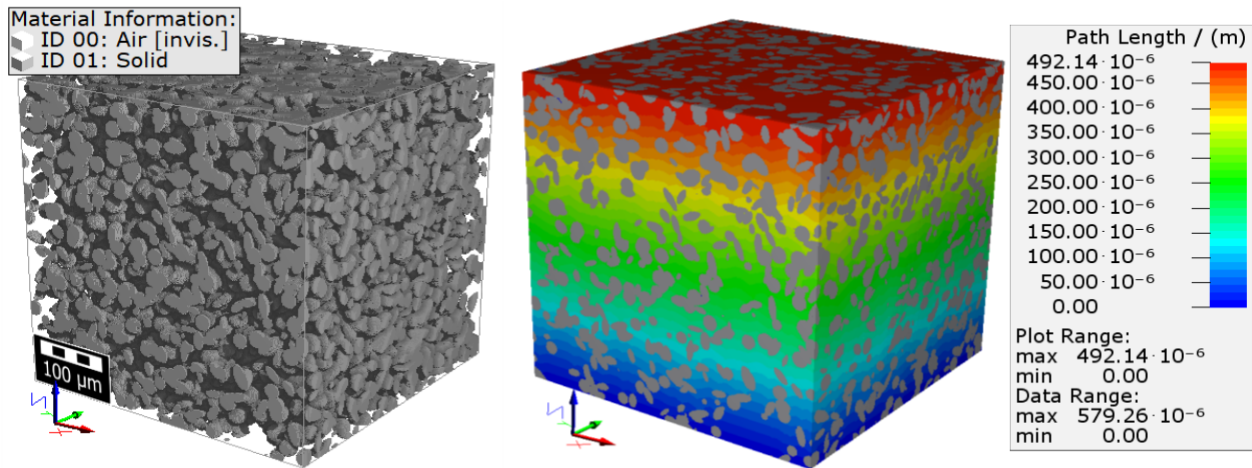


1.9 Geodesic Tortuosity

The **Geodesic Tortuosity** command is accessible from MatDict and PoroDict.

This command computes the tortuosity of paths crossing the material, either through pore space or through solid materials. For every voxel on the outflow plane, the algorithm finds the shortest path through the selected material.

The **Geodesic Tortuosity** dialog opens when clicking the **Edit...** button.



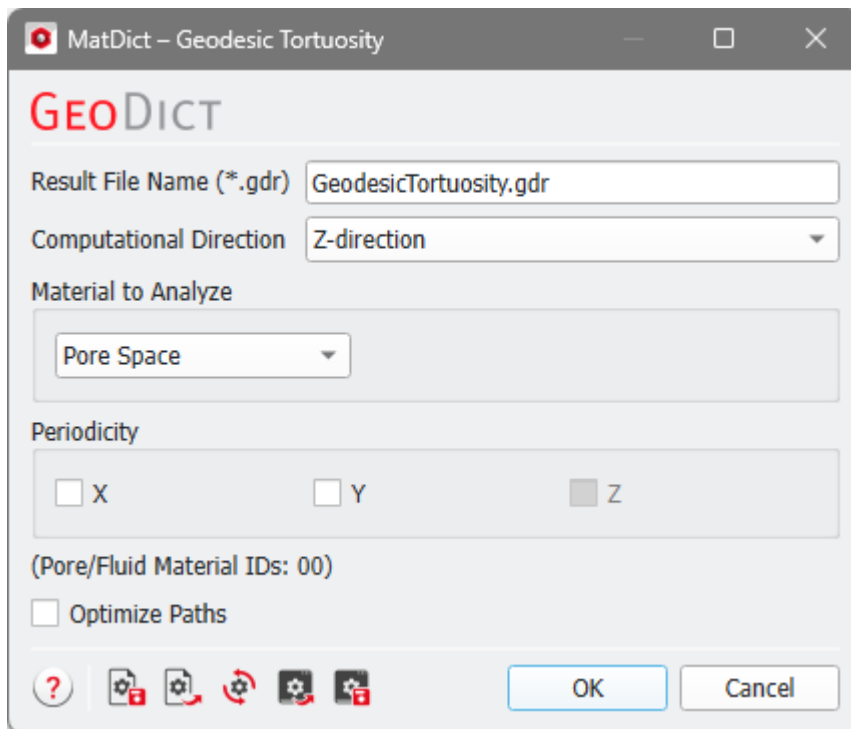
The Geodesic Tortuosity was computed in Z-direction for the air.

The Geodesic Tortuosity command:

- [Options](#)¹³⁸
Set the parameters for the analysis.
- [Results](#)¹⁴⁰
View the computed results.

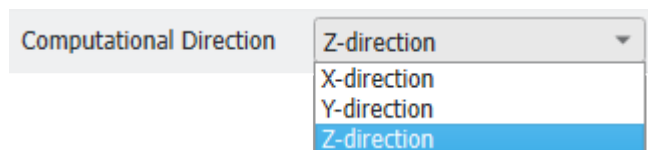
1.9.1 Options

At the top of the **Geodesic Tortuosity** dialog, enter the **Result File Name**. The result file is saved in the chosen project folder (**File** → **Choose Project Folder** in the menu bar).



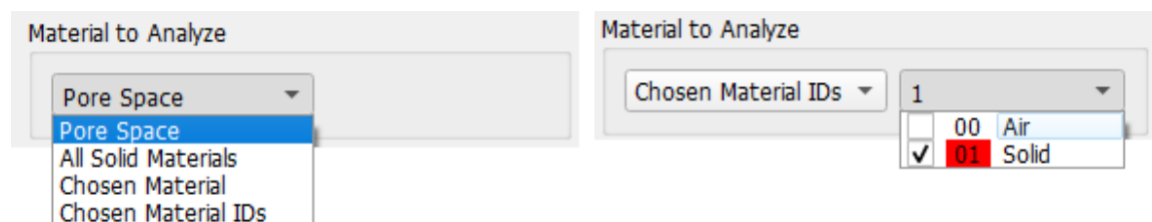
✓ Computational Direction

Set the direction of the paths by selecting the **Computational Direction**.



✓ Material to Analyze

The algorithm searches for paths in the selected **Material to Analyze**, either **Pore Space**, **All Solid Materials**, **Chosen Material**, or a list of **Chosen Material IDs**.



For your convenience, all Material IDs which denote pore space are shown at the bottom of the dialog.

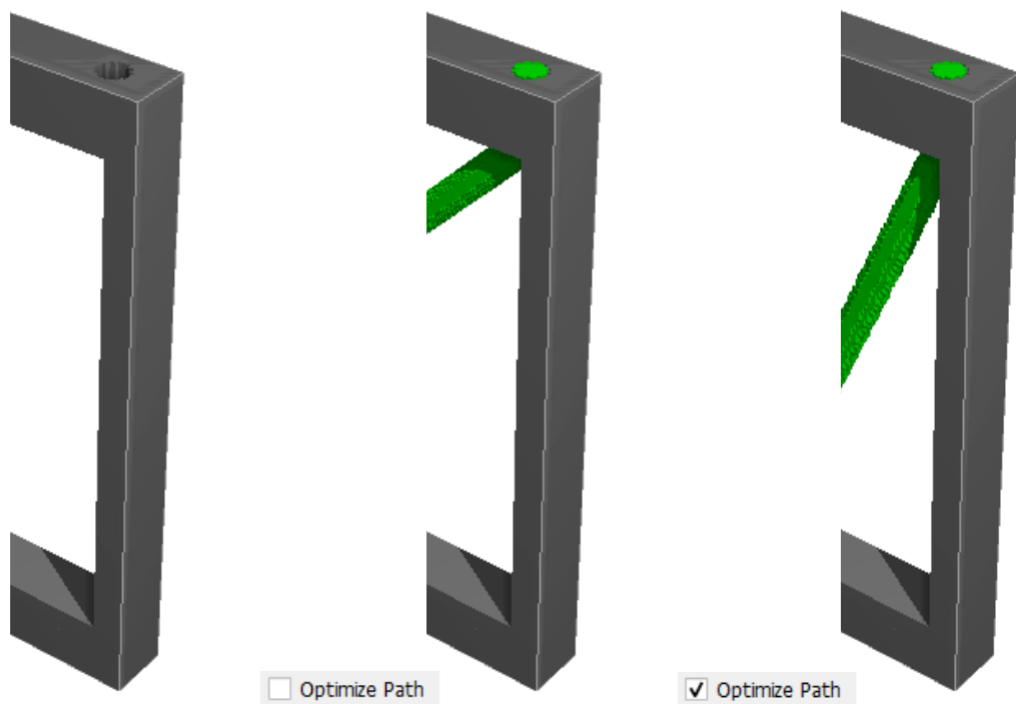
✓ Periodicity

Paths might leave the domain and enter again on the opposite side if **Periodicity** is selected for one or both tangential directions. The chosen computational direction,

however, cannot be chosen to be periodic.

✓ Optimize Path

With Optimize Path, the length of the path is optimized after the calculation. This shortens the calculated path by removing voxel staircase artifacts: The algorithm works on the voxel structure and can therefore only find paths which run directly through connected voxels. Therefore, the default method might not always find the best path in structures with large open pores. In these cases, it is recommended to select Optimize Path (see the examples below).



1.9.2 Results

After the **Geodesic Tortuosity** calculation is finished, the resulting files are saved in the project folder and a Result Viewer with the GeoDict result file opens automatically. The created GeoDict result file (*.gdr) contains five tabs. The computational results are shown under the **Results** tab, and can be loaded for visualization via the **Data Visualization** tab. The other three tabs (**Input Map**, **Log Map**, and **Metadata**) display additional information about the computation.

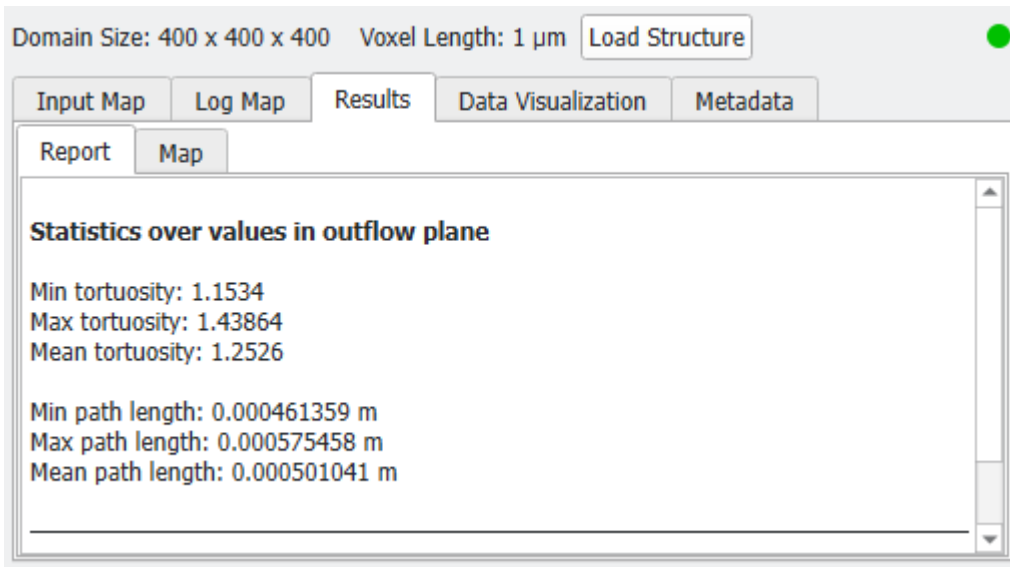
Find more details on the general functionalities in the Result Viewer user guide.

For every voxel on the outflow plane, the algorithm finds the shortest path through the selected **Material to Analyze**. The corresponding geodesic tortuosity is then computed as

$$\tau = \frac{\text{shortest path to inflow plane}}{\text{distance to inflow plane}}$$

(11) Geodesic
Tortuosity

In the **Results - Report** tab, the minimal, maximal, and mean geodesic tortuosity are shown. The corresponding minimal and maximal path lengths and the mean length of all paths are also given.

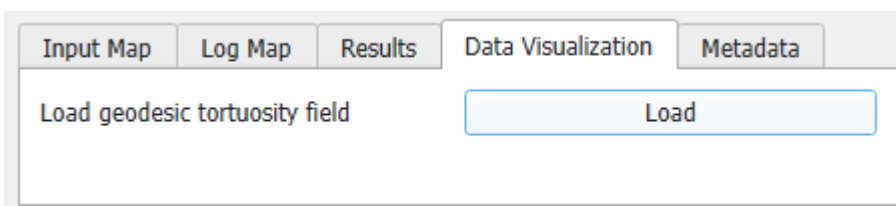


Geodesic Tortuosity Results:

- [Data Visualization](#)¹⁴¹
Load results for a graphical visualization.

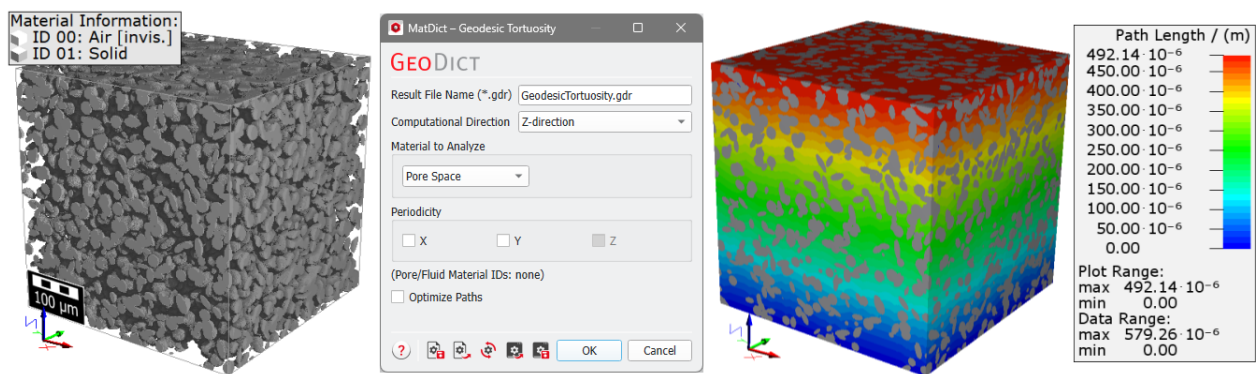
Data Visualization

The **geodesic tortuosity field** can also be visualized through the **Data Visualization** tab when clicking the **Load** button.



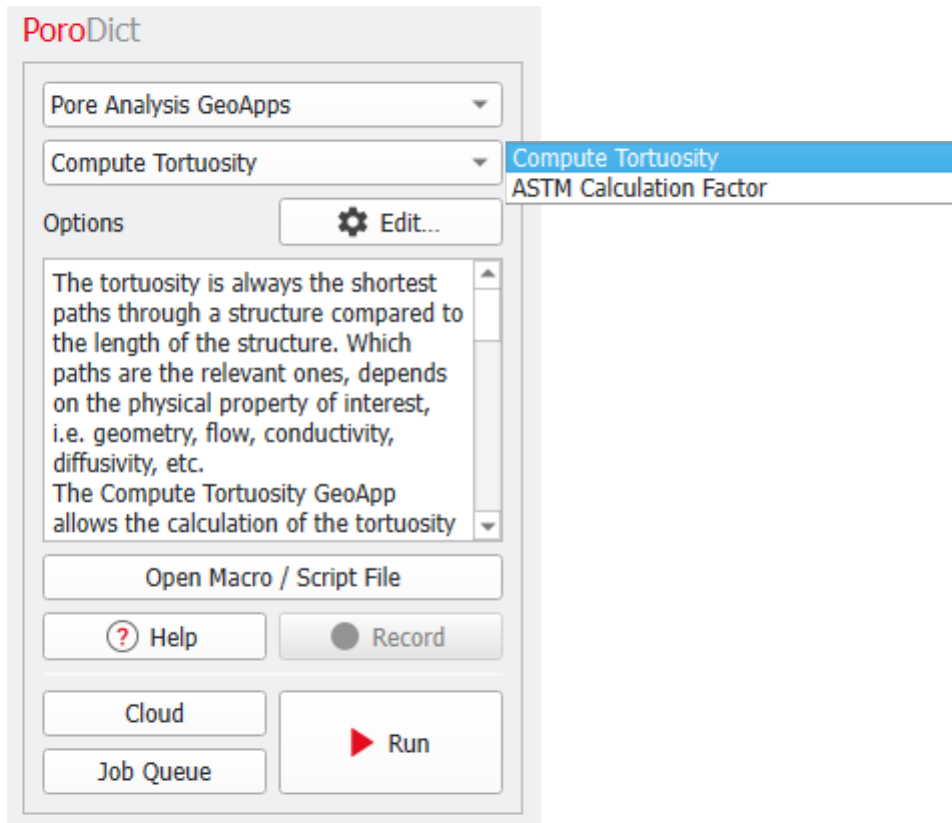
It contains for each voxel the shortest path distance between this voxel and the inflow plane. Therefore, on the inflow plane all voxels contain the value 0. Voxels that do not belong to the **Material to Analyze** also have the value 0.

In the example below, the geodesic tortuosity was calculated for the pore space which is Material ID 00. The inflow plane is Z- and you can observe that the path length for voxel near the inflow plane is smaller than for the voxels at the opposite of the inflow plane.



1.10 Pore Analysis GeoApps

When **Pore Analysis GeoApps** is selected in the PoroDict section, two GeoApps can be chosen from the pull-down menu in the Pore Analysis GeoApps panel. To learn how to add your own custom GeoApps, refer to the GeoApp User Guide.



The Pore Analysis GeoApps:

- [Compute Tortuosity](#)^[143]
Compute pore space tortuosity using different approaches.
- [ASTM Calculation Factor](#)^[149]
Determine the Calculation Factor to convert a test pressure result to a pore size as stated in the ASTM E3278 – 21 norm.

1.10.1 Compute Tortuosity

The **Compute Tortuosity** GeoApp uses different approaches, as described in Holzer et al., 2023, to calculate the tortuosity of the pore space in a chosen computation direction. Additionally, a geometric analysis can be performed and effective transport properties on the macroscale can be predicted based on Holzer et al., 2013.



Modules needed to run this GeoApp (depending on the selected options):

PoroDict + MatDict, DiffuDict, ConductoDict, FlowDict, AddiDict



Note! Also have a look at our [website](#) for more information.

Generally, three different kinds of tortuosity can be computed:

- **Geometric Tortuosity**, which is directly derived from the microstructure,
- **Physical Tortuosity** or physics-based tortuosity, which is indirectly derived by transport mechanisms,
- **Mixed Tortuosity**, which uses a mixture of determinations based on geometric analysis and physical transportation phenomena.

Click **Edit** to open the **Compute Tortuosity** parameter dialog.

Select a **Result File Name** and the **Computation Direction** in the **General Settings** panel. Also, the **Boundary Conditions in Computation Direction** and **in Tangential Direction** must be defined.

After activating **Use Advanced Settings** you can define the **Parallelization**, the **Bin Sizes** for **Streamlines** and **Porosimetry & Granulometry**, the **In- / Outlet Length for Stokes Flow**, and **Dense Sampling of Streamlines**.

☒ Use Advanced Settings

☐ Use Maximum Parallelization

DiffuDict Parallelization	8
ConductoDict Parallelization	8
FlowDict Parallelization	8
PoroDict Parallelization	8

Streamline Bin Size

Porosimetry and Granulometry Bin Size

In- / Outlet length for Stokes Flow

☐ Use a Dense Sampling of Streamlines

In the **Tortuosity Calculation** panel, select the properties to be computed.

☒ Geometric Tortuosity

There are two options available for the **Geometric Tortuosity**. These tortuosity values are derived directly from the morphological characteristics of the analyzed structure and are defined solely by the structure.

The general definition of the **Geometric Tortuosity** is the comparison of the effective geometric path length L_{eff} to the shortest geometric path length L_0 :

$$\tau = \frac{L_{eff}}{L_0} \quad (12) \quad \text{Geometric Tortuosity}$$

The geometric tortuosity options are:

- **Geodesic Tortuosity** in [PoroDict](#)^[138]: Computing the mean geodesic tortuosity from the percolation pathway starting from every voxel in the inlet, i.e., the shortest path in pore space is compared to the direct path.
- **Percolation Path Tortuosity** in [PoroDict](#)^[119]: Computing the mean value of the percolation pathways with the 50 largest diameters, i.e., the length of the path of large particles (largest possible diameters) through the structure (median axis) is compared to the direct path.

☒ Physical Tortuosity

There are four options available for the **Physical Tortuosity**. These tortuosities are indirectly derived and do not use the geometric path lengths:

$$\tau \neq \frac{L_{eff}}{L_0} \quad (13)$$

Physical tortuosities are determined using effective properties to deduce a tortuosity value indirectly. Therefore, the effects of microstructure such as bottleneck effects are included. A physical tortuosity is only meaningful if it is based on a transport phenomenon that is relevant to the simulated material. Thus, different tortuosities can be determined depending on the dominating transport mechanism: diffusion of molecules or ions, conductivity of electrons, etc.

Consider, for example, the effective diffusion of gas through a porous membrane compared to the gas's self-diffusion. In this case, the diffusion tortuosity is of interest, as described in the DiffuDict user guide. GeoDict can output both, the value for the tortuosity τ and the value of the tortuosity factor κ by comparing the effective diffusion to self-diffusion:

$$\tau_{indir,diff} = \sqrt{\kappa_{indir,diff}} = \sqrt{\frac{\varepsilon}{D_{rel}}} \quad (14)$$

where ε is the porosity and D_{rel} the relative diffusivity due to the porous-media dependent part of the effective diffusion. The numbers τ and κ can be converted in each other by the general relation between them:

$$\tau = \sqrt{\kappa} \quad (15)$$

The available physical tortuosities are:

- **Diffusional Tortuosity** in DiffuDict: Diffusion as indirect, physical approach (see also Epstein, 1989). The tortuosity will be extracted from the DiffuDict **Laplace** or **Knudsen** Diffusion result files, respectively.
- **Conduction Tortuosity** in ConductoDict: **Electrical** or **Thermal** conductivity as indirect, physical approach (see also Ullman et al., 1982). The tortuosity will be extracted from the respective ConductoDict result file.

✓ Mixed Tortuosity

There are five options available for the **Mixed Tortuosity**. The mixed tortuosities are derived from a mixed determination including the geometrical analysis of streamlines and pathways from simulations of diffusion, flow, advection, etc. The available mixed tortuosities are:

- **Tortuosity from Laplace Diffusion Flux** in DiffuDict (see also Tye, 1983): The mean value of the DiffuDict Laplace diffusion flux streamlines and/or the tortuosity is calculated based on the volume average of the DiffuDict Laplace diffusion flux.
- **Tortuosity from Electrical Current Density and Thermal Heat Flux** in ConductoDict: The mean value of the streamline length of the ConductoDict streamlines and/or the tortuosity is calculated based on the volume average of the electrical current density and thermal heat flux.
- **Tortuosity from Stokes Flow Velocity** in FlowDict (see also Duda et al., 2011): The mean value of the streamline length of FlowDict Stokes flow velocity streamlines and/or the tortuosity is calculated based on the volume average of FlowDict Stokes flow velocity.
- **Tortuosity from Advection Particle Path Length** in AddiDict: Computes the mean value of the particle path length for advection.
- **Tortuosity from Particle Diffusion Path Length** in AddiDict: The mean value is calculated based on effective isotropic diffusivity.

✓ Microstructure Characteristics

In addition to the different tortuosities, the **Compute Tortuosity** GeoApp can calculate **Microstructure characteristics**. Three options are available:

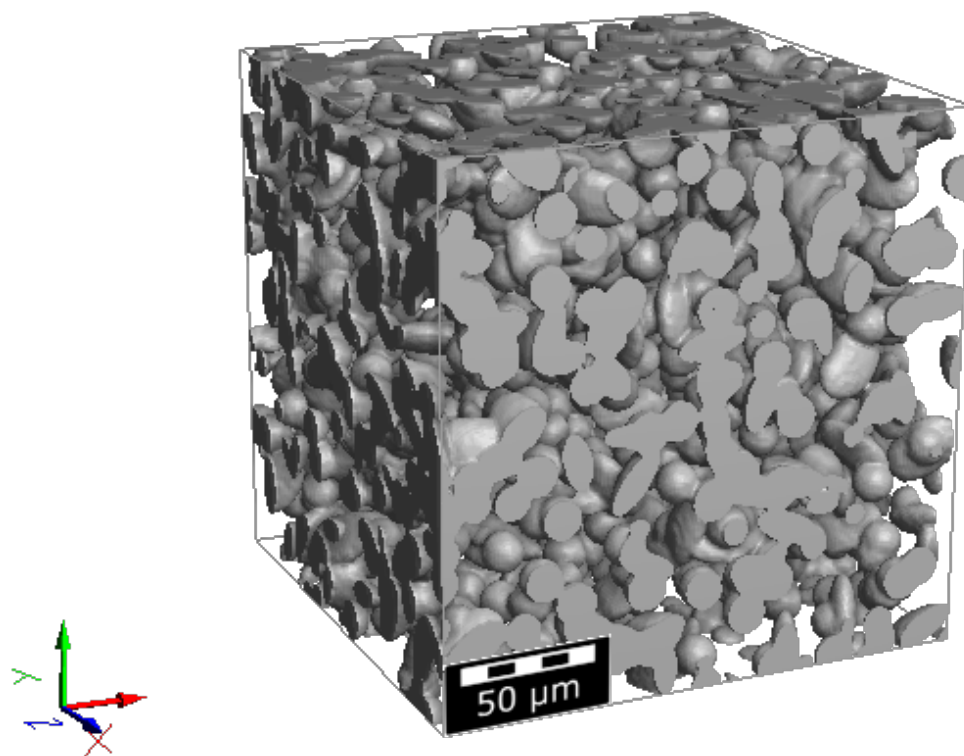
- **Characteristic Diameters from Granulometry** in [PoroDict](#)²³: Computing D10, D50, and D90.
- **Characteristic Diameters from Porosimetry** in [PoroDict](#)³⁷: Computing D10, D50, and D90.
- **Surface Area** in MatDict: Specific surface area between pore space and solid materials.

Results

Below the exemplary results for the following structure are shown.

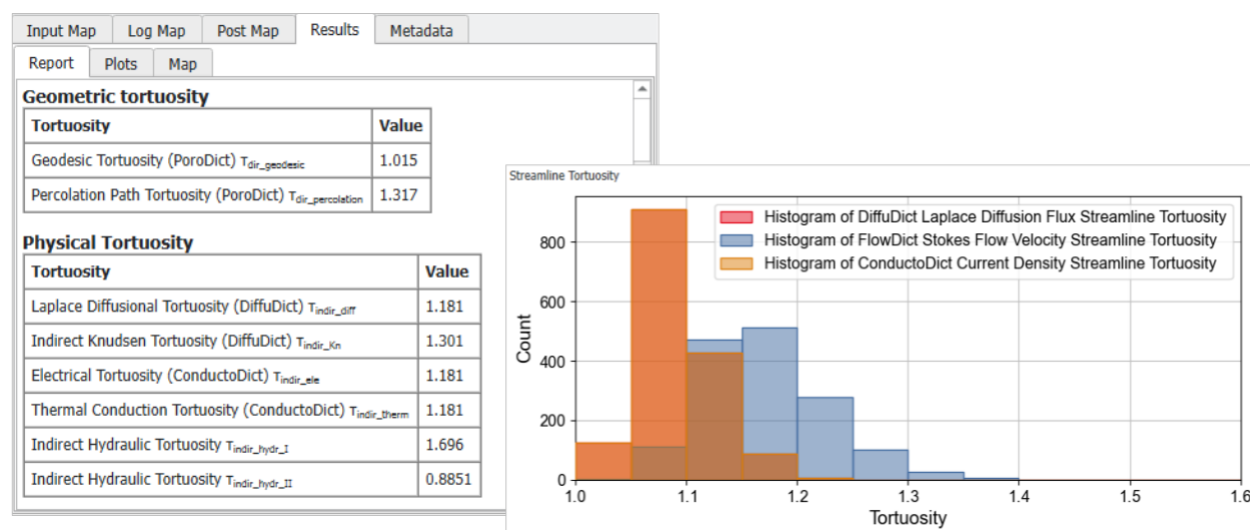
Material Information:

-  ID 00: Air [invis.]
-  ID 01: Solid

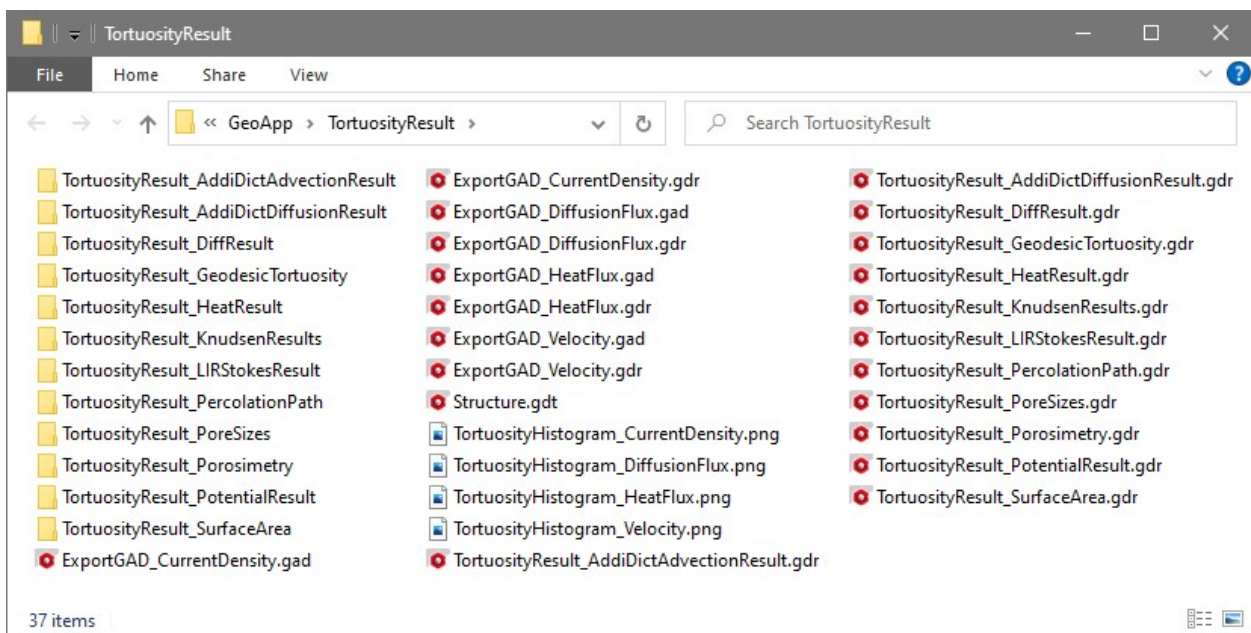


The result file's **Result Viewer** opens automatically when the **Compute Tortuosity** app finishes. The result file provides detailed information about the formulas used to calculate the different tortuosities, the microstructure characteristics, the pore phase and transport properties, as well as those used to predict effective transport properties.

Depending on the selection in the **Compute Tortuosity** parameter dialog, the respective results are given in tables. If the calculation of the tortuosity based on streamlines was selected, the evaluation of streamline length is shown as a **Streamline Tortuosity** plot.



Additionally, the corresponding result folder contains the detailed GeoDict results for all selected tortuosity computations.



1.10.2 ASTM Calculation Factor

The Pore Analysis GeoApps section contains a GeoApp for the calculation of the ASTM pore size calculation factor according to the ASTM E3278-21 standard.

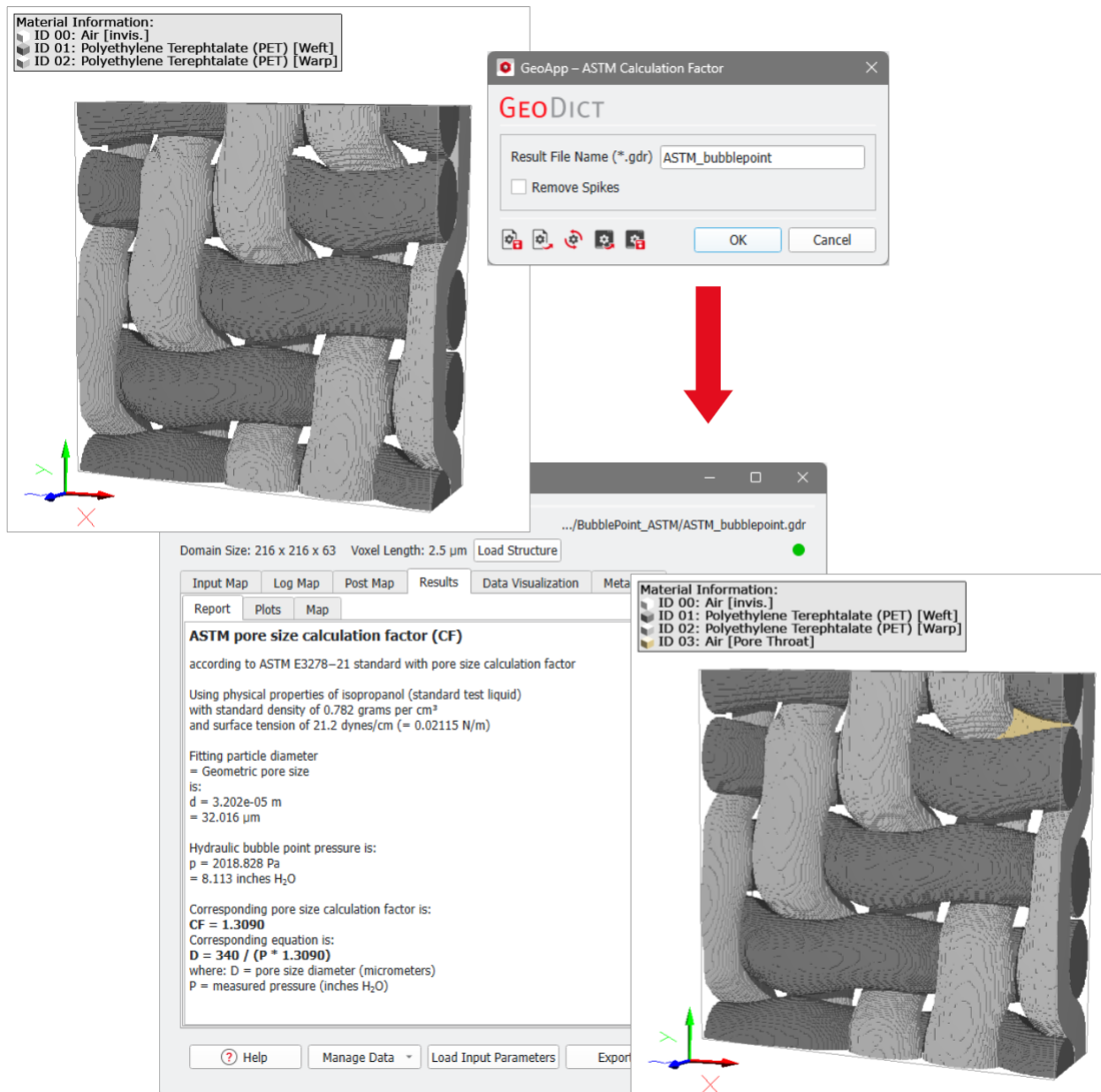
In this standard, the hydraulic diameter bubble point pressure, percolation path fitting particle diameter, and pore size calculation factor (CF) are generated using the PoroDict module of GeoDict. The CF is used to calculate the pore size of filter cloth from the measured bubble point pressure. These parameters are derived from the non-circular cross-section of the bottleneck through-path of the filter cloth.

This method employs a capillary flow technique in which air pressure is applied to drive a bubble through a flat specimen of industrial woven wire filter cloth wetted with a liquid of known surface tension. As the required pressure is inversely proportional to the pore size, the measured bubble point pressure is used to determine the pore size. The procedure defines the measurement and standardization of pressure and the calculation of pore size using the CF factor.

For further details, refer to the [GeoDict website](#) and [ASTM E3278-21](#) standard.

The bubble point pressure calculation factor can be determined using only geometric information, i.e., pore throat area and pore throat circumference. To calculate the CF, a distance map and a percolation path are computed, and local minima in the distance map are used to identify candidate pore throat locations. At each candidate, cutting planes with varying orientations are evaluated using planar ray tracing to determine the cross-sectional area and circumference. The plane with the minimum area defines the effective pore throat, from which the CF is computed. This approach enables accurate bubble point estimation for complex, non-circular pore geometries.

The computation of the ASTM pore size calculation factor was tested and optimized on several metal wire weaves. In the ASTM test, the wire weaves are put in a containment filled with water, while air is injected from below the weave. The bubble point pressure is reached when the first air bubble pushes through the weave layer.



The available result files in the **Data Visualization** tab of the Result Viewer are the same as for the [Bubble Point](#) command.

1.11 References

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