RELEASE NOTES - PERGEOS 1.7, JANUARY 2018

Thermo Scientific™ PerGeos 1.7

3D Analysis Software for Digital Rock Data

Dear PerGeos User,

With this document, we would like to inform you about the most important new features, improvements, and changes in the 1.7 version of PerGeos. Please read these Release Notes carefully. We would appreciate your feedback regarding this version. If you encounter any problems or have any suggestions for improvement, please do not hesitate to contact us at fei-sw-support@fei.com. We would like to thank you in advance for your cooperation.

January 2018, the PerGeos team

PERGEOS ENHANCEMENTS AND NEW FEATURES

MESHING WORKSPACE

The Meshing workspace is introduced in PerGeos 1.7. This workspace is currently available only on Microsoft Windows platform. Using this workspace, tetrahedral meshes are generated directly on labeled voxel data. The underlying algorithm for generating a mesh is based on Delaunay refinement. This is different than the legacy meshing tool in PerGeos, which is based on the advancing front method. With this new workspace, generating a volume mesh has been made easier and more seamless.

CREATING A VOLUME MESH

The only input required for creating a tetrahedral volume mesh in the Meshing workspace is a Label dataset. This dataset is typically the result of a segmentation process on a gray-scale image. Multiple options are available for optimizing or refining the mesh. A micro-CT image of a Berea sandstone segmented into pores, intermediate phase, and grains is used to generate a tetrahedral mesh in Fig. 1. A clipping button is available to clip the mesh in the viewer.

EXPORTING A VOLUME MESH

The tetrahedral mesh generated in the Meshing workspace can be exported in a variety of formats and used in 3rd party applications. Fluent, Abaqus, and NASTRAN are some of the formats in which the tetrahedral mesh can be exported (see Fig. 1).

ASSIGNING BOUNDARY CONDITIONS

Boundary conditions can be assigned to the generated mesh. A variety of boundary condition types are available for assigning to a set of selected triangles. Plane, contact, and equation modes are available for selecting a set of triangles from the volume mesh to assign the boundary conditions. In Fig. 2, triangular faces in the pores material that are on the

X-min and X-max planes are selected and assigned the pressure inlet and pressure outlet boundary conditions, respectively.

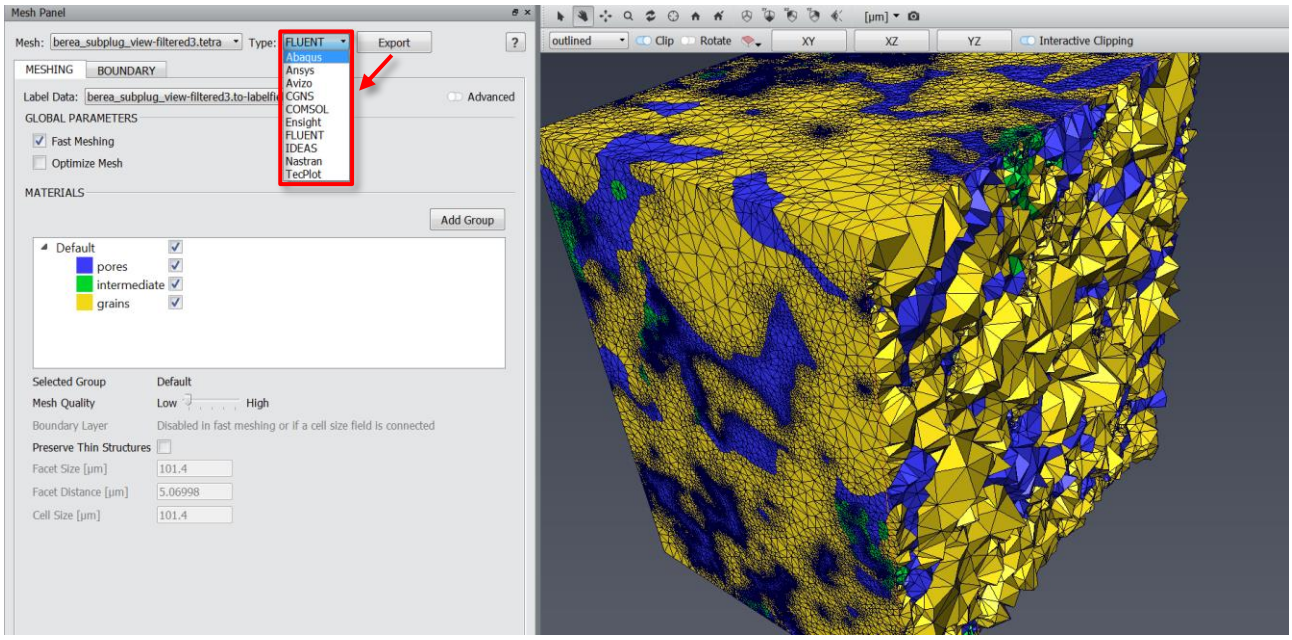

Figure 1. Tetrahedral mesh of a Berea sandstone image is generated directly on the segmented data using the Meshing workspace. This mesh can be exported in a variety of formats.

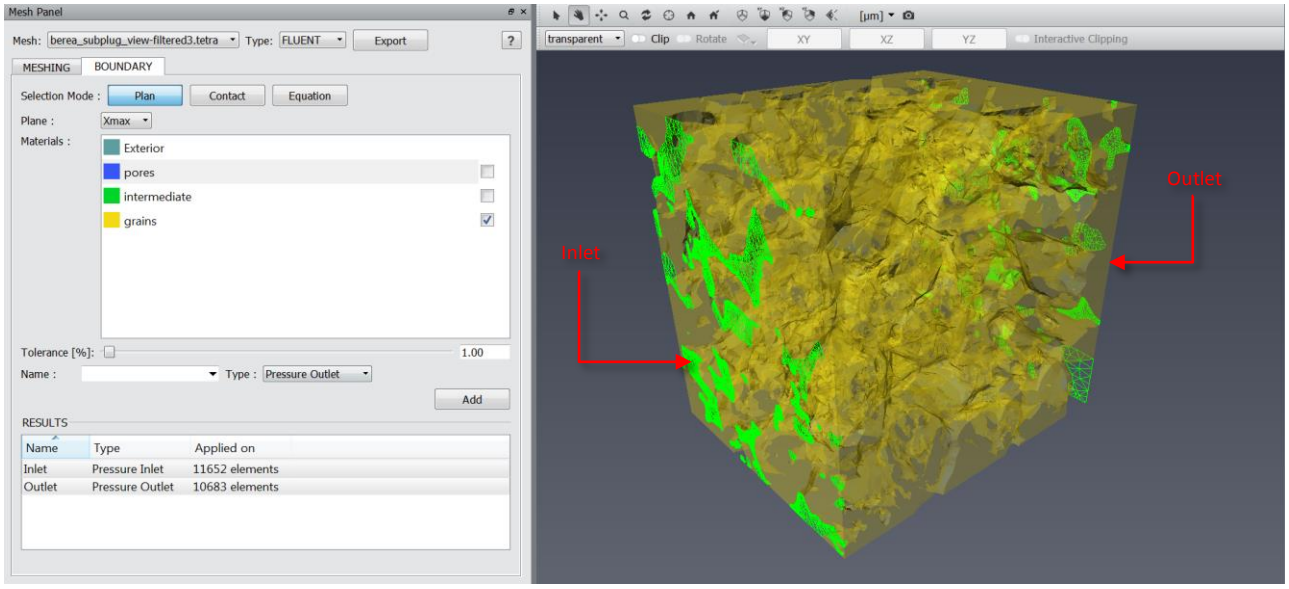

Figure 2. Pressure inlet and outlet boundary conditions are assigned to the pores on the min and max X planes, respectively.

DISPLAYING INFORMATION FOR TETRAHEDRAL MESHES

In PerGeos 1.7, information about the physical size and number of elements in a tetrahedral mesh can be viewed in the Preview panel (see Fig. 3).

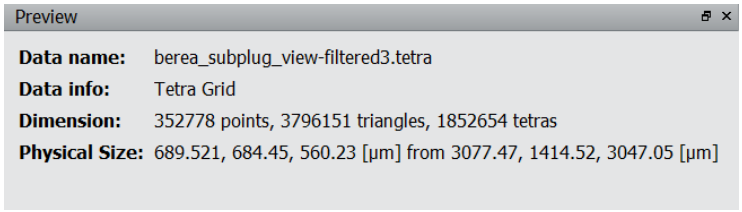

Figure 3. Tetrahedral mesh information is displayed in the Preview panel.

RECIPES PANEL

SAVING INTERMEDIATE DATA

In the previous versions of PerGeos, the user could keep or remove the intermediate results from a recipe all together. In PerGeos 1.7, there is an additional option to keep the results from one or more steps of the recipe by selecting it directly in the Recipes panel. This option overrides the Remove Intermediate Data option, which is under the preferences, for the steps that it is selected. This enables the user to minimize the amount of memory usage during the execution of a recipe, and also keep the important results from a select number of steps. See Fig. 4.

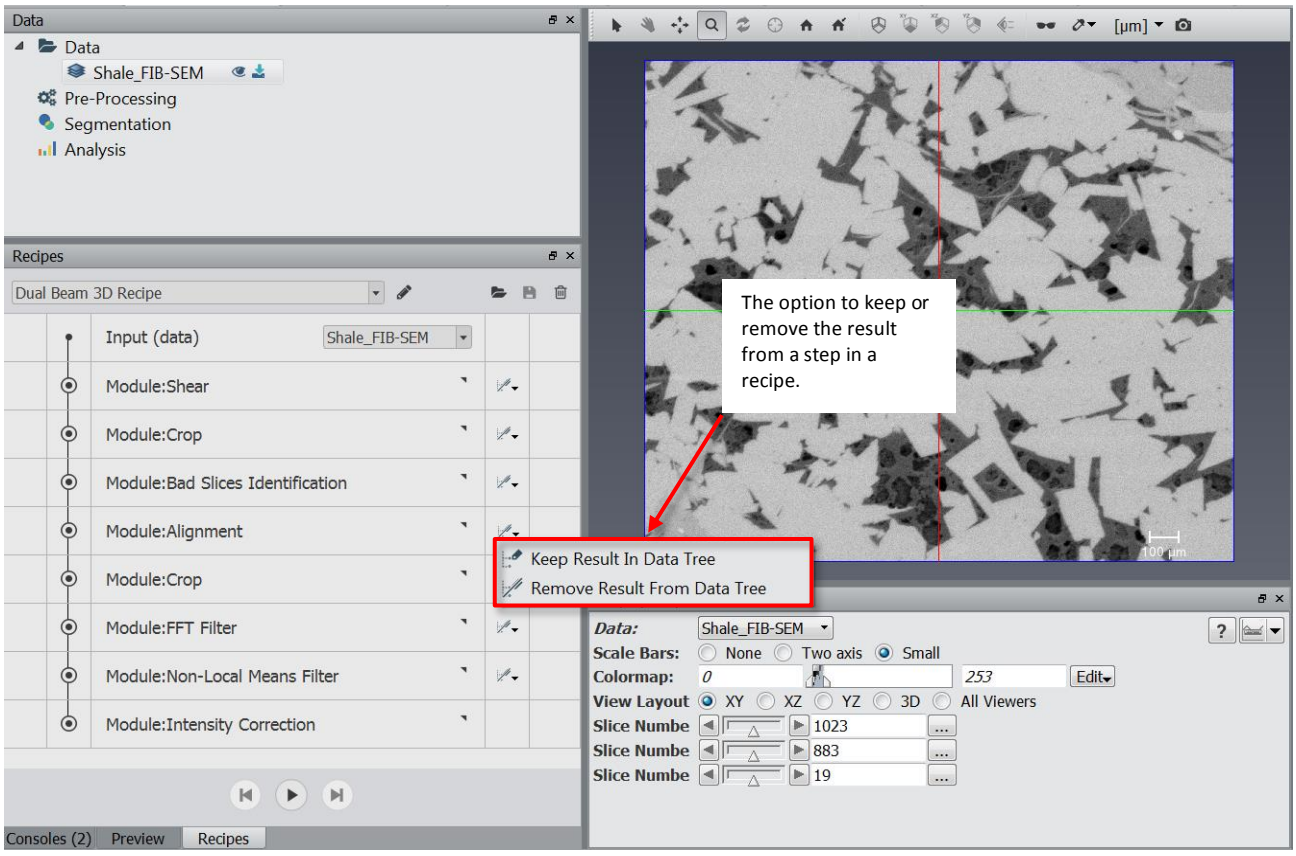

Figure 4. The user can select to keep or remove the result from a step in a recipe.

SLAB PROCESSING

Slab processing tools were first introduced in PerGeos 1.5 as a set of basic tools for processing large out-of-core data. In PerGeos 1.7, we introduce a number of additional tools to this set that provide more flexibility.

RECIPE BY SLAB

The “Binarization by Slab” tool has evolved and is now called “Recipe by Slab – Binary”. There are also “Recipe by Slab – GrayScale” and “Recipe by Slab – LabelField” tools available in the Explore workspace. Using these Recipe by Slab tools, the user can apply recipes that generate gray-scale or labeled data in addition to the previously available binary output. Currently, only a select number of tools are supported in the recipes that are used in the slab processing tools. For more information, please refer to the Help section on these tools. In the example shown in Fig. 5, an 80 GB size dataset acquired on a Thermo Scientific™ HeliScan is processed and segmented on a machine with 32 GB of memory, using the Recipe by Slab tools in PerGeos 1.7.

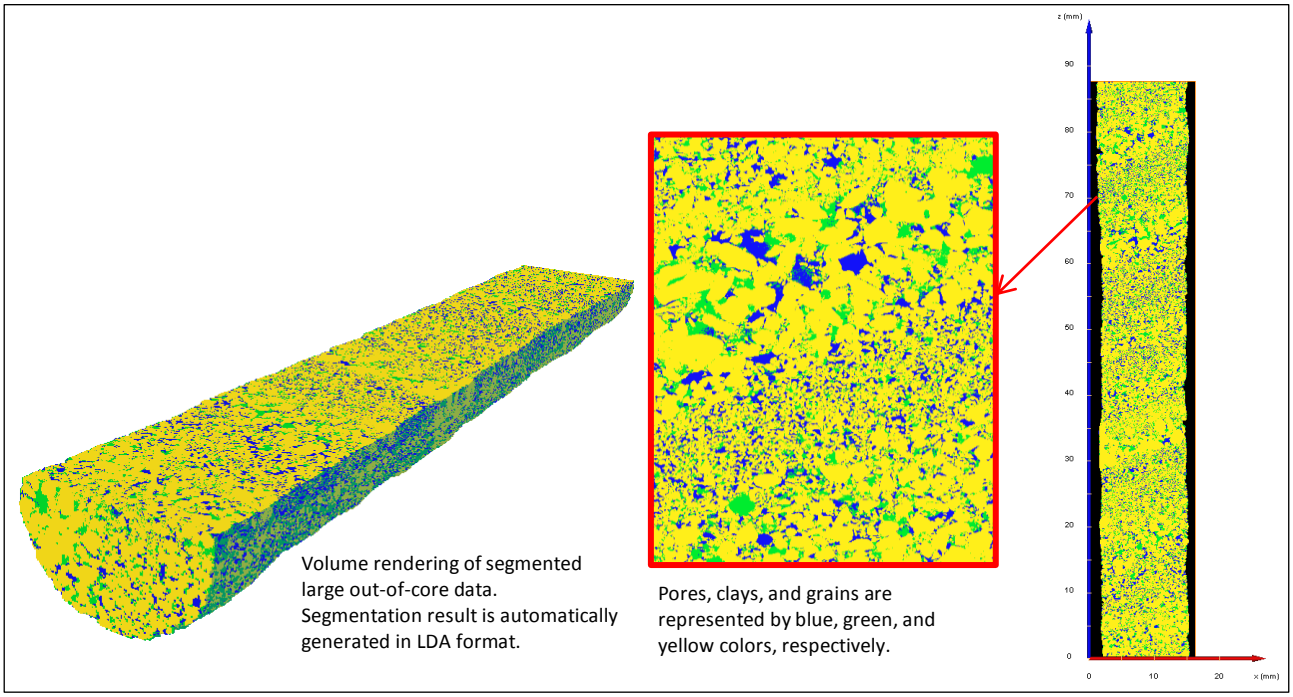

Figure 5. An 80 GB HeliScan micro-CT dataset of a laminated sandstone is segmented into pores, clays, and grains using Recipe by Slab tools.

MULTIPLE INPUTS

Recipes with multiple inputs are now supported in the slab processing tools. The output will have the same dimensions as the primary input of the recipe.

VOLUME FRACTION OF LABELS

The Volume Fraction by Slab tool now supports labeled input data, in addition to the previously supported binary data.

OUT-OF-CORE (LDA) DATA SUPPORT

SAVING A TRANSFORMED LDA DATASET

The changes made to the metadata of an LDA dataset can now be saved as part of the same or a new LDA dataset. This includes transformations, minimum coordinates, and the data window range.

COLORWASH FOR LDA DATASETS

The ColorWash option is now available and supported for LDA datasets in the Compare Properties panel.

EXPORT IN LDA FORMAT

A dataset that is loaded into the memory can now be exported in the LDA format. This new export option is available through Export Data As, and is called VolumeViz LDA (*.lda) (see Fig. 6).

CONVERT TO LDA

An LDA conversion tool can now be created through the Console panel in the Explore workspace by typing “create HxConvertToDiskData”. Using this tool, the user can select a list of input datasets from the disk and convert them to the LDA format. The converted datasets will be available in the Data panel (see Fig. 7).

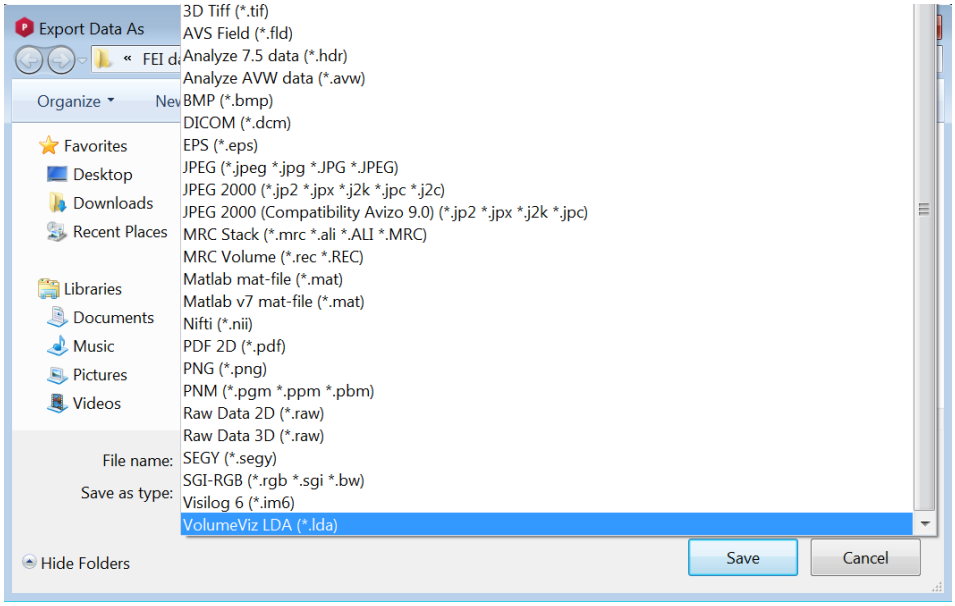

Figure 6. Data loaded into the Data panel can now be exported in LDA format.

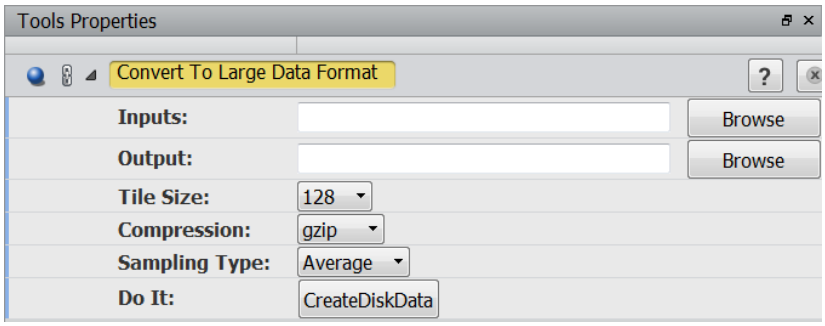

Figure 7. An LDA conversion tool can accessed through the Console panel in the Explore workspace.

USER INTERFACE

NEWS FEED

A news section is now available on the Start Page. This section is updated with news regarding PerGeos. An internet connection is needed to receive the latest updates.

LEARNING CENTER

A PerGeos Learning Center with video tutorials is now available on YouTube. The link to this learning center can be accessed via the Help section on the Start Page. A hyperlink is also available here.

CORE PROFILE ENHANCEMENTS AND NEW FEATURES

VISUALIZATION

OVERLAY VISUALIZATION

There is a new Overlay Visualization section available in the Slice Properties panel, in the Core Profile workspace, that enables the user to visualize any data overlaid with CT images. This feature can be used to overlay segmented rock types, fractures, laminations, and other features on CT data in the Core Profile viewer. The transparency of the visualization can be adjusted (see Fig. 8).

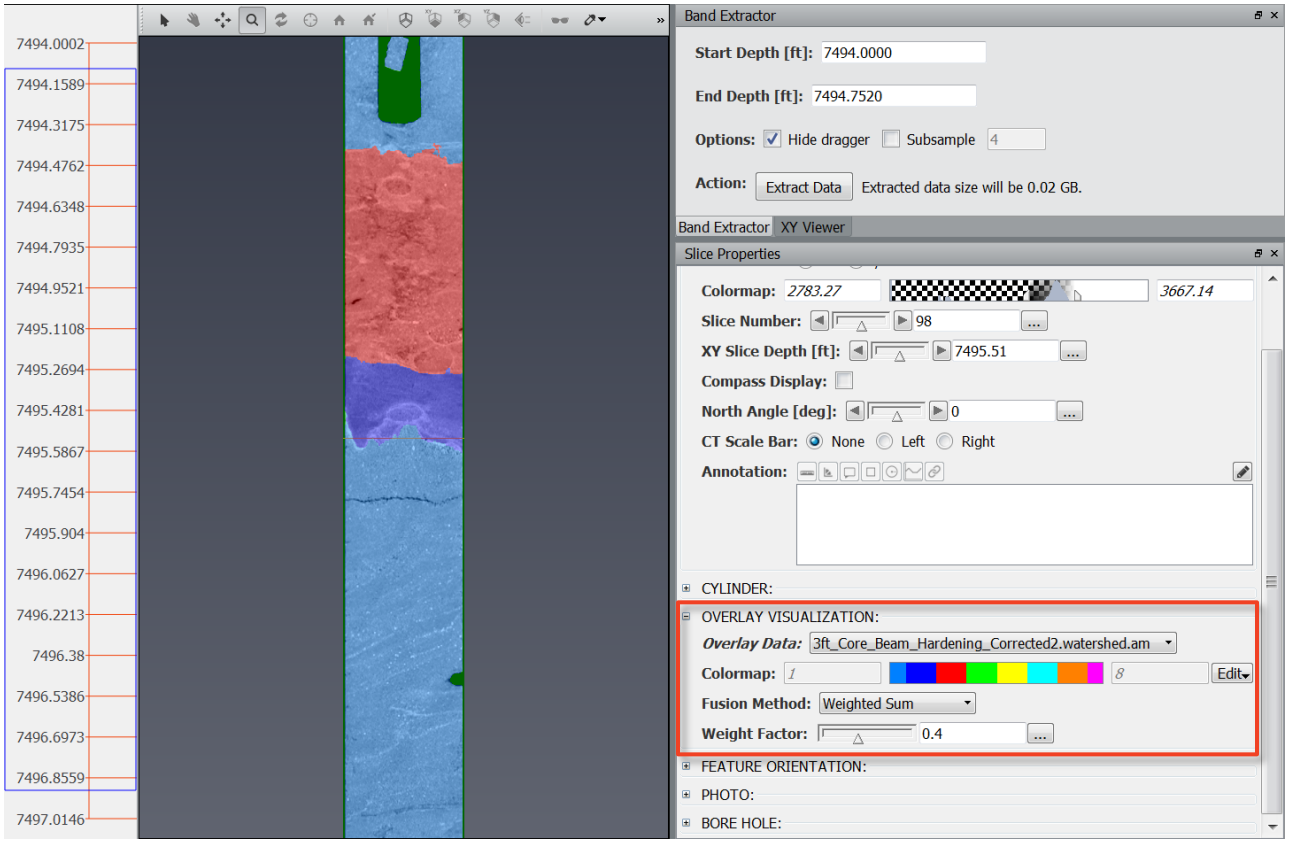

Figure 8. Segmented rock types data is overlaid with CT images using the new Overlay Visualization section in Core Profile.

PICKABLE XY SLICE INDICATOR

The XY slice indicator, which is an orange line in the CT viewer, can now be picked and dragged with the mouse (see Fig. 9).

XY SLICE IN DEPTH UNITS

The XY slice slider is now displayed in depth units (see Fig. 9). This was shown in slice numbers in previous versions.

CORE ASSEMBLY

LAUNCH CORE ASSEMBLY WIZARD THROUGH GUI

The core assembly wizard can now be launched through the GUI in the Core Profile workspace. The launch button is available in the Assembly Wizard menu at the top left corner of the GUI.

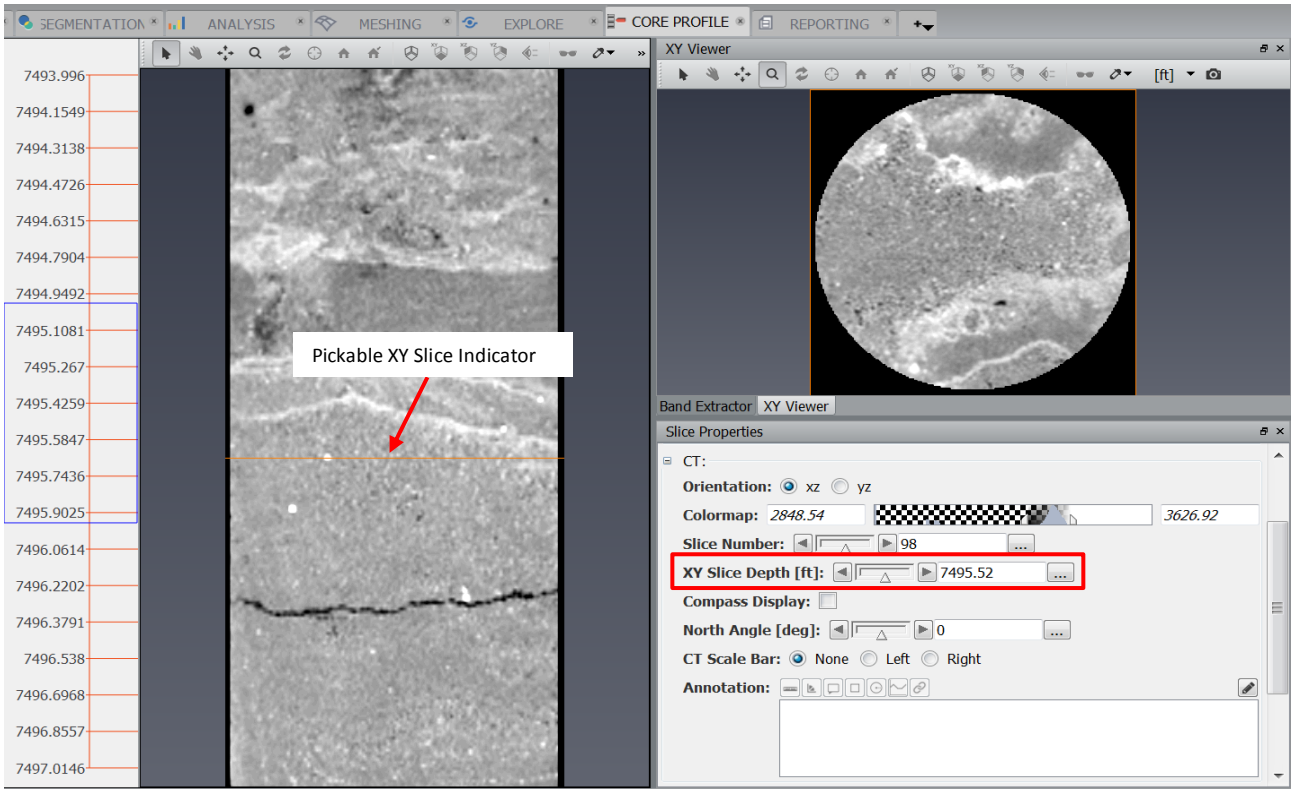

Figure 9. XY slice indicator can be picked and its associated depth is displayed in length units in Core Profile.

DICOM HEADER READER

A new user interaction step, during the core assembly, is introduced that enables the user to match the information in the DICOM headers to the attributes related to the well. The DICOM tags that are matched to the well attributes will be remembered for future assemblies.

PETROPHYSICS ENHANCEMENTS AND NEW FEATURES

SINGLE PHASE FLOW SIMULATION

ABSOLUTE PERMEABILITY LATTICE BOLTZMANN

A new lattice Boltzmann-based fluid flow simulator is introduced in PerGeos 1.7. This new solver is called Absolute Permeability Lattice Boltzmann, and it is accessible through the Analysis workspace. It utilizes fully parallel CPU computations, and has a smaller memory footprint compared to the legacy absolute permeability solver in PerGeos. The MPI library is used for communication between multiple CPU processes. The user can set the number of processors to use for this simulation. Fluid flow in larger samples can be simulated using this new solver. The user can run flow simulations in all three principal directions to obtain the full absolute permeability tensor. In addition, a velocity profile is generated along the macroscopic direction of flow (see Fig. 10).

ELECRICAL CONDUCTANCE SIMULATION

FORMATION FACTOR RANDOM WALK

A new electrical conductance simulator is introduced that is based on the random walk method. This new solver is called Formation Factor Random Walk, and it is accessible through the Analysis workspace. This is a fully parallel implementation that utilizes the MPI library. The random walk technique simplifies the calculation of formation factor and generates faster results compared to the legacy formation factor tool in the Petrophysics module. In addition, due to the smaller memory footprint it enables calculation of formation factor on larger samples.

In this new solver, there is an option for the user to include the micro-porous phase, i.e., the clays, in the calculations. Four different types of clays and three types of brines are available to pick for the simulations. The brine concentration can also be adjusted to match the formation brine. In addition, simulations are performed in all three principal directions and the convergence data are plotted as a result (see Fig. 11).

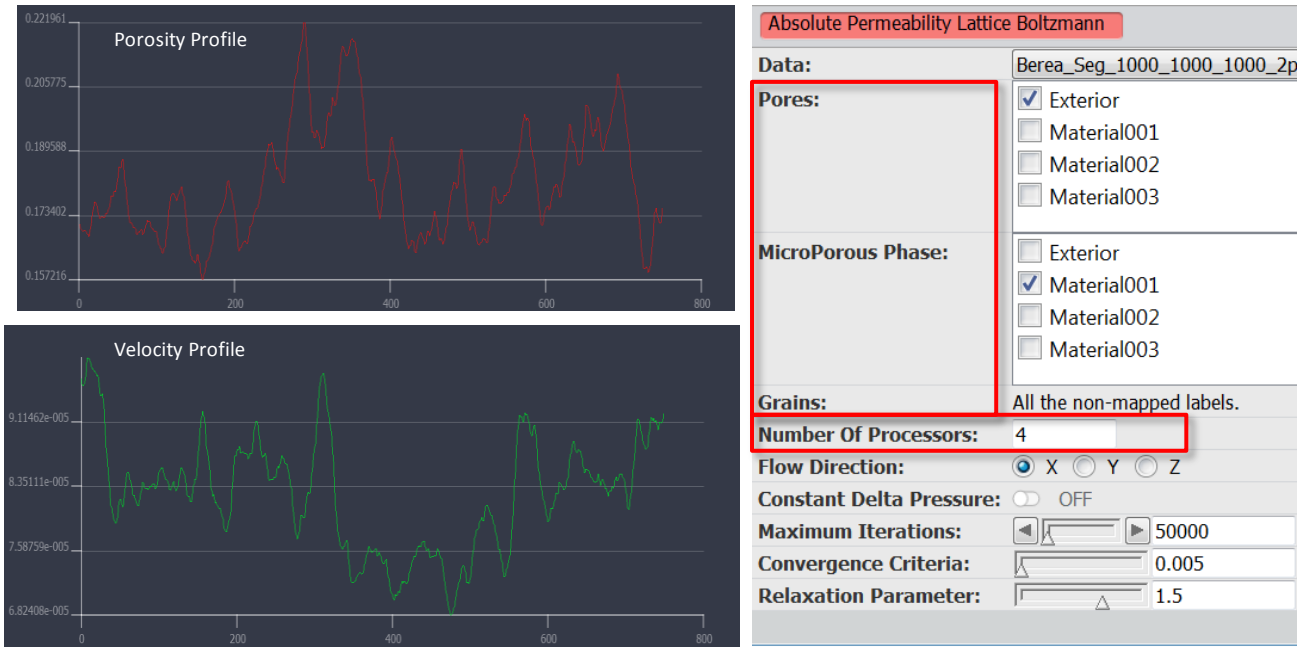

Figure 10. Velocity profile is generated as a result of a lattice Boltzmann flow simulation. Labels mapping and number of processors are specified in the Absolute Permeability Lattice Boltzmann tool.

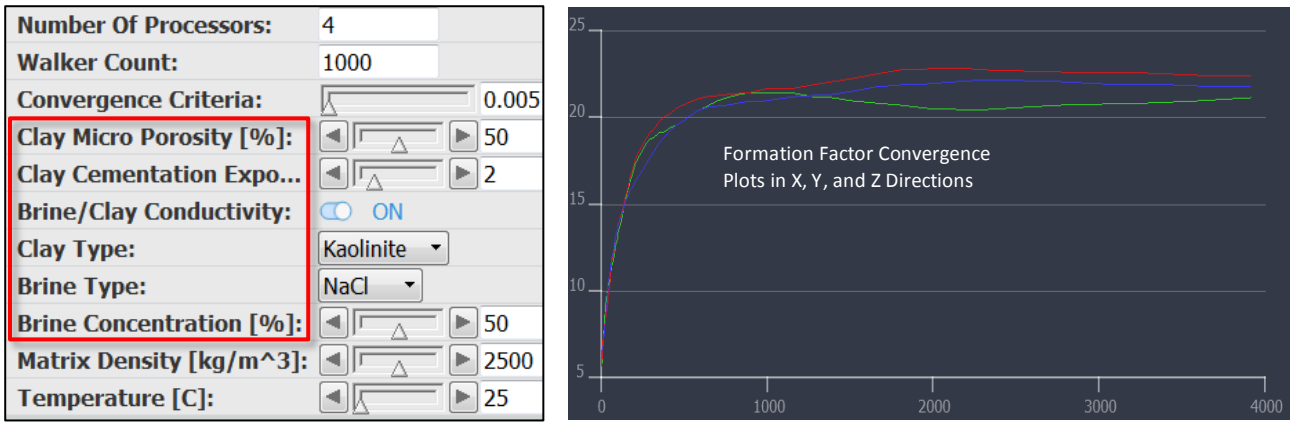

Figure 11. Clays can be included in the calculations in Formation Factor Random Walk. Convergence data are plotted as a result of simulation in three principal directions.

LABELS TO MATERIALS

LABEL MAPPING

A new optional attribute is added to label data that enables the user to specify which labels correspond to pores, micro-porous phase, and grains. This attribute is used in the Absolute Permeability Lattice Boltzmann, Formation Factor Random Walk, and Pore Network Model Extraction (PNS module) tools. Once this attribute is set in one of the aforementioned tools, it can be saved and remembered while using another tool (see Fig. 10).

PORE NETWORK STATISTICS ENHANCEMENTS AND NEW FEATURES

PORE NETWORK MODEL EXTRACTION

The Generate Pore Network Model tool has evolved, and it is now called the Pore Network Model Extraction tool.

NEW METHOD

There is a new Grain-Based PNM method available for generating a pore network model. The previous technique is still available by selecting the Pore-Based PNM method. In the new grain-based method, the input image is the result of a segmentation process. No separation of pores or grains needs to be performed while using this new method. A label mapping section is also available in the tool that enables the user to select the labels that correspond to pores and micro-porous phase (see Fig. 10). The selection of micro-porous phase is optional. But if it is selected, its partial pore volume will be available in pores and throats properties spreadsheet. The pore network model generated using this new grain-based method is used in the new Two-Phase Flow Simulation tool, which is part of the new Pore Network Flow module.

PERMEABILITY AND TORTUOSITY

A new option called Generate Properties is available when the Pore-Based PNM method is selected. When switched on, this tool calculates absolute permeability and tortuosity of the pore network model.

VISUALIZATION

PORE AND THROAT SCALE AND COLORING IN DISPLAY PROPERTIES

In PerGeos 1.7, the user can set scale and color maps to pores and throats in the Display Properties panel. This option was previously available only through the Pore Network Model View tool in the Explore workspace.

PORE NETWORK FLOW (NEW EXTENSION)

The Pore Network Flow (PNF) module is introduced in PerGeos 1.7. This new module offers a platform for simulating two-phase flow processes using a pore network model-based solver. This module also includes the tools available through the Pore Network Statistics module.

TWO-PHASE FLOW SIMULATION

SIMULATING TWO-PHASE PROCESSES

The Two-Phase Flow Simulation tool which is part of the Pore Network Flow module is available through the Analysis workspace. This tool enables the user to run simulations of concurrent flow of two immiscible fluids inside porous materials. A pore network model generated using the grain-based method is used as an input of this tool. Primary drainage, waterflooding, and secondary drainage processes can be simulated using this new tool. The wettability of the rock-fluid system is modeled by assigning contact angle distributions for each two-phase flow process. Relative permeability, capillary pressure, and resistivity index plots are generated for each simulated process (see Fig. 12). A spreadsheet containing the summary of simulation results including the residual oil saturation is also generated. A two-phase flow simulation tutorial is now available in the User's Guide.

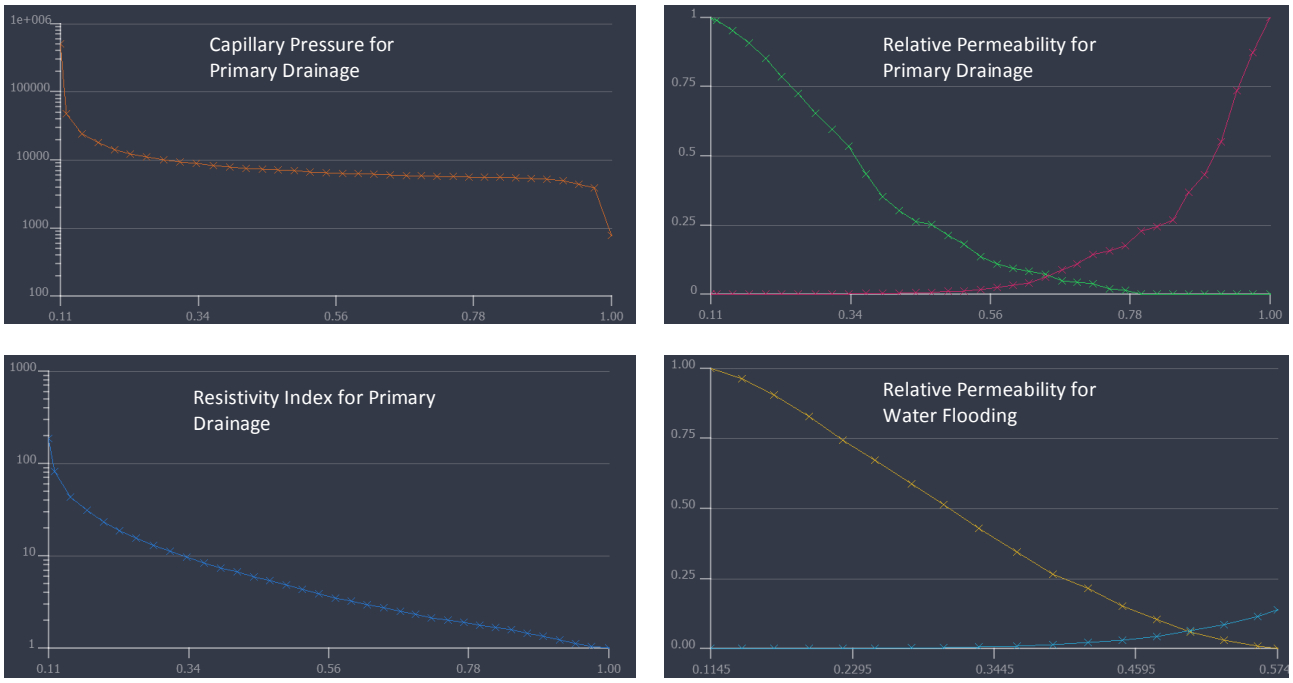

Figure 12. Capillary pressure, relative permeability, and resistivity index plots are generated for each simulated two-phase flow process.

References

- **3-D Pore-Scale Modelling of Sandstones and Flow Simulations in the Pore Networks,** S. Bakke and P.E. Øren, *SPE Journal*, Volume 2, Pages 136-149, June 1997 – SPE 35479
- **Extending Predictive Capabilities to Network Models,** P.E. Øren, S. Bakke, O.J. Arntzen, *SPE Journal*, Volume 3, Issue 4, Pages 324-336, December 1998 – SPE 52052
- **Reconstruction of Berea Sandstone and Pore-Scale Modelling of Wettability Effects,** P.E. Øren and S. Bakke, *Journal of Petroleum Science and Engineering*, Volume 39, Issues 3-4, Pages 177-199**,** September 2003
- **Pore-Scale Modeling of Capillary Trapping in Water-Wet Porous Media: A New Cooperative Pore-Body Filling Model,** L.C. Ruspini, R. Farokhpoor, P.E. Øren, *Advances in Water Resources*, Volume 108, Pages 1-14, October 2017
- **Investigation into the Reliability of Predictive Pore-Scale Modeling for Siliciclastic Reservoir Rocks,** O. Lopez, A. Mock, J. Skretting, E.B. Petersen Jr., P.E. Øren, A.B. Rustad, *Society of Core Analysts*, SCA 2010-23
- **Relative Permeability Assessment in a Giant Carbonate Reservoir Using Digital Rock Physics,** Z. Kalam, S. Seraj, Z. Bhatti, A. Mock, P.E. Øren, V. Ravlo, O. Lopez, *Society of Core Analysts*, SCA 2012-03
- **Gas-Water Steady-State Relative Permeability Determination with Two Approaches; Experimental and Digital Rock Analysis, Strengths and Weaknesses,** R. Farokhpoor, E. Westphal, N. Idowu, P.E. Øren, B. Fletcher, *Society of Core Analysts*, SCA 2016-12

LICENSING

The PerGeos 1.7 licensing mechanism has been upgraded to FlexNet Publisher 11.14. If you are using a FlexNet license server, make sure you have installed version 11.14.0 or higher of the FlexNet tools on your system. For more details and download links, please refer to http://www.fei-software-center.com/support/flexnet-server-doc/.

OPERATING SYSTEMS

PerGeos 1.7 runs on:

- Microsoft Windows 7/8/10 (64-bit).
- Linux x86 64 (64-bit). Supported 64-bit architecture is Intel64/AMD64 architecture. Supported Linux distribution is Red Hat Enterprise Linux 6.

In order to add custom extensions to PerGeos with PerGeos **XPand**, you will need

- Microsoft Visual Studio 2013 (VC12) Update 4 on Windows.
- gcc 4.4.x on Red Hat Enterprise Linux 6.

SOLVED ISSUES

The PerGeos 1.7 release provides various enhancements and solutions to known problems, including the following:

Align Slices	62738	The image would disappear from the viewer when using some actions of the Align slices tool. This has been fixed.
Colormap Editor	63792	The colormap can now be edited from the home room.
Core Profile	60405	The data window of the colormap is now correctly set when using the cylinder view.
Correlation Panel	44921	In Correlation panel, negative values are now managed by the logarithmic scale.
Data Panel	46787	Save icon was displayed when a transformed data was loaded. This has been fixed.
	37035	The icon of an unloaded data was not displayed in the data tree when reloading a saved project. This has been fixed.
	54227	Projects with special characters in the folder name are now properly loaded.
Data Properties	56005	The voxel size of the data bounding box cannot be set to inconsistent values anymore (0 or negative value).
Generate Pore Network Model	63674	The transformation of the input was not applied on Generate Pore Network Model output. This has been fixed.
Histogram Panel	45757	In the Histogram panel, axis tick values are now properly displayed when enabling logarithmic scale on X or Y axis.
History log	62603	The application could become unresponsive when loading a data with an extremely large history log. This has been fixed.
Labeling	51741	The labeling tool could fail to detect label connections on some datasets. This has been fixed.
Link Annotation	60319	Link Explorer histograms could disappear when displayed in split layout. This has been fixed.
Multi Thresholding	54558	The multi thresholding tool could fail when launched on a large dataset. This has been fixed.
Non Local Mean Filter	63834	Non Local Means Filter can generate inaccurate results when used with the 3D filter option. A new version of the 3D filter is now available by loading the script object located at <PerGeos Installation Directory>/share/script-objects/NonLocalMeansFilter.scro.
Pore Network Node-Link	51774	Units are now managed in the Pore Network Node-Link reader.
Recipes	61033	Data computed by the Alignment step in the Dual Beam 3D recipe was cropped. This has been fixed.
	60365	New block Processing scripts are available in <PerGeos Installation Directory>\data\tutorials\batch_processing\FullData_byBlocks.

		These scripts allow you to execute a recipe by block on a 2D or 3D dataset. The result will be saved on disk.
	64340	Intermediate data are now properly removed in recipes having a material selection step in the Segmentation panel.
	61923	It is now possible to uncheck the markers during a recipe execution using the Marker-Based Watershed tool.
	63064	Recipes using the Marker-based Watershed tool did not work properly on 16-bit data. This has been fixed.
Reporting	53149	CPU usage in the Reporting workspace has been improved.
Segmentation	62756	Selecting a label dataset with a large number of labels in the Segmentation panel could make it become unresponsive. This has been fixed.
Series Animation	60209	Series Animation execution did not always match the files order when the files names included numbers. This has been fixed.
Surface View	60449	On ATI Radeon graphic board, surface data was not properly displayed. This has been fixed.
	56189	Surface View would fail when trying to display BoundaryId selection on a surface with no boundary condition. This has been fixed.
Volume Rendering	60781	Volume rendering was not properly displayed on Intel HD 530 graphic board. This has been fixed.

Our team is dedicated to solving as many issues as possible to make your experience with PerGeos as satisfactory as possible. For this purpose, we would greatly appreciate your feedback regarding this version. If you encounter problems, or if you have suggestions for improvement, please report them to fei-sw-support@fei.com.