thermo scientific

PERGEOS SOFTWARE

for digital rock analysis

Release notes – Version 1.8

November 2018

With this document, we would like to inform you about the most important new features, improvements and changes in the 1.8 version of Thermo Scientific™ PerGeos Software. 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.

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Table of Content

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REBRANDING

This new version of PerGeos Software has been fully rebranded.

Warning: The Recipes default directory has been renamed from %APPDATA%/FEI/Recipes directory to %APPDATA%/Thermo Fisher Scientific/Recipes. If you had stored recipes in the former default directory, you can copy the contents of %APPDATA%/FEI/Recipes into %APPDATA%/Thermo Fisher Scientific/Recipes.

The launch icon has also been changed. It is now a red square with PG letters.

NEW DUAL ENERGY COMPUTED TOMOGRAPHY EXTENSION

The Dual Energy Computed Tomography (DECT) Extension is introduced in PerGeos Software 1.8. DECT is required to access the features described in this section. X-ray CT data provide a proxy for density and atomic number of a sample under study. By acquiring X-ray CT data at two different energy levels and using the DECT tools described in this section, you can calculate density and effective atomic number for the sample on a voxel-by-voxel basis. This enables you to compare whole-core CT images across multiple formations and wells. In addition, a characterized materials image that can be considered a rock-typed image is created based on a list of reference materials. This technology adds value to whole-core CT analysis workflows by providing actual density information that can be compared with density logs and used for further characterization of rock formations.

The DECT tools are located in the Analysis Workspace in the Dual Energy CT folder and in the Explore Workspace in the Advanced Compute/Scripts folder inside the Dual Energy CT subfolder. These tools include:

- DECT Coefficient Generator
- DECT Mean Intensity
- DECT Merge and Match
- Iterative DECT
- Linear DECT
- DECT Batch Processing

DECT calibration

A DECT system must be calibrated using reference standards with known density and composition (see Fig. 1). PerGeos Software includes a set of tools that enable calibration of a DECT system through calculation of linear (α) and angular (β) coefficients based on the information obtained from the images of the aforementioned reference standards. These tools are described below.

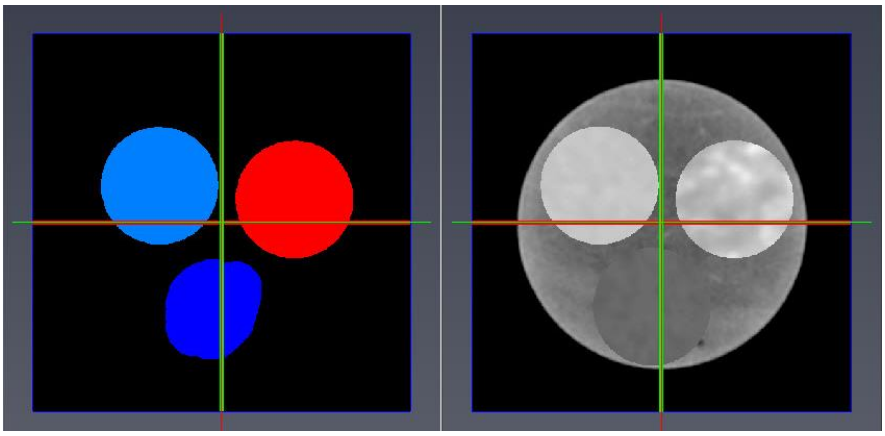

Figure 1. Examples of a grayscale (right) and labeled (left) image of reference materials used for calibration.

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The DECT Mean Intensity is used to calculate average intensities of reference standards at two energy levels. The labeled image of reference materials along with the grayscale intensity images acquired at two energy levels are used as inputs for this tool. The result is a spreadsheet containing the average intensities for each material at each energy level (see Fig. 2).

	Material	Low Energy	High Energy
1	Al	2641.443848	2052.679443
2	Quartz	1768.457275	1404.931274
3	Granite	2611.361084	2040.36377

Figure 2. Mean intensities spreadsheet.

The DECT Merge and Match tool is used to match the labels in the mean intensity spreadsheet to those in the input spreadsheet containing the density and Z_{eff} properties of the reference materials (see Fig. 3). The two spreadsheets are then merged to form an input for the DECT Coefficient Generator tool (see Fig. 4).

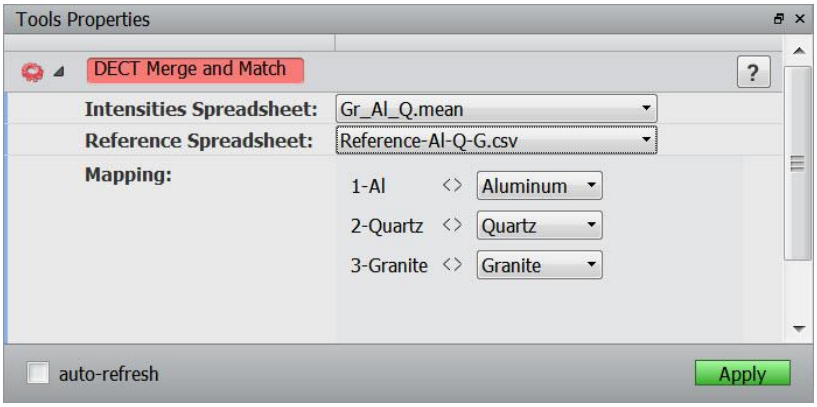

Figure 3. DECT Merge and Match tool.

	ReferenceName	Low Energy	High Energy	Density	EffectiveAtomicNumber
1	Aluminum	2641.443848	2052.679443	2.71	13
2	Quartz	1768.457275	1404.931274	2.2	11.8
3	Granite	2611.361084	2040.36377	2.62	12

Figure 4. Matched spreadsheet containing high and low energy intensities, densities and Z_{eff} values for each reference material.

The DECT Coefficient Generator tool is used to calculate linear (α) and angular (β) coefficients for each energy level based on a spreadsheet containing mean intensities and material properties. Hounsfield unit, linear attenuation (1/cm) and mass attenuation (cm^2/g) intensity types are supported in this tool (see Fig. 5).

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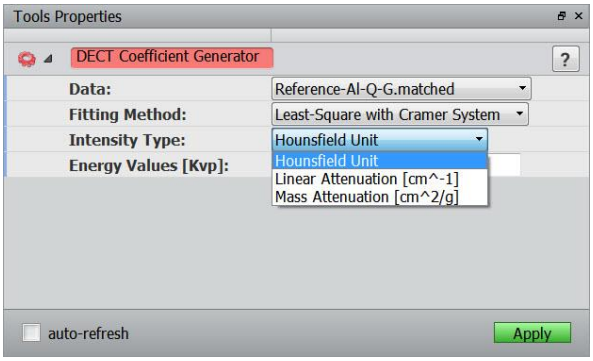

Figure 5. DECT Coefficient Generator tool.

A DECT-Calibration recipe is available in the list of default recipes for all tools described in this section. This concludes the calibration of the DECT system. The information obtained in this section is used for DECT analysis of samples with unknown properties.

DECT analysis

DECT Analysis is the process of calculating densities and Z_{eff} values and identifying different materials in a sample through use of X-ray CT images acquired at two energy levels. PerGeos Software has a set of tools that enable DECT Analysis. These tools are described in this section.

The Linear DECT tool inputs two grayscale images obtained at two energy levels. The default type for these images is Hounsfield Unit (see Fig. 6); however, the linear attenuation (1/cm) type is also supported and can be chosen under the Data Type port in the Advanced category. A binary input mask can be used with this tool to limit the calculations to the voxels inside the mask. A material database with known densities and Z_{eff} properties is required as an input of this tool. The information in the material database is used to identify the materials in the sample under investigation (see Ref. 1 and Fig. 7).

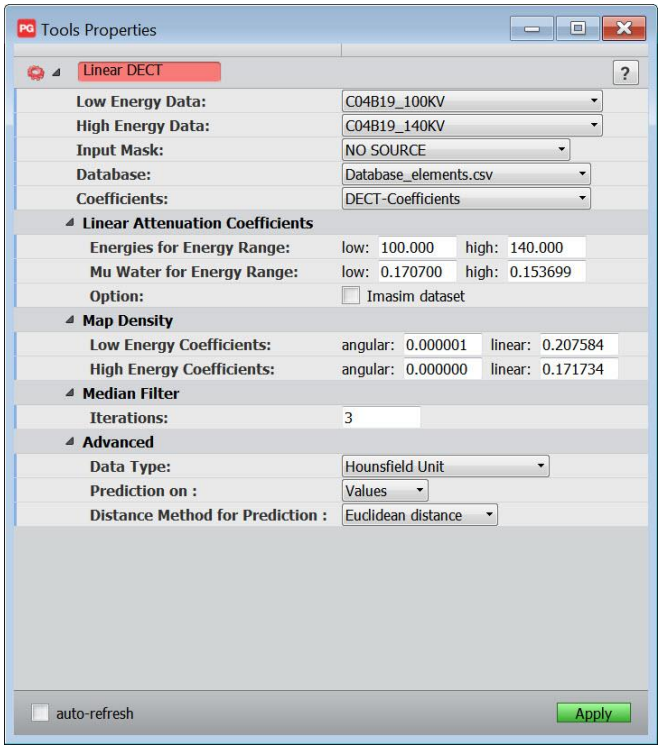

Figure 6. Linear DECT tool.

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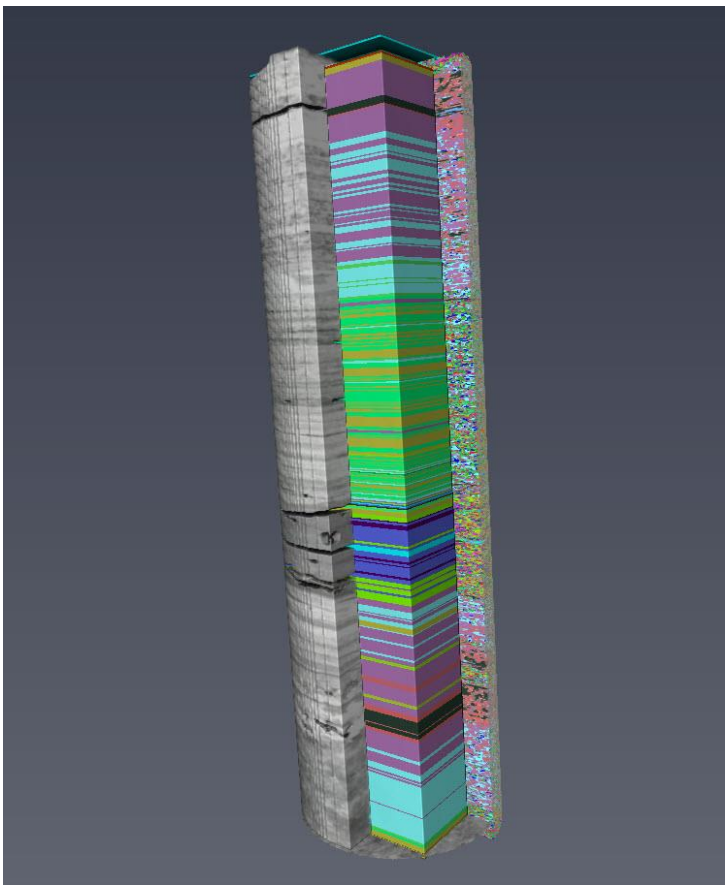

Figure 7. Volume rendering of grayscale input image, characterized materials and majority rock-typed image of a core sample characterized using Linear DECT tool.

In addition to the grayscale images and coefficients, the Iterative DECT tool also utilizes density, Z_{eff} and mass number information of one of the reference materials in the analysis (see Ref. 2).

These tools output a density map, a Z_{eff} map, a filtered Z_{eff} map, a map of predicted materials (based on the database) and a map of Z_{eff} errors. In addition, with the Linear DECT tool, logs of average density and Z_{eff} are produced.

Handling transformed data

Even though it is recommended that the DECT images are acquired without repositioning the sample, in some cases, registration of these images may be required. The Linear DECT tool takes into account the transformation information of registered images; therefore, these images do not need to be resampled before using them in the Linear DECT tool.

DECT Batch Processing

A DECT Batch Processing tool is available in the Explore Workspace. This tool applies the Linear DECT analysis on a select list of folders found in a root directory. In addition, it can write out the results to the same root directory or a new user-specified folder. The folder structure and hierarchy are preserved in the output directory. A pattern recognition mechanism is available to find and list all sub-folders in the root directory that contain the Low Energy and High Energy patterns specified by the user (see Fig. 8). DICOM and AM (i.e. native PerGeos file format) files are supported in this tool.

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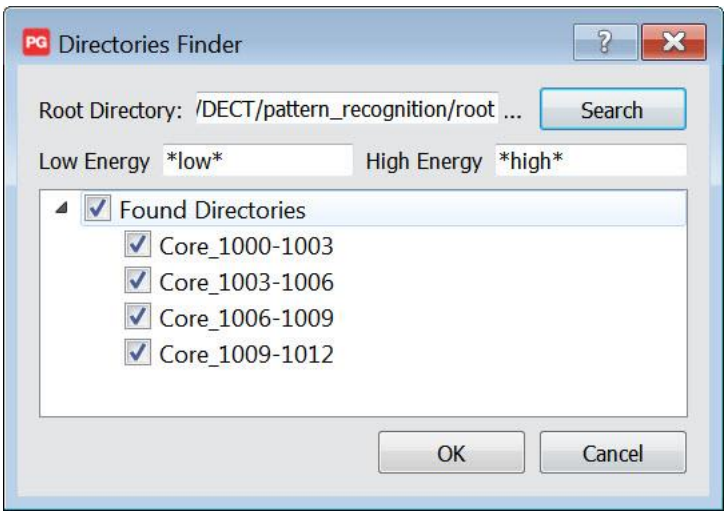

Figure 8. Directories Finder window in DECT Batch Processing tool.

References

1. **Methodology for attainment of density and effective atomic number through dual energy technique using microtomographic images,** H. Alves, I. Lima, R.T. Lopes, *Applied Radiation and Isotopes,* Volume 89, Pages 6-12, 2014
2. **Application of a dual-energy monochromatic X-ray CT algorithm to polychromatic X-ray: A feasibility study,** S. Chang, H.K. Lee, G. Cho, *Nuclear Engineering and technology,* Volume 44, Pages 61-70, 2012

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PORE NETWORK STATISTICS EXTENSION – PORE NETWORK FLOW EXTENSION ENHANCEMENTS AND NEW FEATURES

Pore network model extraction: Methods

The Pore Network Model Extraction tool has evolved in PerGeos Software 1.8. Three methods are now available for pore network model extraction:

- Statistics and Single Phase
- Pore-Based 2 Phase Flow
- Grain-Based 2 Phase Flow

The Statistics and Single Phase method is the Pore-Based PNM method from the previous version. This method creates a network of spherical pores and cylindrical throats based on the pore-space of the sample. The size properties of pores and throats, as well as the coordination number for each pore, are calculated with this method. In addition, by using the Generate Properties option and specifying a flow direction, you can calculate absolute permeability and tortuosity. The pore network model generated with this method is not compatible with the Two-Phase Flow Simulation tool (Pore Network Flow Extension).

Pore-Based 2 Phase Flow and Grain-Based 2 Phase Flow methods create a pore network model that is compatible with the Two-Phase Flow Simulation tool. The PNM generated with these methods contains pores and throats with angular cross-sections that represent the pore-space, and it can accommodate wetting and non-wetting fluids simultaneously.

In the Pore-Based 2 Phase Flow method, the skeleton of the pore-space is generated to detect pores and throats. This method preserves the pore-space connectivity that is observed in the input voxel image. This method can be used on samples with granular and non-granular structures and is recommended for carbonates, fractures, tight sands and samples with low connected porosity.

In the Grain-Based 2 Phase Flow method, the skeleton is generated by growing the grains into the pore-space and identifying pores and throats based on the contact points of grains. This method is suitable for samples with clearly defined grain-based structures, such as sandstones.

Pore network model extraction: Label Interpretation

A new Label Interpretation port is introduced in version 1.8. This port enables the user to select the type of labels in the input image. The Multiphase option refers to a label image where pores, clays and grains are segmented and labeled. When this option is selected, a label mapping section appears, allowing you to map the available labels to pores and a micro-porous phase. The other option in this port is Separated Pores. This option refers to a label image where individual pores are separated and labeled. No micro-porous phase can be assigned with this option (see Fig. 9).

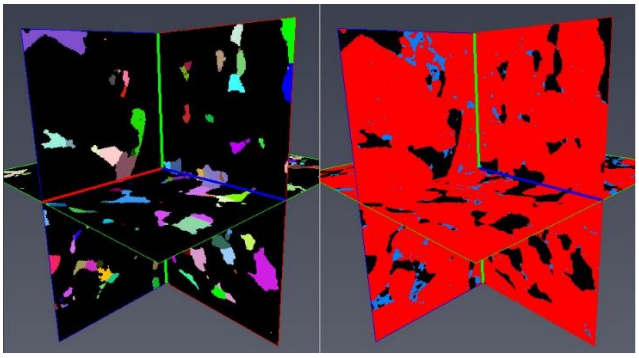

Figure 9. Examples of Multiphase (right) and Separated Pores (left) label images.

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Pore network model extraction: Displaying properties

A Generate Properties button is also available for the 2 Phase methods. With this option on, pore and throat size distributions and the pore-throat aspect ratio are output and plotted. In addition, statistical information such as numbers of pores and throats and min/max values for pore and throat properties are generated.

Pore network model extraction: Data type

The Pore Network Model Extraction tool now supports 8-bit and 16-bit types for all available methods.

PORE NETWORK FLOW ENHANCEMENTS AND NEW FEATURES

Two-phase flow simulation

In this version, relative permeability and resistivity indexes are always calculated during simulation. The Properties to Calculate category is removed and replaced by the Target Saturations category. This new category contains Saturation Step and Sw to Stop ports.

The internal simulation-state file that is used to store the fluid occupancy and displacement information has been changed from text to binary format. This will result in higher precision in simulations and shorter transfer times for large pore network models.

CORE PROFILE EXTENSION ENHANCEMENTS AND NEW FEATURES

Reporting

The log window from the Core Profile workspace has been added to the automatic report template. A new section is available in this report template that contains the logs that are displayed in the Core Profile workspace (Fig. 10).

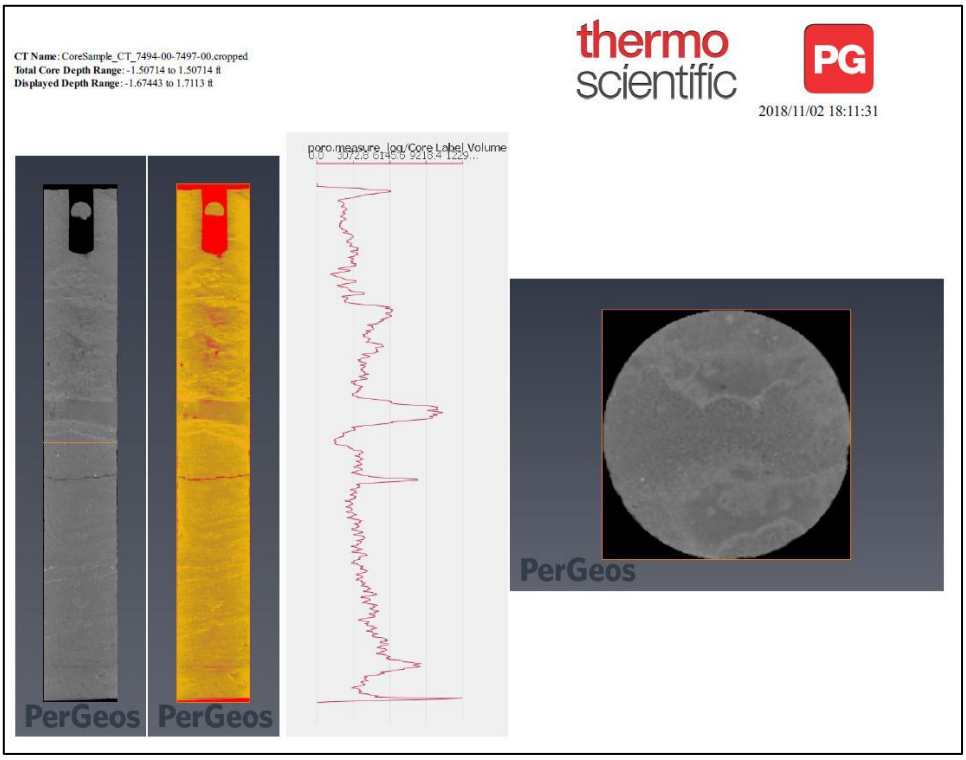

Figure 10. Log window from Core Profile workspace has been added to the auto reporting template.

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FUTURE DEPRECATION

This section documents the features that will be deprecated or removed from next PerGeos Software version.

gcc 4.4.x and Red Hat Enterprise Linux 6 will no longer be supported. The next version will support gcc 4.8.x and Red Hat Enterprise Linux 7 only.

OPERATING SYSTEMS

PerGeos Software 1.8 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 Software with XPand Extension, you will need:

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

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SOLVED ISSUES

The PerGeos Software 1.8 release provides various enhancements and solutions to known problems, including:

Absolute Permeability	73856	Removed unappropriated reference to use of a "cluster".
Core Profile	33172	Number of voxels no longer unexpectedly updates when input unit is modified.
	68048	Increased precision of display during "Summary" step of the Assembly Wizard.
	73870	Corrected random bad scale bar and inability to display top of the core after assembly wizard.
	73869	Corrected slowness when logs display.
	73439	Corrected Assembly Wizard problem when generating certain LDA files.
DICOM	73365	IMA files are now managed by the Assembly Wizard.
Explore	68041	Solved problem with Porosity MultiPhase Mean Logs tool becoming unresponsive.
	70237	On compute REV, numerical values are modified to match with units. Units are now displayed in the column titles of the result sheet for clarity.
PNM	69056	Corrected imprecise calculation on PNM connectivity.
Recipe by slab	70371 70285	Fixed data loss that occurs while merging slabs during label separation.
	70231	If output is not a binary, an error message is now displayed to avoid unresponsive situation.
Save	69864	Saving project: Now, when a project is modified, the associated GUI floppy disk is correctly updated.
	70538 70847	Saving "LDA"/"Pack and Go": Corrected problem with LDA files not being properly managed in pack and go project.
Segmentation	71912 71864	Corrected unresponsive situation due to simultaneous multi-thread access.
Volume Rendering	72392	Graphic card P5000 is now correctly supported.

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

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