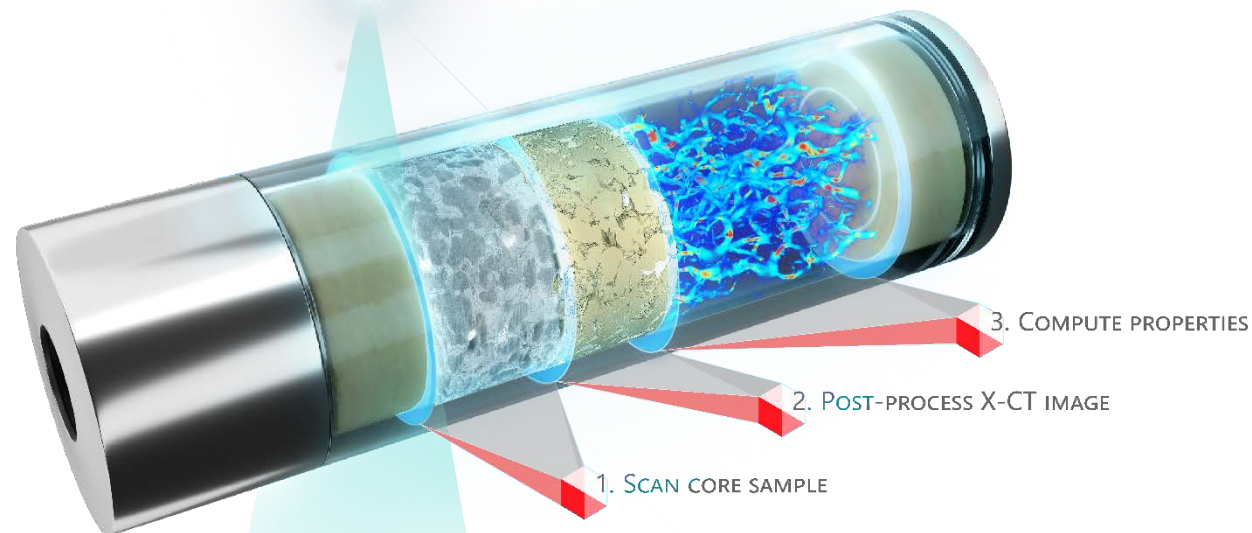
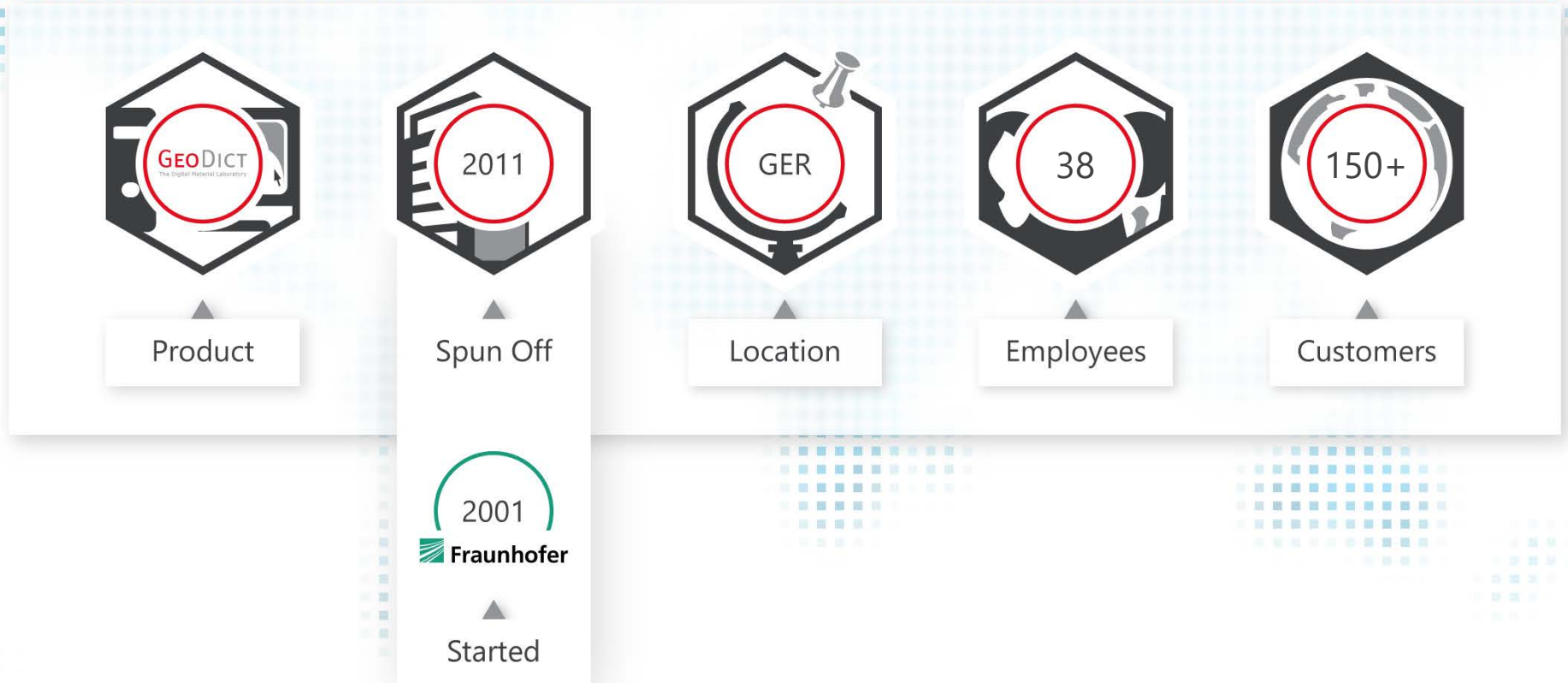


GEO-DICT: SHAPE ANALYSIS FOR GRAINS AND PORES ON 3D DIGITAL IMAGES

Interpore 2018
New Orleans

Fabian Biebl,
Tom Cvjetkovic,
Jens-Oliver Schwarz,
Erik Glatt,
Andreas Wiegmann





SELECTED CLIENTS

MATH 2 MARKET



Wir leben Autos.



WORLD WIDE WEAVE



BOSCH



TU Clausthal
Clausthal University of Technology



HAVER & BOECKER



VOLKSWAGEN

AKTIENGESELLSCHAFT



INNOVATING TOGETHER

TOYOTA



MANN + HUMMEL



UPPSALA
UNIVERSITET



FORSCHUNGSZENTRUM



Karlsruher Institut für Technologie



九州大学
KYUSHU UNIVERSITY



PURDUE
UNIVERSITY.



NC State University



EUROPEAN COMMISSION



TECHNISCHE UNIVERSITÄT
KAISERSLAUTERN



UNIVERSITE
JOSEPH FOURIER
SCIENTIFICS TECHNOLOGIE SANTE



Fleetguard



Fraunhofer

ETH

Eidgenössische Technische Hochschule Zürich
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CHALMERS



DLR



JOHANNES GUTENBERG
UNIVERSITÄT MAINZ



TTRI
Taiwan Textile
Research Institute

RWTH AACHEN
UNIVERSITY

THE UNIVERSITY OF
TEXAS
AT AUSTIN



DHBW
Duale Hochschule
Baden-Württemberg



DE LA RECHERCHE & L'INDUSTRIE
cea



PAUL SCHERRER INSTITUT
PSI



MODEL & DESIGN MATERIALS



ANALYZE & SIMULATE MATERIAL PROPERTIES



EXPLORE THE BEHAVIOR OF MATERIALS



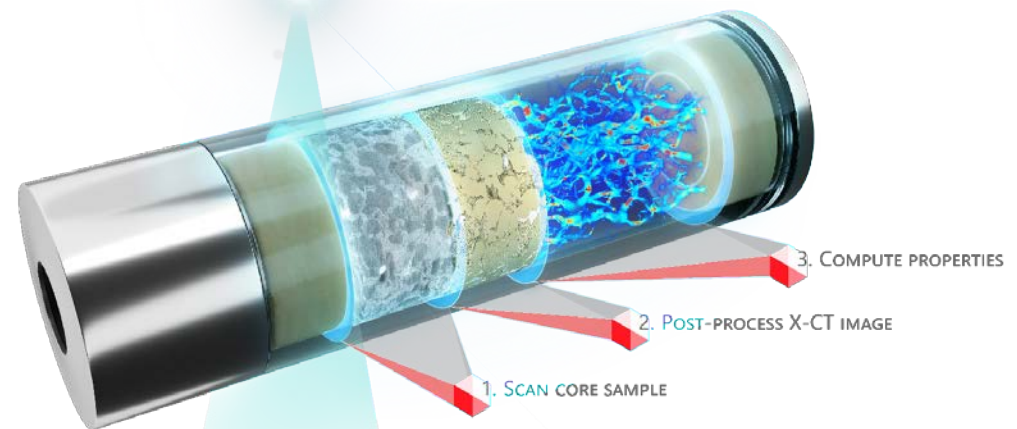
DEVELOP NOVEL MATERIALS



OPTIMIZE PROCESSES



- Digital Rock Physics (DRP) is a tool for computing physical rock properties (e.g. permeability, porosity, tortuosity, ...)
- DRP complements or replaces expensive and time-consuming laboratory measurements
- DRP improves and predicts oil recovery processes



GEODICT: DIGITAL ROCK PHYSICS PORTFOLIO (EXAMPLE: BAREA SANDSTONE)

GEODICT

Visit us at: www.geodict.com

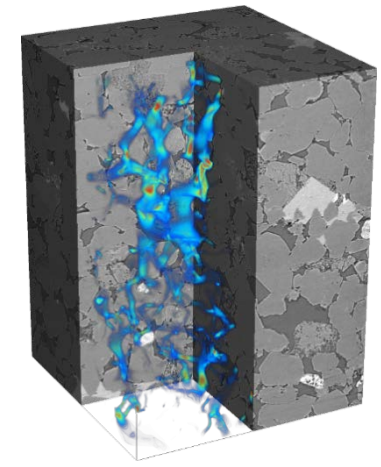
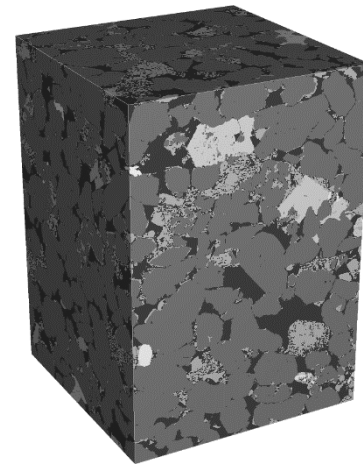
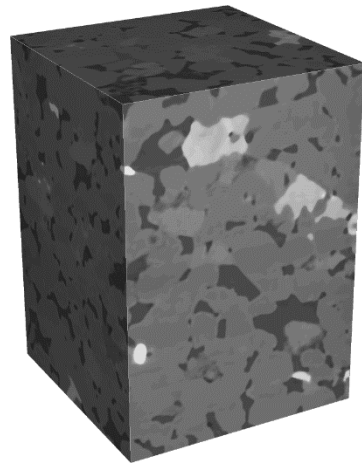
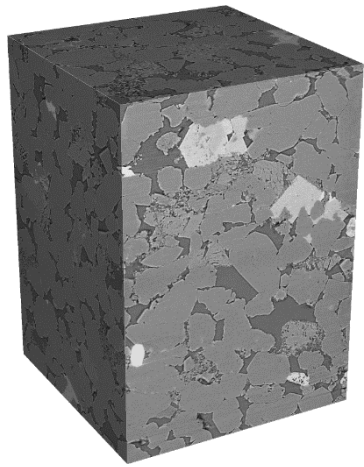


Image import	Image processing	Image segmentation	Property simulations
<ul style="list-style-type: none"> ■ μCT scans ■ Synchrotron CT scans ■ FIB-SEM images ■ Data from other imaging techniques 	<ul style="list-style-type: none"> ■ Adjust image size ■ Adjust resolution ■ Non-local means filter ■ Phansalkar filter ■ Sharpening filter 	<ul style="list-style-type: none"> ■ Single threshold ■ Multiple threshold ■ Auto-segmentation with Otsu method 	<ul style="list-style-type: none"> ■ Geometric parameters ■ Flow parameters ■ Electrical parameters ■ Mechanical parameters ■ NMR in preparation

Berea Sandstone taken from Andrä et al. 2013, Computers & Geosciences 50 (2013) 25–32

GEODICT: DIGITAL ROCK PHYSICS PORTFOLIO (EXAMPLE: BAREA SANDSTONE)

GEODICT

Visit us at: www.geodict.com

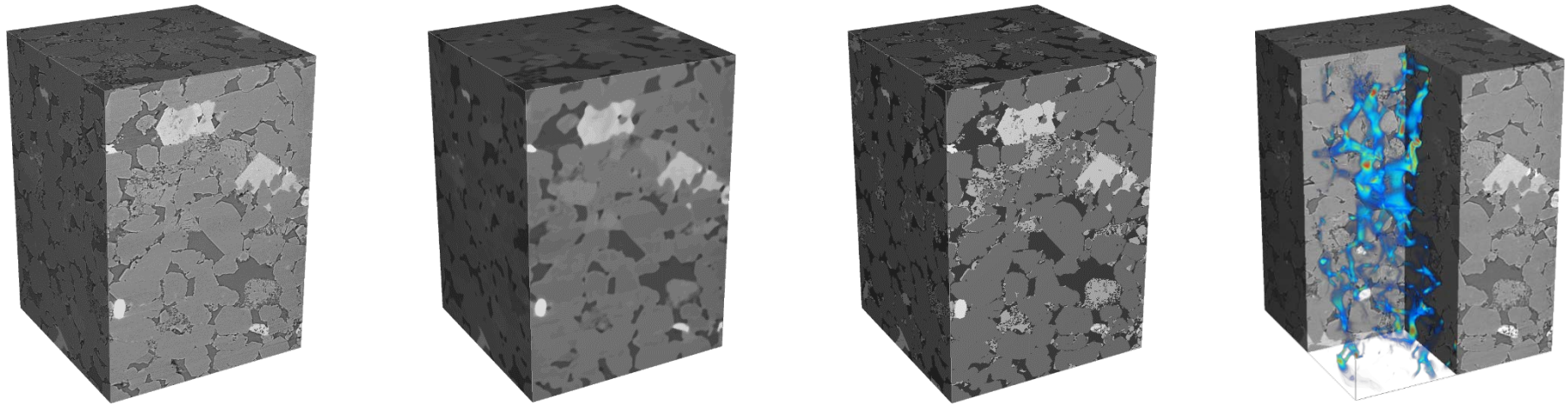
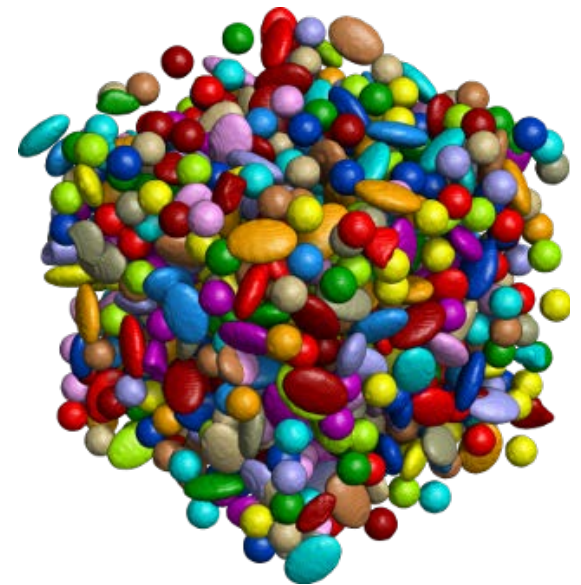


Image import	Image processing	Image segmentation	Property simulations
<ul style="list-style-type: none"> ■ μCT scans ■ Synchrotron CT scans ■ FIB-SEM images ■ Data from other imaging techniques 	<ul style="list-style-type: none"> ■ Adjust image size ■ Adjust resolution ■ Non-local means filter ■ Phansalkar filter ■ Sharpening filter 	<ul style="list-style-type: none"> ■ Single threshold ■ Multiple threshold ■ Auto-segmentation with Otsu method ■ Identify Grains/Pores 	<ul style="list-style-type: none"> ■ Geometric parameters ■ Flow parameters ■ Electrical parameters ■ Mechanical parameters ■ NMR in preparation

Berea Sandstone taken from Andrä et al. 2013, Computers & Geosciences 50 (2013) 25–32

GrainFind and PoreFind



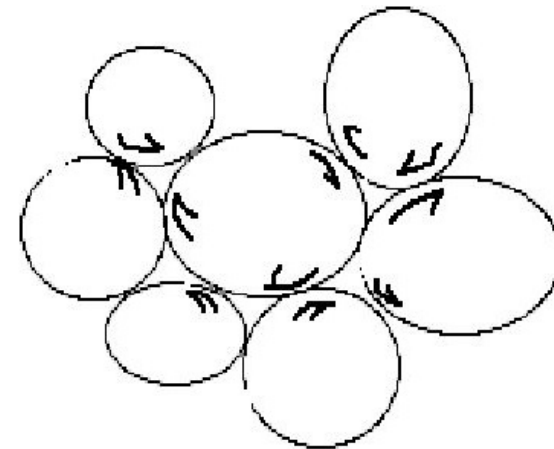
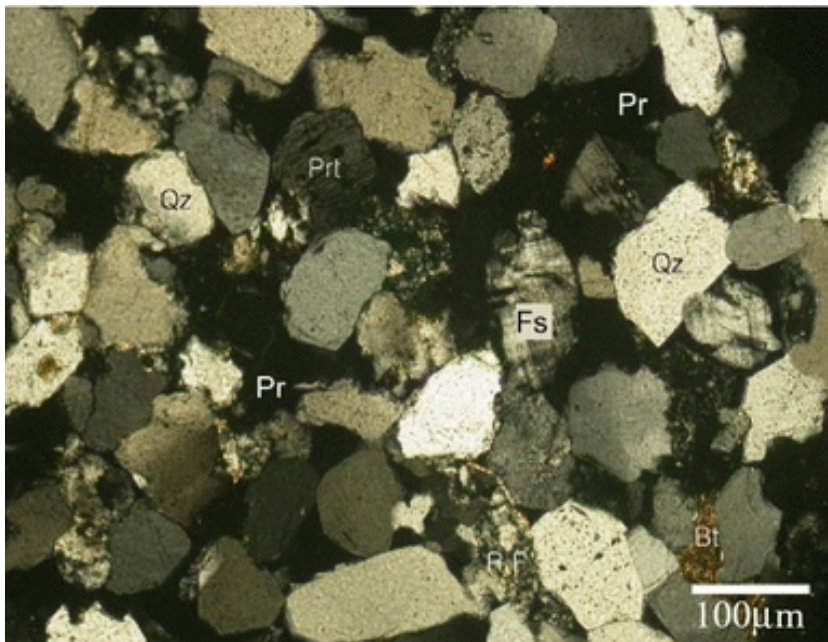
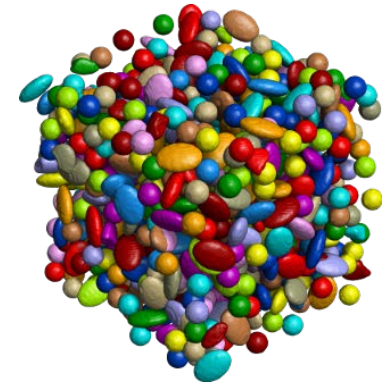
THE CAPABILITIES OF GRAINFIND AND POREFIND

- Algorithm:
 - Find grain/pore fragments by watershed algorithm
 - Reconnect grain/pore fragments
- Some of the results per grain/pore:
 - Size of grains and pores.
 - Size of grain contacts and pore throats
 - Sheppard and Krumbein sphericities
 - Diameters of a fitted shape (ellipsoid, box, or cylinder)
- Find statistics about grains and pores, grain contacts and pore throats.
- Easy classification of grain types and pore types



DIGITAL ROCK PHYSICS: MOTIVATION FOR GRAIN IDENTIFICATION

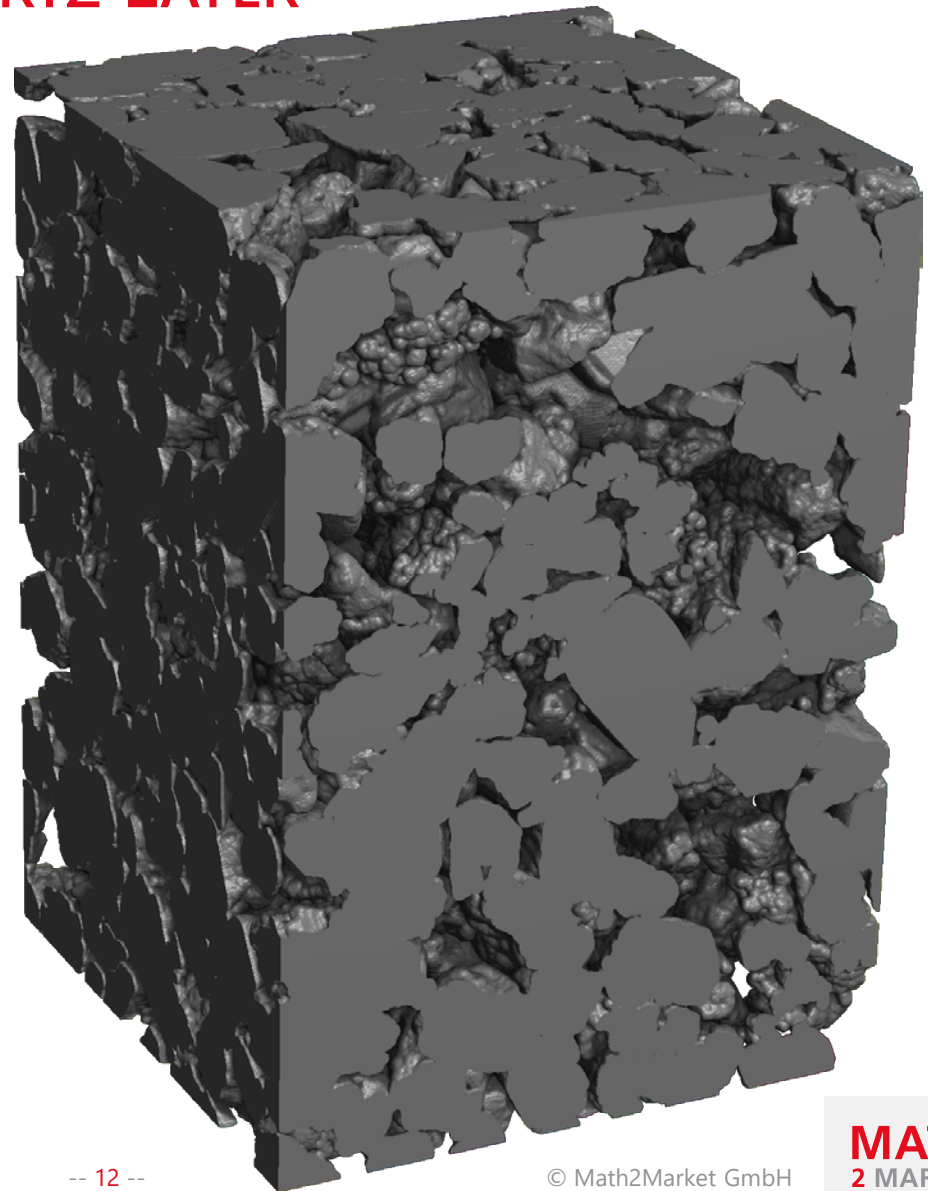
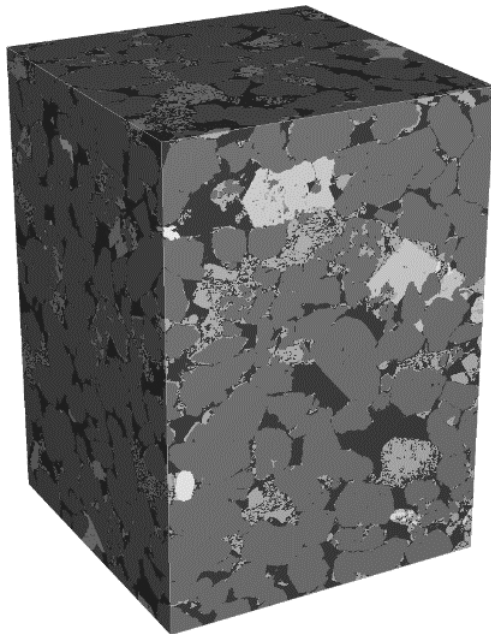
- Grain identification for more accurate mechanical simulations
 - Anisotropic grain properties. E.g., assign different crystal orientation to every grain (Orientation Mapping)
 - Grain boundary sliding. E.g., change material properties on boundary to simulate grain shifts



GRAINFIND: GRAIN IDENTIFICATION WITHIN BAREA SANDSTONE'S QUARTZ LAYER

GEO DICT

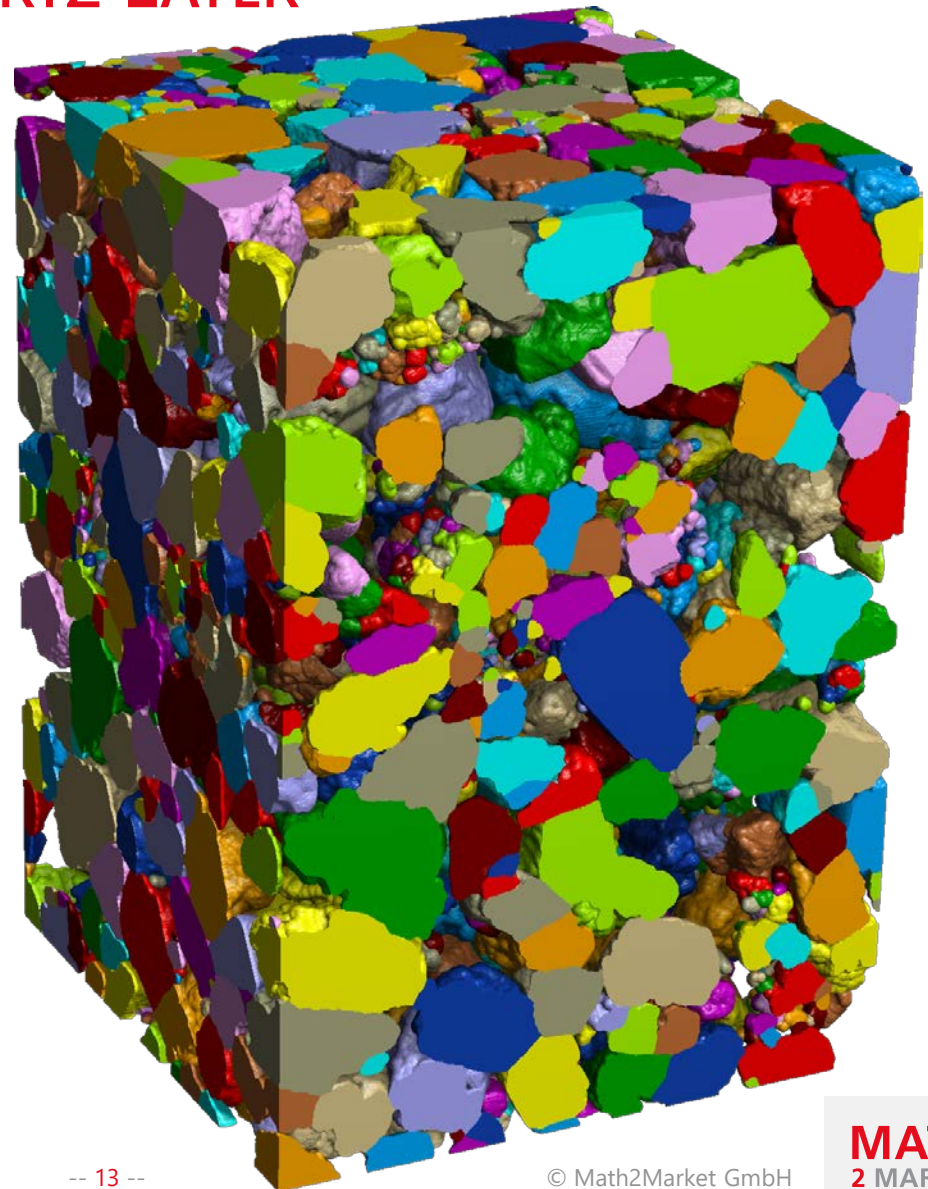
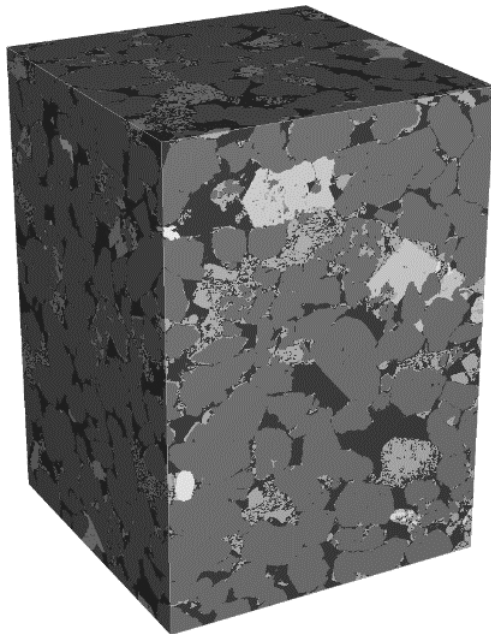
- Quartz layer



GRAINFIND: GRAIN IDENTIFICATION WITHIN BAREA SANDSTONE'S QUARTZ LAYER

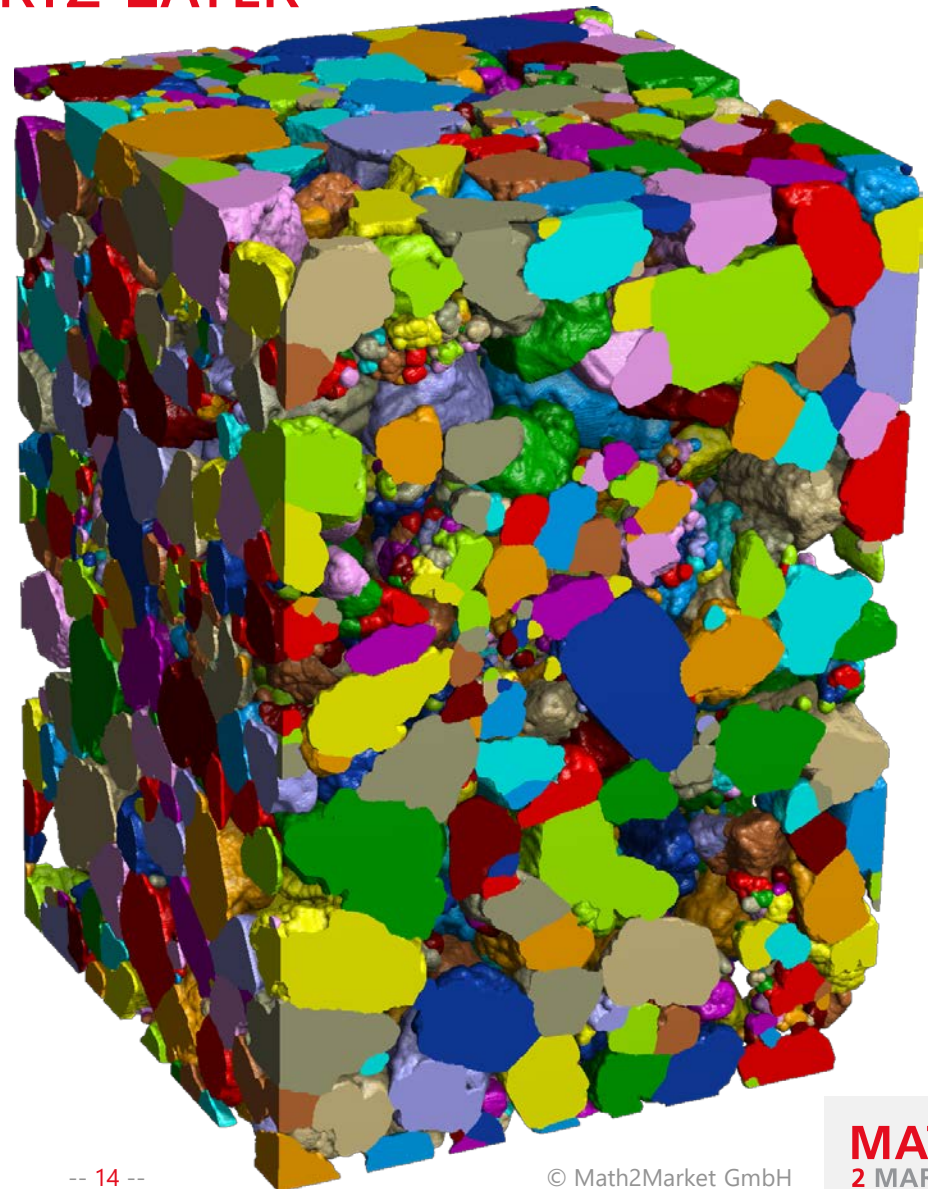
GEO DICT

- Quartz layer with identified grains



GRAINFIND: GRAIN IDENTIFICATION WITHIN BAREA SANDSTONE'S QUARTZ LAYER

- Quartz layer with identified grains
 - Mean Coordination Number
5.21
 - Mean Sphericity
0.76
 - Mean surface area
 $2587 \mu\text{m}^2$
 - Dominant grain diameter
(Diameter of the 50% largest grains)
 $39.6 \mu\text{m}$



DIGITAL ROCK PHYSICS: MOTIVATION FOR IDENTIFICATION OF PORES

- Problem: Relation of porosity and permeability is ambiguous
- Need for additional information about pore space to remove ambiguity
- Pore identification provides
 - Porosity
 - Tortuosity
 - Pore sphericity (new)
 - Pore surface area (new)
 - Pore connectivity, i.e. coordination number (new)
 - Pore throats (new)

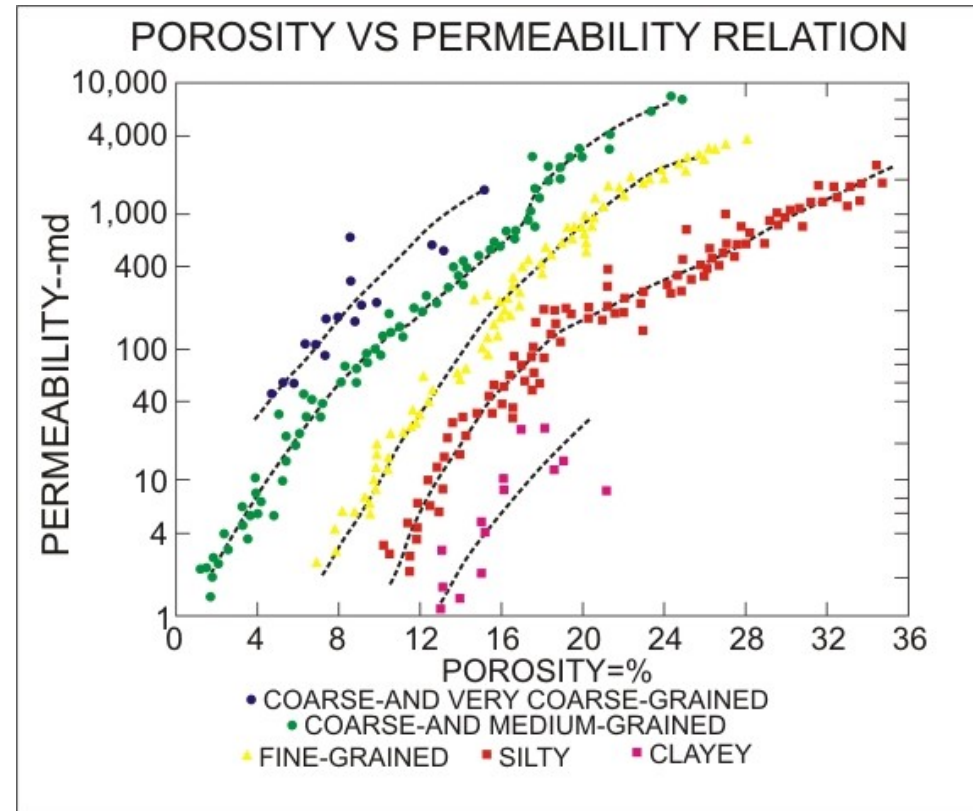
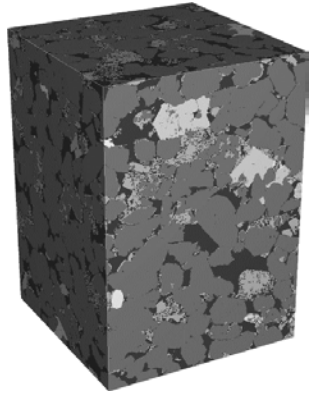


Figure taken from Roger Slatt, Stratigraphic reservoir characterization for petroleum geologists, geophysicists, and engineers, Elsevier, 2006



Berea Sandstone 1

Berea Sandstone 2

Fontainebleau Sandstone

- Size $0.5 \times 0.5 \times 0.7 \text{ mm}^3$, Res. $0.7 \mu\text{m}$
- Porosity 18.1%
- Permeability 110 mD

- Size $2.1 \times 2.1 \times 2.1 \text{ mm}^3$, Res. $2 \mu\text{m}$
- Porosity 18.2%
- Permeability 733 mD

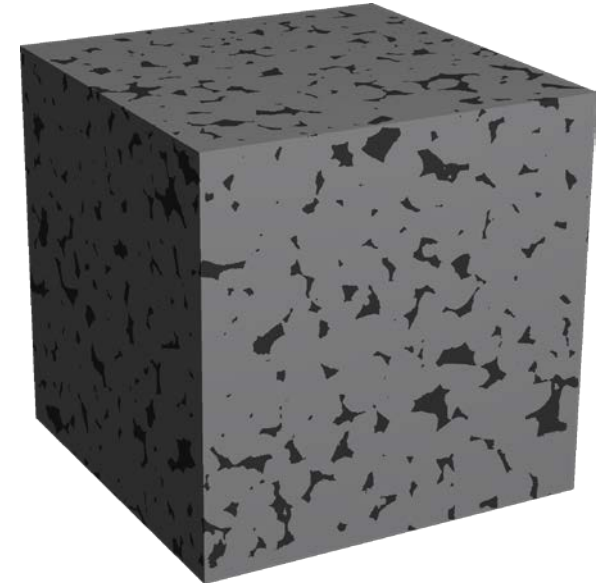
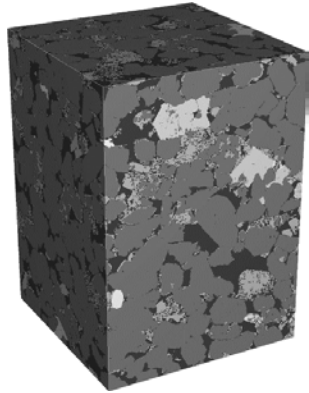
- Size $2.2 \times 2.2 \times 2.2 \text{ mm}^3$, Res. $2 \mu\text{m}$
- Porosity 9.3%
- Permeability 137 mD

Berea Sandstone 1 taken from Andrä et al. 2013, Computers & Geosciences 50 (2013) 25–32

Berea Sandstone 2 and the Fontainebleau Sandstone are Rock1 and Rock3, respectively, in Saxena et al. 2017, Advances in Water Resources 109 (2017) 211–235

PORE FIND: PORE IDENTIFICATION RESULTS

GEO DICT



Berea Sandstone 1

Berea Sandstone 2

Fontainebleau Sandstone

- Size 0.5 x 0.5 x 0.7 mm³, Res. 0.7 μm
- Porosity 18.1%
- Permeability 110 mD
- Coordination Number 3.86
- Dominant Pore Size 4.1 μm
- Mean Sphericity 0.74

- Size 2.1 x 2.1 x 2.1 mm³, Res. 2 μm
- Porosity 18.2%
- Permeability 733 mD
- Coordination Number 5.17
- Dominant Pore Size 27.3 μm
- Mean Sphericity 0.73

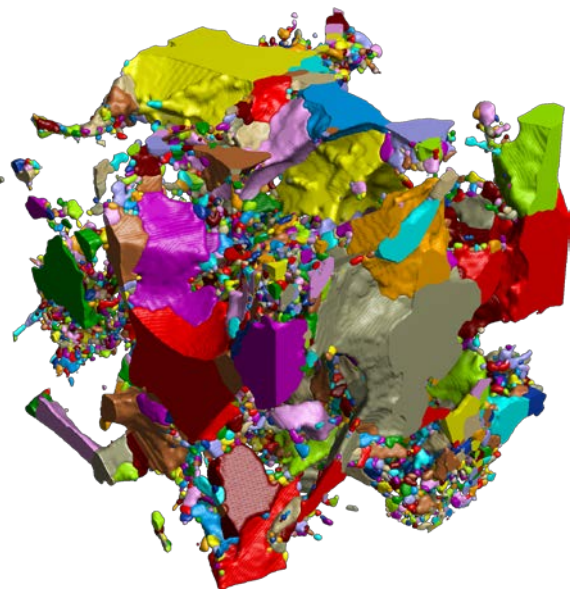
- Size 2.2 x 2.2 x 2.2 mm³, Res. 2 μm
- Porosity 9.3%
- Permeability 137 mD
- Coordination Number 3.28
- Dominant Pore Size 39.0 μm
- Mean Sphericity 0.71

Berea Sandstone 1 taken from Andrä et al. 2013, Computers & Geosciences 50 (2013) 25–32

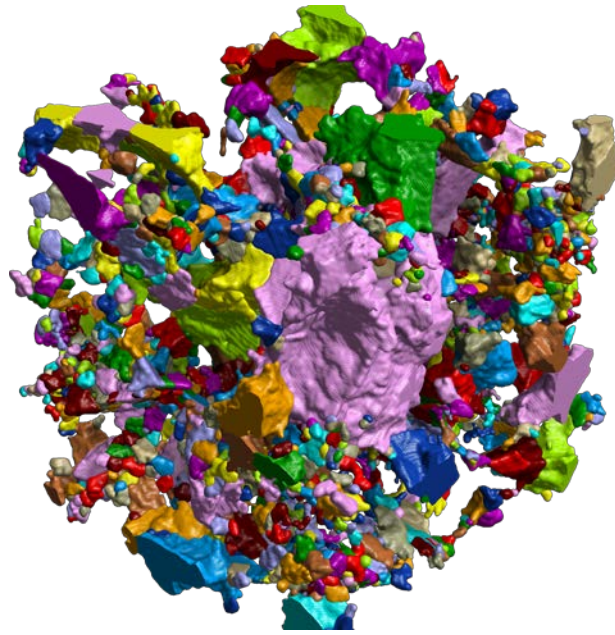
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PORE FIND: PORE IDENTIFICATION RESULTS

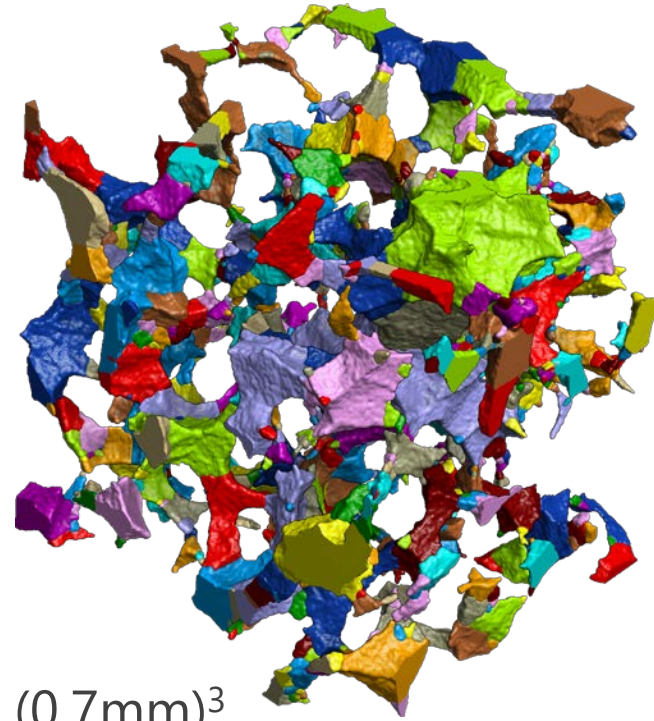
GEO DICT



$(0.2\text{mm})^3$



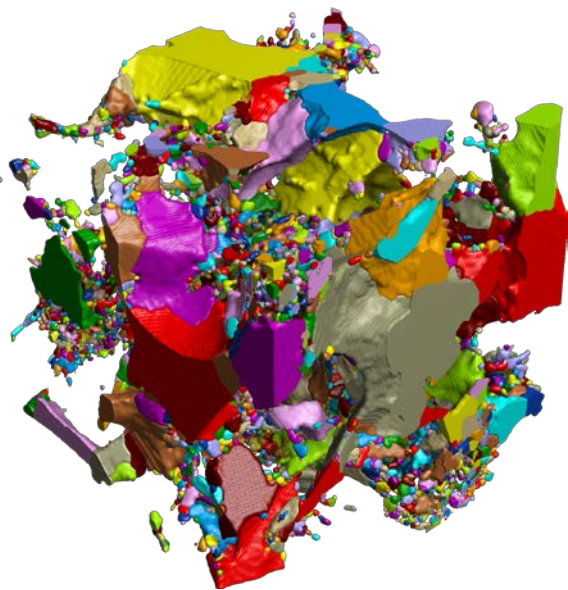
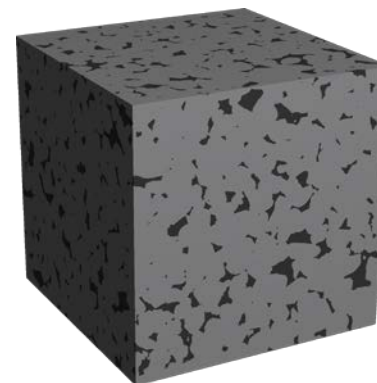
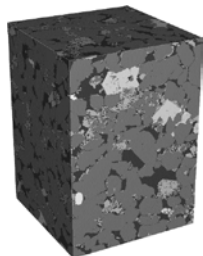
$(0.6\text{mm})^3$



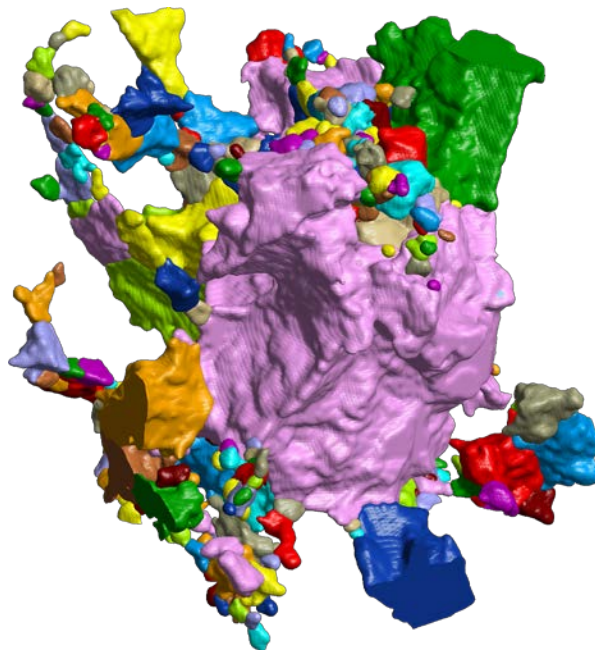
$(0.7\text{mm})^3$

PORE FIND: PORE IDENTIFICATION RESULTS

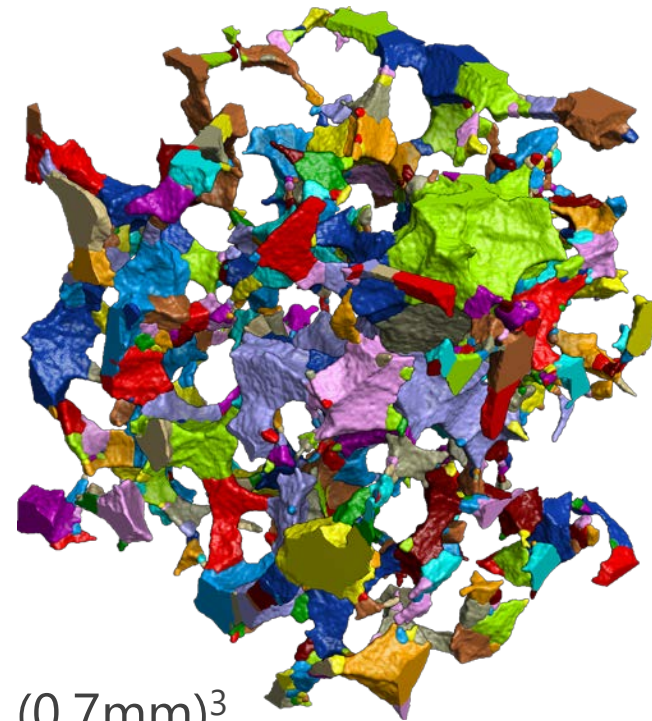
GEO DICT



$(0.2\text{mm})^3$

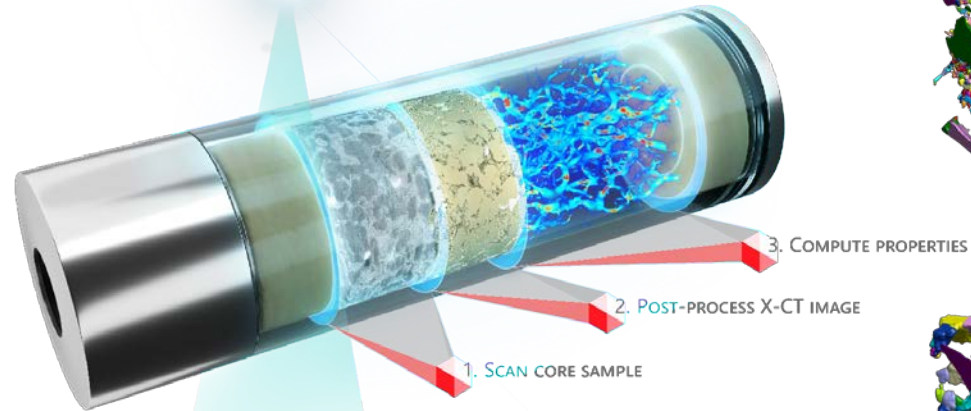
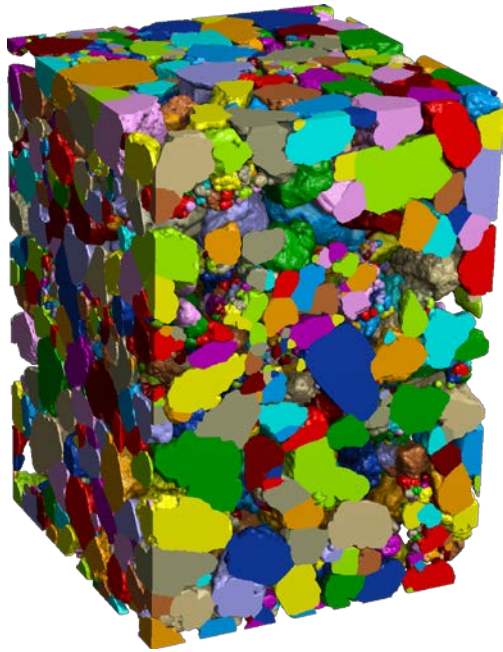


$(0.3\text{mm})^3$

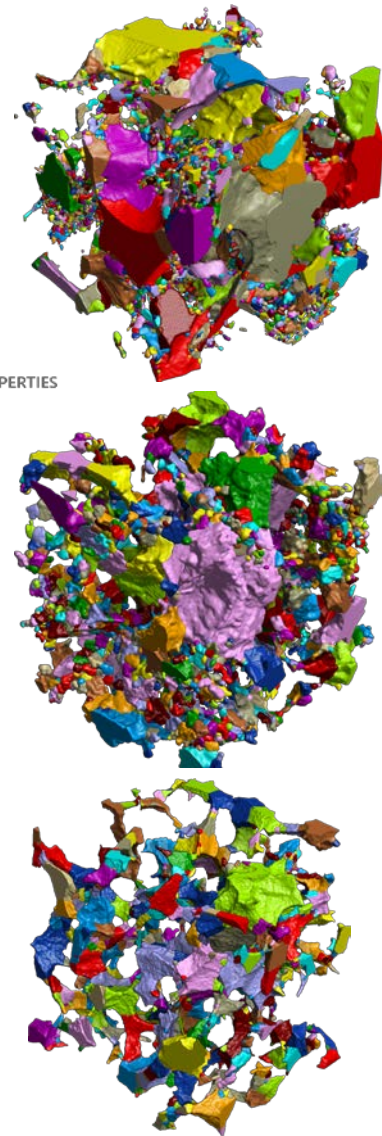


$(0.7\text{mm})^3$

CONCLUSIONS



GEO DICT



- New features in **GeoDict2019**:
 - **GrainFind**: Grain identification
 - **PoreFind**: Pore Identification

- **Math2Market: Meet us at booth 8**

Thank you for your attention.

GEO DICT

Meet us at **HALL I-1 BOOTH #8**

