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Geomechanics and Seismics in Digital Rocks

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Introduction

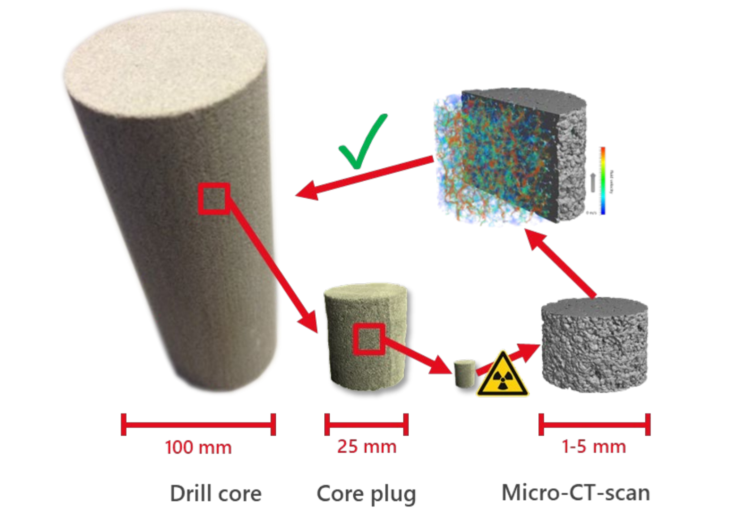

Figure 1. Digital Rock Physics workflow: from sampling and rock imaging, to property simulations

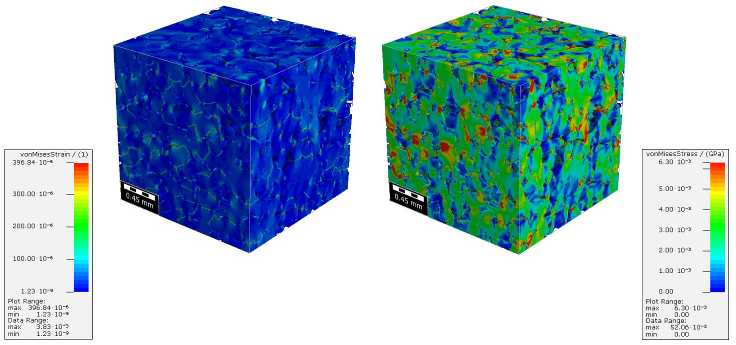

Figure 2. Visualization of computed stress and strain fields in GeoDict for sandstone in elastic property simulation

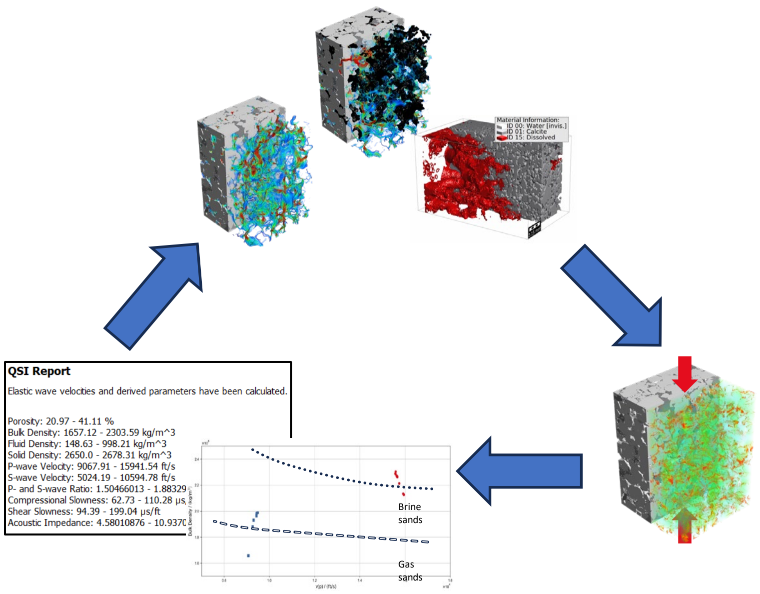

Figure 3. Predictive modelling and iterative optimization of QSI for different flow and stress states via DRA workflows

Digital Rock Analysis

DRA delivers properties of 3D rock models from rock scans via numerical solvers applying known physics.

Imaging of rock samples requires sampling at sufficient resolution, so that pore throats are resolved in the resulting 3D scan. Rocks can be characterized from scans obtained by µCT, FIB-SEM, and similar devices.

Digital Rock Physics (DRP) is a non-destructive, cost- and time-efficient approach to obtain rock properties.

Elastic rock properties

Elastic parameters include properties such as Youngs, bulk and shear moduli, and Poisson ratio.

The prediction of elastic rock properties of 3D models numerically via DRP in GeoDict carried out by solving equations of linear elasticity, i.e., stress equilibrium, strain-displacement field, and Hooke's law[1,2].

Predicting elastic parameters is critical to reservoir geomechanics and wellbore stability. It also relates rock and fluid properties with seismic response via fundamental equations of primary/secondary wave velocities.

Quantitative Seismic Interpretation (QSI)

QSI facilitates reservoir monitoring during hydrocarbon production or CO_2 storage.

Seismic properties, such as P/-S-wave, acoustic impedance and compressional slowness[3,4], are related via elastic parameters to petrophysical characteristics of formations.

Predictive modelling of QSI parameters via integrated DRA optimizes planning, risk reduction, reservoir modelling, and field development.

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[1] Browaeys & Chevrot, 2004
[2] Rutka et al., 2006
[3] Mavko et al., 2009
[4] Gassmann, 1951

Motivation

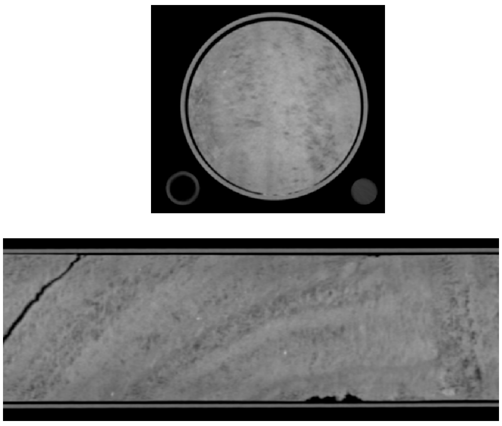


Figure 4. 2D slices of whole core CT scan[1] that may not fully resolve elasticity-relevant features

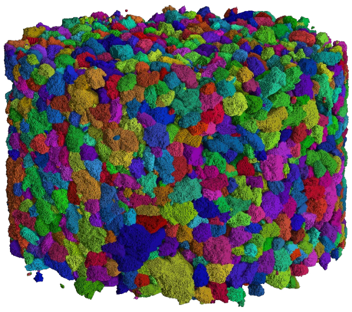


Figure 5. Sandstone[2] with segmented grains, where complex phenomena such as grain movement during compaction may not be fully captured

Elasticity overprediction

Results of rock elasticity simulations from different industrial and academic studies indicate an overprediction of stiffness and the need for calibration of the used models.

One of the highlighted reasons is the image resolution, which may not sufficiently capture elasticity relevant features, thus resolving smaller pores as solid and resulting in higher values for the properties.

In addition, gray value segmentation may not capture the full mineralogy, especially in heterogeneous samples, while mineral elastic properties may vary significantly.

Another reason is that the mathematical approximations used in various elasticity solvers may not be fully applicable to granular structures such as rocks. Complex physical phenomena, such as grain movement during compaction, may not be completely considered in current state-of-the-art solvers. The added setup complexity may not be practical for general use, even when advanced modeling is possible.

a) b) c)

Figure 6. Traditional workflow to identify and distribute properties of grain contacts.

6a) 2D slice of a 3D rock model with binary pore and solid segmentation in white and green, respectively.

6b) Same slice with identified grains (different colors) via watershed algorithm.

6c) Identified grain-to-grain contacts (in blue) with the same elastic properties

Limitations of current solutions

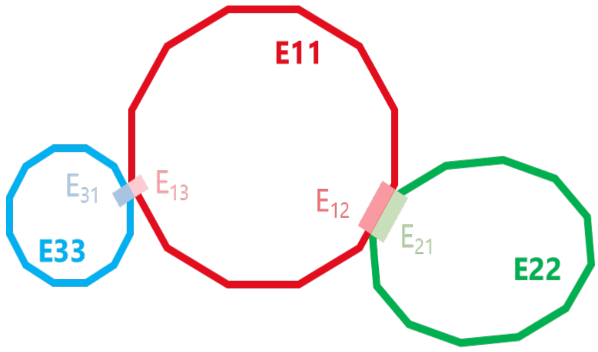
A traditional approach to address and reduce overprediction of elastic parameters is to computationally determine grain-to-grain contacts, often using a watershed algorithm, and reduction of applied elastic properties for grain contacts.

This method has been around for some time, but often the parameterization of grain-contact elastic properties is based on matching experimental results without considering the physical aspects of grain contacts.

The methodology presented in this paper addresses this issue to ensure that structural physics are considered during grain property calibration.

[1] Victor et al., 2017
[2] Berg et al., 2016

Methodology and Results



$$f_{a(12)} = 1, f_{a(13)} \approx 0.3$$

Figure 7. 2D Illustration of three different grains (in blue, red, and green) and their contact areas with distinctive contact strength based on contact surface and grain mineralogy

Contact Surface-Dependent Stiffness – Methodology

Our approach identifies grains, and grain contacts followed by the calculation of calibration factors based on the surface area between grains and their respective mineralogy. This has the effect of making grain contact with a smaller area appear more brittle, which is the expected physical phenomenon and better aligns with real-world experiments.

The stepwise workflow is:

1. Identify grains and grain contacts
2. Determine contact mineralogy
3. Normalize by maximum contact area (per mineral group)
4. Apply the computed factor to strength of contact area groups

Initial structure

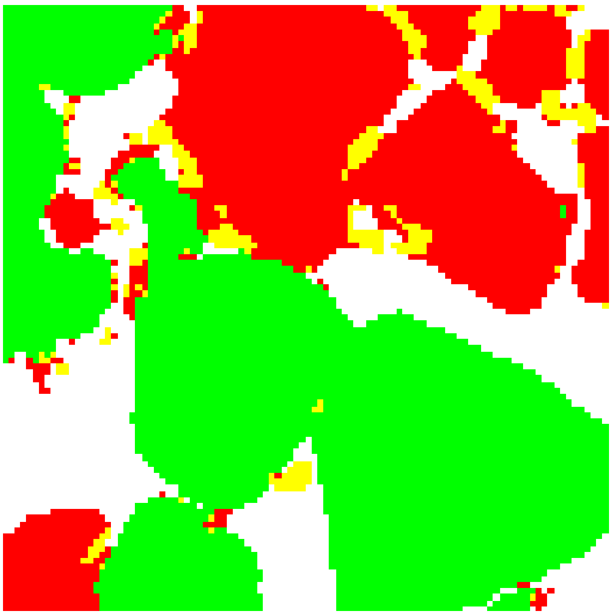


Figure 8. 2D slice visualization of 3 original solid minerals (e.g., quartz, feldspar and calcite) in green, red, and yellow.

Structure with factorized contacts

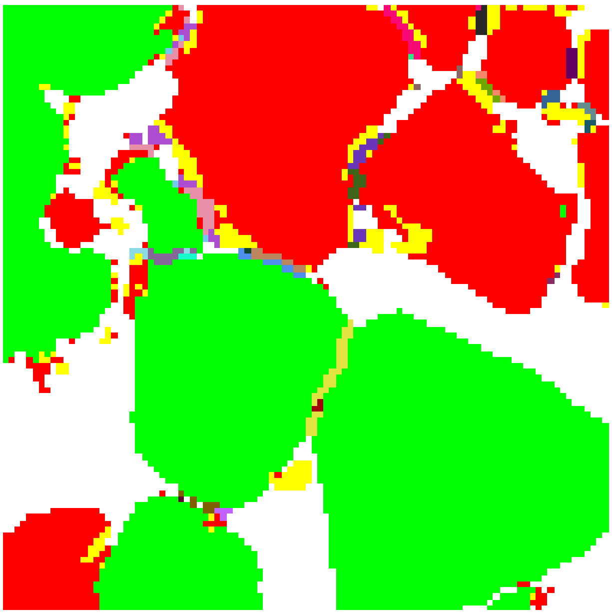


Figure 9. 2D slice visualization of 3 original solid minerals and their factorized contacts in different colors based on surface area.

Table 1. QSI properties computed for the 3D rock model of the initial structure.

Porosity	%	18.70577037
BulkDensity	kg/m^3	2301.5409311511876
FluidDensity	kg/m^3	993.3128218
SolidDensity	kg/m^3	2602.5637062863602
P-WaveVelocity	m/s	4522.063275338846
S-WaveVelocity	m/s	2740.0156967767325
P/SRatio		1.6503786020855493
CompressionalSlowness	m/s	0.00022113799367946
ShearSlowness	m/s	0.00036496141287671027
AcousticImpedance	(kg/m^3)*(m/s)	10407713.721447958
StructureName1		Structure.gdt
Water (Distilled)Saturation1	%	100.0

Table 2. QSI properties computed for the 3D rock model of structure with factorized contacts.

Porosity	%	18.70577037
BulkDensity	kg/m^3	2301.540931151187
FluidDensity	kg/m^3	993.3128218
SolidDensity	kg/m^3	2602.5637062863607
P-WaveVelocity	m/s	3746.087805787075
S-WaveVelocity	m/s	2254.8325070870965
P/SRatio		1.6613596770548849
CompressionalSlowness	m/s	0.0002669451576802787
ShearSlowness	m/s	0.00044349192095507 31
AcousticImpedance	(kg/m^3)*(m/s)	8621774.416705292
StructureName1		Structure.gdt
Water (Distilled)Saturation1	%	100.0

Conclusion and Outlook

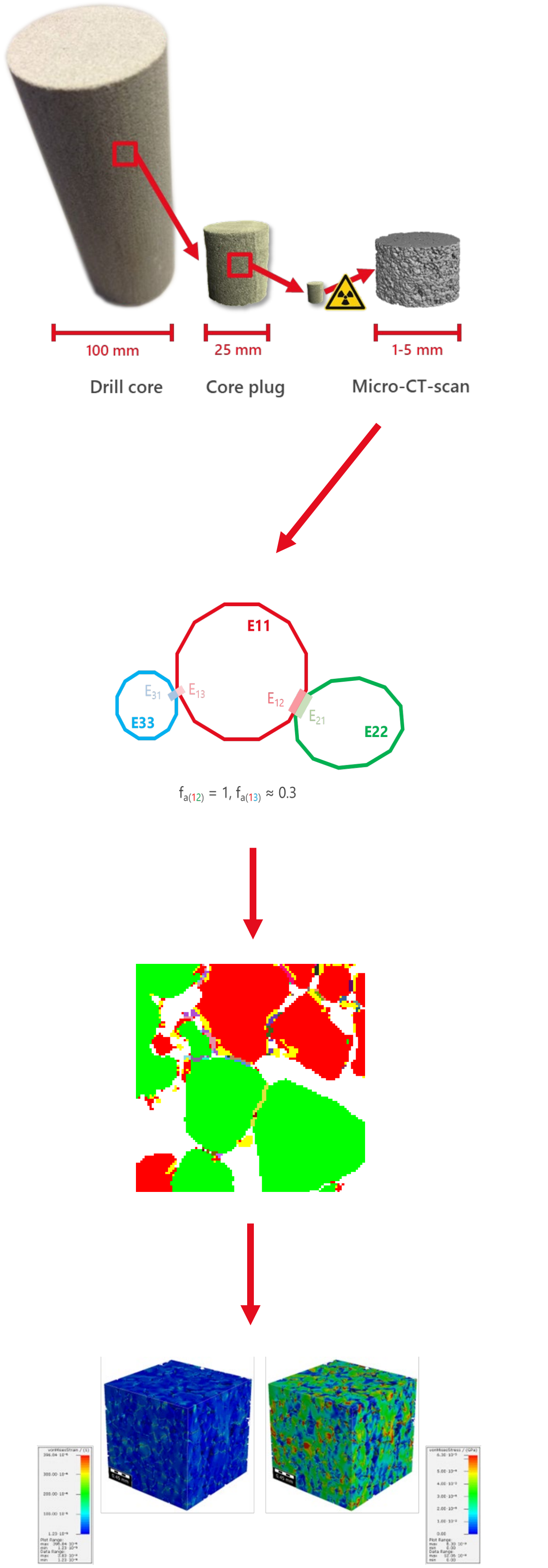


Figure 10. DRP workflow: from μCT scans of rocks to identified grain contacts based on surface area and mineralogy, for prediction of elastic rock properties in applications, such as QSI.

Conclusion

The application of DRA shows significant potential for the efficient and cost-effective characterization of petrophysical and geomechanical properties.

The application of DRA to obtain elastic properties for advanced monitoring techniques such as QSI enables predictive modelling of expected seismic responses for different scenarios of gas storage or hydrocarbon production.

The mitigation of the rock image resolution trade-off is possible via grain contact modelling. The proposed enhancement to the predictive model for elastic properties, based on contact surface and mineralogy, results in improved computed results.

Outlook

A case study is currently underway to further validate the approach.

To achieve an even higher level of automation, we are developing an AI approach for determining grain contacts.

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