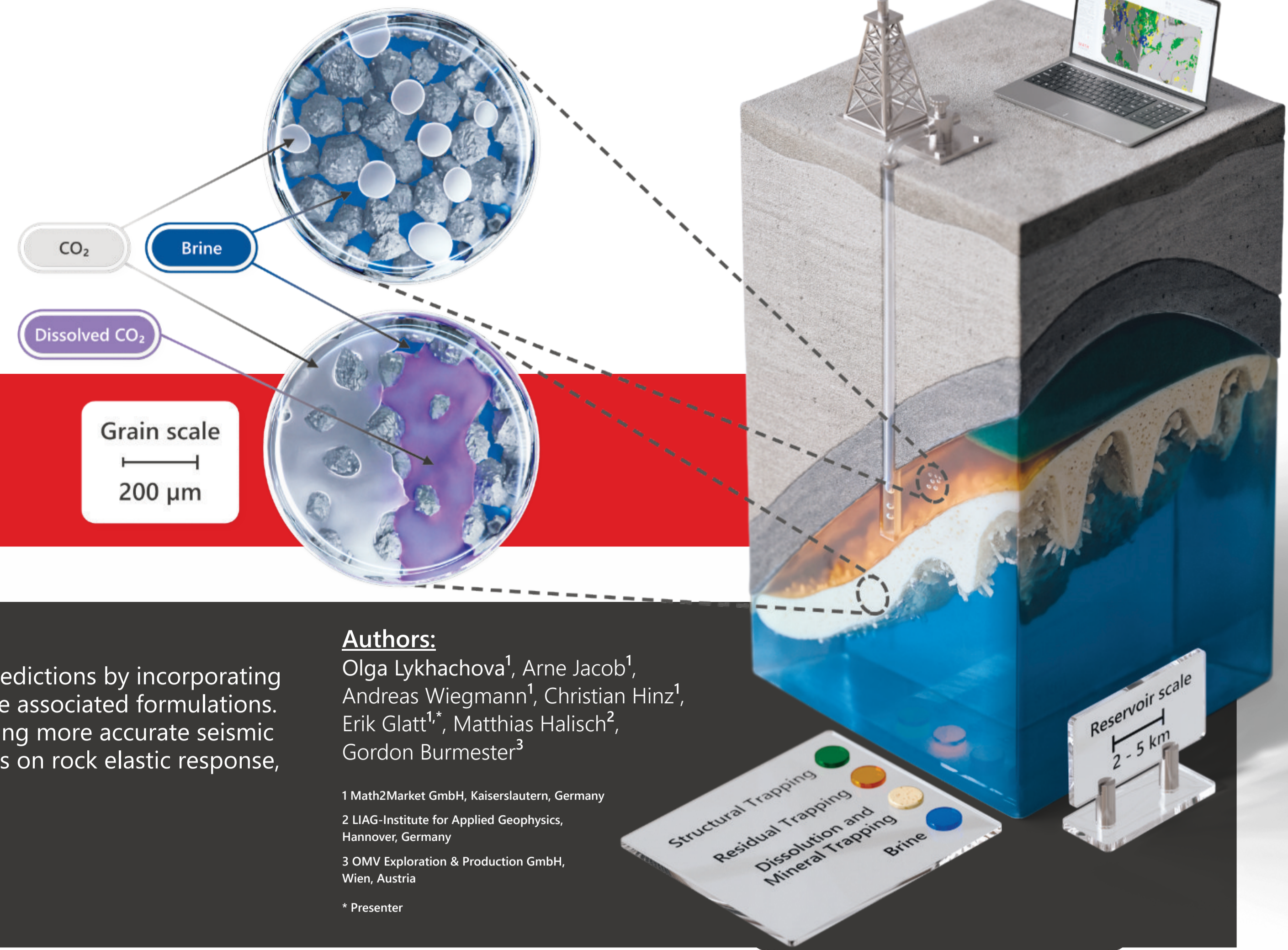


GEO DICT

The Digital Material Laboratory

CONTACT-AWARE GRAIN MECHANICS FOR IMPROVED ELASTIC AND SEISMIC PROPERTY PREDICTION IN DIGITAL ROCKS



MOTIVATION

CO₂ storage is a key component of the energy transition and requires reliable prediction of subsurface flow and containment during injection. Seismic monitoring provides critical "eyes underground," but its interpretation depends on accurately linking fluid distributions to elastic and acoustic properties of rocks.

Digital Rock Physics (DRP) enables pore-scale simulation of fluid-dependent rock physics based on μCT rock scans. However, important effects, such as grain-scale mechanical interactions are not fully resolved in μCT images and remain a major source of uncertainty in acoustic property prediction.

GOAL

This work advances DRP-based elastic and seismic predictions by incorporating pore-scale grain-contact modelling and validating the associated formulations. This improves pore-to-seismic scale upscaling, enabling more accurate seismic monitoring, better prediction of CO₂ migration effects on rock elastic response, and optimized storage performance.

Authors:

Olga Lykhachova¹, Arne Jacob¹,
Andreas Wiegmann¹, Christian Hinz¹,
Erik Glatt^{1*}, Matthias Halisch²,
Gordon Burmester³

¹ Math2Market GmbH, Kaiserslautern, Germany

² IUG- Institute for Applied Geophysics, Hannover, Germany

³ OMV Exploration & Production GmbH, Wien, Austria

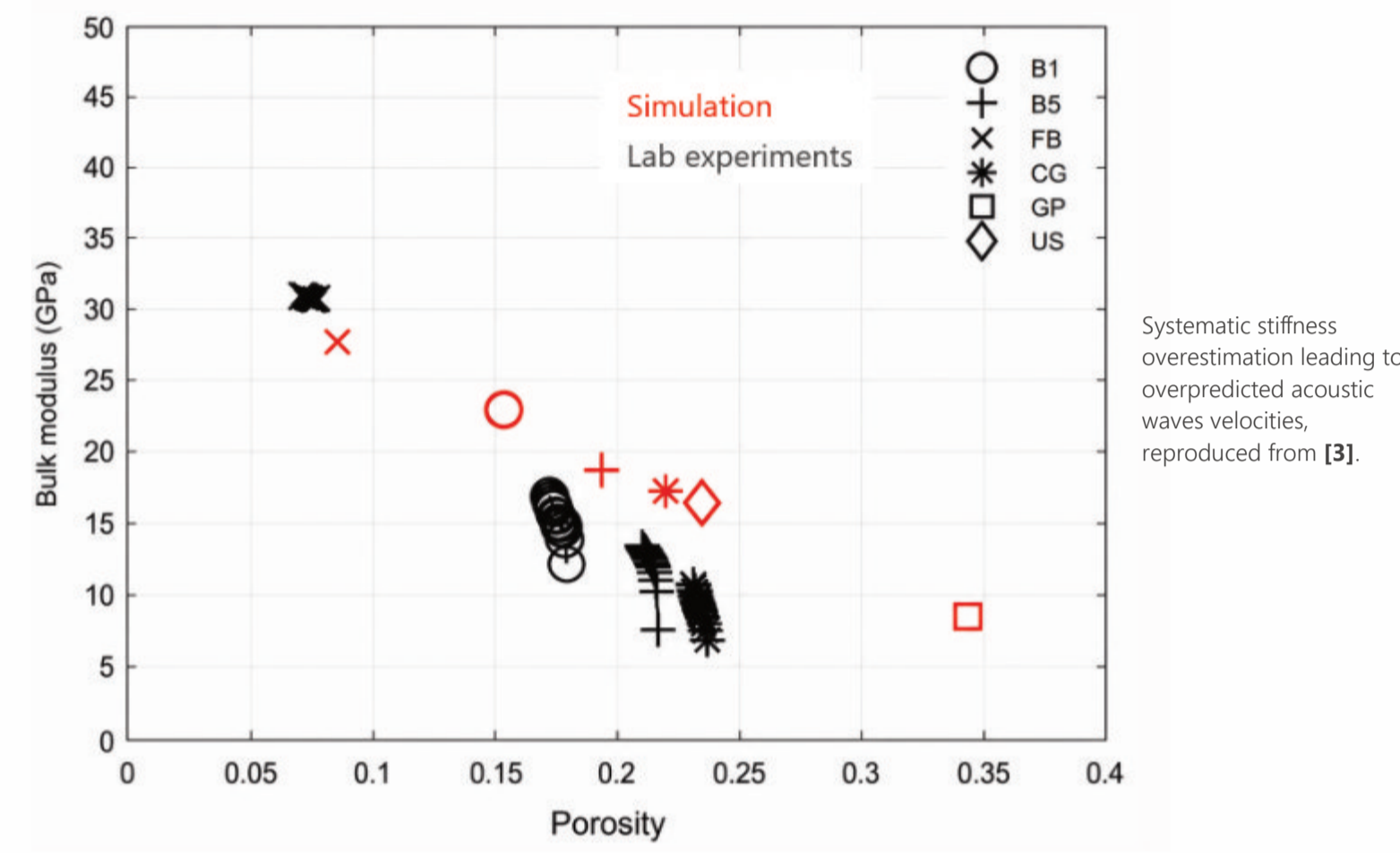
* Presenter

CO₂ MIGRATION MONITORING: PATH FROM PORE TO SEISMIC SCALE

Limited μCT image resolution, together with field-of-view and solver settings, often results in overestimation of elastic moduli relative to laboratory measurements [3].

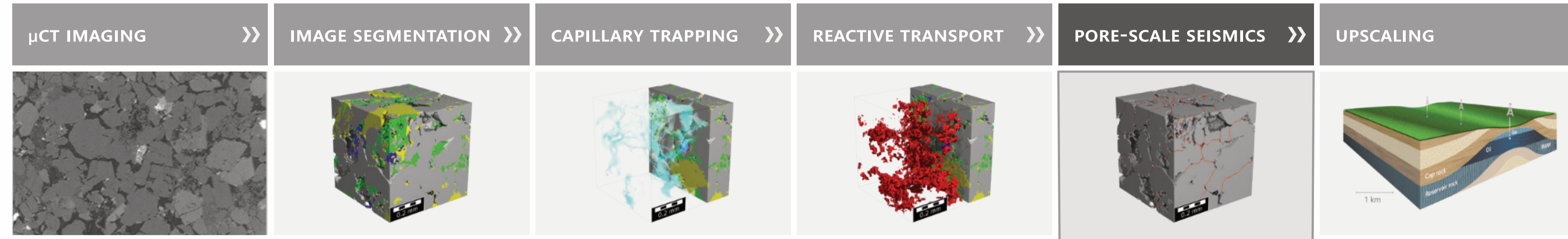


Illustration of a common limitation in standard DRP workflows:
1: 3D visualization of Gildehauser sandstone [4]
2: 2D μCT slice showing pore space and mineral grains
3: Grain-contact features unresolved during segmentation due to limited scan resolution.



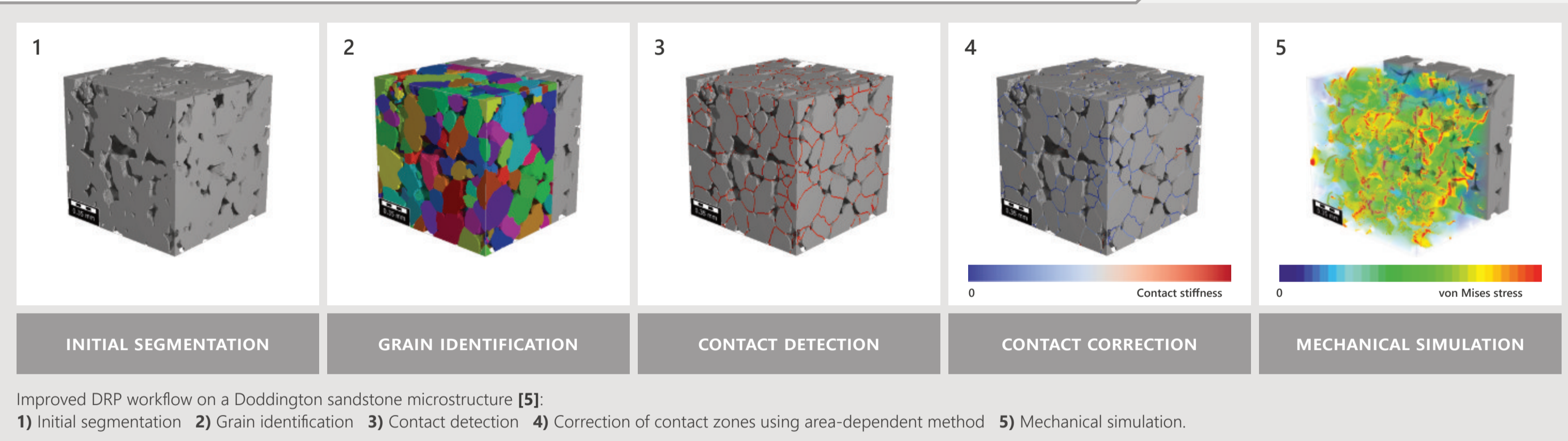
Systematic stiffness overestimation leading to overpredicted acoustic wave velocities, reproduced from [3].

APPROACH IN DIGITAL ROCK PHYSICS

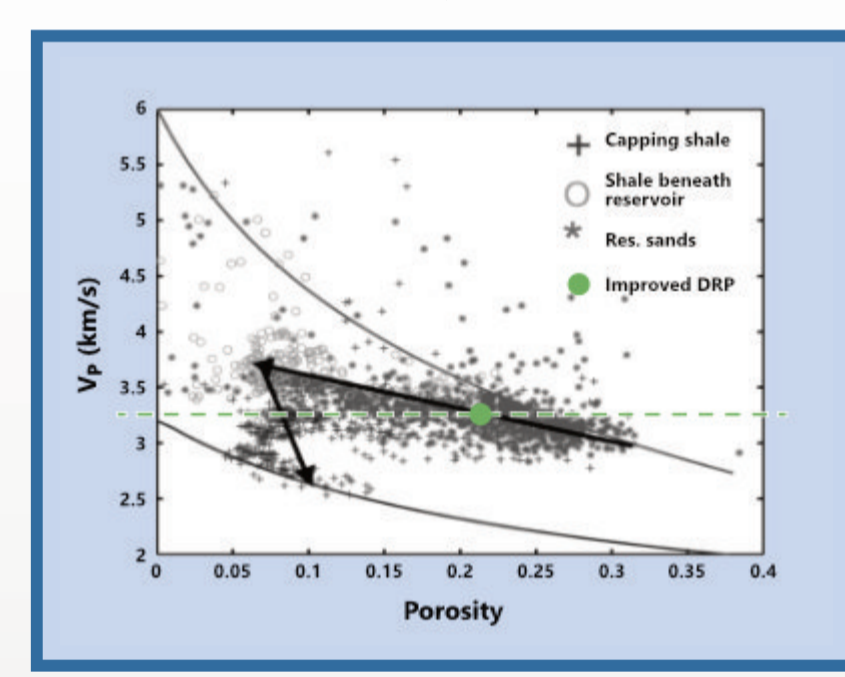
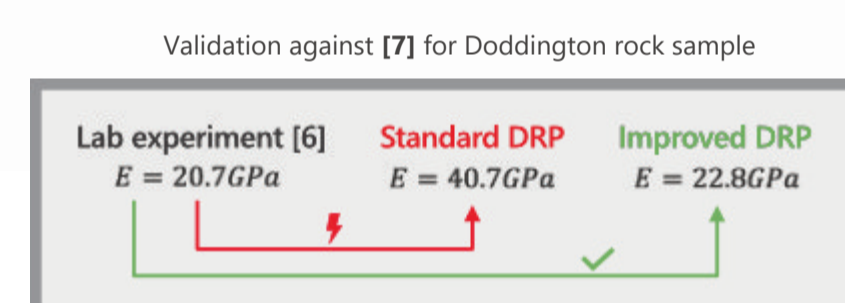


IMPROVED DRP WORKFLOW: CONTACT CORRECTION METHOD

To overcome limitations in standard DRP workflows, an area-dependent method [1, 2] was developed and integrated into the improved DRP workflow. The method preserves the original voxel geometry while correcting contact stiffness by applying a two-part area-dependent modification to the elastic moduli E_p .

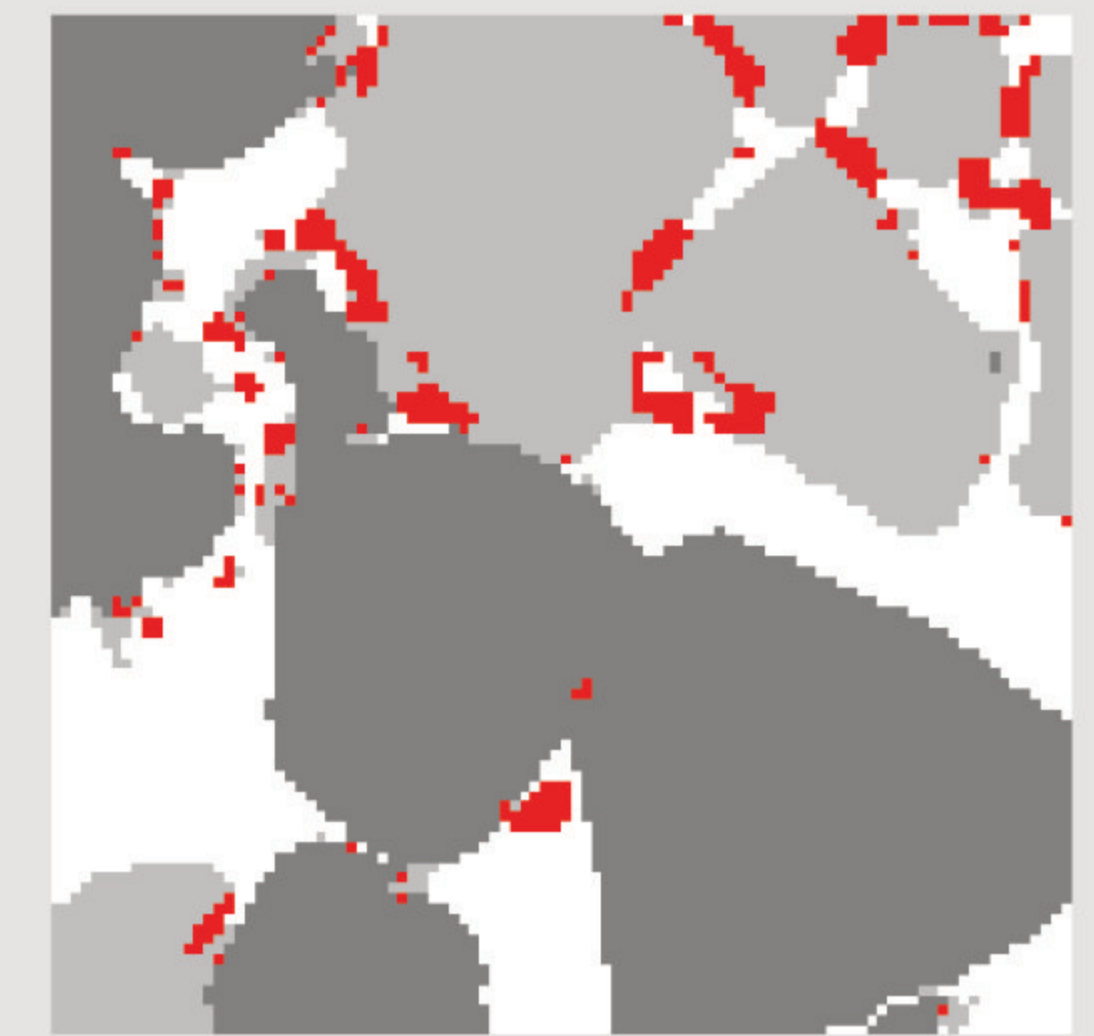


Improved DRP workflow on a Doddington sandstone microstructure [5]:
1) Initial segmentation 2) Grain identification 3) Contact detection 4) Correction of contact zones using area-dependent method 5) Mechanical simulation.



CHALLENGES

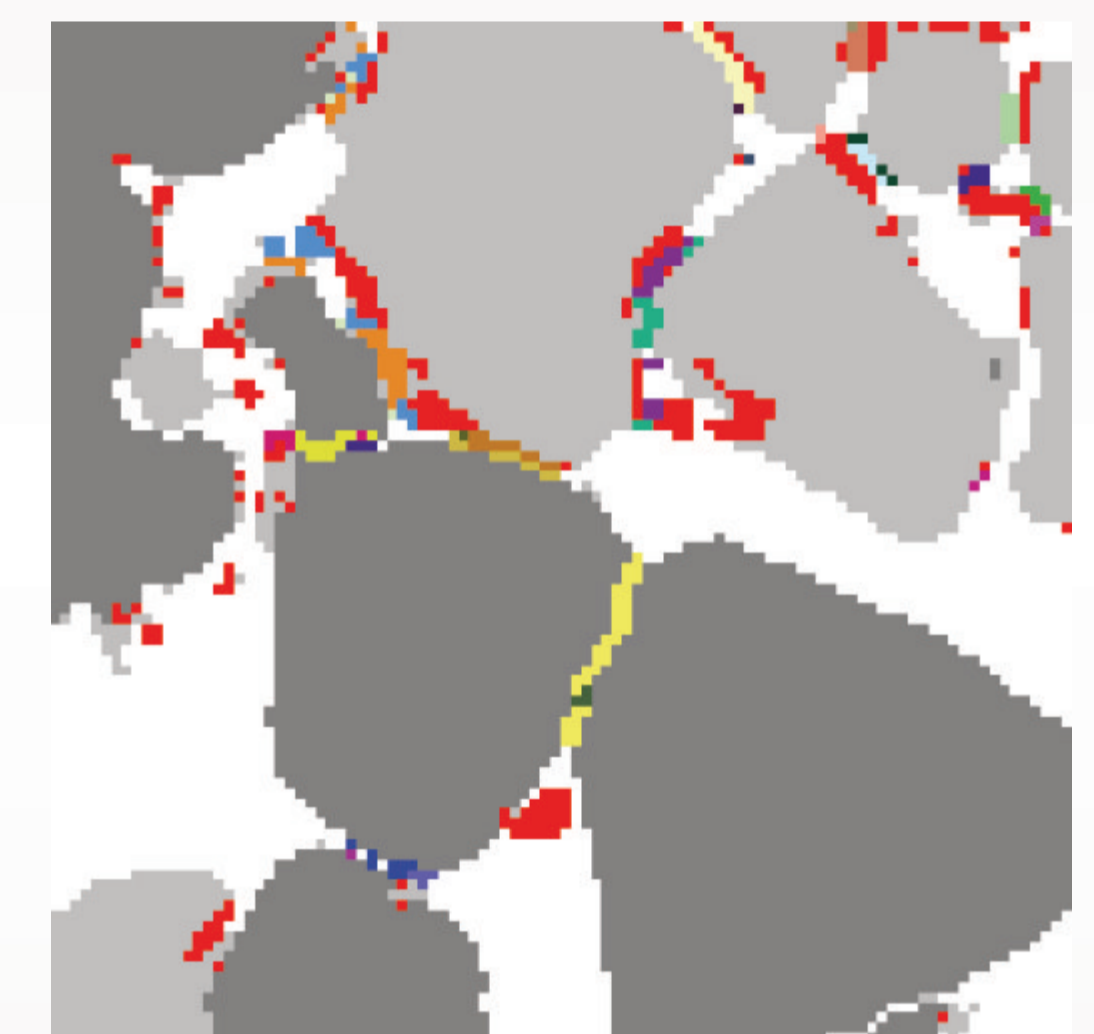
Limited μCT resolution causes thin intergranular gaps to appear as stiff grain contacts, resulting in systematic stiffness overestimation in standard DRP workflows.



2D slice of a Sandstone rock sample in a standard DRP workflow.

MECHANICAL & ACOUSTIC SIMULATIONS

In the improved DRP workflow, stiffness is simulated using corrected grain contacts. Seismic wave velocities (V_p , V_s) and acoustic impedance (I_p) are derived from the computed elastic properties, namely bulk modulus (K), shear modulus (G), and bulk density (ρ).



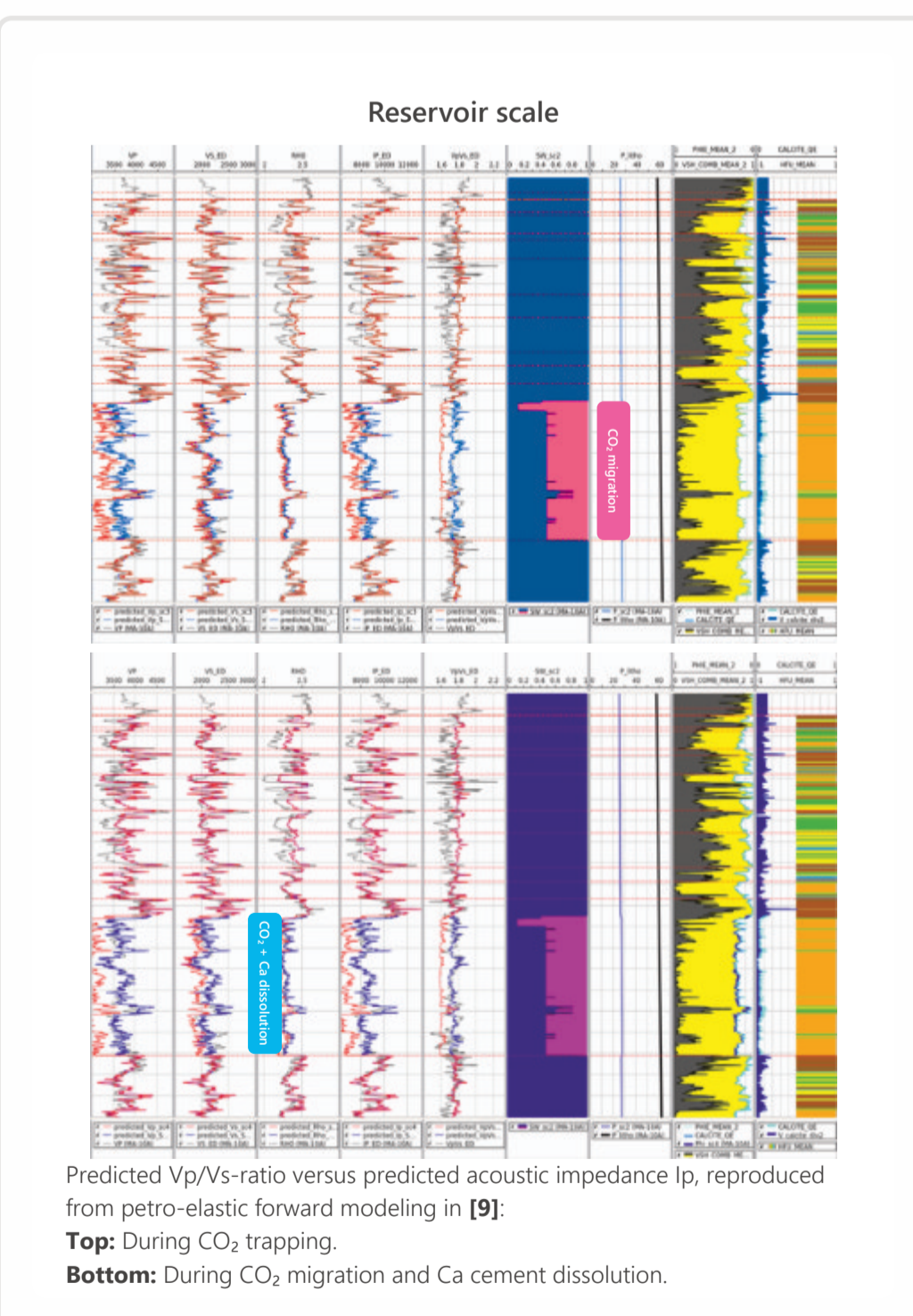
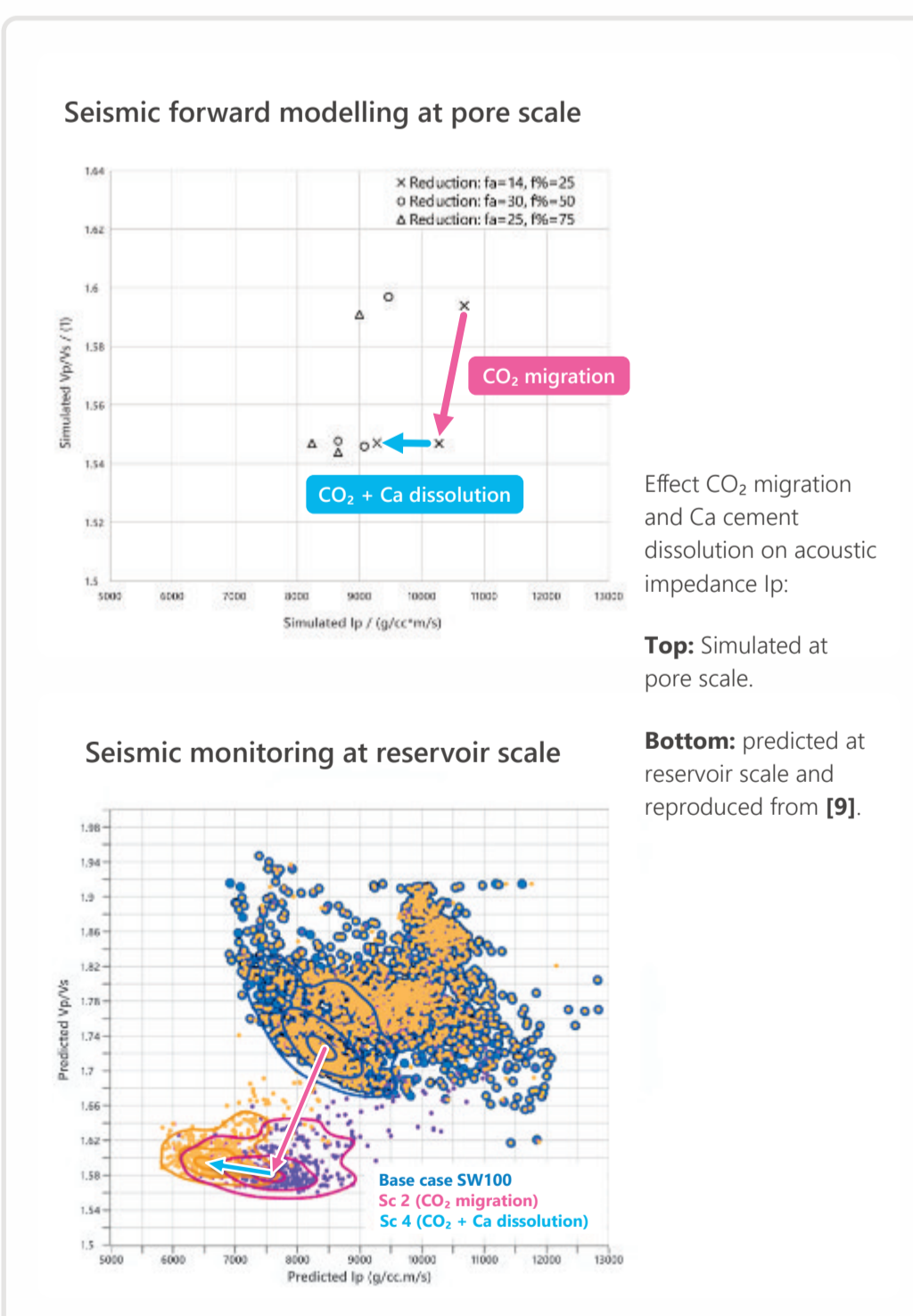
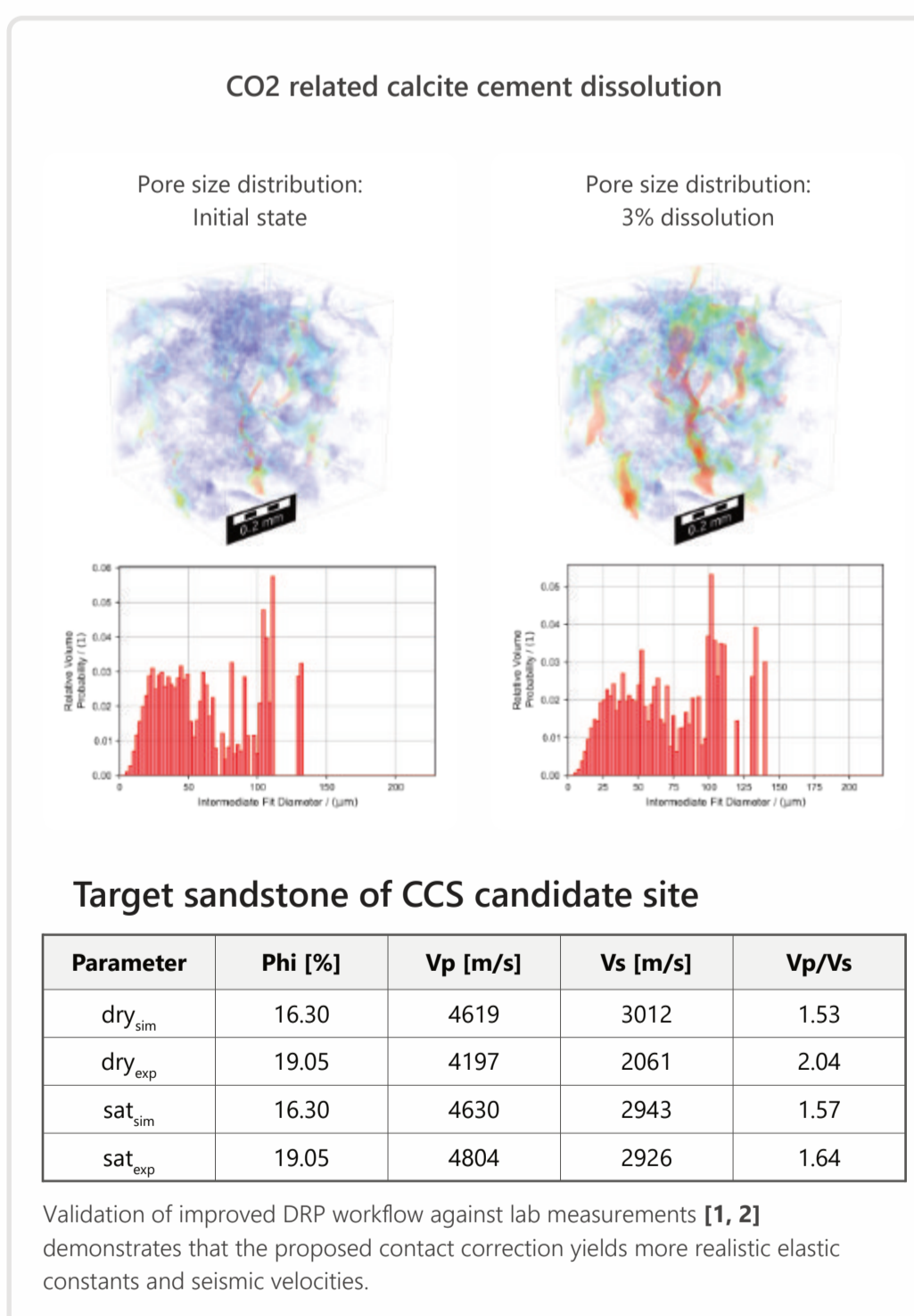
2D slice showing identified contact zones with factorized contact stiffness in various colors.

ELASTICITY, REACTIVE TRANSPORT, AND SEISMIC RELEVANCE

Applied two-phase flow simulations [1, 2] were used to derive fluid distribution states that induce systematic variations in acoustic rock properties, based on an extended and more dynamic version of the pore morphology method introduced in [8].

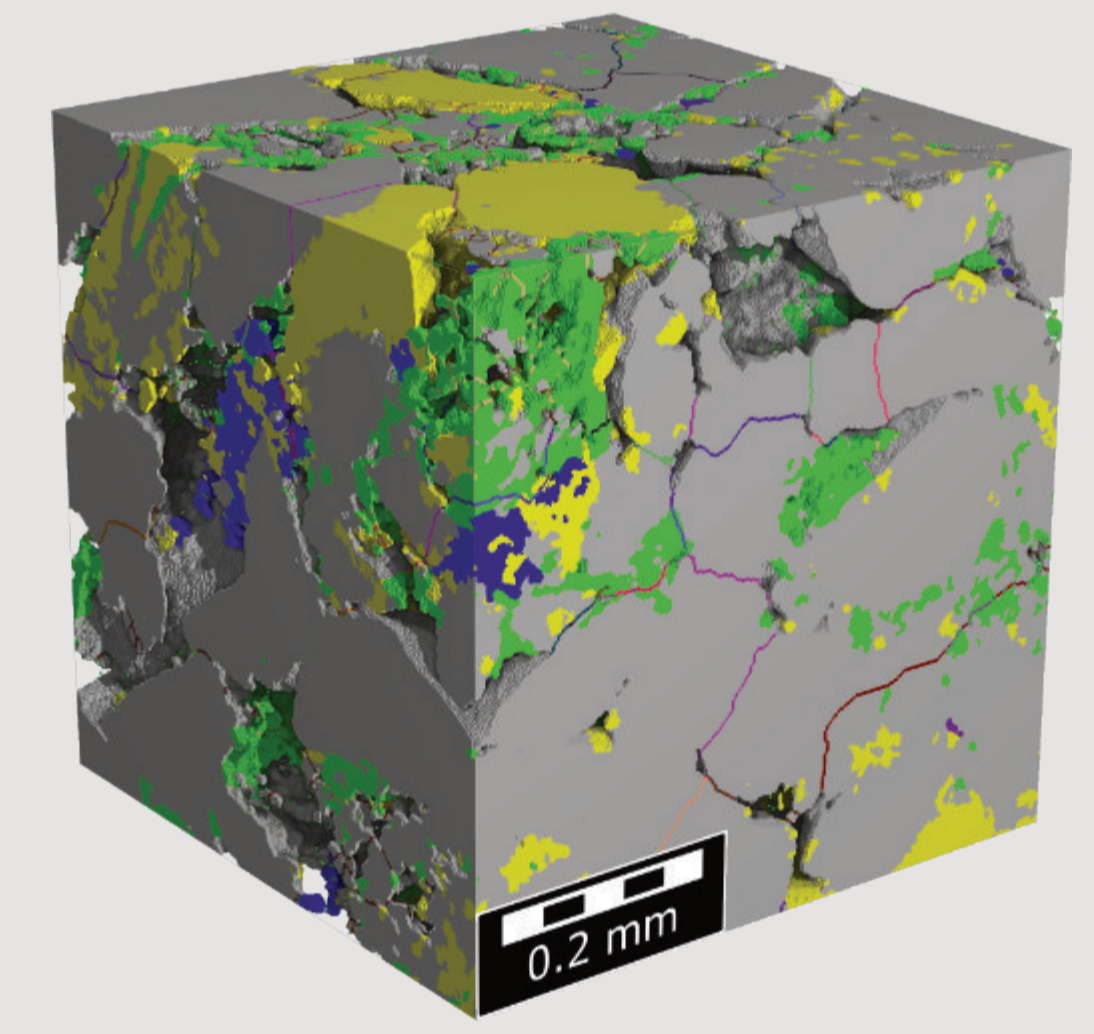
Fluid-rock interaction simulations [1, 2] further revealed localized mineral dissolution and associated changes in solid matrix geometry, affecting the pore-scale elastic response. These structural changes were correlated with seismic monitoring data to support upscaling of digital rock properties to log and reservoir scale [2].

CO₂ migration effects were reflected in variations of the V_p/V_s ratio and acoustic impedance obtained from DRP simulations.



RESULTS & IMPACT

The proposed contact-based stiffness correction significantly improves agreement between simulated and experimentally measured V_p/V_s values, especially under saturated conditions.



Target Sandstone rock sample with corrected contacts in the improved DRP workflow.

ACCURATE MODELING OF THE MECHANICAL AND SEISMIC IMPACTS OF CARBONATE DISSOLUTION USING GEO DICT IMPROVES PREDICTION AND MONITORING CAPABILITIES FOR CARBON CAPTURE AND STORAGE PROJECTS.

CONCLUSIONS & OUTLOOK

The improved DRP workflow integrates advanced grain segmentation with targeted stiffness correction at grain-grain interfaces to overcome the systematic overestimation of elastic properties in digital rock models.

Reactive transport simulations successfully capture progressive carbonate dissolution and the associated evolution of porosity and elastic stiffness.

Nonlinear trends in the V_p/V_s ratio and acoustic impedance (I_p) in response to cement dissolution demonstrate their potential for seismic monitoring of geochemical alteration.

The digital workflow enables integrated prediction of mechanical and hydraulic property evolution, supporting field-scale CCS planning, injectivity control, and 4D monitoring strategies.

Our project partners:



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Math2Market GmbH | Richard-Wagner-Str. 1 | 67655 Kaiserslautern, Germany
+49 631 205 605 0 | drp@math2market.de

WWW.MATH2MARKET.COM

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