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Deep Within the Rocks

New oil and natural gas deposits can be recognized using X-ray computed tomography (CT) technology, and their potential value can be evaluated using increasingly advanced computational methods.

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Unconventional deposits of oil or natural gas trapped in sedimentary rocks (called *tight gas/oil, shale gas/oil*) are a target of increasing interest from both the oil industry and research institutions, in terms of their exploration and subsequent extraction of hydrocarbons (crude oil, natural gas) in economically viable quantities.

Such hydrocarbon deposits have varying reservoir parameters in terms of total and effective porosity and absolute permeability, as compared to conventional deposits. *Total porosity* refers to the amount of space (pores) filled with water and/or hydrocarbons in the rock. *Effective porosity*, on the other hand, only measures the part of the pore space that is actually interconnected (meaning that fluids can flow through the rock). *Absolute permeability* is the ability of the rock to transport the fluids inside it.

Tight gas is natural gas accumulated in isolated rock pores (empty spaces between the solid parts of the rock). Low-porous and low-permeable rocks with tight gas trapped inside them, such as sandstones or limestones, have limited pore space (closed pores, limited or no connections between pores), with a predominance of nanopores (pores with diameters on the nanometer scale). *Shale gas*, in turn, is natural gas found in shale rocks (mudstones, claystones).

These two types of deposits require more work than conventional ones, especially at the stage of exploration, because here the hydrocarbons accumulate mainly in closed pores. This requires additional technology, such as hydraulic fracturing (also known as "fracking"), which seeks to connect the pores and ensure the flow of reservoir fluids, thus allowing a well to be exploited more effectively. Before such technologies are used, however, the properties of a given deposit must be studied very carefully.

A modern approach to integrating various lab test results on drill cores (a fragment of rock extracted from a well for testing) and detailed analysis of the pore space, made possible thanks to new techniques for testing solids, are helping to expand our concept of potentially reservoir rocks beyond the criteria used thus far. The results obtained may be useful in further exploration and appraisal of new deposits.

Computed tomography

One crucial aspect of reservoir rocks is the shape and size of the pore spaces where hydrocarbons accumulate. In recent years, researchers have been using X-ray computed tomography as a modern and non-invasive method of studying rocks in this respect.

Readers may be familiar with X-ray computed tomography (or CT-scans) as an imaging technique often used in hospitals. It is also, however, a laboratory method providing unique information on the internal structure of various materials, such as pore space in rocks.

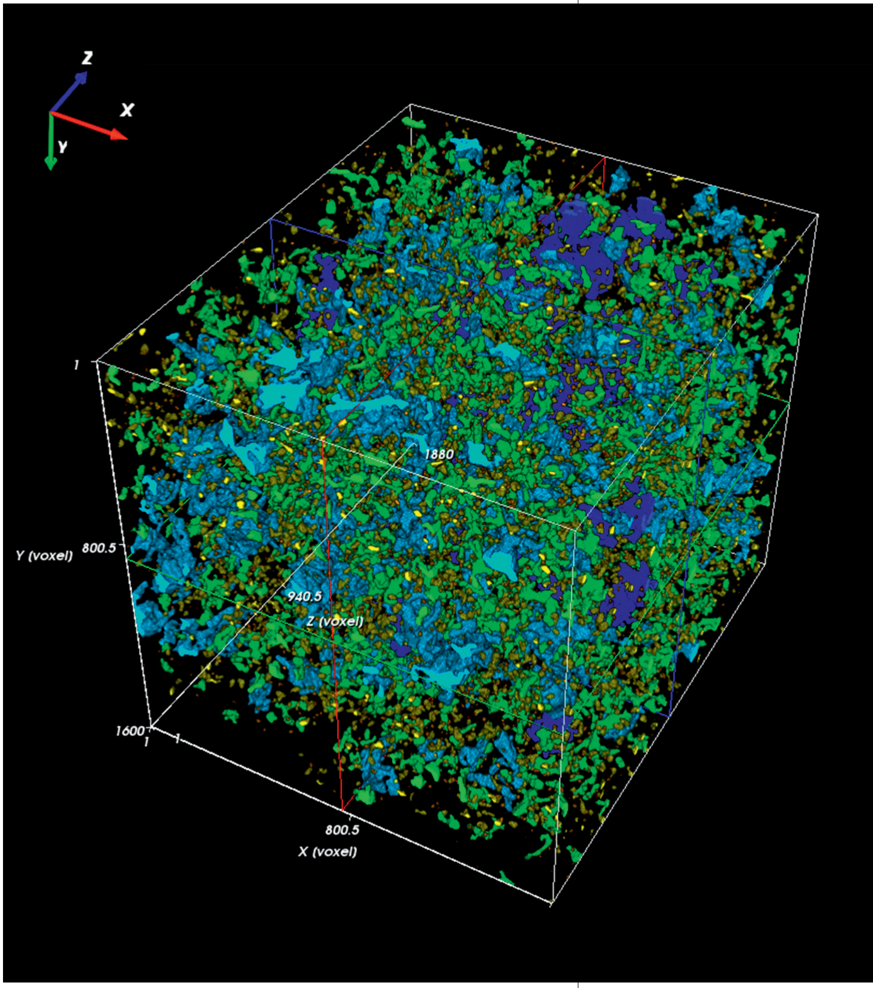
Computed tomography involves the use of X-rays to examine a rock sample, providing a 3D image of the rock, its mineral skeleton and pore space. Microtomographs offer imaging resolutions on the scale of individual gas and oil molecules, while nanotomography can provide key information about nanopores. Low-porous and low-permeable rocks have a mostly heterogeneous pore structure.

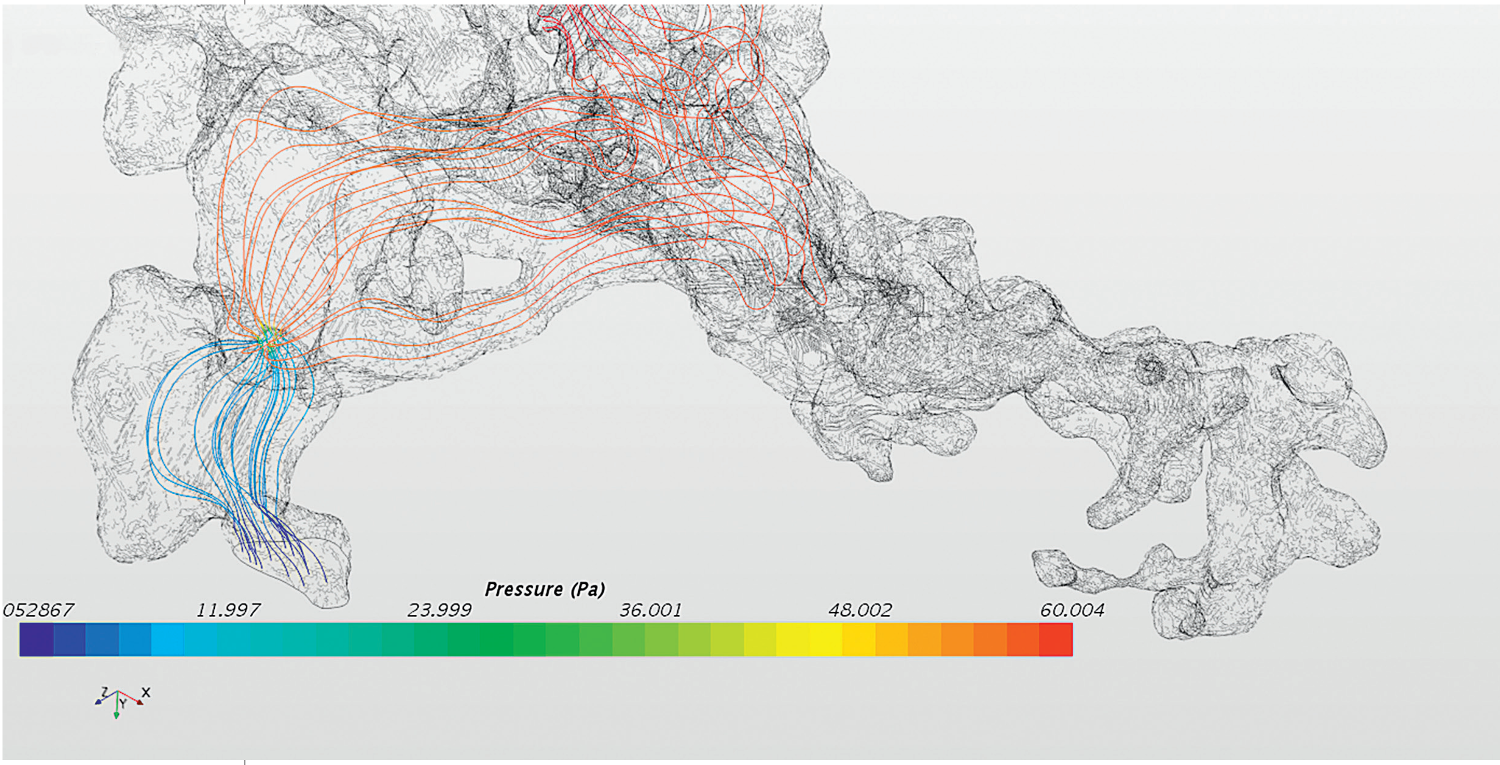
The tomographic image of the pore space helps us to understand its geometrical features in detail. X-ray tomography provides information on porosity, pore distribution in the pore space, their diameters and shape, the presence of micro-cracks, as well as information on the tortuosity of pore channels, important when assessing the rock's ability to allow reservoir media to flow through it.

A CT-scan study starts with an X-ray beam emitted from an X-ray tube. The sample casts a shadow on the detector, creating a 2D projection. As the radiation passes through different parts of the sample, it is absorbed, or weakened to a certain degree, depending on the structure of the object. The denser the object, the greater the weakening of the beam. A full scan involves recording X-ray projections at various angles from 0 to 360°. The smaller the angle of rotation between each scan, the greater the detail of the image, but the longer the full scan takes. Tomographic cross-sections of a sample, a slice of complex projections, are obtained through a back-projection algorithm, which in effect allows us to view the changes in linear absorption. The back-projection algorithm is a group of reconstruction algorithms, a mathematical technique of obtaining a processed image.

As the sample is rotated during the scan, the cross-sections forming the reconstructed 3D images are recorded. Computed X-ray tomography thus provides a complete picture of the rock sample's pore space. The size of the pores depicted depends on the

A 3D image of the pore space in a Cambrian sandstone. Different colors represent different pore volumes.





Part of a pore space with marked fluid flow paths, shown on a screenshot from the Star CCM + software. The 3D image of the pore space was obtained from the results of the X-ray CT scan and used to simulate the fluid flow to determine the filtration properties of the rock.

resolution of the CT scan. They may be pores with dimensions in the micrometers (microtomographs) or nanometers (nanotomographs).

Fluid Modeling

The results of X-ray CT scans can be presented in the form of two-dimensional or three-dimensional images of the mineral skeleton and pore space, the pore space alone, or a selected rock-forming mineral.

CT scans have proved to be a very important technique for the qualitative and quantitative study of rock pore spaces. They make it possible to assess the total porosity of rocks and the complexity of the pore space, which is important when planning the fracturing process, and also to generate a three-dimensional image of the pore space to simulate fluid flow through the porous medium and calculate absolute permeability. However, methods need to be used to turn the information provided by CT scans into useful quantitative descriptions of the pore space and mineral grains, including such numerical characteristics as their diameter, elongation, sphericity, etc. The correct determination of the porosity and permeability of rock formations is of great importance, since the estimated amount of hydrocarbon resources depends on it.

Absolute permeability is significant for determining the filtration properties of rocks. In addition to laboratory measurements of drill cores (direct measurement), computer simulations of fluid flow through a porous medium are conducted to determine absolute permeability indirectly. In recent years, the field of Computational Fluid Dynamics (CFD) has developed dramatically, becoming an important engineering tool for conducting detailed analyses of fluid flow, including in porous rock media. The simulation process to determine absolute permeability requires an accurate 3D image of the rock's pore space. 2D or 3D images of the pore space can be obtained through X-ray computed tomography. CT scans are used to create a geometric model of the rock pore space for fluid flow analysis. The combination of CT scan results and simulated fluid flow through the porous medium provides information on the rock's filtration potential. Research is still ongoing with regards to multiphase flows in rocks, involving a mixture of reservoir water and natural gas. The development of computer simulation methods for determining the absolute permeability of rocks in the case of low-porous and low-permeable formations is an important issue with great potential in terms of both research and application.

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Further reading:

https://infolupki.pgi.gov.pl/gaz-lupkowy

https://infolupki.pgi.gov.pl/pl/gaz-zamkniety

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