Tomography in Geology: 3D Modeling and Analysis of Structural Features of Rocks Using Computed Micro-Tomography

A A Ponomarev, R A Mamadaliev and T V Semenova
Industrial University of Tyumen, 38 Volodarskogo st., Tyumen, 625000, Russia
E-mail: ponomarev94@mail.ru

Abstract. The article presents a brief overview of the current state of computed tomography in the sphere of oil and gas production in Russia and in the world. Operation of computed micro-tomograph Skyscan 1172 is also provided, as well as personal examples of its application in solving geological problems.

1. Introduction
Computed micro-tomography, or micro-CT, is recreation of X-ray binary models in three-dimensional images. Figure 1 illustrates how it works. A sample is placed inside the scanner on a table which rotates during scanning. An X-ray source generates beams that travel through the sample leaving shadow projections on the detector (camera). Following each rotation a separate projection is captured (a separate two-dimensional image corresponding to the X-ray intensity passing through the sample in question is called shadow projection).

Brightness (varying grayscale) on an X-ray shadow projection represents X-ray radiation attenuation due to dispersion and absorption of the signal passing through the sample. [1,3]

Attenuation depends on the density and thickness of the object in question, as well as on the effective atomic number the object is composed of.
When X-ray radiation passes through some material the level of absorption can be related to four
types of interaction: photoelectric absorption, Compton scattering, electron-positron pair creation
and coherent Rayleigh scattering. In case of studying geological objects, when radiation sources with up to
100 keV are used, photoelectric absorption is the primary process determining X-ray radiation
attenuation.

Upon completion of scanning and during reconstruction, projections are converted into slices of
single-voxel thickness, from which a 3D model is then constructed and analyzed. For SkyScan 1172
the maximum size of the sample in length/width should not exceed 64 mm, maximum height – 70 mm.

In Western Siberia, the time when wells were flowing is gradually coming to an end. The new era
of depleted deposits and hard-to-recover reserves dictates the necessity to introduce innovative high-
precision computer technologies into a complex of standard petrophysical core analyses. [3]

2. Current state of computed tomography application in studying petophysical rock properties
Developed Western countries use a comprehensive approach to apply this technique. In Russia
computed micro-tomography has been developing for over five years now; the first micro-tomograph
was introduced by Schlumberger. At present, a majority of well-developed oil and gas companies
utilize tomographs to evaluate large-size pore space features in full-size core samples (cavern porosity,
large jointing). However, the resolving power of a tomograph is not sufficient to obtain precise
porosity data that is why computed micro- and nano-tomography is resorted to. Main advantages are:
• determining porosity and pore space morphology of varying genesis to predict permeability
and porosity properties of core samples;
• studying core samples which lithological and petrophysical properties are impossible to study
accurately, samples with defects that make it impossible to carry out standard laboratory tests
(chipping, fractures), cuttings, and samples from sidewall core sampler;
• studying reservoirs categorized as hard-to-recover which can’t be studied by standard
laboratory tests (lack of equipment, considerable variability of sample properties during
testing, extreme PVT parameters) or test results do not provide an accurate study of the test
object (exclude processes at a pore or micro-pore level), as well as studying core samples
basic analyses of which are significantly time-consuming. [2]

Over the last couple of years complex tomography has become a mainstream technique in core
analysis. International companies apply it to analyze and simulate various kinds of petrophysical and
lithologic rock properties. For example, such companies as Shlumberger, iRockTechnologies,
INGRAIN, FEI can use computed tomography data to precisely calculate porosity, permeability and
wettability, and to simulate multi-phase filtration displacement processes and enhanced oil recovery
techniques. This proves that for Russian oil and gas sector it is necessary to develop its own software
and new methods of introducing the reviewed technique into petroleum field geology.

3. Personal experience in applying micro-tomography in geology
TSOGU research geochemical laboratory is equipped with a computed micro-tomograph Skyscan
1172. Its standard software package is unable to directly determine permeability and model filtration,
EOR techniques and rock mechanics. However, even without this it is possible to obtain a fair bit of
information on rock structure or determine porosity in samples with difficult sample preparation.
Some of the analysis examples are given below.
Figure 2. A sample determination of rock mineral composition, with cement segregation.

The percentage of all these minerals, including clay in grain structure and in rock cement, relative to the entire sample volume, can be calculated using the software.

In geology, to calibrate tools used for well logging it is necessary to know the shale volume. Calibration and re-interpretation of the obtained data for the entire formation are performed according to the amount of clay matter in core samples. A standard technique of determining shale volume is not precise enough, as it determines clay matter in cement. It is due to the actual experiment procedure of grain size analysis. Therefore, data on clay matter in grains are lost. Computed microtomography allows for both correct determination of shale volume and its segregation into two categories: in cement, in grain structure. [3]

Aside from calculations, computed tomography allows for construction of the sample 3D models. Modeling, as well as calculations, is performed based on the selected range of thicknesses, i.e. all we can see with a naked eye on tomograms (figure 3) can be simulated in 3D. Let us look at the example of the simulated pore structure of a microcement-based rock sample (figure 3).

Figure 3. A sample pore space 3D model and its development in 3 cross-sectional planes.
As seen from the 3D model, the sample is mostly comprised of pores isolated from each other, which is a success for the cement rock developers as permeability will be almost equal to zero.

The device is unique in that it provides non-destructive control of the sample. To calibrate well logging tools precise calculations of rock properties must be available. As a rule, they are obtained from core analysis; after that correlation dependence is built and interpreted for the entire formation.

Core analysis is done in stages; in this particular case, salt content (halite (NaCl) and sylvite (KCl)) in terrigenous rock had to be determined by two methods: standard (leaching) and micro-tomography. But prior to conducting analysis, rocks were saturated with formation water to determine electrical resistivity necessary for logging tools calibration. Subsequently, micro-tomography was performed (figures 4-5).

![Figure 4. Development in 3 cross-sectional planes, sample 1 (presence of industrial salinization).](image)

Figure 4. Development in 3 cross-sectional planes, sample 1 (presence of industrial salinization).
As the analysis discovered, during formation water saturation one of the samples experienced industry-induced deformation of the rock structure, namely salt precipitation on rock walls (figure 5). This phenomenon causes distortion of all physical and mechanical rock properties during further analysis. Only computed microtomography is capable of identifying such industry-induced irregularities.

4. Conclusion
The paper covered key aspects of tomography and micro-tomography development. The operating principle of a computed micro-tomograph Skyscan 1172 was overviewed, as well as some results of its work. There are no ready-to-use GOST techniques for the micro-tomograph, wherefore the accuracy of the obtained results depends almost completely on the interpreter’s experience.

Based on this work we can make a conclusion that oil and gas companies should realize the need to advance research in this area in order to gradually improve the capacity and preciseness of analysis on computed tomographs, micro-tomographs and nano-tomographs.

Applying this method makes it possible, in some cases, to simplify the process of obtaining petrophysical properties of rocks (such as cuttings, loose soil, cavernous and fractured reservoirs).
Micro-tomography is also a helpful tool of comparative analysis, allowing researchers to study rocks before and after some tests and make conclusions based on its results.

References

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