

Analysis of the core microstructure of terrigenous reservoirs based on lithological-petrographic studies to support the creation of digital core model

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Abstract

The question of digital core modelling appears highly relevant due to the fact that there is not always a sufficient amount of core material available from studied wells: in some cases, it is not possible to select core material (in case of loose, weakly cemented rocks); in others, such material may be completely absent. In order to create a computer model of a digital core, it is necessary to have a correct understanding of the pore space microstructure and rock lithological composition and structure, among the most important features determining the quality of sedimentary reservoir rocks. Such information can be obtained by carrying out lithological-petrographic studies of thin sections of reference (standard) core samples.

The aim of the present work is to study petrographic thin sections for their further use in creating a digital core model. The article discusses the methodology and results of laboratory lithological and petrographic studies of thin sections using the available core information.

The paper presents the results of laboratory studies of thin sections of terrigenous sandstones obtained from the Berea Sandstone formation (USA). The choice of the Berea Sandstone is due to its wide recognition by specialists, as well as its homogeneity, both in terms of the grain size of constituent rocks and their filtration and reservoir properties. The work also presents the results of data analysis on lithological and petrographic studies of core material from the terrigenous deposits obtained in the Timan-Pechora province in northern Russia.

The research results can be used for mathematical modelling of the pore space microstructure in a digital core model.

Keywords

computer modelling, digital core, lithological and petrographic studies, lithological composition, petrographic thin sections, pore space microstructure, sandstone, Terrigenous reservoirs

Introduction

Currently, digital core modelling technology is a popular and developing direction in the assessment of geological oil reserves. The use of this technology is recommended as a supplement to physical laboratory studies, providing a fast and efficient way to model rock properties by extracting information from 3D images (Belozеров et al. 2017).

Attempts to use this technology in practice have mainly been undertaken in the last decade, although the first results of its application to the analysis of reservoir rocks were obtained in the 1980s (Mavko et al. 2003). The development and creation of a digital core in the future will reduce the need for a large number of laboratory experiments and shorten research periods, as well as solving a number of prospecting and exploration tasks allowing the computational recreation of the hydrodynamic picture and real reservoir conditions of a particular field to an acceptable error tolerance (Gubaidullin et al. 2017).

In order to create a digital core model, it is expedient to have some prior information concerning a number of petrophysical characteristics (porosity, permeability, granulometric composition of rocks, etc.), as well as the hydrodynamic and lithological-petrographic parameters of rocks. Based on the obtained parameter values, a digital model of the porous medium is created.

Materials and methods

At the first stage of the study, ten standard size core samples were obtained from sandstone obtained from the terrigenous Berea Sandstone (USA) deposit. The reason for selecting test samples from this deposit is due to these sandstones being widely recognised and considered advantageous by specialists in the oil

industry for conducting applied research and testing various technologies. These rocks have minimal filtration anisotropy and reservoir properties, relatively high porosity and permeability, as well as homogeneous grains of constituent rocks and good sorting. Based on the studied samples, the values of the main filtration-capacity properties were determined. Filtration studies were additionally carried out in order to obtain the dependences of fluid permeability coefficients on temperature.

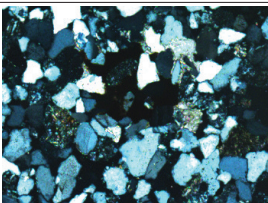
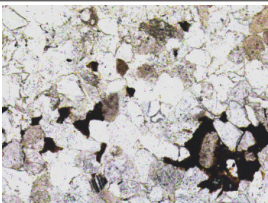
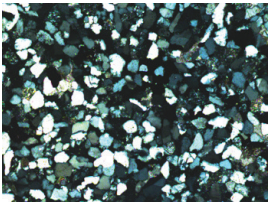
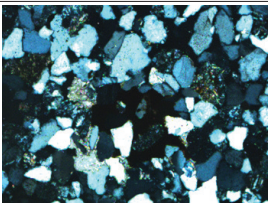
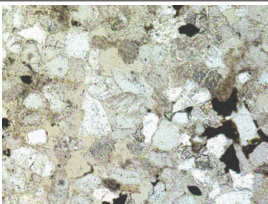
For detailed characterisation of sandstones, siltstones and clayey rocks, as well as clarification of the combination of granulometric elements in them, various granulometric analysis methods are used for studying rock structures using thin sections under a microscope (Khanin 1969). In order to obtain such information, a petrographic description of 10 thin sections of the terrigenous Berea Sandstone deposit was carried out. The sections were made from the available core material at random, since the rocks were quite homogeneous in their material composition.

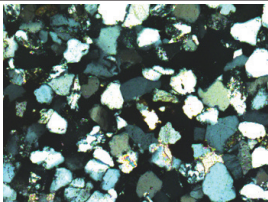
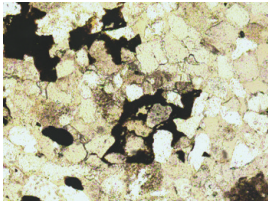
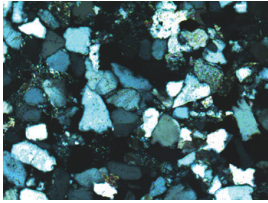
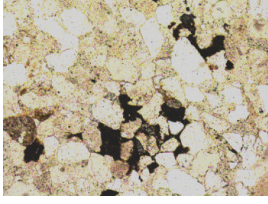
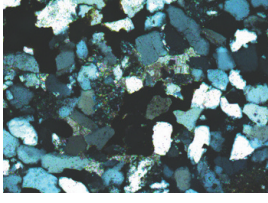
The studied rocks are represented by light grey sandstones of medium-fine-grained, fine-medium-grained, predominantly appearing as reservoirs of moderately useful capacity with pore type III class (Khanin 1969). Their porosity, according to the data of petrophysical analyses, varies in the range of 17–20% (for thin sections up to 15%). The determination of porosity from thin sections is carried out according to the generally accepted methods used in the description of petrographic thin sections.

In terms of material composition, the rocks are characterised by quartz content of 70–85%, feldspars 2–5%, rock fragments of various genesis 10–20%, mica 1–2%. Mixed cement: locally developed contact type cementation with conformal contacts of individuals; regenerative quartz does not exceed 1%; clay pore-film cement 2–5%; authigenic carbonate acts as pore corrosive cement (2–5%).

It should also be noted that the increased porosity in these rocks is due to the quartz grains and other fragments being packed less densely on account of their irregular and semi-rounded shape. The results of studies of thin sections are presented in Table 1.

Table 1. Results of studies of thin sections

Section No.	Porosity,% by thin sections,%	Grain size, mm	Sorting	Brief lithological description	Photo of thin sections
1	2	3	4	5	6
1	10	0.22–0.40	good	Fine-medium-grained oligomictic quartz sandstone with combined cement, pigmented with bitumen, porous. The spotty texture is due to the uneven pigmentation of the BOM. The structure is psammitic fine-medium-grained.	 <p>Magnification ×100. Polarised light.</p>
2	Up to 15	0.20–0.45	good	Fine-medium-grained oligomictic quartz sandstone with combined cement, pigmented with bitumen, porous. The spotty texture is due to the uneven pigmentation of the BOM, porous. The structure is psammitic fine-medium-grained.	 <p>Magnification ×100. Daylight.</p>
3	10	0.15–0.35	good	Medium-fine-grained oligomictic quartz sandstone with contact type cementation (compaction), porous carbonate cement, rare quartz regeneration cement, spotty oil-saturated. The spotty texture is due to the uneven distribution of carbonate material and BOM. The structure is psammitic, medium-fine-grained.	 <p>Magnification ×25. Polarised light.</p>
4	10–12	0.20–0.40	Medium	Fine-medium-grained oligomictic quartz sandstone with combined cement, unevenly oil-saturated. The texture is spotty. The structure is psammitic fine-medium-grained.	 <p>Magnification ×100. Polarised light.</p>
5	10	0.25–0.40	Medium	Fine-medium-grained oligomictic quartz sandstone with combined cement, pigmented with bitumen, porous. The texture spotty is due to the pigmentation of the BOM. The structure is psammitic fine-medium-grained.	 <p>Magnification ×100. Daylight.</p>

Section No.	Porosity, % by thin sections, %	Grain size, mm	Sorting	Brief lithological description	Photo of thin sections
6	10–12	0.22–0.35	Medium	Fine-medium-grained oligomictic quartz sandstone with contact-type cementation, areas with pore-type carbonate cement, pigmented with bitumen. The texture is spotty. The structure is psammitic fine-medium-grained.	 <p>Magnification ×100. Polarised light.</p>
7	10–15	0.15–0.32	Medium	Medium-fine-grained oligomictic quartz sandstone with contact type cementation, quartz regeneration cement, locally with porous carbonate cement, spotty oil-saturated. The spotty texture is due to uneven oil saturation. The structure is psammitic, medium-fine-grained.	 <p>Magnification ×100. Daylight.</p>
1	2	3	4	5	6
8	10	0.25–0.35	good	Medium-grained oligomictic quartz sandstone with contact type cementation, sporadically with porous carbonate cement and quartz regeneration cement. The texture is spotty. The structure is psammitic, medium-grained.	 <p>Magnification ×100. Polarised light.</p>
9	10	0.25–0.40	good	Medium-grained oligomictic quartz sandstone with contact type cementation, quartz regeneration cement, sporadically with chlorite-hydromica cement of film-porous type. The texture is unclear. The structure is psammitic, medium-grained.	 <p>Magnification ×100. Daylight.</p>
10	10–12	0.22–0.40	good	Medium-grained oligomictic quartz sandstone with combined cement, pigmented with bitumen, porous. The spotty texture is due to the pigmentation of the BOM. The structure is psammitic, medium-grained.	 <p>Magnification ×100. Polarised light.</p>

In addition to lithological and petrographic studies of rocks from the Berea Sandstone formation, an analysis of the lithological and petrographic data of

rocks for five deposits of the Timan-Pechora province was carried out in order to identify the main factors that determine the porosity and permeability of

terrigenous reservoirs. Based on the analysis, it was found that the grain size of rock-forming minerals is one of the main factors.

By definition, rock porosity corresponds to spaces in a rock that are free of the solid mineral phase (Malysheva 1993), i.e. theoretically, grain size should not affect porosity. This is evidenced by the lack of a direct relationship between the grain size distribution and porosity (Fig. 1). Rocks of different granulometric composition can have the same porosity.

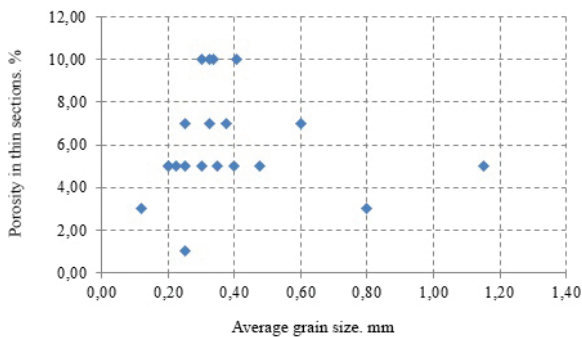


Fig. 1. Dependence of open porosity on the average grain size of the studied rocks

The permeability coefficient of terrigenous rocks is influenced by: granulometric composition of rocks, sorting, grain shape and packing (Mikhailov 2006). The reservoir properties are also influenced by the composition and content of the cementing material.

Results

In the course of the analysis, it was revealed that the more homogeneous the rocks in terms of particle size, the higher the porosity. This is also evidenced by the data published in (Amosova 2000). It follows that the porosity of a containing space consisting of identical spheres with cubic packing is 47.6%, while with the densest rhombohedral packing, the porosity is 25.96%. In both cases, the deviation of individual spheres from the total size will be accompanied by a decrease in porosity: the greater the porosity, the lower the sorting (homogeneity) of fragments. This

is due to the fact that small fragments are located in large pores (Amosova 2000).

No direct relationship was found between grain size and porosity. The degree of porosity and permeability is influenced by the degree of roundness of the clastic material. Thus, rock fragments of irregular shape and semi-rounded particles are packed less densely, leading to an increase in porosity.

As a rule, the more heterogeneous the sandstone is in terms of the size of its particles, the lower is its porosity, since fine grains clog the pores of the sand formed by large particles (Mikhailov 2006). Such rocks exhibit good sorting of clastic material.

Discussion

For further use in a digital model, the obtained petrographic description of thin sections is semantically well-arranged, making it possible to extract meaningful lexemes and apply latent semantic analysis (LSA) as a text processing method. LSA is a natural language information processing technique that analyses the relationship between a collection of documents and the terms used in them (Susan 2005). In future, this will allow the context-dependent values of lexemes to be extracted from the description for the subsequent clustering of thin sections according to their photographs using machine learning methods, and, thus, to extract information essential for the model of the core microstructure from available petrographic information derived from the reports on the core studies.

Due to the grain size of rock-forming minerals being one of the main factors determining the porosity and permeability of terrigenous reservoirs, the microstructure of the rock technology can be modelled by packing spheres with the same size distribution as the size distribution of the grains of the modelled rock. For a more efficient construction of rock microstructure during modelling, elements other than spheres should be considered, for example, spheropolyhedrons, since, in the studied rocks, quartz grains and rock fragments having an irregular shape and semi-rounded particles are packed less densely, leading to an increase in porosity.

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