SOCAR

SOCAR Proceedings

Oil and Gas Fields Exploration, Geology and Geophysics

journal home page: http://proceedings.socar.az

INDEXED IN EMERGING SOURCES CITATION INDEX THOMSON REUTERS

Scopus

GEOMECHANICAL PROPERTIES OF CARBONATE RESERVOIR ROCKS AND MIDDLE CARBON CAP ROCKS OF THE IVINSKOE OILFIELD

V.E. Kosarev[1], E.R. Ziganshin*[1], I.P. Novikov[2], A.N. Dautov[1], E.A. Yachmeneva[1], E.S. Bystrov[1]

[1]*Kazan (Volga region) Federal University, Kazan, Russia*

[2]*JSC «Tatneftteprom», Kazan, Russia*

Abstract

Laboratory studies of the geomechanical properties of rocks are an important and integral part in building a geomechanical model. This study resulted in a set of data on geomechanical and elastic properties of the rocks that compose the lower part of the Middle Carboniferous section of the Ivinskoye oilfield (Russia). Relationships between various elastic parameters were also established. The distribution of geomechanical properties correlates with structural/textural features of the rocks under study and their lithological type. This information can be used as a basis for geomechanical modeling and in preparation for hydraulic fracturing.

Keywords:
Geomechanics;
Elastic properties;
Carbonate rock;
Laboratory core studies.

1. Introduction

Geomechanical properties are one of the most important and meaningful petrophysical parameters that are directly related to the internal structure of rocks [1]. The following constants are used to describe the properties of a perfectly elastic medium: Young's modulus (E), Poisson's ratio (ν), cohesion, angle of internal friction (φi), etc. All of them are related to stress and resulting deformation. The only direct method for studying geomechanical properties is the laboratory studies of core samples. Usually, laboratory measurements produce dynamic elastic parameters (which are derived from the velocities of elastic ultrasonic waves in rocks) and static elastic parameters (which are determined by applying stress to the rock and measuring the deformation). There is always a difference between the static and dynamic properties caused by the difference in the rates of stress-induced deformation. The laboratory studies are a very valuable source of information that allows prediction of the rock's behavior under changing conditions. Dynamic and static elastic parameters can be used for correlation of the core samples, which is necessary for calibration of well log data [2].

Keywords: geomechanics, elastic properties, carbonate rock, laboratory core studies.

**E-mail:* eduard-ziganshin@mail.ru
http://dx.doi.org/10.5510/OGP2021SI200561

2. Study object

The study object was the core sample retrieved from one of the wells in the Ivinskoye oilfield. The main purpose of these studies was the collection of information on the geomechanical properties of reservoir and non-reservoir rocks within the Middle Carboniferous strata. The second objective was revealing the patterns and relationships between the geomechanical properties, strength parameters and lithological features.

The Ivinskoye oilfield is located in the Republic of Tatarstan (Russia). Most of the the oil-bearing rocks belong to the Tournaisian stage, the Bobrikovsky and Tulsky horizons of the Lower Carboniferous, and the Bashkirian and Vereian horizons of the Middle Carboniferous. According to the tectonic maps of the region, the object of study is located in the western part of the South Tatar Arch (a positive tectonic structure of the first order within the Volga-Ural anteclise) (fig.1).

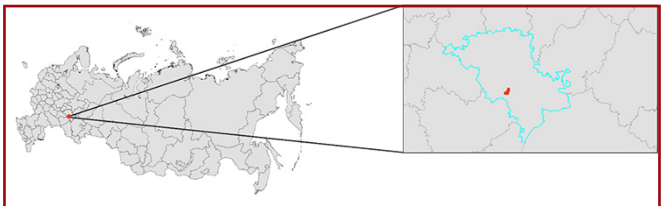

Fig.1. Location of the study object

3. Methodology

Cylindrical samples with a diameter of 30 mm were drilled from the original core samples. Density of each sample was determined by the gravimetric method using a laboratory balance.

Physical, mechanical and elastic properties of the samples were determined in accordance with the current regulatory documentation [3-6]. Elastic properties of the core samples were measured on the PIK-UZ installation. The installation consists of two ultrasonic sensors, a signal generator and an oscilloscope. The generator produces a 1 MHz signal. The signal goes to one of the sensors, which emits S- and P-waves. The waves pass through the core sample installed in the core holder and are detected on the other side by the second sensor. Then the received signal goes to the oscilloscope. The oscilloscope is connected to a computer which records and analyzes the received signal.

All geomecanical studies were carried out using the GTYAN.441179.050 installation designed for determining elastic properties.

The full cycle of geomechanical tests included: 1) multistage testing in a triaxial compression chamber; 2) uniaxial compression test; 3) fracture resistance test. The following geomechanical parameters were measured for this study: 1) P- and S-wave velocity; 2) dynamic Young's modulus and Poisson's ratio, static Young's modulus and Poisson's ratio; 3) cohesion; 4) angle of internal friction; 5) crack resistance; 6) tensile strength.

From the core samples under study, 2.5×2.5 cm thin (~0.03 mm) sections were made. They were then studied with the Axio Imager transmission polarizing microscope (Carl Zeiss, Germany). A standard Nikon digital camera connected to the eyepiece with a special adapter was used for documentation.

4. Results

Table 1 presents the geomechanical properties of reservoir and non-reservoir rocks within the Middle Carboniferous strata. The lithological types of the rocks under study were also identified and microscopic analysis was conducted. All the samples can be divided into several types.

1. The first type is represented by limestone (oolitic-fusulinid grainstone) with patchy and banded oil saturation. Microscopic studies showed that the rock has biomorphic structure and homogeneous texture. The limestone is 85% organic debris and 15% cement. The organic debris is represented by well-preserved adjoining bioclasts with an average size of 0.2-0.6 mm. The organic debris forms a dense rock skeleton with a predominantly rhombohedral packing (leaning against each other). The bioclasts are cemented with calcite. This type of rocks was found in the Kashirian and Vereian horizons, and is represented by three samples. Mean values of the geomechanical parameters are presented in table 1.

2. The second type is represented by diagenetic dolomite (clayey, light gray, fine-grained, indistinctly layered, dense). Microscopic studies showed that this rock has a fine-grained structure and indistinctly layered texture (due to the uneven layer-by-layer distribution of clay). The dolomite is composed of tightly packed grains, 0.01-0.05 mm in size. The grains are isometric and have a xenomorphic shape. The dolomite is dense, slightly porous (intergranular subcapillary pores). Structural and textural features of this type (small grain size, dense packing and small number of pores) cause high values of elastic and strength parameters (tabl.1).

3. The next type is represented by epigenetic calcareous evenly oil-saturated dolomite. It is slightly sulfated, dark brown, fine-grained, cavernous, with a patchy texture. Microscopic studies showed that this rock has a fine-grained structure and spotted texture (due to the presence of large pieces of organic debris and calcite grains). The organic debris range in size from 0.25 to 1.0 mm and vary in a degree of preservation (depending on the degree of replacement by dolomite aggregates). In addition to the organic debris, the dolomite contains large (up to 0.5 mm) monograins of secondary xenomorphic calcite. Relatively large (up to 1.0 mm) caverns formed in the rock mass during dolomitization of organogenic limestone.

Table 1

The geomechanical parameters of the studied rocks

Rock type	Bulk density, g/cm³	Vs, m/sec	Vp, m/sec	Young›s modulus (dyn.), GPa	Poisson›s ratio (dyn.), unit fr.	Young›s modulus (stat.), GPa	Poisson›s ratio (stat.), unit fr.	Tensile strength	Fracture resistance, MPa cm 0.5	Internal friction angle, deg.	Cohesion, MPa
Limestone (Grainstone)	2.5	2871	5409	54.3	0.3	20.3	0.23	4,7	7.7	31.7	19.3
Dolomite (diagenetic)	2.58	2892	5104	54.5	0.26	20.4	0.24	2.95	6.2	50.9	18.4
Dolomite (epigenetic)	2.28	2291	4049	29.3	0.26	12.56	0.28	3.54	1.8	37.8	7.3
Limestone (Mudstone)	2.43	2502	4109	36.9	0.2	11.9	0.23	4.3	6.5	41.4	16.2
Quartz sandstone, argillite	2.2	2224	3673	27	0.21	7.3	0.23	1.7	3.6	35.1	6.5
Crinoid-peloid packstone, dark gray	2.67	3118	5891	67.8	0.31	28.6	0.32	7.7	8.8	44.8	29.7

The caverns are isometric and elongated, with sizes ranging from 0.25 to 1.0 mm. The caverns are interconnected by intergranular channels. Large caverns and organic debris contribute to relatively low values of geomechanical parameters (tabl.1).

4. The fourth type is represented by limestone (mudstone). It is slightly silty, evenly oil-saturated, dark brown, pelitomorphic, indistinctly layered due to uneven desalination. The limestone is composed of densely packed calcite grains (0.01-0.05 mm). The rock also bears traces of algal debris. Although the algae fragments have already decomposed, their presence is indicated by specific elongated cavities in the carbonate rock, repeating the outlines of former plants. The limestone's porosity is 6-8%. Slit-shaped (or less commonly isometric) desalination pores (up to 0.1 mm in size) are isolated from each other in a dense carbonate mass. This type of limestone consist of small grains (0.01-0.05 mm), similar to the diagenetic dolomite described above. This fact explains relatively high values of geomechanical parameters (tabl.1).

5. The next type includes rocks containing primarily terrigenous and clay components: sandstone, silty sandstone, siltstone and argillite. These rocks are similar in their geomechanical characteristics and show low elastic-strength parameters (tabl.1).

Microscopic studies showed that the sandstones and siltstones are 70-75% terrigenous component and 25-30% cement. The terrigenous component is represented by fragments of minerals (45%) and bioclasts (55%). Among the mineral fragments, elongated slightly rounded grains of quartz predominate (80%); angular feldspar grains (15%) and muscovite flakes (5%) are present in smaller amounts.

Argillite is chlorite-illite type, calcareous, slightly silty, dense, with a pelitic structure and horizontally layered texture. This rock is composed primarily of clay particles (illite and chlorite). Argillite contains up to 5% of silty detrital particles (0.01-0.05 mm in size), evenly distributed within the rock. The detrital material is represented by rounded grains of quartz and single flakes of muscovite.

6. The next type is represented by crinoid-peloid limestone (packstone), dark gray, dense, with a biomorphic structure and homogeneous texture (tabl.1). Microscopic studies showed that the rock has a biomorphic structure and massive texture. The limestone is 75-80% organic debris and 20-25% cement. Organic debris (0.25-0.5 mm) are represented primarily by micro lumpy aggregates: peloids (60%) and crinoid fragments (30%). The rock's porosity is 3-4%. The pores are intergranular, of subcapillary size (~0.01 mm). This type of rock has the highest elastic-strength properties among all studied samples. This is most probably caused by the grain size, mineralogical composition and large amount of cement.

Summing up these results leads to the following conclusions. Among all studied rocks, sandstone, silty sandstone, siltstone and argillite showed the lowest elastic properties. Epigenetic calcareous dolomite showed slightly greater results. Next goes mudstone, then diagenetic dolomite, and finally grainstone. Crinoid-peloid packstone showed the highest elastic properties. As mentioned before, this distribution correlates with structural and textural features of the rocks, as well as with the amount of clay and terrigenous components, porosity, size of pores, size and shape of grains. Figure 2 shows the average values of the geomechanical parameters for each rock type.

5. Data analysis

Principal component analysis was chosen as a primary method for determining the relationship between the measured parameters and the degree of this relationship. Nine variables were used in the analysis and three independent factors were identified (tabl.2). The first factor demonstrates the

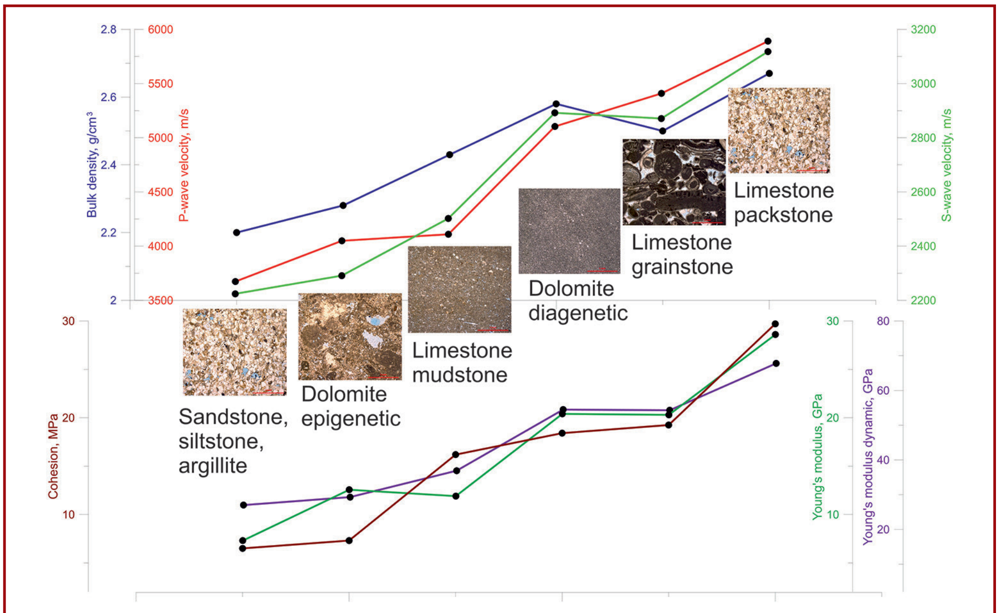

Fig.2. Elastic properties distribution

Table 2

Principal Component Analysis Results

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Bulk density, g/cm^3	-0.82312	-0.09745	0.481095	-0.15176	-0.01828	0.225812
S-wave velocity	-0.96139	-0.07651	0.111863	-0.075	0.198172	-0.07929
P-wave velocity	-0.97245	0.146278	-0.09742	-0.02922	0.130277	-0.00561
Young's modulus (dynamic)	-0.97719	0.037132	0.134847	-0.02055	0.124932	-0.05878
Poisson's ratio (dynamic)	-0.60841	0.526307	-0.52093	0.240067	0.018218	0.152288
Young's modulus (static)	-0.94598	0.060122	-0.16564	0.054828	-0.07009	-0.12536
Poisson's ratio (static)	-0.42961	-0.57387	-0.61779	-0.30776	-0.08676	0.039685
Angle of internal friction	-0.45132	-0.79107	0.064243	0.405628	-0.02503	0.022852
Cohesion	-0.87062	0.231687	0.194642	-0.00376	-0.36808	-0.05534
%	65.70695	14.75044	11.04575	3.88705	2.45629	1.16479

relationship between bulk density, wave velocities, dynamic and static Young's modulus and cohesion. The second factor shows the relationship between dynamic and static Poisson's ratio and angle of internal friction. The third factor reflects the relationship between dynamic and static Poisson's ratio and bulk density. The first relationship involves parameters that are more dependent on cohesion of rock particles, that is, on the quality of cement. The second and third relationships are related to the friction between the particles.

The data obtained during this study were used for correlation-regression models and equations for the relationships between the measured parameters.

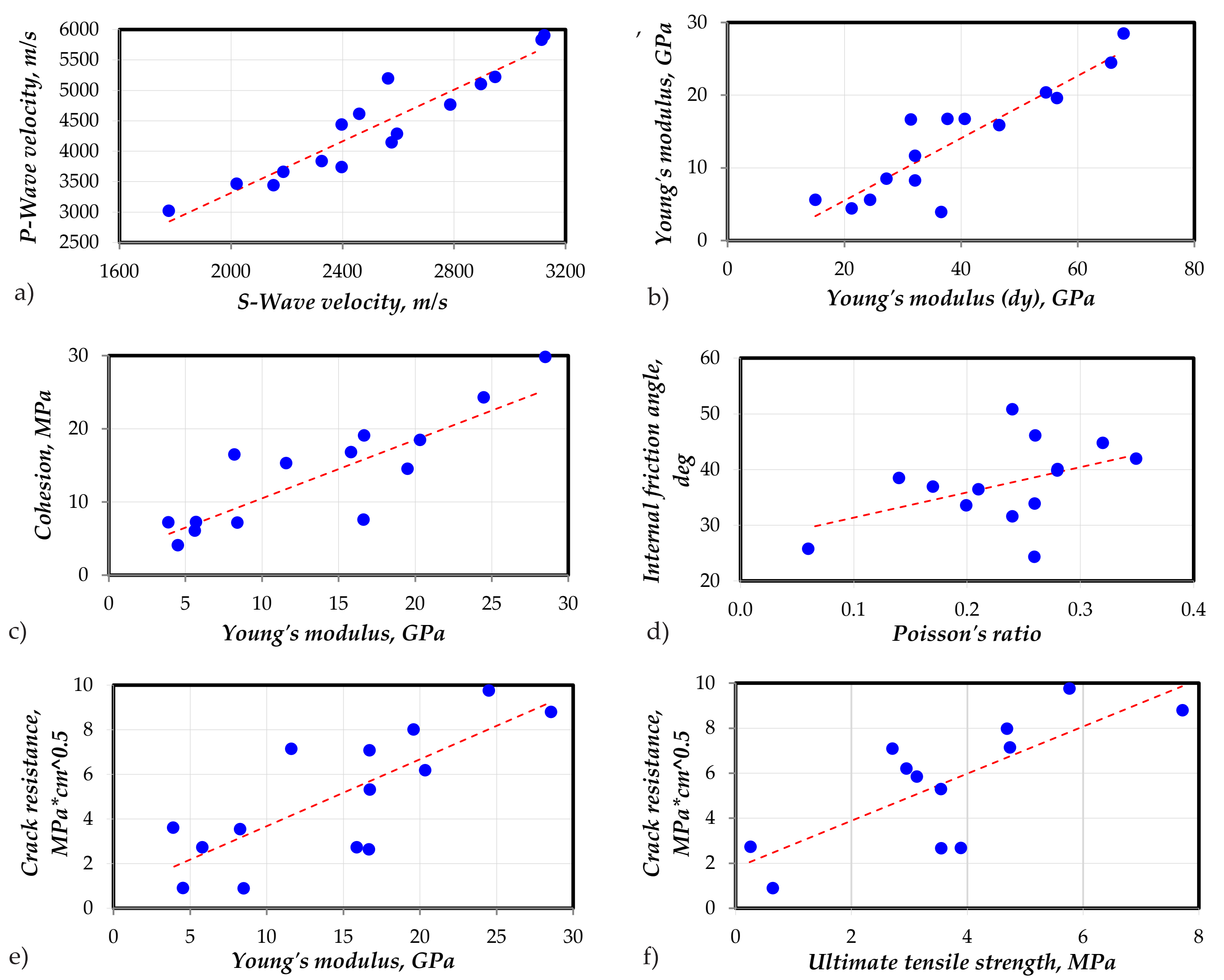

Fig.3. Relationships established based on the geomechanical study results

The following relationships were established: 1) between *P*- and *S*-wave velocities (V_p and V_s); 2) between dynamic (E_{dyn}) and static (E_{stat}) Young's modulus; 3) between static Young's modulus and cohesion; 4) between static Poisson's ratio (μ_{st}) and the angle of internal friction (Φ_i); 5) between Young's static modulus and fracture toughness (K^{IC}), between fracture resistance and tensile strength (σ_t) (fig.3).

The equations for these relationships are presented below:

1) V_p=2.1335*V_s-980.25
2) E_{stat}=0.4301*E_{dyn}-3.0926
3) Cohesion=0.799*E_{stat}+2.4058
4) Φ_i=45.369*μ_{st}+26.783
5) K^{IC}=0.3007*E_{stat}+0.6202
6) K^{IC}=1.0561*σ_t+1.6858

Conclusion

This study resulted in a set of data on geomechanical and elastic properties of the rocks that compose the lower part of the Middle Carboniferous section of the Ivinskoye oilfield. Relationships between various elastic parameters were also established. The distribution of geomechanical properties correlates with structural/textural features of the rocks under study and their lithological type. This information can be used as a basis for geomechanical modeling and in preparation for hydraulic fracturing.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation under agreement No. 075-15-2020-931 within the framework of the development program for a world-class Research Center «Efficient development of the global liquid hydrocarbon reserves».

The paper presented at the International Scientific and Practical Conference «The Decision of EU about Decarbonization and a New Paradigm of Developments Fuel and Energy Complex Russian Federation» in section «Rational development of the planet's liquid hydrocarbon reserves», Kazan, Russin Federation, 31 August - 01 September 2021.

References

1. Zoback, M. D. (2007). Reservoir geomechanics. *Cambridge: Cambridge University Press*.

2. Mavko, G., Mukerji, T., Dvorkin, J. (2009). The rock physics handbook. *Cambridge University Press*.

3. ASTM D2845-08. (2008). Standard test method for laboratory determination of pulse velocities and ultrasonic elastic constants of rock (Withdrawn 2017). PA, *West Conshohocken: ASTM International*. www.astm.org

4. ASTM D3967-08. (2008). Standard test method for splitting tensile strength of intact rock core specimens. PA, *West Conshohocken: ASTM International*. www.astm.org

5. ASTM D7012-14. (2014) Standard test methods for compressive strength and elastic moduli of intact rock core specimens under varying states of stress and temperatures. , PA, *West Conshohocken: ASTM International*. www.astm.org

6. (2015). The ISRM suggested methods for rock characterization, testing and monitoring: 2007–2014 / ed. Ulusay, R. *Switzerland: Springer International Publishing*.

Изучение геомеханических свойств карбонатных пород коллекторов и покрышек среднего карбона Ивинского месторождения

В.Е. Косарев[1], Э.Р. Зиганшин[1], И.П. Новиков[2], А.Н. Даутов[1], Е.А. Ячменева[1], Е.С. Быстров[1]
[1]Казанский (Приволжский) федеральный университет, Казань, Россия
[2]АО «Татнефтепром», Казань, Россия

Реферат

Лабораторные исследования геомеханических свойств горных пород являются важной и неотъемлемой частью построения геомеханической модели. В результате исследования был получен набор данных о геомеханических и упругих свойствах пород, слагающих нижнюю часть среднего карбона Ивинского месторождения (Россия). Установлены также взаимосвязи между различными упругими параметрами. Распределение геомеханических свойств коррелирует со структурными / текстурными особенностями изучаемых пород и их литологическим типом. Эта информация может быть использована в качестве основы для геомеханического моделирования и при подготовке к гидроразрыву пласта.

Ключевые слова: геомеханика, упругие свойства, карбонатная порода, лабораторные исследования керна.

İvinsk yatağının Orta Karbon dövrünün karbonatlı kollektor süxurlarının və örtüklərinin geomexaniki xassələrinin öyrənilməsi

V.E. Kosarev[1], E.R. Ziqanşin[1], İ.P. Novikov[2], A.N. Dautov[1], E.A. Yaçmeneva[1], E.S. Bıstrov[1]
[1]Kazan (Privoljsk) Federal Universiteti, Kazan, Rusiya
[2]«Tatnefteprom» SC, Kazan, Rusiya

Xülasə

Dağ süxurlarının geomexaniki xassələrinin laboratoriya tədqiqatları geomexaniki modelin qurulmasının mühüm və ayrılmaz hissəsidir. Tədqiqat nəticəsində İvinsk yatağının (Rusiya) Orta Karbon dövrünün aşağı hissəsini təşkil edən süxurlarının geomexaniki və elastiki xassələri haqqında məlumatlar toplusu əldə edilmişdir. Həmçinin müxtəlif elastik parametrlər arasında qarşılıqlı əlaqələr təyin olunmuşdur. Geomexaniki xassələrin paylanması tədqiq olunan süxurların struktur/tekstura xüsusiyyətləri və onların litoloji tipi ilə əlaqələnir. Bu məlumat geomexaniki modelləşdirmə və layın hidravlik yarılmaya hazırlanması zamanı əsas kimi istifadə edilə bilər.

Açar sözlər: geomexanika; elastik xassələr; karbonatlı süxurlar; kernin laborator tədqiqatı.