Geomechanical parameters of sedimentary rocks of Southern Sakhalin

P A Kamenev\(^1\), L M Bogomolov\(^1\), O M Usoltseva\(^2\), P A Tsoi\(^2,3\) and V N Semenov\(^2\)

\(^1\)Institute of Marine Geology and Geophysics Far Eastern Branch of the Russian Academy of Sciences, Yuzhno-Sakhalinsk, 693022, Russia
\(^2\)Chinakal Institute of Mining of the Siberian Branch of the Russian Academy of Sciences, 54, Krasny ave., Novosibirsk 630091, Russia
\(^3\)Novosibirsk State Technical University, 20, K. Marksa ave., Novosibirsk 630073, Russia

E-mail: *p.kamenev@imgg.ru

Abstract. The samples of terrigenous rocks of the Sakhalin were selected for geomechanical studies: the rocks of the Nevelskaya and Kholmskaya Formations from the Petropavlovsk quarry; ones of the Kholmskaya Formation on the west coast of the south of Sakhalin, rocks of the Junonskaya Formation on the east coast. The Kholmskaya Formation N_1 hl is represented by siltstones and interlayers of fine-grained sandstone. The Nevelskaya Formation N_1 nv is represented by siltstones with inclusions of tufogenic material. The Junonskaya Formation T_2 Jun is represented by variegated greyish-green jaspers. Their static and dynamic parameters (strength limits, static Young's modulus and Poisson's ratio, cohesion and angle of internal friction) were determined. The obtained results are characterized by a significant spread of values, which is likely explained by the significant fracturing of the initial samples and the effect of anisotropy.

1. Introduction

The development and exploitation of hydrocarbon fields, in conditions of high tectonic activity, in most cases are accompanied by the study of the geomechanical properties of the drilled rocks [1, 2]. For the selection and optimization of the bit, it is extremely important to know the values of the uniaxial compression strength of rocks. The Poisson's ratio values, the angle of internal friction, and cohesion are necessary to calculate the optimal density of the drilling mud. Moreover, all these parameters must be known before the construction of the well. Thus, the importance of the mechanical properties of rocks is obvious, but a researcher or an engineer addressing such problems faces significant problems. There are no regional geomechanical databases, it is impossible to find a drill sample for the laboratory tests, the drilling core sampling is expensive. As a result, there are very few regional works in this direction. The recent work [3] involving similar studies of the Daginskaya Formation may confirm this state of the art. Actually, core material studied in [3] was too limited. In such situations, sampling rocks is done from outcrops located near the site of interest or from a locally outcropping stratigraphic unit. Another approach to the study of the mechanical properties of rocks is the use of empirical relations obtained based on the logging data or directly from the data of modern acoustic logging [4]. This work aims to continue studying the mechanical properties of sedimentary rocks of the south of Sakhalin by laboratory methods. Taking into account
the development of modern laboratory equipment, the needs of oil and gas production, the
development of the construction industry and infrastructure, it is reasonable to continue these works
in order to clarify the geomechanical parameters of sedimentary rocks of southern Sakhalin. This
work can be considered as a continuation of [4, 5].

2. Main results
At the initial stage of the study, we selected rock samples of the Nevelskaya and Kholmskaya
Formations from the Petropavlovsk quarry located a few dozen kilometers from Yuzhno-Sakhalinsk.
The next stage of the study was sampling on the east and west coast of the south of Sakhalin (figure
1).

![Figure 1](image.png)

**Figure 1.** The map of Sakhalin Island with indication of sampling locations.

The samples on the east coast were collected in the Korsakovsky district at Cape Ptichiy. The series
is represented by variegated greyish-green jaspers, which are fractured. The cracks in samples are
healed mostly with calcite or hardened siliceous-clay rocks of the Junonskaya T2-Jjun Formation. The
rock samples on the west coast were taken in the Nevelsky district, 3 kilometers north of the village of
Shebunino. The series is represented by strong, from light grey to grey, sometimes bleached with a
yellowish tinge by siltstones of the Kholmskaya Formation N1hl with layers of fine-grained sandstone.
Strong, from light grey to grey sandstones of the Kholmskaya Formation N1hl, from fine-grained to
course-grained, with inclusions of tuff material. The Kholmskaya and Nevelskaya Formations
deposited mainly on the southwestern coast of Sakhalin and the adjacent shelf. The northern border of
the formations can be traced along the southeastern shore of Sakhalin, in the southern part of the
Poronaisky district. The deposits of the Kholmskaya Formation N1hl nearby the Petropavlovsk quarry
are divided into three bundles [6]. The lower one is represented by sandstones, tuffs and tuffstones;
tuffaceous siltstones, siltstones and claystones are less common. The middle pack includes
overlapping tuffs, sandstones, siltstones, claystones, tuffaceous siltstones. The upper pack is mainly
tuffaceous siltstones and siltstone with rare interlayers of tuffstones, tuffs, sandstones and tuffites.
Sandstones are mainly volcanics, glauconite is often found in them. Siltstones are from dark grey to black in color, often fractured, with abundant inclusions of claystones, sandstones and tuffs. The Nevelskaya Formation $N_{nv}$ is divided into lower and upper sub-formations. The lower sub-formation is represented by a flysch interlayer of siltstones, tuffstones, sandy tuffites, claystones. The Verkhnevelskaya Sub-Formation is composed of finer-grained rocks containing in large quantities the remains of diatoms, up to the transition of rocks into tufodiatomites and diatomites. The sandstones of the Nevelskaya Formation are mainly volcanics or represented by tuffstones. Geomechanical parameters (uniaxial compression strength (UCS), static Young's modulus and Poisson's ratio, cohesion and internal friction angles) were determined using an INSTRON 8802 testing machine, a radial confining pressure chamber, strain gauges for measuring axial and radial deformations by INSTRON. The methodology for rock samples testing is described in [7]. Moreover, the propagation velocities of elastic compressional and shear waves were measured using an ultrasonic control and measuring device Pundit Lab. Laboratory density studies were carried out by weighing samples of standard sizes (cylinders 60 by 30 mm and 30 by 30 mm) shown in figure 2. The measurements of density and elastic wave velocities allowed determination of dynamic values of Young's moduli, $E_{din}$, and Poisson's ratios, $\nu_{din}$ [4, 5].

![Figure 2](image.png)

The deformation and strength properties of core samples were studied using the following experiments: uniaxial compression – 13 tests, extension – 20 tests, triaxial compression – 11 tests. During the triaxial compression test, simultaneous loading with axial force and radial pressure was carried out up to a radial confining pressure value of 5 MPa, then with constant radial confining pressure – loading with axial force until destruction (so-called Karman test) in the figure 3. The values of the dynamic ($E_{din}$) and static ($E_{st}$) Young's modulus, Poisson's ratio ($\nu_{din}$) ($\nu_{st}$), uniaxial compressive strength (UCS) were obtained as a result of testing samples of siltstones of the Kholmskaya $N_{hl}$ and Nevelskaya $N_{nv}$ Formations. The values of cohesion $C_0$ and the angle of internal friction $\phi$ were determined as well (Tables 1, 2, 3).

Dynamic tests were performed only for rocks selected in the Petropavlovsk quarry. The tensile strength varies in a wide range from 8.6 to 193 MPa for the same type of rocks of the Kholmskaya and Nevelskaya Formations. In the rock of the Junonskaya Formation, it varies from 3.4 to 63.2 MPa. The static shear modulus is from 2.12 to 25 GPa and 3.5 to 5.9 GPa, respectively.

The static Poisson's ratio is from 0.10 to 0.31, in the case of samples of the Junonskaya Formation – 0.17. The cohesion is from 7 to 13.5 MPa and 7.7 to 7.9 MPa in the Junonskaya Formation. The angle of internal friction is 28.3–58.2 degrees and 47.6–50.5 degrees, respectively. Thus, quite heterogeneous characteristics have been obtained. Such a spread is due to several reasons at once. There are various types of static tests: uniaxial compression, tension and triaxial compression, which results are involved for the comparison. The following reasons significantly affect the mechanical properties: a natural fracturing (latent in the case of core sample), a probable anisotropy of
properties associated with stratification. It should also be noted that rather large variations in the values of static and dynamic properties are available and given in Table 1.

Table 1. Test results of samples of siltstones of the Kholmskaya and Nevelskaya Formations from the Petropavlovsk quarry.

| Sample No | Test type | UCS, MPa | E_st, GPa | v_st | E_din, GPa | v_din | ρ, g/cm³ | C_0, MPa | φ, deg |
|-----------|-----------|----------|-----------|------|------------|-------|----------|----------|--------|
| 1–1       | Triaxial compression 5 MPa | 60.9     | 4.61      | 0.11 | 8.98       | 0.26  | 1.99     | 13.1     | 29.7   |
| 1–2       | Triaxial compression 5 MPa | 91.2     | 9.59      | 0.17 | 43.6       | 0.70  | 8.95     | 22.27    | 33.86  |
| 2         | Uniaxial compression | 18       | 2.12      | 0.15 | 8.27       | 0.24  | 1.97     | 6.93     | 13.5** |
| 3–1       | Uniaxial compression | 73.5     | 10.02     | –     | 35.27      | 0.27  | 2.50     | 20.33    | 24.35  |
| 3–2       | Uniaxial compression | 43.6     | 2.09      | 0.12 | –          | –     | 2.19     | 19.10    | 21.5   |
| 4         | Triaxial compression 5 MPa | 193      | 25.04     | 0.12 | 33.86      | 0.23  | 2.52     | 21.5     | 53.9   |
| 5         | Triaxial compression 5 MPa | 156      | 19.84     | 0.13 | 24.35      | 0.27  | 2.30     | 21.5     | 49     |
| 6         | Uniaxial compression | 89.4     | 12.95     | 0.1  | 22.27      | 0.26  | 2.27     | 26.1     | 28.3   |
| 7         | Uniaxial compression | 54.8     | 11.48     | 0.17 | 20.33      | 0.19  | 2.24     | 7        | 58.2   |
| 8         | Uniaxial compression | 69.6     | 9.05      | 0.1  | 19.10      | 0.24  | 2.19     | –        | –      |

Table 2. Test results of siltstones samples of the Kholmskaya Formation from the western coast.

| Sample No | Test type | UCS, MPa | E_st, GPa | v_st | E_din, GPa | v_din | C_0, MPa | φ, deg |
|-----------|-----------|----------|-----------|------|------------|-------|----------|--------|
| 2–1       | 31.6      | 4.043    | 0.137     | –    | –          | –     | 11.4*    | 41.5*  |
| 2–2       | 53.4      | 6.617    | 0.146     | –    | –          | –     | 13.5**   | 50.2*  |
| 2–3       | 51        | 6.613    | 0.313     | –    | –          | –     | 10.2     | –      |
| avg       | 45.3      | 5.758    | 0.199     | –    | –          | –     | 102.9    | 0.129  |
| 2–4       | 81.7      | 8.895    | 0.164     | –    | –          | –     | 83.1     | 0.137  |
| 2–5       | 5 MPa     | 81.7      | 8.895    | 0.164 | 13.5** | 50.2* |
| avg       | 89.2      | 8.693    | 0.143     | –    | –          | –     | 10.2     | –      |
| 2–7       | 1.02      | –        | –         | –    | –          | –     | 11.1     | –      |
| 2–8       | 9.6       | –        | –         | –    | –          | –     | 9.6      | –      |
| 2–9       | 8.6       | –        | –         | –    | –          | –     | 8.6      | –      |
| avg       | 9.9       | –        | –         | –    | –          | –     | 10.2     | –      |
| 2–10      | 28.2      | 4.257    | 0.165     | –    | –          | –     | 32.6     | 0.152  |
| 2–11      | 23.1      | 2.439    | 0.175     | –    | –          | –     | 75.2     | 0.144  |
| avg       | 28.0      | 3.714    | 0.164     | –    | –          | –     | 75.2     | 0.144  |
| 2–12      | 81.1      | 7.176    | 0.142     | 6.7* | 43.7*     | –     | 74.2     | 0.169  |
| 2–13      | 74.2      | 8.136    | 0.169     | 8.3** | 54.3** | –     | 74.2     | 0.169  |
| avg       | 76.8      | 7.123    | 0.152     | –    | –          | –     | 76.8     | 0.152  |
| 2–14      | 5.8       | –        | –         | –    | –          | –     | 5.8      | –      |
| 2–15      | 6.2       | –        | –         | –    | –          | –     | 6.2      | –      |
| 2–16      | 5.3       | –        | –         | –    | –          | –     | 5.3      | –      |
| avg       | 5.6       | –        | –         | –    | –          | –     | 5.6      | –      |

Notes. *– the envelope is constructed according to the extension and uniaxial compression circles; **– the envelope is constructed according to the extension and triaxial compression circles.
Table 3. Test results of samples of jasper of the Yunonskaya Formation from the eastern coast.

| Sample No | Test type     | UCS, MPa | \( E_{st}, \) GPa | \( C_0, \) MPa | \( \varphi, \) deg |
|-----------|---------------|----------|-------------------|----------------|------------------|
|           | Uniaxial compression |         |                   |               |                  |
| 3–1       | 34.9          | 3.552    | 0.177             | 7.7*          | 47.6*            |
| 3–2       | Triaxial compression 5 MPa | 63.2     | 5.957             | –             | 7.9**            |
| 3–3       | 4.1           | –        | –                 | –             | 50.5**           |
| 3–4       | Extension     | 3.4      | –                 | –             |                  |
| 3–5       | 11.4          | –        | –                 | –             |                  |
| 3–6       | 4.1           | –        | –                 | –             |                  |
| **avg**   | 5.8           | –        | –                 | –             |                  |

Notes. *– the envelope is constructed according to the extension and uniaxial compression circles; **– the envelope is constructed according to the extension and triaxial compression circles.

One can see from the Table 1 that the results of static tests give large dispersion of the values of geomechanical parameters of tested siltstones from the Petropavlovsk quarry. The dispersion static moduli \( E_{st} \) for siltstone samples from the western coast is not so large: there is nearly two – fold difference between maximum and minimum value. The similar difference in \( E_{st} \) values is in the case of Table 3 (samples from the eastern coast). Meanwhile previous data on \( E_{st} \) of Sakhalin siltstones samples gave even higher dispersion (maximum and minimum values were different by order of magnitude or more [8, 9]). So, the mean values of geomechanical parameters in Tables 1–3 seem informative.

3. Discussion and Conclusion

Three series of sedimentary rocks were selected in the western, central, and eastern parts of southern Sakhalin. Studies of the mechanical properties of cores manufactured from the selected rocks have been carried out. Static and dynamic characteristics (strengths, static and dynamic Young's modulus and Poisson's ratio, cohesion, and internal friction angle) have been obtained by methods, which are conventional for high-strength rock. This allowed obtaining the refined data on geomechanical parameters of some sedimentary (but consolidated) rocks. The tests revealed a considerable dispersion of static Young's modulus, cohesion, and internal friction angle. Such dispersion is caused likely by the internal (hidden) fracturing of the tested rocks samples. From methodical viewpoint this dispersion is to signify that «short» sampling of 3 items is not enough to triaxial compression tests of sedimentary rocks like siltstones. Samplings of 5–7 items are necessary to get more confident evaluations. So, presented mean values of geomechanical parameters may be preliminary estimates. Additional experiments are planned to involve tests of similar samples of sediment rocks under various steps of lateral pressure. Also, the anisotropy effect is to be investigated experimentally.

In spite of dispersion the obtained averaged characteristics may be applicable for geomechanical modeling aimed to the construction of wells and their hydraulic fracturing, to slope stability assessments.

Acknowledgements

The authors are grateful to Alexander Shemenda for valuable comments and discussion of the primary results of the work.

The tests have been carried out using the equipment of the Shared Use Center for Geomechanical, Geophysical, and Geodynamic Measurements at the Siberian Branch of the Russian Academy of Sciences.
References

[1] Zoback M D 2007 *Reservoir Geomechanics* (Cambridge: Cambridge University Press) p 505
[2] Dubinya N V 2019 An Overview of Wellbore Methods of Investigating Stress State of the Upper Layers of the Earth’s Crust *Izv. Phys. Solid Earth* **55** pp 311–326
[3] Zhukov V S 2020 Estimating the strength and elasticity of rocks in the Dagi formation on the Sakhalin shelf *MIAB. Mining Inf. Anal. Bull.* **4** pp 44–57
[4] Kamenev P A and Bogomolov L M 2017 Depth distribution of internal friction coefficient and cohesion in sedimentary rocks of Sakhalin island *Geophysical Research* **18** pp 5–19
[5] Kamenev P A, Usoltseva O M, Tsoi P A, Semenov V N and Sivolap B B 2017 Laboratory research of geomechanical parameters of sedimentary rocks massifs in the South Sakhalin. *Geosystems of Transition Zones* **1** pp 30–36
[6] Tyutrin I I and Dunichev V M 1985 Tectonics and petroleum potential of the northwestern part of the Pacific belt (Moscow: Nedra) p 174
[7] Usoltseva O M, Eremenko A A, Shaposhnik Yu N, Tsoi P A and Semenov V N 2019 *IOP Conf. Series: Earth and Environmental Science* Laboratory studies of geomechanical properties of deep-level rocks **262** 012081
[8] Skorikova M F 1970 Elastic properties of rocks of the southern part of Sakhalin and their use in the interpretation of geophysical observations (Moscow: Nauka) p 176
[9] Skorikova M F 1965 Physical properties of Southern Sakhalin rocks *Exploratory geophysics* **7** pp 30–39