Study of Unconventional Reservoirs in the North-East of Sakhalin

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Abstract. According to the results of geological fieldworks in the north-east of Sakhalin Island on the Schmidt Peninsula and in the Pogranichny Depression, Cenozoic outcrops were studied in order to explore the siliceous deposits of the Pilskaya formation. Samples were taken for analytical studies, small structural forms that are indicators of tectonic stress, were studied. It is shown that the fracture intensity depends on the lithology, the position of the observation point relative to disjunctive and/or pli cative structures. A sharp nonuniformity of the stress field in the vicinity of the Pogranichny Depression is noted, reflected in the nature of the bedding planes, structural discontinuities and parageneses.

1. Introduction

Currently, due to the exhaustion of the fund of large oil and gas fields with a traditional (pore) type of reservoir, deposits with a so-called unconventional reservoir are becoming increasingly important. Such reservoirs include, in particular, fractured reservoirs of siliceous rocks with almost zero matrix permeability, where the determining factor of the quality of the collector is its fracturing. To effectively predict the spread of fracture zones during geological exploration and hydraulic fracturing design, it is necessary to study the patterns of stress distribution and the associated initial fracturing of the research area. This, in turn, entails the study of the structural forms of deposits available for study on the daytime surface.

In 2020, on the Schmidt Peninsula and in the Pogranichny Depression of Sakhalin Island (Figure 1), the LLC “RN-SakhalinNIPImorneft” together with the Schmidt Institute of Earth Physics of the Russian Academy of Sciences (IEF RAS) and the Institute of Marine Geology and Geophysics of the Far Eastern Branch of the Russian Academy of Sciences (IMGG FEB RAS) conducted geological fieldworks to study siliceous deposits of the Pilskaya and Pilengskaya formations to develop a methodology for locating oil deposits in fractured reservoirs. The objectives of the study included: the study of natural outcrops of Cenozoic sediments and the collection of samples for analytical studies (geomechanical, geochemical, lithological), the study of small structural forms (folds, minor faults, slickensides, tension gashes, joints, shear fractures), which are indicators of tectonic deformations of the rock massive; then the draw of fracture diagrams based on methods of structural geology and tectonophysics, inversion of the stress-strain state.
This article focuses on the regional geodynamics and structural geology of the Schmidt Peninsula and the Pogranichny Depression based on the results of two expeditions.

2. Results

In the area of the Schmidt Peninsula, the entire Cenozoic section is represented by siliceous and silica-containing rocks with a decrease in the silica content from Oligocene recrystallized gauze of the Tumskaya Formation (P_{tm}) to diatomites of the Upper Miocene-Pliocene Mayamrafskaya Formation (N_{2}mm) and terrigenous lignite-bearing deposits of the Upper Pliocene Pomyrskaya Formation (N_{2}pm) [2]. For the eastern coast of the Schmidt Peninsula, the main discontinuous structures of the study area are the Kheytonskiy and Longriskiy faults, which, according to [3], have right-thrust kinematics at the present stage.

During the fieldwork, we encountered an extreme heterogeneity of the structure of the Pilskaya formation, associated primarily with tectonic deformations in the Kheyton section. For example, in the fault zone (Figure 2), the hanging wall is very intensively crumpled into small folds and crushed. The nature of folding in the hanging wall indicates a strong compression: the folds are multidirectional, have small dimensions (up to 1 m), the walls are wavy, the rock layers in the core often diverge, in

Figure 1. Overview scheme of Sakhalin Island with highlighted study areas according to [1].
places there are crushing zones. The footwall has high dip angle, but the beds are practically not broken and slightly fractured.

![Image](image_url)

**Figure 2.** Rock deformation in the walls of a fault. Schmidt Peninsula, East coast, Kheyton section.

Field observations also showed that the zone of intense dislocations has an extremely insignificant thickness – as a rule, the first tens of meters.

Another feature confirmed by field observations: the intensity of fracturing depends on the position of the observation point relative to the structural elements of the fold. For example, the most intense fracturing is observed in the axial plane of the fold, along the fold axis. Here, under compression conditions, small, multidirectional, closed joints are formed, in some places - local zones of rock crushing. Fan-shaped open folds are formed in the hinge, the frequency of which decreases from the hinge line of the fold to the limbs. Thus, the prevailing direction of cracks, the intensity and the character of fracturing strongly depends on the position relative to the structural elements of the fold (up to 180°) (Figure 3). The foundation of the Pogranichny Depression is composed of Upper Cretaceous sediments, they are represented by stratified beds with thick olistostrom horizons and tectonogenic complexes in the form of linear zones of polymictic melange, which are characterized by a complex scaly-thrust type of dislocations. The Cenozoic deposits belong to the Eocene carboniferous molasse (the Lukaminskaya formation), which is replaced up the section by the gaize and siliceous-clay formations of the marginal inter-arc basin, the Pilengskaya ПPG and the Borskaya Бр formations. These features of the structure of the Pogranichny Depression caused large differences in the strength, direction and time of the impact of tectonic stresses on various blocks of the foundation and sedimentary cover. The strength, direction and time of the impact of compressive and tensile stresses on various blocks of the foundation and sedimentary cover were different. Therefore, in neighboring blocks, even small in size (the first hundreds of meters), the bedding planes, the character and intensity of fracturing (Figure 4), and with significant movements, the lithology often radically differ. This is reflected, in particular, in the nature of the distribution of the stress field in the vicinity of the Pogranichny Depression.

If the geodynamic regime of sublatitudinal compression is most characteristic for the stressed state of the entire Sakhalin [4]. According to recent regional seismological studies, a regime of subhorizontal compression stress of the NE-SW direction is observed in the central part of Sakhalin [5]. Then in the area of 50°N, closer to the Okhotsk sea coast, judging by the earthquake focal mechanisms, the orientations of the compression and stretching axes radically change. A sublatitudinal compression is observed closer to the center of the island, and a submeridional compression is already observed to the east. In addition, according to seismological data, the regime of submeridional stretching is also noted on the coast for this research area. This character of the stress field change is inherent in a rather limited area on the island scale, approximately 0.5° × 0.5°.
Figure 3. Change in intensity and direction of fracturing within a local fold. The Kheyton cross-section of the Schmidt Peninsula.

Consider by the geological and geophysical signs, there is a pronounced anomaly of the stress field in this area. In geological terms, this, in particular, is manifested in a sharp change in the stratification from almost horizontal to subvertical (Figure 4). Such a sharp contrast can be observed on a scale of several hundred meters. The most intense tectonic activity of the Pogranichny Depression under conditions of powerful compression was occur at the border of the Mesozoic and Cenozoic [6]. The result of this activity was the creation of thick olistostrom horizons in the Berezovskaya Formation (K2br) and the Rakitinsky tectonogenic complex (mpsP1,2r). The predominance of the transtensional regime of the Pogranichny Depression since the Eocene is confirmed by the structure of the Cenozoic section in the area of the river Huzi, where the sub-vertical bedding of rocks of the Pilena formation is combined with the almost complete absence of small plicative deformations and fracturing. In the northern part of the Depression, in the lower current of the Kerosinnaya River, for 600 m in the sides and bottom of the canyon, there are numerous debiting oil seeps associated with open fracturing, which obviously indicates the stretching regime that continues to this day. Some blocks of the Cenozoic cover (for example, the block in the area of the Pilenga River) practically did not involve tectonic impact, as evidenced by the flat elements of the occurrence and an insignificant number of joints and slickensides. Under these conditions, the intensity of fracturing depends primarily on the lithology. This dependence is especially clearly observed in the upper part of the Pilskaya Formation, where a purely siliceous section turns into a siliceous-clay one (Figure 5). The structure of measurements of slickensides is dominated by normal faults, less often by strike-slip faults kinematic types, which is quite consistent with the results of works on regional tectonics by other authors. The
sharp heterogeneity of the stress field, reflected in the nature of the bedding planes, structural dislocations and parageneses, indicates the need for additional study of this area.

**Figure 4.** Pogranichny Depression, Berezovskaya formation (K_br). Subvertical bedding zone, crumpling zone and fault zone (marked in red).

**Figure 5.** Pogranichny Depression, Pilenga formation. Low angle dip of strata. The joints density is higher in the upper part with more siliceous bed.
3. Conclusion
Field observations have shown that the zone of intense dislocations has, as a rule, an extremely insignificant area – the first tens of meters. A sharp inhomogeneity of the stress field in the places of the Pogranichny Depression and the Schmidt peninsula is noted, reflected in the nature of the bedding planes, structural discontinuities and parageneses. This fact indicates the need for additional study of the areas. In the lower current of the Kerosinnaya River, oil seeps were noted, indicating a probable stretching regime. The intensity of fracturing of Cenozoic sediments in the study areas strongly depends on the lithology, the distance of the point relative to the fault and on the axis of the plicative structures. The direction of joints varies depending on the position relative to the elements of local folds and on the position of the block (with a small-block structure). The conducted studies show that structural analysis in areas with such a complex and intensive history of tectonic development as active continental margins is extremely necessary to obtain high-quality geological information. Such data are very relevant both for fundamental research in tectonophysics and structural geology, as well as applied research in order to study in more detail unconventional types of reservoirs, in particular fractured ones.

4. References
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