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# On the Relationship of an Active Fault Seismicity with the Gas Production Dynamics by Example of the Aniva Gas Fields on Sakhalin Island

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**Abstract.** On the example of the Aniva gas fields, Sakhalin island located in the immediate vicinity of the active Central Sakhalin Fault, the dependences of the seismicity level on the gas production rate are shown. The distribution of earthquake epicenters is usually confined to the boundaries of the developed fields. While the areas of the fields themselves remain almost aseismic. The main contribution to the level of local seismicity is made by the regional Central Sakhalin Fault and its impact zone structures. It is noted that during the entire production time, there was no significant earthquake in their vicinity that would have caused damage to the social infrastructure. However, the obvious correlation between the production dynamics and seismic activity makes it necessary to further study and monitor the seismicity in the fields area.

## 1. Introduction

Sakhalin Island is one of the oldest oil and gas producing regions in Russia. And Sakhalin is characterized by a high level of seismicity, which is due to the interaction of lithospheric plates, the boundaries of which are drawn directly along the island itself [1]. With rising in the anthropogenic impact on the environment associated with the extraction of natural resources, a number of authors note an increase in the level of technogenic-induced seismicity [2]. In some cases, we are talking about a negative impact leading to man-made accidents [3]. On Sakhalin, the main attention of researchers is drawn to the development of offshore projects. Most of the oil and gas fields are located in the north-east of the island, while most of the inhabitants live in its southern part. Moreover, it should be noted that the most populated territories are located in the vicinity of the active Central Sakhalin Fault (CSF). The strongest earthquakes in the zone of the southern segment of this fault are as follows (from south to north): Krillonskoe 1911, 1912, 1921 years ( $M = 4.7-5.1$ ); Anivskiye 1951 ( $M = 5.5$ ) and 1964 ( $M = 5.0$ ); Perevalsko-Sinegorskiye 1923 and 1924 years. ( $M = 4.5-4.8$ ); Perevalskoe 1949 ( $M = 5.2$ ) and Naibinskoye in 1928 ( $M = 4.9$ ), Takoyskoye in 2001 ( $M = 5.2$ ). Their epicenters are confined mainly to the areas where the Central Sakhalin Fault intersects with the minor faults. From this example, it follows that the fault is able to generate sufficiently strong earthquakes that can pose a threat to both the population and infrastructure.

In the south of Sakhalin, the Aniva gas fields (AGF) are currently being actively developed, located in the fault impact zone folds of the southern part of the CSF. The location of the fields in the zone of the fault itself can serve as a trigger for the occurrence of a strong seismic event. Exploration phase on



the field began in 1969, and production – in 1997. Currently, intensive production continues at the AGF, which contributes to their depletion, this is reflected both in the drops in well production rates, and, probably, in the induced seismicity. Thus, AGF monitoring is a promising and interesting task in the framework of observations of the geodynamic activity of the southern segment of the CSF. This article is devoted to the study of seismicity in the area of the Aniva fields and the study of possible technogenic-induced seismicity.

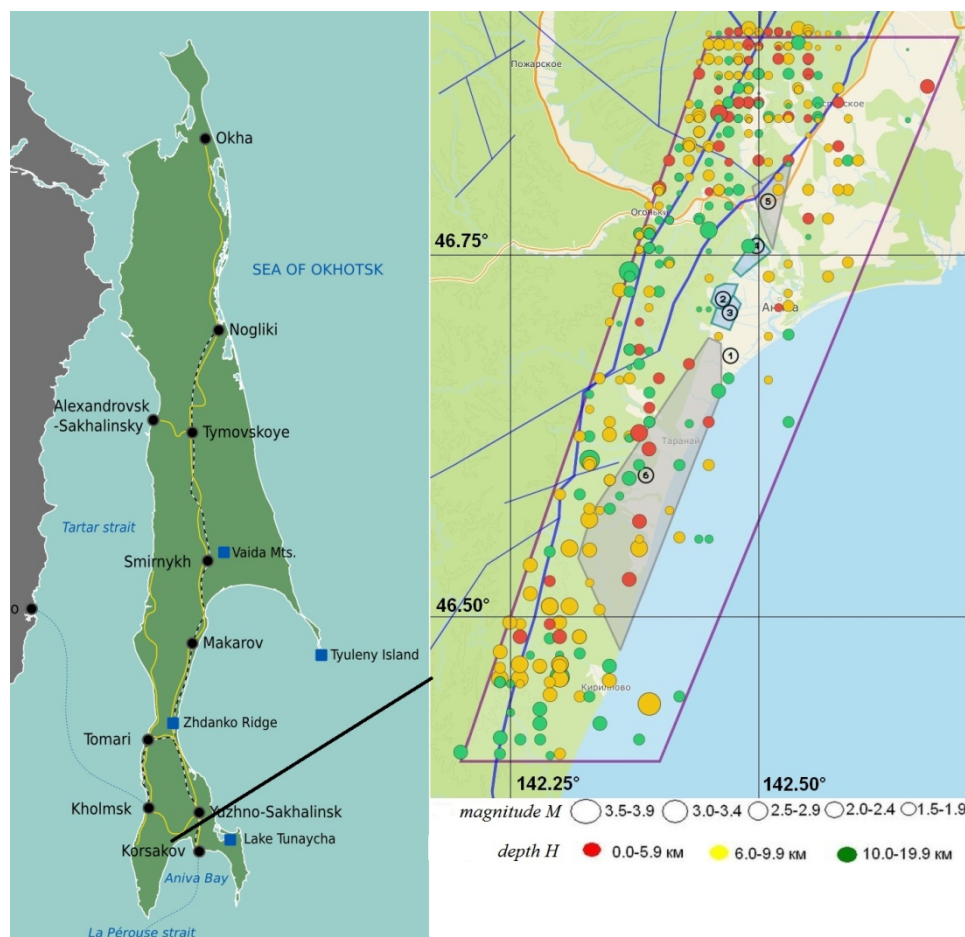
## 2. Results

The Aniva gas fields are confined to the trough of the Aniva Bay and are represented by Upper Miocene-Pliocene terrigenous rocks. The tectonic structure of this part is determined by the southern end of the CSF and includes the Aniva zone of the fault impact folding. It is a system of longitudinal thrusts with the western dip, complicated by minor faults [4]. The Maruyama formation  $N_{1-2}mr$ , which is productive, as well as the Kholmskaya, Nevelskaya and Kurasiyskaya formations  $N_{1kr}$ , were discovered by the wells of the field. The deposits of the Maruyama formation  $N_{1-2}mr$  are located in the coastal zone of the Aniva district [5]. In the southern part of the Aniva district (south of the village of Taranai), the formation are traced along the coastal zone in a 5-6 km strip. In the northern part of the Aniva district – on the western side of the Susunai lowland. The northern border of the Maruyama formation extends to the Makarovsky district and the adjacent shelf. Detailed characteristics of this formation are given in [5]. The formation is composed mainly of siltstones, less often sandstones in its lower part; and sandstones and gravelites with lignite interlayers in its upper part. The Kholmskaya and Nevelskaya formations occur mainly on the southwestern coast of Sakhalin and the adjacent shelf. The northern boundary of the formations is traced along the south-eastern shore of Sakhalin, in the southern part of the Poronai district. The deposits of the Kholmskaya formation  $N_{1hl}$  at the Anivskoye field are divided into three formation member [4]. The lower formation member is represented by sandstones, tuffs, and tuff sandstones. Less common are tuff-siltstones, siltstones, and claystones. The middle formation member includes interbedded tuffs, sandstones, siltstones, claystones, and tuff-siltstones. The upper formation member is mainly tuff-siltstones and claystone with rare interbeds of tuff sandstones, tuffs, sandstones, and tuffites. The sandstones are mainly volcanosedimentary, and glauconite is often found in them. Siltstones are dark gray to black in color, often fractured with abundant inclusions of claystones, sandstones, and tuffs. Marl nodules with fauna are often present. The Nevelskaya formation  $N_{1nv}$  is subdivided into the lower and upper sub-formations. The lower sub-formation is represented by a flysch interlayer of siltstones of tuff sandstones, sandy tuff, and claystones. The Upper Nevelskaya sub-formation is composed of finer-grained rocks containing large amounts of the remains of diatoms before the transition of the rocks to tuff-diatomaceous and diatomaceous rocks. The sandstones of the Nevelskaya Formation are mainly volcanosedimentary or represented by tuff sandstones and have a sandy structure. Roundness of grains of class 0-3 with a characteristic poor sorting of grains by dimension. Siltstones with cement of opal-hydrosludic-kaolin composition. Tuffs are mainly sandy.

One of the ways to assess the stress-strain state of the environment in the vicinity of the field and, as a consequence, its seismicity, is computer modeling [6]. Similar studies are also being conducted for the southern segment of the CSF [7]. At the moment, the previously constructed model with a larger scale is being detailed for the vicinity of the Aniva gas fields. Another area of research is the observation of seismicity in the area of these fields.

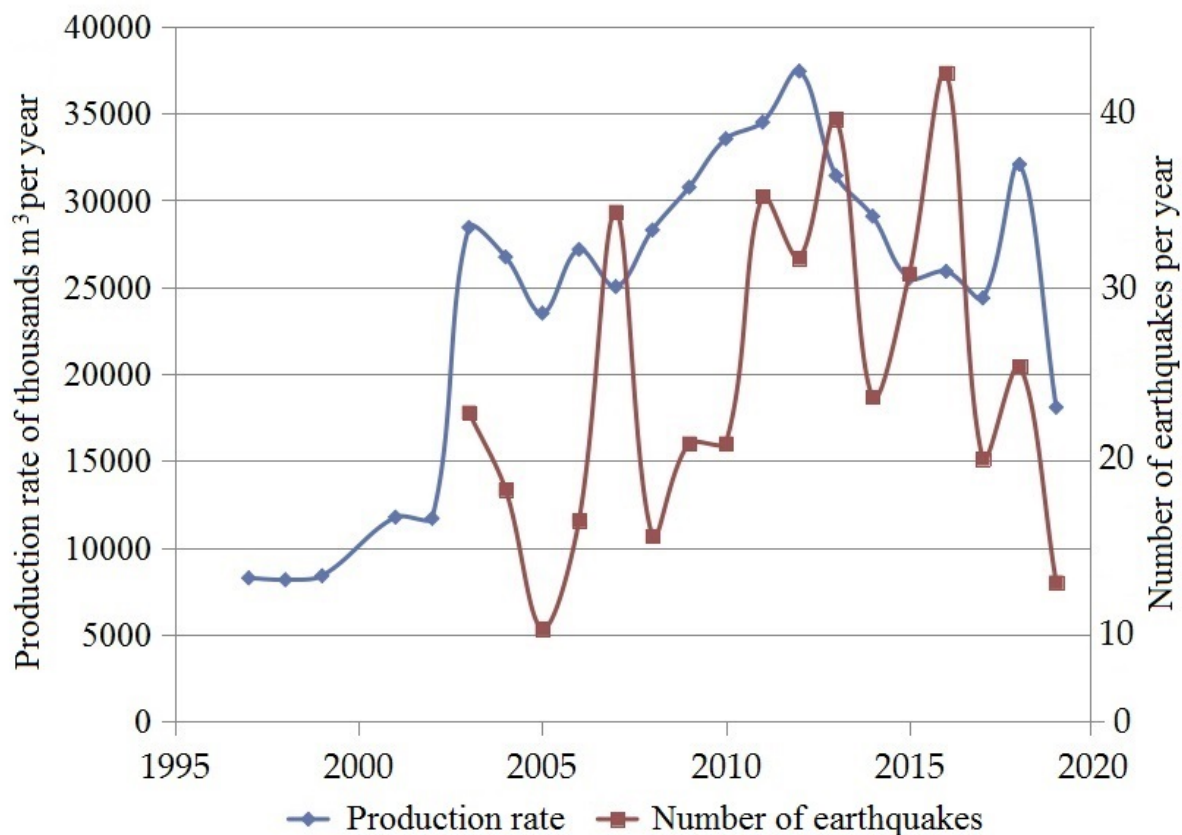
A map of the earthquakes distribution in the vicinity of the AGF in the period from 2003 to 2018 was constructed on the basis of the earthquake catalogues of the Sakhalin Branch Geophysical Survey Russian Academy of Sciences (SB GS RAS) [8]. This time interval coincides with the most intensive phase of the fields production. It follows from figure 2 that in the area of the developed AGF structures (blocks 1, 2, 3, 4) for 15 years in the period from 2003 to 2018, earthquakes were practically not observed. Although the largest number of earthquakes is associated with the CSF, nevertheless, a much larger number of events were recorded at the northern and southern boundaries of the fields, at the same distance from the fault as in the case of blocks 1, 2, 3 and 4. Blocks 1, 2, 3, and 4 are

brownfields these have been developed for a long time. Apparently, the production affects the stress-strain state in such a way that the maximum stresses are concentrated at the edges of the structures, which is expressed in a higher level of seismicity at the boundaries of the field, although this level is not as high as directly at the CSF.



**Figure 1.** Aniva gas fields (numbers 1–6) and seismicity of the selected zone in the period from 2003 to 2018. Structures: 1 – Vostochno-Lugovskaya, 2 – Yuzhno-Lugovskaya, 3 – Zolotorybnaya, 4 – Zarechnaya; the most developed. Structures: 5 – Lugovskaya, Petropavlovskaya, 6 – Yuzhno-Taranayskaya and Bachinskaya; are perspective and under developed now. Circles marked seismic events.

To study the effect of gas production on local seismicity, a graph of the distribution of the number of earthquakes from the production rate was constructed. The obtained dependence of gas production in the period from 1997 to 2018 years and local seismicity from 2003 to 2018 years is shown in Figure 2. As you can see from the graph, the level of seismicity correlates quite well with the level of production. Thus, the decline in production from 2003 to 2005 years corresponds to a decrease in the level of seismicity. The gradual increase in the dynamics of production from 2005 to 2012 from 23,496 to 37,427 thous m<sup>3</sup> is also accompanied by an increase in the level of seismicity from 10 to 42 events. In 2012, the production level increased to its maximum level of 37,427 thous m<sup>3</sup>. At the same time, there is a high level of seismicity up to 42 events per year. Then the dynamics of production decreases due to the depletion of the field and the wells reconstruction. The level of seismicity also decreases from 42 events per year to 13.



**Figure 2.** The level of gas production and the number of earthquakes per year for the period from 1997 to 2018 years.

In 2016, the level of production grown compared to the previous year, this corresponds to an increased level of seismic activity to the maximum value, then there is a cycle of falling and raising production, which is accompanied by a corresponding level of seismicity.

### 3. Conclusion

Summing up, it should be noted that during the active operation of the fields, there were no significant seismic events in their surroundings that pose a threat to the population or infrastructure. At the same time, the presented results reflect the correlation between the level of seismicity in the vicinity of the fields and the dynamics of gas production on them. Thus, more detailed and close monitoring of seismic activity in the area of the productive fields is necessary. The existing network of geophysical observations of the SB GS RAS is not able to provide such observations, as it pursues other goals and objectives. To monitor local and technogenically-induced seismicity, it is necessary to deploy a short-period seismic network like [9; 10].

Technically, the implementation of such works is not difficult, since the AGF are located in an area with a developed infrastructure, and with the ability to transmit data in real time. This makes the object of research very attractive, because one of the problems of conducting such work is inaccessibility. Such work was started in IMG FEB RAS [8], but unfortunately, it was curtailed due to lack of funding. If there is interest from the scientific community, industry or government agencies, it will be easy to renew them.

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