Starogroznenskoye field: oil and gas production and seismic activity

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Abstract. Here, we deal with oil deposits development in regions with geodynamic activity. We analyze connection between oil and gas extraction with seismic activity on the example of Starogroznenskoye field, which has been developed for more than a century. We give recommendations on creation of a geodynamic polygon at the development field to control techno-genic seismic activity.

1. Introduction

Seismic activity problem caused by oil deposits development appeared in 1920th, gas deposits development and high pressure water pumping into Earth's crust – in the middle of 1960th. Seismic activity mechanisms at the oil and gas fields include mostly surrounding stress variation, pore or layer pressure change, fluid movement inside the surroundings, peculiarities and degree of applied forces and loads. These mechanisms are interconnected, and often, several mechanisms of seismic activity are possible depending on action peculiarities, geologic structure and rock massif tectonic setting.

During continuous development of carbon deposits layer equilibrium conditions break and it can result in crucial stress distribution in the developed layer and surrounding rocks. Pumped fluid can flow into the cracks and result in excessive pore-crack stress, can act as some kind of lubricant in rock discontinuity zones. These reasons sometimes result in seismic activity induced by production. The literature describes production induced earthquakes at oil and gas production sites in Russia and other countries [1-6]. At the same time there are no concurrent views on the nature of these earthquakes. Chechen Republic area is characterized by high seismic activity, there are numerous factors of strong and medium seismic activities both of tectonic and production caused character. In recent years in some Russian oil deposits regions geodynamic polygons have been created (GDP) to study seismic settings of oil deposits areas. Nowadays creation of such polygons at oil deposits in Chechen Republic is acute as most of the deposits are too close to the cities.

2. Materials and methods

We analyze the problem on the example of Starogroznenskoye field, one of the oldest in Russia. Starogroznenskoye field is 17-20 km to the north-west from Groznyy center, within Groznyy mountain range, stretching towards Sunzhensk mountain range. There are numerous oil deposits in Caragen-Chokrak sand rocks, Upper-Cretaceous oil and oil in Apt deposits. Besides, there is a commercial gas inflow rich in hydrogen sulfide in Valanginian deposits.

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Miocene deposits. In Over-Maikop sedimentary complex thrust breakthrough divides brachy-anticline into two parts: an overthrusting wing and underthrust. In Caragen-Chokrak overthrusting wing deposits at the depth of 0-1200 m there is 21 oil deposits in porous sand collectors. Under thrust stratum is nearly vertical. The deposits are narrow long stripes restricted by longitudal breakthrough at the top and by contour waters below and refer to tectonic traps.

Upper Cretaceous deposits. Upper Cretaceous deposits are connected hydro dynamically with superincumbent foraminiferal deposits collectors, presenting single reservoir with common water-oil surface. Foraminiferal deposits (lower and middle stratum) are composed of thin chalky clays and lime rocks (30 m). Upper Cretaceous productive sediments are represented by lime rocks stratum mostly of grey and dark colors separated by crack system of different direction. Usable storage deposit capacity is conditioned by fracture and micro holes capacity that characterizes this collector as fractured-vuggy reservoir rock. Multimeter stratum of Maikop clay is a cap rock. An average deposit depth is 4100 m.

Early Cretaceous deposits. Within Aptian stage formation is designated at II, III and IV levels. Superjacent Apt and Albian clays are cap rocks. Cover thickness of the II top horizon is 4500 m. The formation is represented by firm fine grained fractured sand stones and siltstones. At Early Cretaceous Deposits there is a branchy-anticline restricted to flat deposit without tectonic fractures. Its size at the elevation is 5100 m of the II Apt layer cap is 4x33 km at the height 1015 m. South wing inclination degree is 65-70º, of the North is 50-55º. Starting position of oil-water surface is at the point 5085 m. Crest reservoir uppermost mark is 4070 m, pool depth (oil saturated layer) is 1015 m. The deposit refers to multi-pay common contact pool. The overall thickness changes from 133 to 180 m, average thickness is 168 m. Overall thickness of highly porous formation changes from 0 to 21.8 m, making in average 10 m.

Caragana-Chockrack deposit. Miocene deposits development of over thrusting wing started in 1893 year. Collectors are porous and permeable sandstones. Reservoir condition was from gravitational to water-driven. All oil saturated stratums of over thrusting wing were developed before 1903 year. In 1945 year commercial oil content of Miocene deposits at periclinal area of Starogroznenskoye field was set – Tashkalinsk region. These deposits were developed by draining depletion with reservoir energy exhaustion till 1949 year. For complete oil recovery and increase of current oil extraction since 1949 year secondary recovery methods were applied in separate layers by water pumping into border zone, hot air into raised croppings, and in separate layers water and air simultaneously. All in all 98 objects at 34 layers were developed using secondary methods with considerable oil reserves but low formation pressure. Volumes of pumped water and air determined well performance efficiency. With recovery methods implementation increase results in incremental oil production. In 1950 year 3.1 thousand tons, in 1955 year – 51.1 thousand tons, and in 1960 year – 136.9 thousand tons were extracted additionally. In consequent years implemented methods efficiency lowered gradually. Due to oil deposits exhaustion, and consequently, increase of injected fluid consumption. Total water consumption at objects in 1985 year changed from 0.3 m^3 per day to 41.6 m^3 per day and air from 1.2 thousands of m^3 per day to 7.5 thousands m^3 per day. Thanks to secondary oil recovery methods at exhausted sites by previous development it became possible to recover additional 216.5 thousand tons of oil and increase oil recovery factor. Thanks to increase of work over programs at producer wells (return at overlying stratum, commingling, insulating works, and oil well stimulation) decline rate slowed down, and at separate stratums current oil production even increased. Caragane-Chokrakskiye oil deposits are at final stage of development and exploited according to the data of 01.01.2006 year mechanically with average oil production rate of 0.38 tons per day. Promising remaining recovery reserves are 2279.0 thousand tons.

Upper Cretaceous Deposits. Since 1964 year a deposit of upper cretaceous carbonaceous rocks, connected with fractured reservoir rocks is developed. The deposit is a tectonically isolated reservoir with local hydro dynamic system. The deposit is characterized by closed-elastic mode. Upper cretaceous oil deposits is at the final development stage and is exploited according to the data of 01.01.2010 year with free flow production method with high watering of the extracted product - 93-97%.

Lower Cretaceous Deposits. These deposits of Starogroznenskoye field is developed since 1973 year. The deposit is developed without action on the productive stratums using natural elastic energy of the oil deposit itself. Well productivity decreased but there were periods of its stabilization and productivity increase in comparison with initial productivity. According to data of 01.01.2010 year recovery oil indexes vary from 0.6 to 11.9 thousand tons per month and well production rate in the range from 19.0 to 385.0 tons per day with extracted product watering up to 2,0 %.

Picture 1 shows the graph parameters dynamic of Starogroznenskoye field development. It shows data on total carbon extraction from all deposits, as well as data on the extracted fluid. This picture shows that maximum oil and gas recovery at the given deposit was at the end of 1960 beginning of 1970 years.

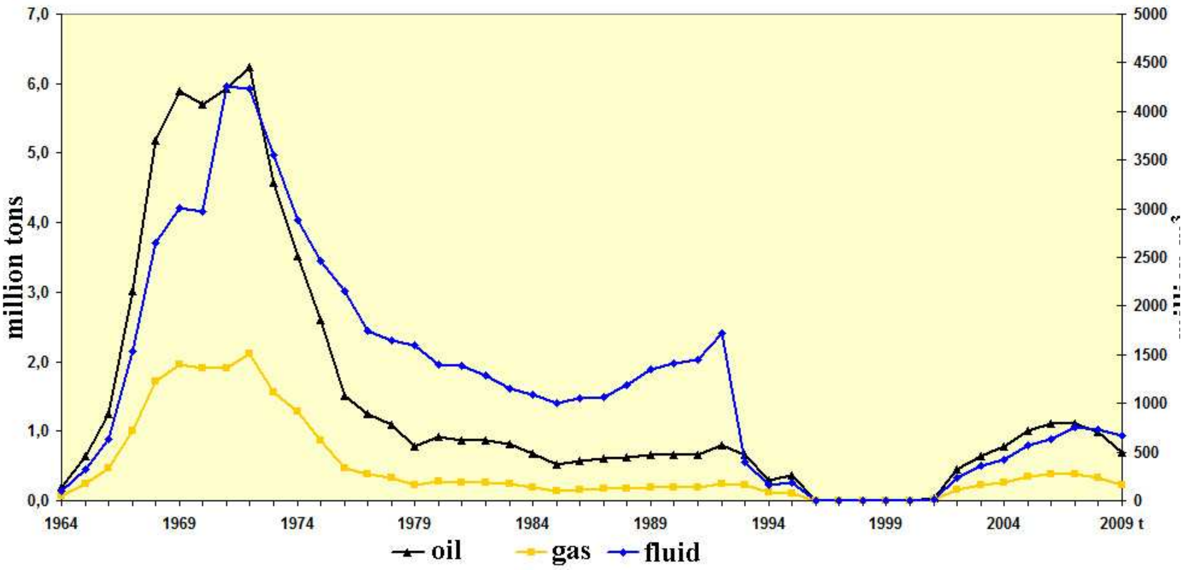

Figure 1. Summary graph of development parameters change at Starogroznenskoye oil and gas field.

Contemporary seismic activity. According to the repeated four time leveling (1973-76 year) some peculiarities are distinguished: Starogroznenskaya structure is highly active rising structure, fractures limit the structure from the north and south outstand by narrow 1-2 km high-gradient zones with amplitude of modern movement from to 4-5 mm/year and size up to 5 mm/year. In size of earth crust displacement at the north slope of the structure the changes are 4-5 mm/year, of the southern – 14-15 mm/year, that is conditioned by unidirectional but with different speeds movement of adjoining blocks from the south and north [7].

Seismic activity. Weak earthquakes at Starogroznenskoye field were frequent, as before the development, as at different period of utilization. Together with weak earthquakes in 1938 year and 1963 year there were significant earthquakes with M=3,8-4,1, caused by different oil deposit development factors. On the 26th of May 1971 there was a strong earthquake with the epicenter at village Neftemaisk, with M=4,3, h=2,8 km, I_0 =7 points, with the destruction of living and industrial buildings. The earthquake in 1971 was caused by sharp pressure decrease, huge oil extraction water pumping into the deposits for intensive extraction. This earthquake caused earth quake swarm, called Groznenskiy swarm. The earthquake swarm started in Neftemaisk, migrated along the width fracture on the north wing of Starogroznenskoye field up to village Ivanovo, then changed its direction and along Benoisk-Eldarovskiy fracture across west edge of Groznyy city the swarp migrated to Octiabrskiy oil deposit. The earthquake in 1971was studied by M.N. Smirnova and N.V. Shebalin. The final recommendation was to slow down oil recovering at this deposit [6]. In consequent years there were significant seismic events at Starogroznenskoye field in 1983, 1989, 2010.

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Picture 2 shows epicenters of earthquakes (period of 1960-2010 years), placed over cap rock structural map of Upper Cretaceous deposits at Starogroznenskoye field and adjacent deposits. This picture shows that earthquake epicenters coincide with fractures and their intersections. Picture 3 shows geological crossections profile across Starogroznenskoye deposit with marked earthquake hypocenters. In this case there is also a connection between hypocenters and fractures; a number of epicenters are within deposits.

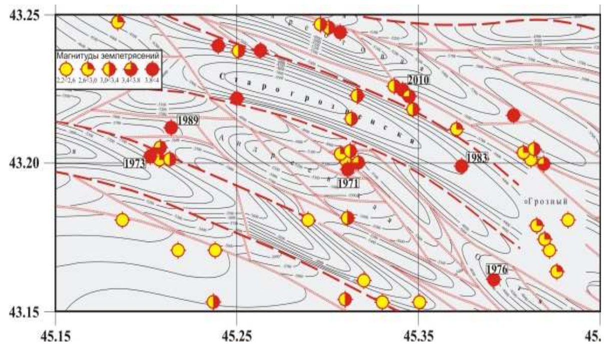

Figure 2. Starogroznenskoye field. Earth quake epicenters map

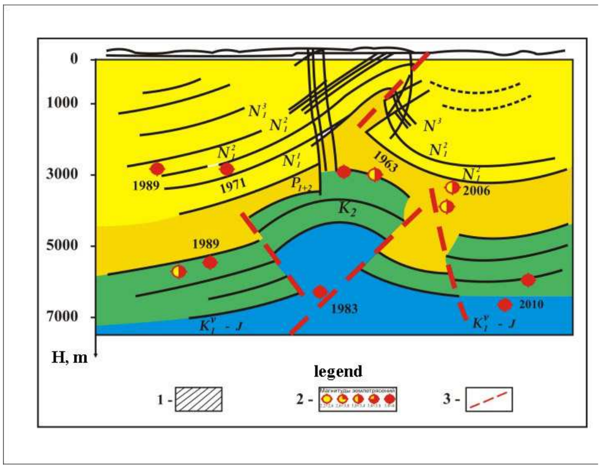

Figure 3. Starogroznenskoye field. Geological section

Following parameters were calculated to analyze seismic activity [2]:

1. Number of earthquakes (N_z) per year (1960-2010).
2. Earth quake intensity logarithm (LgE) energy classes K=9÷12.
3. Benioff graph or nominal strain accumulation graph, showing connection between separate earthquakes intensity and appearing deformation as the result of these earthquakes in supposition that deformations are proportional to energy square root.
4. Seismic activity (A_{10}) according to Riznichenko Yu. V. formula
5. Cumulative oil production

Picture 4 shows the graph of earthquake distribution (N_z) at Starogroznenskoye field during years (1960-2010), picture 5 shows seismic activity changes (A_{10}) at this region during 1960-2010. Picture 6 shows Benioff graph (conditional deformations cumulation graph) during 1960-2010, and picture 7 shows increasing oil recovering at Starogroznenskoye field during this period.

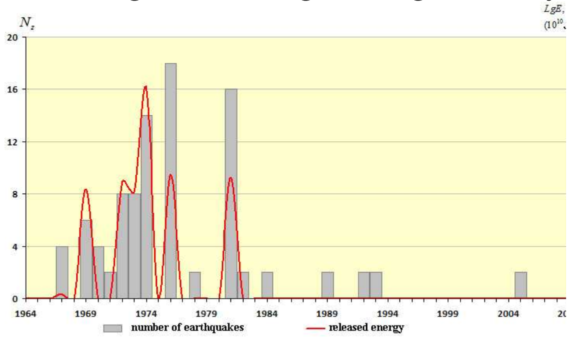

Figure 4. Graph N_z and LgE

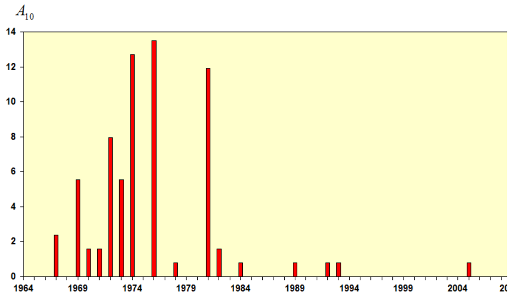

Figure 5. Graph A_{10}

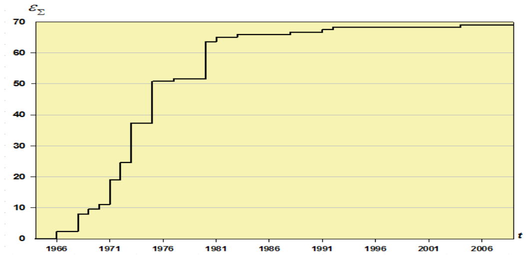

Figure 6. Benioff graph

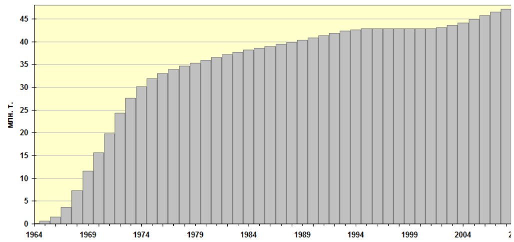

Figure 7. Increasing oil extraction

3. Conclusion

Contour map analysis over Upper Cretaceous cap rock and earthquake epicenters map in Starogroznenskoye field allows drawing a conclusion that seismic activity and fault tectonics in Starogroznenskoye field are interrelated. Geologic profile analysis with earthquakes hypocenters on it proves that the latter are connected with faulting fractures and oil deposit disposition. Connection of seismic activity time course and fluid recovery dynamics, significant calculated creeping speed of reservoir bed rock cap (10-20 mm/year) evidence active development of geodynamic processes. Earthquakes number graph analysis, energy logarithm and seismic activity A_{10} (pic. 4, 5) and comparing it with development data dynamics in Starogroznenskoye oil and gas field (pic.1), evidence that high seismic activity coincides with the period of active development of hydrocarbon deposits at the end of 1960-beginning of 1970. Comparing Benioff graph or nominal strain accumulation graph, (pic. 6) and increasing oil recovery at Starogroznenskoye field graph (pic.7) evidences about high correlation of these processes. It is evident that fluid pumping out is accompanied with vertical disposition of overlying rocks towards the production level, causing Earth crust subsidence. Stratum vertical strains are caused by compression of pumped out deposits, with peak strain in producing formation top, but when the depth is lessened vertical strains die out.

Taking into account the reservoir dome structure and high reservoir pressure, it is anticipated that the reservoir is isolated from the neighboring areas. Such conditions are rather unfavorable when forecasting oil and gas reservoirs production, as due to the full reservoir isolation during mineral deposits recovery there is permanent formation pressure decrease and continuous earth crust subsidence, which in several years of recovery can make meters. The ambiguity can be removed by taking into account geodesic and geophysics investigation data, rock properties specification and fluids and gases saturating the massif, their possible change during massif deformation and deposit recovery.

Thus, complex geological structure, presence of active tectonic faults, significant formation pressure decrease and changes, high seismic activity and positioning of Starogroznenskoye field on densely populated area (Groznyy city and neighboring areas) allow recommending it for creating a geodynamic polygon on its area. The main purpose of geodynamic monitoring is creating analysis system massif rock stressed–deformed state (SDS) influence on the development of negative geological-engineering processes. Geodynamic monitoring at the fields will significantly decrease expenses on emergency consequences relieving as they will be predictable. Investigation complex at geodynamic polygon at oil and gas deposits should include the following activities [4]:

- Plane coordinates measuring and ground altitudes and other datum points using second order leveling data, GPS-dimensions, satellite interferrometry.
- Reservoir stress pattern seismological monitoring in order to specify stress concentration zones and estimate seismic hazard.
- Gravitational field variation measuring.
- Geothermal measurements.
- Field geological-engineering investigation of exogenous geological and hydro geological processes.
- Earth surface crucial subsidence estimation.

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