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SEISMICITY AND THE STRESSED STATE OF THE STAROBIN POTASSIUM SALT DEPOSIT IN BELARUS

Purpose. To carry out the investigations in the the East European Platform southwest with a special emphasize made on the Soligorsk region, where the Starobin deposit of potassium salts of the Late-Devonian age is located. The interest of scientists to just this region is explained by the fact that a swarm of crustal earthquake foci is restricted within this deposit area, which is in marked contrast to other seismic events that are few and far between and rather evenly distributed over the other territory of Belarus. **Methods.** The stressed state was reconstructed for the studied region using methods: seismotectonic method with the use of data of earthquake source mechanisms; tectonophysical method, based on the analysis of geometry of Mesozoic-Cenozoic sedimentary rock fracturing. Changes of the environment stressed state as a result of rock extraction and redistribution served as a mechanism triggering a swarm of earthquakes at Boundaries of rather large tectonic blocks in deep fault zones located within the deposit region. **Results.** A team of the Russian and Belarusian scientists undertook some years ago joint geodynamic investigations for the project entitled “Study of the lithosphere stressed state and seismicity in the East European Platform (EEP) southwest” under financial backing of the Russian and Belarusian Funds of Fundamental Investigations. Some of the results obtained were already reported [Belousov et al., 2006a, 2006b; Aronov et al., 2009]. The investigations was carried out in the western part of East European platform with a special emphasize made on the Soligorsk region, where the Starobin deposit of potassium salts of the Late-Devonian age (D3 fm, Famennian stage) is located. The fact of local seismicity instrumentally recorded in the Starobin deposit region against a total absence of seismic events for several last decades over the most part of Belarus suggests the recent activation of faults in the Soligorsk region. **Scientific novelty and practical significance.** The stressed state of the geological environment caused by the rock extraction and deposition has been continuously changed and can be obviously a reason to suggest the induced nature of earthquakes observed. Seismotectonic deformations in the studied region are found to be well correlated with numerous disjunctive deformations manifested at the most recent stage of evolution. The seismotectonic environment of shear deformation with evidences of submeridional compression and, respectively, sublatitudional extension appears to be typical of the northwestern part of the Pripyat Trough. Beginning from the Late Pleistocene till the present the maximum compressional axis has been oriented NNW, that was determined from the earthquake source mechanisms. The investigations performed showed some evidences of a considerable activation, which had occurred in the deposit region in the Late Cenozoic, when the velocity of vertical movements increased and their direction changed in some faults. Amplitudes of slip in these faults were as high as 30 m and more for the last 25–28 million years.

Key words: seismicity; mechanism of earthquake; tectonics; hazard; monitoring

Introduction

Seismicity of the territory

The interest of scientists to the region under study is explained by the fact that a swarm of crustal earthquake foci is restricted within this deposit area, which is in marked contrast to other seismic events that are few and far between and rather evenly distributed over the other territory of Belarus (Fig. 1).

The territory of Belarus is situated in the west of the ancient East European Platform (EEP), which involves the Baltic and Ukrainian Shields, Russian and Volyn-Azov plates and is rated as a low-magnitude seismic zone according to the seismotectonic zoning. Belarus, the Baltic States and the western regions of Russia comprise the single seismotectonic region described by the similar evolution and common recent geodynamic conditions. The region shows a rather low seismic activity, however, some seismic events with a magnitude $M\leq5.5$ were recorded within its limits [Aizberg et al., 1997; Aizberg et al., 1999; Aronov et al., 2003; Aronova, 2007].

The seismicity of the territory of Belarus has been studied in more details in recent years. In doing so the results of continuous instrumental observations presented in bulletins of seismic stations since 1965 till the present time were used. After analysis and generalization of the data from seismological bulletins and with the revealed historical earthquakes taken into consideration the Catalogue of earthquakes of the territory of Belarus since 1887 till 2012 was compiled.

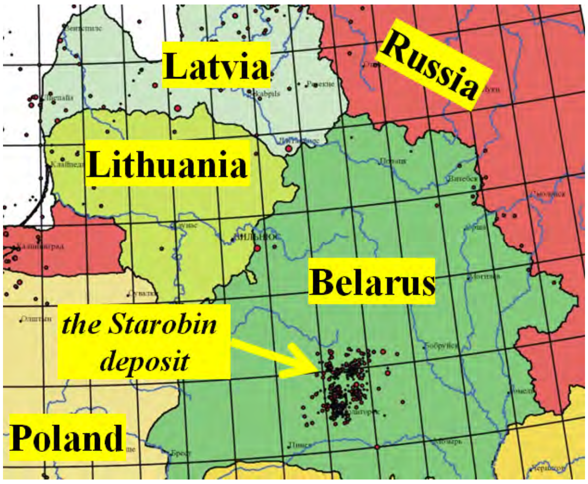

Fig. 1. The seismicity of the western part of the East European Platform

The Catalogue includes 1,327 seismic events with M≤4.5 among which there are four historical earthquakes of 1887, 1893, 1896, 1908. The Catalogue of earthquakes of Belarus since 1887 till 2012 was used as a basis of the Map of epicenters of seismic events of the territory of Belarus. The major part of the Catalogue includes the data of instrumentally recorded events that are presented in the seismological bulletins of the Centre of Geophysical Monitoring of the National Academy of Sciences of Belarus. This Catalogue was compiled to involve all the seismic events with magnitude M≥3.0 without exception beginning from 1965, and those with magnitude M≥1.0 beginning from 1983 for the Soligorsk mining region. The minimum level of earthquake magnitudes was not specially specified, since the estimates are not single-valued and being converted to the MLH magnitude taken as the main one like in «Summary Catalogue of earthquakes of the East European Platform» [Aronov et al., 2007] exhibit an error as great as a unit of magnitude. The unification of magnitude values of relatively small seismic events included in the Catalogue is a very complicated problem, which will be the subject of special investigations in the near future. In this context the Catalogue compiled should be considered as a first, but not final stage of works for solving this problem.

According to division of the western part of EEP into seismotectonic regions, the territory of the Starobin deposit of potassium salts is related to the Pripyat potentially seismic super zone with a magnitude M=4.0 and a focus depth H=5 km [Garetsky et al., 1997].

Purpose

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Methods

The stressed state was reconstructed for the studied region using methods:

seismotectonic method with the use of data of earthquake source mechanisms;

tectonophysical method, based on the analysis of geometry of Mesozoic-Cenozoic sedimentary rock fracturing.

Changes of the environment stressed state as a result of rock extraction and redistribution served as a mechanism triggering a swarm of earthquakes at Boundaries of rather large tectonic blocks in deep fault zones located within the deposit region.

Results

Tectonic setting and geological history of the Starobin Potash Deposit

The Starobin potassium salt deposit is rated third in the world in the sylvinite ore reserves and output. The reserves at individual mines can be utilised another 20 to 115 years. The deposit is located within the zone of junction of the Pripyat Trough and Belarussian Anteclise. Structurally, it is a flat sheet deposit. Potassium salts occur inside the rock salt beds (Fig. 2). Saliferous strata in the Starobin deposit are inter-bedded members of potassium salt and carbonate-clayey rock, as well as of sandstone and siltstone layers.

According to Belarusian geologists [Makhnach et al., 2001] the Starobin deposit had been formed 300 million years ago, at the end of the Devonian period. The present-day Polessic territory was occupied at the time by a shallow sea with vast lagoons. Intense evaporation and vertical movement acting together in the Starobin region were responsible for the deposition of sodium and potassium salts alternated with clayey-carbonate beds. According to the data available the axis of the maximum horizontal compression ($S_{H,\ max}$) during the period of salt accumulation was oriented towards NNE at an azimuth of 10-15^{o} [Belousov et al., 2006a, 2006b].

The deposit territory is of clearly defined block structure. It is bounded by the sub regional Liakhovichi and Glusk faults with vertical movement amplitudes ranging from 150 to 350 m on the north, and by a set of faults forming the Southern tectonic zone on the south. The Central, North-Western, Northern (Guliayevo) faults are running immediately within the deposit and divide the territory into the eastern, central, western and northeastern block. Mining works at the Starobin deposit of potassium salts started in the early sixties of the past century. At present, four potassium mining works are operating and the fifth one is under construction. The II and III potassium horizons located at depths from 400 to 1000m. The total thickness of impermeable layers ranges from 210 to 250m. The potassium horizon II and the lower sylvinite bed of the horizon III are being worked out. At present the potassium ore is recovered at four mining fields which are bounded by tectonic blocks and only in the southern flanks of the deposit – by pinching-out potassium horizons. The II potassium horizons occur in the depth range from 250 to 700 m, the III potassium horizons – from 350 to 1000 m.

Fig. 2. An exposure of interbedded potassium (red colour) and rock salts of the Starobin deposit at a depth of ~ 670 m (Dr. Sh.A. Mukhamediev)

In the region of the Starobin deposit the crystalline basement occurs at depth of 1700-2100 m. A thickness of sub salt clayey-marlaceous deposits varies between 230 and 560m. Mining geological conditions of extraction of the second and third potassium horizons in general are quite favourable. The roof rocks are rather rigid and are prone to fracturing, the soil is swelling. Various systems of mining development work are used at the deposit fields. Extraction of minerals at the first stage of deposit mining began with room mining systems on rigid pillars. A few methods of room mining were used, which was due to insufficient knowledge of mining geological and hydrogeological conditions. The main methods of room mining at the Starobin deposit are described in [Yermolenko et al., 1993; Tomchin et al., 1998]. The man-caused influence from mining potassium horizons and rock salt beds can be seen in appearance of shift troughs on the earth's surface, deformation of buildings and constructions.When potassium ores were mined in the Starobin deposit region a number of geological features was revealed, such as: rock fissuring, zones of rupture dislocations, zones where sylvinite was replaced by potassium salt in productive beds, subsidence troughs and their associated gas-dynamics phenomena, squeezing-out brine inflows into mine works [Vysotsky et al., 2003]. Long term potassium extraction also causes geomechanical and geodynamic changes in the Soligorsk mining region, which in its turn contribute to increasing number of induced earthquakes [Aronov et al., 2003].

The seismic monitoring

As to induced earthquakes, the first of them was recorded in 1978 (M=3.0, I_0=V) by the seismic station "Minsk" located at a distance of 170 km from it. Continuous instrumental seismic observations in the deposit region were carried out after 1983 by equipment with short period seismographs. A seismic network was installed in 2004, and the information was transmitted into computer. Each station was instrumented with three-component short-period seismic detectors with capacitance-type transducer and magnetic-electrical feedback. A reception range was at least 25 km. Part of seismic stations has been installed in mining workings at depths ranging from 400 to 800 meters.

In different time periods the number of seismic stations changed from 1 to 6. Accuracy of epicentre coordinates determination taking into account a detailed study of the environment structure ranges within ± 1 km, and the foci are located at a depth of 0–5 km.

As a result of long-term seismic monitoring the database was compiled. It contains:

- general geological and geophysical information on the territory under monitoring, specific data on the seismograph network, tectonic blocks, velocity models, seismic wave travel time curves, etc;
- digital seismograms of recorded seismic events, arrival times and amplitudes of seismic phases, major wave groups with maximum amplitudes, parameters of foci of seismic events as well as some other parameters, etc;
- the main results of interpretation, i.e. space and time, energy.

The data are considered to be most important for studying geodynamics of the Soligorsk industrial region.

The fact of local seismicity instrumentally recorded in the Starobin deposit region against a total absence of seismic events for several last decades over the most part of Belarus suggests the recent activation of faults in the Soligorsk region. Since 1983 the whole seismic network recorded more than 1,200 seismic events of the energy classes K=4.0–9.5 (magnitude M=0–3), five of them being sizeable: 10 May 1978; 1 December 1983; 17 October 1985; 16 March 1998; 17 March 1998 (Fig. 3). The energetic class which is connected to the magnitude as K=1,8M+4 for those events is located within the diapason of 8,0–9,5. The intensity of soil shaking rose up to 4–5 scores MSK-64 [Medvedev et al., 1965]. All the earthquakes were accompanied by macro-feelings: rumble, window glass rattling, swaying of hanging objects, furniture and floor creaking on the ground floors of wooden constructions. The scattered plaster cracks were observed. During the earthquakes 1978 and 1998 roof collapse took place.

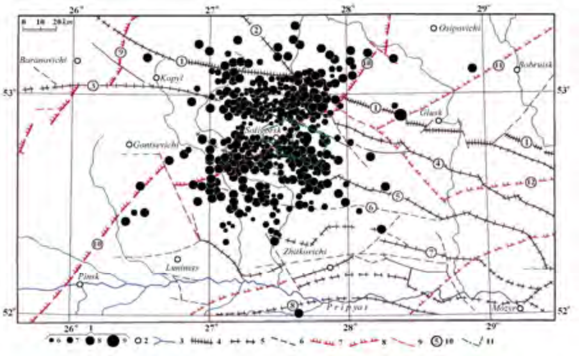

Fig. 3. Map of epicentres of seismic events (1983–2012) in the Soligorsk mining region:

1 – energy class *(K)*; 2 – locality; 3 – rivers; 4–6 – faults penetrating into the sedimentary cover (4 – superregional faults restricting the largest structures; 5 – regional ones restricting large first- and second order structures; 6 – local); 7-9 – faults which do not penetrate into the sedimentary cover (7 – superregional ones restricting the largest areas of different processing age; 8 – regional ones restricting the largest areas of different processing age; 9 – local); 10 – faults (numerals in the circles: 1 – North-Pripyat, 2 – Naliboki, 3 – Liakhovichi, 4 – Rechitsa, 5 – Chervonaya Sloboda-Malodusha, 6 – Shestokovichi, 8 – Skolodin, 9 – Wyzhevsk-Minsk, 10 – Stokhodsk-Mogilev, 11 – Krichev, 12 – Chechersk faults); 11 – border of mine fields in the Soligorsk mining region

The correlation of the earthquake space and time distribution with the region structural plan evidently suggests that most faults are seismically active. The epicentres of seismic shocks are more abundant along faults of various trends, i.e. minor earthquakes generally trace the faults. When discussing the dynamics of the seismotectonic process evolution, it is necessary to keep in mind the space-time migration of seismic activation revealed when correlating seismicity maps compiled from data for different periods [Aronov et al., 2009].

The map (Fig. 3) also shows rupture dislocations active at the present-day stage. The strongest seismic events recorded recently in the Soligorsk region are confined to zones of tectonic disturbances active at the latest stage. These are a set of the North-Pripyat super regional faults, the Chervonaya Sloboda and Stokhodsk-Mogilev fault systems. This is also evidenced by the prevailing fracturing orientation measured immediately in mines and by the regional stress system of the western part of EEP.

The necessity of the tectonic stress accounting

The stressed state (SS) of the geological environment caused by the rock extraction and deposition has been continuously changed and can be obviously a reason to suggest the technogenic nature of earthquakes. However, some seismic manifestations recorded outside the working zone of the Soligorsk mining region evidently indicate that for some time the seismic process is mainly governed by regional geodynamic factors and to a lesser extent depends on mining works. This suggestion may be supported by at least three facts:

- Restriction of the bulk of epicentres within the fault zone junction areas, which is well seen in the map of epicenters distribution (Fig. 3).
- Almost a total absence of a relationship between the underground mining intensity and seismicity. The extracted ore output can serve as a parameter of mining intensity, and the total number of recorded events since 1983 till the present – as the seismicity level value.
- Absolute majority of seismic events take place outside mining areas. This is a typical feature of induced seismicity, when the epicentral area migrates over the zone as a result of the seismic process evolution.

In the present state of the art, it is not actually possible to obtain reliable geodynamic results without a detailed analysis of the orientation of the horizontal maximum ($S_{H,max}$) and minimum ($S_{H,min}$) compressional axes.

Rock jointing in the western part of East European platform

The geometry of rock joint systems is considered to be convenient object to reconstruct the principal axes of paleostresses because of the universal occurrence of rock fracturing. Rock jointing develops everywhere in rocks of various genesis and age. It is observed both at natural outcrops and at walls of various mining activities (Fig. 4). Joints are not chaotic and generally exhibit regularity revealed in quasiperiodic and quasiparallel systems. The systems can often be observed visually but occasionally are characterised only on the basis of measured data processing.

It is not the intent of this paper to go into details of our approach to paleostress reconstruction as this was discussed elsewhere, e.g., [Belousov et al., 1997; Mukhamediev et al., 2007]. It should be noted only that we distinguish primary and secondary joint systems. The former (or, at least, their prototypes represented by weakened planes) originate during diagenesis of sediments while the latter are actually formed as brittle cracks in already lithified rocks in response to subsequent tectonic processes or due to industrial activities. The neglect of the different nature of the primary and secondary joints and attempts to consider the whole set of joints observed at an exposure as originated by a single mechanism may introduce large errors into interpretations. During diagenesis plastic shear deformations are localised in regularly spaced thin zones, which form the skeleton of the future primarily conjugate joint systems. The bisector of the acute angle between the systems is coincident with the orientation of the maximum horizontal compressive stress $S_{H,max}$.

Unlike the models based on the strength criteria, or analysis of kinematic indicators of irreversible slip (slickensides and slide marks), the method developed enables the authors to determine the time when paleostresses reconstructed from the primary jointing were in operation, which coincides with the age of the sedimentary rock.

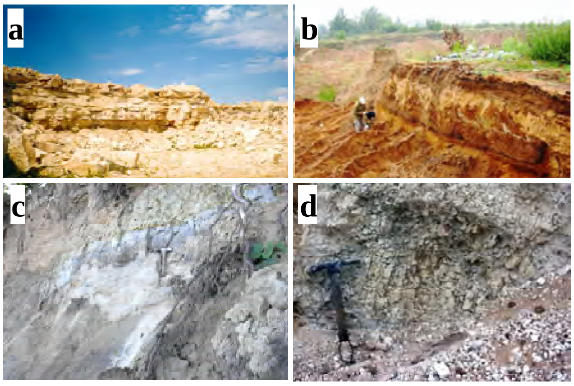

Fig. 4. Examples of sedimentary rock outcrops in the western part of EEP

a – Moscow syneclise, artificial exposure of limestone (Devon); b – Smolensk region, artificial exposure of brown sands (Neogene); c – Minsk area, natural exposure of lake sandy loam (Quaternary); d – Briansk region, artificial exposure of fragmented chalk (Cretaceous)

During the field tectonophysical investigations performed within the western part of EEP Mz –Kz elements of the sedimentary rock fracturing were

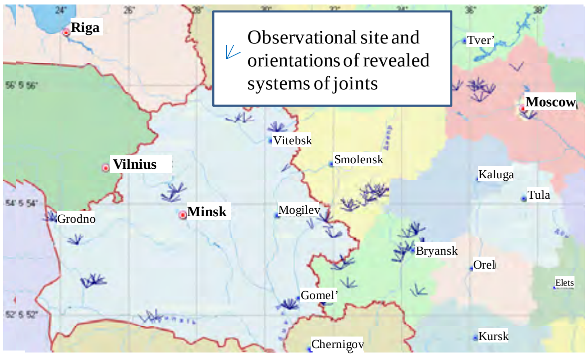

Fig. 5. Observational sites of measurements of sedimentary rock jointing in the western part of the East-European platform

measured in more than 100 observation sites (OS, Fig. 5): Jurassic – 40 S, Cretaceous – 25 OS, Palaeogene – 10 OS, Neogene – 6 OS, Pleistocene – 60 OS, Holocene – 1 OS. The rock fracturing in Belarus was studied in more details. Three OS were located within the Starobin deposit at a depth of about 670 m. The intralayer geometry of the studied Mesozoic-Cenozoic sedimentary rock jointing was used to reconstruct orientation of the principal axes of alpine paleostresses and to infer the main features of their evolution in the EEP western part. The results of analysis are discussed below.

Evolution of paleostresses in the lithosphere of EEP

Orientation of the $S_{H,max}$ axis in different regions of the western part of EEP at different times is shown in Fig. 6.

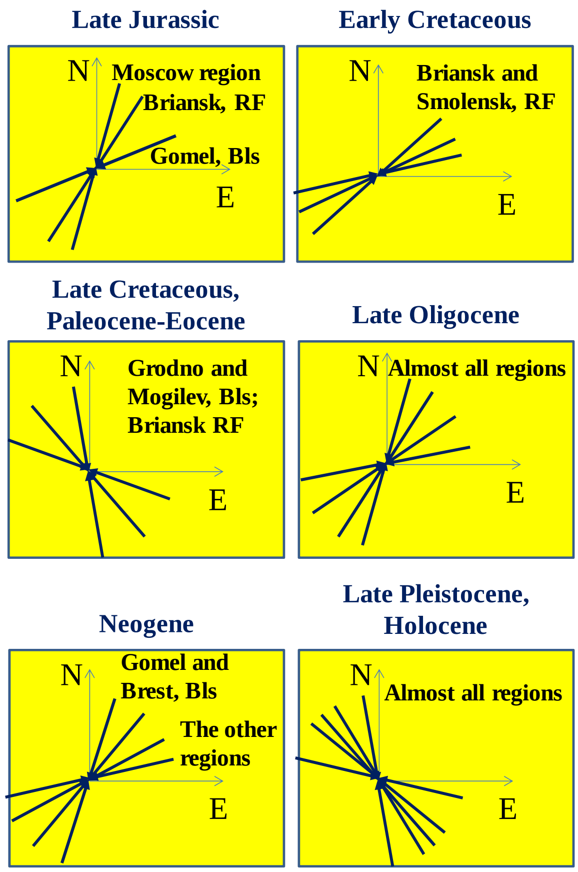

Fig. 6. Orientation of the compressive paleostress axes in the western part of EEP

The compressional stress showed almost the same orientation in the territory of the Gomel (ENE, 70–80°) and Briansk (NNE, 15–20°) regions, as well as in the west of the Moscow region (NNE, 5–10°) in the Late Jurassic. At the same time the $S_{H,max}$ axis rotated in a counter-clockwise direction from ENE (80°) to NNE, from west to east in the geographical coordinate system. In the Early Cretaceous the maximum compression axis was oriented NE-ENE (40–85°) in the Smolensk and Briansk regions.

A short geodynamic reconstruction took place in the Late Cretaceous and changed the maximum compressional axis direction contributing it a stable WNW-NNW orientation within a considerably vast area from the Grodno region to the Briansk region. So, the compression was oriented WNW-NNW (275–340°) in the Grodno region in the second half of the Cretaceous. The compression is oriented WNW-NW (275–310°) as recorded in most observation sites in the Mogilev region, WNW-NNW (275–350^{o}) in the Briansk region. The compressional axis orientation in the first half of the Paleogene (Paleocene-Eocene) remained similar to that in the Late Cretaceous (310–355°).

The $S_{H,max}$ axis became again oriented NNE-ENE (15–80°) within the most part of the East European Platform in the Late Oligocene, i.e. a geodynamic alteration took place within the studied area before the beginning of the neotectonic stage of evolution. This was apparently due to the Carpathian mountain system which was incipient from the southwest and exerted its influence to the EEP.

In the Neogene, the maximum compressional axis showed the same orientation as in the Oligocene – from NNE to ENE (15–75°) in the southern Gomel and Brest regions of Belarus. Almost the same orientation of the compressional axis (NE-ENE, 55–80°) remained unchanged in the EEP Southwest till the Late Pleistocene.

In the Late Pleistocene the maximum compressional axis in all the observation sites (20) was oriented WNW-NNW (275–355°). The similar axis orientation was most likely characteristic of the Holocene too. So, in the Moscow region it was oriented at an azimuth of 330° (NNW).

Scientific novelty and practical significance

Other determinations of the recent $S_{H,max}$ orientation

The axis of the recent maximum compression in the Soligorsk region was determined from the earthquake source mechanisms [Aronova, 2006]. An analysis of local mechanisms of swarm earthquake foci has shown that the NNW direction of compressional stress is also dominant (Fig. 7). Recent seismotectonic deformations in the studied region are found to be well correlated with numerous disjunctive deformations manifested at the most recent stage of evolution. The seismotectonic environment of shear deformation with evidences of submeridional compression and, respectively, sublatitudional extension appears to be typical of the northwestern part of the Pripyat Trough.

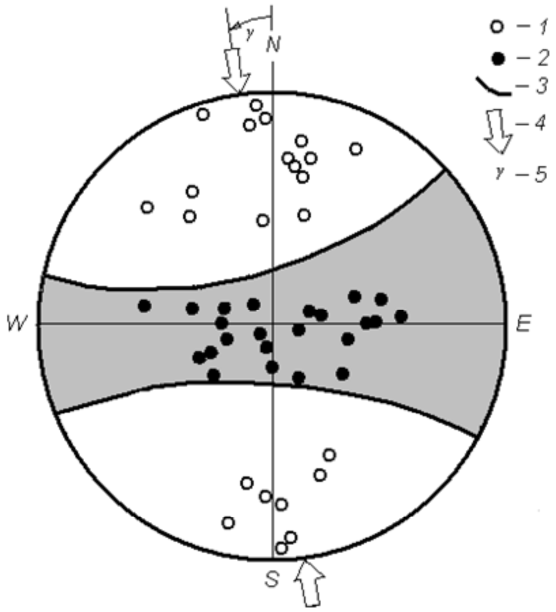

Fig. 7. Summary diagram of local mechanism axes and nodal lines of the averaging mechanism

1 – compressional stress axis (P); 2 – extensional stress axis (T); 3 – nodal lines; 4 – direction of principal compressional stress; 5 – angle of principal compressional stress axis inclination

According to geological data [Makhnach et al., 2001], the formation of recent platform structures in the territory of Belarus is dictated by mainly regional tensor of stresses with submeridional compression axis and sublatitudinal tension axis. In such a stress field faults of northwestern strike are right-lateral faults in Belarus, and those of northeastern strike – left-lateral faults. Submeridional fractures show typical features of either slip faults, or normal faults.

So, the stressed state was reconstructed for the studied region using three methods:

- tectonophysical method, based on the analysis of geometry of Mesozoic-Cenozoic sedimentary rock fracturing;
- structural method based on the study of disjunctive deformations in the region;
- seismotectonic method with the use of data of earthquake source mechanisms.

Summarizing all the results obtained by the above methods, a conclusion may be drawn that beginning from the Late Pleistocene till the present the maximum compressional axis has been oriented NNW. The investigations performed showed some evidences of a considerable activation, which had occurred in the deposit region in the Late Cenozoic, when the velocity of vertical movements increased and their direction changed in some faults. Amplitudes of slip in these faults were as high as 30 m and more for the last 25–28 million years.

Conclusions

The correlation of the space and time distribution of earthquake foci with the tectonic features of the Soligorsk mining region suggests that most faults are seismically active. The majority of minor seismic events are concentrated along various strike faults, or their parts, i.e. minor earthquakes generally trace faults, and changes of the environment stressed state as a result of rock extraction and redistribution served as a mechanism triggering a swarm of earthquakes at boundaries of rather large tectonic blocks in deep fault zones located within the deposit region. Seismic processes in the region of the potassium salt deposits of Soligorsk have shown that the zone of epicenters of seismic events are larger that mining area. This feature, which is typical of the stimulated seismicity zones, has a simple mechanical explanation. Indeed, the mining area due to excavated rocks can be considered as a "soft" inhomogeneity exposed to remote tectonic stresses $S_{H,max}$ and $S_{H,min}$. High level stresses are always concentrated around such inhomogeneities.

The monitoring of the potassium salt deposit of Soligorsk is of high scientific and economic interest. The accumulated seismic and technological data will allow studying the problems of the seismic hazard assessment more effectively. By means of such observations it would be possible to correlate the mechanism of generation of the seismic events with the local and regional tectonics as well as with technological activities within the mine. Seismic investigations at the surface can be used to calibrate the numerical models and to verify the obtained results.

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REFERENCES

Aizberg R., Garetsky R., Aronov A., Karabanov A., Safronov O. Seismotectonics of Belarus and the Baltic region // Technika poszukiwan geologisznych, in geosynoptika i getermia. – Krakow. – 1999. – Rok XXXVIII. – Zeszyt 1 (195). – pp. 28–37.

Aizberg R.E., Aronov A.G., Garetsky R.G., Karabanov A.K., Safronov, O.N. Seismotectonics of Belarus and the Baltic region // Litasfera. – Minsk. – 1997. – № 7. – pp. 5–17.

Aronov A.G., Seroglasov R.R., Aronova T.I. Seismicity of the territory of Belarus // Earthquakes and microseismicity in modern geodynamics problems of the East European platform, in Earthquakes / Part. 1: Earthquakes. – Petrozavodsk. – 2007. – pp. 357–364.

Aronov A.G., Seroglasov R.R., Aronova T.I. Belarus // Earthquakes in Northern Eurasia in 1997. – Obninsk, GS RAS. – 2003. – pp. 172–180.

Aronov A.G., Seroglasov R.R., Aronova T.I., Kulich O.N. Seismicity and seismogenic zones of Belarus // Int. conf. Dushanbe 9–14 July 2009– Dushanbe. – 2009. – pp. 64–74.

Aronova T.I. Belarus // Earthquakes in Northern Eurasia in 2001. – Obninsk, GS RAS. – 2007. – pp. 243–247.

Aronova T.I. Peculiar features of seismotectonic processes in the territory of Belarus // Litasfera. – Minsk. – 2006. – № 2 (25). – pp. 103–110.

Belousov T.P., Kurtasov S.F., Mukhamediev Sh.A. Divisibility of the Earth crust and paleostresses in seismically active and oil-production regions. – Moscow: UIPE, 1997. – 325 p.

Belousov T.P., Mukhamediev Sh.A., Karabanov A.K. Fracturing of Mesozoic-Cenozoic rocks and stressed state of the East European Platform western part // Active geological and geophysical processes in the lithosphere. Methods, way and results of study. – Voronezh. – 2006b. – Vol. I. – pp. 82–87.

Belousov T.P., Mukhamediev Sh.A., Kurtasov S.F., Karabanov A.K., Aronov A.G., Seroglasov R.R. Fracture pattern in Mesozoic-Cenozoic deposits of Belarus and the adjacent regions of Russian // Litasfera. – Minsk. – 2006a. – №. 2 (25). – pp. 52–62.

Garetsky R.G., Aizberg R.Ye., Aronov A.G., Karabanov A.K., Safronov O.N. General seismic division of the Belarusian-Baltic region // Dokladi Akad. Nauk Belarusi. – 1997. – Vol. 41 (4). – pp. 98–102.

Makhnach A.S. et al. (eds). Geology of Belarus. – Minsk: The Institute of Geological Science, 2001. – 815 p.

Medvedev S.V., Shponkhoiyer V., Karnik V. Scale of seismic intensity MSK-64. – Moscow: MGR AN SSSR, 1965. – 11 p.

Mukhamediev Sh.A., Nikitin L.V. Application of the material force concept to formation of discontinuities in soft sedimentary rocks // Archive of Applied Mechanics. – 2007. – Vol. 77 (2–3). – pp. 155–163.

Tomchin L., Smychnik A. Experience of development of the Starobin deposit of potassium salt // Mining magazine. – 1998. – № 11–12. – pp. 79–84.

Vysotsky E.A., Gubin V.N., Smychnik A.D., Shemet S.D., Yashin, I.A. Potassium salt deposits of Belarus: geology and efficient management of mineral resources. – Minsk: BSU, 2003. – 263 p.

Yermolenko V.A., Bordon V.Ye. Belarusian agricultural ore: geology, economy, ecology. – Minsk: The Institute of geology, geochemistry and geophysics, 1993. – 183 p.

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СЕЙСМИЧНОСТЬ И НАПРЯЖЕННОЕ СОСТОЯНИЕ СТАРОБИНСКОГО МЕСТОРОЖДЕНИЯ КАЛИЙНЫХ СОЛЕЙ В БЕЛАРУСИ

Цель. Провести исследования в юго-западной части Восточно-Европейской платформы в пределах центриклинального замыкания Припятского прогиба, где расположено Старобинское месторождение калийных солей верхнедевонского возраста. Интерес учёных именно к этому району объясняется тем, что в районе данного месторождения находится скопление очагов коровых землетрясений, которое

заметно отличает его от остальной территории Беларуси, где немногочисленные сейсмические события распределяются достаточно равномерно. **Методика.** Напряженное состояние изученного региона было реконструировано с помощью следующих методов: сейсмотектонический метод с применением данных о механизмах очагов землетрясений; тектонофизический метод, основанный на анализе геометрии разрывных нарушений в мезозойско-кайнозойских осадочных породах. Изменения напряженного состояния среды в результате извлечения и перераспределения горных пород послужили механизмом, инициировавшим ряд землетрясений на границах достаточно крупных тектонических блоков в зонах глубинных разломов, расположенных в районе месторождения. **Результаты.** Несколько лет назад команда ученых из России и Беларуси провела совместное геодинамическое исследование в рамках проекта «Изучение напряженного состояния литосферы и сейсмичность юго-западной части Восточноевропейской платформы» при финансовой поддержке Российского и Белорусского фондов фундаментальных исследований. О некоторых из полученных результатов уже сообщалось [Белоусов и др., 2006a, 2006b; Аронов и др., 2009]. Проведены исследования в западной части Восточноевропейской платформы, где особый акцент делается на Солигорском районе, на территории которого расположено Старобинское месторождение калийных солей позднего девонского периода (D3 fm, фаменский век). Инструментально зарегистрированная локальная сейсмичность района Старобинского месторождения на фоне практически полного отсутствия сейсмических явлений на большей части территории Беларуси на протяжении нескольких последних десятилетий позволяет предположить наличие современной активизации разломов в Солигорском районе. **Научная новизна и практическая значимость.** Напряженное состояние геологической среды, обусловленное горнодобывающей деятельностью, постоянно изменялось, что дает основание предположить индуцированную природу наблюдаемой сейсмичности. Выявлено, что сейсмотектонические деформации в изучаемом регионе хорошо коррелируются с многочисленными дизъюнктивными нарушениями, в основном проявившимися в последнюю стадию развития. Сейсмотектоническая обстановка сдвигового деформирования с проявлениями субмеридионального укорочения и, соответственно, субширотного удлинения оказывается характерной для зоны северо-западной части Припятского прогиба. Начиная с позднего плейстоцена до настоящего времени ось максимального сжатия ориентирована в направлении северо-северо-запад, что определено во взаимосвязи с механизмами сейсмических очагов. Выполненные исследования выявили некоторые проявления значительной активации, которая произошла в районе месторождения в позднем кайнозое, когда возросла скорость вертикальных движений, и их направление изменилось на некоторых разломах. Амплитуды сброса на этих разломах достигали 30 м и более в последние 25–28 миллионов лет.

Ключевые слова: сейсмичность; механизм землетрясения; тектоника; опасность; мониторинг.

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