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Neogeodynamics and recent geodynamics at northern prospect area of Petrikov potash deposit, Belarus

Neogeodynamika i współczesna geodynamika północnej części złoża soli potasowej Pietrykov, Białoruś

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Abstract

The results of studies of neogeodynamics and recent geodynamics at northern prospect area of Petrikov potash deposit in Belarus are discussed. The models of intensity of neogeodynamic and recent geodynamic processes over the period from the end of Middle Pleistocene to Holocene have been calculated using lineament and structural-geomorphological analysis in ArcGIS 10 on the basis of digital topographic maps of the scale 1 : 5 000, digital orthophotomaps of the scale 1 : 5 000, and free multi-zone satellite images.

Key words: geodynamics, lineament, lineaments density, morphostructures, endogenic/exogenic morphosculptures, geodynamic activity zone, geographic information systems

Streszczenie

W pracy omówiono wyniki badań neogeodynamiki i współczesnej geodynamiki północnej części Pietrykowskiego złoża soli potasowej na Białorusi. Modele przebiegu intensywności procesów neogeodynamicznych i współczesnych geodynamicznych, obejmujące okres od końca środkowego plejstocenu do holocenu, zostały przedstawione w oparciu o analizę strukturalno-geomorfologiczną z wykorzystaniem programu ArcGIS 10. Materiałem bazowym były cyfrowe mapy topograficznych w skali 1:5000, cyfrowe ortofotomapy w skali 1:5000 oraz wielospektralne obrazy satelitarne.

Słowa kluczowe: geodynamika, lineament, gęstość lineamentów morfostruktury, endogenne / egzogenne morforzeźby, strefy aktywności geodynamicznej, systemy informacji geograficznej

Introduction

Petrikov potash salt deposit includes Northern and Southern prospect areas, and is situated mainly within Petrikov district of Gomel region of Belarus.The total area of the deposit is 450 km^2, and the area of Northern prospect is 141 km^2.

Crystalline basement at the Northern prospect occurs at a depth of 2576-2865 m. In terms of tectonics the area is situated within Pripyat Trough that was formed mainly during the epoch of Hercynian orogeny (Makhnach et al., 2001). The largest tectonic faults (North-Shestovichi, Brinev, Skrygalovsk-Slobodsky, Shestovichi-Gostovsky) have been formed during the rift period.

Sedimentary cover is formed by the deposits of Neoproterozoic (starting from the depth of 2510 m), by Devonian (from the depth of 210-445 m), Carboniferous (214-331 m), and Permian (210-421 m) systems of Paleozoic, by Triassic (166-313 m), Jurassic (128-192 m), and Cretaceous (82-120 m) systems of Mesozoic, and by Paleogene (26-68 m), Neogene (10-39 m) and Quaternary systems of Cenozoic. Potash-bearing horizons occur in the deposits of Upper Devonian.

The basic features of the relief of the area have formed during the Dniaproŭski (Drenthe) stage of the Pripyat (Saalian) glaciation (Matveyev, Gursky & Levitskaya, 1988). In the end of Middle Pleistocene the area of Northern prospect was affected by melt waters of Sožski (Drenthe stage of Saalian) glacier. Melt waters formed the large lake reservoir that has existed through the end of Middle Pleistocene and in the Late

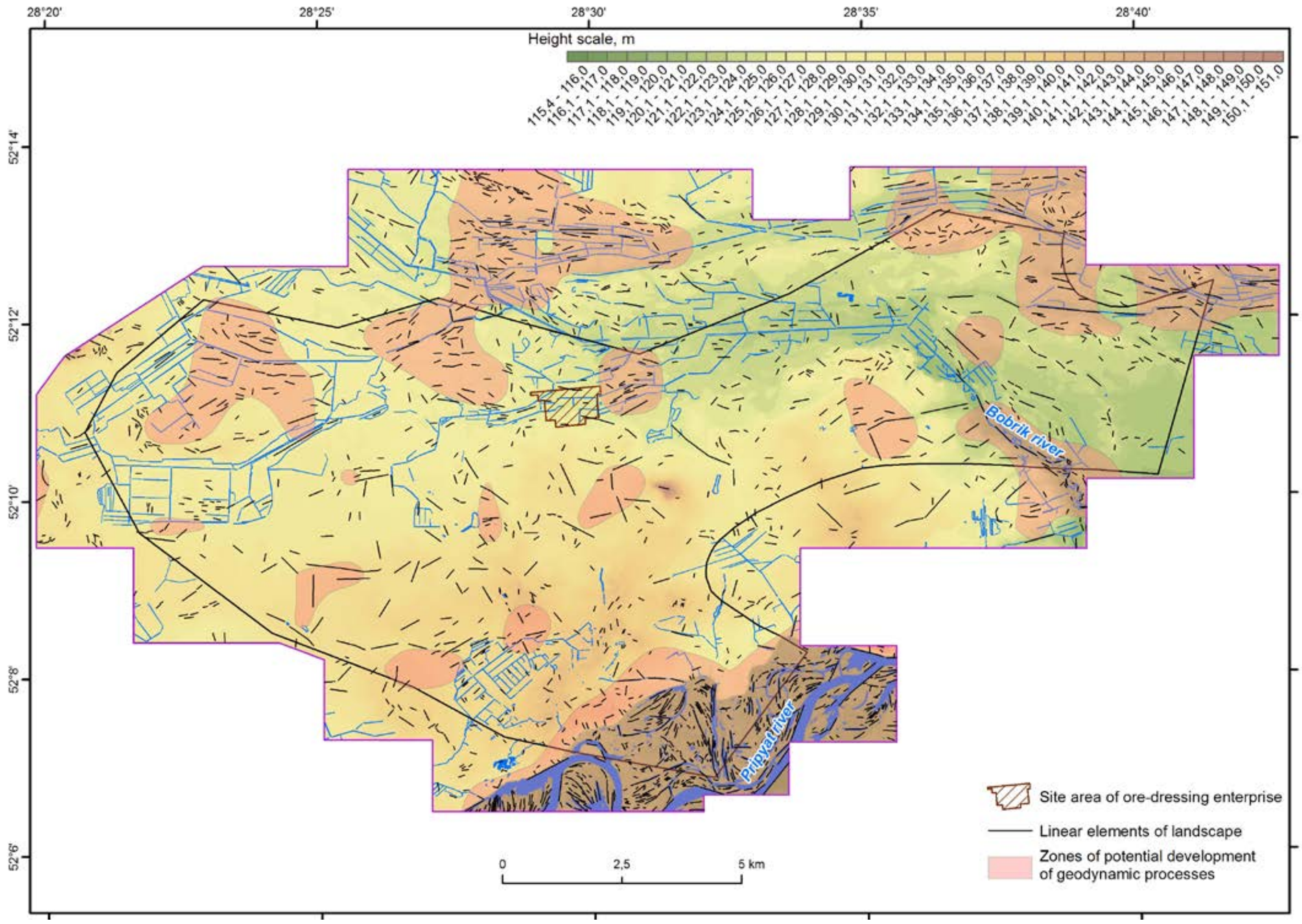

Fig. 1. Geodynamic model of Northern prospect of Petrikov potash deposit (based on results of lineament analysis).
Ryc. 1. *Model geodynamiczny północnej części pietrykowskiego złoża soli potasowej (na podstawie analizy lineamentów)*

Pleistocene (as fragments in Paaziorski (Weichselian) time). The valley of the main waterway of the area, Pripyat river, has formed in the end of Middle Pleistocene and Late Pleistocene.

Endogenic and exogenic processes, active in the Late Oligocene – Pleistocene period (*neogeodynamics*), as well as Holocene processes (*recent geodynamics*) have been studied at Northern prospect with the complex of methods, including lineament (Gubin, Kovalev, 2008; Matveyev, Nechiporenko, 2001; Matveyev et al., 1993; Garetsky et al., 2012) and structural-geomorphological (Florinsky, 2011; Codilean et al., 2006; Philosophov, 1975; Aristarkhova, 2000) analysis.

Research methods

Lineament analysis. Linear elements of landscape have been defined as a result of analysis of digital topographic maps of the scale 1 : 5 000, digital orthophotomaps of the scale 1 : 5 000, and free multi-zone satellite images in the environment of Geographic Information System (GIS) using ArcGIS 10 software. Those linear landscape elements included linear sections of hydrographic network (excluding man-made objects), ravine and gully network, linear sections of lakes shores (except those of artificial reservoirs), and linear micro- and mesolandforms.

The analysis of spatial differentiation of lineaments has been done through generation of a model of their density. Correlation analysis and analysis of orientation of linear vectors have been carried out with ArcGIS 10 environment in order to reveal relationships between faults in crystalline basement, faults in sedimentary thickness, and lineaments.

As it was determined in the result of conjoint analysis of the map of correlation of density fields, of vectors of lineaments and faults, clear relationship between those features is absent. Locations of lineaments, faults and peaks of density fields coincide only within certain limited areas.

Joint analysis of rose-diagrams of orientation of lineaments and faults has revealed that they have similar orientation (latitudinal or nearly latitudinal). Analysis of lengths determined that lineaments occur as relatively small segments (in the most cases less than 500 m). The lengths of faults are bigger than those of lineaments. Prevailing length of faults ranges from 2 to 6 km.

Based on the above results we conclude that faults and lineaments represent independent groups of linear structures that only in limited details repeat each other within the boundaries of the study area. The majority of faults within Pripyat Trough had formed during the Hercynian tectonic epoch.

Those faults occur on the surface of crystalline basement and penetrate through the Lower (pre-rift) and Middle (rift) stores of the Trough. At the Upper (post-rift) store the faults turn into flexures and completely disappear.

We came to the conclusion that lineaments are conditioned mainly by Pleistocene-Holocene geodynamic processes that have taken place in the area of Carpathians and Baltic Sea, as well as by the influence of Pleistocene glaciers (isostatic sinking under glaciers, uplift of earth crust blocks along a periphery of glaciations areas, glaciotectonic alteration of substratum). Lineaments correspond to the weakened zones in the earth crust. In the cases when they do not coincide with faults, they relate to the areas of higher fracturing of rocks without vertical displacement of strata.

The resulting block of lineament analysis was a development of geodynamic model of Northern prospect, fig. 1. For this purpose the model of density of lineaments was re-classified. The areas with density of lineaments more than 1.5 km/km² were defined as separate zones of potential development of geodynamic processes. These zones represent slackened zones of the earth crust, where higher fracturing of rocks may occur. Such zones occupy 25% of the area of Northern prospect (35.04 km^2).

Structural-geomorphological analysis has been carried out based on the methods elaborated by V.P. Philosophov and L.B. Aristarkhova (Philosophov, 1975; Aristarkhova, 2000). Digital elevation model (DEM) was developed in ArcGIS 10 environment based on digital topographic maps of the scale 1 : 5 000. The DEM was used to generate the map of river valleys of different orders. The orders of valleys (tributaries) were assigned using classification proposed by R. Horton. The valley of the first order does not have any tributaries. The valley of the second order is being formed in the result of confluence of two valleys (tributaries) of the first order. The valley of the third order is being formed in the result of confluence of two valleys (tributaries) of the second order, and so on. It should be emphasized, that the valleys of lower orders are being frequently referred to as linear erosional landforms of temporary streams (ravines, gullies, outwash rills, and other similar landforms). The valleys of the lower orders are of the Holocene age, while those of the higher orders are significantly older.

The maps of base surfaces were created by conjoint analysis of the DEM and the vector layer of orders of river valleys. Base surfaces are the surfaces that unite locale base levels of erosion. The maps of base surfaces of the 1st – 5th orders have been generated using ArcGIS 10 software for the area of Northern prospect.

The method of developing the base surface map was as follow, for example, for creation of the map of base surface of the 2nd order only the river valleys of 2nd and higher orders were selected. After that the points of intersection of picked out river valleys with topography altitude contours were identified. A set of points with absolute heights was acquired as a result of this computation. The grid-model was developed by means of interpolation. Isobasites (lines with equal bases of erosion) were derived from this model. The valleys of the 1st and 2nd orders were not taken into account when the map of 3rd order base surface was developed.

The base surface of the highest level is referred to as the lowest limit of denudation peneplation plane, to which level lowers the relief on the stage of downwards development. The base surface lowers due to erosional deepening of valleys under conditions of tectonic vertical uplift of earth crust, and rises as a result of accumulation in the valleys due to downwards tectonic movements.

Base surfaces were used to develop models of their differences in ArcGIS 10. A set of maps of differences between base surfaces of 1st and 2nd, 2nd and 3rd, 3rd and 4th, and 4th and 5th orders has been developed for the area of Northern prospect of Petrikov deposit. The differences between base surfaces show algebraic sum of vertical tectonic movements of earth crust during certain time periods: differences between base surfaces of 1st and 2nd, 2nd and 3rd orders - during short time periods, and differences between base surfaces of 3rd and 4th, and 4th and 5th orders - during longer time periods.

Relic glacial morphosculpture occupies a leading place in the modern relief of North prospect. Azonal morphosculpture plays secondary, but still important role. These azonal landforms include inherently developing river valleys, ravines, gullies, small depressions, etc.

As it was determined in the result of structural-geomorphological analysis, none of morphometric methods allows excluding from analysis the landforms of exogenic (glacial) origin. Therefore morphostructural pattern of the study area was analyzed on the surface of roof of pre-Quaternary deposits. This surface was developed by means of raster GIS analysis of boreholes data.

Morphoisohypses were plotted on the basis of upper-surface of pre-Quaternary deposits. Morphoisohypses represent graphic processing of palaeoisohypses with the purpose of exclusion of "secondary" exogenic landforms and by these means with the purpose of reconstruction of "primary" surface, not altered by subsequent exogenic processes. This "primary" surface is a framework for structural-tectonic relief. Morphoisohypses outlined morphostructures that are buried landforms formed in the end of Mesozoic – in the beginning of Cenozoic, fig. 2. The main factors, conditioned development of morphostructures, include static (structure and composition of earth crust) and dynamic (tectonic movements and deformations) properties of geological substratum.

Morphostructural features of Northern prospect of Petrikov potash deposit have been significantly altered by Pleistocene glaciers during Quaternary period. Nevertheless,

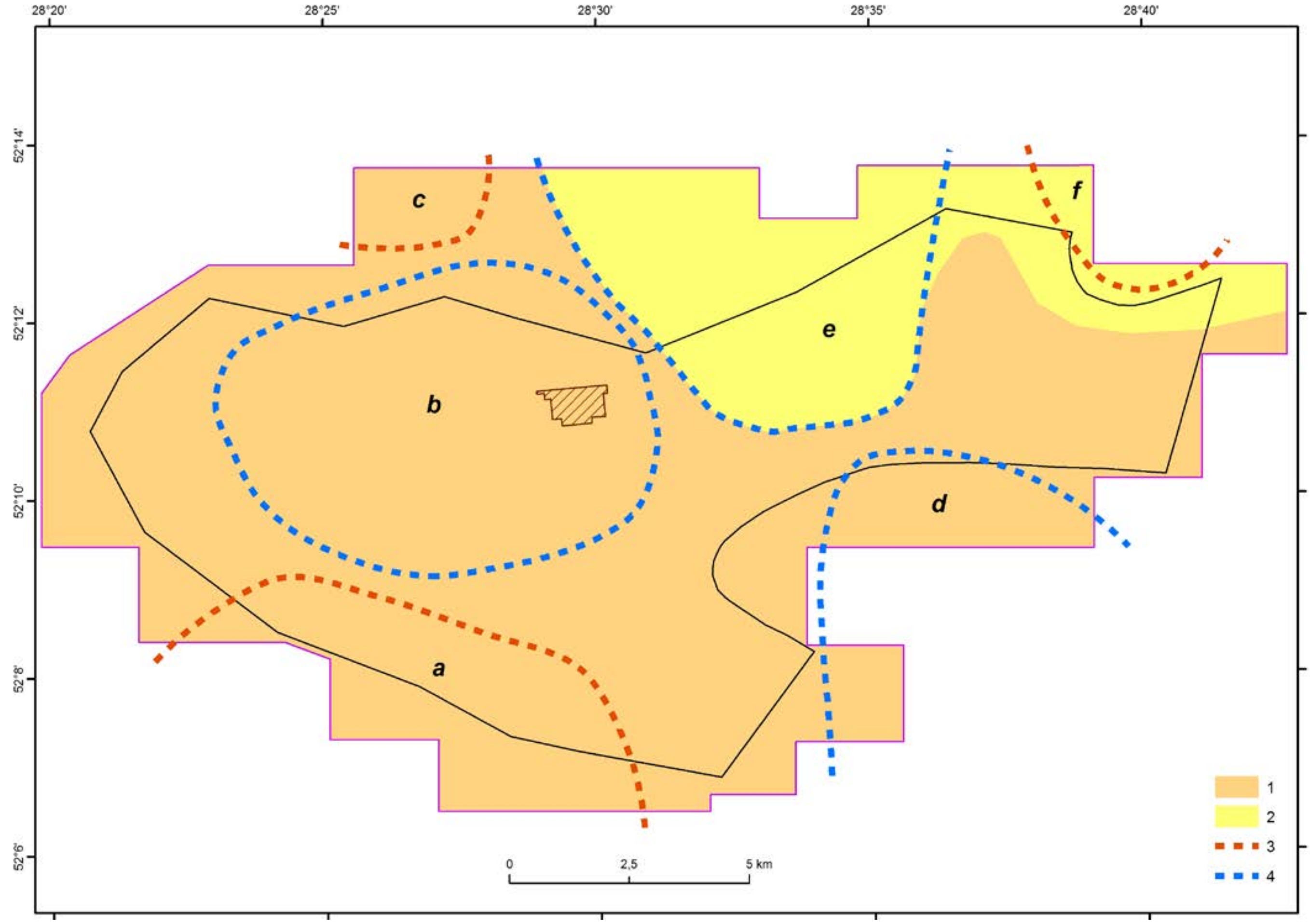

Fig. 2. Morphostructures of Northern prospect area of Petrikov deposit
Morphostructural units: 1 – South-Belarusian high stratal-denudational table-topped plane; 2 – Central-Belarusian high stratal-denudational plane. Morphostructures in relation to tectonic structures of crystalline basement: 3 – normal; 4 – inverted. Morphostructures labeled with letter symbols: a – Makarichi; b – Pervomai; c – Sotnichi; d – Belanovichi; e – Srednerudensk; f – Akrionsk

Ryc. 2. *Morfostruktury północnej części złoża pietrykowskiego*
Jednostki morfostrukturalne: *1 – wysoka warstwowo-denudacyjna stołowo-ostańcowa równina południowo-białoruska; 2 - wysoka warstwowo-denudacyjna równina środkowo-białoruska. Morfostruktury w odniesieniu do struktur tektonicznych fundamentu krystalicznego: 3 – normalne; 4 – odwrotne. Litery odnoszą się do struktur morfologicznych: a – makaryczckiej; b – pierszamajskiej; c – sotniczckiej; d – biełanowiczckiej; e – śródkoworudneńsiej; f – akriońskiej*

intensity and forms of glacial litho- and morphogenesis have been influenced by endogenic processes (Korzhuev, 1974). Endo-exogenic morphosculptures have been formed. Endogenic processes have participated in concealed and complicated way in their formation, and influenced their development. Certain morphologic elements of morphosculptures have been formed by exogenic processes.

Base surfaces of five orders have been developed for Northern prospect area through the structural-geomorphological analysis. These base surfaces reflect five stages of the history of neotectonic activity. Base surfaces of first order insignificantly differ from our-days topographic surface, and reflect tectonic movements that took place during Holocene (recent geodynamics). Base surfaces of higher levels significantly differ from topographic surface, and reflect the history of tectonic development of the area in the Middle and Late Pleistocene (neogeodynamics).

Regional and local endo-exogenic morphosculptures were defined through generalization of information from maps of valleys of different order, from maps of base surfaces of 3rd – 5th orders, and from maps of differences between base surfaces. In total 7 regional and 65 local endo-exogenic morphosculptures have been defined, fig. 3. Some morphosculptures inherit morphostructures that were defined on the upper-surface of pre-Quaternary deposits.

We think that the main factors, conditioned pattern and development of non-linear morphosculptures, were geodynamic processes that took place in the areas of Carpathians and Baltic Sea, as well as the influence of Pleistocene glaciations (isostatic sinking under glaciers, uplift of earth crust blocks along a periphery of glaciations areas, glaciotectonic alteration of substratum).

The character of pattern of base surfaces, developed in the framework of structural-geomorphological GIS analysis,

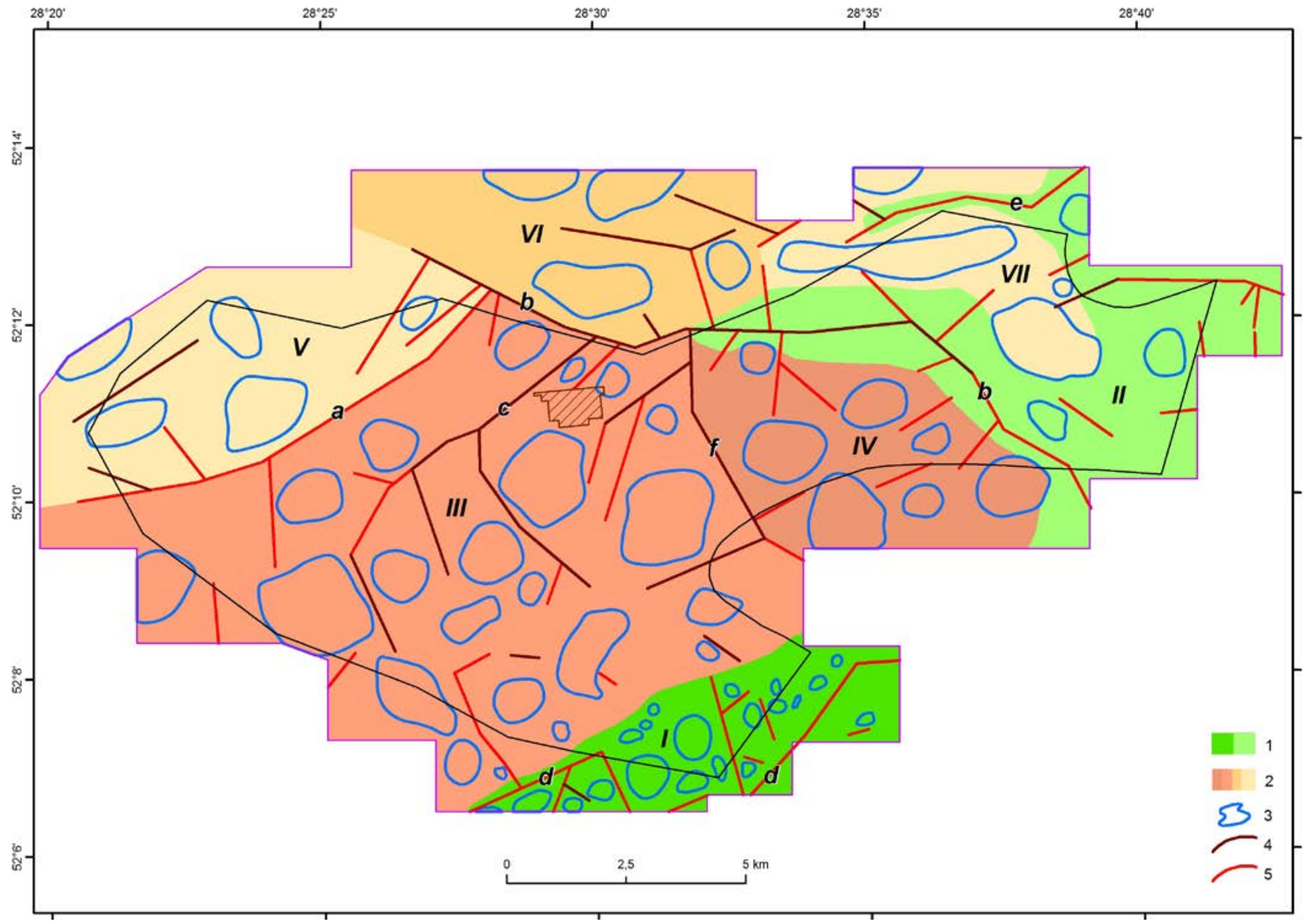

Fig. 3. Endo-exogenic morphosculptures
1 – regional negative endo-exogenic morphosculptures; 2 – regional positive endo-exogenic morphosculptures; 3 – local positive endo-exogenic morphosculptures. Linear endo-exogenic morphosculptures: 4 – morphosculptures representing active fragments of faults in crystalline basement and sedimentary cover; 5 – morphosculptures developed during neotectonic epoch.
Labeled with numbers: I – Pripyat depression; II – Bobrik-Lukichi depression; III – Petrikov dome; IV – Novoselki dome; V – Belolesnenski dome; VI – Smetanichi dome; VII – Muliarovsky dome. Labeled with letters endo-exogenic linear morphosculptures: a – Zheleznitsky; b – Bobrik; c – Pervomaisky; d – Pripyat; e – Lukichi; f – Belanovichi

Ryc. 3. *Endo-egzogenne morforzeźby*
1 – morforzeżby regionalne ujemne endo-egzogenne; 2 – morforzeżby regionalne pozytywne endo-egzogenne; 3 – morforzeżby lokalne pozytywne endo-egzogenne. Endo-egzogenne morforzeżby o liniowym charakterze: 4 – aktywne fragmenty pęknięć fundamentu krystalicznego i pokrywy osadowego; 5 – które są przejawia się w etapie neotektonicznej.
Liczby oznaczają: I - Pry acka depresja, II - Bobrikovska-Łukiszska depresja; III - Pietrikowska kopuła; IV - Novasielkincka kopuła; V - Beloleśneńcka kopuła; VI - Smetaniczcka kopuła; VII - Muliarowska kopuła. Litery oznaczają: A - Żeleżnitcka; b - Bobrykowska; B - Pierszamajska; g - Prypiacka; d - Łukiszska; e - Biełanowiczska morforzeżby endo-egzogenne o liniowym charakterze

was analyzed in order to define linear endo-exogenic morphosculptures.

Linear morphosculptures are distributed unevenly over the area of Northern prospect of Petrikov potash deposit, fig. 3. The most of them are grouped along elongated zones that intersect the entire area of prospect and sometimes extend beyond its limits. In total more than 50 linear endo-exogenic morphosculptures have been defined.

Linear endo-exogenic morphosculptures of near-latitudinal, near-longitudinal and longitudinal orientation prevail. Typical length of linear morphosculptures within the prospect area varies from 2 to 6 km.

Linear endo-exogenic morphosculptures were compared with the known faults of crystalline basement that allowed defining two main groups of morphosculptures: 1) morphosculptures, corresponding to activated fragments of the faults of crystalline basement and sedimentary cover; 2) morphosculptures, formed at neotectonic stage.

Morphosculptures, representing activated fragments of the faults of crystalline basement and sedimentary cover, inherit (coincide or similar by spatial arrangement and orientation) fragments of earlier existed network of platform or pre-platform disjunctives. Morphosculptures, formed at neotectonic stage, represent systems of zones of high fracturing that do not relate to ancient faults.

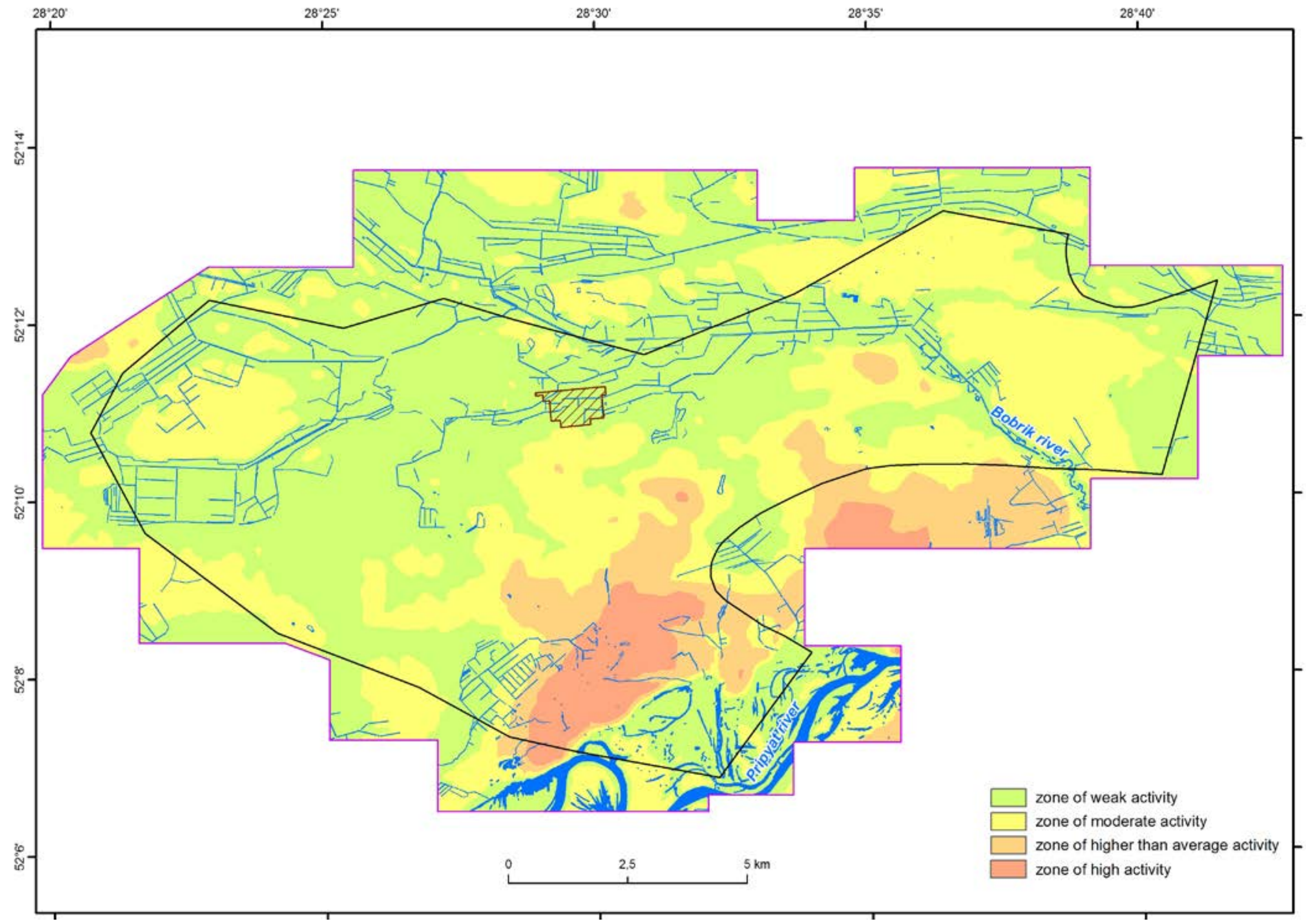

Fig. 4. Neogeodynamic activity of the Northern prospect of Petrikov deposit (from the end of Middle Pleistocene to the end of Late Pleistocene)
Ryc. 4. *Aktywność neogeodynamiczna północnej części złoża pietrykowskiego (od końca środkowego plejstocenu do końca późnego plejstocenu)*

The maps of differences of base surfaces were used for determination of amplitudes of vertical tectonic movements.

Zoning of the area of Northern prospect by the intensity of neogeodynamic activity (during the period from the end of Middle Pleistocene to the end of Late Pleistocene) was carried out using the results of morphometric analysis. The principle of the zoning is the following. Algebraic sum of amplitudes of vertical tectonic movements was calculated for all the differences of base surfaces of the orders from 4-5 to 2-3. In the result the surface of sums of amplitude was obtained. Cells of this surface were than divided into 4 classes that correspond to four levels of activity of the area: weakly active, moderately active, active more than average, and highly active, fig. 4. The boundaries for the classes were differences of sums 1.5, 5, and 10 m.

The area of the zone of weak activity at Northern prospect is 76.11 km^2 (54 % of total area), that of the zone of moderate activity is 46.39 km^2 (33 %), of the zone of higher than average activity is 11.40 km^2 (8 %), and of the zone of high activity is 6.94 km^2 (5 %).

Difference of base surfaces of 1st and 2nd orders was used as a source of information on recent (Holocene) geodynamic state of the study area. In order to obtain the desired results re-classification of the surface was carried out for the purpose of zoning of the Northern prospect area with respect to intensity of recent geodynamics, fig. 5. Three classes of intensity of Holocene geodynamics were defined: the zone of weak intensity with sum of amplitude of movements up to 0.25 m; the zone of moderate amplitude from 0.25 to 2 m; and the zone of higher than average activity with the intensity of movements more than 2 m.

The area of the zone of weak activity within Northern prospect is 109.52 km^2 (78 % of total area of the prospect), that of the zone of moderate activity is 27.05 km^2 (19 %); and of the zone of higher than average activity is 4.29 km^2 (3 %).

Summary

As a result of lineament analysis, it was determined that the most area of Northern prospect of Petrikov potash deposit is stable in terms of resent geodynamics. The zones of potential development of geodynamic processes occupy only 25% of the area of prospect. These zones are referred to areas of weakened earth crust, within which higher fracturing of rocks may occur.

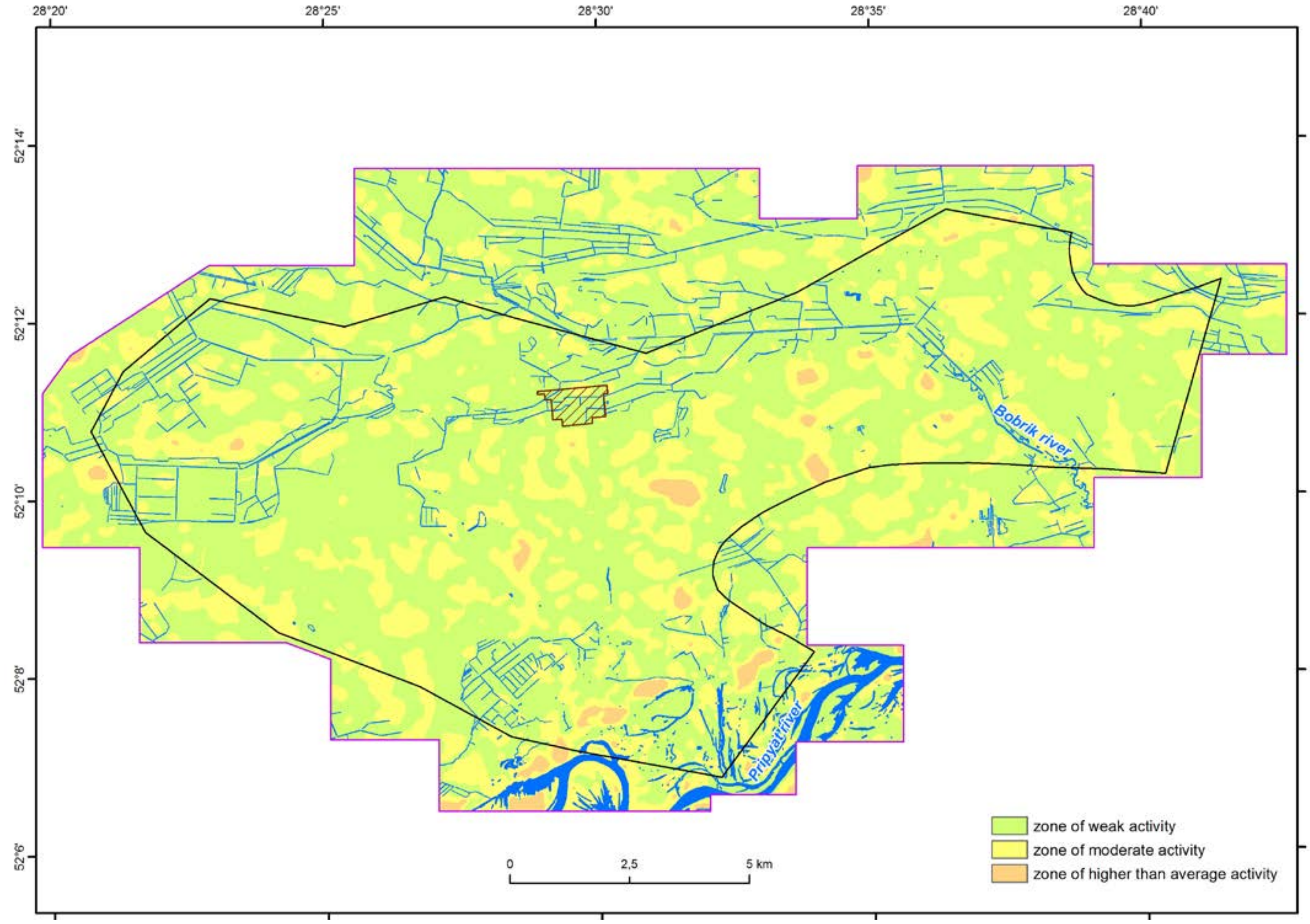

Fig. 5. Recent (Holocene) geodynamic activity of the Northern prospect of Petrikov deposit
Ryc. 5. *Aktywność geodynamiczna w holocenie północnej części złoża pietrykowskiego*

Based on the results of structural-geomorphological analysis, the models of neogeodynamic activity for the period from the end of Middle Pleistocene to the end of Late Pleistocene were developed. Moreover, the assessment of the recent (Holocene) geodynamics intensity was carried out.

During the period from the end of Middle Pleistocene to the end of Late Pleistocene, a weak intensity of geodynamic processes occurred for 54% of total area of Northern prospect, a moderate intensity was registered for 33%, and higher than moderate and high intensity was characteristic for 13% of total area.

In Holocene a weak intensity of recent geodynamic processes is registered for 78% of the research area, moderate intensity is relevant to 9%, and higher than moderate intensity is recorded for 3% of study area.

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