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DETECTION OF NEAR-SURFACE GEOLOGICAL HETEROGENEITY AT STARUNIA PALAEONTOLOGICAL SITE AND VICINITY (CARPATHIAN REGION, UKRAINE) BASED ON MICROGRAVITY SURVEY

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Abstract: Results of a microgravity survey performed in the abandoned Starunia ozokerite mine (Carpathian region, Ukraine), where in the early 20th century well preserved remains of large, extinct mammals were found, are discussed in the paper. A number of gravity anomalies indicating the geological heterogeneity at the sub-Quaternary strata have been observed. The assumed measurement observations also enabled the authors to interpret the results in view of density changes in the Quaternary strata. Most of the registered microanomalies coincide with the high-halite and ozokeritic Miocene salt-bearing Vorotyshcha beds. The distribution of the microanomalies reveals neither their correlation with the thickness of overburdens, nor any gravity impact of numerous abandoned wells. Gravity anomalies were mostly connected with the lithology of sediments and rocks obtained from geological boreholes drilled in the years 2007 and 2008, on the basis of which the anomalies' origin could be determined. A concentric, relatively negative gravity microanomaly of *ca*. 25 m in diameter was registered in the place, where very well preserved relics of the woolly rhinoceros had been found. They may be indicative of the existence of Pleistocene lakes (and/or palaeoswamps), into which the woolly rhinoceroses had sunk. Hence, an assumption can be made that the further search for successive zoological relics can be made in areas with similar anomalies under the low-density sub-Quaternary subcrop.

Key words: geophysics, microgravity, Quaternary sediments, Starunia, Carpathian region, Ukraine.

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INTRODUCTION

Microgravity survey was a part of an interdisciplinary research project focused on study of the Starunia area. During the 2006–2009 period, comprehensive investigations were carried out in an abandoned ozokerite (earth wax) mine at Starunia (Kotarba, 2009), about 130 kilometres southeast of Lviv, Ukraine (Fig. 1), where remains of a mammoth and three woolly rhinoceroses, and one nearly completely preserved rhinoceros were found in 1907 and 1929. Such a good state of preservation can be attributed to the presence of preserving components, *i.e*. oil and brines (Kotarba *et al.*, 2009). These media abundantly occur in the near-surface beds of the Starunia area.

Complex surveys aiming at a detailed recognition of the geological setting in this area started in 2004 (Kotarba, ed., 2005). Gravimetry was one of the measurement methods and its use was dictated by the variable density of rocks, caused be the presence of brines, oil and ozokerite veins.

In the course of gravity surveys high-halite and ozokerite beds were localized within the Miocene salt-bearing Vorotyshcha beds (Madej & Porzucek, 2005), through which oil migrated from the deeper formations to the surface (Koltun *et al.*, 2005). Gravity surveys were continued in the years 2007 to 2008 and as a result a detailed description of geological setting in the area of former ozokerite mine could be worked out (Porzucek & Madej, 2009). At that time, microgravity surveys aiming at recognizing geological setting of the Quaternary sequence were also made. They were focused on determining areas where extinct animal remains can be potentially found.

METHOD

The gravity methods (microgravity surveys being their variant) make use of the gravity field distribution as a function of depth variation of the analysed rock formation (Fajk-

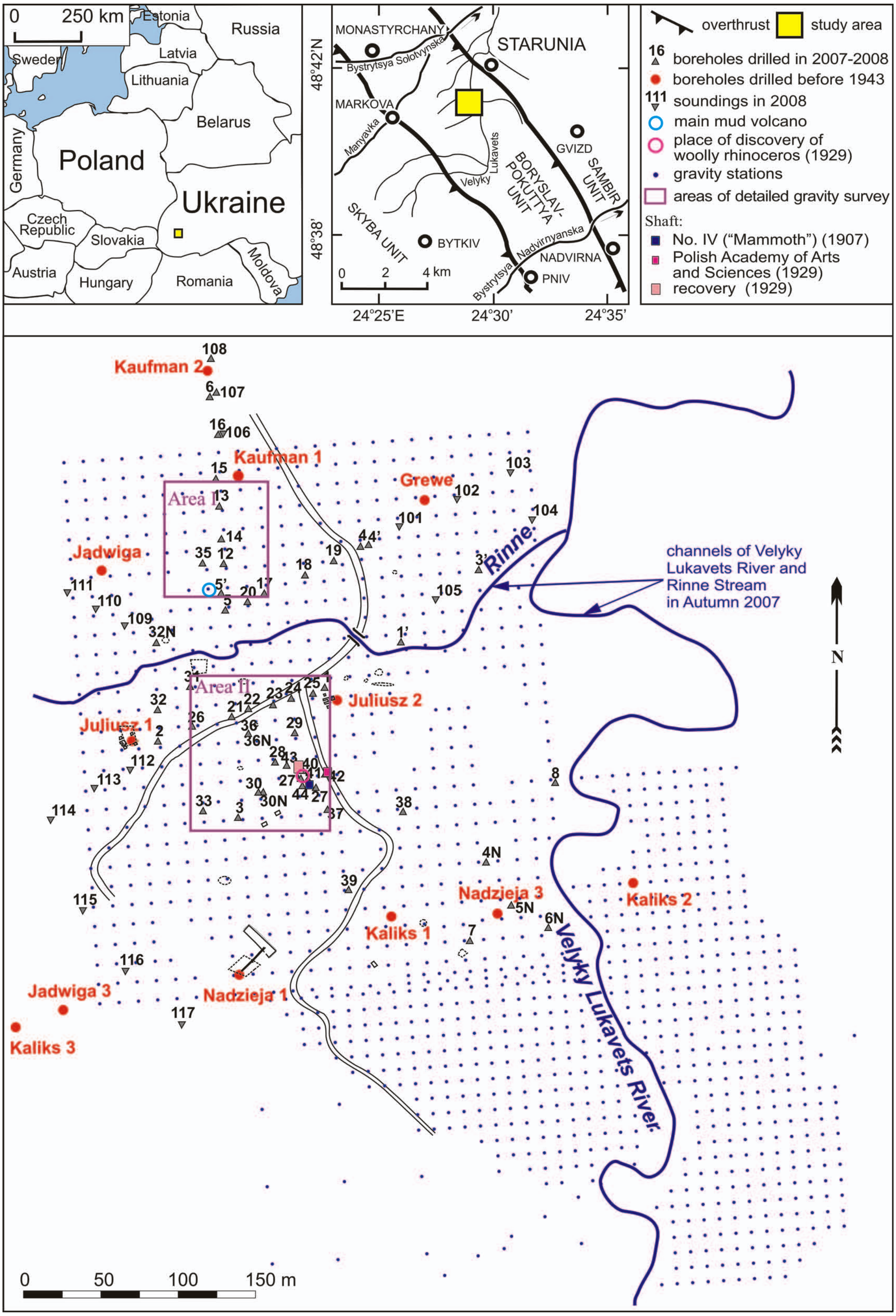

Fig. 1. Sketch map of the Starunia palaeontological site and surrounding area (Carpathian region, Ukraine) showing the location of the microgravity survey

lewicz, 2007). Such a variation can be attributed to the presence of geological forms and structures, the bulk density of which varies from those of the surrounding rocks.

The results of gravity surveys are presented in the form of gravity anomalies. If the density of rocks making up the geological structure is lower than that of the surroundings, then a relatively negative gravity anomaly is generated. A relatively positive anomaly is responsible for the presence of a structure of increased bulk density compared to the surrounding rocks. The magnitude of the observed anomaly depends on the difference in bulk density between geological structures, their depth and size.

The measured distribution of gravity anomalies is interpreted and on this basis their relation with the geological setting can be established.

In the analysed case this relation was limited to the analysis of anomalies, which can be attributed to the heterogeneities in the near-surface bed of the rock formation. At that depth interval, morphological fossil forms can occur, such as old swamps, marshes and lakes, being potential traps for animals. It was assumed that such forms have their representation in the form of relatively negative gravity anomalies.

Bearing in mind the objective of surveys, *i.e.* the recognition of near-surface beds of the rock formation, the authors localized the gravity stations at a distance of 10 m to 12.5 m. Microgravity observations were carried out with a Canadian gravimeter CG-3 Scintrex (accuracy ±0.01 mGal, and repeatability ±0.005 mGal).

The results of observations created the basis for calculating gravity microanomalies at the gravity stations. Allowances for the force of gravity were made in the calculations. The determined Bouguer microanomalies were related to the local reference level.

STUDY AREA

Microgravity surveys were made in the years 2007 to 2008 over a total area of *ca*. 0.2 km^2. The study area is presented in Fig. 1 at the background of a simplified topographic outline. In 2007, the surveys covered an area of *ca*. 0.1 km^2 in a grid of mesh 12.5×12.5 m, and in 2008 in a similar area, in a grid of 10×10 m mesh. In 2007, after prior analysis of the results, more detailed microgravity surveys were performed in two areas I and II, shown in Fig. 1. The measurements were made in the accessible nodes of a square grid (6.25 m side) in both these places, covering the areas of 130×110 m and 70x50 m.

GEOLOGICAL SETTING

In the area of the abandoned Starunia ozokerite mine, the Quaternary sediments of the Velyky Lukavets River valley are developed as clayey muds with plant remains, peat, biogenic muds, and peat muds (Sokołowski *et al.*, 2009; Sokołowski & Stachowicz-Rybka, 2009). Details of geology and petroleum occurrence in the Starunia area were published by Adamenko *et al.* (2005), Alexandrowicz (2004, 2005), Koltun *et al.* (2005), Korin (2005), Kotarba & Stachowicz-Rybka (2008), Sokołowski *et al.* (2009), Sokołowski & Stachowicz-Rybka (2009) and Stachowicz-Rybka *et al.* (2009) (see also references therein).

The top surface of the salt-bearing Miocene Vorotyshcha beds of the Boryslav-Pokuttya Unit in the Starunia area, which underlie Quaternary deposits, occurs at a maximum depth of 17 metres (Sokołowski *et al.*, 2009). The Miocene strata are sandstone-claystone breccias with halite, potassium-salt, gypsum and calcite layers, and veins of ozokerite (Mitura, 1944; Korin, 2005). Within these sediments many brine and salt water springs occur in the Starunia's vicinity. The Boryslav-Pokuttya Unit is the main oil and gas reservoir in the Ukrainian Carpathians. Tectonically, the unit represents a stack of superimposed nappes, each of them comprising the flysch sequence covered by molasse (Koltun *et al.*, 2005).

RESULTS

Microgravity surveys enabled authors to obtain a distribution of Bouguer gravity anomalies (*cf*. Fig. 2). An extensive, relatively negative gravity anomaly dominates there. Its NW to SE trend corresponds with the Miocene Vorotyshcha salt-bearing beds (Korin, 2005). The modelling reveals that the presence of a high-halite saline formation with ozokerite veins, described by Mitura (1944), is a source of this microanomaly (Porzucek & Madej, 2009). The density in this part of the formation is over 0.2 g cm^{-3}, *i.e.* lower than the density of the surrounding rocks.

The dominant anomaly consists of negative gravity anomalies, which owing to their amplitude and range will be later called microanomalies (Fajklewicz, 1980). These microanomalies are indicative of density variations of the near-surface part of the formation.

Six anomalous areas from A to F (Fig. 2) can be distinguished from the analysis of distribution of Bouguer anomalies. Negative, concentric, loop-shape anomalies are visible in anomalous areas B, C, D and E. They denote the existence of lower-density beds in these places. The analysis of lithological logs of boreholes explicitly shows that these microanomalies do not have any correspondence with the increased thickness of the overburden.

In the north-western part of the analysed area, near the Rinne fault, an anomalous area A was determined. In the gravity anomaly distribution, this area can be seen as a local lowering of gravity horizontal gradient, indicative of the existence of lower-density beds. Lithological borehole logs reveal that their formation may be attributed to the existence of a several metre-thick peat layer, the density of which is much lower than that of the remaining ones (Sokołowski *et al.*, 2009).

Similar to anomaly A, another gravity anomaly area denoted as F, is shown as a lowering of gravity horizontal gradient. It can be found near the confluence of the Rinne Stream to the Velyky Lukavets River. The cause of its generation remains unknown. Judging from borehole No. 3' on the river bank, the anomaly can not be attributed to the existence of the peat layer.

Anomalous areas A and B were subjected to more detailed microgravimetric surveys, the results of which will be presented later in this paper. It should be noted that the woolly rhinoceros was found at the edge of the microanomaly in area B, whereas area A was close to mud volcanoes.

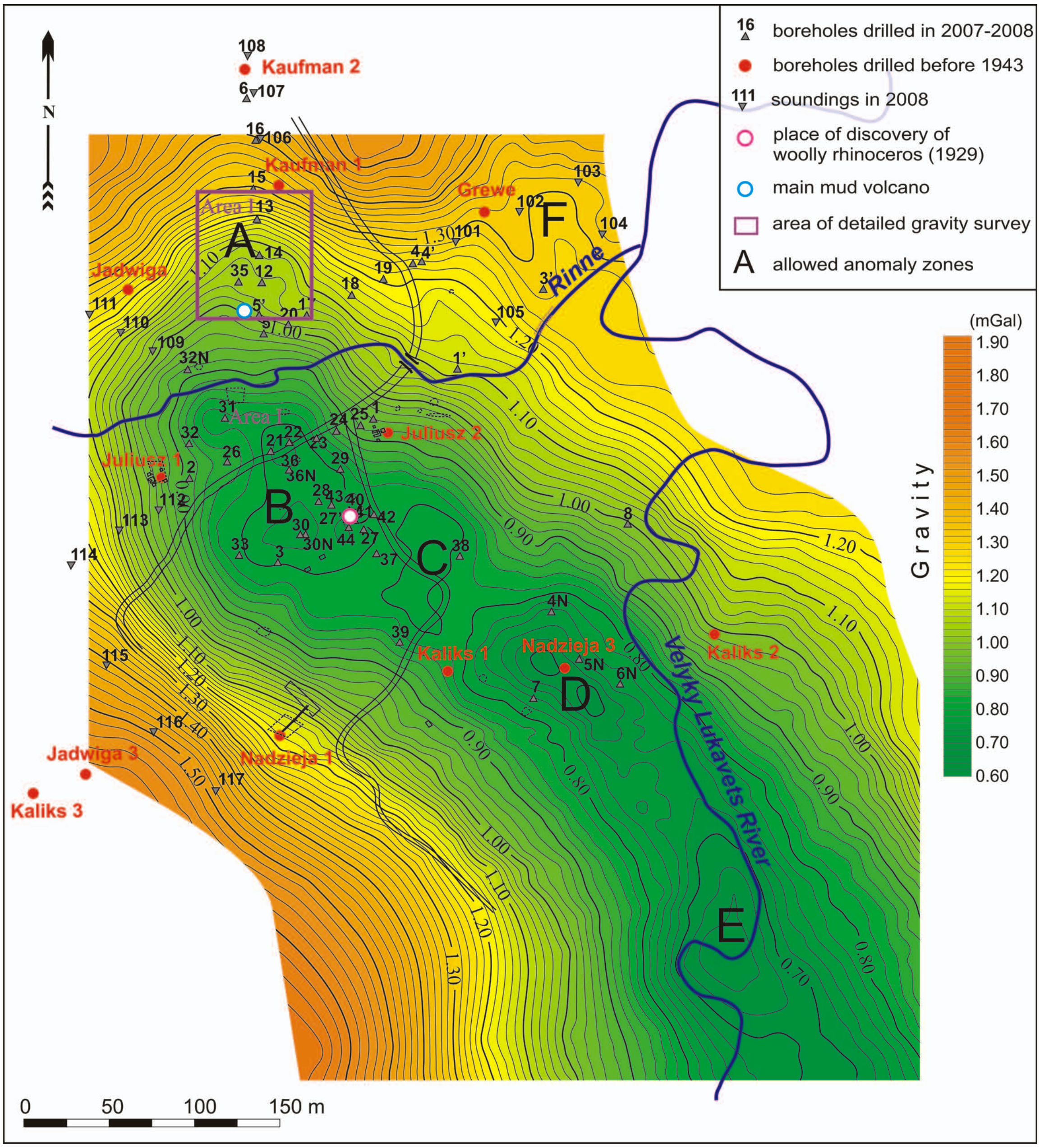

Fig. 2. Surface distribution of the Bouguer microanomalies

INTERPRETATION AND DISCUSSION

The interpretation of gravity results lies in finding a relation between the measured distribution of gravity microanomalies and the geological setting. However, the measured distribution of gravity microanomalies is a superposition of gravity impact of regional structures and local geological forms. The influence of local forms is represented by local microanomalies, whereas deep and large geological structures are caused by regional anomalies.

The qualitative interpretation lies in specifying, which of the measured gravity anomaly area is regional and which one is local. This can be done with various methods, and the selection of the proper one depends on a number of factors. The most important element determining its selection is the form of the regional area obtained from transformation, which should approximate the shape of the measured anomalies. In practice, the regional area is assumed to represent a distribution having a smooth shape of isolines. At the same time, the interpreted shape of the regional area should convene with the regional geological setting. Therefore, the determined trend of regional area should be first of all ascribed a geological interpretation in the discussed case. The trend will correspond to the gravity influence of the salt-bearing structure. For determining the trend, *i.e.* the shape of the regional area, the Griffin's averaging method was used (Griffin, 1949). The choice of this method was dictated by its filter-based character. The shape of the thus calculated field in the area of microgravimetric measurements remains unaffected by other, distant fields of gravity distur-

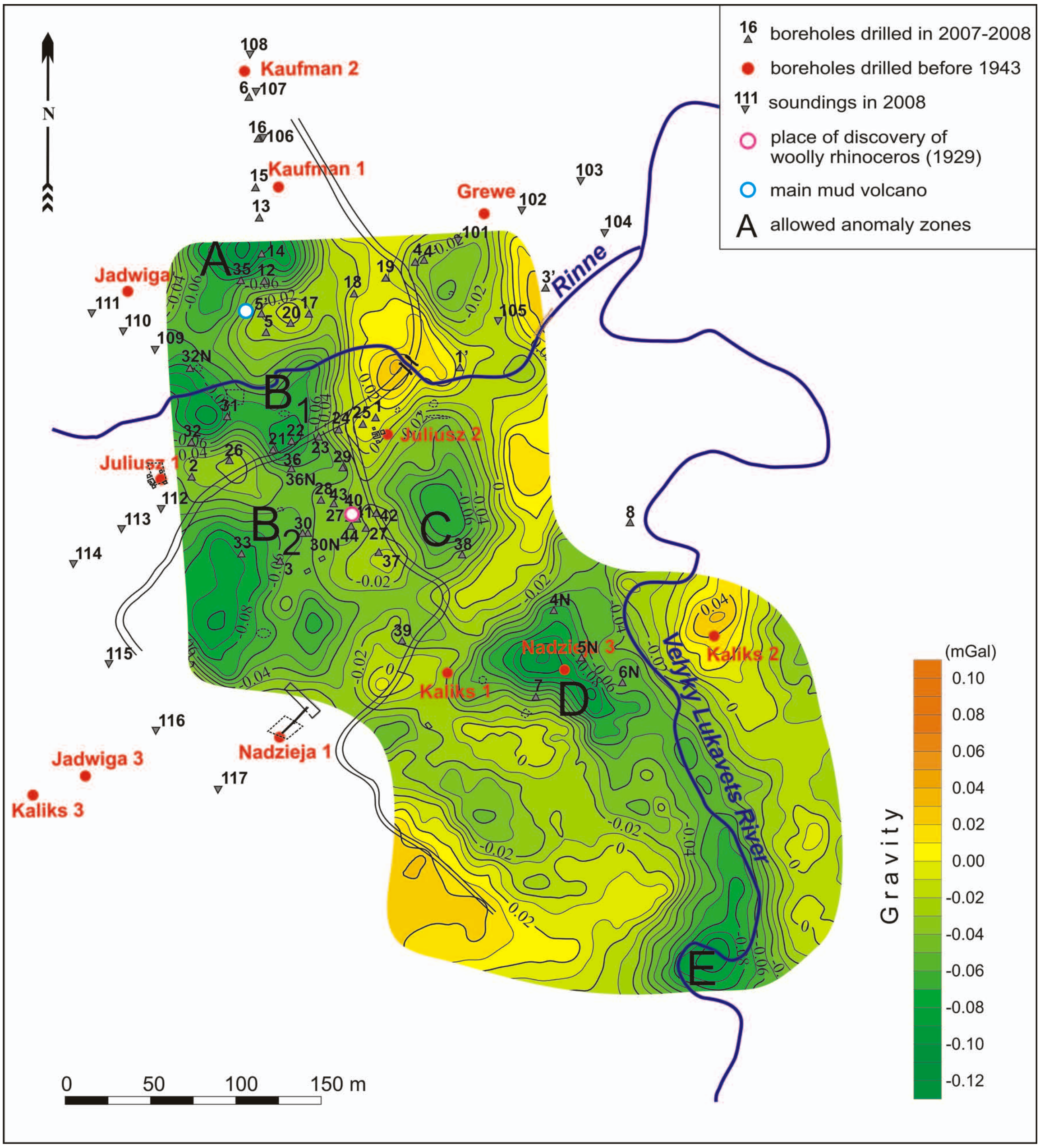

Fig. 3. Surface distribution of the residual microanomalies (regional field was calculated using the Griffin's method for radius 50 m)

bances. In the Griffin's method, the weighted average of a circle drawn from the measurement station point is assumed to be the regional gravity anomaly at that point. The shape of the thus defined regional anomaly depends on the assumed radius of averaging of the measured field values. Thus, a number of local anomalies can be obtained when calculating the local anomaly as a difference between the measured value and the regional anomaly. In reality, however, only one local anomaly exists as its existence depends on a specific near-surface geological setting. Accordingly, calculated anomalies are usually called local residual anomalies, which, owing to their small size and amplitude, will be later called residual microanomalies. Residual microanomalies were determined with the Griffin's method for two radii: 50 m and 25 m long.

The distributions of residual microanomalies calculated on the basis of values of a regional area, established with the Griffin's method for radii equal to 50 m and 25 m, are presented in Figs 3 and 4, respectively.

The distribution of residual microanomalies for a radius equal to 50 m is given in Fig. 3. The courses of relatively positive and negative local microanomalies can be seen in the distributions. They contain the already determined anomalous areas (A to E). The calculation of residual anomalies with the Griffin's method results in losing information at the edges of the analysed area, the width of which equals to the assumed radius, and the anomalous area F is not indicated. The obtained courses of microanomalies represent the distribution of density in the sub-Quaternary part of the Miocene beds.

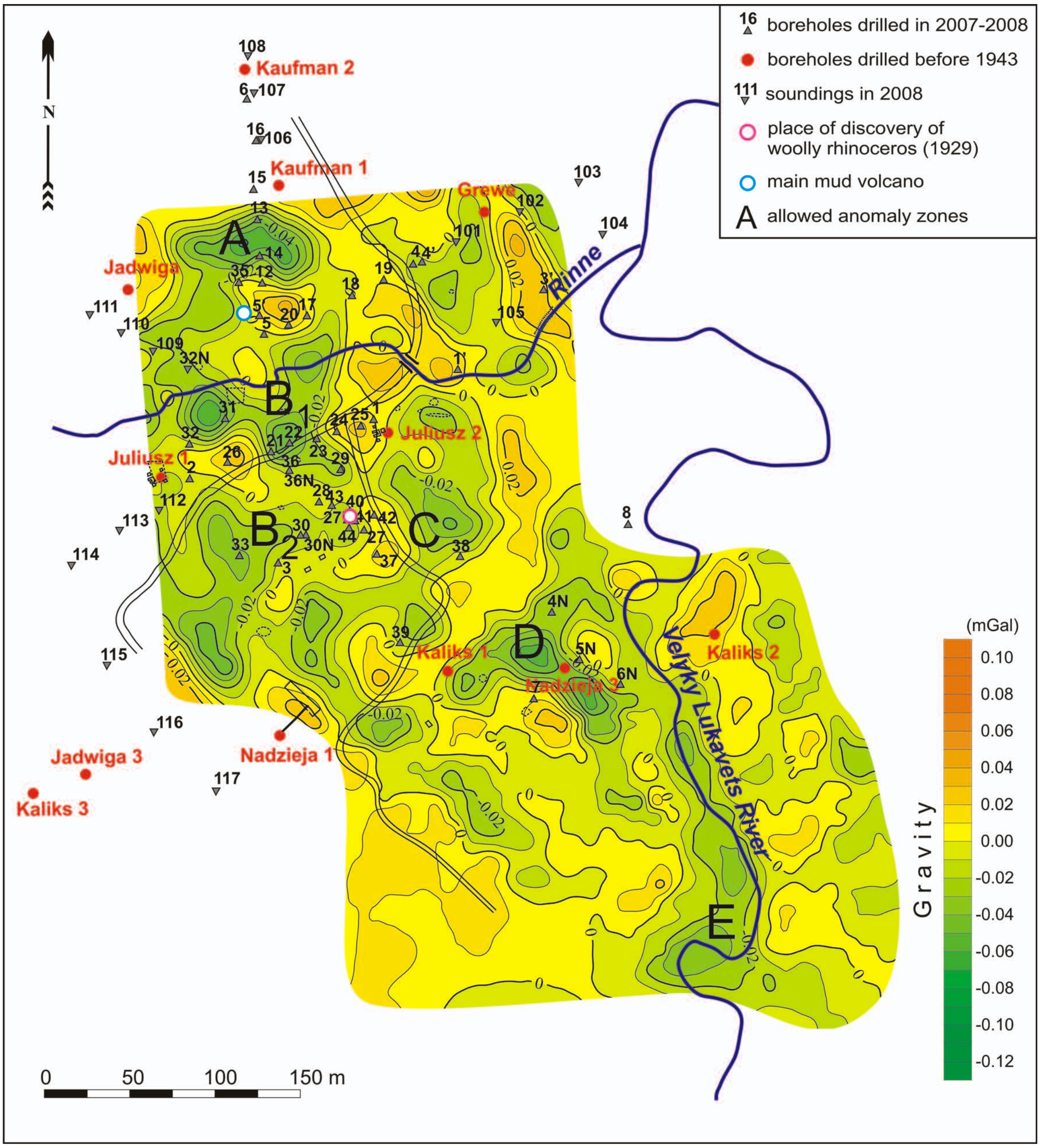

Fig. 4. Surface distribution of the residual microanomalies (regional field was calculated using the Griffin's method for radius 25 m)

The distribution of residual microanomalies obtained for a radius equal to 25 m generally represents the distribution of density in Quaternary strata (Fig. 4). The already determined anomalous areas are clearly visible in the distribution, except for area F.

A relatively negative residual anomaly of concentric shape appears in the anomalous area A (Fig. 4). Descriptions will be used for denoting all the microanomalies further in this paper. As already mentioned, the causes of its generation should be attributed to the presence of a peat layer. This is evidenced by lithological logs of boreholes Nos 13 and 14, located at the edges of the microanomaly, where a 3-m-thick peat layer was found. Detailed microgravity surveys were made in this area. The results are presented in Fig. 5 in the form of a distribution of Bouguer microanomalies and a distribution of residual microanomalies calculated with the Griffin's method for radii equal to 10, 15, 20 and 25 m, respectively. A microanomaly can be observed even for a 10 m radius. This may indicate a very shallow origin of the microanomaly and prove its relations with the peat layer. The successive distributions of residual microanomalies reach deeper layers, data are gathered from the surface, and the range of peat occurrence can be better determined.

The already defined anomalous area B (Fig. 2) is very interesting as zoological relics, *e.g.* a very well preserved woolly rhinoceros, were found there. In the distribution of residual anomalies (Fig. 4), two relatively negative residual microanomalies B_1 and B_2 can be found in that area. Microanomaly B_1 continues to the north and northwest, assuming

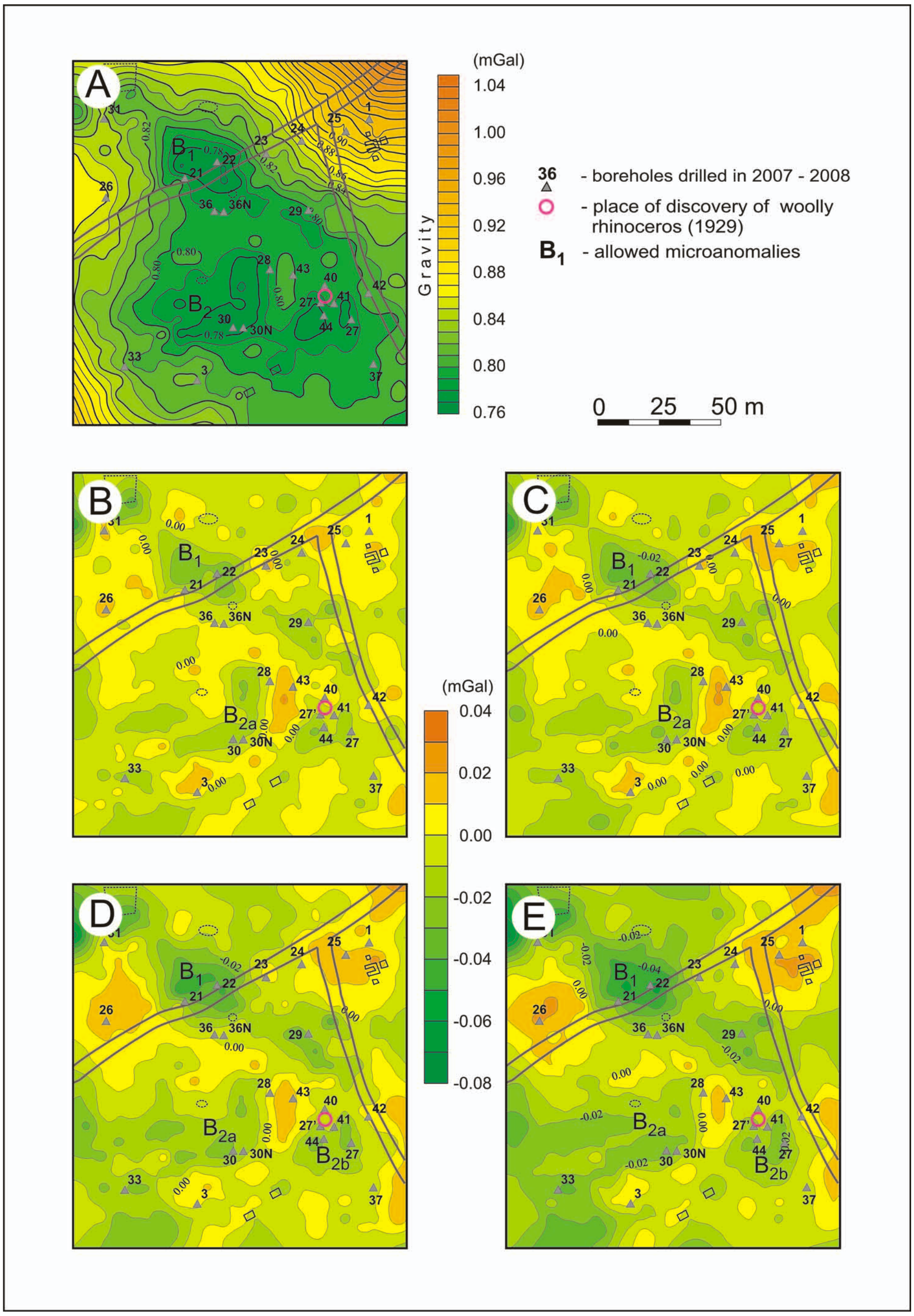

Fig. 5. Surface distribution of the Bouguer microanomalies (**A**) and surface distributions of the residual microanomalies (**B–E**) (regional field was calculated using the Griffin's method for radii: 12.5, 15, 20 and 25 m, respectively) in area I

a V shape. Data from boreholes Nos 21 and 22 point to the existence of over 1-m-thick peat layer, very near the surface. Therefore, microanomaly B can be related with the existence of these layers, analogous to microanomaly A. Microanomaly B_2 continues to the west from the place of finding of zoological relics. Borehole data are not indicative of the existence of lower-density beds, generating this anomaly.

Detailed microgravity surveys were performed in the anomalous area B and the results are presented in Fig. 6. In the Bouguer microanomaly distribution (Fig. 6A), a fragment of microanomaly B_1 is well visible and the relatively negative microanomaly B_2 splits into two microanomalies B_{2a} and B_{2b}. Similar to detailed surveys of anomalous area A, the residual microanomaly was determined with the Griffin's method for radii equal to 10, 15, 20 and 25 m (Fig. 6B–E). The distributions for the successively increasing radii illustrate deeper sources of microanomaly generation. These distributions confirm that near-surface density changes are the source of microanomaly B_1, therefore, linking this microanomaly with the existence of peat is justified. Boreholes Nos 30, 30N and 33 were drilled within the area

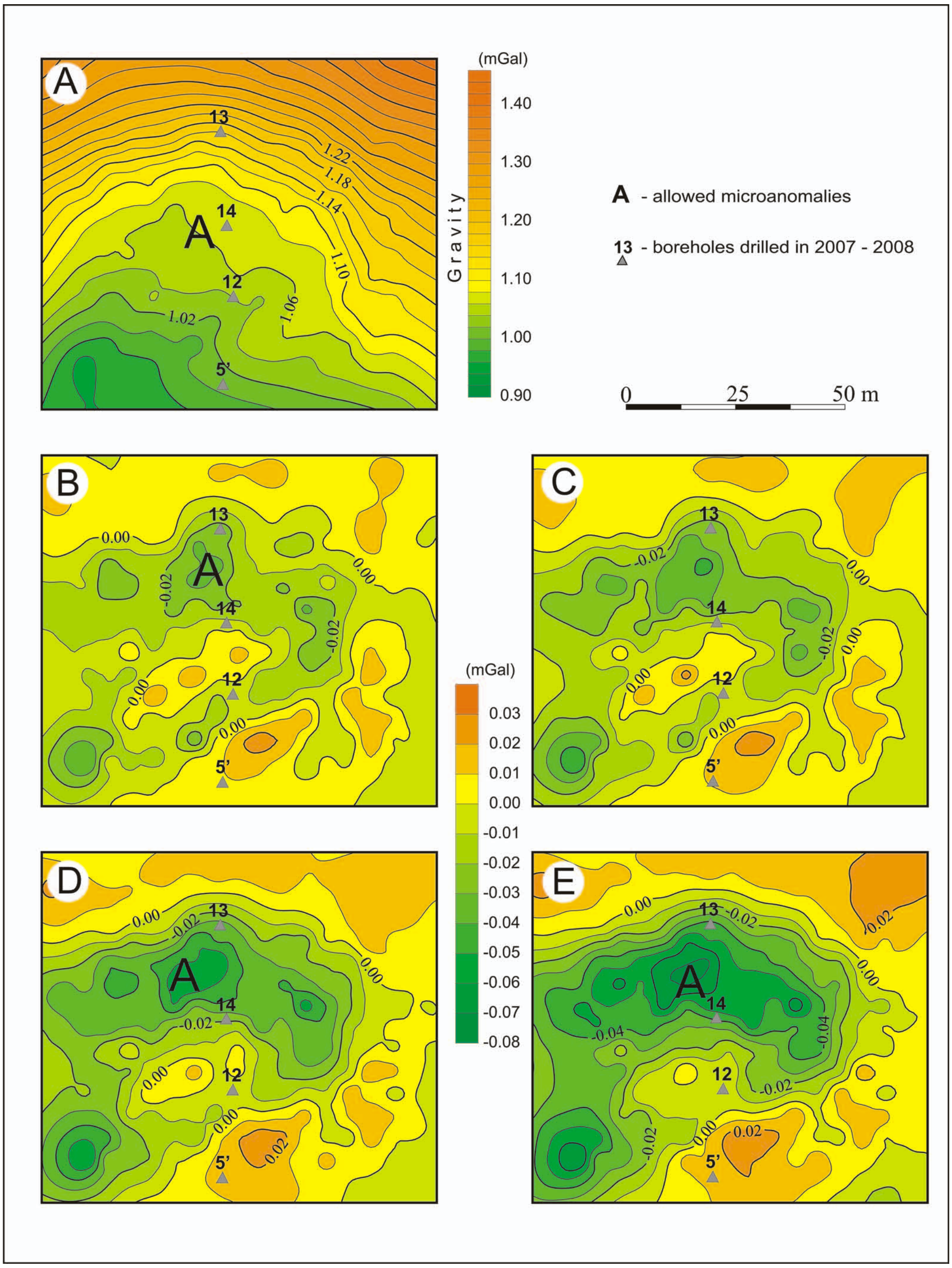

Fig. 6. Surface distribution of the Bouguer microanomalies (**A**) and surface distributions of the residual microanomalies (**B–E**) (regional field was calculated using the Griffin's method for radii: 12.5, 15, 20 and 25 m respectively) in area II

of microanomaly B_{2b}. The lithological logs of these boreholes do not point to the existence of lower-density beds, *i.e.* potential sources of the microanomaly. It seems likely that the microanomaly was generated from minor density changes within the Quaternary strata, which do not have any direct connection with the lithology, and which can be inferred from the non-concentric shape of the micro-anomalies.

The relatively negative microanomaly B_{2b} is practically invisible for a radius 10 m long, weakly visible for a radius of 15 m, and clearly visible for longer radii. The microanomaly, *ca*. 25 m in diameter, is concentric in shape. Boreholes Nos 27, 27', 41 and 44 are localized within this microanomaly. In all these microanomalies, the overburden dominated in the lithological profile. Nevertheless, the existence of an increased overburden thickness should not be associated with the presence of microanomalies, which can be proved by lithological logs of boreholes Nos 40 and 43, situated beyond the range of the microanomaly. It is especially well visible for borehole No. 43, which is localized within the relatively positive microanomaly (Fig. 6B–E). Although the borehole data are most reliable, one should remember that these are point data. The concentric microanomaly B_{2b} points to the existence of beds having lower density than that of the surrounding formation. The shape of the microanomaly can be attributed to the gravity impact of the possible palaeoswamp, on the edge of which zoological relics were buried. This hypothesis seems to be plausible, especially since a woolly rhinoceros was found at the edge of microanomaly B_{2b}.

A concentric and relatively negative residual microanomaly is visible in the anomalous area C (Fig. 4). Unfortunately, no boreholes were drilled there. This microanomaly is localized in a course of relatively negative residual microanomalies, coinciding with a small water course running from "Nadzieja 1" well to the vicinity of borehole "Juliusz 2". One can associate the course of anomalies with the water route, and with the low density near-surface layers formed and transformed by water. Besides, the centre of microanomaly C coincides with the remains of an artificial water reservoir.

The distribution of residual microanomalies (Fig. 4) in the anomalous area D differs from the distribution of Bouguer anomalies (Fig. 2). After removing the regional trend, a T-shape microanomaly could be distinguished. Borehole No. 4N was drilled inside, whereas boreholes Nos 5N, 6N and 7 are located at the edge of this microanomaly. A fragment of the microanomaly, forming the upper part of the "T", can be explained by the existence of swamp areas, which analogically to microanomaly C, can generate a relatively negative microanomaly. The cause of origin of the remaining part of the microanomaly (greater amplitude and visible in the distribution of the Bouguer anomaly; Fig. 2) is probably different. The Euler deconvolution method (Thompson, 1982) in a version adjusted to interpretation of microgravity results (Porzucek, 2004) was used for determining the depth of the body responsible for generating this part of the microanomaly. Accounting for the elongated shape of the microanomaly, the authors assumed that the microanomaly was generated by a horizontal cylinder. The calculations indicated that the axis of the assumed horizontal cylinder was located at a depth of *ca*. 8.5 m. Unfortunately, boreholes Nos 5N, 6N and 7 were located at the edges of the microanomaly and the lithological section of beds in the central parts of the microanomaly remained unknown. However, the high sand and gravel contents were observed for these boreholes. Perhaps, more such beds are present within the microanomaly, and their density is lower than that of the clayey muds that dominate in the Quaternary strata.

The anomalous area E (Fig. 2), is another relatively negative residual gravity microanomaly (Fig. 6). The course of these microanomalies clearly coincides with the course of the Velyky Lukavets River. Hence, a conclusion appears that the river primarily contributed to the relatively negative microanomaly formation. The vicinity of the river, which is cut into the formation by several metres, results in dewatering and weakening of the formation in its immediate neighbourhood. Moreover, the localization of measurement stations in the immediate vicinity of the river introduces the element of error, because of the gravity impact of the complex morphology of the area.

CONCLUSIONS

Microgravity surveys in the area of abandoned Starunia ozokerite mine revealed six anomalous areas of relatively low gravity values (Fig. 2). Four of them (B, C, D and E) are localized under a layer, the density of which is lower compared to the neighbourhood, and belonging to the Miocene Vorotyshcha salt-bearing beds (Porzucek & Madej, 2009). The anomalous area A is located in the Rinne fault zone (Porzucek & Madej, 2009), whereas area F at the confluence of the Rinne Stream with the Velyky Lukavets River.

The residual gravity microanomalies determined on the basis of the Griffin's method were calculated during interpretation. The distribution of residual gravity microanomalies calculated for a radius of 50 m showed a density variability of the sub-Quaternary part of the Miocene beds (Fig. 3). By removing the regional trend from the Bouguer anomaly by employing the Griffin's method for a radius equal to 25 m, the authors obtained a distribution of residual gravity anomalies, being a representation of the distribution of density in the Quaternary strata (Fig. 4). This distribution confirmed the existence of earlier anomalous areas, making their description more precise. Accordingly, the relatively negative microanomalies A and B_1 (Fig. 4) should be associated with the existence of a shallow peat layer. This has been also proved by detailed investigations in areas A and B (Figs 5, 6).

The courses of relatively negative residual gravity microanomalies are visible in Fig. 4; after relating them with areas C and D one may arrive at a conclusion that their origin is connected with the existence of near-surface loose layers formed by the activity of small water courses.

The major part of microanomaly D (Fig. 4) may be attributed to the potential existence of high sand and gravel layers in the Quaternary strata.

Area E is certainly related with the existence of the Velyky Lukavets River, which may cause a decrease in the density of the neighbouring beds by dewatering processes. The gravity values may be also lowered owing to the complex landscape.

Detailed microgravity surveys enabled finding microanomaly B_{2b} (Fig. 6). At its edge, a very well preserved woolly rhinoceros was previously found. Should the hypothesis that the rhinoceros had sunk in the palaeoswamp be true, the area of the gravity microanomaly might coincide with the range of the swamp.

Microgravity surveys were performed in the area of the abandoned Starunia ozokerite mine with numerous shafts opening up into the field. Based on our experience, abandoned shafts were observed to have no impact on the distribution of gravity microanomalies based on microgravity surveys. Detailed surveys performed for the two areas did not reveal any influence of the abandoned shafts on the measured gravity values. This may indicate that the average density of material, with which the shafts were covered, was equal or similar to that of the neighbouring formation. No dependence between the thickness of overburden and the distribution of gravity microanomalies was observed. This confirms that the density of the overburden material was similar to the density of the Quaternary strata.

Beds of the same lithological composition may have different densities, which in turn may generate small-amplitude microanomalies. These anomalies, however, should be bigger in size and more concentric in shape, like, *e.g.* microanomaly B_{2a}.

The results of microgravity surveys explicitly reveal that the most interesting zones within the Pleistocene sediments should be limited to the sub-Quaternary low-density salt-bearing subcrop (Porzucek & Madej, 2009). The thickness of Quaternary sediments was increased owing to flood incidents and presence of local swamp areas (peat). Microgravity surveys revealed a number of gravity microanomalies in this region. They reflect the presence of changes of geological material from that of the neighbouring formation. Detailed analysis of the selected areas may result in finding small, concentric microanomalies, potentially connected with the existence of hypothetical palaeoswamps, where the Pleistocene animals could have drowned.

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REFERENCES

Adamenko, O. M., Stelmakh, O. R., Zinchuk, M. S. & Kotarba, M. J., 2005. History of petroleum exploration in the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 53–61.

Alexandrowicz, S. W., 2004. Starunia and the Quaternary research in the tradition and initiatives of the Polish Academy of Arts and Sciences. (In Polish, English summary). *Studia i materiały do dziejów Polskiej Akademii Umiejętności*. Polska Akademia Umiejętności, Kraków, 3, 261 pp.

Alexandrowicz, S. W., 2005. The history of Starunia – a palaeontologic site and old ozokerite mine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 21–38.

Fajklewicz, Z., 1980. *Mikrograwimetria górnicza.* (In Polish). Wydawnictwo Śląsk, Katowice, 264 pp.

Fajklewicz, Z., 2007. *Grawimetria stosowana.* (In Polish). Uczelniane Wydawnictwa Naukowo-Dydaktyczne, AGH, Kraków, 433 pp.

Griffin, W. R., 1949. Residual gravity in theory and practice. *Geophysics*, 14, 1: 39–56.

Koltun, Y. V., Dudok, I. V., Kotarba, M. J., Adamenko, O. M., Pavluk, M. I., Burzewski, W. & Stelmach, O. R., 2005. Geological setting and petroleum occurrence of the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 61–77.

Korin, S. S., 2005. Miocene salt-bearing Vorotyshcha Beds in the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 79–86.

Kotarba, M. J. (ed.), 2005. *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków, 218 pp.

Kotarba, M. J., 2009. Interdisciplinary studies at Starunia palaeontological site and vicinity (Carpathian region, Ukraine) in the years 2006–2009: previous discoveries and research, purposes, results and perspectives. *Annales Societatis Geologorum Poloniae*, 79: 219–241.

Kotarba, M. J. & Stachowicz-Rybka, R., 2008. Wyjątkowe stanowisko paleontologiczne i środowisko osadów plejstoceńskich, w których znaleziono nosorożce włochate w Staruni (Karpaty Wschodnie). (In Polish). *Przegląd Geologiczny*, 56: 442–452.

Kotarba, M. J., Więcław, D., Toboła, T., Zych, H., Kowalski, A. & Ptak, S., 2009. Bitumen and salt contents within the Quaternary sediments at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 447–461.

Madej, J. & Porzucek, S., 2005. Elements of geological setting of former ozokerite mine based on gravity survey in Starunia, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 115–124.

Mitura, F., 1944. *Geologia złoża wosku w Staruni*. (In Polish). Unpublished report, Archive of the Jagiellonian University, Kraków, 18 ms. pp.

Porzucek, S., 2004. *Dekonwolucja Eulera w interpretacji ilościowej wyników badań mikrograwimetrycznych.* (In Polish). Unpublished Ph.D. thesis, Archives of the AGH University of Science and Technology, Kraków, 105 pp.

Porzucek, S. & Madej, J., 2009. Recognition of geological structures at Starunia palaeontological site and vicinity (Carpathian region, Ukraine) based on gravity surveys. *Annales Societatis Geologorum Poloniae*, 79: 357–363.

Sokołowski, T. & Stachowicz-Rybka, R., 2009. Chronostratigraphy and changes of environment of Late Pleistocene and Holocene at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 315–331.

Sokołowski, T., Stachowicz-Rybka, R. & Woronko, B., 2009. Upper Pleistocene and Holocene deposits at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 255–278.

Stachowicz-Rybka, R., Granoszewski, W. & Hrynowiecka-Czmielewska, A., 2009. Quaternary environmental changes at Starunia palaeontological site and vicinity (Carpathian region, Ukraine) based on palaeobotanical studies. *Annales Societatis Geologorum Poloniae*, 79: 279–288.

Thompson, D. T., 1982. EULDPH – A new technique for making computer-assisted depth estimates from magnetic data. *Geophysics*, 47: 31–37.