GEOLOGIJA. 2008. Vol. 50. No. 3(63). P. 156–169
DOI: 10.2478/v10056-008-0041-2

Comparison of mineral resources calculation methods for different genetic types of gravel and sand deposits

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Patašova T., Jurgaitis A. Comparison of mineral resources calculation methods for different genetic types of gravel and sand deposits. *Geologija*. Vilnius. 2008. Vol. 50. No. 3(63). P. 156–169. ISSN 1392-110X

Calculation of mineral resources and their proper assessment is relevant, since the stock of resources determines the economic independence of the state. The present work discusses gravel and sand deposits of different genetic type (kames, eskers, marginal glaciofluvial ridges, sandurs, glaciofluvial deltas and redrifted glaciofluvial aeolian formations). Their geological structure and formation conditions have been assessed; quality characteristics of mineral resources have been analysed; calculation of resources has been performed by applying old methods used in Lithuania up to now, such as those of geological blocks, profiles and isolines, as well as the up-to-date GRID method created on the basis of the triangle method in GIS environment. Comparison of resources assessed by different methods has revealed their advantages and disadvantages.

Key words: mineral resources, gravel and sand deposits, genetic types, different methods

Received 06 May 2008, accepted 20 June 2008

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INTRODUCTION

The knowledge of land subsurface as an exclusive national property, and assessment of resources lying in it is always a very important thing because it determines the economic independence of a state. At present, when local raw materials get growing significance in economic development, a forecast should be made how the potential of land subsurface could be maximally used. One of key factors for rational use of resources is a correct inventory of resources, which was started at the time when the mankind has understood that the resources are not infinite. Presently, there are about twenty methods of calculation used to assess the resources, but only few are used for practical purposes. The methods of profiles, geological blocks, exploitation blocks, polygons, triangles and isolines are most popular and often used (Авдонин и др., 2007; Ажгирей и др., 1954; Борзунов, 1969, 1982; Каждан, 1984).

In Lithuania, the method of geological blocks is most often used, whereas methods of profiles and isolines are rarer applied. With computer technologies, new opportunities appear to improve resources inventory by modern computer techniques (Bell, 2007); nevertheless, in Lithuania, simpler calculation methods are used, resulting, however in, a deficit or surplus of resources and thus raising new problems: it is unclear whether a calculation error occurred the or initial data were unreliable, then, all the hypotheses should be checked out, additional time and investments being consumed. Therefore, with the evolution of the national economy as well as new opportunities appearing, it is expedient to adjust and improve the employed methods as well as the normative documents regulating them.

The present work deals with several selected gravel and sand deposits of different origin, their geological structure and formation conditions have been evaluated; quality characteristics of mineral resources have been analysed; calculation of resources has been performed by different methods.

METHODS

Gravel and sand deposits of different genetic type (kames, eskers, marginal glaciofluvial ridges, sandurs; glaciofluvial deltas and drifted glaciofluvial aeolian formations) (Table 1) situated in Lithuania's area (Fig. 1) have been selected for our investigation.

Databases of the Lithuanian Geological Survey and G. Juozapavičius PE "Magma" enabled to highlight contours for calculation of resources in the selected deposits, and on profile structure and composition obtained during prospecting drillings in these deposits were accumulated. After all the material had been collected, calculations were made first of all to determine the thickness of mineral beds in a deposit and the altitudes of the top and bottom of the beds. All these data were necessary to form the geological / lithological profiles,

Table 1. **General data on mineral deposits studies (Šinkūnas, Jurgaitis, 1998)**
1 lentelė. **Tirtų telkinių bendri duomenys (Šinkūnas, Jurgaitis, 1998)**

Genetic group and subgroup	Genetic type	Genetic subtybe	Genetic variety	Relation to glacier	Deposit title	Deposit type	District	Area, ha	Mineral bed			
									Structure	Thickness, m		
										Min	Max	Ave
Glaciofluvial	Intraglacial	Kames	Glaciofluvial (kame-fluvial)	Glacial environment, intraglacial sub-environment	**Boguškiai II plot 1**	G	Alytus	3.5	Gravel, in places-sand with gravel in the lower part	12.1	16	14.1
					Boguškiai II plot 2	G	Alytus	12.1		8.6	18.9	14.7
					Boguškiai II plot 3	G	Alytus	2.6	Various grained gravel and sand	9.5	16.5	14.2
		Eskers	Radial	Glacial environment, subglacial sub-environment	**Kušlėnai**	GS	Mažeikiai	23.8	Coarse or fine gravel, also various-grained sand	3.20	18	10.1
	Marginal	Marginal ridges	Stream-laid	Periglacial environment, terminal glacial sub-environment	**Sniegiai**	G	Rokiškis	31.9	Various coarseness gravel with rare sand lenses	2	26.8	15.6
	Periglacial	Sandurs	Outwash (sandur) plain	Periglacial environment, proglacial sub-environment	**Šklėriai**	S	Trakai	36.1	Various coarseness gravel and sand	5.5	18.3	10.6
		Deltaic	Valley mouth	Periglacial environment, proglacial sub-environment	**Selmoniškiai**	G	Tauragė	9.4	Coarse or fine gravel, and various-grained sand in the upper part	1.5	12.5	8.35
Eolian		Redrifted glaciofluvial		Periglacial environment, extraglacial sub-environment	**Sandrupys**	S	Varėna	95.3	Various-grained sand	3.6	23.9	13.9

Notes. G – gravel deposits, S – sand deposits, GS – gravel and sand deposits, Min – minimum, Max – maximum, Ave – average.

Fig. 1. Location of mineral deposits:
1 – site of deposits
1 pav. Tirtų telkinių situacijos schema:
1 – tirtų telkinių vieta

mineral bed thickness values, top and bottom surfaces to be used for calculation of resources performed by applying old methods used in Lithuania up to now – those of geological blocks, profiles, isolines – as well as the up-to-date GRID method elaborated on the basis of the triangle method in GIS environment.

Method of geological blocks. This method is the simplest one and requires least labour expenditures. The calculation of resources in this case is based on dividing a geological mineral body into separate figures or blocks, their height being the mean thickness of a mineral bed in each block. In dividing the body into blocks, such things as quality characteristics, bed thickness, occurrence conditions, hydrotechnical and hydrogeological conditions are taken into account. The volume of a mineral bed in each block is calculated according to the formula (Deltuva et al., 2006; Авдонин и др., 2007; Борзунов, 1982):

$$V = S \times h_{vid} , \quad (1)$$

where S is the area of the block, and h_{vid} is the mean thickness of the mineral bed in a block.

The total volume of the mineral bed is a sum of mineral bed volumes in all blocks.

In the simplest case of using this method, a geological body is treated as one block without dividing it. In practice, it is called the mean arithmetical method.

Method of profiles. This method may be used for deposits prospected by drilling along straight lines suitable to make geological profiles. These profiles divide a geological body into separate parts, i. e. blocks. To calculate the resources, first of all the area of a mineral bed in each profile is measured. Then the distance between the two adjacent profiles is measured. This distance is divided by half. The product of the mineral bed area in a corresponding profile and the sum of inter-profile distances is the volume of a mineral bed in a block:

$$V = S_{pr} \times (a_1 + a_2), \tag{2}$$

where S_{pr} is mineral bed area in a profile, and a_1, a_2 – distances between adjacent profiles.

Summation of the volumes of separate blocks gives the total volume of a mineral bed in a deposit.

Such calculation technique is applied in the cases of parallel profiles. In practice, however, often non-parallel profiles occur. In this case, A. Zolotarev's formulas can be used (Авдонин и др., 2007; Борзунов, 1982; Каждан и др., 1990; Кноринг и др., 1989):

– when the angle between the profiles in the plan is less than 10°:

$$V = \left(\frac{S_{pr1} + S_{pr2}}{2}\right) \times \left(\frac{H_1 + H_2}{2}\right), \tag{3}$$

where S_{pr1}, S_{pr2} are mineral bed area in the profiles, and H_1, H_2 are the lengths of perpendiculars falling from the profile area centre projections upon the opposite prospecting line;

– when the angle between the profiles in the plan is more than 10°:

$$V = \left(\frac{\alpha}{\sin\alpha}\right) \times \left(\frac{S_{pr1} + S_{pr2}}{2}\right) \times \left(\frac{H_1 + H_2}{2}\right), \tag{4}$$

where α is the angle between the profiles, in radians; other signs as in formula 3.

The main difficulty in using A. Zolotarev's formula is determination of the weight centre (Борзунов, 1982). To calculate resources between non-parallel profiles, a simplified method by A. Prokofyev is also used. This method, however, gives higher errors if the geological body is oblique in space.

J. Kolmogorov, as well as E. Pogrebicki and V. Ternov proposed a method that gives lower errors and stands good even if the geological body is oblique (Борзунов, 1982). Its point is that a whole block between two non-parallel profiles is divided into two sub-blocks: one of the profiles is projected so that the projection is parallel to one of the profiles. The volume of the first sub-block is calculated according to the formula:

$$v_1 = \left(\frac{S_{pr1} + S'_{pr2}}{2}\right) \times A, \tag{5}$$

where A is a distance between the profile and the other profile's projection onto a plane parallel to the first profile, S'_{pr2} is the area of a mineral bed in the profile projection, calculated according to the formula:

$$S'_{pr2} = S_{pr2} \times \frac{l'_2}{l_2}, \tag{6}$$

where l_2 is the profile length and l'_2 is the length of profile projection (parallel to another profile).

The volume of the second sub-block is calculated according to this formula:

$$v_2 = \frac{S_{pr2} \times h}{2}, \tag{7}$$

where h is a perpendicular falling from a profile projected of a marginal point onto a projection line.

Method of isolines. This method was described many years ago (Ажгирей и др., 1954), but it was not outspread in Lithuania. Using it, first of all, a map of mineral bed thickness isolines should be compiled. When the calculation of resources used to be performed manually, without a computer, the drawing of isolines was a rather complicated process. This was one of the reasons why this method was not widely used.

On compiling the map of mineral bed thickness isolines, the resources are calculated in the following way: from the plan of bed thickness calculations, the area limited by each isoline is measured, and after the frustum principle the volume of each segment is calculated using the formula:

$$V = (S_{virš} \times h_p) + (S_{ap} - S_{virš}) \times h_n, \tag{8}$$

where $S_{virš}$ is the area limited by the top isoline, S_{ap} is the area limited by the bottom isoline, h_p is the mineral bed thickness in the overlain zone and h_n is the mineral bed thickness in the non-overlain zone, in m.

The sum of all segment volumes gives the total volume of a mineral bed in the deposit.

GRID method. This method is based on the triangle method in GIS environment. In order to calculate the resources by this method, Geomap, Civil, MapInfo and ArcGIS or other types of GIS software are needed. The Geomap 2008 was used in the present work to calculate the resources. The GRID method uses approximations which depend on grid density. The denser the grid step the more precise is the volume calculated between the two active surfaces. The bottom and top surfaces of mineral bed are usually taken for calculations. The volume between them makes the volume of the mineral bed to be calculated. Using this method to calculate the volumes, both surfaces of an active surface group (i. e. the top and the bottom of a mineral bed) are covered by a grid. The programme uses prismoidal (a volume under 3D triangle) volumes of all grid cells and sums them up. The advantage of this method is that the surfaces remain active all the time; therefore, if the values in one of them change, the changed volume is also recalculated automatically. This is important after starting a mineral deposit utilisation, since it provides the possibility to monitor the changes of resources (calculate utilised volumes of resources and the remainder according to the same principles). Thus, this plan of calculation of resources becomes a dynamical model of resource calculation.

RESULTS AND DISCUSSION

On selecting the mineral deposits of different genetic types and generalised information about them, first of all the mineral bed thickness values, top and bottom surfaces as well as geological-lithological profiles have been built. In order to do this, Geomap 2008 and Mapinfo 9.0 Vertical Mapper software was used. Later, the calculation of resources was performed by the methods described above. To compare the different methods, the difference in resources from those obtained by the GRID method was expressed in percentage.

The results of resource calculation by the block method for several mineral deposits of different genetic types show that rather reliable data are obtained for even bottom deposits occurring under unchanging relief and dense borehole network conditions. The difference from GRID method results does not exceed 3%. When the relief's surface is irregular, the reliability of results is lower. This is shown by the calculation done for the Sandrupys aeolian sand deposit notable for a greatly dissected relief. Abutted dune massifs prevail in the environs of this deposit. Dune ridges are extending from north to south or southeast. Relative elevations range from 3–5 m to 15–20 m, and dune slopes are rather steep, reaching 15–20°. Absolute heights of the aeolian surface range here from 135.1 to 150.4 m. The mineral bed is formed here of Late Glacial and Holocene aeolian deposits which occur below the dune bottom on the glaciofluvial deposits of valley streams. Changes in the sand bed are caused by a greatly dissected relief of continental dunes. The thickness of this bed is the least in the interhill areas and the highest at dune tops. So, the mineral bed thickness ranges from 3.6 to 23.9 m, or 13.9 m on average. To assess such a great variation of mineral deposit by the block method is very difficult, since the calculation of resources by this method uses only data of boreholes, dug holes and interpolation points and the dissected relief is not taken into account, although this factor in the deposits of this genetic type affects the result of bed thickness determination. Unreliable results are obtained also in the case when the borehole network is not dense. This problem appeared when the block method was applied for calculating resources in the Selmoniškiai glaciofluvial deltaic gravel deposit. The difference form the GRID method results reached here even 11%. The structure of this deposit is not intricate, but in its axial part there is an ice-marginal valley with the highest thickness of the mineral bed. The network of drilled boreholes is insufficient to assess an increase in thickness of a mineral bed in such a valley. Moreover, applying the method of blocks becomes difficult after starting the exploitation of such a deposit because of slopes caused by excavation. When the deposit development takes place in several sites and the front of excavation is uneven, many levels of development are formed in different sites. One level is separated from another by excavation slopes. To make the calculation of the dug mineral and its remainder most precise, the blocks of resources are divided into sub-blocks and the resources are calculated separately for the development slope, its top and the bottom. Thus, in the case of many slopes formed in different sites during a deposit development, the resource calculation by the method of blocks becomes more complicated due to higher expenses. This is well illustrated in the plan of resource calculation performed for the Kušlėnai esker gravel and sand deposit (Fig. 2, Tables 2 and 3).

Table 2. **Kušlėnai esker gravel and sand deposit resources in block II calculated by the method of blocks**

2 lentelė. **Kušlėnų ozo žvyro ir smėlio telkinio išteklių II bloke apskaičiavimas blokų metodu**

Sub-block No.	Area, m²	Average thickness, m	Volume, m³
a	475	4.2	1 996
b	925	6.0	5 549
c	1 194	7.0	8 297
d	10 791	10.6	114 379
Total	**13 384**		**130 220**

Table 3. **Kušlėnai esker gravel and sand deposit resources calculated by the method of blocks**

3 lentelė. **Kušlėnų ozo žvyro ir smėlio telkinio išteklių apskaičiavimas blokų metodu**

Block No.	Area, m²	Average thickness, m	Volume, m³
I	196 645	12.8	2 513 126
II	13 384	9.7	130 220
III	25 947	7.8	203 332
IV	1 945	14.9	29 019
V	100 271	8.7	868 188
	Total		**3 743 886**

A disadvantage in the application of the method of profiles is that it is necessary to place the prospecting drilling points on a straight line. However, this is difficult to achieve in practice, especially for deposits of complicated structure and under dissected relief conditions. Another disadvantage is that the data available are insufficient for compiling reliable profiles. The reliability of the compiled profiles often depends on the competence and intuition of a geologist. Moreover, errors can appear when the inclination of a mineral deposit bed is not taken into account. As the results of the present work have confirmed, precise calculation results are obtained only in the case when the profile lines are perpendicular to the occurrence of the mineral bed. To perform calculation of resources by the method of profiles, vertical geological-lithological sections were built and placed in a nearly parallel way at a similar distance from each other (Fig. 3). The investigations showed that with enough data and a straight-line position of boreholes, the reliability of results is similar for deposits of different genetic type. This method cannot be recommended, if there is an insufficient number of boreholes, if they are situated not on a straight line; in this case, to compile the profiles, an artificial projection of data should be performed. This is especially important in when a deposit is of a complicated structure. It is well illustrated by the examples of resource calculations made by the method of profiles for the Sandrupys aeolian deposit and Plot 2 of the Bogušiškiai II kame gravel deposit (Figs. 3 and 4, Tables 4 and 5). The complicated Sandrupys deposit structure and the related difficulties in resource calculation are described above. The surface of the Bogušiškiai deposit Plot 2 is a large undulating elevation of a positive macroform, which is lowering south-eastwards. At the southernmost margin, a large isometric hill is notable (Basalykas, 1965).

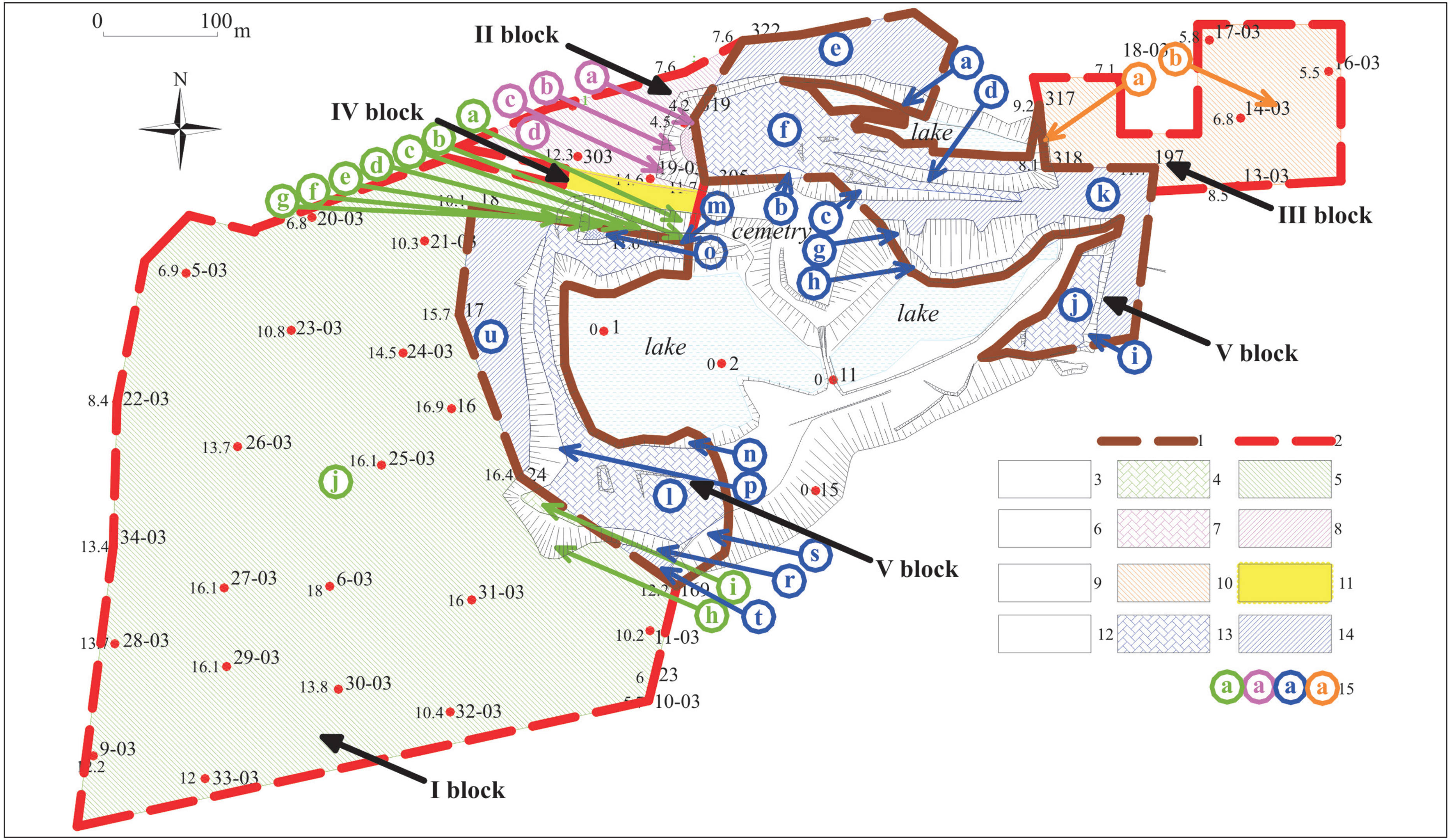

Fig. 2. Kušlėnai esker gravel and sand deposit resource calculation by the method of blocks.

1 – 1984 resource calculation boundary; *2* – 2004 resource calculation boundary. Resource calculation areas. *Block I: 3* – slope; *4* – slope bottom; *5* – slope top; *block II: 6* – slope; *7* – slope bottom; *8* – slope top; *block III: 9* – slope; *10* – slope top; *block IV: 11* – slope top; *block V: 12* – slope; *13* – slope bottom; *14* – slope top; *15* – numbers of sub-blocks

2 pav. Kušlėnų ozo žvyro ir smėlio telkinio išteklių apskaičiavimas blokų metodu.

1 – 1984 m. išteklių apskaičiavimo riba; *2* – 2004 m. išteklių apskaičiavimo riba. Išteklių apskaičiavimo plotai. *I bloke: 3* – šlaite; *4* – šlaito apačioje; *5* – šlaito viršuje; *II bloke: 6* – šlaite; *7* – šlaito apačioje; *8* – šlaito viršuje; *III bloke: 9* – šlaite; *10* – šlaito viršuje; *IV bloke: 11* – šlaito viršuje; *V bloke: 12* – šlaite; *13* – šlaito apačioje; *14* – šlaito viršuje; *15* – subblokų numeriai

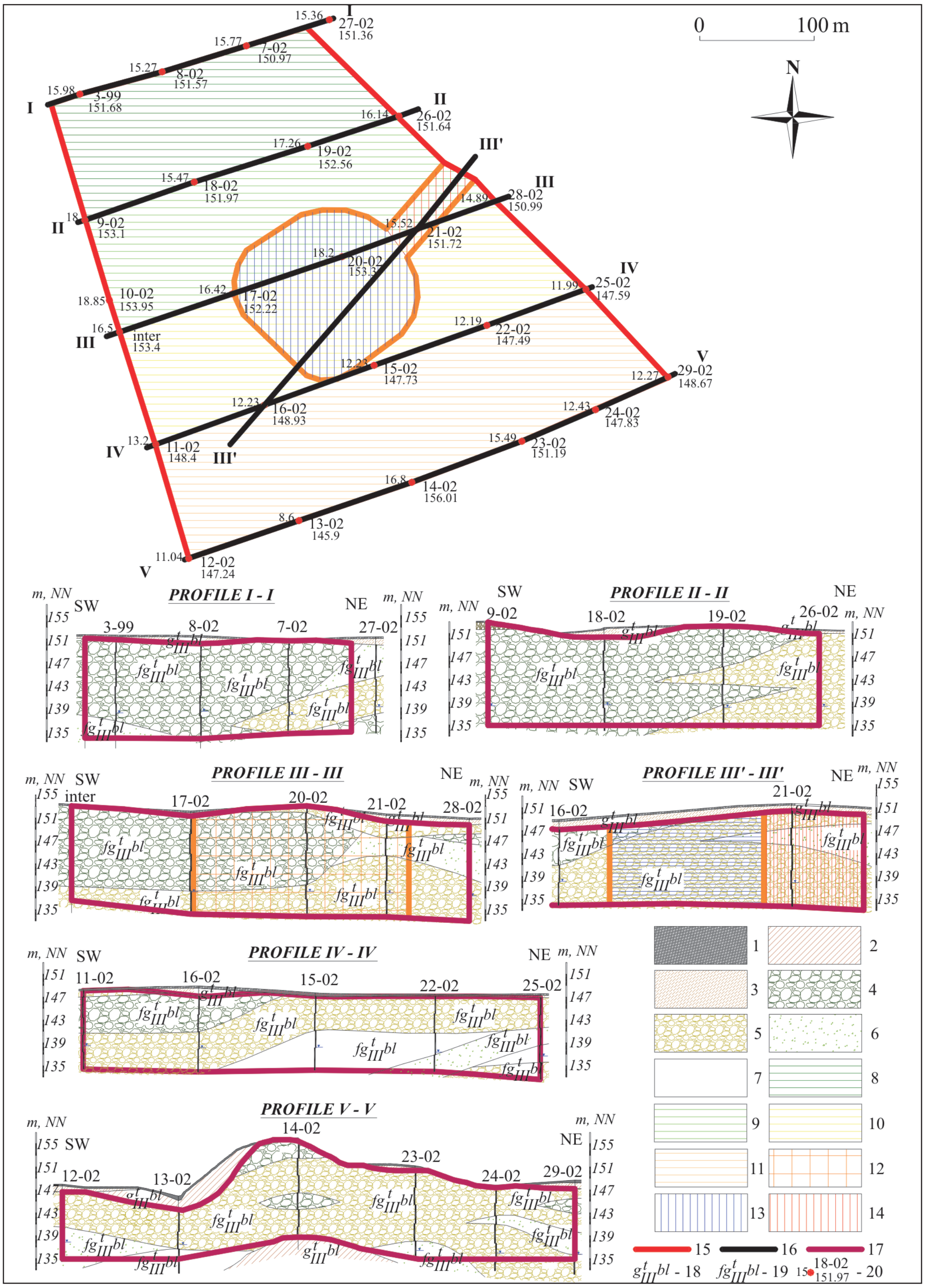

Fig. 3. Bogušiškiai II kame gravel deposit Plot 2 resource calculation by the method of profiles.

Lithology signs: *1* – soil; *2* – loam; *3* – sandy loam; *4* – gravel with fraction coarser than 5 mm exceeding 20%; *5* – gravel with fraction coarser than 5 mm ranging in 10–20%; *6* – sand with gravel; *7* – fine sand. Resources calculation area in horizontal projection: *8* – area between profiles I and II; *9* – area between profiles II and III; *10* – area between profiles III and IV; *11* – area between profiles IV and V. *12* – homestead area; *13* – resources calculation in the homestead site block 1; *14* – resources calculation in the homestead site block 2; *15* – resources calculation contour; *16* – geological-lithological profile line; *17* – resources calculation area in vertical projection. Stratigraphical-genetical signs: *18* – Upper Pleistocene Baltic Subformation marginal glacial deposits; *19* – Upper Pleistocene Baltic Subformation marginal glaciofluvial deposits; *20* – borehole; its number top right, surface altitude (mNN) at bottom right, mineral bed thickness (m) left

3 pav. Bogušiškių II keimų žvyro telkinio antro sklypo išteklių apskaičiavimas pjūvių metodu.

Litologiniai ženklai: *1* – dirvožemis; *2* – priemolis; *3* – priesmėlis; *4* – žvyras (daugiau kaip 20% frakcijos, rupesnės už 5 mm); *5* – žvyras (10–20% frakcijos, rupesnės už 5 mm); *6* – žvirgždingas smėlis; *7* – smulkus smėlis. Išteklių apskaičiavimo plotai horizontalioje projekcijoje: *8* – plotas tarp I ir II pjūvio; *9* – plotas tarp II ir III pjūvio; *10* – plotas tarp III ir IV pjūvio; *11* – plotas tarp IV ir V pjūvio. *12* – sodybos užimamas plotas; *13* – išteklių apskaičiavimo sodybos užimame plote 1 blokas; *14* – išteklių apskaičiavimo sodybos užimame plote 2 blokas; *15* – išteklių apskaičiavimo kontūras; *16* – geologinio-litologinio pjūvio linija; *17* – išteklių apskaičiavimo plotas vertikalioje projekcijoje. Stratigrafiniai-genetiniai ženklai: *18* – viršutinio pleistoceno Baltijos posvitės kraštinių darinių glacigeninės nuogulos; *19* – viršutinio pleistoceno Baltijos posvitės kraštinių darinių fliuvioglacialinės nuogulos. *20* – gręžinys, dešinėje viršuje – gręžinio numeris, dešinėje apačioje – paviršiaus altitudė (mNN), kairėje – naudingo klodo storis (m)

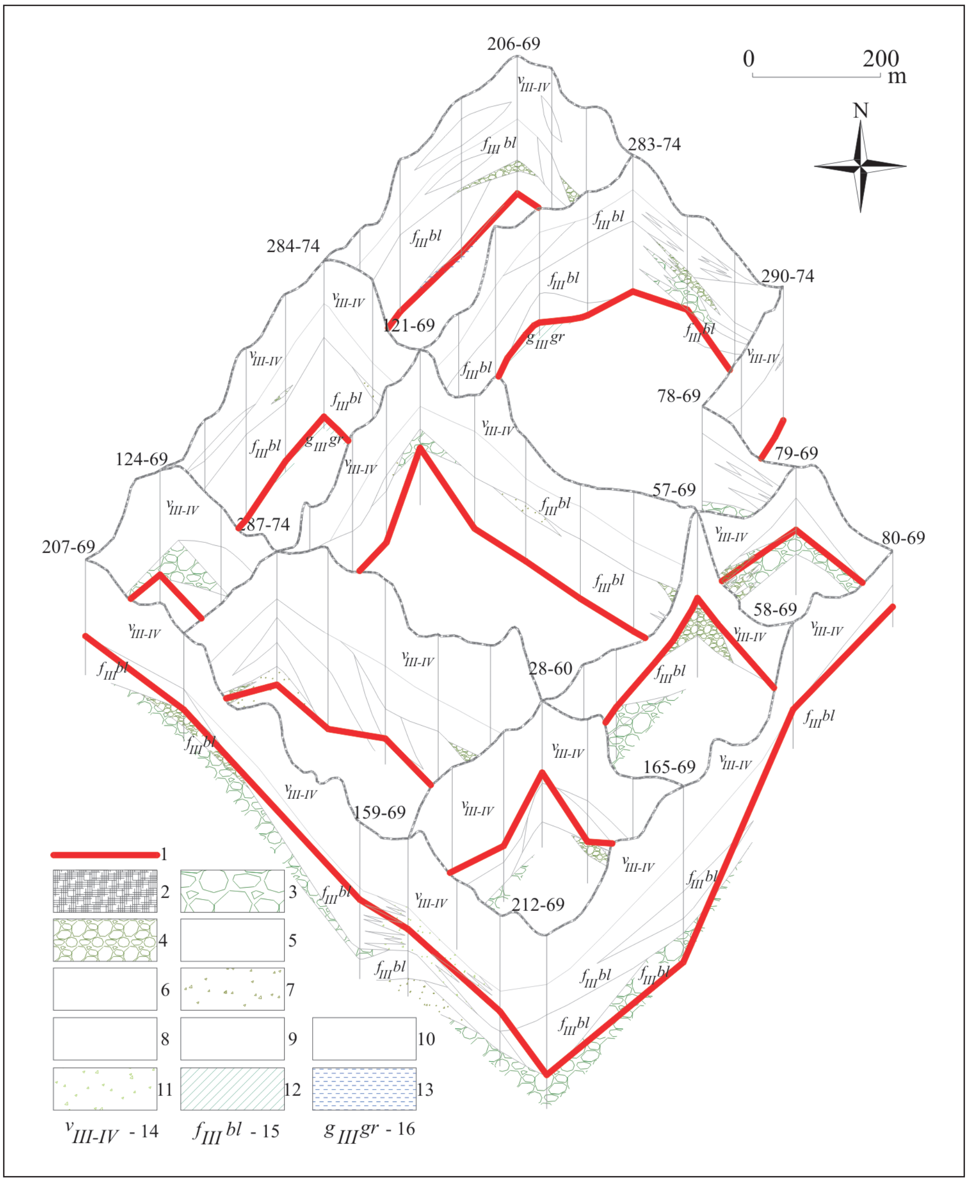

Fig. 4. Sandrupys aeolian sand deposit resource calculation by the method of profiles.

1 – resources calculation contour. Lithological signs: *2* – soil; *3* – coarse gravel; *4* – fine gravel; *5* – coarse sand; *6* – various-grained sand; *7* – moderately gravely sand; *8* – moderate-grain sand; *9* – fine sand; *10* – very fine sand; *11* – fine sand with gravel; *12* – loam; *13* – aleurite. Stratigraphical-genetical signs: *14* – Late Glacial and Post-Glacial aeolian deposits; *15* – Upper Pleistocene Baltic Subformation marginal glaciofluvial deposits; *16* – Upper Pleistocene Grūda Subformation glacial deposits

4 pav. Sandrupio eolinio smėlio telkinio išteklių apskaičiavimas pjūvių metodu.

1 – išteklių apskaičiavimo kontūras. Litologiniai ženklai: *2* – dirvožemis; *3* – stambus žvyras; *4* – smulkus žvyras; *5* – stambus smėlis; *6* – įvairiagrūdis smėlis; *7* – vidutiniškai žvirgždingas smėlis; *8* – vidutinis smėlis; *9* – smulkus smėlis; *10* – itin smulkus smėlis; *11* – smulkus žvirgždingas smėlis; *12* – priemolis; *13* – aleuritas. Stratigrafiniai-genetiniai ženklai: *14* – vėlyvojo ledynmečio ir poledynmečio eolinės nuogulos; *15* – viršutinio pleistoceno Baltijos posvitės fliuvioglacialinės nuogulos; *16* – viršutinio pleistoceno Grūdos posvitės glacigeninės nuogulos

Table 4. **Calculation of average resultant distance between profiles in Bogušiškiai II kame gravel deposit Plot 2**

4 lentelė. **Vidutinio tolygaus atstumo tarp Bogušiškių II keimų žvyro telkinio antro sklypo pjūvų apskaičiavimas**

Block	Profile No.	Area, m²	Profile No.	Profile length, m	Average distance, m
1	I–I, II–II	26307	I–I	233	**101.1**
			II–II	287	
2	II–II, III–III	32090	II–II	287	**101.1**
			III–III	348	
3	III–III, IV–IV	37454	III–III	348	**100.2**
			IV–IV	400	
4	IV–IV, V–V	44325	IV–IV	400	**104.6**
			V–V	448	

Table 5. **Bogušiškiai II kame gravel deposit Plot 2 resources calculated by profile method**
5 lentelė. **Bogušiškių II keimų žvyro telkinio antro sklypo išteklių apskaičiavimas pjūvių metodu**

Block	Profile No.	Spr_1, m²	S_{pr2}, m²	Average distance, m	Volume, m³
In all resources calculation contour					
1	I–I, II–II	3866	4774	101.1	436824
2	II–II, III–III	4774	6097	101.1	549402
3	III–III, IV–IV	6097	5376	100.2	574830
4	IV–IV, V–V	5376	5819	104.6	281167
Total, m³					**1842222**
In homestead and protection zone occupied area					
1	III'–III'		1985	132.4	262931
2	III'–III'		1451	30.1	43623
Total, m³					**306554**
Total volume less resources under homestead, m³					**1535668**

Relative elevations here reach 8–10 m and the absolute heights range within 144.95–156.63 m NN. The calculation of resources in this deposit was complicated by the presence of a homestead in the central part of Plot 2. The homestead was planned to remain here, therefore the resources in the area of the homestead and its protective zone had to be calculated separately in order to subtract them from the total resources and to categorise them as potentially valuable resources. For this purpose, an additional profile III'–III' was compiled in such a way that it was, as much as possible, parallel to the area of the homestead and its protective zone. Unfortunately, the homestead area is not an exact geometric figure; hence, the calculation of resources by the method of profiles gives large errors.

Applying the method of isolines for calculation of resources, the difference obtained for deposits of different genetic type from the GRID method results is the lowest among the results obtained by other calculation methods and does not exceed 3% on the average. To use this method, the map of mineral bed thickness isolines should be compiled, followed by measurement of the area limited by each isoline (Fig. 5, Tables 6 and 7). In the case of undulating surface, depressions and elevations are distinguished in order to calculate them separately. When the calculation of resources was performed without using computer techniques, drawing of isolines and measuring their areas was a rather complicated process. Therefore, this method was not widely used. With the development of computer technologies, the possibility appeared to draw isolines on a computer and to measure an area limited by isolines by using a certain software. The Geomap software based on Autodesk was pioneering in the Lithuanian market in this field. The calculation of resources for production is often performed as deep as a certain horizon which is often limited by an average groundwater table. In such a case, the bottom of a mineral deposit is rather even. Moreover, compiling the map of mineral bed thickness isolines on the topographic basis, changes in the relief are taken into account; therefore, the calculation results are rather reliable. The disadvantage of this method is that the measurement of an area limited by each isoline is a process consuming much labour. If an error is made during the calculation, the entire process should be repeated from the very beginning. One more disadvantage is a complicated resource record control, since during the check-up the area limited by each isoline should be measured anew.

The last method applied in the present work to calculate the resources was the GRID method worked out on the basis of a triangle method in GIS environment. Applying the long known triangle method (Ажгирей и др., 1954), a whole deposit is divided into bevel cut prisms so that their top and bottom surfaces are triangles, the boreholes being their apexes. Side edges of the prisms coincide with the thickness of a mineral deposit in a borehole. The volume of resources is calculated for each prism separately according to geometric formulas. A sum of the prism volumes gives the total volume of a deposit. Although this method is long known, it had not been used, first of all, because the triangles should be plotted manually following certain requirements, and, secondly, the data of every borehole should be used at least three times, thus creating difficulties for calculations and consuming more labour. Moreover, the reliability of results obtained by this method was not very high, since applying this method for resource calculation by a non-computer method, only borehole data were used, without taking into account changes in the relief. With developing computer technologies, this method was moved into the GIS environment and referred to as the GRID method. Its use in GIS environment has been improved, since not only borehole data, but also the topographic basis are used and, hence, the relief complexit is accounted for. Applying this method for volume calculations, the surfaces of a mineral bed top and bottom are built (Fig. 6). The volume between these two surfaces is the volume of a mineral bed. To calculate the volume, both surfaces are covered by a grid formed of cells set in rows and columns according to freely given parameters (x and y sizes of cells). The thickness of a mineral bed is automatically calculated for every grid cell (in the cell angles) according to the data of the surfaces formed. The surface of each cell is divided into two triangle prisms. The volume is automatically calculated separately for each triangle cell and summed up. The most precise data of resources are obtained when the grid density is lower than the mean distribution of surface data. This method, however, has also a flaw: if at least one prism angle is lost from the surface limits, the whole prism is removed from the calculation. But, having in mind that the smallest cell size is usually chosen, this flaw does not trigger big errors. The advantage of this method is that the surfaces remain active all the time; therefore, if one of them changes, the volume changes are calculated anew automatically.

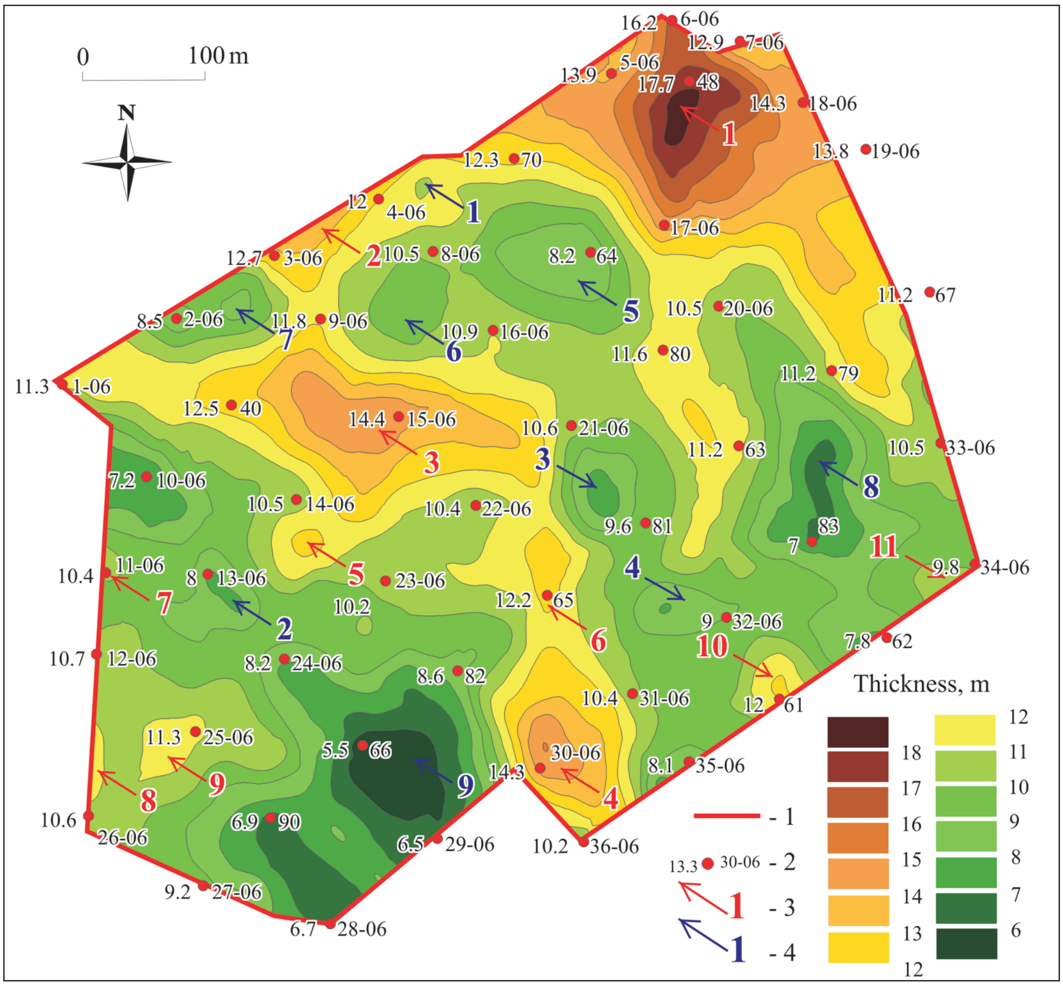

Fig. 5. Šklėriai sandur gravel and sand deposit resource calculation by the method of isolines.
1 – resources calculation contour; *2* – borehole; its number on the right top, mineral bed thickness on the left (m); *3* – number of positive landform top for mineral bed calculation massifs; *4* – number of concave landform top for mineral bed calculation massifs

5 pav. Šklėrių zandro žvyro ir smėlio telkinio išteklių apskaičiavimas izolinijų metodu.
1 – išteklių apskaičiavimo kontūras; *2* – gręžinys, dešinėje – gręžinio numeris, kairėje – naudingo klodo storis (m); *3* – esamo naudingo klodo apskaičiuojamų masyvų teigiamų formų viršūnių numeriai; *4* – esamo naudingo klodo apskaičiuojamų masyvų neigiamų formų viršūnių numeriai

Table 6. **Calculation of area limited by thickness isolines in Šklėriai sandur gravel and sand deposit**
6 lentelė. **Šklėrių zandro žvyro ir smėlio telkinio vienodo storio izolinijų apribotų plotų apskaičiavimo schema**

Thickness, m	Thickness isoline area, m²															
	Thickness elevations and No. of their apexes								Thickness sinkings and No. of their apexes							
	1	2	3, 4	5, 6	7	8, 9	10	11	1	2, 3	4	5	6	7	8	9
18	430															
17	3682															
16	8441															
15	13944															
14	23784		4779													
13	32341	970	15161													
12	46050		31741	1633												
11		133566				2390	1194		150							
10		208830			360	15568	3271	636				10747	3022			
9					302111					6255	2420	3894		109		
8					332044					273					5373	
7					347273										1085	
6–0					360646											3758

Table 7. **Šklėriai sandur gravel and sand deposit resources calculated by thickness isoline method**

7 lentelė. **Šklėrių zandro žyro ir smėlio telkinio išteklių apskaičiavimas vienodo storio izolinijų metodu**

Apex No.	Area, m^2			Volume, m^3
	Limited by top isoline	Limited by bottom isoline	Uncovered part	
Thickness isoline elevations				
1		430	430	215
	430	3 682	3 253	2 056
	3 682	8 441	4 759	3 062
	8 441	13 944	5 503	11 193
	13 944	23 784	9 840	18 864
	23 784	32 341	8 556	28 063
2–11				3 807 945
Total				3 874 397
Thickness isoline sinkings				
1		150	150	75
2		273	273	137
	273	6 255	5 982	3 264
4		2 420	2 420	1 210
5		3 894	3 894	1 947
	3894	10 747	6 853	7 320
6		3 022	3 022	1 511
7		109	109	55
8		1 085	1 085	543
	1085	5 373	4 287	3 229
9		3 758	3 758	1 879
Total				21 169
Total in deposit				3 853 228

Note. Thickness in uncovered zone 0.5 m, covered 1 m; from 2 to 11 thickness elevation tops of given volume.

This is important when a mineral's exploitation is started, since it provides an opportunity to monitor changes in the resources (i. e. to calculate production rate and the remainder by the same principles) (Fig. 7). Thus, a scheme for estimating deposit resources turns into a dynamical model of resource calculation.

The generalised results of the present work for selected deposits of different genetic types are given in Table 8. To compare different methods, as mentioned above, the difference from the GRID method results in percentage was determined. Nevertheless, this method should not be treated as the most perfect one; used in computer software, it just facilitates the estimation of resources. If this method is used to model the thickness of resources, finally it becomes not only a 3D but also a 4D model.

Table 8. **Results of resource calculation in deposits of different genetic types**

8 lentelė. **Išteklių skaičiavimo rezultatai skirtingų genetinių tipų telkiniuose**

Calculation method	Volume, m^3	Difference, %	Area, m^2
Kušlėnai gravel and sand deposit (esker)			
GRID	3 710 993	0	237 920
Isolines	3 819 000	3	
Profiles	3 845 354	4	
Blocks	3 743 886	1	
Bogušiškiai II gravel deposit plot I (kames)			
GRID	475 692	0	34 878
Isolines	486 110	2	
Profiles	516 243	9	
Blocks	489 586	3	
Bogušiškiai II gravel deposit plot II (kames)			
GRID	1 711 310	0	120 638
Isolines	1 740 017	2	
Profiles	1 535 668	–10	
Blocks	1 756 293	3	
Bogušiškiai II gravel deposit plot III (kames)			
GRID	367 000	0	25 783
Isolines	372 153	1	
Profiles	380 533	4	
Blocks	366 817	–0.05	
Sandrupys sand deposit (eolian)			
GRID	17 047 220	0	952 923
Isolines	17 291 870	1	
Profiles	13 901 375	–18	
Blocks	18 345 216	8	
Šklėriai gravel and sand deposit (sandur)			
GRID	3 823 000	0	360 646
Isolines	3 853 228	1	
Profiles	4 025 998	5	
Blocks	3 858 911	1	
Sniegiai gravel deposit (marginal glaciofluvial ridges)			
GRID	4 969 000	0	318 687
Isolines	4 975 782	0.1	
Profiles	4 795 627	–3	
Blocks	4 867 091	–2	
Selmoniškiai gravel deposit (glaciofluvial delta)			
GRID	786 000	0	
Isolines	761 916	–3	
Profiles	770 945	–2	
Blocks	697 080	–11	94 036

CONCLUSIONS

Each of the methods of resource calculation used in the present work has its advantages and disadvantages. The method of geological blocks is the least labour-consuming one. As the results of estimation of deposits of different genetic type have shown, the block method is reliable under the conditions of a simple structure of a deposit, an even relief and a dense borehole network. This method is not recommended for deposits of a complicated structure. Moreover, after the exploitation of resources has started, the advantages of this method, if compared to other ones with regard to labour consumption, disappear since in order to get the most precise volume of a mineral dug out and that of the remainder, the blocks of resources are divided into subblocks, and the volumes are assessed separately for the excavation slope, the top and the bottom.

The method of profiles can be applied for deposits of a complicated structure. If data are sufficient and boreholes lie in a straight line, the reliability of results is similar for deposits of different genetic type (Table 8). However, in practice, it is often difficult to build the borehole network in straight lines, especially under conditions of a complicated deposit structure and a dissected relief.

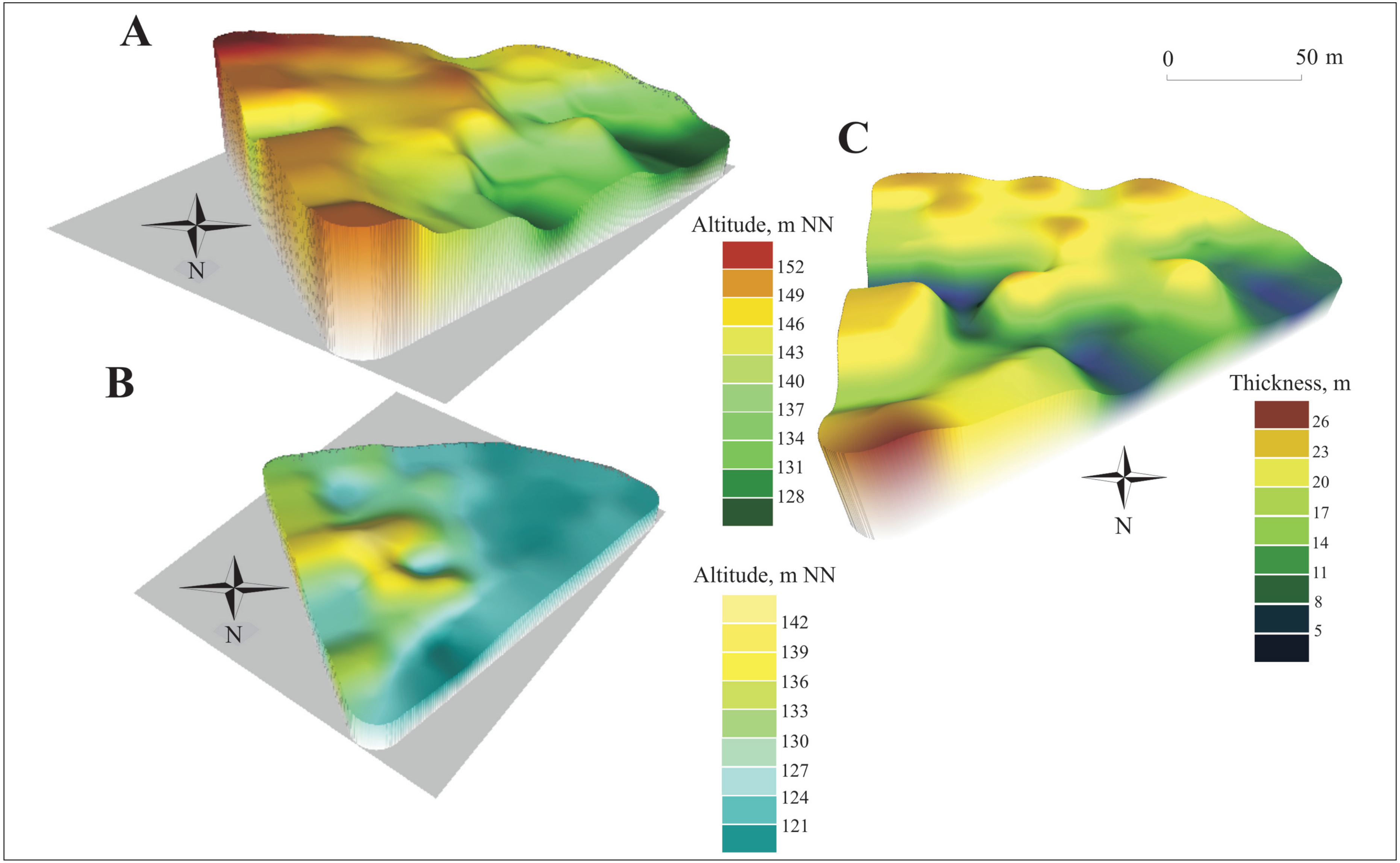

Fig. 6. Gravel deposit resource calculation by GRID method in Sniegiai marginal glaciofluvial ridges.
A – mineral bed top surface; *B* – mineral bed bottom surface; *C* – mineral bed thickness 3D picture

6 pav. Žvyro telkinio išteklių, esančių Sniegių kraštiniuose fliuvioglacialiniuose gūbriuose, apskaičiavimas GRID metodu.
A – naudingo klodo kraigo paviršius; *B* – naudingo klodo aslos paviršius; *C* – naudingo klodo storio 3D vaizdas

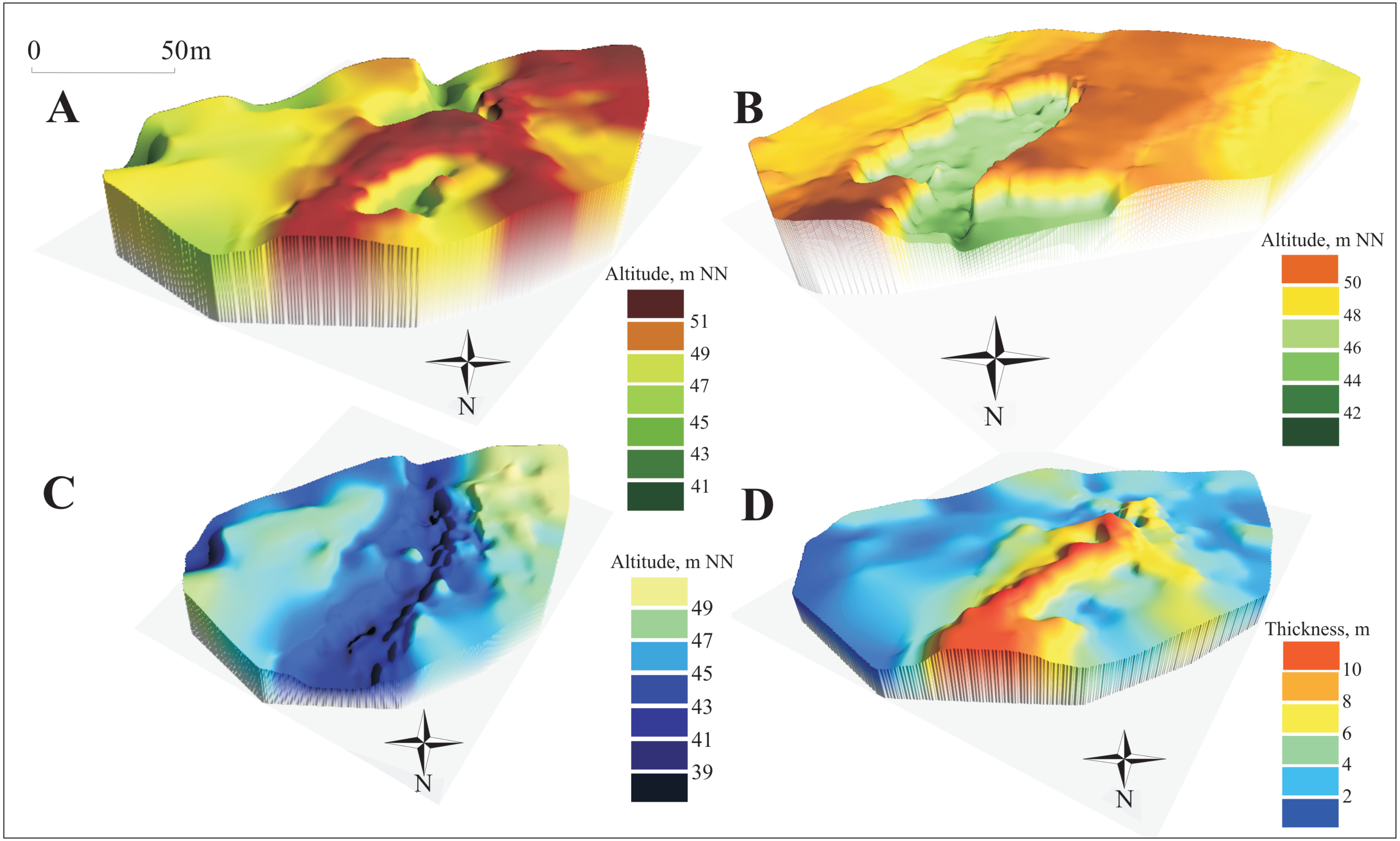

Fig. 7. Gravel deposit resource calculation by GRID method in Selmoniškiai glaciofluvial delta.
A – mineral bed top surface; *B* – 2007 remainder mineral bed surface; *C* – mineral bed bottom surface; *D* – mineral bed thickness 3D picture

7 pav. Žvyro telkinio išteklių, esančių Selmoniškių fliuvioglacialinėje deltoje, apskaičiavimas GRID metodu.
A – naudingo klodo kraigo paviršius; *B* – 2007 m. likusio naudingo klodo paviršius; *C* – naudingo klodo aslos paviršius; *D* – naudingo klodo storio 3D vaizdas

Another disadvantage of this method is related to insufficient data necessary to form reliable profiles. Errors also appear when the inclination of a mineral bed is not taken into account. Precise results are obtained only when the profile lines are perpendicular to the occurrence of a mineral bed. This method is not recommended when the number of boreholes is insufficient, when the boreholes lie not in straight lines, and artificial projections should be made in order to get the profiles. After the development of a deposit has started it is not expedient to use this method, since the production area can be only within the area located between two profiles.

Applying the method of isolines for the calculation of resources, the average difference in results obtained for selected deposits of different type, if compared to those obtained by the GRID method, is the lowest among the other methods applied and does not exceed 3%. To calculate the resources by the isoline method, a map is compiled with isolines of a mineral bed thickness, using the topographic basis that enables assessment of relief variations. Therefore, this method is good even for deposits of a complicated structure. A disadvantage of this method is, however, that measuring the area for each isoline is a process consuming much labour and the control of resource estimation is complicated.

Development of computer technologies enables improving resource estimation. The GRID method is one of the most up-to-date methods of resources calculation, although its basis is a long known triangle method which was not widely used because of large labour expenses and not very reliable results, since all the calculations are performed using only borehole data. The GRID method in GIS environment uses not only borehole data, but also the topographic basis enabling to take into account the complexity of the relief, which is very important when deposits are of a complicated structure. Although this method has some flaws, it seems to be improved in the future by cooperation with software experts. It is important that using this method a dynamical model of a mineral deposit is obtained, and it can be applied after the development of a deposit has started. Thus, with the national economy developing and new opportunities appearing, it is expedient to adjust and improve the resource estimation methods and the normative documents regulating them.

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ĮVAIRIŲ GENETINIŲ TIPŲ TELKINIŲ ŽVYRO IR SMĖLIO IŠTEKLIŲ APSKAIČIAVIMO METODŲ PALYGINIMAS

Santrauka

Žemės gelmių, kaip išimtinės valstybės nuosavybės, pažinimas ir jose esančių išteklių įvertinimas yra visada aktualus, nes susijęs su šalies ekonominiu savarankiškumu. Vienas pagrindinių veiksnių, lemiančių racionalų išteklių naudojimą, yra teisinga išteklių apskaita.

Šiame darbe buvo atrinkti įvairių genetinių tipų (keimų, ozų, kraštinių fliuvioglacialinių gūbrių, zandrų, fliuvioglacialinių deltų ir eolinių darinių) žvyro ir smėlio telkiniai, įvertinta jų geologinė sandara, susidarymo sąlygos, išanalizuotos naudingųjų iškasenų kokybinės charakteristikos, seniai žinomais ir iki šiol Lietuvoje taikomais metodais – geologinių blokų, pjūvių, izolinijų ir naujausiu GRID metodu, sukurtu trikampių metodo pagrindu GIS aplinkoje, – apskaičiuoti ištekliai; buvo nustatyti panaudotų metodų privalumai ir trūkumai.

Mažiausiai darbo sąnaudų reikia geologinių blokų metodui. Išteklių apskaitos skirtingų genetinių tipų telkiniuose duomenimis, šis metodas gali būti patikimai taikomas esant nesudėtingai telkinio sandarai, lygiam reljefui, tankiam gręžinių tinklui. Nerekomenduojama šio metodo naudoti sudėtingos sandaros telkiniuose. Be to, darbo imlumo požiūriu jis nėra pranašesnis už kitus metodus, kadangi, norint kuo tiksliau apskaičiuoti iškastą naudingųjų iškasenų kiekį ir išteklių likutį, išteklių blokai dalijami į subblokus ir tik tuomet atskirai įvertinamas išteklių kiekis gavybos šlaite, jo viršuje ir apačioje.

Pjūvių metodas gali būti taikomas ir sudėtingos sandaros telkiniuose. Gauti rezultatai rodo, kad, esant pakankamam duomenų kiekiui ir gręžinių išsidėstymui tiesiose linijose, rezultatų patikimumas įvairiuose genetinių tipų telkiniuose yra panašus (8 lentelė). Tačiau išdėstyti gręžinių tinklą tiesiomis linijomis, ypač sudėtingos sandaros ir raižyto reljefo telkiniuose, ne visada pavyksta. Kitas šio metodo trūkumas – tai nepakankamas duomenų, būtinų patikimų pjūvių sudarymui, kiekis. Tikslūs rezultatai gaunami tik tuo atveju, jeigu pjūvių linijos yra statmenos naudingųjų iškasenų slūgsojimui. Šis metodas nerekomenduojamas, kai gręžinių nepakanka, jie išsidėstę ne tiesiose linijose ir norint sudaryti pjūvius tenka dirbtinai projektuoti duomenis.

Izolinijų metodas gerai tinka net sudėtingos sandaros telkiniams, kadangi sudarant naudingo klodo storio izolinijų žemėlapį naudojamas topografinis pagrindas, kuris leidžia įvertinti reljefo kaitą, o tai labai svarbu tokios sandaros telkiniams. Šio metodo trūkumas tas, kad kiekvienos izolinijos ploto išmatavimas gerokai užtrunka, o išteklių apskaitos kontrolė yra sudėtinga.

GRID (tinklelio) metodas yra vienas naujausių išteklių apskaičiavimo metodų, nors jo pagrindas yra seniai žinomas trikampių metodas, kuris nebuvo plačiai naudojamas daugiausia dėl didelių darbo sąnaudų. GRID metodas, lyginant su trikampių, yra geresnis ne tik tuo, kad ištekliai apskaičiuojami automatiškai, bet ir tuo, kad jų apskaitai naudojamas topografinis pagrindas. Tokiu būdu yra įvertinamas reljefo sudėtingumas, ypač svarbus sudėtingos sandaros telkiniuose. Nors šis metodas irgi turi tam tikrų trūkumų, tačiau kartu su programinės įrangos kūrėjais ateityje jį galima dar labiau patobulinti. Svarbu tai, kad šiuo metodu sukurtas naudingųjų iškasenų išteklių modelis yra kaitus ir gali būti taikomas pradėjus telkinio eksploataciją.

GRID metodas nėra tobuliausias, tiesiog jis yra naudojamas kompiuterinių programinių įrangų, labai palengvina išteklių apskaitą, o sudarant juo išteklių storio modelius, šie ilgainiui tampa ne tik 3D, bet ir 4D modeliais. Plėtojantis šalies ūkiui, atsiveriant naujoms galimybėms, verta tikslinti ir tobulinti šiuo metu naudojamus išteklių apskaitos metodus bei juos reglamentuojančius norminius dokumentus.

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СРАВНЕНИЕ МЕТОДОВ ПОДСЧЁТА ЗАПАСОВ МЕСТОРОЖДЕНИЙ ПЕСЧАНО-ГРАВИЕВЫХ ОТЛОЖЕНИЙ И ПЕСКА РАЗНЫХ ГЕНЕТИЧЕСКИХ ТИПОВ

Резюме

Изучение недр земли и оценка полезных ископаемых в них актуальны, поскольку наличие последнего обусловливает экономическую самостоятельность страны. Одним из факторов, влияющих на рациональное использование полезных ископаемых, является правильный подсчёт их запасов. Для оценки методов подсчёта полезных ископаемых были выбраны месторождения песчано-гравиев отложений и песка разных генетических типов: камы, оз, краевые флювиогляциальные гряды, зандр, флювиогляциальная дельта и эоловые отложения. Были отобраны месторождения разных генетических типов, оценены условия их образования, геологическое строение, качественная характеристика полезных ископаемых, подсчитаны их запасы давно известными и до сих пор применяемыми в Литве методами – геологических блоков, разрезов, изолиний и новым методом GRID (сетка), созданным на основе метода треугольников в среде ГИС (географических информационных систем). После подсчёта запасов полезных ископаемых в месторождениях разных генетических типов, осуществленного вышеназванными методами, установлены преимущества и недостатки каждого из последних.

Самым простым и наименее трудоёмким является метод геологических блоков. Как показали результаты подсчёта запасов месторождений полезных ископаемых разных генетических типов, этот метод надёжен в тех случаях, когда форма и строение месторождения являются несложными, рельеф равнинный, имеется густая сеть разведочных скважин. Не рекомендуется применять этот метод для подсчёта запасов месторождений сложного строения (например, краевых флювиогляциальных гряд). Кроме того, если начинается добыча полезного ископаемого, указанный метод теряет свои преимущества перед другими, поскольку при желании более точно подсчитать запасы, необходимо делить блоки на субблоки, определять количество запасов для каждого отдельного уступа.

Метод разрезов можно успешно применять для подсчёта запасов месторождений сложного геологического строения. Полученные результаты показали, что при наличии достаточного количества разведочных скважин и при их расположении по более или менее параллельным линиям точность подсчёта запасов месторождений полезных ископаемых разных генетических типов схожа (табл. 8). Однако размещение разведочных скважин по более или менее параллельным линиям, особенно в месторождениях сложного геологического строения и рельефа, не всегда возможно. Достоверные результаты получаются лишь в том случае, когда линии разрезов расположены перпендикулярно залеганию полезного ископаемого. Этот метод не рекомендуется, если имеется недостаточное количество скважин, если они расположены не параллельно и при построении разрезов требуется искусственное проектирование данных.

Метод изолиний применим для месторождений всех типов. Его преимущество состоит в том, что при построении карт мощности полезного ископаемого используется топографическая поверхность месторождения, что позволяет учесть сложность форм рельефа, а это в свою очередь имеет большое значение для месторождений сложного строения. Недостатком метода изолиний является сложность графических построений и вычислений, так как измерение площади каждой изолинии – это трудоёмкий процесс. Второй недостаток – сложность проверки подсчёта запасов, для которой требуется произвести полный перерасчёт запасов.

Метод GRID (сетка) является одним из новейших, хотя создан он на основе метода треугольников, давно известном, но не получившем широкого применения в основном из-за сложности применяемых вычислений. Метод GRID (сетка) по сравнению с методом треугольников усовершенствован, так как подсчёт запасов полезных ископаемых производится автоматически, кроме того, используется топографическая основа. Таким образом учитывается сложность форм рельефа, что, как было упомянуто выше, имеет большое значение для месторождений сложного строения. Этот метод также не идеален, но в дальнейшем в сотрудничестве с программистами его можно совершенствовать. Важно то, что при его применении модель запасов полезных ископаемых становится динамической, используемой и после начала эксплуатационных работ.

Для сравнения разных методов подсчёта запасов полезных ископаемых была вычислена разница (в процентах) по отношению к методу GRID (сетка). Однако это не означает, что метод GRID (сетка) идеален, просто именно он используется в компьютерных программах, которые в свою очередь значительно облегчают подсчёт запасов полезных ископаемых. Кроме того, этим методом построенная модель мощности полезного ископаемого со временем может быть не только 3D-, но и 4D- моделью. Поэтому при развитии технологий и открытии новых возможностей следует уточнять и совершенствовать применяемые в настоящее время методы подсчёта запасов полезных ископаемых и регламентирующие эти методы нормативные документы.