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Dynamic models of non-metallic mineral deposits and their use during the development of a deposit

SUMMARY OF DOCTORAL DISSERTATION

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VILNIAUS UNIVERSITETAS

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Nerūdinių naudingųjų iškasenų telkinių dinaminių modelių sudarymas ir jų panaudojimas telkinio eksploatavimo eigoje

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INTRODUCTION

Humans cannot live without using nature resources. In order to reach the welfare in economics, the provision with material resources is very important for each country in the world. The evolution of the civilisation is based on the use of subsurface resources; therefore, the extraction of useful minerals is an inevitable process. Nevertheless, the extraction (mining) industry and related problems make a rarely studied subject.

Relevance of the study. Presently, the issue of spatial (dynamical) geological modelling related to application of computer technologies is a new wave in geological researches both in Lithuania and abroad. The application of the spatial (3D) modelling in geology enables to automate many processes (recording of useful mineral resources, their observation in time, and making design solutions), thus, saving time and money allocated for these purposes. A rather rich experience has been accumulated by now, and certain results have been achieved in application of information technologies in geological sciences; however, their use in geology cannot be seen as positive enough. This is related to the specificity in application of information in geology, since this information is, as usually, is of a descriptive character that is difficult to be introduced and interpreted by computer programs; therefore there are quite a few unsolved problems in this sphere.

The targets of the research were the deposits of different genetic type – kames, eskers, ice-marginal glaciofluvial ridges, sandurs, glaciofluvial deltas, wind-drifted glaciofluvial aeolian gravel and sand deposits, as well as promising areas in the area of Lithuania.

The aim of the study was to automate the analysis of mineral prospecting data and the elaboration of production course (mining) designs in order to optimise the volumes of minerals dug out and rehabilitation of the damaged areas into the natural landscapes. To reach this purpose the **main tasks were set as follows:**

⇨ to explore the possibilities of automated analysis and evaluation of mineral deposit prospecting data;

⇨ to create the methodology for automation of mineral deposit use design solutions and to introduce it into a computer software;

⇨ to explore the possibilities of automation for calculation of production (mining) volumes according to the surveyor measurements;

⇨ to explore the possibilities of automation for recording and controlling the production (mining).

Main statements defended:

⇨ While using GRID technique the model constructed for mineral resources is dynamic and it can be applied for the projection and the development of a deposit.

⇨ 3D geological models can be used in the analysis of geological setup of a deposit and its formation conditions, in assessment of geological and recoverable resources, in making design solutions, in recording and controlling of the mining process. The models introduced into the register can be successfully used in the field of territorial planning.

⇨ The model created by an introduction of the fourth dimension - the time, opens up the possibility of mineral deposits 4D modelling and enables to investigate the geological structure in time.

The novelty of the research. The present work defines the principle applied for construction of dynamical models of non-metal mineral deposits and use of the model constructed for evaluation of the geological setup of the deposits and their formation conditions, as well as performing deposit designing works and developing the deposits. The modelling is done in 3D space enabling to see 3D perspective images of a pit from any point selected and prognosticate the course of excavation works. Presently, the system has already been programmed and being tested at UAB GJ Magma (a joint-stock company). After this system is finally mastered, the 3D (spatial) designing of the deposits will be started. This pit designing system has no analogues in Lithuania.

Practical relevance of the research. The results obtained during the research and discussed in the dissertation will be applied for the analysis of geological setup of the mineral deposits, their formation conditions and making design solutions, and used by the enterprises dealing with prospecting and exploration of minerals and designing of pits. They also can be used by the governmental management and control institutions and in the territorial planning sphere.

Approval of the scientific work. The results obtained during the research have been presented at two international scientific conference and two seminars, as well as discussed at the Nordic-Baltic GIS Summer School:

- ⇨ Gävle University (a poster). Sweden, Gävle, 2007.
- ⇨ Saint Petersburg Mining Institute, International Conference of Young Scientists (oral presentation). Russia Saints Petersburg, 2009;
- ⇨ 7-oje the 7th International Conference on Geomorphology (a poster). Australia, Melbourne, 2009;
- ⇨ Saint Petersburg Institute for Informatics and Automation (oral presentation).Russia, Saint Petersburg, 2009;
- ⇨ Saint-Petersburg Aerospace Instrumentation University (oral presentation). Russia, Saint-Petersburg, 2009;

Two papers have been published with co-authors in a peer-reviewed Lithuanian scientific journal introduced into the Master list of the Institute for Scientific Information:

- ⇨ Patašova (Sukova) T., Jurgaitis A. Comparison of mineral resources calculation methods for different genetic types of gravel and sand deposits. Geologija, 50, p. 156-169, 2009.
- ⇨ Sukova T., Vainilaitis L., Development and application of a mathematical cartographical model to sand / gravel deposits and prospective areas. Geologija, 52, p. 45-52, 2010.

Structure of the dissertation. The dissertation consists of introduction, 6 chapters, conclusions, the list of references and the list of the author's publications. The work is presented in 154 pages, including 27 tables and 98 figures.

REVIEW OF INVESTIGATIONS

All the deposits and prognosticated areas selected for the dissertation research were investigated during the prospecting of the minerals, and their selection was based on genetic dependence. The peculiarities of preparations for the mining process in the deposits of different genetic subtypes were analysed during the research, therefore the reference deposits of corresponding subtypes were selected.

Bogušiškės area belongs to the kame genetic subtype. The initial researches of the gravel deposits in the area had been carried out in 1961–1962. In 1969, the further prospecting had been performed in the area (Gurklienė V., 1969) and detailed exploration followed later in 1974 (Nenartavičienė D., Taločkienė V., 1974), 1999 (Juozapavičius G., Kilda K., 1999), as well as in 2002, 2006 and 2008 (UAB GJ Magma).

Kušlėnai area belongs to the esker genetic subtype. The investigations of Kušlėnai gravel and sand deposit had been launched in 1980 (Lietuvos TSR Geologijos valdybos kompleksinė geologinė ekspedicija [Lithuanian SSR Geological Board complex geological expedition], 1980), later detailed exploration was continued in 1983 (Lietuvos TSR Geologijos valdybos kompleksinė geologinė ekspedicija [Lithuanian SSR Geological Board complex geological expedition], 1983), 2004 and 2007 (UAB GJ Magma).

Sniegiai–Šemetai area belongs to the ice-marginal ridge genetic subtype. In the area of glaciofluvial ice-marginal formations west of Sniegiai gravel deposit, in 1964 the Šemetos gravel deposit had been detected and evaluated by detailed prospecting (Šakys V., Gurklienė V., 1964). Later, in 1975, the prospecting works were continued (Kličius J., Piepolienė V., 1975). Detailed investigations in this area were performed in 1980, 1983 and 2007 (UAB GJ Magma).

In order to reveal the peculiarities of the complex setup of the deposits, the Rūsteikiai area of ice-marginal formations was chosen in Zarasai District. The prospecting works had been performed here in 1963–1964 by the Geological Prospecting Expedition. Later, in 1971, this area was repeatedly checked by the Complex Geological Expedition, and in 1974-1975 it was explored in detail (proved reserves). In 1989-1990 the areas around the deposits explored in detail had been preliminary prospected (probable reserves); and in 2007–2008 three areas explored in detail had been singled out within the preliminary prospected zone (UAB GJ Magma).

Šklėriai area belongs to the sandur genetic subtype. It was detected in 1970–1971 and preliminary prospected in 1976 by the Complex Geological Expedition. This outwash plain contains several large gravel deposits such as Serapiniškės, Šventininkai, and Miškiniai. The detailed exploration of the Šklėriai deposit had been carried out in 2006 by UAB GJ Magma.

Selmoniškės area belongs to the delta genetic subtype. Occurrence of glaciofluvial deposits in the area had been detected in 1961 during a medium-scale geological survey. The investigations had been continued in 1982–1983 by the Lithuanian Geological Institute. Moreover, the Quaternary surface setup and occurrence of lithological varieties had been studied in detail in 1982–1985, when the geological mapping was performed in a major part of the Žemaitija (Samogitia) area. The data made a basis to compile a summarised digital map of the Quaternary in Lithuania. In 1986 the additional geological prospecting had been performed. In 1990, the preliminary prospecting had been carried out by the State Road Designing Institute; and the detailed geological exploration works had been done in 1999 by UAB GJ Magma in one area, and in 2004 in one more area.

Sandrupys sand deposit was explored within the area of continental dunes. The initial prospecting works had been done in 1968 (Ненартавичене Д., 1968). Later, the investigations were continued in 1969 and 1970 (Ненартавичене Д., 1969, Петроните В., 1970). Final geological exploration had been carried out in 1975 (Ненартавичене Д., 1975).

The material of all these investigations has been used to perform the dissertation work by analysing the geological setup of the deposits selected and the prognostic areas as well as their formation conditions. Based on this material, the modelling of the selected areas has been performed.

Modelling is an essential and concurrent part of the scientific activities. In modelling the following factors are important: an opportunity to explain the past events and forecast the future events (determining areas prospective for minerals) and control the processes (the model is used during the development (mining) of the deposit), the costs of use, especially in combination of several models (the costs of model creation and its use), simplicity and aesthetic appearance.

In mid-1990s, a general tendency in geology and other sciences showed up, i.e., creation of digital data bases applying computer technologies. The progress in modern computer technologies enabled to pass from the flat maps and sections to 3D models, which are used to solve both theoretical and practical tasks in the 3D space. The next step is to be the 4D modelling by introducing the fourth parameter – the time.

The methods used in modelling are based on geometrisation. The pioneer in mining geometry as a separate science is the Russian scholar P.K. Sobolevsky. Creating his theory he relied upon the fact that there is an intricate complex of geochemical fields and occurrence conditions in the Earth's subsurface; but this is not an accidental and chaotic accumulation of different materials. He maintained that the Earth's subsurface has a certain setup and regularity in distribution of minerals that can be expressed mathematically with a certain accuracy (Букринский В. А., Славоросов А. Х., 1954). Generally, V – the digital value of structural beds and qualitative indices of a useful mineral – is a variable that can be expressed as follows:

$$V = f(x, y, z, t) \qquad [1],$$

where:

f is a function, x, y – coordinates of a studied point, z – altitude, and t – time.

The methods described by him met difficulty of using them in practice, since there were no powerful computers at that time. Now, as the information technologies are developing quickly, the application of geometrisation methods in geological practice is a very important issue discussed by many scholars in the world: including Kessler H., Mathers S., Lelliott, M., Bridge, D., Ford, J., Sobisch, H.-G., Mathers, S.,Price, S., Merritt, J., Royse, K., Kessler H. et al. (2005, 2009) in the United Kingdom; Hans-Georg Sobisch et al. in Germany; Baojun V., Bin S., Zhen S. in China; Apuhtina I.V., Glazniov V.V., Matusevich A.V., Lukichev S.V., Ovsov M.K., Sharif D.A. et al. in Russia; Nazarenko V.M., Homenko S.A., Borejko L. in the Ukraine et al.

Now there is a global attempt to create fully computerised models starting from those to be used for the analysis of exploration data and continuing with models to be used during the development of a deposit. There are 5 leading companies in the world dealing with the geological modelling, evaluation of useful minerals and designing of mining works, i.e., Gemcom, Maptek, Mintec, Surpac and Datamine.

Products of these companies in the Lithuanian market were not detected, and automated analysing and designing had not being performed previously. UAB GJ Magma started the project "Introduction of Business Control System" under funding by the European Union structural support. Thus, a possibility appeared to apply the practical know-how obtained working for UAB GJ Magma to elaborate a software package for the automated modelling of deposits and to prepare the present dissertation work. The software being created is to be used in automated evaluation of the mineral deposit exploration data and design solutions under the Lithuanian conditions.

INVESTIGATION METHODS

The investigation of prospecting data is related to the laboratory analyses which are treated by the automated program for the evaluation of useful mineral quality indices. The results obtained are used in modelling of the selected deposits (a 3D model is created). The 3D graphical computer modelling method is based on geometrisation. The key elements in the 3D models of deposits are as follows: models of geological surfaces and models of geological bodies.

The created 3D model of a deposit is, first of all, used in assessing the spatial setup of deposits and prospecting areas as well as their formation conditions. The information obtained by investigating the created 3D models and conclusions made were checked by the conclusions of the previous researches. So, to substantiate the deposit accumulation conditions and ways, the bedding investigation results were used, as well as the bed occurrence angles with circular and rose diagrams of bedding azimuths were used to validate the hydrodynamic activity of deposit-forming streams and direction of material input, and so on.

The next stage is related to the use of the created 3D model for the calculation and evaluation of geological resources of the useful minerals. The calculation of resources is performed by 4 methods: block, isoline, profile and GRID methods. The calculations have been done for all selected reference deposits of different genetic subtypes. An attempt was made to determine the advantages and disadvantages of the methods applied and calculation errors obtained by different resources calculation techniques.

Finally the 3D model is used to make design solutions according to the pit's outer bench non-mined slope angles, which are selected by the system according to the bed lithology to design the overburden removal and mineral mining slopes; as well as solutions necessary to perform pit rehabilitation and measures to lessen pollution. Moreover it can be used to single out the untouchable strip at the deposit margin, assessment of mining losses and recoverable reserves, building 3D models for the dug out quarries, planning the dynamical excavation intensity and 3D modelling of the rehabilitated pits. All these calculating and modelling efforts are done for a three-dimension space.

I. AUTOMATED ANALYSIS AND EVALUATION OF MINERAL DEPOSIT EXPLORATION DATA

1.1. AUTOMATED EVALUATION OF ANALYTICAL INDICES OF MINERAL QUALITY, DETERMINATION OF USEFUL BED LIMITS, AND TRANSFER OF PARAMETERS INTO PLANS

The present work discusses the automated evaluation of grain-size composition, since it makes a basis of the Lithuanian standards applied for gravel and sand deposits. Two classifications have been used for creation of the automated grain-size software:

1. a derivative classification formed according to the use of gravel and sand as building material or road ground (generalised by UAB GJ Magma head G. Juozapavičius);
2. motor road ground classification (after LST 1331:2002 lt).

The computer programme has been created using the data base control system Microsoft Office Access (programmed by A. Juozapavičius). The laboratory analyses of grain size are introduced into the programme in Microsoft Office Excel format, the fraction amounts are expressed as percentages, and the classification is performed after the above mentioned types. Also the tables are generated automatically as follows: grain size composition of the ground in all mineral deposit, the resultant grain size for the ground analysed, the grain size of the ground in the useful bed according to the resultant values in the boreholes, the resultant grain size for different ground groups (according to the average values of resultants in the boreholes), the potential of utilisation of useful bed, as well as such parameters of the deposit as Cu (sorting coefficient) and Cc (setup index).

The format for the derivative data is Microsoft Office Excel. All the initial data are introduced with the coordinates (X, Y); thus, the information treated can be directly transferred into the plans, which are compiled by the graphic automated designing system created on the AutoCAD Civil 3D basis after the order by UAB GJ Magma (programmed by UAB Infoera).

Description of boreholes according to the grain size analyses is made by using the programme that enables to do this in automated way. The software was programmed by the Python language (programmed by UAB GJ Magma geologist D. Azaravičius). The laboratory grain size analysis data are introduced into the software as grams or percentages (i.e., partly treated and obtained usually from the archives of the Lithuanian

Geological Survey). The data input is done using the comma delimited CSV file format for data storage and is treated according to the above mentioned classifications, while the output is given in XHTML format that is opened by a browser window.

After the quality indices of a mineral are analysed, the limits of the useful bed are estimated, i.e., a general industrial contour with the reserves of useful mineral delimited from the rocks containing them is determined. Minimum thickness of the mineral bed, overburden removal coefficient (stripping factor), economic efficiency of the deposit development, environmental requirements, as well as the conditions of land and forest use (necessity in various protection zones) are taken into account.

The programs described above were applied for the automated evaluation of mineral quality in the deposits selected for the study and prognostic areas. The results of the study are given in the present dissertation.

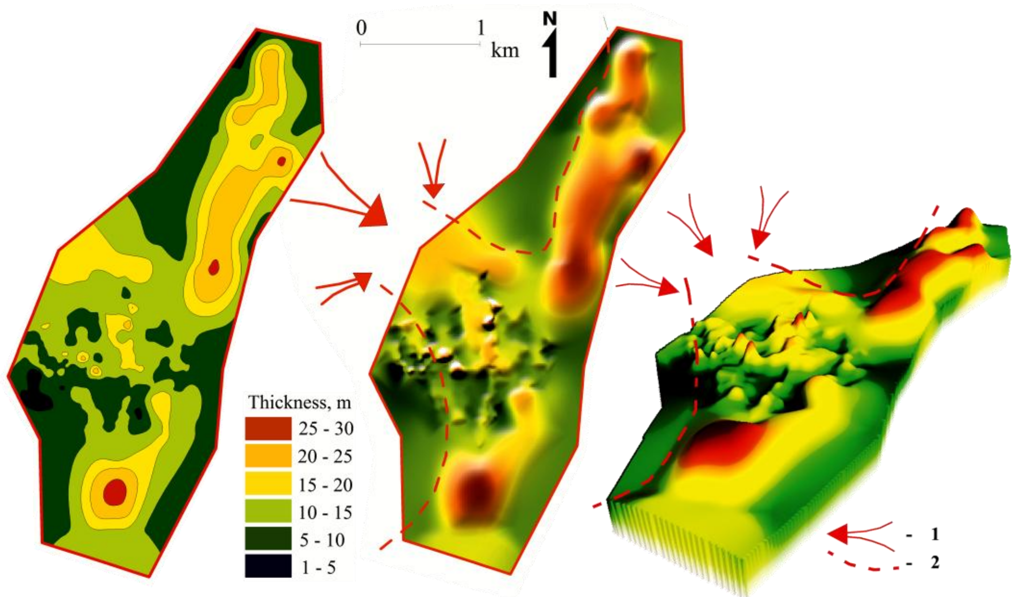
1.2. AN AUTOMATED SPATIAL STUDY OF DEPOSIT SETUP AND QUALITY INDICES

The main task of the spatial study was to determine the form of mineral beds and rocks containing them and their occurrence conditions based on the researches and quantitative measurements.

After the analytical indices of a mineral are assessed and transferred into the plans, it is possible, by automated actions, to make various surfaces necessary for the study of the deposit setup and formation conditions, i.e., draw schemes of useful bed thickness, amounts of different fractions, clay distribution in the deposit etc. As an example, the plan of thicknesses of glaciofluvial deposits in the studied area of the Rūsteikiai gravel pit is given with their 3D view and distribution of gravel and cobble (fraction > 4 mm) in the glaciofluvial deposits (also 3D view).

Thickness of the glaciofluvial deposits in the Rūsteikiai area ranges from 1 to 30 m. Maximum thickness was detected in the zones of the ice lobe marginal zones (Fig. 1). Distribution of gravel and cobble (fraction > 4 mm) in the glaciofluvial strata enables to perform more detailed investigations on the direction of the material transport by the glaciofluvial streams (Fig. 2). It confirms the direction of the outwash fan. The coarser is the material the more rapid is stream and deposit thickness. To confirm these assumptions additional bed the circle diagrams of inclination angles and rose diagrams of azimuths were constructed (Fig. 2). The measurements were performed by

L.Vainilaitis (2009). We can see that the biggest inclination angle is above 50 degrees, but majority of measured beds were inclined at 0–25 degree angles (Fig. 2, A). This shows that the stream intensity was varying and not always it was strong. The rose diagram of oblique lamina is highly scattered (Fig. 2., B). This shows that the matter input direction was not stable (Юргайтис А., Микалаускаус А., Юозапавичюс Г., 1982.). The main direction of the matter transport was from the northwest; and this confirms the direction of outwash fan formation and sites of ice lobe margins (Figs. 1 and 2).



1 – main direction of outwash fan formation, **2** – probable sites of glacier tongue margins.

Fig. 1. 2D and 3D glaciofluvial deposit thickness models

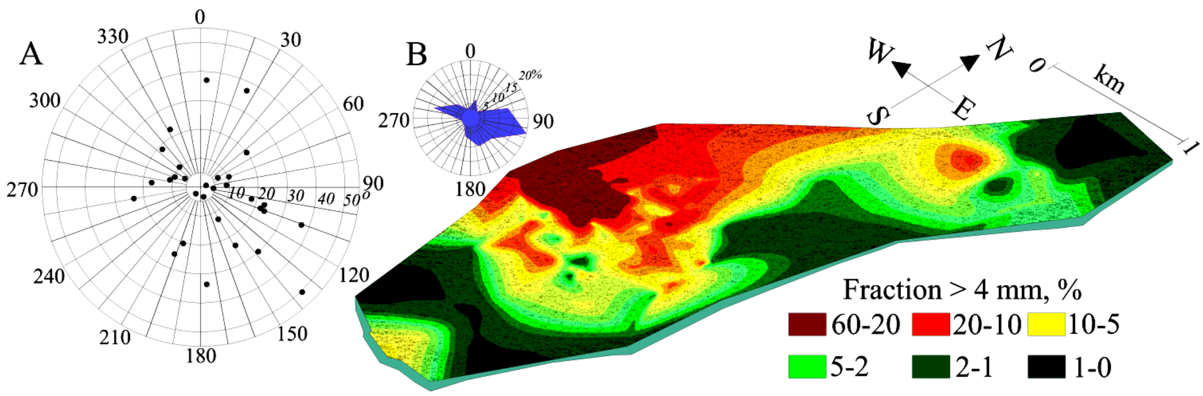


Fig.2. Distribution of gravel and pebble deposits (fraction > 4 mm) in glaciofluvial bed, as well as inclination angles circle (A) and direction rose diagrams (B) of the oblique strata

1.3. CONSTRUCTION OF DYNAMICAL MODELS OF GEOLOGICAL BODIES OF DYNAMICAL RESERVES AND CALCULATION OF THEIR VOLUMES

1.3.1. Construction of 3D models for geological bodies

Having completed the study of archive material on the selected deposits and prognostic areas as well as qualitative indices, it was switched to the construction of 3D models for geological bodies and calculation of mineral volumes. A special 3D modelling modulus attached to the Geomap-2010 software elaborated during the dissertation work was applied for this purpose. The opportunity to realise this idea became real due to the support by UAB GJ Magma and European Union. The company UAB GJ Magma started to perform the project "Introduction of Business Control System" funded also by the European Union structural assistance that was used for elaboration of software package capable to optimise formation of mineral deposit models and automation of pit designing.

The top and bottom surfaces of lithological varieties were constructed for the deposits and prognostic areas selected for investigations. The thickness of beds between the top and bottom surfaces distinguished makes a geological body of a corresponding lithological variety. The bodies joined into one entity make full 3D models of deposits and prognostic areas.

Top and bottom surface models for all relief and lithological varieties selected have been constructed based on this principle and used to model the geological bodies of the deposits and prognostic areas. The principle of geological body model creation is presented in Fig. 3 on the example of Sniegiai gravel deposit (explored in detail, i.e. proved, in 2007). First of all, as described above, the surface of the top of a real body is created. The example shows model of all useful bed body in the Sniegiai gravel deposit; therefore first of all the top and bottom surface models were created (Fig. 3, 1). Then these models were pieced together, thus forming a closed spatial geological body (Fig. 3, 2). After such surface models are created for all lithological varieties, closed spatial bodies are created for each of the variety. Finally, the models are pieced into one entity producing a 3D model of a whole mineral deposit or prognostic area. The tops and bottoms of the surfaces are created and joined in automated way; it remains only to choose the surfaces which are intended to be joined. All this is calculated and modelled in a three-dimension space. This enables to view 3D images of prospective deposits and prognostic areas from any point selected, as well as they can be turned or inclined and cut in any direction. It is also possible to divide the created 3D geological body into separate seams. Such divided geological model reflects visibly basic features of the geological setup of the modelled area. It is also possible to see, where different sediments deposits occur. For instance, a divided 3D geological model in a part of the Bogušiškės II gravel pit shows clearly that the fine gravel bed is significantly less thick in the north-eastern part of the pit than that in its other parts; while there is no such bed at the pit margins (Fig. 4). It is also seen that sand deposits occur only locally.

Moreover, the created 3D geological model is applied to create the derivative surfaces, both 2D and 3D (Fig. 3, 3 and 4). The figure shows the thickness of a whole useful seam in 2D and 3D space as a derivative model obtained from the general geological model of the useful mineral between its top and bottom surfaces. This model is also used to investigate the geological setup and formation conditions of deposits and/or prognostic areas, as well as in making the design solutions.

The 3D models constructed for all areas studied are given in the dissertation. Some of them are constructed only in the detailed exploration (proved) areas for separate years the explorations were performed

1.3.2. Geological resources of a useful mineral

Correct records of resources make one of key factors conditioning their rational use. The recording or resources started when humans understood that the resources were not inexhaustible. Presently, there are about twenty methods applied for calculation of resources. The most often used ones are as follows: profile, geological block, exploitation block, polygon, triangular and isoline methods (Авдонин и др., 2007; Ажгирей и др., 1954; Борзунов, 1969,1982; Каждан, 1984).

The automated deposit modelling program (Geomap 2010 with a corresponding addition) uses the GRID method for calculation of resources. In order to see the advantages and disadvantages of this method to be used for the deposits of different genetic subtypes, the calculation of resources has been performed by this method and several other techniques used commonly for this purpose in Lithuania and abroad. The calculations were performed for the detailed exploration (proved) areas.

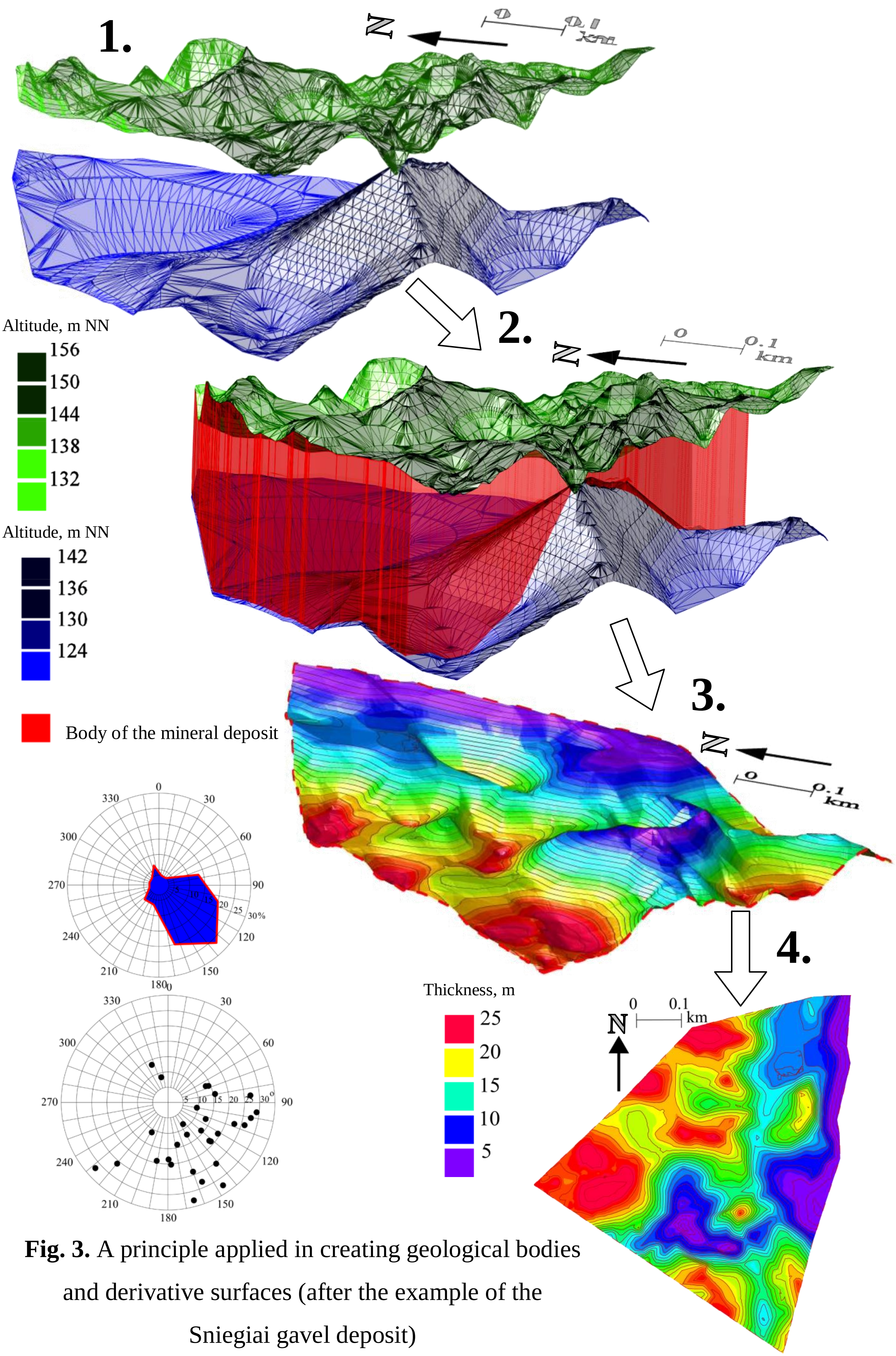


Fig. 3. A principle applied in creating geological bodies and derivative surfaces (after the example of the Sniegiai gavel deposit)

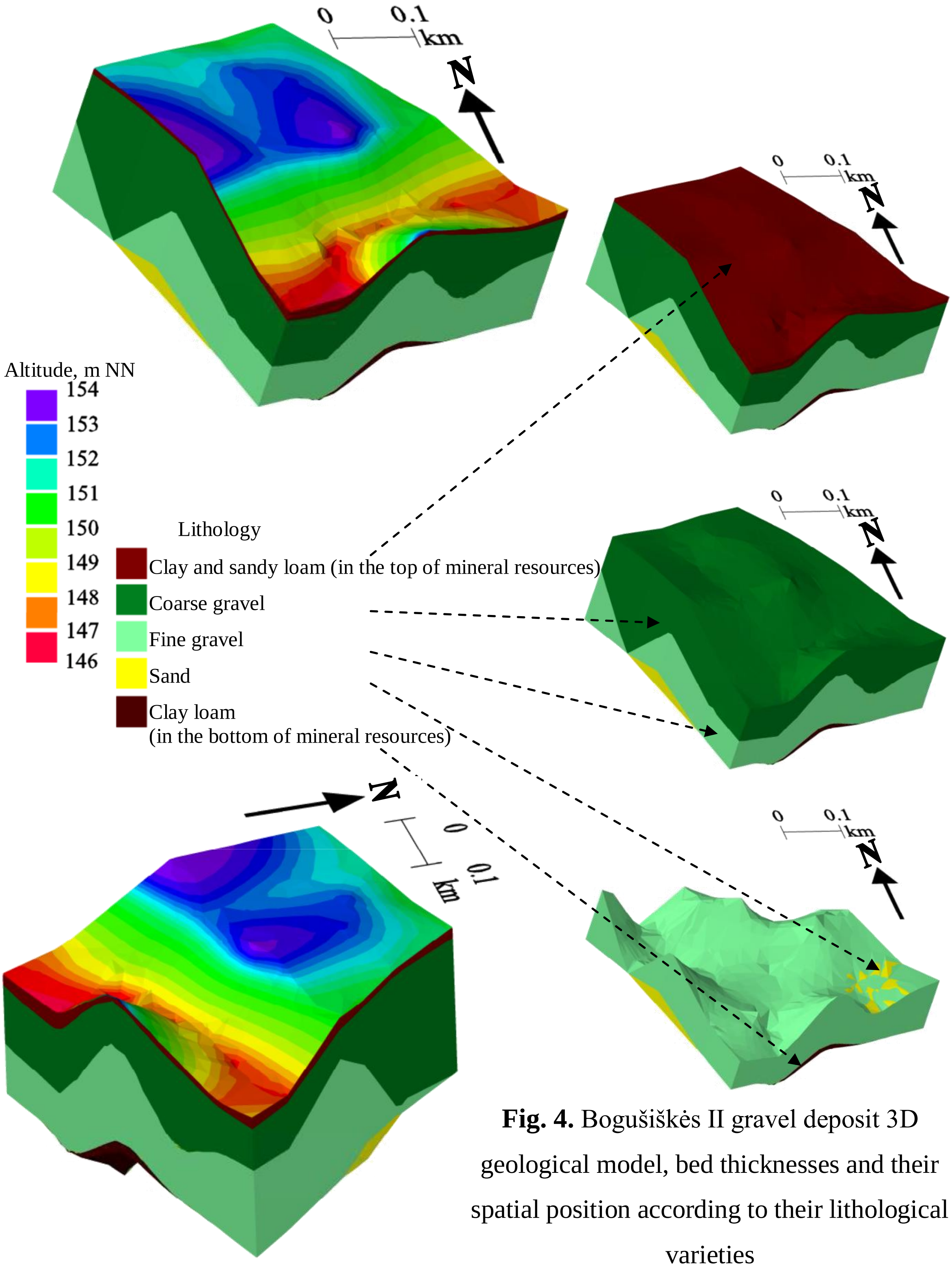


Fig. 4. Bogušiškės II gravel deposit 3D geological model, bed thicknesses and their spatial position according to their lithological varieties

The results of the resources calculation made by the *block method* for the deposits of different genetic subtypes showed that rather reliable data of calculation were obtained in the deposits of stable relief and even bottom under the conditions of dense borehole network. The difference from the GRID method did not exceed 3 percent under the mentioned conditions. When the relief is varying, the reliability of the results decreases. This is shown by the calculation done for the Sandrupys aeolian sand deposit notable for a rather rough relief. Unreliable results are also obtained in the case of insufficient density of boreholes. This problem was revealed during the calculations made by block method for the Selmoniškės glaciofluvial delta gravel deposit, where even 11 percent difference from the GRID method was obtained. The setup of this deposit is not complex, but its axial part has an old ice-marginal valley with the thickest seam of the useful mineral. The borehole network is insufficient for the reliable evaluation of the bed thickness increase in the valley area. Moreover, the application of block method is aggravated due to the fact that the mining in the deposit has started. The extraction of the mineral is followed by formation of production slopes. If the mining takes place in several sites thus making uneven front of excavation, many benches are formed in different sites. One production bench is separated from another by production slopes. In order to calculate reliable amount of mineral dug out and the rest reserves, the blocks of a mineral are divided into sub-blocks, and the reserves are determined separately for the production slope, its top and its bottom. Thus, as many production slopes are formed in different sites, the calculation by block method requires more intensive work.

A disadvantage of the *profile method* is that, for its application, the deposit should be explored by borings done at straight lines. However, in practice, it is difficult to do this in practice, especially in the case of complex setup and rough relief conditions. Another disadvantage of this method is related to the insufficient data available for reliable formation of a profile. Often the reliability of the profiles drawn depends on the competence of a geologist and his intuition. Moreover, the errors are possible when the inclination of the mineral seam is not taken into account. Correct calculation results are obtained only in the case of perpendicular occurrence of a mineral bed. This is confirmed by the results obtained during the present dissertation work. To make the calculations by the profile method, vertical geological/lithological profiles were drawn for each deposit studied in parallel at nearly similar distances. The study showed that, if the data available are sufficient and boreholes are located in straight lines, the reliability of results is similar for the deposits of different genetic types (Table 1). This method cannot be recommended to be applied when the boreholes are insufficient in number and they lie not on straight lines; therefore, in order to draw profiles, the data should be artificially projected. Especially this is important in the case of complex deposit. This is well-illustrated by the calculations done by the profile method for the mineral reserves in Sandrupys aeolian sand formations and Bogušiškės kame gravel deposit plot.

As the isoline method is applied for the calculation of reserves in the deposits of different genetic type, the average difference from the GRID method, if compared to other calculation methods used in the present work, is the least and does not exceed 3 percent. To calculate the reserves by this method, the isoline map of useful mineral seam isolines should be compiled and the areas corresponding to each isoline should be measured. In the case of undulating surface, depressions and elevations should be singled out and evaluated separately. When the reserves had been calculated without computers, the drawing of isolines and calculation of their areas was tricky; therefore this method was not popular. With the computer technologies developing, the drawing of isolines and calculation of areas marked by them became possible by using computer software. The Geomap software created on the Autodesk basis is among the first computer programs created in the Lithuanian market. The calculation of the reserves for mining is usually performed by a certain level that is limited by the groundwater table. In this case the floor of the mineral bed is rather even; due to the fact that compiling isoline maps of useful beds relying upon the topographic base, the relief changes are taken into account, the calculation results are rather reliable. A disadvantage of this method is that the measurement of areas for each isoline is labour-consuming process. Moreover, if an error is made during this measurement, it is necessary to repeat all calculation process anew. One more disadvantage is the complexity of reserve calculation control, since for checking, each isoline area should be measured anew.

The GRID method also was used in the present work for calculation of mineral reserves. It is based on a triangle method basis in GIS environment. The core of it is that the whole mineral deposit is divided into bevel-cut prisms, the upper and lower bases of which are triangles with boreholes at their apices. The side edges of the prisms depend on the thickness of the mineral in a borehole. The size of the reserves is calculated for each prism separately by geometric formulae. By summing the volumes of all selected prisms, total volume of a deposit is obtained. Although this method is old-established, it was not widely used because of necessity to draw triangles graphically relaying on certain conditions; moreover, the data of each borehole were used at least three times, therefore, this inconveniences the calculations and requires more labour.

Furthermore, the results of such calculation were of low reliability, since using this method without help of computer, the data were used only from boreholes without taking into account the changes in relief. With computer technologies developing, this method was transferred into the GIS environment and was named the GRID method. Its use in GIS environment is perfected so that not only borehole data but also the topographic base is used. In such a way, the complexity of the relief is assessed. Using this method for calculation of volumes, usually the top and bottom surfaces of useful bed are formed. The volume between these two surfaces makes the volume of the useful mineral. It is calculated in automated way for each triangular cell and then summed up.

Table 1. Results of resources calculation in the deposits of different genetic types

Calculation method	**Volume, m³**	**Difference, %**	**Area, m²**
Kušlėnai gravel and sand deposit (esker)			
GRID	3710993	100	237920
Isolines	3819000	3	
Profiles	3845354	4	
Blocks	3743886	1	
Bogušiškės II gravel deposit plot I (kames)			
GRID	475692	100	34878
Isolines	486110	2	
Profiles	516243	9	
Blocks	489586	3	
Bogušiškės II gavel deposit plot II (kames)			
GRID	1711310	100	120638
Isolines	1740017	2	
Profiles	1535668	-10	
Blocks	1756293	3	
Bogušiškės II gravel deposit plot III (kames)			
GRID	367000	100	25783
Isolines	372153	1	
Profiles	380533	4	
Blocks	366817	-0.05	
Sandrupys sand deposit (eolian)			
GRID	17047220	100	952923
Isolines	17291870	1	
Profiles	13901375	-18	
Blocks	18345216	8	
Šklėriai gravel and sand deposit (sandur)			
GRID	3823000	100	360646
Isolines	3853228	1	
Profiles	4025998	5	
Blocks	3858911	1	
Sniegiai gravel deposit (marginal glaciofluvial ridges)			
GRID	4969000	100	318687
Isolines	4975782	0.1	
Profiles	4795627	-3	
Blocks	4867091	-2	
Selmoniškiai gravel deposit (glaciofluvial delta)			
GRID	786000	100	94036
Isolines	761916	-3	
Profiles	770945	-2	
Blocks	697080	-11	

The advantage of using this method is that the surfaces remain active all the time, therefore, when the values of any of them change, the changed volume is re-calculated automatically. This is important after the mining of a mineral is started, because it enables to monitor the varying reserves (calculate mineral production volumes and the rest by the same principles). Thus, this plan of deposit reserve calculations turns into a dynamic model for calculation of reserves.

The summarised results of the work described in this chapter for deposits of all selected genetic types are given in Table 1. To compare different methods, as mentioned above, the difference from GRID method was calculated and expressed in percentage. However, this does not mean that this method is most perfect; it is just used in the computer programs and makes the calculations of the reserves significantly easier. Furthermore, using it to construct the models of mineral thickness, the model obtained, eventually, is to turn not only into a 3D but also a 4D model.

1.4. A STUDY OF INTRODUCTION OF DYNAMICAL MODELS OF MINERALS RESERVES INTO THE REGISTER OF THE LAND SUBSURFACE AND NATIONAL MANAGEMENT AND CONTROL INSTITUTIONS

The introduction of dynamical plans of mineral reserves into the land subsurface register would ensure more reliable management and control of the resources. The creation of modulus of the exchange between different registers would enable different institutions having certain interests in the sphere of useful minerals to use easily these dynamical models in making solutions there. For instance, the territory planning specialists would be able to use the models in the analyses of territory developments and their tendencies, the environmentalists in evaluating the disturbed territories, etc. The position of the plans of mineral reserves in the state management and control institutions is shown in Fig. 5.

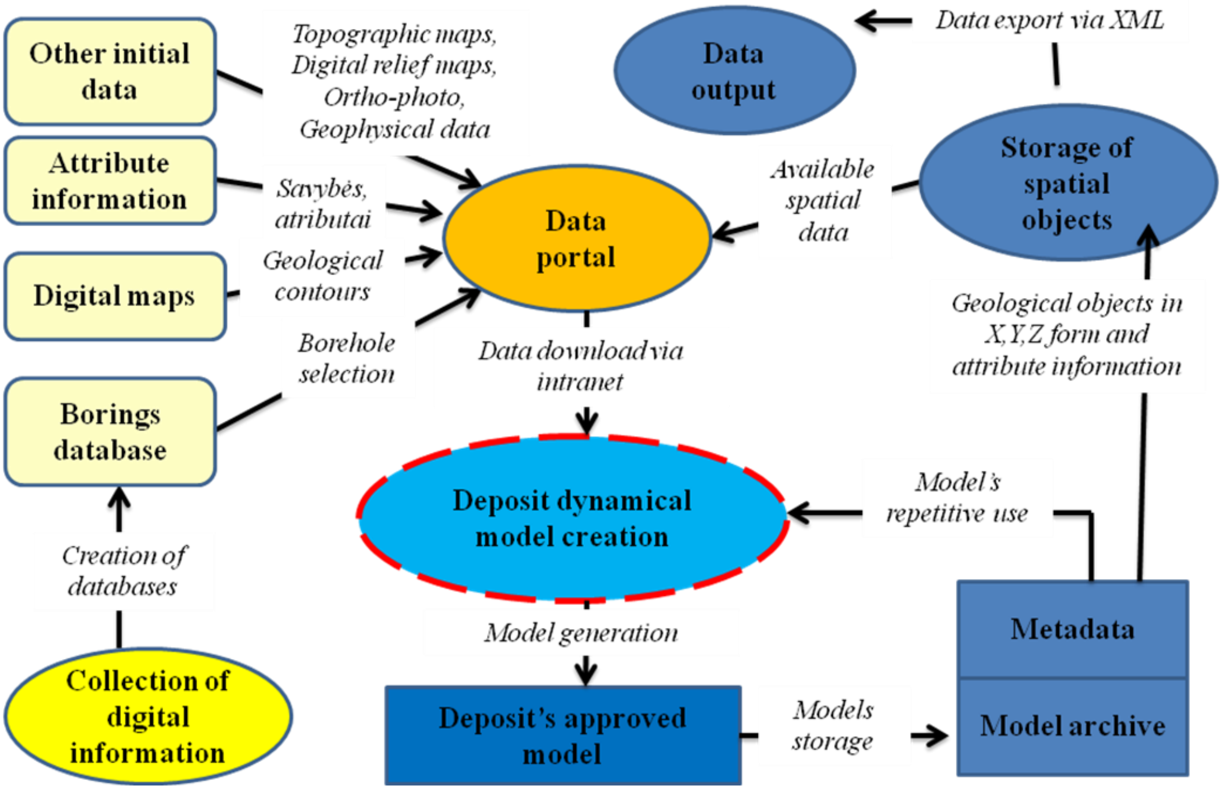


Fig. 5. Position of dynamical model of a deposit among other LGT cyber-infrastructure elements

II. METHODS FOR AUTOMATION OF MINERAL DEPOSIT UTILISATION DESIGN SOLUTIONS

The final goal of the modelling is the designing of the deposit utilisation. In general case such a design consists of five parts: excavation, re-cultivation, environment protection, and economic study.

2.1. DYNAMICAL MODEL FOR CALCULATION OF RECOVERABLE MINERAL VOLUMES

The dynamical model for calculation of recoverable reserves is constructed on the basis of 3D geological model after all potential losses of a mineral are evaluated during the planning of deposit's utilisation. It is used to calculate really possible quantities of a mineral to be extracted.

Having the dynamical plans of reserve calculations, the planned losses of a mineral (i.e., those in the untouchable strip of the deposit's margin, designed non-mined batters (slopes) and areas inconvenient for mining etc.) are calculated automatically, after the untouchable strip, non-mining slopes and inconvenient areas are distinguished by the methods described in the dissertation. These methods are integrated in the modulus of the software to be created; its action principle is given in the dissertation.

Calculation of the losses is performed for the same surfaces which were used for calculation of geological reserves, i.e., top and bottom of the useful bed. The volume between the surfaces in a selected plot (after the necessity of untouchable strip is assessed, and the area of mining slopes is determined, etc.) makes the volume of the mineral to be dug-out. Subtracting the calculated amounts of the mineral from the total geological reserves, the losses are determined in the untouchable strip, designed non-mining slopes and under them, as well as areas inconvenient for mining etc.

The schemes of losses calculated in such a way, as well as drafts of geological reserve calculations are dynamical and can be change easily if necessary. The can also be applied for registration and control of the useful mineral.

The assessment of the losses and calculation of recoverable reserves given in the dissertation are done for several deposits selected for a study, because in substance all they are very similar. The dissertation presents the schemes for calculation of losses in Bogušiškės gravel pit Plot 2, Sniegiai gravel, Šklėriai gravel and sand, and Rūsteikiai gravel pits.

2.2. EVALUATION OF STABILITY OF THE PIT SLOPES AND WORKING BATTERS

This chapter of the dissertation presents general information about the factors affecting the slope stability and its evaluation methods as well as describes the engineering means used to calculate the pit batter stability.

Working on the dissertation, laboratory analyses have been done in the area of the marginal formations in the Rūsteikiai area, where the main features (affecting the pit's working slope inclination) of the ground were determined: unit (specific) weight γ (kN/m^3); angle of internal friction φ (in degrees); cohesion c (kPa). To determine internal friction angle and cohesion, the shear strength τ was used. The ground was tested by the direct shear testing system (BCB 25 TY 34-72-10779-85) by consolidation test with a stable velocity and fixed vertical stress σ (at 50, 100, 150 k Pa).

Future pit's working slope parameters to ensure slope stability are determined by introducing the slope stability safety factor (ks) that was 1.10 in this dissertation, i.e. with a 10 percent reserve. The results conformed to the angles of stable slopes as recommended in the requirements. Due to this reason and expensive testing, the angles of stable slopes were not determined in other deposits selected for the study. Their values were taken as corresponding to the recommended ones.

2.3. AUTOMATION OF DIVISION OF A DEPOSIT INTO MINING BENCHES ACCORDING TO THE PARAMETERS OF THE MACHINERY USED

The present work discusses the mining of minerals by an open-pit process.

During the open-pit mining, the overburden removal and mining works are performed. Depending on machinery parameters (excavator digging depth, loader height, digging and loading radius) the overburden removal and mining works can be performed in several steps.

Numbers of overburden steps and mining benches as well as their location are designed taking into account the machinery type, geomorphological situation and geological setup of a deposit. The numbers of steps and elements of each step should be determined. According to the bench height (thickness), its top and bottom altitudes, the mining drafts are compiled and further used in making timetables.

This stage of designing is described in the dissertation for the Bogušiškės plots 1 and 2, as well as the deposits of Sniegiai (exploration in 2007) and Šklėriai (exploration in 1975).

2.4. CALCULATION OF DUG-OUT SPACES AND COMPILATION OF DYNAMICAL MINING INTENSITY DRAFTS

After the mining situation is revealed, number of mining benches is determined, each bench surface plans are made and all benches are joined into one entity and added to the surface of the untouched deposit, the draft of the dug-out pit is obtained; the latter can be used for calculation of the spaces to be dug out. All these works are performed within the computer software Geomap-2010. Formation of surfaces is performed according to the same technology as for the surfaces of lithological varieties. First of all, the top and bottom surfaces of the useful bed planned to be dug out are created. The data necessary are entered from Microsoft Excel using the .csv (comma delimited) file format. Further the untouchable strip steps and the top of first mining bench are determined. Finally, the “sloping”, i.e. designing of non-mining slope positions for each bench, is performed.

The draft of the dug-out pit also contains the sites of dug-out waste soil, mineral transportation road and, if necessary, other objects.

The 3D models of the dug-out pits Bogušiškės Plot 1, Kušlėnai, Sniegiai (explored in 2007), Rūsteikiai (explored in 1975) and Šklėriai (explored in 2006) are given in the dissertation. The Bogušiškės Plot 1 dug-out 3D model is given in the summary of the dissertation – Fig. 6.

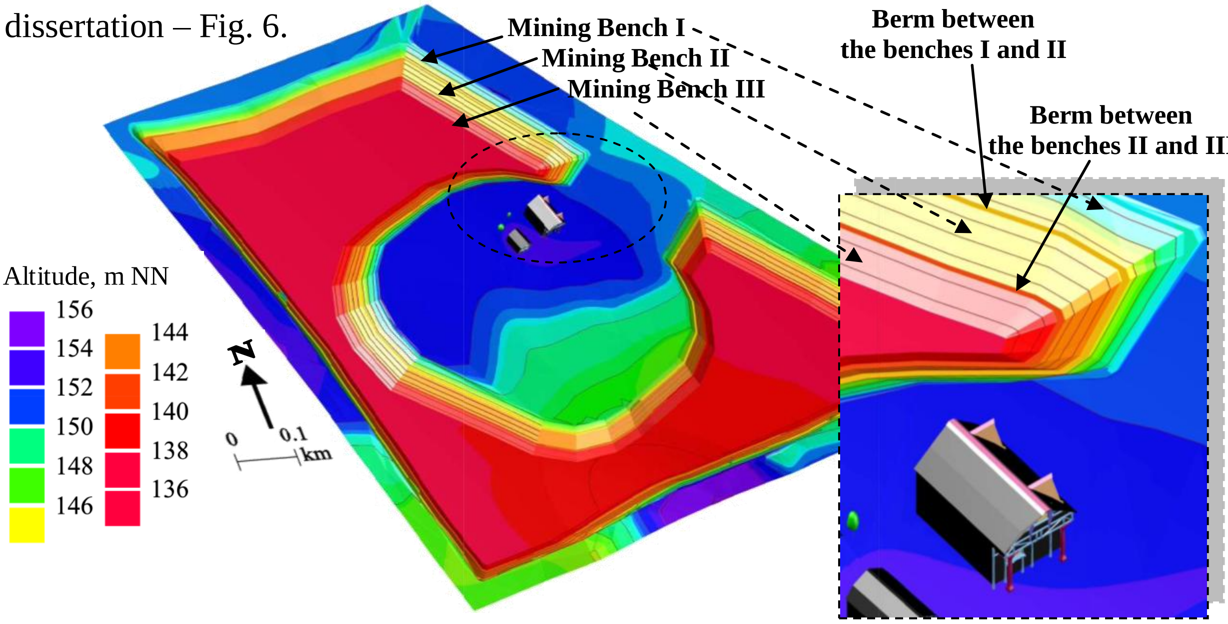


Fig. 6. The Bogušiškės Plot 2 dug-out 3D model

The timetables of mining in a deposit are drawn according to the annual demand in a mineral taking into account the raw mineral transportation costs, which make about 1 percent of the planned yearly demand in the mineral. This is done in automated way by using surfaces of the benches formed. Moreover, the annual demand of the raw mineral, the start position of excavator place (the start line of mining) and direction of mining front shift also should be indicated.

The timetables of mining intensity for each mining bench in the deposits of Bogušiškės plots 2 and 3 are given in the dissertation.

2.5. INTEGRATION OF MINING-DAMAGED AREAS INTO THE NATURAL LANDSCAPE

The development of mineral mining, rational use of nature resources and environment conservation are interests which are difficult to be matched together. Any development of human economic activities is nearly always related to the increase in technogenic impact on the natural environment. The resources-saving technologies or even waste-free technologies outdistance the negative consequences but do not remove them.

In a course of civilisation the economic material interests make the priority; when they are satisfied, the environmental problems come to surface and, finally, the aesthetic demands become important. Similarly, the evolution of activities in the field of mineral mining shows that initially humans were interested in digging (to satisfy the demand in minerals), then they began observing the environment and now dealing with pit rehabilitation, i.e., integration of the mining-damaged areas into the natural landscape. It is important, already at the very start of the pit designing, to envisage proper type of rehabilitation and its terms. This requirement conforms to the goal of the environment-protecting territorial planning, i.e., to turn from the battle against the consequences to the war against the reasons and during the planning stage take into account not only the demands but also to meet the limitations and consistently prepare the territorial planning documents and implement them. It is necessary to avoid violating the specific land and forest use conditions and preserve the cultural values.

The models of rehabilitated deposits of Bogušiškės plot 2, Sniegiai (explored in 2007), Šklėriai (explored in 2006) are presented in the dissertation; they are constructed using the automated pit designing modulus at the Geomap-2010 software.

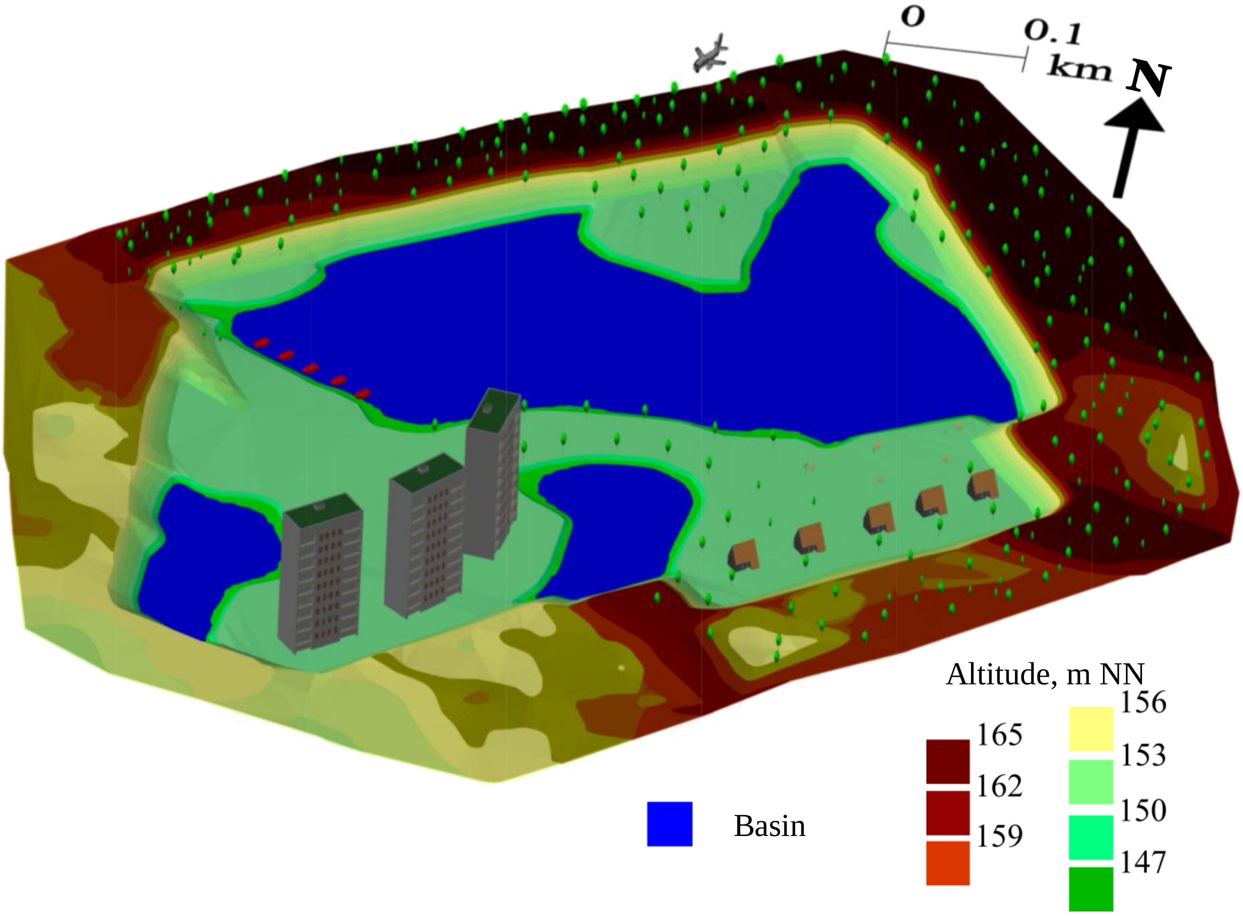


Fig. 7. The Šklėriai (explored in 2006) rehabilitated pit model

III. AUTOMATED CALCULATIONS OF MINING VOLUMES ACCORDING TO THE SURVEYOR MEASUREMENTS USING DYNAMICAL PLANS OF RESERVE CALCULATIONS

The surveyor plan should contain distinguished areas where the mining took place after the previous survey measurement. The dug out mineral volumes, the quantities of overburden removed (the removed soil evaluated separately) and mining losses are calculated in the areas distinguished. The mining losses are calculated in the area of mining done during the record time span in accordance with the deposit utilisation plan.

An operative and correct solution of surveyor tasks is a necessary ground for correct planning, selection of excavation direction and its change, control of implementation of the deposit utilisation, evaluation of the balance and losses of reserves. The losses calculated, after their substantiation is checked at the Lithuanian Geological Survey, are removed from the balance of the deposit reserves.

Automation of the above-mentioned actions is very important, because it makes the performance time shorter and enhances the reliability and quality of the results.

During the detailed prospecting and designing of mining, after the dynamical drafts for calculation of reserves are made, the surveyor measurement-based calculations of mineral volume require determination only of the altitudes of the surfaces of mining damaged areas. The altitudes are used to make the mineral surface plan for the day when the surveyor measurements were performed. The volume between this surface and the top of the undamaged pit or the surface obtained during previous surveyor measurements will make the volume of a mineral dug out during an estimated time period. If the dug-out volume is subtracted from that of the useful bed at the estimated time period, the remainder of the mineral reserves is obtained for the end of the estimated time period. The newly formed surface of a mineral bed will be a reference point for calculation of the volume to be mined in the next year.

The analysis of the mining on the Bogušiškės II plots 2 and 3 is given in the dissertation, and the Bogušiškės II Plot 3 is presented in the summary as an example.

The data about the operation of the Bogušiškės II deposit Plot 3 have been taken for a three-year period (2006, 2007 and 2008). This plot is operated by UAB Skirnuva. Figs. 8 and 9 show the analysis of the mining in this deposit. The 3D models of surfaces for each year separately are given in Fig. 8, while Fig. 9 depicts the mineral volumes dug out from the bodies between these surfaces. The models made were used to calculate the dug-out mineral quantities by the GRID method described above. In 2006, 2007 and 2008 the mineral volumes dug out in the Bogušiškės II Plot 3 made up, respectively, 27 000 m^3, 31 000 m^3 and 5 000. m^3. The design volume was 50 000 m^3. The front of mining corresponded to that envisaged in the design.

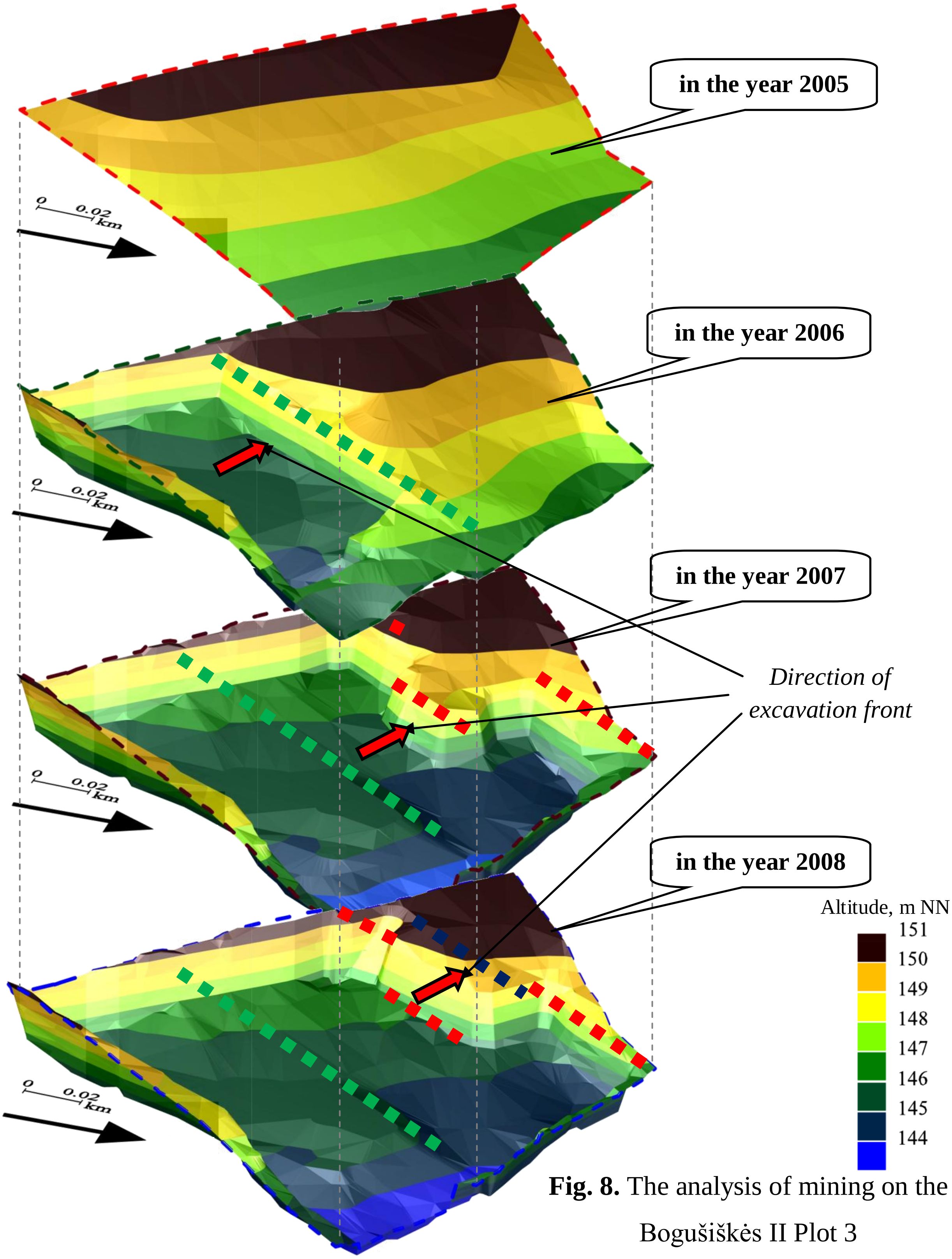


Fig. 8. The analysis of mining on the Bogušiškės II Plot 3

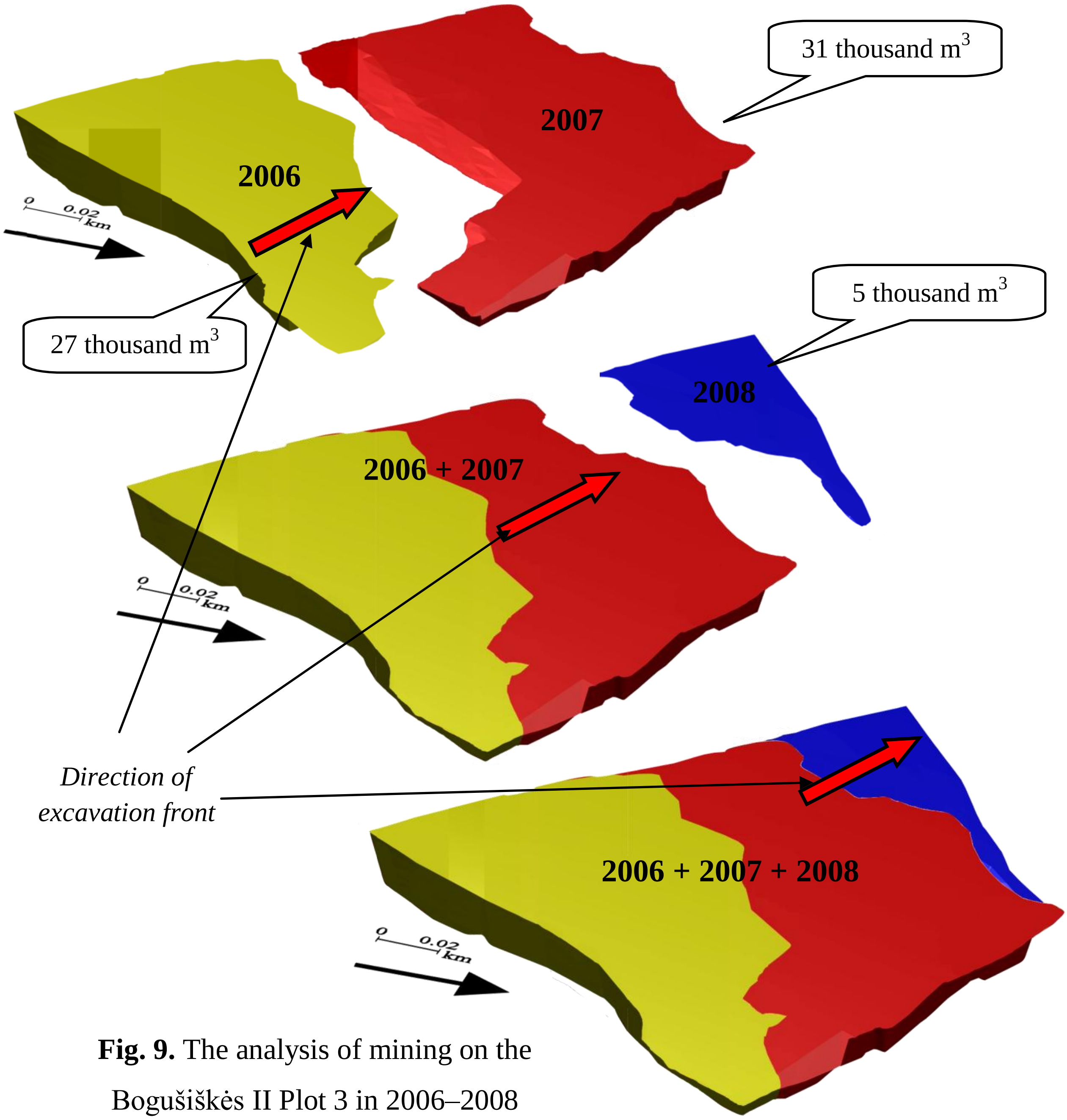


Fig. 9. The analysis of mining on the Bogušiškės II Plot 3 in 2006–2008

IV. AUTOMATED RECORDING AND CONTROL OF MINING WORKS ACCORDING TO THE DYNAMICAL PLANS OF DEPOSIT UTILISATION AND SURVEYOR MEASUREMENTS

The recording and control of the mining process is performed by the Lithuanian Geological Survey that is provided with the surveyor measurements, which are used to check the conformity of mining to that defined in the design. It is also checked whether the mining keeps to the limits of the mining plot, whether the land of other owners is trespassed, whether the untouched land strips are left for rehabilitation works etc. The reports also make the basis for checking or correcting the balance of mineral reserves.

If the created 3D dynamical models were integrated into the land subsurface register, this process would be more reliable and efficient in regard with the labour and time consumption.

The control of mining process is also important for other institutions dealing with the environment protection, labour security and territorial planning; thus the dynamical models should be available for specialists of these fields. Performing the territorial planning, the attention should be paid to the geological state of a territory. If the created 3D models of deposits were integrated into the land subsurface register and its availability was ensured for specialists of other fields, the territorial planning would become more efficient and rational. The mining of a deposit ant its rehabilitation would become clearer. One would be able to see how much time is needed to dug-out the planned amount of minerals, what is the rehabilitation method envisaged (water body, forest etc.). All this would facilitate the work of specialists dealing with territorial planning and improve the quality of solution making in this sphere. All this is very important for Lithuania, the area and mineral resources of which are not large on a global scale.

CONCLUSIONS

1. The dynamical models of mineral deposits can be used for the study of geological setup of deposits and their formation conditions, the calculations of geological reserves, making design solutions, performing surveyor measurements, as well as recording and control of mining process.
2. The results of the study on geological setup of deposits of various genetic subtypes confirmed the tendencies typical of their genetic subtypes. Three kames with typical setup have been distinguished in the Bogušiškės area. The setup of the Kušlėnai area is typical of esker formations. The conditions under which this deposit had been forming determined its varying composition across the ridge axis and longer beds of similar composition along the ridge length. The study of the Rūsteikiai area clearly shows complex polygenetic course of ice-marginal formations starting from the glaciolacustrine conditions, followed by glaciofluvial sedimentation of various intensity at the ice margin and finally to the formation of marginal glacigenic sediment cover due to a slide of unwashed till matter from a glacier. The same complex setup has been detected in the

area of the Sniegiai ice-marginal formations. The Šklėriai area is a typical sandur formed by dynamically unstable glacier meltwaters wandering freely over a large periglacial plain. The Selmoniškės gravel deposit in a glaciofluvial delta was formed under the conditions which determined a simple setup and occurrence of beds in a continuous seam. The useful mineral bed in the Sandrupys deposit is formed of Late Glacial and Holocene aeolian sediments occurring below the dune bottoms above the glaciofluvial sediments laid by valley streams. Variations in sand bed thickness were caused by very rough relief of continental dunes; it is minimal in the areas between the hills and high at the top of the dunes.

3. Using different methods for calculation of mineral reserves in the deposits of different genetic subtypes, different calculation biases are obtained. Calculations of reserves in the deposits of simple setup, the errors remained in permissible limits (to 10%), while those made for the deposits of complicated setup (rough relief, wedging-out etc.) showed the errors exceeding the permissible levels.

4. The GRID method introduced into the automated designing programme for calculation of mineral reserves was found to be the most efficient according to labour and time consumption. The GRD method-based drafts for calculation of reserves become dynamic and can be applied for making design solutions and performing surveyor calculations.

5. After the mining in a deposit started, the created dynamic model can be used both by the production companies and the state institutions for recording and control of the mining, performing surveyor measurements and planning the mineral excavation volumes. The next stage in creation of the geological models is the four-dimension (4D) modelling, where the fourth dimension – time – is entered. The 4D models will enable to investigate the geological setup in time.

6. The models introduced into the land subsurface register can be successfully applied by specialist of various fields, especially in territorial planning to project the tendencies in the development of the territories.

PUBLICATIONS:

In peer-reviewed scientific journals introduced into the Master list of the Institute for Scientific Information:

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

2. Sukova T., Vainilaitis L., Development and application of a mathematical cartographical model to sand / gravel deposits and prospective areas. *Geologija*, ISSN 1392-110X. 2010, Vol. 52, No 1-2 (69-70), p. 45-52.

In other reviewed international, foreign and Lithuanian periodical, serial and onetime journals:

1. Juozapavičius G., Sukova T., Kadūnas V., Šliaupa A. Pagiriai anhydrite deposit: extraction and its effect on the environment. *Geologijos akiračiai*. ISSN 1392-0006. 2010, No.1-2, p.26-41. (in Lithuanian)

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3. Sukova T. Mineral resources calculation methods. *7th International Conference on Geomorphology: Modern Perspectives* (poster presentation). Australia, Melbourn, 2009;

4. Sukova T. Using Geo Information System for Building Mathematic-Cartographical Model of Deposits. *Seminar "Informatics and computer technologies"*, Saint-Petersburg Institute for Informatics and Automation of Russian Academy of Sciences (oral presentation). Russia, Saint Petersburg, 2009;

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Nerūdinių naudingųjų iškasenų telkinių dinaminių modelių sudarymas ir jų panaudojimas telkinio eksploatavimo eigoje

REZIUMĖ

Visuomenė negali gyventi nenaudodama gamtos išteklių. Siekiant gerovės ekonomikoje, apsirūpinimas mineraliniais ištekliais yra labai svarbus kiekvienai pasaulio valstybei. Visa civilizacijos raida yra pagrįsta žemės gelmių išteklių naudojimu, todėl naudingųjų iškasenų gavyba yra neišvengiamas procesas. Tačiau kasybos pramonė ir su ja susijusios problemos yra nepakankamai nagrinėjama tema.

Temos aktualumas. Šiuo metu erdvinio (dinaminio) geologinio modeliavimo klausimas, susijęs su kompiuterinių technologijų taikymu, yra nauja banga geologiniuose tyrimuose kaip pas mus, taip ir užsienyje. Erdvinio modeliavimo taikymas geologijoje leidžia automatizuoti daugumą procesų (naudingųjų iškasenų išteklių apskaitą, jų stebėjimą laike, projektinių sprendinių priėmimą), tokiu būdu sutaupomas šiems uždaviniams spręsti skiriamas laikas ir pinigai. Šiai dienai yra sukaupta nemaža patirtis ir pasiektas tam tikras rezultatas informacinių technologijų pritaikyme geologijos moksluose, tačiau jų panaudojimo geologijoje negalima laikyti pakankamai pozityviu. Tai susiję su informacijos taikymo geologijoje savitumu – daugiausia tai būna aprašomojo pobūdžio informacija, kurią sunku įdiegti ir interpretuoti kompiuterinėmis programomis, todėl šioje srityje yra dar daug neišspręstų problemų.

Tyrimų objektais buvo pasirinkti įvairių genetinių tipų – keimų, ozų, kraštinių fliuvioglacialinių gūbrių, zandrų, fliuvioglacialinių deltų ir perpustytų fliuvioglacialinių eolinių darinių žvyro ir smėlio telkiniai bei prognoziniai plotai išsidėstę Lietuvos teritorijoje.

Darbo tikslas naudingųjų iškasenų telkinių žvalgybos duomenų analizės ir gavybos proceso projektų rengimo automatizavimas, siekiant optimizuoti išgaunamų žaliavų kiekį ir pažeistų teritorijų įjungimą atgal į natūralius landšaftus. Siekiant užsibrėžto tikslo, buvo iškelti sekantys **uždaviniai**:

- ⇨ išnagrinėti naudingųjų iškasenų telkinių žvalgybos duomenų automatizuotos analizės ir vertinimo galimybes;
- ⇨ sukurti naudingųjų iškasenų telkinių naudojimo projektinių sprendinių automatizavimo metodiką ir įdiegti ją į programinę įrangą;

- ⇨ išnagrinėti kasybos apimčių pagal markšeiderinius apmatavimus apskaičiavimo automatizavimo galimybes;
- ⇨ išnagrinėti kasybos proceso apskaitos ir kontrolės automatizavimo galimybes.

Pagrindiniai ginami teiginiai:

- ⇨ Naudojant GRID (tinklelio) metodą, sukurtas naudingosios iškasenos išteklių modelis tampa dinaminiu ir yra pritaikomas telkinių projektavimo ir eksploatacijos metu.
- ⇨ Sukurtas 3D telkinių dinaminis modelis pritaikomas įvairios genezės telkinių geologinės sandaros bei susidarymo sąlygų tyrimui, geologinių ir išgaunamų išteklių vertinimui, projektinių sprendinių priėmimui, kasybos proceso apskaitai ir kontrolei. Įdiegti į registrą modeliai gali būti sėkmingai pritaikyti teritorijų planavimo srityje.
- ⇨ Į sukurtą modelį įvedus ketvirtą parametrą – laiką, atsiveria galimybė naudingųjų iškasenų telkinių keturmačių modelių kūrimui ir geologinių kūnų kaitos laike tyrimui.

Mokslinio darbo naujumas. Šiame darbe buvo apibrėžtas nerūdinių naudingųjų iškasenų telkinių dinaminių modelių sudarymo principas, sukurto modelio panaudojimas vertinant telkinių geologinę sandarą, formavimosi sąlygas, atliekant telkinių projektavimo darbus, bei vykdant telkinių eksploatavimą. Modeliavimas atliekamas trimatėje erdvėje, kas sudaro galimybę matyti trimačius perspektyvinius karjero vaizdus iš bet kokio pasirinkto taško ir numatyti kasybos darbų eigą. Šiuo metu ši sistema jau suprogramuota, vyksta testavimas įmonėje UAB „GJ Magma“. Pilnai įsisavinus šią sistemą bus pereita prie tridimensinio (erdvinio) telkinių naudojimo (kasybos ir rekultivavimo) projektavimo. Ši karjerų projektavimo sistema neturi analogų Lietuvoje.

Praktinė darbo reikšmė. Disertacinio darbo rezultatai bus pritaikyti analizuojant naudingųjų iškasenų telkinių geologinę sandarą, formavimosi sąlygas, bei priimant projektinius sprendinius. Darbo rezultatai bus pritaikyti įmonėse, užsiimančiose naudingųjų iškasenų paieškomis ir žvalgyba, telkinių projektavimu. Taip pat jie gali būti pritaikyti valstybinio valdymo ir kontrolės institucijose, bei teritorijų planavimo srityje.

Išvados:

1. Tekinių dinaminiai modeliai gali būti naudojami nagrinėjant telkinių geologinę sandarą, formavimosi sąlygas, atliekant geologinių išteklių apskaičiavimą, priimant projektinius sprendinius, atliekant markšeiderinius skaičiavimus, kasybos proceso apskaitai ir kontrolei.

2. Gauti darbo rezultatai analizuojant skirtingų genetinių potipių telkinių geologinę sandarą patvirtino jų genetiniams potipiams būdingas tendencijas. Bogušiškių plote išryškėjo trys keimai ir jiems būdinga sandara. Kušlėnų ploto sandara yra tipinė ozų dariniams. Šio telkinio susidarymo sąlygos nulėmė gana kaičią jo sudėtį skersai gūbrio ašies ir ilgesnius panašios sudėties sluoksnius pagal gūbrio tįsą. Rūsteikių ploto analizė aiškiai parodo sudėtingą, poligenetinę Rūsteikių kraštinių darinių formavimosi eigą: pradedant nuo limnoglacialinių sąlygų, vėliau - vykstant ledyno pakraščio zonoje įvairaus intensyvumo fliuvioglacialinių nuogulų sedimentacijai ir baigiant kraštinių glacigeninių nuogulų dangos atsiradimu nuo ledyno nušliaužus moreninei nepraplautai medžiagai. Tokia pat sudėtinga sandara buvo nustatyta ir Sniegių kraštinių darinių plote. Šklėrių plotas - tipinis zandras, kurio visą storymę suformavo nepastovios dinamikos laisvai klaidžiojantys po plačią prieledyninę lygumą ledyno tirpsmo vandenys. Selmoniškių fliuvioglacialinės deltos žvyro telkinio susidarymo sąlygos nulėmė nesudėtingą jo sandarą ir sluoksnių slūgsojimą ištisiniu klodu. Sandrupio telkinio naudingąjį klodą sudaro vėlyvojo ledynmečio ir holoceno eolinės nuogulos žemiau kopų papėdžių slūgsančios ant fliuvioglacialinių slėninių srautų suklotų nuogulų. Smėlio sluoksnio kaitą lemia itin raižytas kontinentinių kopų reljefas. Tarpukalnėse jis yra minimalus, o kopų viršūnėse staigiai išauga.

3. Naudingųjų iškasenų išteklių apskaičiavimui įvairių genetinių potipių telkiniuose naudojant skirtingus išteklių apskaičiavimo metodus gauname nevienodas paklaidas. Skaičiuojant išteklius nesudėtingos sandaros telkiniuose nenustatyta neleistina paklaida (10 %), o sudėtingos sandaros (raižytas reljefas, išpleišėjimas ir kt.) telkiniuose išteklių paklaida viršija leistina.

4. Automatizuoto projektavimo programoje įdiegtas „GRID“ išteklių skaičiavimo metodas darbo laiko sąnaudų požiūriu yra efektyviausias. Išteklių skaičiavimo planai, sudaryti jo pagrindu, tampa dinaminiais, gali būti pritaikyti projektinių sprendinių priėmimui, markšeiderinių skaičiavimų atlikimui.

5. Pradėjus telkinio eksploataciją, sukurtą dinaminį modelį galima naudoti vykdant tiek gamybininkų, tiek valstybinių institucijų kasybos proceso apskaitą bei kontrolę, atliekant markšeiderinius apmatavimus, taip pat kasybos apimčių planavimą. Sekantis etapas geologinių modelių kūrime yra perėjimas prie keturdimensinio modeliavimo, kai

įvedamas ketvirtas parametras – laikas. Keturdimensiniai modeliai leis tirti geologinę struktūrą laike.

6. Įdiegti į žemės gelmių registrą modeliai gali būti sėkmingai pritaikyti įvairių sričių specialistų, ypač teritorijų planavime, numatant jų plėtros tendencijas.