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DATA ANALYSIS FOR GEOLOGICAL MODELLING OF POTASSIUM AND MAGNESIUM SALTS BEARING STRATA IN VERKHNEKAMSKOYE FIELD

A.V. Kataev, S.N. Kutovoy, D.A. Meyster, E.M. Efimov, A.P. Rachkova

Perm National Research Polytechnic University (29 Komsomolskiy av., Perm, 614990, Russian Federation)

АНАЛИЗ ДАННЫХ ДЛЯ ГЕОЛОГИЧЕСКОГО МОДЕЛИРОВАНИЯ ТОЛЩИ ВЕРХНЕКАМСКОГО МЕСТОРОЖДЕНИЯ КАЛИЙНО-МАГНИЕВЫХ СОЛЕЙ

А.В. Катаев, С.Н. Кутовой, Д.А. Мейстер, Е.М. Ефимов, А.П. Рачкова

Пермский национальный исследовательский политехнический университет (614990, Россия, г. Пермь, Комсомольский проспект, 29)

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Key words:
potassium salt field, mining-and-geological information system, field drawings processing, software module, digital profiles, data base management system.

The paper discusses the results of data analysis for geological modeling of Verkhnekamskoye field of potassium and magnesium salts at the mines of Solikamskaya area. The assumption is that development of a model will help calculate the expected volume of enclosing rocks during mine planning and define the vertical plane position of a combine as relative to the stratum top at crossing of folds. Strata strength characteristics obtained using the model must become the input data for calculation of development parameters for mine planning. Modelling results are used to estimate the expected risks in the process of mine development and in solving many other tasks.
Initial information concerning deep wells and wells drilled from mine workings is insufficient to build a reliable model to help solve the aforementioned and many other tasks. The authors have developed software modules for the geological service, in order to fill the data base with vector images of stratum and layer boundaries for development working and stopes. Modules are based on the processing of field geological drawings using both scanning and digitizing technology. The developed software has "hardwired" unified catalogues of rocks and the adopted stratigraphic breakdown of the strata. Use of this information will significantly specify and detail the model in the bulk of deep commercial strata.
It has been established that hypsometry variability of commercial strata is by an order of magnitude higher than the variability of their thickness. The considerable difference in fluctuations of thickness and elevation will influence the modelling method.
Software modules developed for geologists are integrated into the corporate mining-and-geological information system of PJSC Uralkali, developed upon the initiative and with direct participation of the authors.

Ключевые слова:
месторождение калийных солей, горно-геологическая информационная система, обработка полевых зарисовок, программный модуль, цифровые профили, система управления базами данными.

Приводятся результаты анализа данных для построения геологической модели Верхнекамского месторождения калийно-магниевых солей на рудниках Соликамской площадки. Предполагается, что разработка модели позволит рассчитывать ожидаемый объем вмещающих пород при планировании горных работ, задавать в вертикальной плоскости положение комбайна относительно кровли пласта при пересечении складок. Прочностные характеристики пластов, полученные с помощью модели, должны являться входными данными для расчетов параметров разработки при планировании горных работ. Результаты моделирования привлекаются для оценки ожидаемых рисков в процессе разработки рудников и при решении многих других задач.
Первичной информации по глубоким скважинам и скважинам, пробуренным из горных выработок, недостаточно для построения достоверной модели, способствующей решению ранее перечисленных и многих других задач. Авторами разработаны программные модули для геологической службы, позволяющие пополнять базу данных векторным изображением границ пластов и слоев по подготовительным и очистным выработкам. Модули основаны на обработке полевых геологических зарисовок как по сканерной, так и по дигитайзерной технологии. В разработанных программах «зашиты» унифицированные справочники пород и принятое стратиграфическое расчленение толщи. Использование такой информации значительно уточнит и детализирует модель в толщах залегания промышленных пластов.
Установлено, что изменчивость гипсометрии промышленных пластов на порядок больше изменчивости их мощности. Существенное различие в колебаниях мощности и высотной отметки повлияет на методику построения модели.
Разработанные для геологов программные модули интегрированы в корпоративную горно-геологическую информационную систему ПАО «Уралкалий», которая создается по инициативе и при непосредственном участии авторов

Anatoliy V. Kataev (Author ID in Scopus: 7003774612) – PhD in Engineering, Associate Professor of the Department of Surveying, Geodesy and Geoinformation Systems (tel.: +007 902 476 87 78, e-mail: geotech@pstu.ac.ru). The contact person for correspondence.
Sergey N. Kutovoy – PhD in Engineering, Associate Professor of the Department of Surveying, Geodesy and Geoinformation Systems (tel.: +007 950 450 60 09, e-mail: geotech@pstu.ac.ru).
Dmitry A. Meyster – Engineer of the Department of Surveying, Geodesy and Geoinformation Systems (tel.: +007 982 475 01 38, e-mail: geotech@pstu.ac.ru).
Evgeniy M. Efimov – Engineer of the Department of Surveying, Geodesy and Geoinformation Systems (tel.: +007 902 473 53 87, e-mail: geotech@pstu.ac.ru).
Anastasia P. Rachkova – Engineer of the Department of Surveying, Geodesy and Geoinformation Systems (tel.: +007 982 475 45 31, e-mail: geotech@pstu.ac.ru).

Катаев Анатолий Вениаминович – кандидат технических наук, доцент кафедры маркшейдерского дела, геодезии и геоинформационных систем (тел.: +007 902 476 87 78, e-mail: geotech@pstu.ac.ru). Контактное лицо для переписки.
Кутовой Сергей Николаевич – кандидат технических наук, доцент кафедры маркшейдерского дела, геодезии и геоинформационных систем (тел.:+007 950 450 60 09, e-mail: geotech@pstu.ac.ru).
Мейстер Дмитрий Александрович – инженер кафедры маркшейдерского дела, геодезии и геоинформационных систем (тел.: +007 982 475 01 38, e-mail: geotech@pstu.ac.ru).
Ефимов Евгений Михайлович – инженер кафедры маркшейдерского дела, геодезии и геоинформационных систем (тел.: +007 902 473 53 87, e-mail: geotech@pstu.ac.ru).
Рачкова Анастасия Павловна – инженер кафедры маркшейдерского дела, геодезии и геоинформационных систем (тел.: +007 982 475 45 31, e-mail: geotech@pstu.ac.ru).

Introduction

Organizationally PJSC Uralkali is an enterprise consisting of several mutually detached mines with centralized management, accounting and control bodies. The company develops Verkhnekamskoye field of potassium and magnesium salts, which has an exceptionally large area [1–3]. In such conditions, real-time exchange of mining graphic information and document turnover is of key importance. Detailed knowledge of such information and gained experience of its use helps specialists to correctly assess the subterranean processes [4, 5, 6], select the best option for mining operations [4], and in a complex mining situation – to take a justified decision based on the data analysis [7–13].

Object details

The field is located in the central part of Solikamskaya syncline of the Pre-Ural Foredeep. Potassium and magnesium salts are located between the overlying and underlying strata of rock salt; the deposit has a layered structure. The salt strata consist of underlying salt, sylvinite and sylvinite-carnallite zones, covered by overlying salt. The strata are rumpled in a complex pattern of folds, from small intrastratal to large, extending to a series of strata [1–3]. Commercial strata are Kr-II, AB and V. Intrastratal folding changes the initial thickness of the strata, increases the volume of enclosing rocks in the broken rock mass and influences its grade. Interstratal folds increase vertical thicknesses of the strata and also reduce the ore grade. The mines have adopted a chamber mining method with rigid band interchamber pillars and use combine method for commercial strata development [4]. Combines are limited by production inclination angle to 8–12 degrees. Therefore, strongly rumpled areas have higher losses of commercial minerals and increased dilution volumes in the ore mass. Along with that, at the stage of stoping planning, there is no sufficiently detailed information concerning the stratum hypsometry across the entire panel width. This information, along with other necessary data, is expected from the geological model [9–13].

Verkhnekamskoye field is prospected by a sparse grid of deep wells drilled from the surface. In the process of operation, detailed exploration wells are drilled in the workings to the depth of commercial strata, with selection of trench samples from the walls of the workings. The disposition plan of deep wells and wells drilled in Solikamskaya area mine workings is presented in fig. 1.

In countries with developed mining industry, companies use mining-and-geological information systems that help solve a wide range of geological, surveying and technological tasks (DATAMINE, MICROMINE, GEOVIA Surpac™, VULCAN etc.) [11, 14–19]. However, only some of them can fully integrate with industrial data base management systems while preserving survey graphics, data referenced to objects of digital layers, and geological modelling results. The authors of the paper are working with the company to develop a system answering the information needs of engineering departments of the entire enterprise [20–26]. The already developed and implemented software applications enabled automated solution of the main production tasks at different levels: operating level for lower tier services, functional level for middle management and strategic level for chief specialist services.

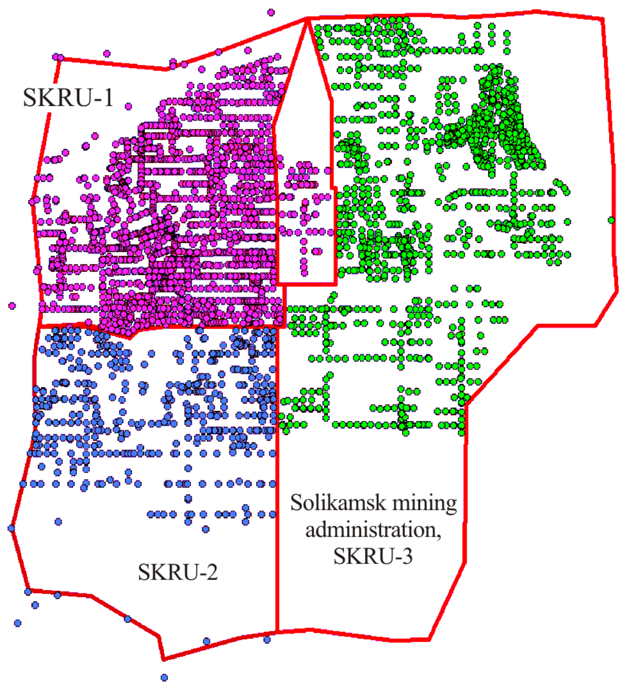

Fig. 1. Location of wells within the boundaries of mining allotments (without Polovodovsky site)

In addition, there are software tools under development which are aimed at ongoing processing of field measurements by engineering services, including survey service [27–31], geomechanical engineers [6, 26], geologists [20, 23], and mining engineers [7]; a program has been developed for geological environment modelling [24].

Analysis and replenishment of existing data

Reliability of the digital geological model under development depends, above all else, on the quality and completeness of initial information. A mine with an area of 7×14 km has maximum one hundred deep drilling wells. According to the requirements of an instruction [32] for mine geological support, geological service specialists must prepare primary geological documentation for mine workings. Geological profiles of development workings are sketched in field books. Sketches of profiles include apparent positions of the top and bottom of formation, position of transversal sections in the workings as per surveying, and survey beacons. Paper drawings are used because mines are hazardous in terms of gas dynamic phenomena, and laptops are forbidden in the mining area. Subsurface drilling wells are located in development workings at a distance of 50–150 m from one another; selection of trench samples is performed as well. All information concerning these wells is entered in the PJSC Uralkali database [22–24, 33].

Field materials for development workings are processed in software tools designed by the authors of the paper. The profile is scanned and referenced to survey beacons; next all visible crossings between strata (fig. 2) are digitized in the module "Longitudinal profile geology" and entered into the data base. We built this work on the old development workings, and geologists perform it for ongoing objects. In stopes, geological drawings are made for transverse sections of workings, surveyed, prepared and entered into the data base by the survey service. The field book with sections can also be scanned with further referencing of images. The software has an even more convenient mechanism for referencing the transverse section images using a graphic tablet. After section referencing, geological information on the tablet is digitized using a pen (stylus), and then entered into the data base. The developed protection modules contain hardwired unified catalogues of rocks and the adopted stratigraphic breakdown of the strata [4]. Fig. 3 shows an example of the processed drawing in the software module "Geology by sections".

Thus, the geological information from transverse sections of each new chamber enters the data base. In old workings this information is seldom present.

In order to calculate volumes of enclosing rocks, the geological service uses programs that allow for the processing of drawings in development workings and stokes as well as for entering them into the data base. Referencing of drawings in the coordinate system of the mine and further digital description of the stratum boundaries enables entry of a large volume of additional information concerning crossings between strata into the data base. Software modules developed for geologists are integrated into the corporate mining-and-geological information system of PJSC Uralkali (MGIS PJSC Uralkali).

Fig. 4 shows three panels for the first Solikamsk mine, approximate size of the site is 1080×1360 m. Only three deep wells are drilled at the boundaries of this site. Distance between neighboring wells is 1000 m. The section has 191 subsurface wells drilled from development workings. For these wells, geologists capture all stratum intersections in field notes. Profiles are available for development workings which are drilled with an interval of 150–180 m on these panels.

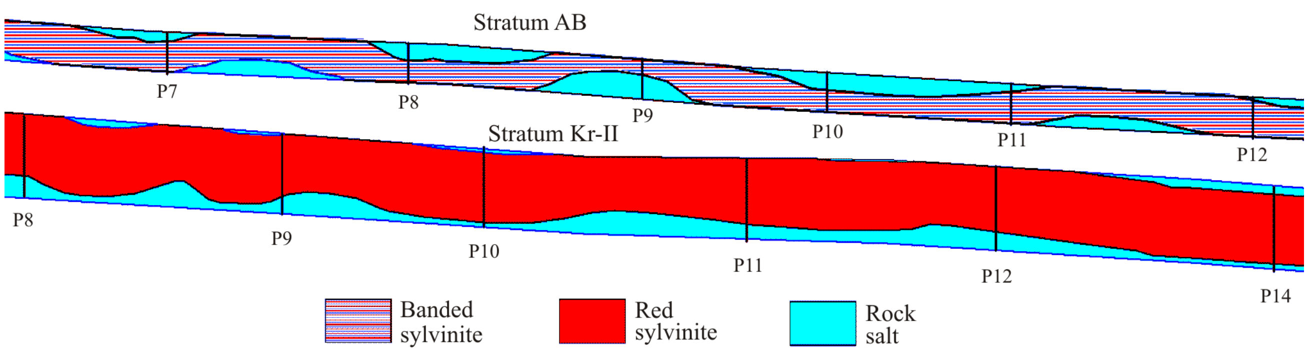

Fig. 2. Fragment of digitized profile along chamber 104 wall (stratum AB, Kr-II, Panel 4 SV)

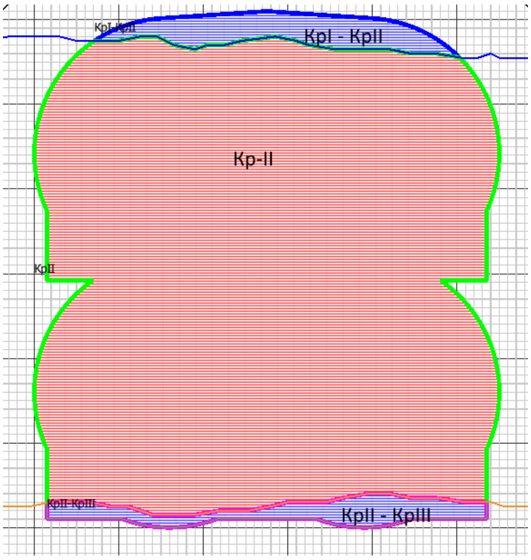

Fig. 3. Boundaries of Kr-2 stratum top and bottom on a digitized transverse section of chamber 118 (12th western panel of SKRU-1, distance from neck 70, 60 m)

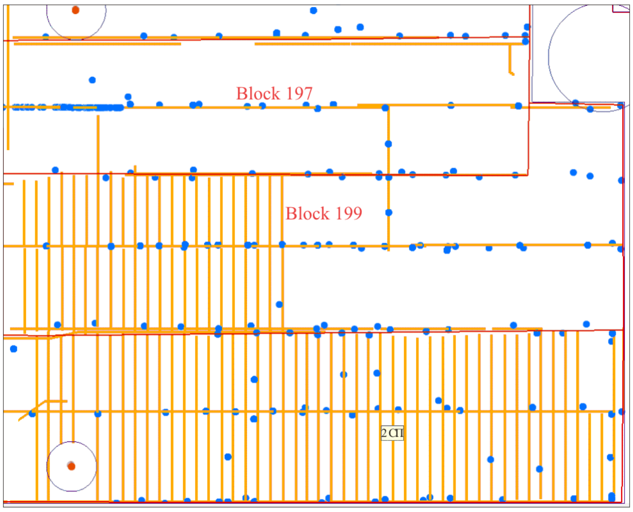

Fig. 4. Location of wells and profiles in three south-eastern panels of SKRU-1

Development workings by strata are made coaxially, therefore a geologist can depict boundaries of all strata under development on the profile. To detail complex areas, layers included in the stratum are also drawn. Results of geological structure interpretation of the strata tapped by the subsurface well are also superimposed on the profiles. They complement the missing information concerning geological boundaries of the layers between commercial strata. In some cases (very seldom) profiles are made in chambers as well. In the figure these profiles are located with an interval of 28 m.

Trench samples are also selected in development workings with an average interval of 50 m. They provide information on qualitative composition. A large volume of available information for productive strata in the developed sites provides detailed knowledge of their geometry and quality. Overburden structural information can only be obtained from deep drilling wells. The study of overburden structure in individual sites generally applies geophysical methods.

Commercial strata variability analysis

In the elaborately studied commercial strata, visual unevenness of stratum hypsometry from Kr-II to V is observed. In the literature discussing field geological structure [1, 2] it has been assumed that hypsometry variability in commercial strata increases from stratum Kr-II to stratum V. However, no comparative analysis in numerical form has been performed. To build a model of the bulk commercial strata, the latter has to be surveyed to identify variability of hypsometry and strata thickness.

For the purpose of the survey, well processing in three mines SKRU-1, SKRU-2 and SKRU-3 was performed. Only subsurface and deep drilling wells were used. Samples were not analyzed due to the following reasons.

Sampling is performed by a geologist along the walls of mine workings. In certain areas, the workings can reveal the position of the stratum top and (or) bottom. During sampling the geologist chooses the most representative part of the workings, where stratum thickness varies insignificantly from the average. Wells tap into the stratum boundaries randomly; there is a higher probability of crossing between the well and the stratum in any flexures, with possible high spread of thickness values.

The table contains the results of statistical processing for wells in commercial strata of three mines. In the course of the processing, only data with non-zero values were taken into account. The processing covered stratum thickness, bottom elevation, and content of valuable component KCl. In some of the wells, the stratum thickness was incompletely represented or the content was not specified; such data was excluded. Some of the sylvinite strata can be replaced with carnallite (e.g. stratum V) or rock salt. Only data with qualified content and thickness value were taken into account for processing. The calculations used stratum thickness, bottom elevation, and content of valuable component KCl.

In subsurface geometry, parameter variability can be determined in multiple ways [34], including the standard deviation value. This statistics was used for analysis of the parameter variability.

In terms of data size, sampling populations for each stratum were representative, results of calculations for Solikamskaya area mines were statistically significant. Calculations suggest an increase of the standard deviation of the lower stratum thickness (Kr-II) to the overlying stratum (fig. 5). Along with that, whereas from Kr-II to AB the dynamics is small or absent (SKRU-2, SKRU-3), the thickness spread doubles from AB to stratum V.

Statistical information for commercial strata

Parameter	Number of wells	Average value m	Minimum, m	Maximum, m	Standard, m
SKRU-1					
Kr-II wells					
m	1438	5.97	2.05	28.4	1.76
N_Kr-II	1439	–150.35	–306.64	18.71	46.15
KCl	429	24.79	16.08	37.95	3.08
AB wells					
m	1565	4.81	1.70	30.45	2.56
_AB	1706	–134.05	–296.34	35.00	48.81
KCl	652	30.08	16.28	46.66	5.34
V wells					
m	1144	9.58	1.70	33.52	4.21
N_V	1153	–125.53	–292.15	41.81	52.65
KCl	596	22.2	16.26	44.53	5.82
SKRU-2					
Kr-II wells					
m	472	6.48	3.43	17.8	1.6
N_Kr-II	472	–147.426	–302.655	–17.66	58.64
KCl	214	23.93	16.68	34.08	3.03
AB wells					
m	485	4.86	1.8	14.74	1.48
_AB	483	–134.067	–293.281	–4.06	60.704
KCl	293	32.19	16.45	40.76	4.02
V wells					
m	463	8.00	3.62	18.99	2.85
N_V	463	–126.387	–286.133	–6.56	62.06
KCl	162	28.21	16.2	47.02	7.71
SKRU-3					
Kr-II wells					
m	1084	4.46	2.1	10.5	0.97
N_Kr-II	1087	–158.69	–228.122	–54.26	39.25
KCl	145	24.80	17.39	37.4	3.48
AB wells					
m	1162	3.37	1.80	13	1.06
_AB	1189	–148.671	–220.05	–40.84	40.49
KCl	461	30.74	17.6	42.37	5.35
V wells					
m	1073	6.98	1.8	16.2	2.49
N_V	1077	–138.072	–216.74	–34.378	41.022
KCl	191	30.27	16.70	40.46	6.43

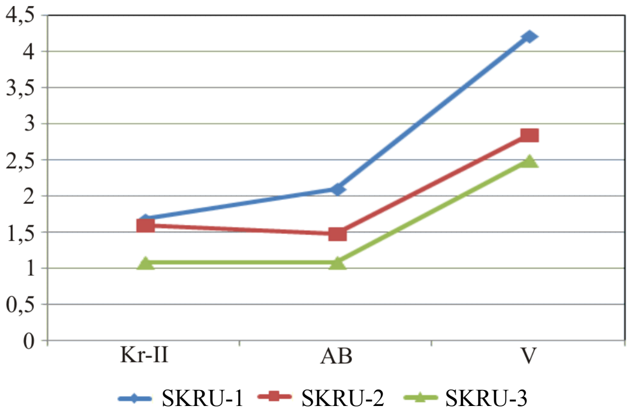

Fig. 5. Stratum thickness standard deviation dynamics in mines

Minimum value of standard deviation amounts to 0.97 m in Kr-II stratum of SKRU-3 and increases to 2.56 m in stratum AB of SKRU-1 (see fig. 5). Stratum AB overlies stratum Kr-II on average by 10–16 m. Stratum V has a more significant thickness variance. Standard deviation of thickness for this stratum increases to 4.21 m at a lesser inter-stratum height (stratum V is 7.5 to 10.5 m higher than stratum AB).

The calculations suggest that the hypsometry standard deviations value in any stratum is many times higher than the thickness deviation. Whereas the average stratum thickness spread amounts to 2.4 m (stratum AB), the standard deviation of bottom of the same stratum is 48.81 m. Spread value of the bottom elevation for various strata ranges between 39.25 for Kr-II SKRU-3 stratum and 62.06 m (AB stratum, SKRU-2).

Valuable component content is also more stable in the underlying stratum; its spread almost doubles in stratum V. The analysis includes only sylvinite stratum V. Visual analysis of geological drawings along the walls of the workings leads to similar conclusions.

Geological strata modelling advice

Traditionally the geological environment modelling process starts from ground surface, and, taking into account the available well information, the subsurface structure is modelled down to the commercial strata [35–43]. In the conditions where the structure of the commercial strata in mine workings is profoundly studied and documented, it makes sense to start strata modelling from the most surveyed and stable stratum. For Solikamskaya area mines, the most continuous is stratum Kr-II. Its hypsometry is also less variable than in the overlying strata. This stratum is used to build the reference surface (or stratum body) which is further used to build up to the next marking horizon or ground surface.

According to the existing concept of Verkhnekamskoye field of potassium and magnesium salts geological structure, the entire bulk of the strata is divided into conformable sequences. The latter consist of stratigraphic elements (a set of strata or bulks of strata) possessing similar stratigraphic and structural characteristics. The sequences include thickness-allied parts of the strata with approximately similar emergence conditions.

As a rule, all strata and layers in one sequence are settled conformably; one model can have several continuous sets of such strata. The strata must not cross sequence boundaries but can wedge out [44, 45]. Azimuths and strata dip angles in different sequences can vary significantly.

Taking into account the structure of the strata and availability of information in the database, the authors recommend the following order of sequence genesis in the bulk of strata for building a geological model:

1) sylvinite stratum;
2) below - underlying rock salt.

Above sylvinite stratum:

3) sylvinite-carnallite stratum;
4) overlying rock salt;
5) salt and marl stratum;
6) variegated stratum;
7) quaternary deposits *Q* (up to the ground surface).

Based on the results of the study, the following conclusions can be made:

– Kr-II stratum thickness has the largest deviation from the average value in comparison to stratum AB and especially V;

– spread boundary of qualified content is increased by 30–40 % compared to thickness change;

– position of strata bottom in height has by an order of magnitude more variability compared to thickness;

– deep drilling wells have insignificantly higher deviation results compared to overall data.

Conclusion

The results of the study will influence the technology of subsurface modelling. The reference surface will be assumed as top (or bottom) of Kr-II sylvinite stratum. Since the stratum top patterns are becoming more complex from bottom up, whereas thickness varies less significantly than the stratum elevation, further building of the model is performed by superposition of overlying strata and interstratal partings on the reference surface within each conformable sequence. Taking into account the stratigraphic and structural features of genesis in each sequence, the strata settle by thickness up to the bottom of sylvinite-carnallite stratum, and further up to the ground surface. Similarly the model is built for the underlying rock salt, to the depth below the bottom of development workings of rock salt.

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