Modeling coal deposits in hard-to-reach regions of Yakutia

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Abstract. The article presents brief characteristics of the Kharbalakhs and Nadezhda deposits currently being mined. Exploration data on their specific structure, the variability of the geometric parameters of the seams, the statistical heterogeneity of the ash content in coal are reported. Frame and block models of the main coal seams are constructed based on the compiled database with use of mining and geological information systems. The paper considers a number of methods for interpolation of coal grade at different density of the exploration network. The spatial distribution of ash content in coal seams is mapped. The use of the obtained results can increase the validity of the decisions made at the planning, mining and coal preparation stages.

1. Introduction

Although coal is being currently replaced by alternative kinds of energy, it yet remains and will be the main source of heat generation in the Republic of Sakha (Yakutia) [1]. This sparsely inhabited region features underdeveloped infrastructure and severe climatic conditions, unfavorable for mineral mining.

The operating and promising coal mine in Central and Northern Yakutia have, as a rule, considerable reserves and resources of various kind and grad solid fuel. When erroneous or inefficient decisions are unpardonable, it is absolutely indispensable to use the available information about these georesources to maximum effect. Such decision-making at the stages of mine planning, design and operation would improve performance of both mines and deposit–consumer chains.

Among other things, this objective can be reached by analyzing mine planning and operation processes using advanced software programs and mining geology information systems (MGIS). The geo-information analysis aims to study properties, arrangement, structure and interaction of objetcs and phenomena in space. To date, it is difficult to image an efficient mine without using such tools as 3D modeling and applications to the effect of production planning and control [2–4], information technologies of mining process supervision meant for optimizing expenses, time and productivity [5], geo-information systems to handle problems connected with spatial analysis and exploration of different objects [6], or ensuring interactive access to data mining tools on Internet servers [7], geostatistical estimation of spatial patterns of qualitative and quantitative data, determination of optimal size and weight of samples [8]; creation, operation and supervision of data bases on sampling and qualimetry of minerals and spatial information [9, 10], etc.

2. Kharbalakhs and Nadezhda coal fields

With regard to the desired improvement of managerial decision-making at mining and allied companies, we are going to discuss in more detail general approaches to comprehensive analysis of georesources based on upgrading of information analysis systems in terms of two coal fields
(Kharbalakh in Central Yakutia and Nadezhda in Zyryansky Coal Basin). These approaches can be later on used to create estimation procedures for appraisal of quality and quantity of mineral reserves in other deposits, including information and analysis support of coal quality management along the mining and delivery chains.

Kharbalakh coal field occurs in the Low Aldan area of the Lena Coal Basin [11, 12]. Commercial-value coal seam Karierny features wide area and is comprised of two coal bands. The seam is from 6.5 to 9.8 m thick; the upper band thickness is 3.1–4.5 m, and the lower band thickness varies from 2.7 to 4.7 m. The seam is consistent, with distinct partition by a dirt band from 0.15 to 1.3 m thick. Coal has medium ash content, is low sulfur and belongs to grade D (long-flame). The remaining reserves in-place intended for extraction by the open pit mining method make 3.5 Mt at the annual output at the level of 150–170 thousand tons. According to the guidelines of the Federal Agency for Mineral Resources of Russia, the deposit is put in difficulty group II. The operating open pit mine supplies coal to populated areas of the central region of Yakutia. For the latest 10 years, open pit mine production has totaled 1.2 Mt of coal at the loss of 5.2%.

Stripping involves blasting and dozing. Owing to thin overburden layer and a dirt band, coal is extracted by four benches: overburden, two coal bands and the parting. ROM coal quality is off any control. Coal is only crushed on a crushing-and-screening plant, which allows dirt and high ash rocks enter the outlet product. Coal is hauled to boiler houses and public sector by trucks at the distinct seasonality of consumption. In view of the demand for more resources, the adjacent area of the open pit mine is subjected to additional exploration.

Nadezhda coal site of Zyryansky open pit min is a part of Zyryansky Coal Basin at the Kolyma River. Commercially valuable are five coal seams of grade ZH (fat) with total in-place reserves of more than 9 Mt. Coal is low-ash, highly calorific, low sulfur and caking. The open pit mine field is divided into three sites suitable for independent development. The minimum thickness of five seams of complex and simple structure is 2 m (upper band 32v—1 m). dip angles vary from 5 to 10° in the north and from 25 to 30° in the south. The average thickness of seams 13, 18 and 22 is from 1.0 to 6.6 m. The overlying seam 32 is consistent, has complex structure and ranges from 4.0 to 12.8 m in thickness. A coal band to 2.7 m thick splits off from this seam in the south. The top-most seam 32v (1.0–3.4 m) has simple structure and is relatively consistent.

Coal is accessed by ramps cut in the center and on sides, with encircling haul roads and an exit to the river dam and a main road. Side strips of the upper bench are removed by dozers. Further stripping is proceeded by the truck-and-shovel scheme with loaders. In addition, drilling-and-blasting and benching by shovels and dozers are involved until a productive seam is exposed. Loose rocks are loaded by shovels to trucks, or are pushed by dozers to mined-out void or to dumps. A stripping bench height varies from 6 to 10 m.

Stage-wise exploration, planning, design and mining assumes implementation of some series–parallel, interconnected and mutually complimentary procedures ensuring persistent improvement of our knowledge on the geosource at hand. The relevant experience accumulated at the Institute of Mining of the North, SB RAS, allows rising to a wholly new level of efficient and resource-saving subsoil management.

First, necessary data are collected from various sources with maximum coverage of information on previous stages of exploration and operation (geology, climate; standards and design data; coordinates of exploring opening, geophysical studies, coal sampling with characteristics of quality and structure of seams; various technical and economic indexes; fuel haulage routes; resource consuming points, etc.). Then, after preliminary consideration in the framework of a uniform information space creation, the source information is digitized and formalized with creation of databases (with state registration if required) on individual deposits.

The next stage is processing of the data using mathematical statistics methods and software support, for instance, Microsoft Excel, with a view to shaping general representation of basic characteristics of the deposits (sites) and their variability (table).
At the general compatibility of the statistical characteristics, the lower band of Karierny seam in Kharbalakh field has the lowest ash content at the high coefficient of variation. In Nadezhda field, seam 32n has the highest ash content and low CV.

Nextly, to get deeper insight into the variation of geometrical parameters of coal seam and coal quality, 2D mapping is implemented (using Golden Software Surfer). The accomplished interpolation and visualization of general ash content across the area of seam 32n in Nadezhda field shows relatively uniform zones of different size and values (Figure 1).

Basic statistical characteristics of total ash content of Kharbalakh and Nadezhda coal.

| Characteristics   | Kharbalakh, Karierny seam | Nadezhda |
|-------------------|---------------------------|----------|
|                   | Upper | Lower | 32v | 32n | 22 | 18 | 13 |
| Average           | 15.7  | 14.5  | 15.1 | 19.6 | 15.2 | 17.5 | 17.7 |
| Standard deviation| 4.6   | 5.7   | 4.8  | 4.2  | 4.8  | 5.8  | 4.2  |
| Coefficient of variation | 29.4 | 39.5  | 31.5 | 21.5 | 31.9 | 32.9 | 23.4 |
| Excess            | –0.4  | –1.3  | 0.1  | –0.5 | 0.6  | –1.2 | –0.7 |
| Asymmetry         | 0.5   | 0.2   | 0.7  | 0.1  | 1.1  | –0.2 | –0.4 |
| Holes             | 23    | 37    | 64   | 72   | 87   | 84   | 71   |

**Figure 1.** Map of total ash content contour lines for seam 32n of Nadezhda field: (a) inverse distance weighting; (b) krigging; (c) Shepard method.

Finalized presentation of coal deposits in the context of sound resource-saving subsoil management is implemented using MGIS as the basic analysis, design and modeling tool.

Review of the key foreign and Russian program products using various information sources (publications, web sites of software designers, user companies, conferences, workshops, webinars, personal communication, application of license and demo-versions) shows that ideologies of architecture and functioning of these systems are mainly alike. The choice of a specific MGIS is often subjective. Available information on efficient application of a software product is of local nature, and the product cannot be automatically used at another deposit or a company without adjustment to its specificity (scale, mineral production output, complex structure, sales market, financial assets, etc.).

The present paper authors posses MGIS systems MINEFRAME [13] and Micromine [14]. Both systems allow integrated decision-making with 3D modeling, multilateral appraisal, planning, design and optimization of mining operations at a various degree of detailing.

Using the MGIS data, 3D frame and block models of the discussed coal fields are constructed (Figure 2), and ash contents of coal seams are assessed.
In the course of work, for comparison, many variants of the models were constructed using different methods of geostatistics, mainly, inverse distances and krigging, with various sets of parameters, to study nature and patterns of spatial distribution and quality of coal reserves. Coal quality mapping involved such procedures as coarsening of grid to estimate influence of exploration grid density on delineation accuracy of coal reserves by useful quality; testing of different methods of bridging data gaps on coal sampling in seams; 2D and 3D modeling of coal seams using geostatistics techniques with delineation of zones of relatively uniform quality coal (Figure 3).

3. Conclusions
1. The result of the stage-wise analysis of coal seam parameters and properties in accordance with the proposed approach is the additional knowledge on the georesource. This knowledge is a more reliable information background for determination of order and sequence of mining in extraction panels with regard to quality of coal; for studying geotechnologies with a view to optimizing their parameters; for improvement or creation of quality management systems with regard to the interests of final consumers—boiler houses in hard-to-reach regions.
2. Depending on coal quality requirements imposed by consumers, complexity and unique nature of coal deposits, as well as objectives, goals and capabilities of subsoil users, it is possible to use any course of geoinformation-based analysis of deposit structure, including the proposed and discussed approach.
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