Application and Development of the Method of Geodynamic Zoning According to Geodynamic Hazard Forecasting at Coal Mines in China

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Abstract. In China, the method of geodynamic zoning had three periods of its development: “formation”, “development”, and “innovation”. At the first stage, a significant preparatory work was performed, and the investigations were carried out to identify the geodynamic hazard zones at the Beipiao coal deposit field. At the second stage, models were created linking the block structures of the crustal tectonic plates and coal minefields, the work was continued on the geodynamic zoning of deposit fields deemed being of hazardous rock bumps occurrence. At the third stage, a program was developed for calculating the stress state of the rock massif, taking into account the data on geodynamic zoning. A model of multifactorial recognition of hazardous sections of minefields by sudden outbursts and rock bursts has been developed, and the corresponding research has carried out at the coal deposit fields. Investigations of the connection between the energy of a rock burst and the size of the massif area involved in this process have been carried out, followed by the creation of the corresponding model. The effectiveness of the method of recognizing areas of an increased geodynamic hazard was provided during the work using examples of particular mines. For the Yue Jin minefield, outburst's hazardous, threatened, and non-hazardous areas have been identified. For the Jingxi minefield, rockburst's hazardous, threatened, and non-hazardous areas have been identified. It is recommended to apply preventive measures based on the results of the forecast being conducted to improve the geodynamic safety in mining.

1. Introduction

1.1. About the geodynamic zoning method

In the late 1970s, Russian scientists Batugina I. M. and Petukhov I. M. developed and presented a method of geodynamic zoning [1]. The main purpose of this method was zoning of areas of the earth's crust according to the degree of geodynamic hazard, which was originally understood as a rockburst hazard at the deposits development. The basis of the method of geodynamic zoning was an idea of the impact of tectonic stress fields and modern block structure of the earth's crust of different hierarchical
levels on geodynamic hazard occurrence. A new science studying the processes occurring during the mineral resources development in the rock massif and the earth's crust as a result of interaction of two systems: natural (geodynamic) and technical [2] began to take shape. In 1990s, in Moscow State Mining University (MSMU), geodynamic zoning research laboratory was created; researches were carried out not only at the rockburst-hazardous ore and coal minefields, but for the first time at hydrocarbon deposits, platforms of engineering structures, pipeline routes [3].

In 1989, the method of geodynamic zoning began to be used in China. Professors of Liaoning Technical University Duan Kexin and Zhang Hongwei, in cooperation with the I. M. Petukhov and Batagina.I. M., carried out research on geodynamic zoning and rockbursts prediction, first at Beipiao mine [4], then in other mines in China (Hua Inan, Pin Dinsani, Ima, Datun, Ho Bin, Ho Gan, Fu Xin, Nan Pyao, Xin Wen, etc.) [5].

1.2. Progress in Development of Research in the area of Geodynamic Zoning in China

There are three stages in the development of research in the area of geodynamic zoning in China. At the first stage (from 1989 to 1995), the method of geodynamic zoning was introduced in China in the frame of cooperation with the Russian Institute VNIMI on the issues of geodynamic hazard prediction in coal mines. Studies on geodynamic zoning were carried out at coal minefields Beipiao [4]. This time, China began to form a scientific group to study geodynamic state of deposits and this period can be called a “formation” of the geodynamic zoning method in China. Using the method of geodynamic zoning, a block structure of the massif was revealed in a number of fields, a model of its interaction with technological processes at the mines was created, equipment for measurement of stresses in the rock mass and software of the stress calculation was developed, analysis of the stress state for the areas of mine fields was performed.

At the second stage (from 1996 to 2005), the center for research on geodynamic zoning was established at Liaoning University of Engineering and Technology, and this period can be called a “mature”, or “development”, in the development of the geodynamic zoning method in China. Based on the geodynamic zoning method, a procedure of pattern analysis was developed to assess the geodynamic hazard of mine fields. Use of identification algorithms has allowed identifying hazardous, threatened and non-hazardous mine fields areas regarding to geodynamic phenomena, to increase the accuracy of regional geodynamic hazards prediction, to ensure safe operation of coal mines. At that time, a number of public projects were performed, such as "Regional forecast of hazardous outburst at Hua Inan coal and gas deposits", "Regional forecast and prevention of coal and gas outbursts at Ho Bin deposit", etc. Method of geodynamic zoning was included into general program for rockburst monitoring [6].

At the third stage (from 2006 to 2015), a research group was established for innovative development of the geodynamic zoning method to study geodynamics of the environment and geodynamic conditions in the mines. At this stage, estimates of the geodynamic state of the rock massif and indicators of geodynamic hazard were obtained; the method of geodynamic zoning is widely used in coal mines in China for rockbursts forecast and monitoring of. The works were done in hazardous deposits of Ima, Pin Dinsani and many others [7-10].

2. Development of geodynamic zoning and innovations in China

2.1. On analysis of geodynamic state of the rock massif

For a geodynamic phenomenon occurrence, relevant geomechanical conditions depending on a number of factors should be met. Geodynamic events have similar features in different fields, in different structural conditions, in different anthropogenic and natural stress fields. Although it is very difficult to exactly predict time, place and strength of dynamic phenomena, it is possible to predict the possibility (probability) of such event occurrence at the particular place [11-13].

Based on the study carried out for the areas where geodynamic phenomena occur, a method for assessing the geodynamic state of the surrounding massif and indicators for appropriate assessing its dynamic hazard, as well as indicators for assessing a hazard of external influence on such a massif was
developed. A model was created, including data on coal and rocks properties, which allows substantiating criterion of dynamic system instability and finding out a mechanism of geodynamic hazard occurrence.

2.2. Key indicators for assessment of a mine field area geodynamic hazard
The practice of mining shows that hazardous dynamic phenomena (rockburst, sudden outburst) occur as a result of joint effect of the geodynamic conditions taking place at the deposit and nature of mining activity. Geodynamic conditions are necessary conditions for the hazardous dynamic phenomena occurrence, and mining activity is a sufficient condition.

Geodynamic conditions include depth of mining, tectonic stress fields, tectonic plates movement, presence of active faults, properties of host rocks, circumstances of hazardous dynamic phenomena occurrence in the neighboring areas of the mine field (Figure 1). The site belongs to the hazardous regarding to dynamic phenomena occurrence if following three conditions are met.

2.3. A model for geodynamic hazard assessment
Division of the studied area into the elements necessary for use of the pattern analysis method was carried out based on the results of geodynamic zoning studies. Based on the study of the relationship of factors affecting the dynamic phenomena occurrence risk, a model for regional forecast of such phenomena was developed and a probabilistic risk prediction criterion was set. Analysis of spatial data allowed developing a scheme for defining the probability of hazardous dynamic phenomena occurrence with identification in the mine field areas of three hazard categories: hazardous, threatened and non-hazardous. This significantly improves the forecast quality and contributes to safe development of coal deposits.

Development of a method for hazardous areas identification by dynamic phenomena from a scientific point of view has contributed to development of the theory of geodynamic zoning method. From a practical point of view, it is possible to increase forecast efficiency and, for the first time in China, to separate all mine field areas into three risk categories.
3. Examples of the geodynamic zoning method application in China

3.1. Research on forecasting hazard of sudden outbursts of coal and gas at Yue Jin coal mine

Studies on identification of mine field areas with different hazard degrees were carried out at Yue Jin mine. For this mine, four main factors affecting a degree of geodynamic hazard were identified: presence of active faults, stress state of rocks, properties of roof rocks and gas bearing capacity of the coal layer. Values \( k \) of sudden coal and gas outburst probability, \( k=0.63 \) and \( k=0.32 \), were used as a criterion for areas separation to hazardous, threatened, and non-hazardous types. Accordingly, three types of mine field were identified by the forecast results. A relatively shallow part of the mine field with \( k<0.32 \) was classified as non-hazardous, areas with \( 0.32 \leq k<0.63 \) were classified as threatened areas, and a relatively deep part of the mine field with \( 0.63 \leq k<1.0 \) was classified as hazardous.

According to observations performed in the period from 2006 to 2008, there were three sudden coal and gas outbursts at the mine, all of them occurred in the areas of the mine field which, according to the
forecast, was classified as "hazardous", Figure 2, Table 1. This event was of great importance for further preventive measures in the hazardous areas.

Table 1. Data on sudden coal and gas outbursts for the mine in the period from 2006 to 2008

| No. | Date       | Location | Category of the area | Additional information                  |
|-----|------------|----------|----------------------|-----------------------------------------|
| 1   | 06.03.2006 | Bottom   | hazardous            |                                         |
|     |            | 3402     |                      |                                         |
| 2   | 17.06.2006 | Bottom   | hazardous            | Outburst of 30 ton of coal               |
|     |            | 3105     |                      |                                         |
| 3   | 13.10.2008 | hazardous|                      | Outburst of 400 ton of coal and 51583 m³ of gas |

Figure 2. Centers of sudden coal and gas outbursts occurred in areas for which a "hazardous" category was set by forecast (red)

3.2. Research on prediction of rock bursts at Jingxi coal mine
Similar studies to identify hazard categories of the mine field areas by rockbursts using the method of multi-factor identification were carried out at Jingxi mine. In this case, values k of rockbursts occurrence probability, k = 0.66 and k = 0.43, were used as a criterion for areas selection to hazardous, threatened and non-hazardous categories by rockbursts. Accordingly, by the forecast results, the mine field areas were divided into three types. The hazardous area includes areas filled with cells with rockburst probability 0.66 ≤ k < 1.0. Areas with the values of the rockbursts probability in the range 0.43 ≤ k < 0.66 were included into the medium-level hazard (threatened) areas. The non-hazardous category includes areas with rockburst probability less than 0.43. Hazardous area regarding to rock bursts accounted for 29% of
the total area of the mine field, the medium risk area was, respectively, 35% and non-hazardous area amounted to 36%, see Figure 3.

![Figure 3. Results of rock burst risk prediction for Jingxi mine (red color – hazardous area)](image)

For hazardous areas, early application of regional preventive measures and planning of local preventive measures are recommended. In this case, enhanced monitoring over the current definition of the rockburst hazard degree during mining operations is necessary. For the area of medium-level hazard, it is necessary to apply limited preventive measures, but at the same time to monitor achieved effect. In non-hazardous areas, mining operations can be carried out without preventive measures, but at the same time, the hazard monitoring should be performed.

4. Conclusions

(1) The method of geodynamic zoning in China has passed three development periods which can be called "formation", "development" and "innovation". Based on the geodynamic zoning method, the program for analytical calculation of the rock mass stress state and software for multi-factor pattern analysis to predict places of the geodynamically hazardous phenomena occurrence in the course of mining operations were developed.

(2) A model and method for assessing the geodynamic state of the rock mass based on influencing factors is developed that is used to address the issues of forecasting and preventing of mining burst and sudden outbursts from coal mines in China.

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