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Classification of Mineral Resources Associated and Accompanied with Coal Measures

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Abstract The paper discusses the concept of mineral resources associated with coal measures. A rational and scientific classification of such mineral resources becomes more necessary with the development of science and technology. A classification scheme is proposed based on compositions and physical properties and the utilization of these associated minerals.

Key words: deposits associated and accompanied with coal measures, concept, classification, multi-purpose utilization

1 Introduction

The coal industry is a very important sector in the national economy of China and the output of coals in China ranks first in the world. Coal measures are often associated with other mineral resources. For some reasons, the associated resources are ignored in many cases while exploring and mining coal. In recent years this situation has attracted attention of the Government as well as researchers and enterprises, but the concept of coal-associated mineral resources has not been widely accepted and their classification and systematic study have not been completed, either. Therefore, the authors discuss some interesting problems in this paper.

2 Current Situation of the Research on Mineral Resources Associated and Accompanied with Coal Measures

Since the founding of the People's Republic of China in 1949, with large-scale coal geological investigations exploration and utilization of mineral resources associated and accompanied with coal measures have been more or less developed. Some previous geological reports covered problems in this aspect, but detailed investigations and researches have been rarely done and the data obtained so far cannot satisfy the needs for the rational development and utilization of

coal resources.

Owing to the economic reform and opening-up policy, China has made rapid progress in science, technology, industry and agriculture, and thus has increased the demand for many kinds of mineral resources. Nonmetallic ores (including most of mineral resources associated with coal measures) become especially important in the national economy. For example, the research and development of hydrocarbon from coal is a new field attracting more and more researchers. In 1989 a research project "Development and Utilization of Coal Associated and Accompanied Mineral Resources" launched by the China Association of Coal Processing and Utilization was put into practice and a research report of this project "On the Development and Utilization of Five Nonmetallic Mineral Resources in Coal Seams" was completed. The Mining and Technology University of China, China National Administration of Coal Geology and Research Institution of Coal Exploration of Xi'an participated in the project. The report gave a systematic and detailed analysis, discussion and comparison in respect to the distribution, type, quality and quantity, conditions of exploitation, current mining situation, methods of mining and processing, utilization, production and marketing, and perspective of the five nonmetallic ore deposits in coal formations, such as kaolin (Zhu et al., 1997), refractory clay, bentonite, tripolite (Gu et al., 1994) and graphite. In 1993,

another project was undertaken, submitting the report of "Research on Development and Utilization of Six Useful Mineral Resources in Coal Mining Districts". Pyrite deposits, oil shale, gypsum and anhydrite, quartz-sandstone, granite and marble resources were evaluated. These resources occur in coal seams or bear some relations with coal seams. Some mineral resources such as quartzite have origins different from the origin of coal seams. In other words, they are not exactly coal-associated mineral resources, but often occur in base rocks of coal seams or within mining districts of coal, so they are called "other useful mineral resources in coal mining districts". This report, for the first time, gave a detailed discussion and summarization of the above six mineral resources and provided valuable data for relevant policy-making departments of the State.

Although outstanding progress has been made, more efforts should still be given to work out a more practical concept, conduct scientific research and make summarization and classification of mineral resources associated and accompanied with coal measures, so as to evaluate, develop and utilize these resources more rationally.

3 Concept of Mineral Resources Associated and Accompanied with Coal Measures and Extension of This Concept

3.1 Concept of mineral resources associated and accompanied with coal measures

There is no clear, scientific and commonly adopted classification and denomination of mineral resources associated and accompanied with coal. The following definitions are adopted in this paper:

(1) Mineral resources: all useful minerals both above or beneath the Earth's surface including combustible organic resources such as coal, oil shale, petroleum and natural gas. Currently, mineralized hot groundwater, inert gases, gaseous CO₂, minerals on seabed etc. are also included.

(2) Accompanied mineral (or element) resources: mineral resources occurring within the same mineral deposit, unsuitable for independent mining and only recovered as by-products while mining the main mineral resources.

(3) Associated mineral (or element) resources: two or more than two varieties of mineral deposits (or orebodies) occurring in different positions or rock layers within the same mineral district (or deposit), which can be located and evaluated respectively.

(4) Associated minerals: different concomitant minerals of the same origin, formed in the same mineral deposit and in the same ore-forming epoch.

(5) Accompanied minerals: different minerals occurring within the same natural region, accompanied with each other spatially regardless of their genetic or temporal relationships.

Based on the above discussion, two definitions are obtained:

(1) Coal-associated mineral resources: mineral resources that are closely related in origin and occur together with coal seams.

(2) Coal-accompanied mineral resources: mineral resources that occur together in coal seams, but do not necessarily have the same origin as the coal.

Thus, the authors came to an idea that coal associated and accompanied mineral resources are those which occur within coal seams and are not always genetically related with coal. Some metal and non-metal ore deposits, rare elements in coal, some radioactive elements, metal elements and combustible organic rocks can be taken into this category.

3.2 Extension of the concept

In coal exploration a more generalized concept is often adopted. In light of the criterion for coal exploration issued by the China National Committee of Mineral Reserves in 1986, useful mineral resources in coal measures refer to "those minerals and elements within coal seams that are of industrial value and accompanied or associated with coal, including all useful mineral resources occurring in overlying or underlying beds of the coal seams." The concept involves all kinds of mineral resources occurring in exploration districts and vertical stratigraphical sections. So the following mineral resources can be included: (1) those occurring in coal seams and having the same formation age and vertical and horizontal distribution with the seams, such as gypsum and anhydrite in the Zimenqiao Formation above Ceshui coal seams in Hunan Province; (2) those in the overlying and un-

derlying layers of the coal seams despite of their different ages of formation, e.g. the gypsum-bearing rock layers in northern China, which are beneath C-P coal seams and cover the base rock, Middle Ordovician limestone.

It is seen from the above discussion that the concept has been extended. Such resources as groundwater, mineral water and gaseous CO₂ in coal exploration areas are also included in the mineral resources discussed. Peat, which can be used in industry and agriculture, is another example of useful resources. In Yunnan Province, for example, some Tertiary coal seams are directly covered by Quaternary peat. In broad sense, the authors can reasonably take peat as one of the coal associated mineral resources. Some high-carbon-bearing and combustible shale in coal-bearing rock layers in some districts where energy is costly can be taken as useful energy resources even though they contain ashes (>40%). In addition, large amounts of gangues are produced during the exploitation of coals and the proper utilization of these products can either turn wastes into treasures or avoid environment pollution.

In general, the extension of the concept about mineral resources associated and accompanied with coal will benefit exploitation, bring about more economic advantages, widen working domains and improve comprehensive utilization of mineral resources.

4 Classification of Coal Associated and Accompanied Mineral Resources

Coal resources are distributed in vast space in North

China, Northwest and Northeast China, and South and Southwest China and occur in strata of a long geological period from the early Palaeozoic to Cenozoic. Such a long period of time and vast space will certainly create multifarious mineral resources associated and accompanied with coal. Except for some epigenetic or metamorphic mineral resources they are all cosedimentary deposits, including nonmetallic and many fuel resources such as natural gas and coal-related gas, as well as metal resources such as trace elements in coal seams, and rare and radioactive elements. Therefore, these mineral resources have a wide distribution, multiple formation ages and rich varieties (Chen et al., 1999; Huang et al., 2000; Zhao et al., 1998).

In this paper, the authors attempt to classify these mineral resources into three categories and three forms according to their compositions, physical properties and utilization (Table 1).

4.1 Solid mineral resources associated and accompanied with coal

Metallic resources include mineral resources used to extract metal elements for industrial utilization, which can be classified into following groups according to their usage: ferrous metals, nonferrous metals, light metals, noble metals, radioactive metals, rare and dispersed elements etc. More commonly found are rare and dispersed or radioactive elements, such as germanium, gallium, uranium and thorium. Uranium deposits occurring in coal seams are the important type of industrial uranium resources. Vanadium in

Table 1 Classification of coal associated and accompanied mineral resources

Classification	Solid	Liquid	Gaseous
Combustible organic resources	Oil shale, high-carbon shale, peat (consolidated and semiconsolidated), ozocerite (consolidated and semiconsolidated)	Petroleum, maltha, coal-related oil	Coal-related gas and coal-bed gas (coal-bed methane)
Metallic resources	Ferrous metals: iron, manganese, vanadium; Nonferrous metals: copper, zinc, tin etc.; Light metals: magnesium, aluminium etc.; Noble metals: gold, silver, platinum; Rare and dispersive metals: niobium, tantalum, lanthanum, germanium, gallium, indium		
Nonmetallic resources	Auxiliary metallurgical raw material, industrial chemicals, building materials, other nonmetallic minerals: kaolin, fire-resistant clay, bentonite, pyrophyllite, graphite, pyrite, illite, quartz sands, gypsum, anhydrite, dolomite, limestone, gem stone (amber) etc.	Mineral water, geothermal water, ground water	Gaseous CO ₂

stone coal is often concentrated as aluminiferous silicate minerals. Germanium and gallium elements are sometimes concentrated on the roof or bottom of coal or in partings of coal. Occasionally some noble metal elements such as gold, silver and platinum are concentrated in coal seams or on the roofs or bottoms. Common ferrous minerals are limonite, hematite and siderite.

Nonmetallic resources include mineral resources used to extract nonmetal elements or for direct usage, which are divided into auxiliary metallurgical raw materials, industrial chemical raw materials, fertilizer chemicals, industrial raw materials, chinaware and glass raw materials, architectural cement raw materials, technical and arts raw materials, gems, casting stones, rubbing materials etc. Generally speaking, except for metal, fuel and ground water, all useful nonmetal mineral resources are included.

Such resources have abundant varieties and wide distribution and are mostly sedimentary deposits. Commonly seen in coal formations are kaolin, fire-resistant clay, diatomite, bentonite, pyrophyllite, graphite, pyrite, gypsum, anhydrite, limestone, dolomite, quartz sands, gem (amber) etc.

Combustible organic rocks include solid, combustible and sedimentary organic rocks composed mainly of carbon and hydrocarbon. They are oil shale, solid bitumen, high carbon shale, ozocerite (consolidated or semiconsolidated) etc.

4.2 Liquid mineral resources associated and accompanied with coal

They include mainly petroleum, maltha, coal-related oil etc. In broad sense, groundwater, mineral water, geothermal water etc. can also be included.

4.3 Gaseous mineral resources associated and accompanied with coal

Mineral resources of this category include coal-related gas composed mainly of coal-bed methane (within coal beds). The development of coal-related gas will bring along marked economic advantages and has become a hot spot in the research of energy tapping and utilization in the world.

5 Conclusions

(1) Coal associated and accompanied mineral resources are defined as those that occur in coal seams

with or without genetic relationships with coal, including solid, liquid and gaseous resources.

(2) The concept of coal associated and accompanied mineral resources can be extended as refers to "all useful mineral sources found in an exploration district and vertical stratigraphical sections". This concept will certainly benefit rational utilization of mineral resources and bring about more economic advantages.

(3) Coal associated and accompanied mineral resources have abundant varieties, extensive distributions and considerable reserves in China, so the research on these resources is a very important topic.

(4) Scientific classification, rational development and multi-purpose utilization of such mineral resources are of more importance in the national economy.

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