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The Characteristics of Karst and Karst Water Hazards in Coal Mining Areas in North China

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Abstract The characteristics of stratum distribution, karst evaluation and karst controlling factors in coal mining areas in North China were comprehensively studied and analyzed.The karst characteristics and the distribution of exposed karst ,shallow buried karst and deep buried karst were given. The relationship among geological structure controlling groundwater, groundwater circulation and the characteristics of Ordovician limestone karst was studied.The distribution characteristics of development types and water abundance of Ordovician limestone karst were obtained. The spatial relationship between major coal seams and Ordovician limestone karst aquifer, the main controlling factors of mine water hazards were studied. From the abundance water-charging sources, the capacity of water inrush–resisting of impermeable layers in seam floor, the geological formation of vertical karst and the development characteristics of water-conducting structures, evaluation of risk zonation of mine karst water hazards in coal mining areas in North China was put forward, providing important scientific basis for water hazard evaluation and control in mining deep coal resources in North China.
Keywords North China, karst, geological structure, water control, coal mining, water hazard evaluation

Introduction

Coal has held the absolute guiding position in China's energy structure. North China has been the key region for the development of coal industry in the country, and Permo-Carboniferous coal resources are the major minable in the region, so safe, highly efficient and sustainable exploitation of the coal resources in the region constitutes the important foundation to ensure energy security in China. However, very thick karst aquifer develops below Permo-Carboniferous seams in North China, and this is seriously restricting the sustainable exploitation of the deep coal resources in the region (Zhao 2006). Therefore, it is necessary to analyze the characteristics of karst development and distribution, to study karst development history and its major controlling factors, to get the inherent relationship among the characteristics of regional structures controlling groundwater, groundwater circulation and Ordovician limestone karst development, to identify the characteristics of the development types, distribution and watery distribution of Ordovician limestone karst, and to conduct zonation evaluation of karst water hazard risk in coal mines in the region. It has important guiding significance for safe and sustainable mining of deep coal resources in the region.

Distribution and characteristics of karst in coal mining areas in North China

The major coal resources and the large scale coal exploitation enterprises are located in Hebei, Shanxi, Central and southern Shandong, west Henan, eastern Weibei, Xuzhou, Huainan, Huaibei, Beijing, Tianjing and Tangshan. This region is the origin of China's coal industry, but also the energy bases to support social and economic development in eastern developed region. The special geological background and geological evolution history has made the major coal bearing strata associated with karst strata. The area of carbonate rock is about 47 km^2 in major coal resource region. Vastly distributed soluble layers have provided necessary material basis for the development of modern karst and palaeo-karst. The major soluble layers mainly consist of Middle Ordovician carbonate and gypsolyte. From sedimentation to anaphase corrosion and erosion transformation, there was a geological process of 600 million years. They become today's most important karst aquifer, associated Permo-Carboniferous seams are the major minable coal resources in North China and mostly distributed above the karst aquifer(Hu 2010) (fig.1). Karst water hazards have threaten the exploitation of coal resources for long time. Through the analysis and study of the characteristics of the regional geological evolution history and modern karst, the following characteristics of the distribution of soluble strata and karst development in major coal mining areas in North China can be obtained:

(1) The soluble carbonate layers are located in the lower of Permo-Carboniferous coal measure. The purity and the sedimentary continuity of carbonate rock are good.

(2) The carbonate rocks in North China tectonic block have not only distributed in the formation of stable platform sedimentary, but also distributed in the formation of active sedimentary zone.

(3) The soluble carbonate deposit center in North China tectonic block migrated from the west to the east and from the north to the south with time. The major Ordovician limestone distribution areas are located in Shanxi, Hebei and Shandong provinces. These characteristics of spatial distribution coincide with the formation of the tectonic block and the order of marine transgression and regression in the region, forming the variation regularity of being thick in the east and thin in the west. The thickness in the east is 1100~1400 m,1000~1100 m in the middle and 800~900 m in the west.

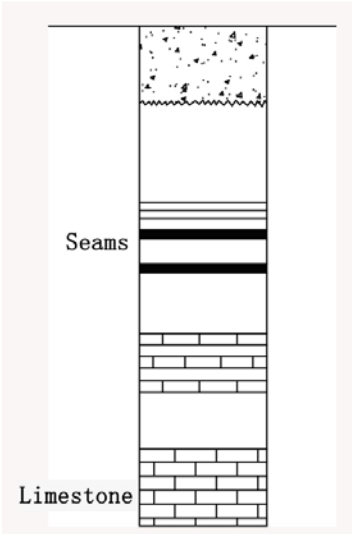

Fig.1 *Relationship between coal and limestone*

(4) Geological and geographical background had evident constraint action on the formation of karst in North China. North China tectonic block is not a united complete block, but consists of some blocks of different level and linear structures between blocks. Faults and folds are developed between blocks, showing typical configuration of structure blocks. Since Mesozoic particularly Cenozoic, Taihang block in the west of the region(equivalent to Shanxi plateau)has uplifted continuously, Shandong and Hebei block in the middle(equivalent to great North China plain)has subsided continuously, while in the east mountainous areas in central and southern Shandong has upheaved relatively. This regional tectonic difference has evident controlling action on the characteristics of karst development. For example, in Shanxi plateau, Taihang mountain, central and southern Shandong, karst is mainly exposed and shallow covered, but in North China plain, karst is of type of palaeo-buried (Hu 2008).

Today's topography and relief of being low in the east and high in the west is restricted by the special geological environment of "uplift in the west and depression in the east" in North China. Mesozoic soluble rock has experienced multiple tectonic activities in the region, making soluble rock transformed in different level time and time again. Different folds, faults, uplifts, faulted depressions, joints and fractures occurred. Through modern and palaeo activities of groundwater and geochemical action, different macro and micro inhomogeneous corrosion, erosion and denudation occurred, forming regional karst of different elevation, different scale and different patterns.

Controlled by various factors such as topography, climate and burial conditions, acted by succession, continuity and superposition of karstification, karst type in major coal mining areas in North China can be divided into three categories, i.e., exposed karst, shallow karst covered and deep buried karst. The area of exposed karst is 73403 km^2,mainly distributed in Yanshan mountain, Taihang mountain and Lüliang mountain, secondarily in central and southern Shangdong, Huainan, Huaibei and western Henan. The area of shallow covered karst is 54668 km^2,mainly distributed in Xuzhou, Huainan, Huaibei, western and southern

Shandong, Weibei, Baoding, Dezhou, zone between Beijing, Tianjing and Tangshan. The deep buried karst is distributed the most vastly, its area is up to 341326 km^2, accounting for 72.7 % of the total karst area. It is concentrated in lower Liaohe river and North China plain, where its area is up to 63717 km^2,geomorphologically it shows depression of palaeo-buried hill. It is also distributed in down faulted basins in Shanxi plateau, southern foot of Yanshan mountain, Weibei and western Henan. Karst induces water hazard for deep coal resource exploitation is exposed karst and covered karst. The biggest threat comes from collapsed karst columns. Karst columns are mainly formed from gypsum dissolution and collapse of palaeo-karst caves, a common karst pattern developed in North China(fig.2).It is the place of groundwater storage, also one of the major passages of mine water inrush. It is the major karst pattern to conduct deep karst water and to threat the safe mining in coal mines. As shown in fig.2, it is mainly distributed in the eastern and the western foot of Taihang mountain.

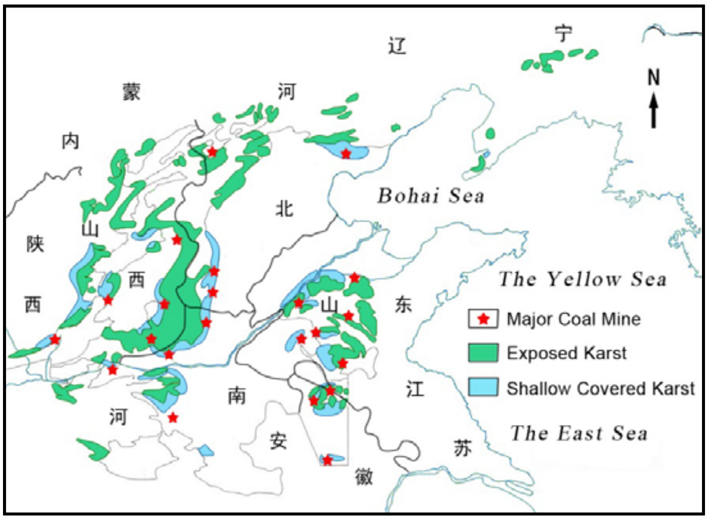

***Fig.2** Karst distribution in North China*

Underground strong karst zone is a key point in hydrogeological research of coal mining, consists mainly of karst fissure net. Mostly it develops along fault zone, valley, interface of soluble and insoluble rocks, and is the major place and passage for migration and accumulation of underground karst water. The major coal mining areas with great amount of karst water are located or near strong karst zone(Dong et al. 2007). Solution fissures are predominant in deep karst pattern, followed by karst caves and karst pores. Deeply buried palaeo-karst and deep collapsed columns are special karst features in coal mining areas. Deep karst has certain influence on coal resource development in the region. Research results indicate that deep karst can be divided preliminarily into five categories, i.e., deep karst with deep tectonic circulation, deep karst with palaeo-buried hill, deep karst with igneous rock contact zone, coastal deep karst, deep karst with strong runoff zone. Deep karst development is closely related with the peculiar North China fault block. Great amount of drilling data and petroleum exploration data in North China verified that deep karst often develops in the middle of Ordovician limestone and is retention of unfilled palaeo-karst. It must notice that deep buried karst and deep collapsed columns coexist, restricting and influencing the development of deep coal resources. Large scale geological structures such as folds, fault blocks and faults control evidently the development of deep karst.

Basin-mountain structural characteristics in North China and their control on the characteristics of karst water circulation

Karst in north China has been influenced by tectonic activities after Triassic, forming inland basins isolated each other. Controlled by Neo-Cathaysian tectonic, small basins ranged in NNE and NE appeared. Faulting activities were frequent, strata were folded and inclined, relief undulation aggravated, rivers and lakes developed, groundwater circulation aggravated. Rivers and lakes, landform and faults have controlled the characteristics of groundwater circulation. Deep circulating water caused modern karst. In this period, large geological units in the eastern region of North China can be divided into three uplifted zones and three depressed zones(fig.3). Three uplifted zones consist respectively of Taihang mountain~Yanshan mountain uplifted zone, Lunxian~Nining uplifted zone and Central Shandong~East Liaoning uplifted zone, three depression zone are respectively Central Hebei depression, Huanghua depression and Linqing~Jiyang~Bozhong~lower Liaohe depression. Regional uplifts and depressions have controlled regional groundwater circulation system. In each uplift and depression, great amount of tectonic fault basins have develop. Each fault basin has constituted a local water circulation system. Many mines in the region (deep coal resources)are exactly located in these fault basins. Due to the formation of fault basin, limestone in a complete fault basin formed often three zones, i.e., outcrop area in low hills, shallow concealed area of Quaternary phreatic aquifer and deep concealed area below coal measures. These burial conditions of soluble limestone have formed particular groundwater circulation conditions and zonation of groundwater circulation. After being uplifted to the ground surface, palaeo-karstified soluble rocks have been effected by vertical water flow in shallow outcrop area, palaeo-karst already filled has been subjected again to modern karstification and formed modern karst zone. Relatively deep unfilled palaeo-karst of the late stage of Caledon was affected by superposition of differential karst, forming karstic underground rivers, large karst caves. Great amount of karst collapsed columns are the karst products of this stage. Differential karst and superposed karst zone were formed.

Generally, a relatively complete hydrogeological unit was often formed from uplift to depression. In this hydrogeological unit, because the burial conditions of aquifer of soluble rocks are different, in the plane, from uplifted exposed area to deep burial area, groundwater circulation zone can be divided into area directly recharged by precipitation in exposed mountains, area recharged by seepage below Quaternary phreatic aquifer, alternating area with intensive groundwater circulation in shallow burial area, alternating area with weak groundwater circulation in medium and deep burial area, high pressure area with slow deep groundwater circulation(fig.4). In recharge area, groundwater moves mainly vertically, aquifer is generally unsaturated aeration zone. Groundwater level shows evident seasonal fluctuation. Water circulation may have double effect on soluble rocks, i.e., biochemical corrosion and mechanical erosion. In alternating area with intensive circulation, groundwater is located in transition zone of vertical movement and horizontal movement, hydraulic gradient of groundwater movement is relatively big, groundwater velocity is high, karst develops intensively, partly filled palaeo-karst is eroded again, the filled zone is not evident at the top of limestone, causing water hazard threatening seriously shallow coal mining. In alternating area with weak groundwater circulation, groundwater moves mainly along layer, the hydraulic gradient driving movement of groundwater is relatively small, the speed of groundwater circulation is relatively slow, palaeo-filled zone is evident. In high confined water pressure area with slow groundwater circulation, the speed of groundwater circulation is very slow, although groundwater moves mainly along layer, the resistance of movement along layer becomes bigger and bigger. Under action of high water pressure, when meeting weak geological structures(e.g. fault and fractured zone, etc.),groundwater tends to leak upward vertically(Yin et al. 2008).Because groundwater movement state in different zones is different, chemical components of groundwater in different zones have different characteristics. It must be noticed that excavation and mining in coal mines add artificially discharge points of groundwater, changing the movement state of groundwater.

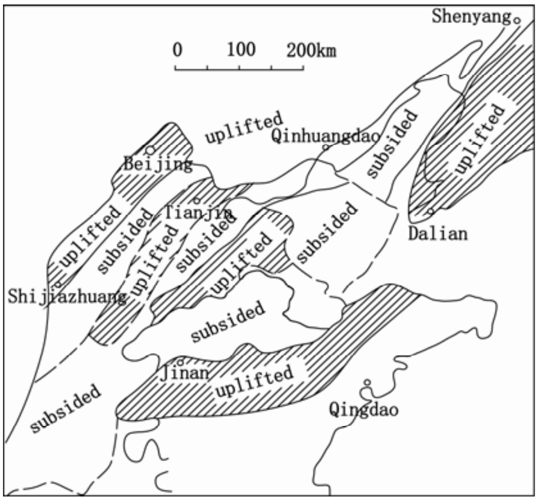

Fig.3.Techtonical structure of northern China

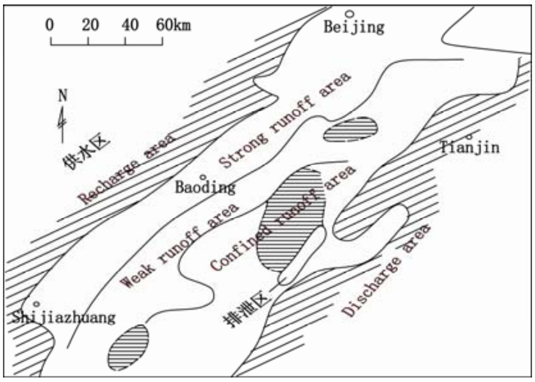

***Fig.4** Different zone of karst water circulation in middle Hebei province*

Karst water hazard level in mining Permo-Carboniferous coal resources in North China and its regional distribution

There are coal mines with karst water hazard in the eastern region of North China. With increase of mining depth, the conditions for karst water hazard occurrence in coal mines may change. This change is shown at following aspects: firstly, with the increase of the burial depth of karst aquifer, the recharge conditions of groundwater become weak evidently, the deep karst water circulation conditions becomes poor, and the dynamic recharge of groundwater is insufficient. Once karst water inrush occurs, water pressure during the initial stage of water inrush is very high, and inrush water volume is relatively big. This threats mine seriously. With the processing of water inrush, inrush water volume decreases quickly. Secondly, when the burial depth of karst aquifer is more than 500 m, because the transformation by modern karst is light, palaeo-karst filled cemented layer of different thickness develops generally at the top of Ordovician limestone, because the layer has good impermeable performance (Hu and Yan 2007; Hu 2007; Hu et al. 2010), during evaluation of mine hydrogeological conditions, it must regard the layer as impermeable layer together with the impermeable layer in seam floor. Consequently, although karst water pressure increases, the thickness of impermeable layer also increases in some degree, improving condition for mine water hazard control. Thirdly, with the increase of depth, the resistance of water movement along layer in aquifer may increase evidently, making deep groundwater leak upward to the shallow part, increasing the aggressive and destructive power of high pressure karst water to break through the impermeable layer of seam floor, so increasing the risk of water inrush in floor of working face. Fourthly, difficulty of hydrogeological exploration in deep karst increases significantly, which is shown in the fact that the current surface boreholes have difficulty to pass through efficiently the shallow mined area and to go into deep aquifer, it is difficult for surface geophysical exploration to the shielding problems caused by shallow mined area, there are technical difficulties for underground water detection and drainage boreholes at aspect of safe control of high pressure water at wellhead. Finally, the difficulty for depressurizing through dewatering in deep mining increases, it is very difficult to realize pre-dewatering of big drawdown, it is difficult for current inrush coefficient for evaluating water inrush conditions in seam floor and the technical norms of remained waterproof pillar to adapt the deep mining environments, there are no new efficient related technical norms and regulations.

Aiming at deep karst water, the major influencing factors and characteristics of karst water hazard in North China, on the basis of comprehensive analysis of karst strata and burial conditions, characteristics of karst development and transformation by later filling, karst groundwater circulation and runoff conditions, water abundance features, the thickness of impermeable layer between coal seams and karst aquifer, we arrived at four comprehensive maps reflecting karst water and karst water hazard conditions in major coal mining areas in North China, i.e., distribution of the thickness of water-isolating and protecting layer of seam floor, zonation evaluation of karst water hazard risk in coal mines(fig.5 and 6). These results of basic research will provide important technical support for water hazard evaluation and control in exploitation of deep coal resources in eastern North China.

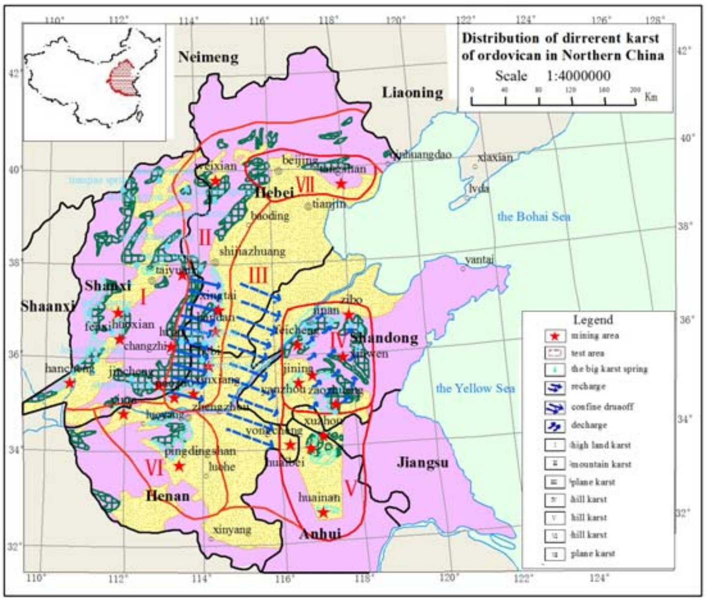

Fig.5 *Distribution of karst development types in Ordovician limestone*

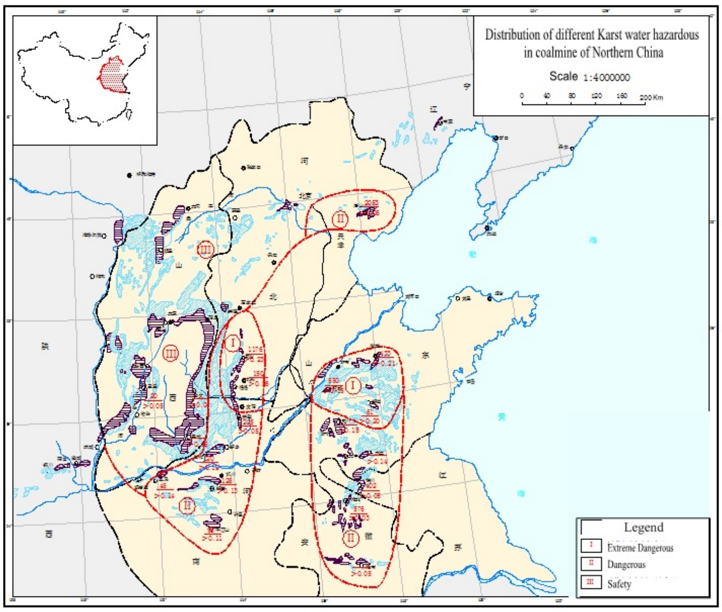

Fig.6 *Zonation evaluation of karst water hazard risk in coal mines*

Conclusions

Through the study of the palaeo-geography and geological history of karst development process, in combination with great amount of revealed karst phenomena and their variation with depth, we analyzed the development and distribution characteristics of soluble strata in major coal mining areas in North China, studied the development history and the major controlling factors of karst of soluble rocks, put forward the development characteristics of three types of karst, i.e., exposed karst, covered karst and buried karst. We studied also basin-mountain structure regionally controlling water, the inherent relationship between the characteristics of groundwater circulation and the characteristics of karst development in Ordovician limestone, obtained the characteristics of karst development type distribution and water abundance distribution of Ordovician limestone. We analyzed and studied the spatial relation between the major mined seams and karst aquifer as well as the major factors for formation of mine water hazard. From the watery of recharge source, the ability of anti-water inrush of impermeable layer in seam floor, vertical karst geological structural formation and the development characteristics of water-conducting structures, we put forward zonation evaluation of mine karst water hazard risk in coal mining areas in North China.

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