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Discussion of Development Characteristics and Causes of Karstic Collapse Columns at Liuqiao No.1 Coal Mine

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Abstract Karstic collapse columns are widely developed in Wanbei Mine Area and karstic collapse columns of Liuqiao No.1 Coal Mine have become one of the main geological disasters during coal mining. This Paper will discuss the causes of karstic collapse columns based on 9 collapse columns discovered at Liuqiao No.1 Coal Mine and analyze their characteristics and development rules.
Keywords karstic collapse columns, development rules, discussion of causes

Issues proposed

With complex hydrogeological conditions, Liuqiao No.1 Coal Mine exposes 9 karstic collapse columns. As a geologic phenomenon with distinctive regional features that is widely discovered in North China Coalfield, collapse columns acting as active water flowing channels have caused flooding of mine and working face repeatedly. The affected coal mines range from Kailuan Coal Mine in the north of North China Coalfield to Pingdingshan Coal Mine in the south and from Weibei Coal Mine in the west to Feicheng Coal Mine in the east, involving almost the whole North China Coalfield. Collapse columns have been one of the most serious disasters for coal mines in the recent 20 years. They can also be found at Wanbei and Huaibei Coal Mine. On March 4, 1996, 7222 working face of Renlou Coal Mine was flooded by the great water inrush from collapse columns, with the maximum water inrush of 34560 m^3/h. The mixed water from the Ordovician limestone and the bottom aquifer of Quaternary System rushed into the mine through the karstic collapse columns, causing direct economic loss of RMB 200 million yuan. It is the second extra serious accident caused by water inrush from collapse columns in North China after the flooding of No. 2171 working face at Fangezhuang of Kailuan Coal Mine in 1984. Such accidents have caused great losses to state property, which also seriously threaten the life of miners and restrict the production and development of coal mines. In consideration of such serious accidents, all coal mines in Wanbei and a lot of mines in North China have treated the risk of water inrush from karstic collapse columns as a major factor affecting the safe production. Therefore, it is very significant to enhance the risk assessment of water inrush from collapse columns.

Hydrogeological characteristics of Liuqiao No. 1 Coal Mine

Located at central Huaibei Plain, Liuqiao No.1 Coal Mine witnesses relatively even terrain and the natural elevation within the deep area of Level II working face is 30.50-32.30m. The mine area is free from exposed bedrocks and covered by the extremely thick Cenozoic loose bed. The underground aquifers may be divided into the following categories based on the occurrence characteristics.

Aquifer and aquiclude of tertiary and quaternary system

The loose bed of the tertiary and quaternary system has a thickness of 93-155 m (with an average of 125 m) which is controlled by the ancient landform and increases from northeast to southwest. As the erosional landform, the ancient landform slopes gently and there are slight ups and downs. The lithology consists of the clay and sand layer and it is lacustrine and channel fill deposit. Four aquifers (groups) and three aquicludes (groups) are identified based on the water bearing and resisting property. Aquicludes 2 and 3 suffer from losses or pitch-out, resulting in local combination of Aquifer 2 and 3 which builds the complementary relationship. Aquifer 3 occasionally meets the sandstone aquifer in coal measures and they have some hydraulic connections.

Sandstone fracture aquifer in Permian coal measures

From the angle of water-bearing property, the aquifer in the Permian system (coal series) is composed of fractured sandstone. The aquiclude is composed of mudstone and siltstone and it is stably distributed between aquifers. The water yield property of interlayer confined fracture aquifer mainly depends on the fracture development, communication and recharge condition of the rock formation. The underground water mainly stores and moves in the network which takes the structural fracture as the main fracture and it is dominated by static reserves. In the mine area, there are four relatively stable aquifers, numbered from top to bottom as aquifer 5, 6, 7 and 8. Aquifer 7 and 8 is the roof and floor of coal seam 4 and 6 respectively, which serve as the direct source of water filling for the mining of the coal seam.

Limestone aquifer of Taiyuan Group

With a total average thickness of about 130 m, Taiyuan Formation consists of mudstone, siltstone and 13 stratums of limestone. The limestone stratum 1 and 2 are composed of the laminar limestone, with a thickness of 2-3 m and poor water-bearing property. The limestone stratum 3 and 4 are relatively thick, with an average thickness of 8-12 m, developed with fracture karst and of good water-bearing property. Generally, the limestone stratum 1 to 4 is regarded as an aquifer group with medium water yield property. As the mine service-life increases, the level of Carbonic limestone water decreases year by year, indicating that the Carbonic limestone water gradually reduces through drainage during production of the mine and the mine area suffers from shortage of Carbonic limestone water recharge.

Usually, limestone stratum 1 of Taiyuan Group is 40-71m away from the floor of coal seam 6 above, with an average distance of 54 m. The lithology mainly consists of marine mudstone and siltstone which is dense and complete, and it is free from fracture and of good water-resisting property which will be greatly impaired under the influence of structural damage or mining-induced stress.

Ordovician limestone aquifer

With a total thickness of about 500 m, Ordovician limestone aquifer is generally composed of limestone and dolomite. It is deeply buried within the mine area and crops out with a large area in the southeast outside the mine area, acting as an active regional aquifer. Years of water level observations indicate small changes of water level because of the decrease of Carbonic limestone water level, which verifies the leakage recharge between the Ordovician limestone water and Carbonic limestone water. The aquifer is more than 180 m away from the floor of coal seam 6 above and exerts no direct impact on the mining of this coal seam. However, if there is any water flowing channel, Ordovician limestone water will cause serious disaster.

Development characteristics of Karstic collapse columns

9 karstic collapse columns have been exposed during drifting since the shaft was built in 1981 and they are identified as A1, A2, A3, A4, A5, A6, A7, A8 and A9. See table 1 for details.

***Table 1** Details of collapse columns*

No.	Date of Discovery	Location	Exposed Point & Position Elevation (m)	Long Axis (m)	Short Axis (m)	Area (m^2)	Angle of Draw (°)	Hydrologic Regime	Mining Status
A1	Aug. 1978	South Roadway	30 m at the bottom of coal seam 4 -330.0	140	75	7400	75	Moist	Roadway passes through 93 m
A2	Aug. 1984	433 track roadway	Coal mine 4 -330.0	48	20	760	79	Moist	Roadway passes through 26 m
A3	Oct. 1989	633、6513 633 and 6513 track roadway	Coal mine 6 -320.0	350	105	29600	80	Drop externally and water pouring internally (1 m^3/h)	Roadway was block after passing through 25 m
A4	Apr. 1988	435 track roadway	Coal mine 4 -323.0	80	40	2400	75	A little water seepage	Roadway passes through 21 m
A5	Jul. 1999	635 track drilling	Coal mine 6 -330.0	110	55	4750	77	Free from water	435 working face was rectified after being exposed; a 30 m coal pillar in II 631 working face is reserved for recovery
A6	Nov. 1989	631 crosscut	Coal mine 6 -198.0	35	15	500	75	Free from water	Roadway passes through 16 m (water from sand fracture)
A7	May 2001	II 635 machine roadway	Coal mine 6 -483.0	150	100	11770	65	Water pouring of 0.5 m^3/h	1 m exposed; 10 m backward; filled with yellow mud bag; external masonry
A8	Feb. 2004	-540 centralized machine roadway	10m at the bottom of coal seam 6 -516.0	95	40	2825	75	Water pouring of 0.5 m^3/h (Carbonic limestone water)	1 m exposed; 20 m backward; filled with yellow mud bag; external masonry; grouting
A9	Jul. 2007	II 465 working face	Coal seam 4 -524.7	40	26	817	/	Free from water and moist in local rock formation	Recovery to Dongfeng Roadway, with a distance of 34 m from Point WF4; length of working face of 175 m; collapse column exposed 40-80 m above the machine roadway of working face

The actual data of down-hole production indicate that there are a number of karstic collapse columns, and 9 collapse columns are exposed in total (exposed 16 times in the roadway, including 9 times in coal seam 4 and 5 times in coal seam 5), which are numbered as A1-A9 in the sequence of time when they are exposed. Some of the collapse columns have been exposed once and some exposed for several times. The South Roadway passes through A1. The layout of the 9 collapse columns (as shown in fig. 1) shows that the collapse columns of Liuqiao No.1 Coal Mine are located around the axis of Chenji Syncline, developing in the east wing of the synclinal axis and becoming dense at the rising end of Chenji Syncline and the long axes of such columns are basically parallel to the synclinal axis.

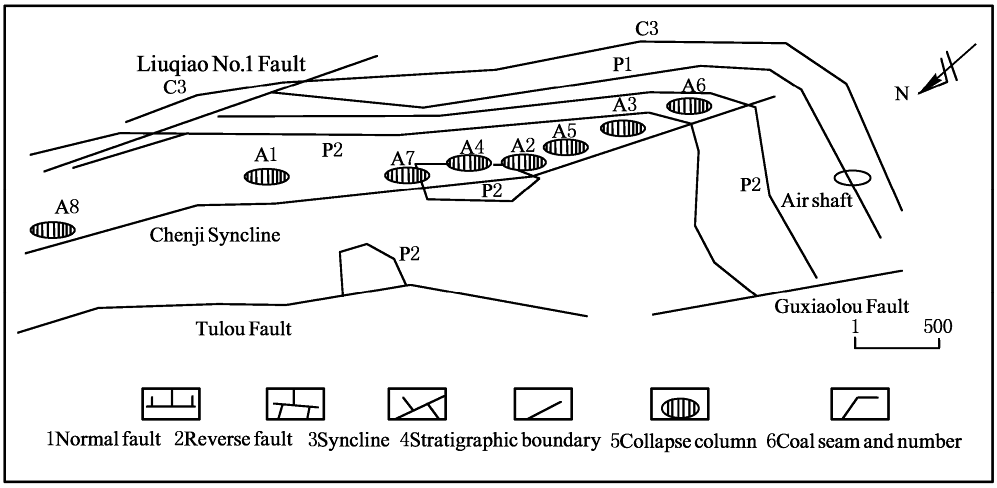

***Fig. 1** Layout of Karstic collapse columns of Liuqiao No.1 Coal Mine*

Table 1 and fig. 1 show that the karstic collapse columns of Liuqiao No.1 Coal Mine are characterized by:

The collapse column has a plane form of an ellipse or a quasi-circular shape, with the long axis of the ellipse near the direction of SN. One the section, it is of small top and big bottom at angle of more than 65° with the horizontal plane. The vertical projections of collapse columns in coal seam 4 are in or near the collapse columns in coal seam 6. A2 branches off upward, which means it is a large collapse column in coal seam 6 and develops into two small collapse columns in coal seam 4 above.

The collapse columns are subject to dramatic change of size. In coal seam 4, the small one has a dimension of about 35 m×15 m, while the large one has a dimension of up to 350 m×105 m, such as A3.

Formed by the stacking sandstone, mudstone and crushed coal in the coal measure strata, the collapse columns is featured with rocks of different sizes and sharp corners on the glide plane within the column. The collapse columns are dense. Most of them are dry and free from moisture. However, some of them are wet and subject to water drop and burst. For instance, the volume of water drop of A8 is 5 m^3/h.

The small fault is found in the surrounding rock of the collapse column. The fault dips to the column with a small fault throw and disappears after a short extension. Such soft strata as the coal seams are found to dip to the column.

Discussion of causes of Karstic collapse column

The long axes of collapse columns of Liuqiao No.1 Coal Mine are substantially parallel to the synclinal axis. The collapse columns are densely distributed at the rising end of Chenji Syncline. Due to the tensile stress produced by the stretch zone of Chenji Syncline, the broken limestone zone, water storage zone, intensive runoff zone and collapse column development zone are formed.

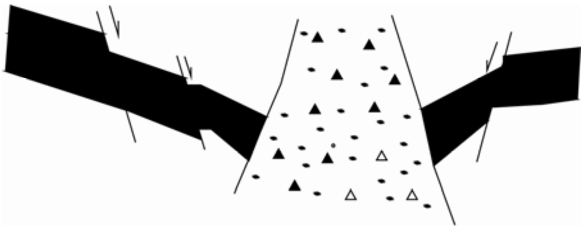

Fig. 2 *Development of small fault in the surrounding rock of karstic collapse column*

Stretch zone (tensile fracture zone in the lower part of Chenji Syncline)

The general analysis of geological structural mechanics shows that 3 zones are formed near the hinge plane of the syncline: compressed structural zone due to the extrusion stress in the upper part, neutralized zone due to no stress or very little stress in the middle part and stretch zone (tensile fracture zone) owing to tensile stress in the lower part, the strain E is less than, equal to and greater than zero respectively.

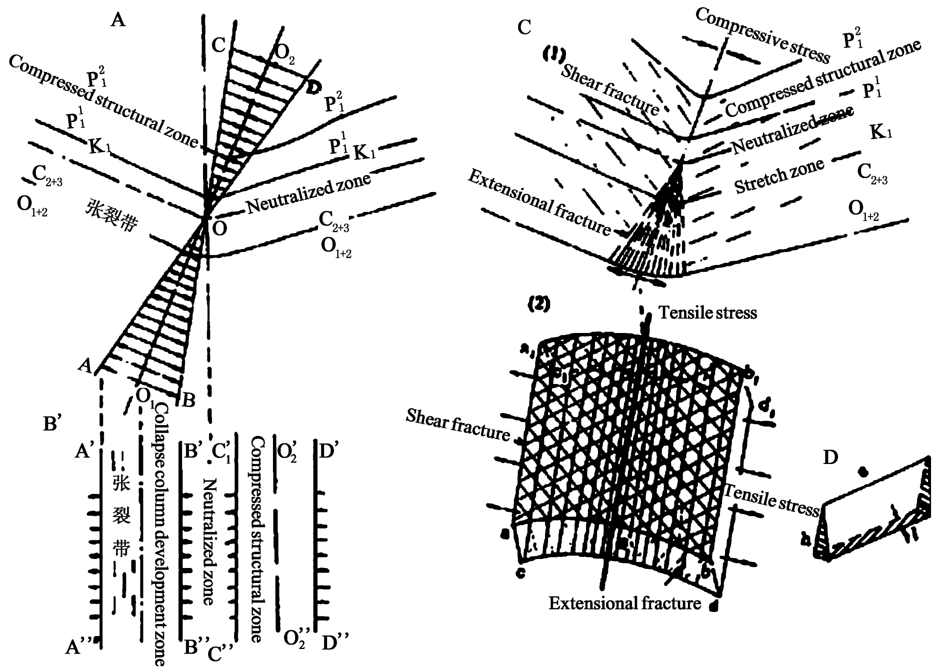

Fig. 3 *Schematic Diagram of Relation between Chenji Syncline and Limestone Karst*

A-Section of Three Zones on Axial Plane; B-Schematic Diagram of Three Zones on Axial Plane; C-Schematic Diagram for Development of Fracture around Axial Plane

Shear Fracture (2) Extensional Fracture (3) Schematic Diagram of Single Longitudinal Extensional Fracture

A and B in fig. 3 show that the extrusion and tensile stress is greater as they are further from the neutralized zone. CD, AB, AB and CD represent both the stress and the strain. Owing to the fact that Chenji Syncline is an asymmetric inclined fold and the hinge plane O_1O_2 inclines toward WN wing, the stretch is in the ES wind of the synclinal axis (fig. 3 shows the left) and the compressed structural zone is in the WN wing of the synclinal axis (fig. 3 shows the right).

Longitudinal extensional fractures are greatly developed in the stretch zone due to tensile stress, which are fan-shaped on the section and line-shaped on the plane, parallel to the synclinal axis. A single longitudinal extensional fracture is wedge-shaped (See fig. 5-2C, D). The *e*, *h* and l are respectively the length, height and width of the fracture.

Besides a number of longitudinal extensional fractures, a group of shear fractures, with the halving line of sharp diagonal parallel to the compressive stress (See fig. 3C), are found in the stretch zone, overlapping and forming into an X shape with the longitudinal extensional fractures.

Fig.3 shows that both many structural fractures and initial fractures are found in the rock formation near the hinge plane of extensional zone. Hence, the extensional zone is not only very broken, but also includes a lot of fractures, cracks, voids and collapse spaces, providing good conditions for the development of karst.

Limestone is found in the extensional zone and a limestone fractured water diversion zone is found in the lower part of the syncline.

Located in the Ordovician and Carbonic limestone around the hinge plane of extensional zone, the fractures become good water reservoirs and water diversion zones since the limestone stratum steeply dips (The inclination of Ordovician limestone is 20°-30° at Liuqiao No.1 Coal Mine and up to 45°-75° including 25°-45° of the stratum exclusive of the coal seam, and it is larger near the axial plane) and the limestone is actually stretching as a result of the tension.

The fractured water diversion zone develops into the runoff zone.

The exposed Ordovician limestone area (limestone water catchment area) is found in the south and east of the field and the rock formation around the synclinal axis dips at 7-13° from the south to the north. In consideration of such accumulative drops as Liuqiao Fault (H=110-240 m), F3 Fault (H=120-155 m), Tulou Fault (H=140-210 m), Liuqiao No.1 Fault (H=90 m), F17 Fault (H=50 m) and F4 Fault (H=60 m), drawdown in the north is 500 more than that in the south in case only the level of -600 m is taken into consideration. In fact, greater drawdown is found northward (at least 500 m less at the lowest place at the syncline). This situation, whether it is formed at the same time as that of Chenji Syncline or at the time which is different from that of Chenji Syncline, provides conditions for the flow of water in the limestone fractured zone of the synclinal axis from south to north in the form of runoff.

The intensive runoff zone develops into the collapse column zone.

With erosion and expansion of the runoff zone, the fracture karst further develops and the karst space expands. At this time, the carven is called karstic carven under the control of runoff zone. When the space (especially the plane) expands to a certain extent, the rock formation over the karst cave gradually falls off (mainly in the vertical direction) under the influence of the dead weight of rock formation and the extruding force of Chenji Syncline structure (Now the carven may be called falling carven). If the Ordovician limestone initially falls off, it will be corroded and carried away constantly. When C_{2+3} stratum starts to fall off, some the fallen rocks will be corroded and carried away while some insoluble rocks will be hydrolyzed and washed away by the runoff, triggering the blockage of the karst. When there are more and more fallen insoluble substances which finally fulfill the fractures, cracks, karst caves and collapse spaces within the runoff zone, the runoff zone will shrink and at last the runoff will stop. However, the rock formation over the carven will not stop falling and more rock formation upwards will fall off gradually. When the carven is fulfilled with crushed and expanded rocks, the collapse column will stop growing.

The cause analysis of the collapse column shows the causality between Chenji Syncline and the collapse column: Chenji Syncline – extensional zone; - water storage zone and water diversion zone – intensive runoff zone – collapse column. Such collapse column controlled by the structure is frequently found in both Liuqiao No.1 Coal Mine and other coal mines.

Conclusions

As the karstic collapse columns have been one of the main geological disasters during the mining of Liuqiao No.1 Coal Mine, analysis and further understanding of the development rule and characteristics are very significant to control the hazards caused by them.

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