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Geothermic Mine Water Forming Mechanism and Integrated Preventive Technologies in Wutongzhuang Mine Area, China

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Abstract These factors, including closed horst structure, good construction of heat reservoir, large area heat from magma activity or local heat raised from deep faults, are the basic elements of geothermal anomaly. In such a tectonic background, groundwater, as the carrier, which often flows stagnant and makes deep circulation, carries heat through the vertical pathways, heats the upper rock masses, or goes into mining spaces, and heats air, then leads to the mine geothermic hazards. Hot water draining ahead for comprehensive utilization and the grout sealing deep vertical structures, in this way, can achieve the goals to prevent water inrush threat and geothermal damage simultaneously.
Keywords geothermic water hazard, geothermic hazard cause, geothermal reservoir, deep water circulation, geothermy and water prevention

Introduction

Mine geothermal unit is the geothermy of layered structure, which is under control of tectonics(Xiao and Yong 1989). Its geothermal field controlls by the tectonic position and stability, historical changes, epigene actions, and depends also on three basic geothermal structures, including coal measures, overburden, sedimentary bedrocks and their combination relations(Zhaojin et al 2010).

Heat sources

Heat sources of the geothermal field mainly come from magma or deep heat sources which guide from the fault zones. Magma heat source includes radioactive decay heat and remaining heat in magma cooling process.

(1) Magma heat source. Coal metamorphic degrees reduce gradually from north to south at the Fengfeng coal field, the opposite is true at Anyang coal field which is close to southern of Fengfeng. Wutongzhuang mine is located at southern of Fengfeng where is center of the highest ancient geothermy. Thus it is speculated that there is ancient anomaly in the mine formed by the invasion of igneous rocks in different periods. But, there are not the magmatism from analysis of the hot water chemical characteristics, so the magma activity should not be the main factors of geothermal anomaly for the mine.

(2) Deep heat source raised from the fault zones. Fault F5 and F26 are boundary of Wutongzhuang mine, their intersection is epicenter of the 7.5 magnitude earthquake happened at Pengcheng in 1830. So, they are deep tectonic fault zones and still frequent activities in Cenozoic era. Geothermal anomaly seems related with the deep heat sources which are guided along new tectonic fracture. But, in fact, geothermal anomaly zones are along Weiwuzhuang anticlinal axis, rather than deep faults according to the results of geological exploration at the coalfield (fig. 1).

(3) Deep circulating hot water. Generally, there would be little magma activity or low intensity in the economically mineable coal deposits because extensive magmatic activities would lose coal industrial value over there. Thus, it is less likely to lead to mine geothermal

anomalies by magma heat only. Direct mine geothermal sources are from hot water, which accepts deep geothermy in deeply vertical circulating.

Ordovician limestone strata at Wutongzhuang mine are water-rich karst aquifers, in which groundwater runoff slowly because of the faults block in the boundaries, this makes it easier to keep heat in water. According to the measurements in-situ, water temperature from bottom of transport roadway, working face 2102, is 38.1℃, and the rock temperature there is 35.2 ℃, the water temperature from bottom of air roadway at the other working face is 41.1 ℃, the rock temperature there is 33 ℃, so, water temperature is higher than rock's, these are to prove that the main heat source are from water other than surrounding rocks.

Geothermal units and structures

Usually, temperature is higher and geothermal gradient larger too at bedrock upheaval area, in which geothermal anomalies are easily formed at the closed systems by fault zones. Most of Fengfeng coalfield belongs to the low temperature areas, geothermal gradient of coal measures strata is less than 2 ℃/100 m. Geothermal anomalies appear in Wutongzhuang mine at low geothermal background, this is bound to have its laws.

Wutongzhuang coalfield just like a south-extension semi-closed triangle horst (fig. 1, fig. 2). In natural condition, the groundwater in Ordovician limestone which receives supply from watershed, and flows from south to north, to be separated into two parts at bifurcation near Yuecheng reservoir. Groundwater for one part goes along the Wutong anticline, cross fault F25 tip at the southwestern corner of field, continual to north out of mining area. The other part goes into the triangular horst, flows sluggish in horizontal, goes only down to deep and does deeply circulating.

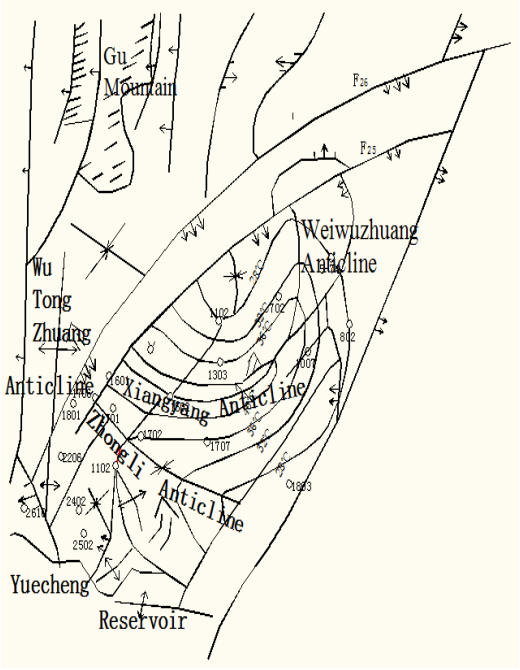

Fig. 1 *Ground temperature contour map in - 500 m level (scale 1:25 00), Wutongzhuang coal mine*

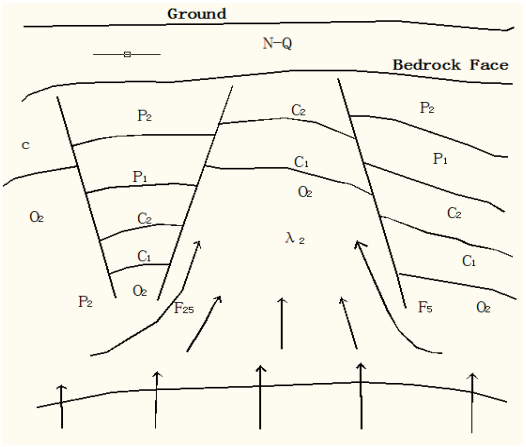

Fig. 2 *Horst structure in prospecting line 20, Wutongzhuang mine*

According to the mine water quality testing data, the temperature and depth for deep hot water can be calculated using the formula (1) and (2). The results show that fiducial

temperature of thermal storage at mining areas is 48.98℃-87.73℃, and the groundwater circulation depth is about 2000 m.

$$T_0=4410/[13.95-\lg(K^2/\mathrm{Mg})]-273.15 \quad (1)$$

$$T_0=1309/[5.19-\lg(\mathrm{SiO_2})]-273.15 \quad (2)$$

T_0 is the depth, m. K^+, Mg^{2+} and SiO_2 are the ion content in the limestone respectively, mg/L.

Karst water in Ordovician limestone gets heat and the temperature rises to 35 ℃-49.5 ℃ in the deep zone, when it flows upward, heat water temperature of Daqing, Shanfuqing, Yeqing limestone and sandstone aquifer under coal seam No.2 rise to 33 ℃-41.4 ℃, 31 ℃-39.9 ℃, 37.5 ℃-43.5 ℃ and 21 ℃-33.4 ℃ successively. Therefore, groundwater become an important carrier for conduction upward in deep geothermy.

According to drilling data, the Cenozoic thickness is about 100-200 m, overburden composed of loose layers with low thermal conductivity greatly hinder heat conduction toward surface, so the heat gathers and preserves in the heat storage layers.

In conclusion, semi-closed thermal storage unit, the good heat reservoir structure with Ordovician limestone and thin multilayer limestones, thick overburden with good thermal-protective overlie coal measures, all these can constitute macroscopically a complete thermal storage unit for the mine. Underground water, which is carrier with good conduction, makes a deep circulation to be heated, flows along vertical structure channels, such as the active faults, paleo-sinkholes, fractures zone or folds axis, etc., rises upward to the mining areas, and results in mine geothermal anomalies.

The main influence factors of heat hazard in hydrothermal mine

There are many factors for heat hazard in mines. Those factors, including changes of the atmospheric state, air self-compression heating, the exothermic mechanical or electrical equipments, and exothermic oxidation, etc., have little influence on hydrothermal mines, the primary effect factors are as follows:

(1) Igneous activity. Coal bedrocks had been invaded by igneous activity, which have heat ability to provide radioactivity heat or remaining heat in cooling down.

(2) Geological structure. Relatively independent-enclosed fields are formed by horst structures and base bulge. Three layers of thermal storage structure, i.e., coal seams, overburden with heat sealing characteristic, thermal storage layers under the coal seams.

(3) Hydrogeological condition. Groundwater moves slowly and circulates deeply in the closed groundwater system.

(4) Vertical pathway. Vertical structures, such as faults, Paleo-sinkholes, develop as water pathways, and groundwater vertical deep circulation is obvious because it is blocked in the horizontal movement.

(5) Base fluctuation and fold structure. High thermal conduction formation in the raised areas have created favorable conditions for geothermal flow conduction, thus resulting in geothermy to flow to the raised area gather there (Fig. 2), where higher temperature is easier to form. Thermal conductivity along strata is higher than that cross them. Therefore, on the same level, geothermal and warming rate at base bulge or anticline are higher than adjacent depression part or syncline. It is reflected that temperature contours are consistent with stratigraphic trend.

(6) Rock thermal conductivity

Dense and hard crystalline rocks which have good thermal conductivity and small warming rates, often show negative geothermal anomalies, soft non-crystalline rocks often as positive anomalies conversely. In the Carboniferous and Permian coal bearing strata, heat

conductivity of dolomite in limestone, sandstone, shale, coal, loose or soft layer, is from high to low.

Prevention and control for hydrothermal disasters in hydrothermal mines

The deep geothermy is the fundamental heat source of the geothermal injury in this kind of hydrothermal mine, but underground hot water is the direct heat source. Airflow heated directly by hot water influxing into the mining space and indirectly by surrounding rocks, are the main reasons for thermal anomalies in the mine. So the key for reducing the airflow temperature is to control and treat hot water.

(1) Comprehensive utilization of hot water draining advanced. Hot water dewatering advanced in the high-temperature center can not only control water-inrush and heat diffusion in mine, but also reduce groundwater temperature because of accelerated circulation, it can be used as heat source, also treated as domestic water to achieve comprehensive utilization of water discharge combination with supply.

Two boreholes in roadway along the Wutongzhuang anticlinal axis were selected to drain water, which was pump directly to ground as the source for air conditioning system.

(2) The direct and indirect heat sources cut in the deep vertical structure by grouting. Water pathways to be cut off from Ordovician limestone by grouting can not only eliminate the threat of water inrush but also prevent the formation of geothermal disasters.

The main channels of limestone water in Wutongzhuang mine are paleo-sinkholes. It has achieved very significant results by grouting in the bottom of paleo-sinkholes at roadways and ground.

(3) Grouting into the floor can control the water inrush and thermal damage together. Generally, the distance between coal seams and Ordovician limestone or thin limestones is short, high pressure water from Ordovician limestone can bring not only water inrush threaten but also the thermal damage. So, water impermeable ability for aquifuge in working face floor is key.

The aquifer transformation in the floor was used in Wutongzhuang mine. Yeqing limestone aquifer which is approximately 40 m under the coal seam No.2 was selected to transform as aquifuge, and the same time faults and weaknesses focused on and filled by grouting at a large area of floor.

With implementing measures, especially draining hot water ahead, grouting karst paleo-sinkholes, and grouting a large area floor reinforced, the mine water has been controlled and thermal damage improved significantly, the mine inflow reduce from 17.5 m^3/min to 4.5 m^3/min, the temperature is below the critical temperature 26 ℃ of the working environment in almost everywhere of the mine.

Conclusion

(1) The local heat from crust, radioactive decay heat from magmatic activity, remaining heat of magma, are sources and necessary conditions, and deep groundwater circulations which are the geothermal media and carrier, are sufficient conditions for the formation of geothermal disasters in the mine.
(2) The main factors of geothermal disasters, including magmatic activity, closed thermal storage structure, deep water circulation, vertically water (hot) pathways, base bulge and anticlinal folds, rocks thermal differences and so on.

(3) Making comprehensive utilization for hot water draining ahead, grouting the deep vertical structure to prevent water upwelling, are the valid ways to prevent and control the water inrush threat and geothermal damage together.

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