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THE EXPERT SYSTEM OF MINE HYDROGEOLOGY

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Abstract Based on absorbing expert knowledge adequately, the expert system of nonferrous metal mine hydrogeologic evaluation was developed. It has five major functions: managing information, judging water—replenishment type of ore deposits, predicting water—make, classifying the degree of complexity of hydrogeologic conditions, and giving the suggestions for water—proof and water—control measures. The practical cases have identified that this system is of fairly high reliability and canhelp hydrogeologists effectively to evaluate the hydrogeologic condition and to select the water-proofplan.

Key words expert system; hydrogeology; mine; Computer application

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Groundwater, which may trigger many environ—mental geology problems, should certainly be taken into consideration in Mining. It is the concern of many scholars how to deal with the influence of ground water on mining so as to give a reasonable suggestion to relieve the damage of mining to environment. Based on analyzing the feasibility of applying the expert system to mine hydrogeologic research, this essay explicates the fundamental theory and technical method etc. of the system, and illustrates practical examples of mine waterproof to check the capability of the system.

1 THE FEASIBILITY OF INTRODUCTION OF THE EXPERT SYSTEM

1.1 The method of mine hydrogeologic analysis and the expert system

Appearance and evolution of water gushing is not an isolate phenomenon, hilt has its internal causality with hydrogeologic conditions. For example, if the water—holding capacity of the top and bottom rock strata of mine gallery is fairly large and there is a certain hydraulic connection between surface water and ground water, the water—make is usually large and hydrogeologic conditions are complex certainly. When we analyze a practical problem, we often use this causal relation by assumed ratiocination "if certain conditions exist, then certain results will be created" to work out the problem. Of course, this kind of analysis is often divided into different levels of importance. So, when we dispose abstractly of the mine hydrogeologic features, we can obtain a series of "if … then …" ratiocinative networks. Obviously, this kind of network is really the same as the network through which the expert system analyzes and resolves problem. In expert system, this assumed ratiocination is called "rule". Based on these rules, the

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expert system can identify and analyze the practical problem, and give the conclusion.

1.2 Experience, analog and expert system

Sometimes, the mine hydrogeologic problems being researched are very complex. With implicit hydrogeologic phenomenona and conditions, incomplete date, or too many other restrictive factors, it is difficult to evaluate the functions and reliabilities of them correctly. In this case, the analysis results depend largely on the worker' s experience and skillful hydrogeologists often resolve problems successfully through analog analysis. Of course, in analog analysis of the subjects being analogued, the more conditions are analogous, the less difference between the factors there is, and the more engineering types and practical knowledge we have, then the more accurate the answer to the problem will be. So it is necessary to possess a lot of information and data to compare with practical problems rapidly. Apparently, computer is very fit for this work. By founding a corresponding data base, absorbing research cases, data and expert experience broadly, the expert system is competent for analog work.

2 THE EXPRESSION METHOD OF KNOWLEDGE

In practical work, we often use assumed ratiocination to analyze problems. The same, if we generalize mine hydrogeologic features, we can also gain a series of orderly ratiocinative networks. If we involve these networks into the expert system' s "ratiocination machine" (the shell of the expert system), we can then do identification, analysis, and give conclusion to a concrete problem. So, we often call this kind of ratiocinative network as "knowledge bank". With the help of some ready—made expert system shells, we can then develope an expert system for a certain field. In developing this system, we mainly selected the CM. 1 expert system shell, Which has four major features: To have logic ratiocinative capability reflecting qualitative and quantitative thought; To have reliability ratiocinative capability reflecting fuzzy thought; To have default ratiocinative capability reflecting expert' s subjective intuition on certain specialty; To have random ratiocinative capability reflecting probability thought. So, the central task of developing this system is to found the knowledge bank, that is, to decompose the course of hydrogeologic analysis into a series of assumed ratiocinations, which are expressed by rule. The rule' s basic form is shown as:

IF condition 1, condition 2, …, condition n

THEN conclusion 1 credibility 1, …, conclusion n credibility n

In which, credibility is mainly used in indefinite facts, knowledge or experience, and the credibility of the conclusions may be drawn from the credibility of indefinite facts, knowledge or experience by credibility calculation. The knowledge bank is made up of rules, and its expression is shown as:

(rule 1, rule 2, rule 3, …, rule n)

3 THE ESSENTIAL OF SYSTEM DEVELOPMENT

3.1 Guiding principle

The system development takes the safety during mining as precondition. It is a central task to find out the water source, water passage, water—gushing strength, water—make, classify the degree of complexity of mine hydrogeologic conditions, and give the suggestions of the water—proof and water—control measures. So, we put emphasis on the analysis, evaluation and classification of the complexity degree of mine hydrogeologic conditions, Which guide the discussion of the other problems. This system solves mainly several mine hydrogeologic problems as followed:

1) Deciding the mineral deposit water—replenish—ment conditions: Mainly including water source, passage, boundary, type of water—replenishment, etc, which are basic problems in mine hydrogeologic evaluation.

2) Determining the characters of aquifer bed and water abundance

3) Predicting water—make

4) Classifying the complexity degree of mine hydrogeologic conditions

5) Giving the suggestions of water—proof and water—control measures

3. 2 The basic principles of system developing

In order to facilitate the mine hydrogeologic work, to evaluate the alone hydrogeologic conditions and to solve the mine hydrogeologic problems with this expert system, in the course of system develop—ing, we followed these principles:

1) The system knowledge comes from the theoretic analysis, expert experience and engineering cases.

To build the expert system, the most importan thing is to make knowledge bank hold enough information as much as possible. The information should come from three aspects: the theoretic analysis, expert experience and engineering cases. Certainly, the knowledge of these three aspects should not only help lead to a conclusion individually, but also give the comprehensive conclusion according to their respective capability of solving problem, that is, credibility. The more knowledge the expert system has, the more "authoritive" the conclusion given by the expert system will be.

2) Introducing the viewpoint of engineering geomechanics

The expert system combined comprehensively with the knowledge of theoretic analysis, expert experience and engineering cases will inevitably meet the problem of how to harmonize its three aspects. To solve this problem, an analyzing model, or a physical model simulating the creation, development and evolution of the problem must be built. Within the limits of the model, the three aspects can supplement instead of contradicting each other. A basic point of building such kind of analyzing model is to introduce the viewpoint of engineering geomechanics.

After studying some mine hydrogeologic information, we discover that the most important work in mine hydrogeologic analysis is to find out the distribution and characters of water migration passage, that is, the structural developing state in geologic body, which is just the basic viewpoint of engineering geomechanics. So, the viewpoint of engineering geomechanics reveals the substance of mine hydrogeologic problems.

3) Bringing in the viewpoint of system engineering

There are many factors mutually affecting the mine hydrogeologic problems. How to consider these factors and their interaction thoroughly and synthetically? This is a concrete application of the system engineering analysis. It will help reveal the physical substance of mine hydrogeologic problems to bring in the viewpoint of system engineering analysis and to syncretize it with the viewpoint of engineering geomechanics, thereby, all factors and their interaction can be considered thoroughly.

4) The system should have good "man—machine interface" ability

To study the problems, besides owning abundant knowledge, the expert system should be good at getting information from users, answering the questions of users and conducting users to supply the concerned information. That means it must be able to "exchange information" effectively with users. This inevitably needs the system to have a good "man—machine interaction" function.

3. 3 The structure chart of the expert system

In order to solve the five problems mentioned above the system uses chain—structure which chains the solution of the five problems into a unit (Fig. 1). The formers offer the proof to the latters and the latters do analysis and ratiocination with some additional knowledge on the basis of the conclusion drawn by the analysis of the formers. At the same time, the system set up a fundamental information bank specially so as to avoid repetitive input of the fundamental information of the same mine.

4 CASE STUDY

4. 1 The data

An ore district lies in the south limb of HuajiaHu syncline, the marginal hill country of Huajiahu basin. Relief is flat.

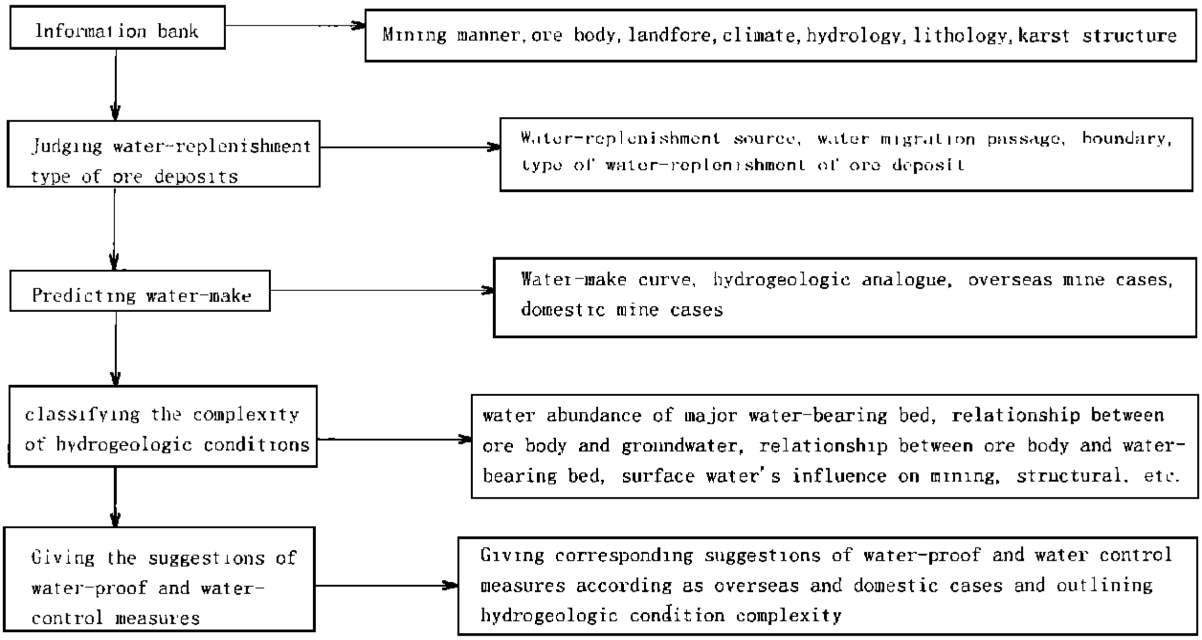

Fig. 1 Structure and flow chart of the expert system

1) The geology and hydrogeology of mineral district

Landform of mineral district: the relief is high in the south and low in the north. The south, east and west of the ore district are surrounded with the hill made up of limestone and quartz diorite, and the mid—dle is covered with the quartz diorite monadnock weathered (Q_4). Relief is inclined to the lake with a gradient of 5‰. The highest point lies in the south, and its elevation is 748 m. The lowest point lies in the side of lake, and its elevation is 20 m. The elevation of the ore district is 24.6 m.

Hydroclimatic conditions: The multi—year average rainfall in ore district is 1399 mm, rainfall concentrating mostly in the range of March to August every year (possessing 74.2% of the whole—year rainfall). The evaporation rate is large than rainfall.

Surface water mass: the lake lies in the northeast side of ore district. Under perennial water level, the lake's edge line is 1.2 km from the ore district. The Highest water level is 22.02 m in 1954 while the majority of mineral district was submerged. The intermittent stream, about 300 m away from the east edge line of mineral district, flows into the lake from the south to the north, and the volume is $0\sim2.1772\times10^4\ m^3/d$.

The lithology of ore district and its periphery area: the distributing strata are Silurian shale, Devonian quartz sandstone, Carboniferous Huanglong and Chuanshan limestone, Permian Xixia, Maokou and Changxi limestone, Triassic limestone. Late Yanshan, magmatic rock intrudes in stock and inter—penetrates in the Triassic limestone in mineral district.

Structural geology setting: the mineral district lies in the east side raising end of secondary syncline in the south side of areal second—order overturned anticline and the west side of leaflike overturned syncline. The north limbs of two synclines (Maokou Daye limestone) constitute hanging wall of orebody. The areal faults produced with the areal fold at the same time are mostly in NWW and NW trend. Its structural fractured zone is Intruded with magma. The secondary faults are in NNW and NE trend. For Example, fracture F_1 is a buried reversed fault, and its trend is N60W. It is about 500 m long and dissects the northeast side of orebody. The trend of fracture F_2 is N40E. It lies in the southeast side of orebody about 600 m long, and its behavior is unknown.

The major water—bearing bed and karst: there are different hydraulic contacts between karstificated rocks of different ages. Those rocks form a unitive hydrous system. $q = 0 \sim 4.52$ L/s. The linear karstification ratio of the marble is 0.27 %. Karst develops mainly in shallow rock formation which is higher than elevation—25 m, and does more in the orebearing contact zone and both sides of structural belt in which the linear karstification ratio increases to 1.75 %, and the hight can reach—3.56 m. The solution cave develops with great diversity in filling degree. Its filling ratio is 10%—91 %, Within the affecting range of mining drainage, the area of emerged limestone is 3 km^2.

The vallery area distributes the Quaternary sediments which is 11.8 ~ 23.5 m thick. From top to bottom, they are silty, sandy gravel, and clay. At the bottom, the clay absents in part along the river bed, and the sandy gravel covers on the marbel (or limestone) directly. At the present, the stream leaks greatly, and the Quaternary filtration coefficient k is 6.8 m/d. So, there is a certain hydraulic connection between the stream and mine gallery groundwater.

At the east side of mining area and the west side of the stream, there are some ascending spring, whose discharge is 16.88 ~ 73.23 L/s. When pumped from group—bore, spring discharge reduces one third.

Structural zone, contact zone, NW and NWW Karstificated fault zone are relatively transmissibility zone.

The minor water—bearing bed are rock mass and orebody. $q = 0.087 \sim 0.1109$ L/s, $k = 0.0864 \sim 0.1099$ m/s.

2) Other information of ore district

The mine was designed in 1966, and was put into trial production in 1970. In 1970 ~ 1973, the water—make was $1.2 \times 10^4 \sim 2.4 \times 10^4$ m^3/d. The mining area was flooded three times by water gushing. The Maximum water gushing reached 6.24×10^4 m^3/d. The Maximum water—discharge was 3.7×10^4 m^3/d while the falling depth of groundwater level increased to 92.35 m during mine gallery drainage test in 1973 ~ 1974.

The practical water—discharge in II —level (—60 m) is 2.9688×10^4 m^3/d. At present, the ground collapses frequently, and stream water fills in it.

3) The major conclusions

The water—impregnated strata are mostly karstificated water—bearing bed; Karstificated marble roof is a major aquifer; The mine hydrogeologic condition is of complex type; There is a water—resisting magmatic rock (aquifuge) which extends in NWW trend and cuts off the water passage in the south; The quartz diorite and sharn form a local aquifuge which limits the water replenishment in the west; There are some big springs in the karstificated limestone in the east which is the major recharging passage of groundwater; The Silurian marble in the north is a aquifuge. All these form the water replenishment boundary that recharges water from one direction and resists water in the other directions.

4.2 Consulting results by expert system

The consulting conclusions by expert system see Table 1.

From the table 1, the consulting conclusions tally with the case in general, and the results are reasonable and creditable. So, this expert system completely possesses the ability of mine hydrogeologic evaluation.

5 CONCLUSIONS

This expert system of mine hydrogeologic evaluation has 46 modules and more than 1 260 rules in all. It has five major functions. So, it belongs to fairly large expert system. The practical cases have identified that this system is of fairly high reliability and can help hydrogeologists effectively to evaluate the hydrogeologic condition and to select the waterproof plan. Of course, there are some problems to be further solved in this expert system. For instance, there is a lack of self—learning ability that some ripe conclusions can be absorbed into the knowledge bank of system—self, which is also a difficulty in the course of developing all kinds of expert system currently. Furthermore it is necessary for this system to be checked up and improved.

Table 1 Consulting results by the expert system

Item	Conclusion	Credibility %	Evaluation
Water source	Meteoric water Surface water ground water	60 93 86	The major water repleishment source is surface water, and the minor is ground water. This conclusion answers to the true case
Water migration passage	Permeable pore Permeable karst passageway	95 80	This conclusion answers to the true case for Quaternary loose accumulation and the karstificated marble possess permeable pore or karst passageway.
Boundary condition	Intensive permeability from one direction Intensive water-bearing roof	93 72	This conclusion answers to the true case
The type of water replenishment of ore deposit	Karst water Pore water Pore-karst complex water	76 36 91	This conclusion answers to the true case
The water abundance of water-bearing bed	Great water-rich	91	This conclusion answers to the true case
Water-make prediction			There is a certain difference between the result and the case because of the lack of many data needed.
The judgment of hydrogeology complexity	Complexity Great complexity Middle complexity Minor complexity	89 76 60 65	Complex and tending to greatly complex. this conclusion answers to the true case

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矿山水文地质评价专家系统

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摘 要 在充分吸收专家知识的基础上, 开发了有色金属矿山水文地质评价专家系统, 并用一些矿山水文地质实例对系统进行了检验。系统以查清矿床充水条件(矿坑涌水水源、通道、边界条件、充水类型等)、涌水量预测以及矿山水文地质工作的复杂程度划分、矿山防治水措施建议为研制主线。主要遵循以下几条原则: 1. 专家知识主要包括理论分析成果、人类专家经验、被实践证实是行之有效的工作方法以及大量的工程实例; 2 基于工程地质力学的观点, 建立问题的分析模型, 从而使上述三方面的知识互相补充, 而不至相互矛盾; 3. 引入系统工程的观点, 以全面分析影响矿山水文地质问题的各种因素及其相互之间的作用。系统共有 1260 余条规则, 拥有五大功能: 信息管理、判定矿床充水条件、矿坑涌水量预测、矿山水文地质复杂等级划分、防治水方案建议。运用该系统可以对矿山水文地质工作进行咨询、对矿山水文地质条件进行评价、对矿山水文地质问题进行解答。

关键词 专家系统; 计算机应用; 水文地质; 矿山