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Influence of Geological Factors on the Economic Benefits of Coalbed Methane Development

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Abstract: China has abundant CBM resource, due to technical restraints, not all CBM resources are suitable for development. In that case, one crucial problem faced by the decision makers is how to select the CBM areas which suit best for further exploration and development. In different kinds of optimal selection methods, geological factors play an important role. Generally, geological factors are scored by expert estimation, in order to determine each of their weights in the optimal selection. However, the treatment of weight determination for those factors is rather subjective, lacking objective basis. For that matter, this study analyzes the correlation between NPV and four geological factors, aiming at finding their influences on economic results of CBM development. The study will provide an objective basis for determining the weight for each geological factor in CBM enriched areas optimal selection.

Key words: Coalbed methane, geological factors, economic evaluation

INTRODUCTION

China is abundant with CBM resources, however, not all of them can bring economic benefits due to present technical restraints. For optimal selection of such multi-factor systems as CBM enriched areas, quantitative sequencing method is commonly used (Gui, 2004). Weighing is the most crucial part in optimal selection. Most present researches relay on expert scoring method or Analytic Hierarchy Process (AHP) to determine the weight for each of the geological factors (Wang *et al*., 2008). However, they are both influenced by experts' subjective judgments, reducing the result's objectiveness. Thus, it is necessary to provide an objective method to determine the weight of geological factors, in order to reach more accurate results. Since the aim of optimal selection is to select the most economic areas under integrated conditions, it is appropriate to analyze the economic contributions of each geological factor to determine their importance in CBM development. By identifying the importance of the geological factors in CBM development, it will provide theoretical basis for determining the weights for the geological factors, reducing errors in subjective judgments and therefore promoting the accuracy in CBM enriched areas' optimal selection.

APPRAISAL OF GEOLOGICAL INFLUENCES ON THE ECONOMIC BENEFITS OF CBM DEVELOPMENT

Many methods are applied in the economic evaluation of CBM development, among which the NPV method is widely used (Zhang *et al*., 2009). As a dynamic evaluation method, net present value method has been widely applied in economic evaluation practice in oil and gas industry. Not only can it reflect the time value of capital, but also it is easy to operate. This study adopts the NPV method to evaluate the economic benefits of a project. Thus, the appraisal of geological influences on CBM development is mainly analyzing correlation between the geological factors and NPV.

Method in defining the relativeness between geological factors and NPV: The analysis aims at measuring the strength of correlation between NPV and the geological factors that influence it, rather than predicting the level of NPV using those factors. Thus, correlation analysis should be applied. Since NPV is influenced by many factors. While leveraging the idea of partial correlation analysis, we use actual data and SPSS to test different kinds of correlations to find the one which may actually exist among the variables. The conclusion is reached by comparing the coefficient of all kinds of correlations.

Selection of geological factors: A CBM enriched area is the necessary condition for an ideal CBM production target. The enriched area depends on many factors, such as coal rank, underground coal seam area, coal seam thickness, buried depth, gas content, gas saturation, permeability, reservoir pressure and critical desorption pressure, etc. (Wang *et al*., 2006). All those factors together determine the original volume of CBM reserves, capacity input and resource development efficiency.

Those factors are divided but connected, affecting NPV to different extents. However, in a specific appraisal,

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it is unlikely to take all factors into consideration or to define each of their degree of influence on NPV. Therefore, the chosen factors should be relatively independent from one another while operable and applicable at the same time. When choosing the factors, both the comprehensiveness and the science of the appraisal should be considered.

The appraisal parameters are divided by Su Fuyi into 49 items and classified into 7 groups, among which, coal seam thickness, gas content and permeability are believed to be the major ones. Zhao Qingbo, etc. suggested that coal rank (Rmax), buried depth, gas saturation and underground coal seam area are also important (Zhao and Zhang, 1999). This study takes coal rank, coal seam thickness, gas content, gas saturation, buried depth and gas bearing area, as the major geological factors in the optimal selection process.

Coal rank can greatly influence a CBM project's economic result. When the coal rank is not too high or too low, higher coal rank is good for commercial development. However, this relationship is not definite. Practically, when other conditions are met, coalbed of any coal rank could be economic. Since coal rank does not definitely influence the economic result, plus its lacking in operability, this study chooses not to analyze it. Furthermore, coalbed gas can only form under a given thickness of coal bed. A thicker coalbed has a positive influence on coal bed gas reserves. However, coalbed thickness is valued under both one-layer thickness and accumulative thickness. In practice, the data of coal thickness is hard to collect. Thus, this study chooses not to analyze it.

After comprehensive analysis, four geological factors, respectively gas bearing area, buried depth, permeability and gas content are taken as the main influencing factors (Luo *et al*., 2011), to explore their correlation with NPV.

Sample data processing: CBM target area, the basic space unit of CBM exploration and development, refers to the current known areas rich in CBM. Appraisal of CBM development based on the target area is a crucial task. China is rich in CBM resources, with numerous CBM target areas. Target areas (mining areas) widely differ in resource conditions, development conditions and other relevant conditions, manifested by differences in geological conditions, resource scales, geographical locations and basic conditions for CBM development etc. In all the 56 gas zones countrywide, there are around 85 target areas. Excluding those that apparently lack development prospects, we take the remaining 61 target areas as the sample for further analysis (Cienfuegos and Loredo, 2010).

After identifying 61 main CBM target areas (Daqingshan, Xuanxia, Xinglong, Kailuan, etc.) in China and filtering out those with unavailable geological factors, 40 of them were finally chosen. As NPV is also influenced by the scale of CBM resources, the selection of samples is also determined by resource scale (Yang *et al*., 2008).

Furthermore, to comprehensively understand both linear and non-linear correlations between geological factors and NPV, according to the theory of partial correlation analysis, some measures are taken to control other factors in a specific range (using median to divide the intervals), thus the net correlation between one specific geological factor with NPV can be properly analyzed.

DATA ANALYSIS AND RESULTS

NPV and gas bearing area: To some extent, gas bearing area determines CBM resources quantity. For a target area, a larger coal seam area will result, ceteris paribus, in a larger resource quantity and in due course, a larger development scale, a longer production life and thus better economic benefits.

When studying the correlation between NPV and gas bearing area, the other three factors (buried depth, permeability and gas content) are set in an interval, shown in Fig. 1. The sample data is standardized before it is input into SPSS for correlation analysis (linear and non-linear). Please note that this kind of measure for sample data is also applied in subsequent sections. The output is shown in Table 1.

As shown in Table 1, the level of R square indicates a strong correlation between NPV and gas bearing area, significant in logarithmic relationship with 80.4% degree of correlation. F-value is 20.55 which indicates the sample can significantly represent the general trend, with the significance level way lower than 0.01 and the confidence level greater than 99%. The value of b is positive which indicates a positive correlation between

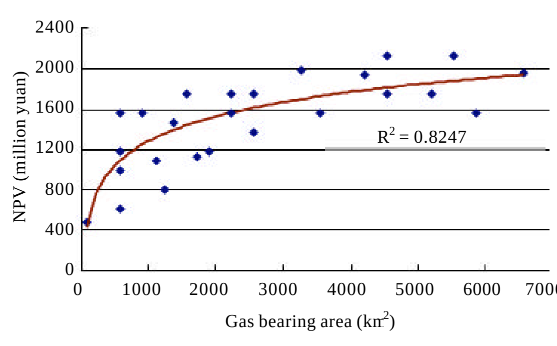

Fig. 1: Scatter diagram of NPV and gas bearing area

Table 1: Correlation model of NPV and gas bearing area, estimated parameters

Dependent variable: NPV (standardized)

	Correlation model			Estimated parameters	
Formation	R square	F	Sig.	Constant	b
Linear	0.528	5.603	0.064	0.61	0.247
Log	0.804	20.555	0.006	0.784	0.058
Compound	0.478	4.573	0.085	0.608	1.446
Power	0.823	23.243	0.005	0.797	0.092
S	0.706	12.031	0.018	-0.357	-0.003
Growth	0.478	4.573	0.085	-0.498	0.369
Exponent	0.478	4.573	0.085	0.608	0.369

Independent variable: gas bearing area (standardized)

Table 2: Correlation model of NPV and buried depth, estimated parameters

Dependent variable: NPV (standardized)

	Correlation model			Estimated parameters	
Formation	R square	F	Sig.	Constant	b
Linear	0.68	14.851	0.006	0.753	-0.483
Log	0.721	18.102	0.004	0.333	-0.211
Compound	0.752	21.282	0.002	0.786	0.400
Power	0.786	25.684	0.001	0.355	-0.397
S	0.791	26.550	0.001	-1.091	0.145
Growth	0.752	21.282	0.002	-0.241	-0.915
Exponent	0.752	21.282	0.002	0.786	-0.915

Independent variable: gas bearing area (standardized)

NPV and gas bearing area. A larger gas bearing area will result in, ceteris paribus, a higher NPV and meanwhile a slower NPV growth rate, as shown in Fig. 1.

NPV and buried depth: The factor of buried depth affects CBM reserves in two dimensions. First, gas component and gas content in the coal seam exhibit vertical zonality. Second, since coal seam is sensitive to pressure, pore volume and permeability of the coal seam change rapidly as over-lying strata's static pressure (depth) increases. Considering the available technology and economic rationality, the buried depth of recoverable CBM is currently limited to 1500 m. Furthermore, the increase of buried depth will drive up drilling capital expenditure and operating expenses, thus influencing the economic benefits of CBM development.

The correlation between NPV and buried depth is shown in Fig. 2 and Table 2.As shown in Table 2, the level of R square indicates a strong correlation between NPV and buried depth, significant in exponent relationship with 75.2% degree of correlation. F value is 21.28 which indicates the sample can significantly represent the general trend, with the significance level way lower than 0.01 and the confidence level greater than 99%. The negative b value indicates a negative correlation between NPV and buried depth. A larger buried depth will result in, ceteris paribus, a lower NPV. The trend is also apparent in the scatter diagram in Fig. 2.

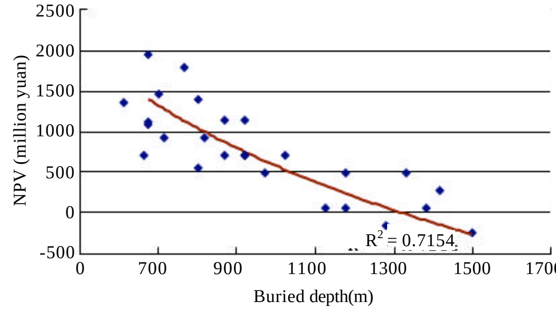

Fig. 2: Scatter diagram of NPV and buried depth

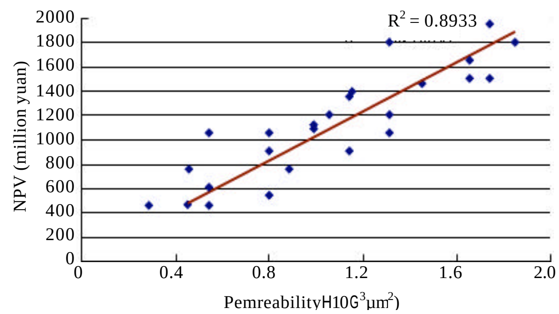

Fig. 3: Scatter diagram of NPV and permeability

NPV and permeability: Permeability which evaluates porous media's fluid flow-through ability, is a crucial factor for economic evaluation of CBM development. Permeability affects the well production dynamic fluctuation and recovering rate of a reserve. It influences gas production by the level of production peak and the timing of peaking. Coal seam with higher permeability has drainage and pressure lowering, wider pressure transmission range and as a result higher gas production and recovery rate. Coal seam is a kind of hypotonic reserve, with relatively low permeability. Generally, a higher permeability benefits the development of a CBM reserve.

Figure 3 and Table 3 show the correlation between NPV and permeability. As shown in Table 3, there is a strong correlation between NPV and permeability, significant in linear relationship with 90% degree of correlation. F-value is 43.18 which indicates the sample can significantly represent the general trend, with the significance level way lower than 0.01 and the confidence level greater than 99%. The positive value of means a positive correlation between NPV and buried depth. A larger buried depth will lead to, ceteris paribus, a lower NPV. The linear trend is also apparent in the scatter diagram in Fig. 3.

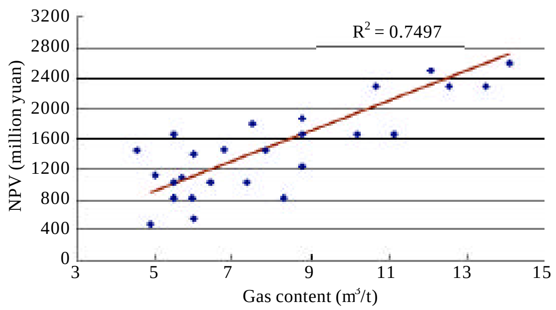

Fig. 4: Scatter diagram of NPV and gas content

Table 3: Correlation model of NPV and permeability, estimated parameters

Dependent variable: NPV (standardized)

	Correlation model			Estimated parameters	
Formation	R square	F	Sig.	Constant	b
Linear	0.896	43.180	0.001	0.432	1.649
Log	0.882	37.239	0.002	1.028	0.181
Compound	0.872	33.963	0.002	0.455	13.966
Power	0.880	36.805	0.002	1.190	0.293
S	0.773	17.050	0.009	-0.225	-0.025
Growth	0.872	33.963	0.002	-0.788	2.637
Exponent	0.872	33.963	0.002	0.455	2.637

Independent variable: gas bearing area (standardized)

Table 4: Correlation model of NPV and gas content, estimated parameters

Dependent variable: NPV (standardized)

	Correlation model			Estimated parameters	
Formation	R square	F	Sig.	Constant	b
Linear	0.75	17.987	0.005	0.567	0.574
Log	0.758	18.772	0.005	0.931	0.123
Compound	0.664	11.866	0.014	0.572	2.213
Power	0.713	14.937	0.008	0.957	0.176
S	0.513	6.331	0.046	-0.247	-0.015
Growth	0.664	11.866	0.014	-0.558	0.794
Exponent	0.664	11.866	0.014	0.572	0.794

Independent variable: gas bearing area (standardized)

NPV and gas content: Gas content of a coal seam is an important factor for the economic evaluation of CBM development. Under the same conditions, a higher gas content benefits commercial development. Gas content of CBM varies dramatically, depending on coal rank, buried depth, reservoir pressure and hydro geological conditions.

It can be seen the correlation between NPV and gas content in Fig. 4 and Table 4. As shown in Table 4, NPV and gas content are correlated, significant in logarithm relationship with 75.8% degree of correlation. F-value is 18.77 which indicates the sample can significantly represent the general trend, with the significance level way lower than 0.01 and the confidence level greater than 99%. B value is positive which indicates a positive correlation between NPV and gas content. The trend is also apparent in the scatter diagram in Fig. 4.

EXAMPLE OF THE RESEARCH

To illustrate geological factors' influences, we use the weight determination method in the selection and sequencing of 85 CBM targets.

Besides geological factors, CBM target's surface conditions and market conditions should also be considered. At first, the weights are defined by experts' subjective judgments. Using quantitative analysis, CBM targets in China are sequenced as follows Table 5 and 6.

However, there is an apparent discrepancy between the result sequences derived from expert judgment and the actual sequences derived from CNPC's production profiles in China's major CBM targets. In that case, the value of application is reduced.

On the contrary, when the weight is defined by the strength of correlation between geological factors and NPV, the sequences are derived, as follows Table 7 and 8.

Table 5: Expert Estimation of CBM Targets' Geological Factors

	Very Important		Important		Less Important		Normal	
Factor	Permeability	Gas content	Coal seam thickness	Gas bearing area	Market	Coal rank	Surface condition	Buried depth
Weight	0.2	0.2	0.15	0.15	0.1	0.1	0.05	0.05

Table 6: China's CBM Targets Sequencing

A level targets: ranking 1-10	SJB, HC, LA, DQS, ZLS, JC, LX, LPS, BD, YQ
B level targets: ranking 11-20	SJS, TF, SZ, GFS, LJ, HS-ZQ, XL, FC, XX, FT
C level targets: ranking 21-30	JZ, LL, ND, YQ, HQST, HY, ZZS, WN, FG, XW
D level targets: ranking after 30	RQG, KL, EH, LGS, PX, DC, FR, FX, HR, PB, CH, HN, etc.

Table 7: Expert estimation of cbm targets' geological factors

	Very Important		Important		Less Important		Normal	
Factor	Permeability	Gas content	Coal seam thickness	Gas bearing area	Market	Coal rank	Surface condition	Buried depth
Weight	0.25	0.2	0.15	0.12	0.1	0.07	0.05	0.05

Table 8: China's CBM Targets Sequencing

A level targets: ranking 1-10	BD, YQ, FC, HS-ZQ, LA, HC, LL, SJB, EEDS, DQS
B level targets: ranking 11-20	LPS, LZS, HN, HS, XN, XL, FC, XX, WB, FT
C level targets: ranking 21-30	JZ, JX, EH, FX, HG, HY, JZ, WN, FG, XW
D level targets: ranking after 30	RQG, ZZS, HL, SZS, LP, LC, TF, GS, LBX, HS, etc.

The result sequences accord with the actual sequences derived from CNPC's production profile. CNPC's major CBM targets, such as Baode and Yangquan, ranks high in the front. The method we use can greatly reduce subjective influences and avoid strategic decision flaws resulted by subjective mistakes (Wang *et al.*, 2002).

CONCLUSION

The correlation study shows that between NPV and the four main geological factors (gas bearing area, buried depth, permeability and gas content) respectively, the strengths of correlation are as follows: Permeability (R2 = 92%), gas bearing area (R2 = 90.1%), gas content (R2 = 75.8%) and buried depth (R2 = 75.2%). All the factors are significantly correlated under the confidence level of 99%. Among those four, the factors of permeability, gas bearing area and gas content are positively correlated to NPV while buried depth is negatively correlated to NPV. Identifying the correlation strengths will lay the ground for determining the weights of geological factors and increase the accuracy in optimal selection of CBM enriched areas. This scientific selection method will feed into CBM companies' decision making, promote rational CBM resource planning and drive rapid development of the industry in China.

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