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Evaluation of CO_2 Sequestration Suitability in Bohai Bay Basin Based on Entropy Weighted TOPSIS Approach

Xiaoting Yuan[1, 2], Xing Zhao[1, 2, *]

[1]School of Earth Science and Engineering, Xi'an Petroleum University, Xi'an 710065, China
[2]Key Laboratory of Oil and Gas Formation and Reservoir Geology, Shaanxi Province, Xi'an 710065, China
[*]Corresponding author

Abstract: CCUS (Carbon Capture, Utilization and Storage) is one of the key technologies to cope with global climate change, and an effective way to reduce greenhouse gas emissions on a large scale and mitigate global warming in the future. Therefore, the evaluation and target selection of favorable areas for CO_2 sequestration are crucial. Based on the five primary geotectonic units in the Bohai Bay Basin, i.e., Canning Rise, Liaodong Bay Depression, Bohai Central Depression, Jiyang Depression, and Huanghua Depression, the entropy-weighted TOPSIS method was used to evaluate the conditions for CO_2 storage based on the conditions of the Bohai Bay Basin, such as sedimentation (sedimentary thickness, sedimentary phases), tectonics (fracture, seismicity, etc.), storage-cover assemblage, geothermal temperature, heat flow, etc. The entropy-weighted TOPSIS method was used to evaluate the conditions for CO_2 storage. Considering the factors of geological safety, storage scale and economic appropriateness, a CO_2 storage appropriateness evaluation index system consisting of 3 first-level indexes and 11 second-level indexes is constructed, and the establishment of this index system is of reference significance for screening and determining the favorable areas of CO_2 storage in the Bohai Bay Basin. The evaluation results show that the order of CO_2 storage suitability in the Bohai Bay Basin is as follows: Huanghua depression, Bozhong depression, Liaodong Bay depression, Jiyang depression, and Canning uplift.

Keywords: Carbon dioxide storage; Bohai Bay Basin; suitability evaluation; entropy weight TOPSIS metho.

1. Introduction

At present, a series of offshore geological storage projects have been carried out both at home and abroad. In the past decades, a number of commercial-scale projects (e.g., Sleipner, InSalah, Snøhvit and Weyburn projects) have demonstrated the feasibility of CO_2 geological storage technology. since 1996, about 1 million tonnes of CO_2 have been injected into Sleipner in the Norwegian North Sea each year and stored in the Utsira Sandstone formation. The Gorgon Brackish Water Sequestration Project in Australia is a large-scale sequestration project to separate CO_2 from the Gorgon gas field and inject it into the brackish water.

The study on the suitability of CO_2 storage needs to consider the influence of multiple factors on carbon storage at the same time, and quantify the influence of different factors on carbon storage based on the degree of their influence, whereas the entropy weight-TOPSIS method (entropy weight- superiority and inferiority solution distance method) can consider multiple indicators at the same time and comprehensively assess them, and does not need to weight the indicators, so as to avoid the influence of subjectivity on the evaluation results. Therefore, this paper will evaluate the suitability of CO_2 storage in the Bohai Bay Basin by using the entropy weight-TOPSIS method on the basis of previous studies, which will provide a scientific basis for the geological storage of CO_2 in the Bohai Bay Basin at a later stage.

2. Regional Geological Profile

The Bohai Bay Basin is located in the eastern part of the North China Plateau and consists of a series of Cenozoic subsidence depressions on land and offshore, with a length of 2,600 km from north to south and a width of 1,200 km from east to west, with a total area of about $20\times104km^2$ [1]. Geographically, the basin is adjacent to the Jiao Liao uplift in the east, the Taihangshan uplift in the west, the Yu-Huai platform fold belt in the south, and the Yanshan fold belt in the north. The overall strike of the basin is NNE, and the central part is near EW, which is ‘knee-shaped’ in plan [2]. The Bohai Bay Basin covers an area of about 6×10^4 km^2, and is divided into five primary tectonic units: the Chengning Rise, the Liaodong Bay Depression, the Bohai Central Depression, the Jiyang Depression, and the Huanghua Depression.

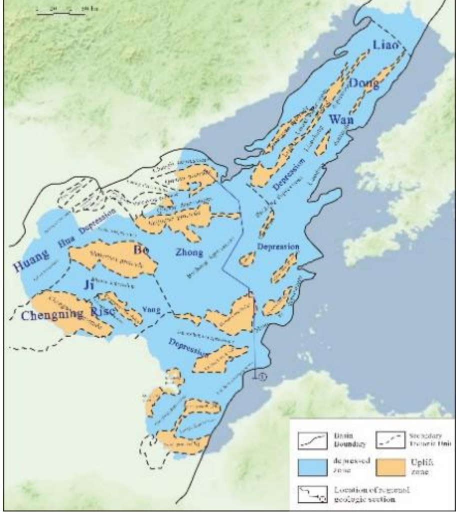

Figure 1-1. Tectonic zoning map of Bohai Bay basin (sea area)

The Bohai Bay Basin developed a discontinuous sedimentary sequence located in the non-marine phase above the crystalline basement of the North China Plate of the Taikai Dynasty (Fig 2-1), and the sedimentary strata are separated from the basement by a set of regional unconformities [3].

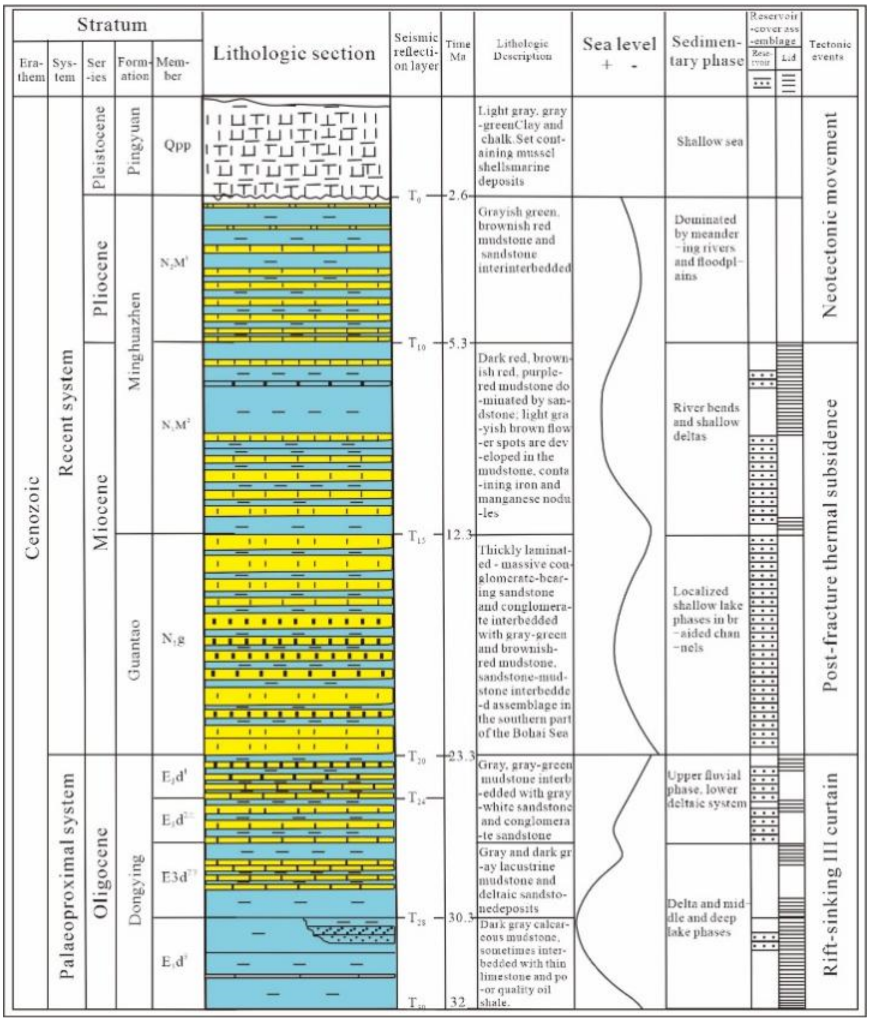

Figure 1-2. Comprehensive histogram of the Cenozoic stratigraphy of the Bohai Bay Basin (sea area) [4]

3. Analysis of Key Influencing Factors for CO_2 Geological Storage

3.1. Fractures and seismicity

The Bohai Bay Basin is located in north China, on the seismic belt of north China , and the coexistence of multiple sets of fractures is a significant feature of the main control fracture system in the Bohai Bay Basin, including the NNE-directed, NE, NW, and near EW, etc[5].

In summary, when selecting sites for CO_2 storage, major large active fracture zones and large fracture areas developed with sedimentation as well as areas with dense epicentres and high seismic magnitude should be avoided as much as possible to ensure the safety of CO_2 storage.

3.2. Stratigraphic thickness

To the Miocene, the Bohai Bay Basin entered the post-cracking thermal subsidence stage, the Guantao Formation depositional period, the Bohai Central Depression became the largest subsidence centre in the period, the overall ‘thick in the middle, surrounded by thin’ depositional characteristics [6]. Until the depositional period of the Minghuazhen Group, the sedimentary thickness gradually decreased from the two sedimentary centres to the surrounding area, and the thickness of the Neoproterozoic sedimentary system was about 400m~4500m.

3.3. Storage Lid Combination

During the depositional period of the Guantao Formation, the basin was dominated by braided-river deposition in general. The Guantao Formation mainly develops braided channels, locally there are shallow lake phase development [7-8], and the porosity of the Guantao Formation is 27.3%~33.5%, the permeability is 1089mD, it is a high porosity and high permeability type reservoir, combined with the purplish-red mudstone dominated by the lower part of the Ming stratum, it can be combined to form a complete set of thick layer reservoir cover.

3.4. Geothermal field characteristics

The Bohai Bay basin, with a temperature gradient of 35°C/km or less, is a cold basin, with only a few areas of higher temperature gradient sporadically distributed: the Liaodong Bay depression's high temperature gradient area is mainly distributed in the Liaoxi Bulge, and with the Liaoxi Bulge as the boundary, the temperature gradient in the southeast of the depression is lower than that in the north-west of the depression[9]. The overall geothermal gradient in the Bozhong depression is low, and the geothermal gradient is higher only in the Bohnan Low Bulge. The Huanghua depression (sea part) is a low-temperature depression with a low overall gradient.

4. Sequestration Suitability Evaluation

4.1. Evaluation system establishment

In this paper, the index system of the Bohai Bay Basin was established by combining the results of previous research and the geological characteristics of the Bohai Bay Basin, including 3 first-level evaluation indexes and 11 second-level evaluation indexes (Table 3-1).

Table 3-1. Grading table of D-level CO_2 geological storage suitability index criteria in Bohai Bay Basin

Level 1 indicators	Secondary indicators	desirable	More appropriate	Generally suitable	Less suitable	Unsuitable
Geological safety	Active rupture	No active fractures	Few active fractures	Fault activity is insignificant	Moderate rupture	Large rupture exists
	Seismic intensity	＜3		3~5		＞6
	Capping thickness	>100	100~50	50~30	30~10	<10
	Geothermal temperature	<30		30~40		>40
	Heat flow	50~70		70~80		>80
Reservoir size	Reservoir thickness	>100	50~80	20~50	10~20	<10
	Reservoir lithology	Clastic rocks	Mixed clastic and sandstone	Carbonate rock	Non-sedimentary rocks	Non-sedimentary rocks
	Porosity (Φ)/%	Φ≥25	15≤Φ<25	11≤Φ<15	7≤Φ<11	Φ<7
	Permeability (K)/$10^{-3}um^2$	K≥100	10≤K<100	1≤K<10	0.2≤K<1	K<0.2
Economic suitability	Offshore distance/(km)	0~100	100~200	200~300	300~400	>400
	Degree of exploration and development	3-D coverage, abundant drilling, high degree of development	More 3-D coverage and drilling, low level of development	2D coverage, few drilling	Little 2D seismic and drilling	No seismic and drilling

4.2. Evaluation results

Evaluation calculation results are shown in Table 3-2, the evaluation results ranked 1, 2 of the construction unit is suitable, ranked 3, 4 that is, general, ranked 5th is not suitable.

Table 3-2. TOPSIS Evaluation Calculations

TOPSISEvaluation Calculations				
primary tectonic unit	positive ideal solution distance D+	negative ideal solution distance D-	relative proximity C	Sorting results
Chengning uplift	2.582	1.529	0.372	5
Liaodong Bay depression	1.602	1.998	0.555	3
Bohaizhong depression	1.538	2.367	0.606	2
Jiyang depression	2.001	1.652	0.452	4
Huanghua depression	1.501	2.329	0.608	1

The evaluation results show that the order of suitability for CO_2 storage in the Bohai Bay Basin is as follows: Huanghua depression, Bozhong depression, Liaodong Bay depression, Jiyang depression and Chengning uplift. It is believed that the Huanghua depression, Bohong depression and Liaodongwan depression are more suitable for CO_2 storage than the Jiyang depression and Chengning uplift.

5. Conclude

(1) Combining the tectonic deposition and geothermal conditions of the Bohai Bay Basin, a CO_2 storage suitability evaluation index system consisting of 3 first-level indicators and 11 second-level indicators was constructed from the consideration of geological safety, storage scale and economic suitability, and the entropy-weight-TOPSIS method was used to evaluate the suitability of CO_2 storage in the Bohai Bay Basin. The results show that the suitability evaluation index system and the entropy weight-TOPSIS method established in this paper are feasible for screening favourable areas for geological CO_2 storage in the Bohai Bay Basin.

(2) From the calculated weighting results, it can be seen that stratum thickness, reservoir-cover combination and fracture factors have a more significant influence on the safety of CO_2 storage, and the weighting of geothermal temperature gradient and heat flux value is relatively low compared with other evaluation indexes.

(3) The evaluation results show that the order of CO_2 storage suitability of each level of tectonic units in the Bohai Bay Basin is as follows: Huanghua depression, Bohaizhong depression, Liaodong Bay depression, Jiyang depression, and Chengning uplift.

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