

1
2
3
4
5
6
7
8
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A multi-scale framework for selecting CO₂ storage sites in oil and gas reservoirs

Multi-scale framework for CO₂ storage site selection in oil and gas reservoirs

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Abstract

Quantified screening of sites for CO₂ geological storage is fundamental to ensuring both the economic viability and safety of CO₂ sequestration. However, existing site selection methodologies—domestically and internationally—predominantly rely on qualitative approaches. The operational indicators for storage site selection remain incomplete and lack comprehensive quantitative characterizations. In response, this study presents a comparative analysis of site selection classification schemes for aquifers located in oil and gas regions. It clarifies the stratified levels of site selection for these aquifers and proposes a corresponding site selection process, along with a robust indicator system tailored for CO₂ geological storage. Additionally, a case database for CO₂ geological storage was developed. This database integrates qualitative comparative selection with semi-quantitative screening based on analytic hierarchy process (AHP). Using this hybrid approach, the study quantitatively prioritizes favorable structural storage bodies, creating a tiered site selection methodology. This method enables three-dimensional identification, extraction, and potential evaluation of structural formation suitable for CO₂ storage using geological modelling. The approach has been successfully applied to aquifer site selection in the oil field A, providing prioritized targets for CO₂ storage site selection across different aquifer levels. This stratified site selection framework lays a solid foundation for large-scale CO₂ geological storage. It is of critical importance for conducting comprehensive research and field demonstrations of carbon capture, utilization, and storage (CCUS) technologies. Moreover, it supports the advancement of national dual-carbon objectives.

Introduction

Carbon capture, utilization, and storage (CCUS) technology represents one of the most pivotal strategies for addressing global climate change. Currently, there is a clear trend toward forming clusters within the global carbon capture and storage (CCS)/CCUS industry. Research and development efforts are accelerating, with projects reaching million-ton and even ten-million-ton scales (Fig 1). As a result, the storage capacity across different countries has significantly expanded. The large-scale geological storage and utilization of CO₂ have emerged as core components in the industrialization of CCUS. Therefore, choosing appropriate storage sites is critical in minimizing engineering costs and ensuring both the safety and long-term stability of storage projects. In the context of the dual-carbon goals, the clear identification of geological storage locations for CO₂, along with the establishment of robust site selection methodologies, is essential. These efforts are instrumental in promoting the large-scale development of CO₂ geological storage sites. This study focuses specifically on aquifers located within oil and gas regions as potential storage sites. It develops a systematic site selection process for CO₂ geological storage and identifies a set of key indicators and boundary conditions that guide the selection criteria. Based on these parameters, a specialized method, tailored to aquifers in oil and gas fields, was established. Furthermore, the proposed method has been applied to the site selection process for an aquifer within Field A (anonymous). This application provides a practical foundation for the scaled implementation of geological CO₂ storage.

Fig 1. Global CO₂ storage capacity distribution map.

In the context of CO₂ geological storage, the selection of appropriate storage sites is crucial to ensuring that the storage process is economically efficient and reliably secure. As an innovative approach to combating global climate change, CO₂ geological storage has attracted considerable

attention from scholars worldwide over the past two decades. Numerous site selection and assessment methodologies have been proposed to guide the practical identification and evaluation of suitable storage locations. The evolution of site selection methods in CO₂ geological storage can generally be categorized into three main stages:

Early Stage: This stage was initially characterized by the basin-level screening approach proposed by Bachu in 2003 [1]. This method incorporated 15 indicators, including basin characteristics, resource availability, and societal factors. These indicators were applicable at both national and basin-level scales for preliminary site screening. The method was noted for its simplicity, ease of application, and operational effectiveness. Subsequent basin-level selection methodologies were largely refinements or updates based on this fundamental approach. In addition, the CO₂ capture, transport, and storage guidelines by Det Norske Veritas (2009) [2] and the World Resources Institute (2008) [3] introduced conceptual frameworks for site characterization and selection.

Development Stage: Around 2004, the Intergovernmental Panel on Climate Change report introduced relevant screening indicators. The Carbon Sequestration Leadership Forum and the European Union's Best Practice Manual became primary references for evaluating and selecting storage sites. Chadwick et al. [4] selected sites based on 11 indicators across three dimensions: reservoir effectiveness (considering both dynamic and static capacities), reservoir characteristics, and caprock integrity. Indicators were categorized into two categories: disqualifying indicators and site-qualification indicators. This approach addressed storage optimization, risk minimization, regulatory compliance, and socio-economic considerations. Moreover, it employed geographic information system tools to assist in identifying potential storage sites.

Mature Stage: In 2011, Technical Committee 265 of the International Organization for

Standardization established international standards for CO₂ storage, which included certain screening elements. However, the precision of these parameters is insufficient to accommodate extensive screening processes. After 2012, several institutions—including PetroChina, Sinopec, and geological survey bureaus—proposed a range of classification schemes. For instance, Shen and Liao [5] at PetroChina introduced a general screening standard and evaluation method for CO₂ geological storage. This framework incorporated 23 indicators and aimed to quantify key factors wherever possible, establishing a reasonable range of values applicable to CO₂ geological storage targets. Similarly, Sinopec achieved notable progress in CO₂-enhanced oil recovery, developing an indicator system specifically for screening and evaluating potential in complex, faulted oil reservoirs influenced by CO₂ injection [6,7].

In summary, current site selection methodologies predominantly rely on qualitative and semi-quantitative approaches [8–11]. These include analogical reasoning, expert evaluation, and multi-criteria decision-making. However, several deficiencies remain—particularly in critical algorithmic research areas, including case analogy, optimization of evaluation indicator systems, and the determination of indicator weights. This study addresses CO₂ geological storage site selection criteria in aquifers located within oil and gas regions. Based on four storage principles—confinement, injectivity, capacity, and safety—the site selection process is structured into three main stages: (1) comparative case analysis, (2) hierarchical analysis screening based on analytic hierarchy process (AHP), and (3) preferential selection of favorable geological formations for CO₂ storage. This structured approach supports a transition from qualitative to more quantitative methodologies in selecting CO₂ geological storage sites. Moreover, it provides novel perspectives and strategic directions for implementing geological storage in aquifers within oil and gas regions.

Method

Scale division and site selection process

No ethical approval or informed consent was required for this study, as it does not involve human participants, animals, or personal data. An oil and gas region refers to the subsurface space within a designated oil and gas mining area. This area encompasses not only the oil and gas reservoirs but also the overlying and underlying stratigraphic intervals, including oil-bearing, gas-bearing, and water-bearing layers. Aquifers located within these regions are considered advantageous for CO₂ geological storage.

Site selection stages and scales

The development of CO₂ geological storage in aquifers within oil and gas regions progresses through two main stages: the **evaluation phase** and the **operational phase**. Correspondingly, the site selection process is categorized into three spatial scales: **basin level**, **structural trap level**, and the **site-specific level**. The basin level pertains to extensive oil and gas basins, such as China's Songliao Basin and Bohai Bay Basin. These basins are principal zones for the accumulation of oil, gas, and aquifers and serve as focal areas for the clustered development of carbon storage initiatives. The structural trap level pertains to the third-order structural units within a basin. These units are fundamental to both oil field development and CO₂ geological storage identification. Examples include anticlines, fault blocks, and lithological traps. The site-specific level designates the area selected for implementing CO₂ geological storage operations. While the basin and structural trap levels are mainly considered during the evaluation phase, the site-specific level becomes critical during the later stages, as it relies heavily on site characterization data quality. This includes data type, quality, and precision, all of which guide the application of site selection

principles (e.g., injectivity, capacity, containment, and safety), from the preliminary reconnaissance stage to detailed surveys (Fig 2).

Fig 2. Scale classification of site selection for CO₂ geological storage in aquifers of oil and gas fields.

Selection workflow

This study presents a comprehensive scheme for selecting sites for CO₂ geological storage in aquifers located within oil and gas regions. The scheme is based on four primary criteria: **confinement, injectivity, capacity, and safety**. In addition to these core elements, the methodology also incorporates considerations of **synergy, safety, and phased storage indicators**. The site selection process begins with the systematic collection of data. Priority is given to geological, engineering, economic, and environmental data that is essential for evaluating the feasibility of CO₂ geological storage. Drawing from a global database of CO₂ geological storage projects, the study establishes selection criteria applicable to both the design and operational phases. These criteria are assessed at both the basin and trap levels. To ensure clarity in the decision-making process, the study specifies the weighting of indicators according to the different phases of storage. Subsequently, storage factors are developed for different storage formations based on representative storage models. This approach facilitates a quantitative assessment framework for CO₂ site selection. Ultimately, the decision-making evaluation conducted at specific storage sites determines their suitability for CO₂ storage, thereby laying a foundation for CO₂ geological storage site selection (Fig 3).

Fig 3. Site selection methods and processes for CO₂ geological storage in aquifers of oil and gas areas.

Indicator framework

This study draws extensively on evaluation methods used in oil and gas reservoirs, underground storage systems, and CO₂ storage projects, while also considering the geological conditions specific to CO₂ storage sites. A comprehensive set of indicators has been developed for assessing the suitability of geological formations for CO₂ storage. These indicators encompass macroscopic geological features, specialized technical indicators, and microscale pore structure characteristics. To identify the influence of these site selection indicators, both geological surveys and laboratory tests are conducted. Subsequently, the AHP is employed to derive a method for calculating the relative importance (weights) of these indicators. This involves constructing a comparative matrix and establishing a weighting system that reflects the significance of each indicator. Based on these weighted indicators, a comprehensive evaluation framework is established for CO₂ geological storage, and a boundary evaluation methodology is proposed.

Key factors in selecting saline aquifers for CO₂ storage within oil and gas regions include structural integrity, trap closure, and seal tightness. Additional considerations encompass the physical properties of the saline aquifer, the nature of fluid boundaries, storage capacity, overburden pressure, burial depth, and geographic location. The indicators related to confinement, capacity, and safety closely mirror those used in conventional oil reservoir extraction. Regarding injectivity, it is necessary to consider both reservoir conditions and the specific characteristics of formation water. These include the formation water type, salinity and the chemical composition of the water, both of which significantly influence injectivity-related indicators for site selection.

Methodologies for site selection in CO₂ geological storage

Case-based method

To conduct a comparative selection of sites for CO₂ geological storage, a methodological framework has been developed. This framework is based on a precise understanding of site selection indicators and draws on analogies from CO₂ geological storage projects implemented worldwide. A comprehensive survey of major global CO₂ geological storage sites was conducted, leading to the construction of a case database structured around the phases of planning, evaluation, and decision-making. As of now, the database comprises 153 demonstration projects, including 7 domestic and 146 international cases (Fig 4). The primary function of this database is to standardize core parameters such as storage capacity, injectivity, and confinement. Standardizing these key technical parameters ensures comparability across different cases. By compiling and organizing data from global demonstration projects, a comprehensive dataset of critical parameters has been established. This dataset supports both data querying and analysis while enabling categorization of existing data. Preliminary data extraction from existing cases includes both static and dynamic components. Static data include trap characteristics (e.g., type, area, thickness), reservoir properties (e.g., porosity, permeability), caprock attributes (e.g., thickness, permeability), fault parameters (e.g., dip angle, throw), fluid characteristics, and temperature-pressure conditions [12–17]. Dynamic database includes injection metrics, temperature and pressure trends, storage volume data, and real-time monitoring results. Through statistical analysis and comparison of these parameters, a preliminary selection module has been developed. This module is equipped with project querying, parameter statistics, and project comparison functionalities. Accordingly, the case-based selection method for CO₂ geological storage involves the following steps:

Fig 4. Case library of CO₂ geological storage.

The **first step** involves benchmarking global projects that utilize saline aquifer storage to ascertain systematic trends and deviations in geological assessments. By leveraging relevant CO₂ storage parameters, specific storage cases can be rapidly identified and displayed within the system. To enhance the efficiency and accuracy of query processes, optimization algorithms such as genetic algorithms, simulated annealing, and ant colony optimization are employed.

The **second step** involves screening and evaluating the storage potential of oil reservoirs. By inputting parameters such as basin type and storage method, the system performs an intelligent filtering process that identifies CO₂ storage cases similar to the input parameters. This step aids in referencing subsequent quantitative selections, facilitating the rapid evaluation of storage parameters, analyzing success factors, and establishing alternative targets for development.

The **third step** categorizes existing engineering projects to determine critical parameters for classification and ranking. Classification standards are established, such as grouping projects into high-, medium-, and low-risk levels. Alternatively, potential storage areas may be comprehensively ranked based on multiple factors, including storage capacity, injection rate, and storage efficiency.

The **fourth step** involves visual analogy methods by employing similarity measurements such as cosine similarity and Pearson correlation coefficient analysis. These techniques are used to compute the degree of similarity between different cases. Ultimately, various graphical representations—including bar charts, radar charts, and scatter plots—are used to compare data from potential CO₂ geological storage sites with successful examples from the case database. This method facilitates the strategic selection of suitable targets, which is a critical component of site selection for CO₂ geological storage.

In contrast to traditional reservoir modeling and numerical simulations used in developing exploitation strategies, the emergence of artificial intelligence offers a compelling alternative. By leveraging extensive case-based artificial intelligence predictions that integrate deep learning models, this approach enables the efficient identification of potential areas for CO₂ geological storage and recommends analogous historical cases. This method is particularly advantageous due to its speed and operational simplicity, allowing for rapid assessment of potential areas for CO₂ geological sites. Thus, it accelerates the transition from early-stage planning to informed decision-making, as shown in Fig 3. This also presents a technologically viable pathway for scaling up the site selection process essential to CO₂ geological storage initiatives.

Hierarchical screening

Evaluating the suitability of a site for CO₂ geological storage is commonly recognized as a complex, multi-criteria decision-making problem. This evaluation process involves two critical components: determining the weights of evaluation indicators and selecting appropriate decision-making methods. Methodologies for determining indicator weights include expert surveys, AHP, principal component analysis, and the entropy weight method. Meanwhile, decision-making evaluation approaches encompass techniques such as gray relational analysis and fuzzy comprehensive evaluation. Among these methodologies, the AHP is particularly effective. It breaks down complex issues into multiple levels, distinctly defining the relationships between various levels and their associated indicators. This capability makes AHP especially suitable for site selection in CO₂ geological storage. The AHP was developed in the early 1970s by Thomas L. Saaty, a professor of operations research at the University of Pittsburgh. It applies principles from network systems theory and multi-objective evaluation to analyze the nature, influencing

factors, and intrinsic relationships of complex decision-making problems. By utilizing a limited amount of quantitative data, AHP transforms the decision-making process into a mathematical model. Consequently, it provides a practical method for addressing complex decision scenarios characterized by multiple objectives, multiple criteria, or unstructured features. This method is particularly well-suited to modeling and evaluating complex systems that resist full quantification. Building on hierarchical analysis and fuzzy evaluation—and incorporating relevant algorithms from the field of artificial intelligence—a CO₂ storage site suitability evaluation module was developed. This module includes functionalities for expert scoring and ranking of evaluation indicators, thereby improving the site selection process for CO₂ geological storage. A key challenge, however, lies in the objective construction of a comprehensive system of evaluation indicators and the scientific assignment of their corresponding weights. To address this, machine learning algorithms—such as random forests and support vector machines—can be employed to analyze these indicators systematically. This framework is then refined through expert scoring to optimize the weights of the indicators. Ultimately, artificial intelligence methods support decision-making in the evaluation of site suitability.

(1) Methodology for Constructing the Evaluation Indicator System

To construct an evaluation indicator system for site selection, qualitative analogies from similar cases in a case database are utilized. Decision tree and K-nearest neighbors algorithms are employed to analyze indicators that significantly influence site selection in analogous cases. These analyses provide a foundation for constructing the subsequent indicator system. The system is then refined by selecting indicators that align with the geological, social, and economic conditions specific to the study area.

(2) Algorithm for Assigning Weights to Evaluation Indicators

The initial determination of indicator weights is based on expert scoring. Experts assign scores based on their knowledge and experience. These scores are then used to construct a judgment matrix, followed by a consistency check. If the weights meet the consistency criterion, they are considered valid. To further refine the weights and mitigate subjective bias, a stratified approach is implemented. In this approach, experts are grouped into different levels, with different weights assigned to each level accordingly. Additionally, the Random Forest algorithm is applied to similar cases to quantitatively assess the impact of each indicator on site selection. This technique enables the adjustment of indicator weights. Using the AHP, storage weights are derived. A comparative analysis of these weights reveals the relative importance of each indicator. The indicators, ranked from most to least influential, are as follows: caprock lithology, caprock thickness, trap type, trap area, fault displacement, shale smear factor, trap closure, caprock breakthrough pressure, permeability, density, temperature, and pressure.

(3) Algorithm for Evaluating the Suitability of CO₂ Geological Storage Sites

The suitability of sites for CO₂ geological storage is assessed using the weighted evaluation indicators via fuzzy logic operations and fuzzy reasoning methods. Additionally, a backpropagation neural network model is constructed using suitability evaluation indicators derived from similar cases. Indicators from new development areas are input into this neural network model. Through the forward propagation mechanism of the neural network, suitability evaluation results are generated for these new areas. This neural network approach facilitates dynamic, responsive assessments that accommodate the unique features and variables of new geological settings.

Formation-based quantitative optimization

Existing site selection methods for CO₂ geological storage—whether qualitative comparative case analyses or semi-quantitative hierarchical screening—encounter several challenges. These include a lack of uniformity in selection criteria and difficulties in expressing results quantitatively. As a result, the process of quantitative site selection for CO₂ geological storage remains hindered. The characterization of favorable geological formations largely depends on traditional “manual analysis,” which lacks intelligent technologies capable of linking geological conditions to storage suitability. The primary mechanisms of CO₂ geological storage include structural storage, solubility issues, capillary pressure retention, and mineralization, among which structural storage is the most significant. However, significant challenges remain in defining the factors influencing structural storage and quantitatively characterizing storage indicators. To address these gaps, this study proposes a model-based analytical approach for evaluating geological formations suitable for CO₂ storage. It also establishes characteristic parameters for such formations, thereby offering quantitative indicators to guide site selection. The proposed methodologies are outlined below.

Geological modeling. Geological formations suitable for CO₂ storage are diverse. Common types include anticlines, monoclines, fault blocks, fault-anticline combinations, and lithological traps. Moreover, the indicators used to evaluate these formations vary significantly. Their characteristic parameters—such as area, thickness, dip, closure, and fault displacement—are often not clearly defined, making effective characterization challenging. Building upon qualitative comparative case analysis and semi-quantitative screening methods, this study introduces a novel approach: *fixing injection–production parameters while varying geological models*. In this method, the injection–production parameters are held constant, while the key parameters of the geological model are systematically varied. This enables the execution of a series of numerical simulations aimed at optimizing storage efficiency. To support this approach, the characteristics of CO₂ storage

geological formations are first described. Then, representative storage models are established. Finally, multiple geological conceptual models are created by modifying selected geological parameters. For instance, in the case of anticlinal traps, a conceptual model is developed, with varying parameters such as area, closure, and dip angle. By adjusting these indicators, a range of geological models is generated to represent different formation scenarios. This modeling process results in the construction of geological models for various types of CO₂ storage formations (see Fig 5).

Fig 5. Quantitative methods for site selection of CO₂ geological storage.

Parameters extraction. Building upon the conceptual model of a geological body intended for CO₂ storage, this section integrates a range of critical parameters, including structural type, area, thickness, dip angle, and closure. To precisely quantify the key characterization parameters relevant to the structural sequestration mechanism, a series of numerical simulations was conducted. These simulations compared various structural models under identical injection–extraction conditions. Subsequently, dimensionless structural sequestration factors were proposed using dimensional analysis. Furthermore, a correlation formula was derived to relate the sequestration rate to the dimensionless structural sequestration factors. By optimizing the relationship between sequestration efficiency and the dimensionless structural sequestration factor, the critical value of this factor was determined (see Fig 5). Consequently, the parameter boundaries for geologically favorable CO₂ storage bodies were clearly defined.

Trap ranking. Following the extraction of the dimensionless structural sequestration factor, the prioritization of geological bodies for CO₂ storage can be conducted at both the structural trap level and the site-specific level. At the structural trap level, planar vector data on structural features,

sedimentation processes, and reservoir characteristics were utilized. Image processing and pattern recognition technologies were employed to extract parameters such as closure area and closure height. These parameters allow for the automated recognition of structural traps. Based on the quantitative characterization parameters of these traps, the dimensionless structural sequestration factor was calculated. Subsequently, the identified traps were ranked accordingly. Furthermore, by integrating geographic information system visualization technology, ranking results are displayed using color gradation, visually identifying the preferred areas for CO₂ sequestration. At the site-specific level, particularly for oil and gas reservoirs, a regional full-strata geological model was constructed using the Petrel platform. Suitable caprock combinations were selected, and geological structures—such as faults and folds—were extracted using image processing and pattern recognition technologies. A neural network model was then developed and trained on these geological features, enabling intelligent recognition of traps within the regional, three-dimensional full-strata geological model. This integrated intelligent prioritization method combines three-dimensional trap identification, volumetric extraction, and computational sorting of favorable sequestration geological bodies. The entire process is guided by geological pattern analysis. Consequently, the method allows for the batch-wise intelligent recognition of favorable sequestration bodies, thereby providing optimized targets for implementing CO₂ geological storage projects.

Case study: Oil Field A

Oil Field A (hereafter referred to as **Field A**) is strategically located in the central part of the Dongtai Depression, within the southern Subei Basin. It is bordered to the south by the Tongyang Uplift, to the north by the Zhe Duo Low Uplift and the Jianhu Uplift, and to the east by the Baiju

Depression. To the southeast, it connects with the Wubao Low Uplift and the Quintong Depression, and to the west, with the Lingtangqiao Low Uplift and the Jinhu Depression. Spanning approximately 100 km in length, the total area of the field reaches 2,670 km². The depression, oriented in a northeast direction, contains the deepest subsidence in the Subei Basin, with Cenozoic sediment thickness reaching up to 7,000 meters. The Gaoyou Depression, where Field A is situated, was formed during the Late Cretaceous Yizheng Movement. It has since undergone several major tectonic activities, including those associated with Wubao and Sanduo. The Zhen 1 Fault serves as the primary boundary fault of the depression. In contrast, the Zhen 2 and Hanliu faults are considered secondary faults, with the Hanliu Fault functioning as a reverse fault compensating for the Zhenwu fracture zone. Based on these primary and secondary faults, the structural pattern of the Gaoyou Depression can be divided into three zones: a southern fault step zone, a central deep depression zone, and a northern slope zone. Together, these structural features create a basin-shaped depression, which is primarily attributed to differential block movements.

Trap comparison

In the case studies of CO₂ storage, system parameters, such as basin characteristics, storage type, and structural features, are taken into account. To expedite the identification of analogous CO₂ storage cases, intelligent retrieval technologies, such as natural language processing, are employed. This comparison method utilizes radar charts to visualize indicator-based evaluations (Fig 6). The primary steps for selecting CO₂ geological storage can be categorized into several stages. First, the site selection parameters are defined from the perspectives of confinement, injectivity, capacity, and safety. At this stage, indicators that not only reflect storage capability but are also readily obtainable are established and standardized. Next, coordinates are set based on the site selection

parameters. Appropriate indicators are selected for different parameter sets, and corresponding axes are established based on parameter correlations. After that, all indicator parameters are normalized. The similarity among site selection indicators is then quantified. Finally, a suitability evaluation of the target storage area is conducted based on the indicator comparison. This process leads to the selection of appropriate areas for CO₂ geological storage. According to the assessment results, storage areas exhibiting overlapping indicator ranges are considered to belong to the same storage tier. The selection of analogous storage areas should rely on broad parameters to identify storage capacity trends and to better clarify the key factors influencing site selection (Fig 7). This method is straightforward and particularly suitable for the rapid preliminary assessment of multiple traps within basins or depressions. As a result, it facilitates the identification of potential storage areas. Furthermore, the diagrammatic analysis reveals that blocks GB and GD of Field A exhibit analogies to the Gorgon, Teapot Dome, and Illinois fields. Meanwhile, blocks GA and GC show similarities to the Ketzin, Zama, Otway, and Frio fields; however, a general comparison with the Sleipner field indicates significant differences.

Fig 6. Comparison radar chart of indicators for different CO₂ geological storage cases.

Fig 7. Comparison radar chart of indicators for different CO₂ geological storage cases.

Block evaluation

For the site selection of Field A in the G depression of the Northern Jiangsu Basin, Blocks GA, GB, GC, and GD were chosen for comparative analysis based on their weighting. The study area is situated adjacent to the Zhen 2 Fault subsidence zone and directly faces the deep depression zone of the Gaoyou Depression, near the Fanchuan Sub-depression. The principal source rock in

this deep depression zone is the E1f4, characterized by semi-deep to deep lacustrine deposits. The lithology of the E1f4 comprises dark gray to gray-black mudstone and calcareous mudstone, interbedded with thin layers of muddy limestone. These rocks contain organic matter of high quality and abundance, providing exceptionally rich oil-source conditions. In this region, the E2d11 high-conductivity mudstone acts as a regional caprock, forming an effective reservoir-caprock assemblage with the underlying E2d12 sandstone. This assemblage is also the primary oil-bearing unit in Block GB. Additionally, the relatively stable mudstone interlayers of the E2d2, along with its internal sandstones, can form localized reservoir-caprock combinations. The stochastic nature of hydrocarbon accumulation within these combinations is noticeably high. This is evidenced by the discovery of oil layers in wells within the E2d23 to E2d25 intervals in Block GB, which further underscores the randomness associated with hydrocarbon accumulation in this assemblage.

To facilitate a weighted comparison among blocks GA, GB, and GC within the Northern Jiangsu Basin, the CO₂ storage weights were calculated based on the unique geological features of each block. The results are as follows: GA, 2.4881; GB, 2.3404; and GC, 2.5800. Based on these values, the GC Block in the Northern Jiangsu Basin is considered the most suitable for CO₂ geological storage (Table 1).

Table 1. Site selection classification for oil Field A.

Indicator (weight)		GA	Storage weight	GB	Storage weight	GC	Storage weight	GD	Storage weight
Reservoir characteristics (0.0448)	Lithology	Clastic rock	0.051	Clastic rock	0.051	Clastic rock	0.051	Clastic rock	0.051
	Permeability, mD	383	0.117	321	0.117	343	0.117	33.5	0.091
	Formation factor (Kh), mD·m	153200	0.0063	54570	0.0056	25725	0.0056	4690	0.0056
	Permeability coefficient of variation	0.5	0.0063	0.5	0.0063	0.4	0.0063	0.5	0.0063
	Connectivity	Good	0.1	Good	0.1	Good	0.1	Good	0.1
	Porosity, %	22.1	0.0648	24	0.0648	28.7	0.0648	18.3	0.0576
	Effective thickness, m	400	0.068	170	0.068	75	0.068	140	0.068

Total	0.4134	0.4127	0.4127	0.3795
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Quantitative results

To address the quantitative requirements for site selection, a comprehensive stratigraphic model at the regional scale was developed for Field A. This model was constructed using the Petrel platform. Based on the nondimensional structural factors of the anticlinal reservoirs, favorable geological bodies for storage were identified through geological modeling and image recognition techniques (Fig 8). The nondimensional structural storage factors were calculated to assess the suitability of different reservoir blocks for CO₂ geological storage. As a result, Block GC exhibited the most favorable characteristics for CO₂ geological storage, showing a higher nondimensional structural factor compared to other blocks. Thus, the prioritization of blocks for CO₂ geological storage in Field A is as follows: GC > GB > GA. This ranking serves as a foundation for future CO₂ geological storage initiatives (Table 2).

Fig 8. 3D Structural trap extraction.

Table 2. Comparison of nondimensional structural storage factors in Field A.

Block	GA	GB	GC
Area/km ²	1.2	1.35	0.8
Angle/°	10	15	25
Thickness/m	10	15	10
Structural storage factor	0.14106	0.36173	0.2487
Suitability classification	Class I	Class II	Class III

Conclusions

(1) To address the critical challenges in site selection for CO₂ geological storage, a comprehensive review of both domestic and international strategies and indicator systems for saline aquifer storage was conducted. The site selection process was carried out in two main phases: **evaluation** and **operational implementation**. Furthermore, site selection was categorized into three spatial scales: the basin level, the structural trap level, and the site-specific level. Based on this framework, a multi-scale and multi-level evaluation indicator system was proposed, which integrates macroscopic characteristics, specialized indicators, and microporous features.

(2) A novel method for CO₂ storage site selection within aquifers in oil and gas regions was developed. This method comprises three components: (a) a qualitative comparative selection based on a case study database, (b) a semi-quantitative screening method based on hierarchical analysis, and (c) a quantitative prioritization method for identifying favorable geological storage bodies. This approach is grounded in geological modeling, which facilitates the quantitative screening of favorable storage bodies. As a result, it offers a more scientific, systematic, and data-driven decision-support framework for CO₂ storage site selection. This methodology improves both the objectivity and practicality of selection decisions, thereby actively facilitating the development and large-scale implementation of CCUS technologies.

(3) This selection methodology was applied to Field A. Through comparative case analysis, hierarchical analysis screening, and prioritization of favorable geological bodies, blocks suitable for CO₂ geological storage were ranked in the following order: GB > GC > GA. This practice demonstrated that the quantitative site selection method—through three-dimensional extraction and evaluation of favorable geological bodies—significantly enhances both the accuracy and efficiency of the site selection process. Consequently, it provides a robust and effective approach for guiding future CO₂ geological storage projects.

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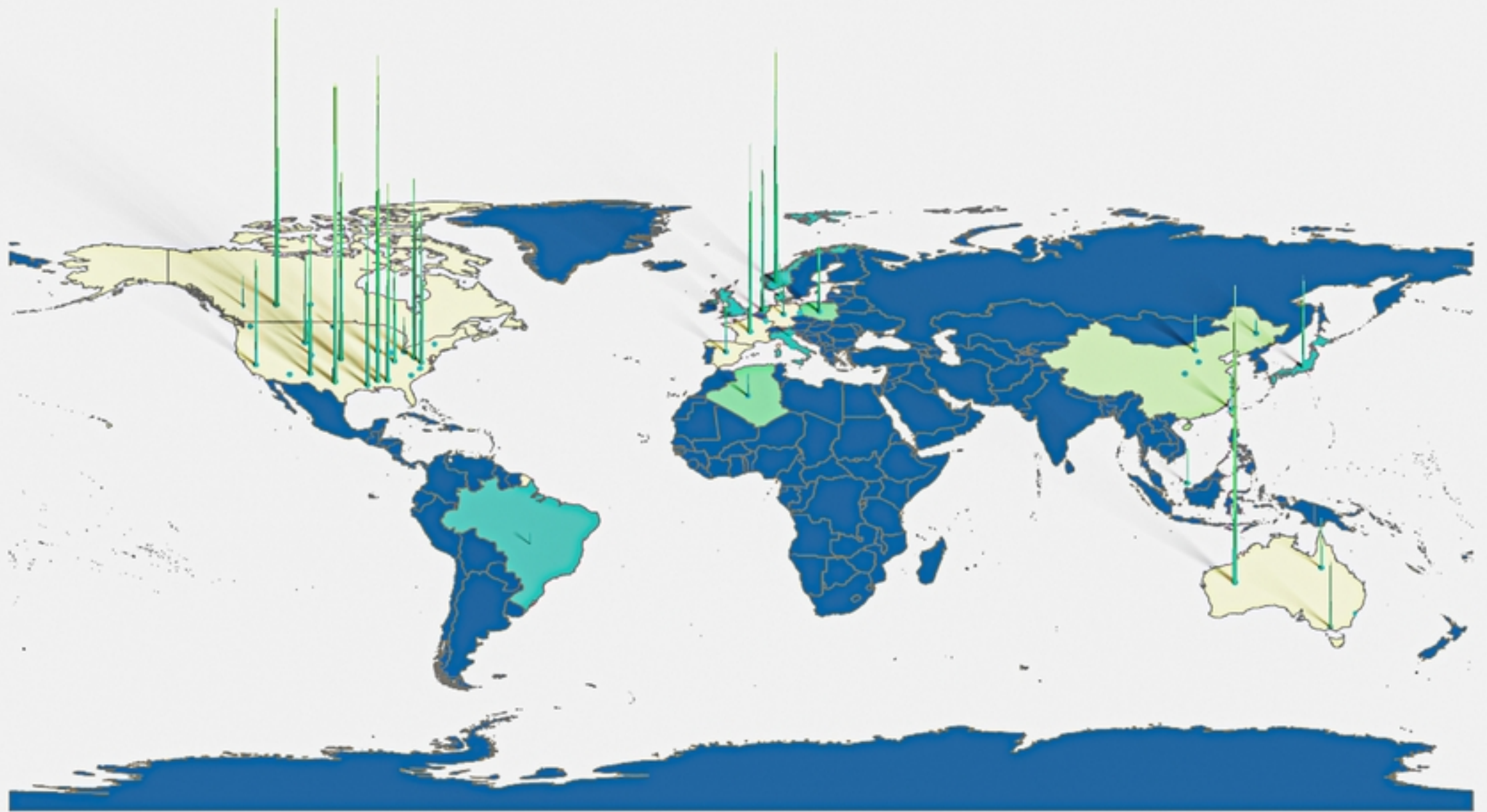
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493



Amount of CO2 Captured/Stored



0 4,743,898

Fig1

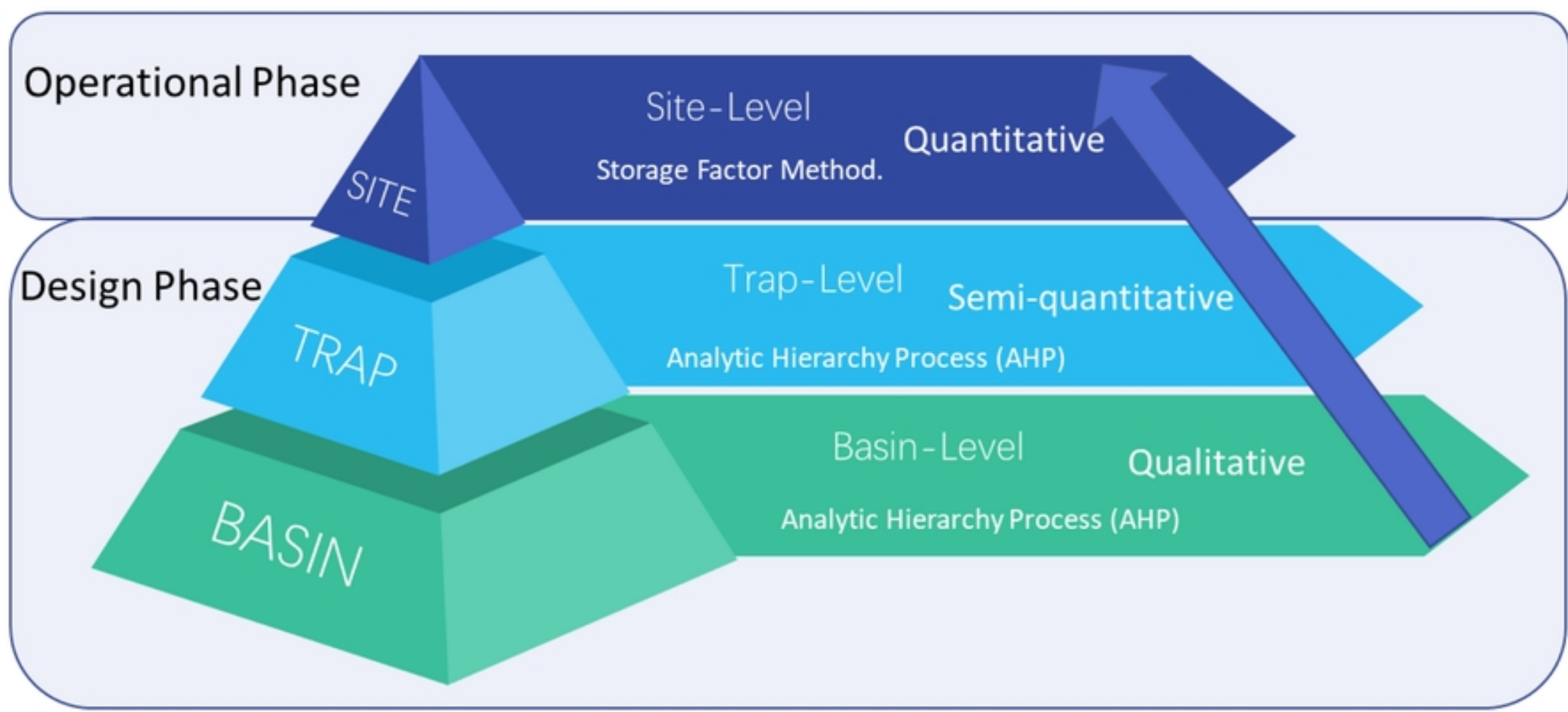


Fig2

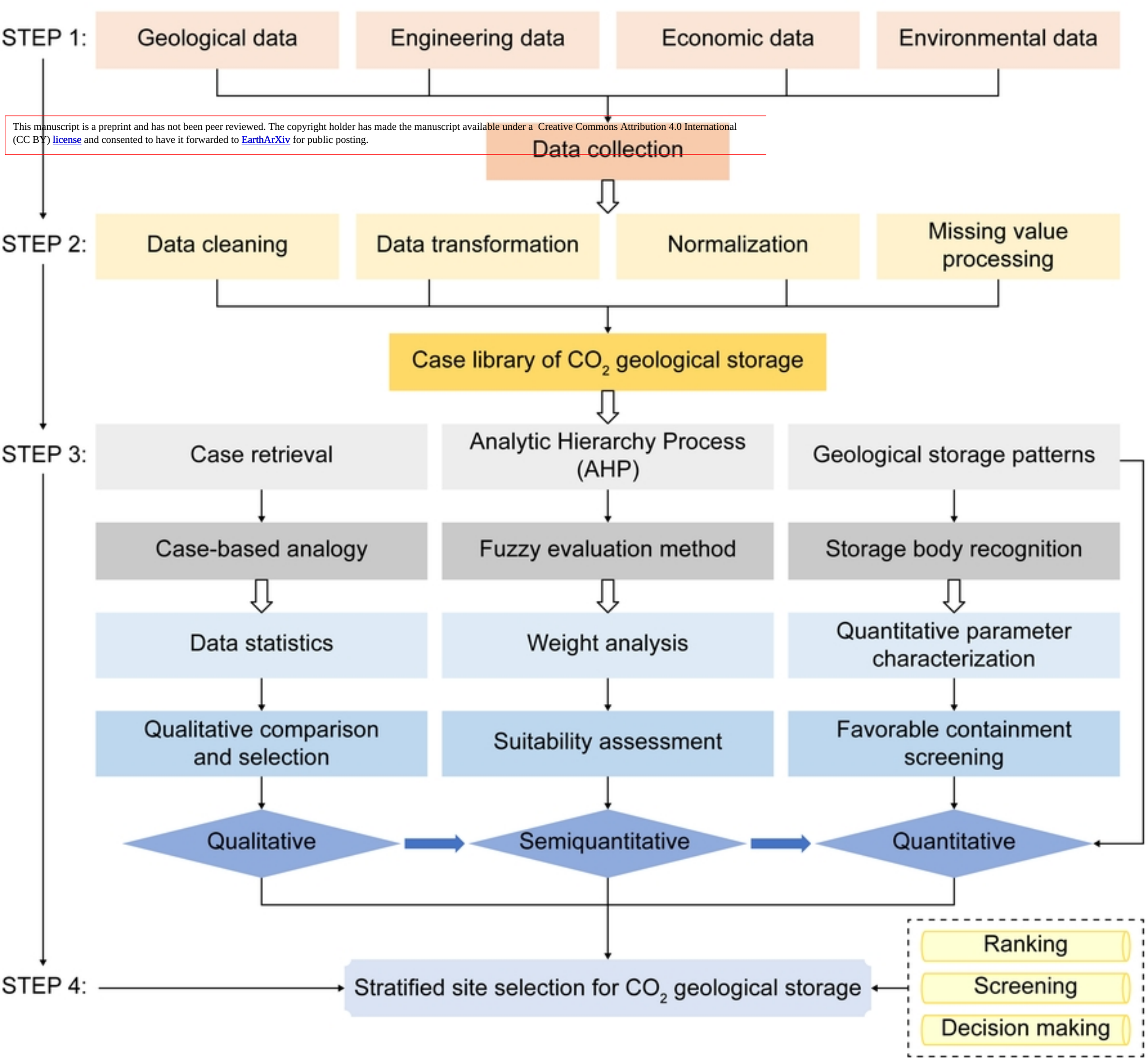


Fig3



Geological storage potential

- ☐ National-level
- ☐ Basin-level
- ☐ Regional-level
- ☐ Prospect-level
- ☐ Storage site capacity

Storage types

- ☐ Deep saline formations
- ☐ Oil and gas reservoirs
- ☐ Coal seams
- ☐ Others

Evaluation metrics

- ☐ Caprock metrics
- ☐ Reservoir parameters
- ☐ Basin metrics
- ☐ Safety indicators
- ☐ Prospectivity metrics

Storage suitability

- ☐ Highly suitable
- ☐ Moderately suitable
- ☐ Marginally suitable
- ☐ Low suitability
- ☐ Unsuitable

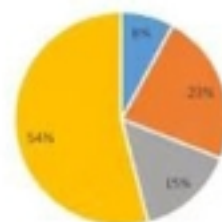


East China Basin



A: engineering geological conditions
 A1: basic indicators
 A2: other indicators
 B: representative potential conditions
 B1: basic indicators
 B2: other indicators
 C: evaluation conditions
 C1: basic indicators

Structural type



• Faulted anticline • Monocline • Fault block • Anticline



• Suitable • Moderately suitable • Marginally suitable • Less suitable • Unsuitable

suitability



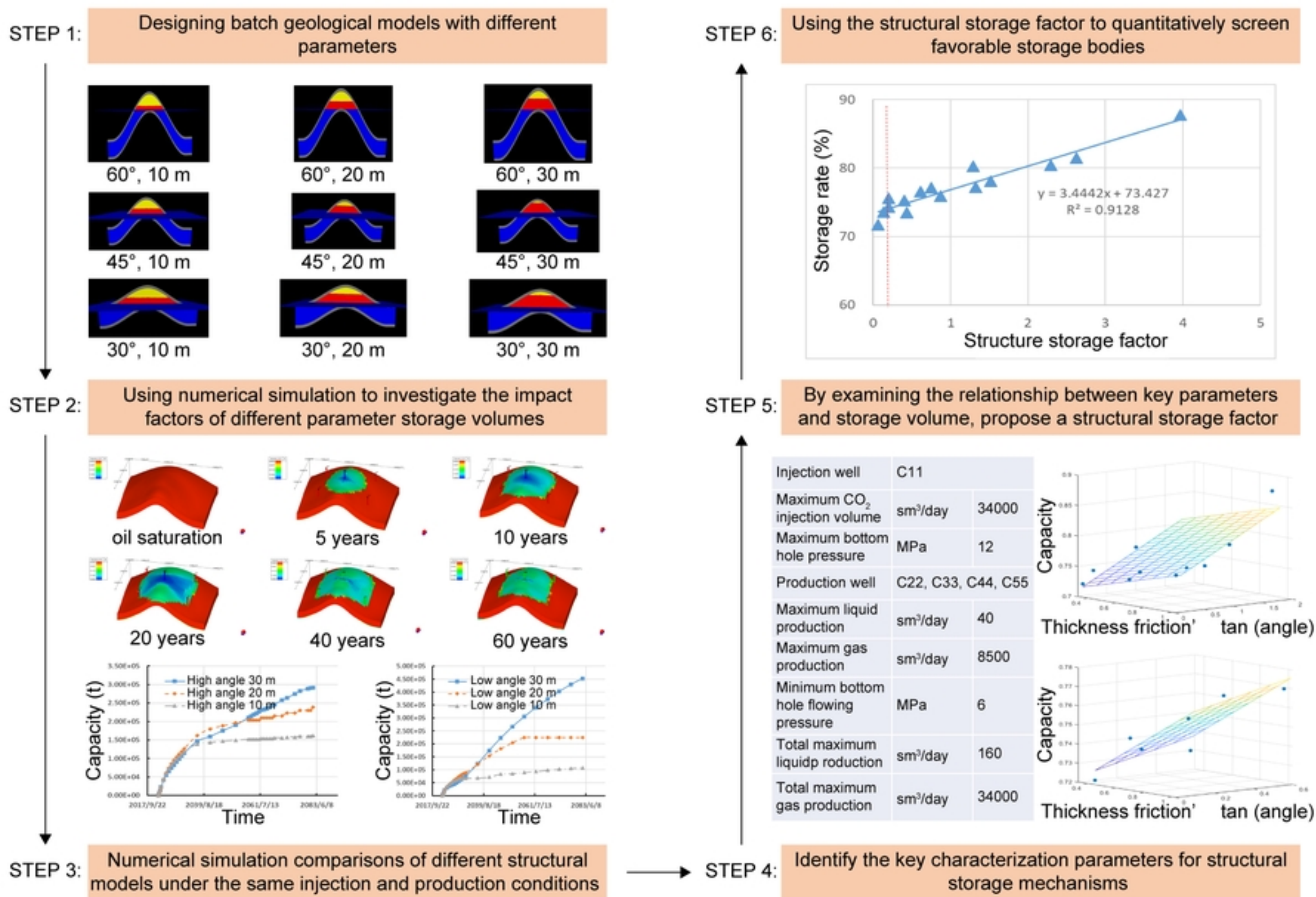


Fig5

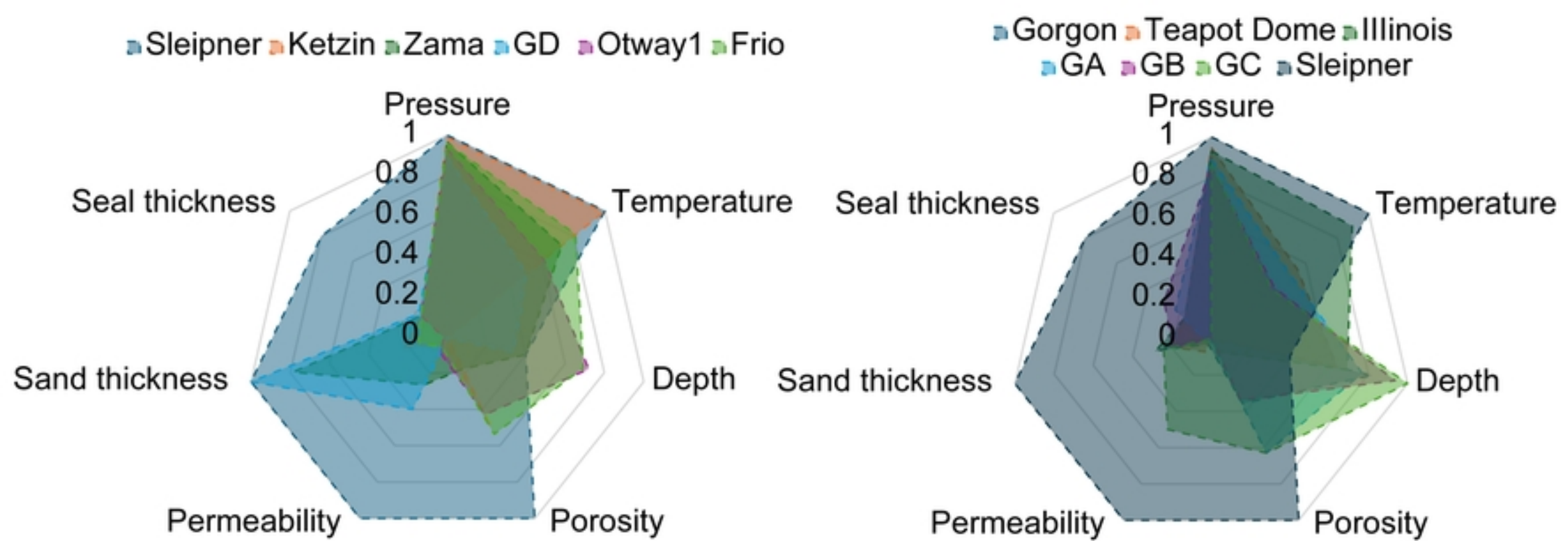


Fig6

Mantel's p

- <0.01
- 0.01–0.05
- ≥0.05

Mantel's r

- <0.2
- ≥0.4

Pearson's r

0.5

0.0

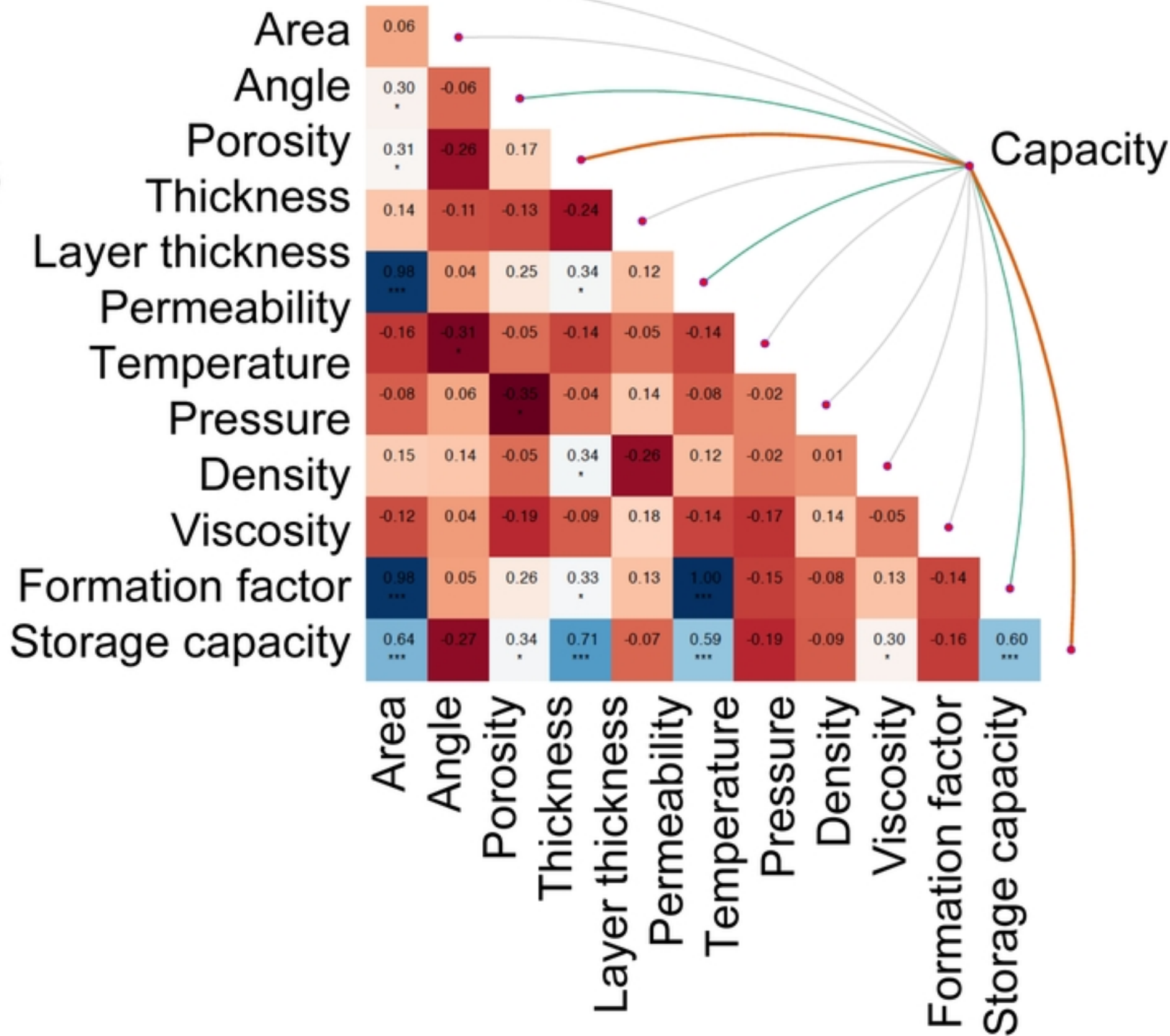


Fig7

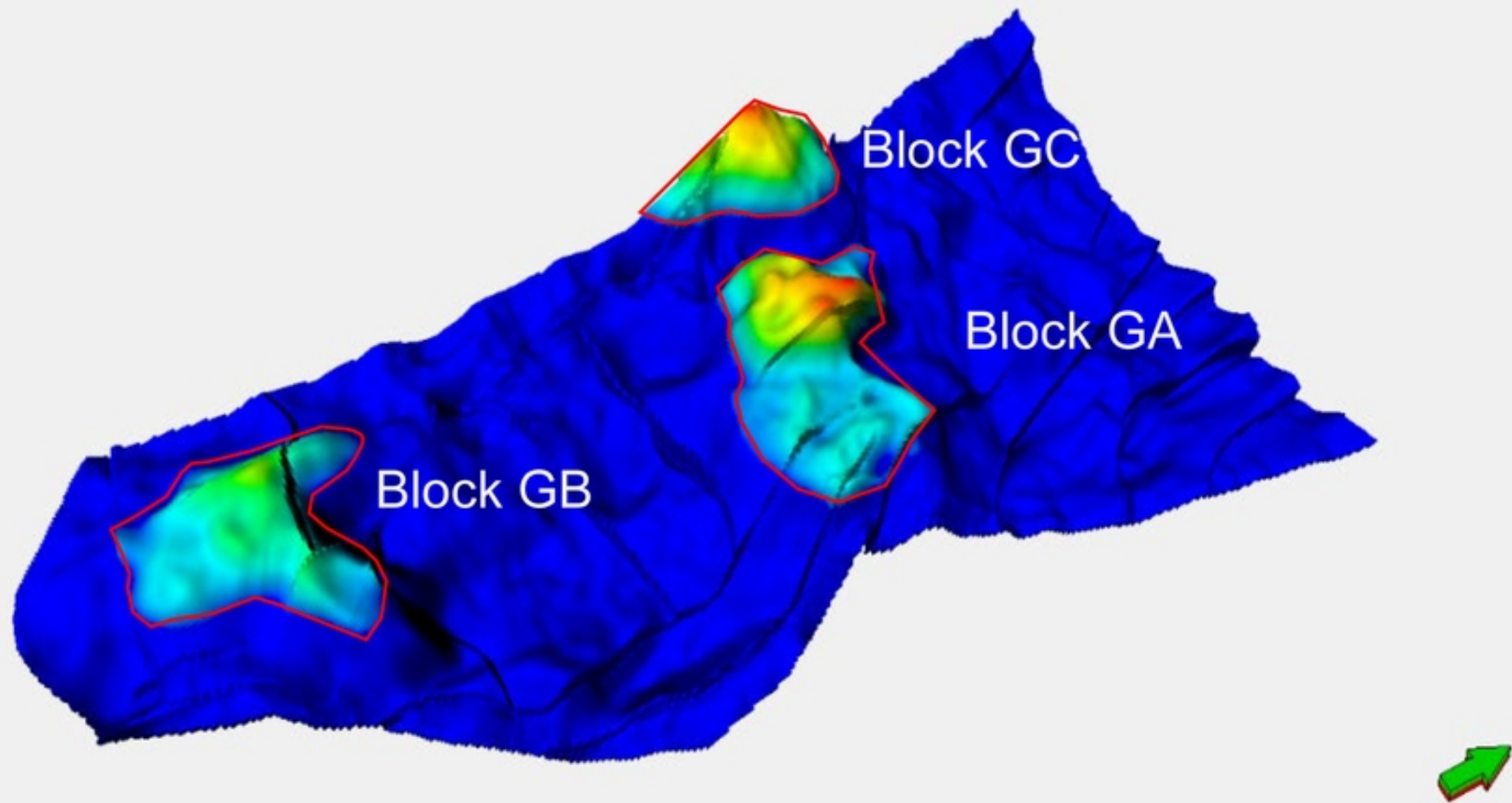


Fig8