Compendium of Earth and Space Sciences
ISSN Print: 3079-5621
ISSN Online: 3079-563X
https://doi.org/10.63313/CESS.4001

Application and prospects of mathematical geology to sedimentary stages in deep-water channels

Xianzhong Gong
Institute of Resources & Environment, Henan Polytechnic University, Jiaozuo 454000, China

How to cite this paper: Gong, X. (2025). Application and prospects of mathematical geology to sedimentary stages in deep-water channels. Compendium of Earth and Space Sciences, 1(1), 1-16. ISSN Print: 3079-5621, ISSN Online: 3079-563X. https://doi.org/10.63313/CESS.4001
Published:2025-03-20

Abstract

The method of mathematical geological model construction is used to quantitatively express the parameters of deep-water channel sedimentary geological body shape and sedimentary sequence configuration. At the same time, the reservoir configuration research is carried out in combination with seismic and logging data, in order to obtain a universal mathematical geological method for further lithologic identification and rock stratum division of oil and gas reservoir structure "generation, reservoir, cap, circle, transportation and preservation" based on the results of sedimentary sequence obtained by using the mathematical method of parameter characterization. The results show that the combination of geological description of deep-water channel sedimentation model and mathematical geological method, and the configuration research idea of "well seismic combination, mathematical transformation, model fitting, and dynamic verification" can finely depict and characterize the spatial distribution, superposition relationship, and sedimentation period of different levels of configuration units, and improve the recognition and division accuracy of single deep-water channel. However, it is still necessary to summarize simpler and more intelligent mathematical geological theories and methods to explain the specific conditions and mathematical laws of "source, reservoir, cap, trap, transportation and preservation" of deep-sea oil and gas reservoirs, so as to fully explore new uses of well seismic data.

Keywords

Deep water channel; Mathematical geology; Sedimentary period; Model building

1.Introduction

Mathematical geology or mathematical geoscience as a natural science and earth science cross-discipline, for a long time the lack of a unified definition of the discipline, resulting in the academic understanding of the discipline is often biased, and often not as an independent discipline, and often even ignored or called “decorative” discipline, to a certain extent, affecting the development of the discipline[1].

To a certain extent, this has affected the development of the discipline. Mathematical Geosciences is often referred to simply as "the application of mathematical and statistical methods in geology (earth sciences), or in the analysis of geological data and the development of quantitative prediction models"[2]. 1962 Vestelius gave an early definition of Mathematical Geology and used it as the name of the international society[3]. 1980s or even earlier, Academician Zhao Pengda founded the discipline of Mathematical Geology in China. In 2008, the IAMG Society changed its name from Mathematical Geology to Mathematical Geosciences.In 2014 Frits Agterberg wrote Geomatics: theoretical foundations, applications and future developments[4]. At this point, mathematical geology has become a sub-discipline of geology, and its emergence reflects the new trend of geology from the qualitative stage of description towards quantitative research, opening up a new avenue of development for geology. It is a product of combining geology with mathematics and electronic computers, aiming at studying and solving geological science problems from the quantitative aspect. According to the three basic tasks of mathematical geology proposed by Academician Zhao Pengda: (1) to find out the mathematical characteristics of geological bodies and to establish mathematical models of geological bodies; (2) to study the characteristics and interrelationships of the relevant factors in geological processes and to establish mathematical models of geological roles; and (3) to study mathematical analysis methods and quantitative theories suitable for the characteristics of geological data, and to establish mathematical models of geological work methods. In particular, the adoption of mathematical methods as an important means of geological work for practical exploration and the realization of digital comprehensive observation and prediction of geological resources are conducive to improving the precision of geological exploration and evaluation work, maximizing work efficiency, highlighting the efficient and practical nature of mathematical methods, and contributing to the reduction of the difficulty of geological work[5].

Deep-water channel is a common geomorphological unit in deep-water sedimentation, which is not only an important link connecting shelf, slope and deep-sea basin, but also an important place for sediment transport and deposition[6]. As a common submarine elongated negative landform developed in continental slopes and deep-sea basins, watercourses are generally formed by gravity-flow erosion, presenting a linear elongated negative topography, with the internal process of erosion in the early stage as a sediment transport path, and the internal process of filling in the late stage as a storage space for sediments. The main feature of the watercourse is the erosional basement, reflecting the undercutting action during the development of early deep-water deposition[7]. Sometimes erosion and deposition occur together. As important sediment channels connecting continents and deep-water basins, they are widely developed along shelf margins around the globe and are at the forefront of current deep-water sedimentological research. Morphologically, deep-water channels often have a V- or U-shaped profile, which, together with the natural dykes on both flanks, form the classic 'gull-wing'; in plan, deep-water channels have a relatively straight or serpentine geomorphological pattern[8,9].In terms of sedimentary composition, deep-water channels develop channel-filling subphases in the axial part of the channel, natural dykes and breakout fan subphases on both flanks, and turbidite lobe at the end of the channel; and channel filling can be further divided into microphases, such as valley-bottom stagnation, sedimentation by landslide debris flow, axial filling, and overburdened mud, and so on[10,11]. In terms of genesis, the watercourses can be divided into gravity-flow watercourses formed by gravity flow, isobath-flow watercourses dominated by isobath-flow, and deep-water unidirectional migration watercourses caused by the interaction between gravity flow and bottom flow according to the process of action[12].As one of the "two deeps and one non-conventional" (deep water, deep earth and unconventional) with the most exploration potential and good exploration prospects, deep water is the main field of oil and gas reserves growth[13], deep waterways as the main deep sea oil and gas reservoirs in the shelf edge basin, and is the main oil and gas endowed storage layer unit formed by deep water gravity flow[14].Deep water channels have been the hotspot and frontier of deep water sedimentological research since they were first discovered and reported by Professor Francis P. Shepard, an American marine geologist, in the first half of the last century.

In the last decade or so, the research on deep-water watercourses has been developing rapidly. There are more studies on the depositional characteristics and types of gravity flow waterways, but the studies on their formation mechanism, main controlling factors and reservoir distribution law are relatively weak, especially the lack of comparative studies on the formation mechanism of different types of waterways[15].From the current progress of domestic research, our scholars in recent years have mainly focused on the identification and description of deep-sea watercourses, analysed the causes of watercourses and sedimentary evolution, and demonstrated the controlling effects of large-scale factors such as relative sea level rise and fall, source properties, tectonic rise and fall movements, and topography and geomorphology on the deep-sea sedimentary system[16].However, with the massive development of deepwater waterway reservoirs, there is an urgent need to carry out development geological research on the construction and fitting of digital models of deepwater waterway sedimentation, and the simulation and derivation of digital sedimentary body analyses of deepwater waterway flow paths to co-sedimentary structures. Therefore, it is necessary to understand the coupling and correlation between the parameters of the waterway flow path and the geometric parameters of the co-sedimentary structure from a quantitative point of view, and then construct a mechanism model of the response of the waterway flow path to the co-sedimentary structure, which is the theoretical basis of the digital geological theory for the efficient development of this kind of reservoirs. This requires the introduction of mathematical geological methods to digitally fit the sedimentary period and geometric parameters of co-sedimentary structures in deepwater watercourses, as well as the proposal of mathematical analysis methods and quantitative theories that are suitable for the characteristics of geological data, so as to realize the digital observation and prediction of the sedimentary geology of deepwater watercourses, and to improve the precision of the geological exploration and evaluation of oil and gas reservoirs in deepwater watercourses.

2.Previous research

Mathematical Geology is a systematic course that takes data and information from different research fields of earth sciences as the research object, and uses statistical analysis to explain geological phenomena such as minerals, rocks, geological formations, mineral resources, etc., and to reveal the process of earth dynamics and the law of distribution of mineral resources, and its main mathematical methods are mainly applied in geology:

1. General mathematical statistical analysis

In order to achieve comprehensive observation and prediction of geological resources, the probabilistic analysis method is used as the main method of geological work. In order to give full play to the role of general mathematical statistical methods in geological survey work and to coordinate geological survey with mathematical methods, the final prediction results can be presented through mathematical quantities[17].

2. Special mathematical statistical analysis

In order to present the geological environment situation more clearly and intuitively, the centre of the data point group is adopted as the reference of geological investigation, and the discrete situation of the data is fully combined to statistically analyse the evolution of the geological situation. Through the special mathematical statistical method, it can achieve the effective control of the mineral geological environment and minimise the error between the statistical results and the actual situation.

3. Mathematical statistical analysis model

In order to further clarify the geological environment change situation, a perfect mathematical statistical analysis model is established. The mathematical statistical analysis model analyses and researches the geological environment without any random components. In order to deeply study the connection between geological void rate and depth, exponential equations are used to calculate and analyse the geology in the process of geological investigation.

At present, the mathematical geological method relies on the Digital Geological Survey System (DGSS) to run through the whole geological and mineral resources survey process, with functions covering regional geological survey, solid mineral exploration, ore body simulation, grade estimation, resource reserve estimation, mine mining system optimisation, etc.; the system is based on the data ‘layer’ model, data flow ‘pool’ technology, data model inheritance technology at different stages, data interoperability technology and 3S technology to achieve seamless digitization and integration of the whole geological survey process. The system realizes seamless digitization and integration of the whole geological survey process based on the data ‘layer’ model, data flow ‘pool’ technology, data model inheritance technology at different stages, data interoperability technology and 3S technology, and innovatively develops a geological 3D compass and a field data collector as an integrated field data collector. The innovative development of field data collector integrating geological 3D compass and field data collection has not only lowered the threshold for geologists to apply high and new technologies, but also greatly improved the precision and efficiency of the research, and enriched the forms of expression of the results and the forms of services.

The application of digital geological survey methods in the integration of information technology has greatly promoted the development of information technology in the field of geology in China, and is now widely used in national regional geological surveys and strategic mineral prospect surveys, mineral resource surveys and evaluations, and surveys of replacement resources in crisis mines, etc., and the scope of application involves basic geological surveys, geological and mineral surveys, estimation of resource reserves, and three-dimensional modelling of mines.

At present, mathematical methods are applied to petroleum geological development, based on the optimisation of problems arising from oil and gas exploration and development, and some better modern algorithms for optimisation have been obtained, mainly Chaotic Genetic Algorithm, a hybrid algorithm of linear inversion and genetic algorithm is proposed, and a parallel genetic algorithm is proposed for solving the TSP problem, etc.; in the area of graph theory and combinatorial matrix, an iterative algorithm for solving the large-scale matrix equations and their optimal approximation problem is proposed. In graph theory and combinatorial matrices, an iterative algorithm is proposed to find the antisymmetric iterative solution of large-scale matrix equations and their optimization approximation problems, and a series of research results are obtained in the generalized symmetric solution of constrained inverse eigenvalue problems and their optimization approximation problems, etc.; a fast dynamic shortest-path tree algorithm is proposed, and a sufficient condition for a graph to have some elimination graphs and coverings is obtained; various nonlinear optimization models are built on a wide variety of data generated in the process of oil and gas exploration and development, which overcome the conventional By establishing various nonlinear optimisation models on various data generated in the process of oil and gas exploration and development, the conventional nonlinear optimisation algorithms relying on gradient information are overcome the excessive reliance on initial values, and the resulting optimisation methods are applied to solve the established nonlinear optimisation models, so as to provide decision-making support for the exploration and development of mineral resources such as the distribution of ore deposits, oil and gas reservoirs, and so on. Through researching these theories and methods and closely combining them with seismic exploration, magnetic exploration, electric exploration, etc., integrating and innovating them to form new theories and methods in oil and gas exploration and development, as well as solving the problems of oil and gas exploration by using these new methods and technologies, in response to the harsh surface topographic conditions and complex underground geological and tectonic coexisting conditions in the marine and terrestrial sedimentary basins.The deepwater environment is limited by the current level of science and technology, we can not spend a huge amount of manpower and economic costs to carry out logging and sampling of every piece of sea at every depth to verify our considerations. Currently, inverse feasibility analysis is one of the most widely used techniques for deepwater reservoir prediction and evaluation. The inverse feasibility analysis is based on logging data, analyses the relationship between petrophysical parameters and reservoir parameters, and selects sensitive parameters that can distinguish between reservoirs and non-reservoirs. Through multi-parameter rendezvous analysis, two parameters, longitudinal wave impedance (Pimp) and transverse wave impedance (Simp), are preferred for reservoir and fluid identification. In the following figure, the Pimp threshold is read through line (1), and the functional relationship between Pimp and Simp is established through line (2), which can distinguish gas-bearing sandstones for the prediction of gas-bearing sandstones. The analysis concludes that reservoir prediction using pre-stack simultaneous inversion is feasible in the deepwater field[18](Figure 1).

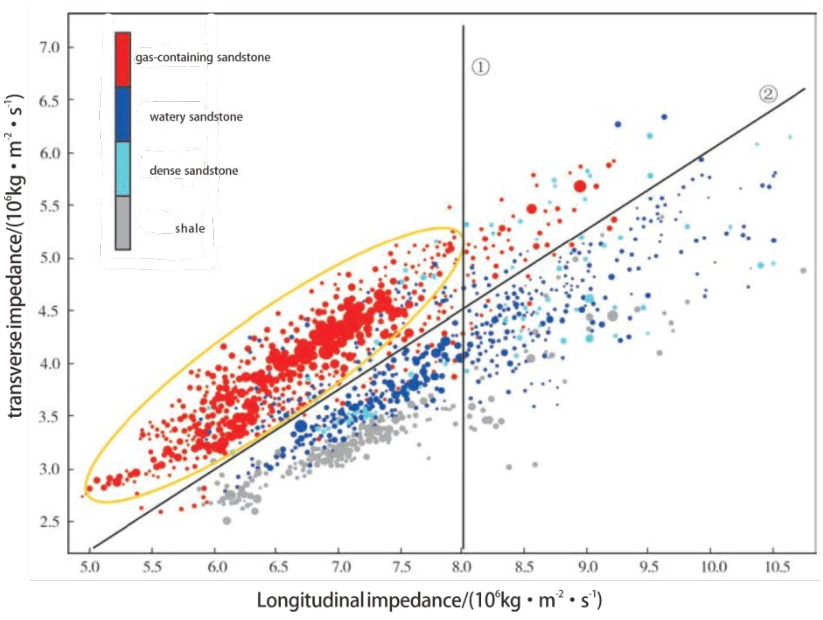

Figure 1: Intersection analysis of petrophysical parameters

In addition to the inverse feasibility analysis technique, reservoir geological modelling, which carries out quantitative characterization of reservoirs from a three-dimensional perspective, has the advantages of three-dimensional quantification, visualization, and integrated prediction of reservoirs and attribute distribution between wells, and is widely used in three-dimensional quantitative characterization of various types of onshore and offshore oil and gas reservoirs, and is an important technological tool for the fine evaluation of oil and gas reservoirs, the prediction of residual oil and high-efficiency development. With the comprehensive application of seismic, logging, core and analytical test data, and under the constraints of stratigraphic and tectonic geological interface grids (level model and fault model), well seismic is combined to establish various types and levels of trend constraints, which are applied as constraints in the process of sedimentary phase modeling, and then carry out the modelling of reservoir physical parameters under the control of sedimentary phase, and then validate the model, so as to realize the establishment of three-dimensional geological model for deep-water sedimentary reservoirs. Establishment of the three-dimensional geological model of deepwater sedimentary reservoir The combination of well seismic, fully exploiting the well seismic measurement information data, and establishing multiple types of trend constraints can significantly reduce the uncertainty of reservoir prediction between wells in the geological model, and significantly improve the accuracy and credibility of the geological model[19], which is of certain reference significance for the geological modelling of offshore oil and gas fields under the conditions of sparse well network, large well spacing, and low well control (Figure 2).

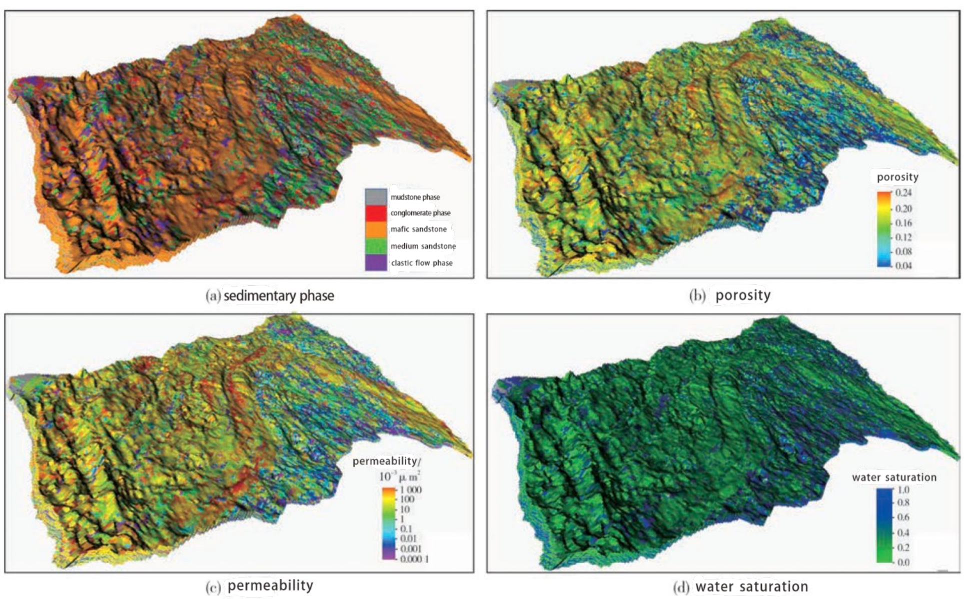

Figure2: Three-dimensional model of sedimentary phases and reservoir properties in a sedimentary basin.

The application of mathematical geology in deep watercourses adopted by the former is more often to use seismic, logging, coring and analytical testing of all kinds of parameters, combined with the geometry of water fluids, to make geological prediction of oil and gas distribution in deep watercourses. Then is it possible to use mathematical geological methods to carry out reservoir configuration for deep water channel sand body deposition period, sand body deposition pattern, sand body deposition characterisation, so as to establish a multi-layer deep water reservoir characterisation and reservoir prediction with deep water reservoir characterisation and reservoir prediction as the main objectives, with deep water channel depositional configuration quantitative model as the theoretical guide, with high precision isochronous grid as the constraint boundary of depositional element analysis, and with the fitting of well seismic model, depositional model controlling. waterway reservoir conformation characterisation, spectrum resolution, and multi-tectonic family attribute frequency fusion as the basis of the analysis technology, and the seismic multi-attribute method with three-level stratigraphic sequence delineation and logging phase control for the deep-water system level sand body planar prediction, which is able to provide theoretical guidance for the exploration and development of deep-water reservoirs, and is applied in the prediction technology of deep-water reservoirs.

3.Previous study

Yin Taiju establishes a high-precision geological model and predicts the remaining oil on the oil sand body movement status, and establishes a downhole geological knowledge base including rock-electricity relationship, sand body geometry, sand body contact relationship and sand body density based on the anatomy of small well distance. Based on the reservoir architecture analysis method to establish the reservoir architecture plan and section model[20].Based on the core, logging and 3D seismic data, Chen Yuhang et al. established the stratigraphic framework of Oligocene sequence in the deep-water area of land slope of Ruvuma Basin in East Africa. By analysing the depositional characteristics of the watercourse and dolomite and combining with the regional geological data, they explored the controlling factors for the sand-rich deep-water deposition of the watercourse and the dolomite, and established the depositional model accordingly[21].Using high-resolution 3D seismic reflection data (covering 4885 Km^2) and 14 logs provided by Equinor ASA (Norway) and ExxonMobil (USA), A. Fuhrmann used the seismic data along with biostratigraphic calibration wells to map seismic and stratigraphic geometries offshore Tanzania, by analysing the sediment, high-resolution seafloor data, and near-bottom current measurements from two locations to address the effects of deep seafloor currents interacting with gravity currents of unstable sediments by interacting eastward-flowing gravity currents with northward-flowing bottom currents (ED), demonstrating how large-scale sedimentary architecture can be established by temporally-invariant coupling of these two globally important sediment transport processes.Bu Fanqing et al. adopted the framework of ‘macroscopic framework and sand group embedding’ to reproduce the vertical accretion and lateral oscillation migration of the seven-phase watercourses in oil group A of block OML130 in the Niger Delta Basin, West Africa. With the help of time-shifted seismic dynamic monitoring information, the water-driven areas were picked up, and the down-cut connectivity zones between different watercourses were accurately identified and characterized, forming a set of modelling methods for quantitative identification of connectivity zones; and a reliable sedimentary microphase model was established through the multi-conditional constraints simulation of sedimentary microphases in deep-water gravity flow.Southwest Petroleum University disclosed a patent for a method of deep-sea lobe reservoir configuration characterisation based on well seismic pattern fitting, which provides ideas for joint underground reservoir configuration research using well seismic and achieves scientific and reasonable prediction of flow paths, geometrical patterns, scale sizes of sand bodies of different grades of genesis and their superposition relationship with each other in deep-sea lobe deposits, and achieves an effective characterisation of the non-homogeneity of deep-sea lobe reservoir reservoirs, thus providing important geological basis and guidance for the deployment of wells in this type of reservoir, well network design, analysis of injection and recovery correspondence, and prediction of residual oil distribution. This will provide an important geological basis and guidance for the deployment of wells, well network design, analysis of the correspondence between injection and recovery, and prediction of residual oil distribution in this type of oil and gas reservoirs[19].

Geological modelling of deepwater oil and gas reservoirs can basically meet the needs of graphical display of 3D geological modelling, such as 3D graphical display of reservoir lattice, reservoir phases and petrophysical parameter distributions, and there are two ways of modelling for the prediction of reservoir characteristics between wells, i.e. deterministic modelling and stochastic modelling. Deterministic modelling is to give deterministic prediction results for the unknown area between wells, while stochastic modelling is to apply stochastic simulation method to give multiple ‘optional’ and ‘equal possibility’ prediction results for the unknown area between wells[20].The sedimentary geological sands in deepwater watercourses are hierarchical and periodical in nature. Previous studies have focused on the scientific and reasonable fuzzy prediction of the source collection, circulation path, geometry, scale, superposition relationship, sand density, contact relationship and control factors of deepwater sedimentary sands[21].Therefore, with the help of the sedimentary interface division, the mathematical modelling of the sequence of sedimentary bodies corresponding to the sedimentary sequence is carried out by applying digital parameter expression, and the modelling is carried out according to different levels of configuration, such as single watercourse, composite watercourse, composite watercourse system and so on, respectively. For different levels of configuration, different modelling parameters reflecting the respective geological features are input, so that the constructed model can reflect the geological reality more objectively. Pattern fitting modelling mainly refers to making reasonable inter-well predictions of the spatial distribution and physical characteristics of the reservoir based on quantitative models of different levels in the modelling process of each level. Hierarchical analysis and pattern fitting should be carried through the whole process of reservoir modelling.

4. Specific conversion ideas

Aiming at the lack of quantitative parametric analysis of the sedimentary stage configuration of deep watercourse sedimentary geological bodies and morphological simulation of sedimentary watercourse configuration in the field of deep watercourse sedimentary geological bodies, i.e., the problem of fuzzy mathematical method of manual judgement in the interpretation of sedimentary stage of deep watercourse, it is proposed to construct mathematical model with the help of interface division of sedimentary sands in watercourses, and to model the order of corresponding sedimentary sequences of the sedimentary bodies according to different levels of configuration by applying the digital parameter expression, and convert the fuzzy mathematical method of geological description into concrete and specific ones. It is proposed to construct mathematical models, model different levels of configuration, and quantify the parameters for quantitative analysis and morphological simulation of deepwater channel configuration based on seismic data, so as to convert the fuzzy mathematical method of geological description into concrete and mathematical quantitative data, thus realizing the quantitative analysis of different configurations of units and channel configurations, morphological simulation, and automated solution for the interpretation system of depositional periods in the sedimentary model of deepwater channels. Interpretation system. This will provide a digital basis for the next step in the study of the establishment and dynamic fitting process of reservoir scale simulation.

Specific methodological ideas to achieve this goal: Grid division of the study area to achieve a lattice-like representation of 2D and 3D layers. Introducing the basic geological data of the study area, starting from the cross-section, spreading on the grid, and proposing the parametric expression of the outer contour of the deep-water channel deposition. Using the anchoring of the deep water channel event depositional interface to the normal depositional interface in the vertical presentation of the grid plane, the geological description interface is transformed into mathematical quantitative data. By comparing interface parameters with outcrop data and interface parameters with interface parameters, sorting is carried out according to the normal depositional sequence of the deep-water channel. Output the sedimentary period results externally and confirm the results manually. Connecting the body with the surface, finally achieving the mathematical model representation of the regional and three-dimensional sedimentary body.

The key to realising the application of mathematical geology in deepwater sedimentary watercourses lies in the translation in the language of mathematics and the mathematical formulation of the connections between the geologies. In the specific use scenario mentioned above, we can transform the sedimentary contours of deepwater watercourses using point and line expressions: in a certain seismic processing data, the existence of deepwater watercourse deposits is assumed in a rectangular area of the vertical interface. Its outer contour interface is the line between the breakpoints of the downgoing seismic reflection waves. In the interpretation of this deep-water channel, we can use curvature to express the degree of curvature of the watercourse and can be graded; the ratio of the line connecting the two distal boundary points at the same horizontal height of the watercourse body to the vertical distance from the lowest point of the watercourse deposit to that horizontal line expresses the numerical magnitude of the downcutting effect during the period of watercourse deposition, which can be graded and managed in accordance with analogous numerical analyses; the same mathematical method can also be implemented on the Morphological transformations of the sedimentary body of a conformational unit such as the external sedimentary interface of a sedimentary watercourse, the external contour of a sedimentary watercourse, and the built-in conformational unit of a sedimentary watercourse. In addition to this, further in-depth discussions can be carried out, such as the built-in configuration unit sedimentary body using the deep-water watercourse event deposition interface and the normal deposition interface anchored in the three-dimensional mathematical model within the vertical display, the division of internal and external natural dykes, block flow, watercourse deposition, sedimentary terraces, and other deep-water system contained within the configuration unit contact interfaces and the use of the appeal to mention the morphology of the watercourse of the geological description of the conversion of the data description of the quantitative parameter methodology, the same criteria are used to transform the conformational units within the deepwater watercourse.

Based on this mathematical thinking, we can similarly convert the period of deposition of geological bodies into a mathematical expression Within the simple depositional model, the sequence of sedimentary bodies was found to be consistent with a general depositional law. Using mathematical statistical analysis methods, this depositional law is applied and transformed into a mathematical parametric model, and the comparison includes the built-in constitutive unit with the external contour of the sedimentary watercourse and the same type of built-in constitutive unit. The comparisons can be divided into two broad categories of cases. The first is a simple built-in unit configuration, i.e., there is only one built-in unit configuration inside the external contour of the deep-water channel, as shown in Case 1 of Figure 3 below: this type of depositional period can be compared with the absolute difference in the height of the bottom point of the depositional centre-axis, which can be transformed into the description of depositional period by the method of mathematical data; the second is a multiple-built-in-unit configuration, i.e., there are more than one built-in unit configurations inside the external contour of the deep-water channel, as shown in Case 2 of figures below. The second type is the configuration with multiple built-in units, i.e., there are more than one built-in units inside the outer contour of the deep-water channel, as shown in Figure 4 below: in addition to the comparison of the absolute difference in heights of the bottom points of the sedimentary centre axis, this type of depositional period can be used to describe the lateral erosion change of the channel by the change of the lateral drift distance. The mathematical relationship between the inner channel configuration unit and the outer contour of the deposited channel in complex cases also shows the corresponding mathematical relationship, which confirms the feasibility of this idea and method.

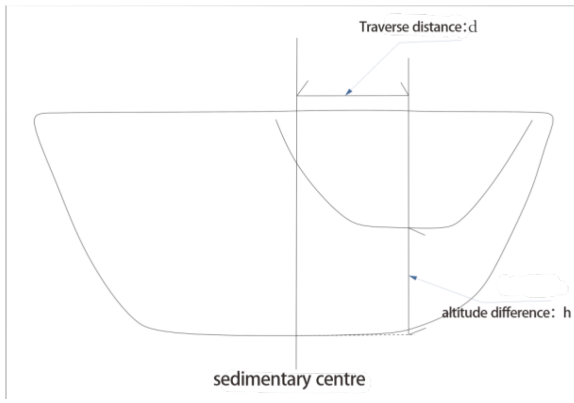

Figure3: Schematic representation of depositional parameters in a simple deep-water channel

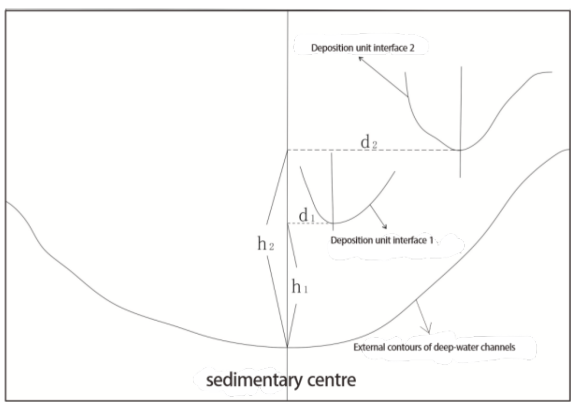

Figure 4: Schematic of depositional parameters of a simple multi-phase deep-water channel

In order to strengthen the mathematical approach to geological description, in addition to the absolute value of the height of the interface bottom point and the drift distance of the sedimentary median axis, the degree of steep inclination of the interface curvature and the situation of the interface intersections can also be compared to increase the comparison conditions, prevent the emergence of polysolvency or multiplicity of possibilities, and ensure that the uniqueness of the built-in sedimentary conformation unit depositional period, and the reasonability conforms to the description of the geological body.

Based on this cross-sectional data, mathematical linking is performed to form three-dimensional stereo model data. Specifically, vertical and transverse sections can be used to identify the sedimentary outlines of the deepwater channels in the region, and the characterisation parameters are transformed according to the differences in the constitutive units. On the vertical section, the width of the waterway is portrayed from left to right according to the curvature; the depth of the waterway can be portrayed by using the seismic wave time-depth conversion method to determine the specific value; the slope of the waterway bank is analogous to the beach, step, valley, and bottom of the terrestrial water body, and the curvature is expressed in combination with the gradient. On the plane projection, the length and curvature of watercourses are classified according to the New Zealand sedimentary watercourse classification method. Eventually[22,23], the geological description of watercourse morphology was transformed into specific data description quantitative parameters such as width, depth, left width, right width, left depth, right depth, left bank slope, right bank slope, curvature, topographic slope, height, thickness, curvature amplitude, curvature length, and so on.

Mathematical geological methods are used to construct a characterisation data model of deepwater channel sedimentation, to unify the data configuration based on morphological simulation, and to establish an analysis and evaluation system and method for universal depositional periods and sequences, so as to transform traditional geological descriptions into quantitative mathematical parameters, to effectively reduce the emergence of multiplicity of solutions, and to ensure uniqueness and reasonableness of the depositional periods of built-in depositional configurations, which are in line with the geological logic of the descriptions. Based on the quantitative analysis of deep-water channel configuration, this method can effectively enter and sort out a large amount of quantitative and qualitative data of deep-water channels, and transform the raw data into mathematical model expressions of representation parameters, control factors, geometric descriptions, regional information and so on according to mathematical parameter calibration. The information is processed by mathematical and geological methods, and the original three-dimensional data and the mixed geological background information are converted into a series of diversified and precise quantitative data expressions of deep-water channel configurations, and simulations and researches are carried out on the morphology changes along the flow direction of the watercourses, sedimentary geomorphological features of the watercourses, spatial arrangement of the internal configurational units of the watercourses, spatial superimposed features of the watercourses, and the period of the built-in configurational unit deposition and are combined with the control factors of the different work zones to compare the different sedimentary units and to find out the results. In addition, the development characteristics and scale patterns of the watercourse configuration under different depositional environments are compared with the control factors of different work areas. On the basis of the large amount of stored data, it can help quantitative research, morphological simulation and depositional period of deep-water channel configuration.

5. Conclusions

The method of constructing mathematical geological models can solve the problem of quantitatively expressing the parameters of the sedimentary period configuration of deep-water channel sedimentary geological bodies in the field of deep-water channel sedimentary geological bodies, and at the same time, combining with seismic and logging data to carry out the study of reservoir configuration, so as to derive a universal mathematical geological method for further lithology identification and rock layer classification in the ‘production, storage, capping, circling, transportation and preservation’ of hydrocarbon reservoirs on the basis of obtaining the results of the sedimentary period by using mathematical geological methods of parameterised expression. In order to use the parametric expression of mathematical geological methods to obtain the results of the sedimentary period, and based on the results of the ‘production, storage, capping, circling, transportation and preservation’ of oil and gas reservoirs, we have developed a universal mathematical geological method for further lithology identification and rock stratification.

In recent years, Yanling Luo, Guangyi Hu et al. Geostatistical inversion of high-resolution reservoir prediction method using mathematical geological methods has been rapidly developed and widely used for oil and gas reservoirs in deepwater waterway sedimentary geological bodies. Reservoir geostatistics is a mathematical method for geostatistically significant reservoir spatial prediction using inversion by combining the vertical resolution of logging data and the horizontal resolution of seismic[24].This method greatly improves the seismic longitudinal resolution, however, the transverse phase change of the river phase reservoir is fast, the river migration oscillates randomly, the composite river sand body is longitudinally multiphase stacked and transversely cut and stacked, and the internal structure is complex. Geostatistical inversion of high-frequency components from stochastic simulation, inversion results of strong randomness[25], low lateral resolution, inversion results often show a more serious modelling, the internal structure of the reservoir is masked, and requires a high degree of well control and uniform distribution, which is not conducive to carry out the anatomy of reservoir configuration under the conditions of offshore sparse well network[26].

By combining the deep-water curved watercourse depositional model with quantitative geological description and mathematical geological methods, and adopting the concept of ‘combination of well seismic, mathematical transformation, model fitting, and dynamic validation’ in the study of the configuration, using the waveform-phase-controlled inversion data that maintains the reservoir structure, the spatial spreading of the configuration units of different grades and their superpositional relationship can be finely characterised, and effectively reduce the uncertainty of the inter-well reservoir configuration prediction and improve the accuracy of the identification and delineation of a single channel. It also effectively reduces the uncertainty of reservoir configuration prediction between wells and improves the accuracy of single channel identification and delineation. However, how to efficiently and fully apply mathematical geological theories and methods to carry out fine geological modeling and numerical simulation, use well seismic data to improve the prediction accuracy of single sand body in reservoirs, finely describe the depositional interfaces and distribution characteristics of sand bodies, and figure out the distribution characteristics of reservoir sand bodies, so as to explain the specific conditions of ‘production, storage, capping, circling, transportation and preservation’ of deep-sea reservoirs and mathematical laws still have challenges. There are still challenges in the interpretation of deep-sea oil and gas reservoirs and mathematical laws, and it is necessary to further play the role of well seismic data and explore new ways of simpler and smarter interpretation of mathematical geological well seismic data.

References

[1] Cheng Qiuming.What are mathematical geosciences and its frontiers?[J]Earth Science Frontiers,2021,28(3):006-025.

[2] HOWARTH R J.Dictionary of mathematical geosciences:with historical notes.[M].Cham,Switzerland:Springer,2017.

[3] VISTELIUS A B.Problems of mathematical geology:a contribution to the history of the problem[J].Geologiya i Geofizika,1962,12(7):3-9.

[4] AGTERBERG F P.Geomathematics:theoretical foundations,applications and future developments[M].Cham,Switzerland:Springer,2014.

[5] ZhouWei.Research progress on architectural patterns and formation mechanisms of deep-water unidirectionally migrating channels[J].JOURNALOFPALAEOGEOGRAPHY.2021,23(6):1082-1094.

[6] Emiliano Mutti,William R.Normark.An Integrated Approach to the Study of Turbidite Systems[J].Frontiers in Sedimentary Geology.1991.

[7] JANOCKO M,NEMEC W,HENRIKSEN S,et al.The diversity of deep-water sinuous channel belts and slope valley-fill complexes[J].Marine and Petroleum Geology, 2013, 41: 7-34.

[8] YAO Yue,ZHOU JiangYu,LEI ZhenYu,et al.High Restriction Seismic Facies and Inner Structural Segmentation Features of the Central Canyon Channel Systems in Xisha Trough Basin[J].ACTASEDIMENTOLOGICASINICA.2018,36(4):787-795.

[9] MAYALL M,JONES E,CASEY M.Turbidite channel reservoirs-key elements in facies prediction and effective development[J].Marine and Petroleum Geology, 2006, 23(8): 821-841.

[10] POSAMENTIER H W,KOLLA V.Seismic geomorphology and stratigraphy of depositional elements in deep-water settings[J].Journal of Sediment Research, 2003, 73(3): 367-388.

[11] GONG C,WANG Y,STEEL R J,et al.Flow processes and sedimentation in unidirectionally migrating deep-water channels: From a three-dimensional seismic perspective[J].Sedimentology, 2016, 63(3): 645-661.

[12] Xu Xuhui,Lu Jianlin,Wang Baohua,et al.Marine basins in China:Petroleum resource dynamic evolution and exploration directions[J].Earth Science Frontiers.2022,29(6):073-083.

[13] Li Hua,He Youbin,Tan Mengting,et al. Evolution of and reservoir distribution within deep-water gravity flow channel-lobe system：A case study of the Ordovician Lashenzhong Formation outcrop at western margin of Ordos Basin[J].Oil & Gas Geology,2022,43(4):917-928.

[14] Li Hua,He Youbin.Research progress on deep-water gravity flow channel deposit[J].Journal of palaeogeography.2020,22(1):161-174.

[15] Zhao Xiaoming,Ge Jiawang,Tan Chengpeng,et al.Research status and prospect of deep sea channel reservoir architecture and its response mechanism to synsedimentary structure[J].China offshore Oil and Gas,2019,31(5):76-87.

[16] ZUO Guoping,FAN Guozhang,SUN Hui,et al.Key evaluation techniques for deep-water petroleum exploration and its application in the offshore of East Africa[J].Marine Origin Petroleum Geology.2021,26(3):211-223.

[17] Lin Chengyan,Chen Shizhen,Zhang Xianguo,et al.Probability constraint method based on multiple trend integration and its application in reservoir modeling[J].Acta Petrolei Sinica.2015,36(6):730-739.

[18] Chen Yuhang,Yao Genshun,Lu Fuliang,et al.Sedimentary characteristics and controlling factors of Oligocene deep-water channel-lobe in Rovuma Basin of the Fast Africaj[J].Acta Petrolei Sinica,2017,38(9):1047-1058.

[19] A.Fuhrmann,I.A.Kane,M.A.Clare,et al.Hybrid turbidite-drift channel complexes:An integrated multiscale model[J]Geology. 2020,48(6):562-568.

[20] Bu Fanqing,Zhang Xu.Geological Modeling of Combined Incised-Channel Systemin Deep-water Sediment Gravity Flow Deposits:A Case of Block OML130 in Niger Delta Basin, West Africa[J].Marine Origin Petroleum Geology.2018,23(2):90-96.

[21] Wu Shenghe, Li Yupeng.Reservoir modeling: Current Situation and Development Prospect[J].Marine Origin Petroleum Geology.2007,12(3):53-60.

[22] Wang Guangxu,Wu Wei,Li Quan,et al.Migration and Sedimentary Evolution of the Miocene Deep-water Channel in the Deep-water Taranaki Basin,New Zealand[J].Acta Sedimentologica Sinica.2023,41(1):85-96+4.

[23] Wang Guangxu,Wu Wei,Lin Changsong,et al.Migration rules and depositional model of Quaterary deep-vater channelin 'Taranaki Basin, New Zealand[J]Journal of China University of Petroleum (Edition of Natural Science),2022,46(3):13-24.

[24] Hu Cuangyi.Xiao Dakun,Fan Tingen,et al.New theory and method of fluvial reservoir architecture studyConcepts,contents and characterization of offshore oilfield fluvial compound sand-body architecture[J].JOU R NALOFPALAEOGEOG R APHY.2019,21(1):143-159.

[25] Luo Yanling.Predicting method by the well and seismic integration for the fluvial facies reservoirs in lamadlan oilfield[J].Petroleum Geology and Oilfield Development in Daqing.2016,35(4):143-146.

[26] Huang Jianting,Li Hao,Pan Guangming,et al.Meandering river reservoir architecture characterization based on seismic inversionmaintaining reservoir structure [J].China Offshore Oil and Gas,2022.34(5).94-100.