Frontiers in Earth Science

TYPE Original Research
PUBLISHED 09 February 2024
DOI 10.3389/feart.2024.1292104

Meteoric water effect of diagenesis processes in deep carbonate reservoirs

Zhen Wang[1]*, Yiqiong Zhang[1], Xueke Wang[1], Yaping Lin[1], Li Jiang[2] and Xiaozhen Zhang[2]

[1]Research Institute of Petroleum Exploration & Development of CNPC, Beijing, China, [2]PST Service Corp, Beijing, China

OPEN ACCESS

EDITED BY
Mohammad Abdelfattah Sarhan,
Damietta University, Egypt

REVIEWED BY
Amir Ismail,
Texas A&M University Corpus Christi, United States
Abdelmoneam Raef,
Kansas State University, United States

*CORRESPONDENCE
Zhen Wang,
✉ wangzhen@samadhi-petrotech.com

RECEIVED 11 September 2023
ACCEPTED 22 January 2024
PUBLISHED 09 February 2024

CITATION
Wang Z, Zhang Y, Wang X, Lin Y, Jiang L and Zhang X (2024), Meteoric water effect of diagenesis processes in deep carbonate reservoirs.
Front. Earth Sci. 12:1292104.
doi: 10.3389/feart.2024.1292104

As the world's main oil and gas resource, the deep carbonate reservoir has great exploration-development potential. However, it is difficult to make development and exploration due to its complex diagenesis processes. During the formation of carbonate reservoirs, the effect of meteoric water forms karst holes for oil and gas reservoirs, but the complex internal mechanism severely restricts the exploration and development of carbonate reservoirs. This paper takes the deep carbonate reservoirs in the Tarim Basin as the research object, studies the diagenesis processes in deep carbonate reservoirs through geological survey, analyzes the effect of meteoric water on porosity and mineral changes in carbonate reservoirs at different diagenetic stages by using laboratory test, theoretical analysis, and numerical simulation research methods. The numerical simulation method is used to simulate the porosity changes and mineral evolution of reservoirs in different diagenetic stages, and the conclusion is drawn that meteoric water has an impact on reservoir minerals and porosity. The results show that the carbonate reservoirs in the Tarim Basin have high porosity and good permeability, and the reservoirs have experienced deposition, compaction, dissolution, and hydrothermal stages, and have experienced meteoric water effects for a long time, resulting in rock dissolution, regenerative precipitation and chemical reaction; Quartz and feldspar minerals are the most in the sample through laboratory tests, the content of quartz decreased first, then increased and decreased, and the content of chlorite and mica changed little during the whole diagenesis processes. With the injection of organic acid, the porosity of the reservoir increases, with the continuous increase of temperature and pressure, the porosity decreases. After the second injection of organic acid, the porosity increases continuously, and finally, the porosity decreases. TOUGHREACT is used to simulate the static reaction of water and rock, simulating six diagenetic stages. With the injection of organic acid, the porosity increases continuously and then reaches equilibrium. The sudden increase in temperature and pressure leads to an increase in porosity, and the porosity of the reservoir changes little during the second injection of organic acid, and the porosity decreases in the final stage. The research results provide theoretical data support for guiding oil and gas exploration in deep carbonate reservoirs.

KEYWORDS

carbonate, reservoir, diagenesis processes, meteoric water effect, oil and gas exploration

Introduction

Deep carbonate reservoirs are one of the major oil and gas resources worldwide, with enormous exploration and development potential. However, the exploration and development of deep carbonate reservoirs face significant challenges, and their complex diagenetic processes lead to many shortcomings in our understanding of their formation mechanisms and physical characteristics. Among them, atmospheric precipitation, as an important link in the sedimentation process of carbonate rocks, has a significant impact on the porosity and mineral composition changes of reservoirs. Therefore, in-depth research on the impact of atmospheric precipitation on the formation and development of deep carbonate reservoirs has important theoretical and practical significance for guiding exploration and development work. This study takes the deep carbonate reservoirs in the Tarim Basin as the research object, and analyzes the impact of atmospheric precipitation on reservoir porosity and mineral composition in different diagenetic stages by means of geological survey and laboratory experiments. The results indicate that atmospheric precipitation is one of the crucial links in the formation process of deep carbonate reservoirs, which can affect the physical and chemical properties of rocks such as dissolution, regeneration precipitation, and chemical reactions, thereby significantly affecting reservoir porosity and mineral composition. Through this study, we can better understand the formation mechanism of deep carbonate reservoirs and provide scientific basis and technical support for oil and gas exploration and development.

Literature review

Located in southern Xinjiang, my country, with a total area of $5.96 \text{x} 10^5 \text{km}^2$, the Tarim Basin is rich in carbonate reservoir resources, which are composed of dolomite and limestone (Asjad et al., 2023). Among them, the dolomite reservoir is a high-quality reservoir type with high porosity and good permeability (Mehrabi, 2023). Formed in the marine environment from the late Paleozoic to the early Mesozoic, the deep carbonate reservoirs are carbonate reservoirs gradually depositing and formed by biological and abiotic substances in seawater, which are mainly distributed in the Piedmont areas and the central uplift zone on the north and south sides of the Tarim Basin (Desbarats et al., 2022).

This paper takes the deep carbonate reservoirs of the Tarim Basin as an example. As China's most important marine carbonate oil and gas basin, the Tarim Basin has proven oil reserves of $2.5 \times 10^9 \text{t}$ and natural gas reserves of $2 \times 10^{11} \text{m}^3$. Deep-ultra-deep carbonate rocks have great potential for oil and gas exploration (Khosravi et al., 2023). The evolution of deep carbonate reservoirs in the Tarim Basin has gone through deposition, compaction, dissolution, and hydrothermal stages, and was mainly formed from the Paleozoic to the Mesozoic (Rizwan et al., 2023). As the basis of deep carbonate reservoir formation, sedimentation includes many types such as carbonate sedimentation, biological processes, chemistry deposition, and so on. Carbonate reservoirs undergo compaction with sediment accumulation, making the rock more compact (Shatskiy et al., 2022). Deep carbonate reservoirs have experienced long-term dissolution, forming rich pores and fracture systems. Hydrothermal action had an important impact on the diagenetic evolution of deep carbonate reservoirs, which changed the pore structure and chemical composition of the reservoir and played an important role in the formation and evolution of the reservoir (Xiang et al., 2023). During the diagenetic evolution of deep carbonate reservoirs, the meteoric water effect has been experienced for a long time. The water in the atmosphere enters the ground through precipitation, evaporation, and infiltration, and interacts with the underground water body, which plays an important role in the dissolution of rocks, reprecipitation, and chemical reactions (Memon et al., 2023).

Currently, the most significant oil and gas reservoirs are the deep carbonate ones (Yousef et al., 2023). It is crucial to comprehend the diagenetic evolution to enhance exploration and development of oil and gas. Reservoirs undergo physical, chemical, and biological changes during diagenesis due to factors like high temperature, pressure, and groundwater. The rock mass undergoes dissolution, sedimentation, and recrystallization processes. As a result, the characteristics of the reservoir pores, permeability, and oil and gas storage properties are in a constant state of change. China has the world's largest inland basin, with well-developed deep carbonate reservoirs and enormous potential for oil and gas exploration and development. Exploration technology has revealed that meteoric water dissolution affects the porosity of carbonate reservoirs during diagenesis. Large karst holes can be found at depths below 200 m in reservoirs due to the strong ability of meteoric water to dissolve carbonate rocks. However, it is difficult to maintain meteoric water in the early stages of formation, making it impossible to accurately analyze the mechanism of action between meteoric water and carbonate rocks (Yang et al., 2023). Studying the impact of meteoric water on pore development in reservoirs is crucial for the exploration and extraction of oil and gas resources. However, accurately and quantitatively analyzing this influence remains a challenge. Therefore, investigating the meteoric water effect during the diagenetic evolution of deep carbonate reservoirs is of great significance.

Scholars have conducted research on how meteoric water affects carbonate reservoir diagenesis in various regions. Jiu et al. (2021) examined how meteoric water leaching affects carbonate reservoirs. They focused on five typical carbonate reservoirs in the Tarim Basin and conducted quantitative studies using theoretical analysis and numerical simulation. Their research investigated how the leaching of meteoric water under various conditions affected mineral dissolution, precipitation, transformation, and porosity changes in the reservoirs. The impact on the reservoirs varied depending on leaching speed and time, and different mineral types experienced distinct dissolution, precipitation, and transformation processes (Jiu et al., 2021). A study conducted by Yang and his colleagues in 2023 focused on the freshwater diagenetic effect of carbonate rocks in the Xisha Islands. By analyzing drilling cores, they were able to determine the diagenesis age, mineral composition, major and trace elements, and carbon and oxygen stable isotopes of the cores. The mineral composition of the cores revealed that the upper section (0–20 m) consists of aragonite and high and low magnesium calcite, while the middle section (20–40 m) consists of aragonite and low magnesium calcite, and the lower section (40–55 m) consists mainly of stable low magnesium calcite. The carbon and oxygen isotope values in the lower section indicate a significant negative impact of freshwater diagenesis, while the middle and upper sections show less impact with positively biased carbon and oxygen isotope values and high amplitude and frequency changes in unstable aragonite and high-magnesium calcite. The study suggests that the lower section has experienced a greater impact of meteoric water diagenesis compared to the middle and upper sections (Yang et al., 2023). In their research, Da Conceicao et al. (2022) examined the effects of water-rock interaction on alkaline carbonatite reservoirs. They chose to study the Alkaline Carbonatite in Upper Parnaíba and found that it contains Nb, P, Ti, Ca^{2+}, and HCO_3^- among other elements. The dissolved load of the water has an annual average flux of 49 t/km and is highest in the summer. The annual flux of Cl^-, PO_4^{3-}, and NO_3^- in the water is negative, suggesting that these ions are primarily introduced through rainwater. Silicate weathering, dissolution, and rainfall contribute to this process. Additionally, the chemical weathering rate of alkaline rock is approximately 4–5 m/M (da Conceição et al., 2022). Zhang et al. (2022) examined the changes in the physical and chemical properties of carbonatite minerals under the influence of melts through metasomatism. They used SIMS technology to measure the water content of peridotite xenolith suites and found that as silicate metasomatism intensifies, the water content in olivine increases. However, the water content in carbonate metasomatized olivine decreases, indicating that silicate metasomatized olivine has higher water solubility. Additionally, the study suggests that lithium enters olivine preferentially during the silicate metasomatization process, while carbonatite metasomatism remains in the melt. These two different metasomatic processes result in distinct lithium isotope behavior (Zhang et al., 2022). A study conducted by Chen et al. (2021) analyzed the type and evolution mechanism of geothermal water resources enriched in carbonate rocks in Southwest China. The researchers collected 20 samples of geothermal water from the region and used various methods such as XRD, SEM, mineral saturation index, inverse geochemical simulation technology to analyze the water's type and evolution mechanism in carbonate rocks. The study found that the main components of geothermal water in the area are $CaSO_4$, $Mg(HCO_3)_2$, and NaCl, and the source of the water is primarily recharged by atmospheric precipitation. The salt rock reservoirs in the region consist of dolomite, calcite, halite, a small amount of clay minerals, and quartz. During the geothermal water runoff, there is a strong interaction between the water and surrounding rocks of the thermal reservoir, leading to the formation of carbon. The findings of this study on the evolution mechanism of geothermal water in salt rock areas can provide useful references for the development, utilization, and protection of geothermal water resources (Chen et al., 2021).

In the creation of carbonate reservoirs, the presence of meteoric water contributes to the formation of karst holes that hold oil and gas reservoirs. However, the intricate internal mechanism presents significant obstacles to the exploration and development of carbonate reservoirs. This study focuses on the deep carbonate reservoirs in the Tarim Basin and conducts geological surveys to examine the diagenetic evolution process of carbonate reservoirs in the area.

Methods

This research explores the impact of meteoric water on deep carbonate reservoirs during their diagenetic evolution. The study investigates changes in fluid composition, rock minerals, and rock porosity at different stages of diagenesis to analyze the evolution of water-rock chemical reactions, reservoir porosity, and mineral composition throughout the process (Yang et al., 2023). The research utilizes a reservoir diagenesis simulation system, an electronic balance, a scanning electron microscope, and an X-ray spectrometer, all developed in the author's home country. The reservoir diagenesis simulation system comprises six systems, including a heating furnace, pressure, liquid supply, product collection, overall control platform, and auxiliary systems. The system can adjust temperatures up to 500°C, the static rock pressure is 28 MPa/km, and the maximum pressure is 280 MPa (Yang et al., 2020).

The diagenetic physical simulation system used in this paper mainly consists of four parts: reaction kettle body, pressure pump, central control system and fluid supply and transportation system (As shown in Figure 1).

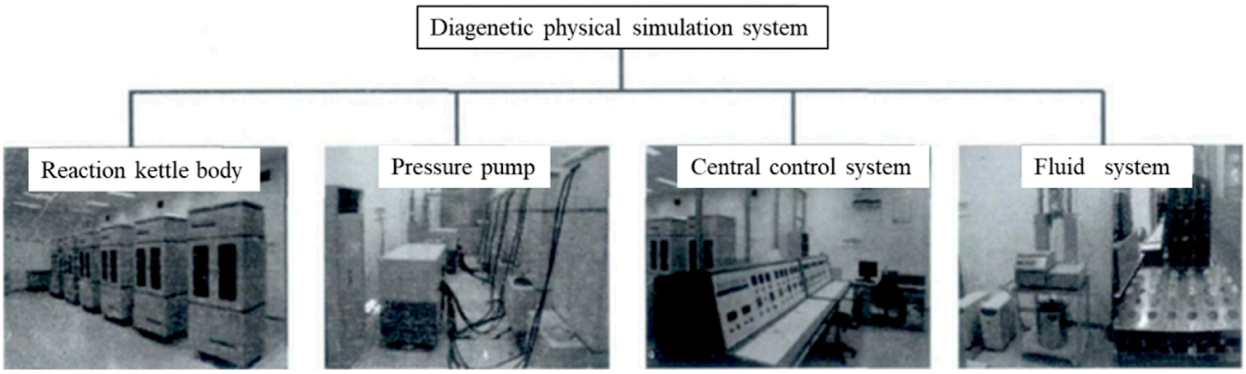

FIGURE 1
Photos of diagenetic physical simulation system.

TABLE 1 Quality and relative content of minerals in rock samples.

	Quartz	Potassium feldspar	Albite	Calcite	Granite	Tuff	Plaster
Particle size (mesh)	150-300-450	140–280	140–280	500–800	140–280	140–280	60–120
Required mass (g)	36	17	13	15	9	6	4
Relative content (%)	36	17	13	15	9	6	4

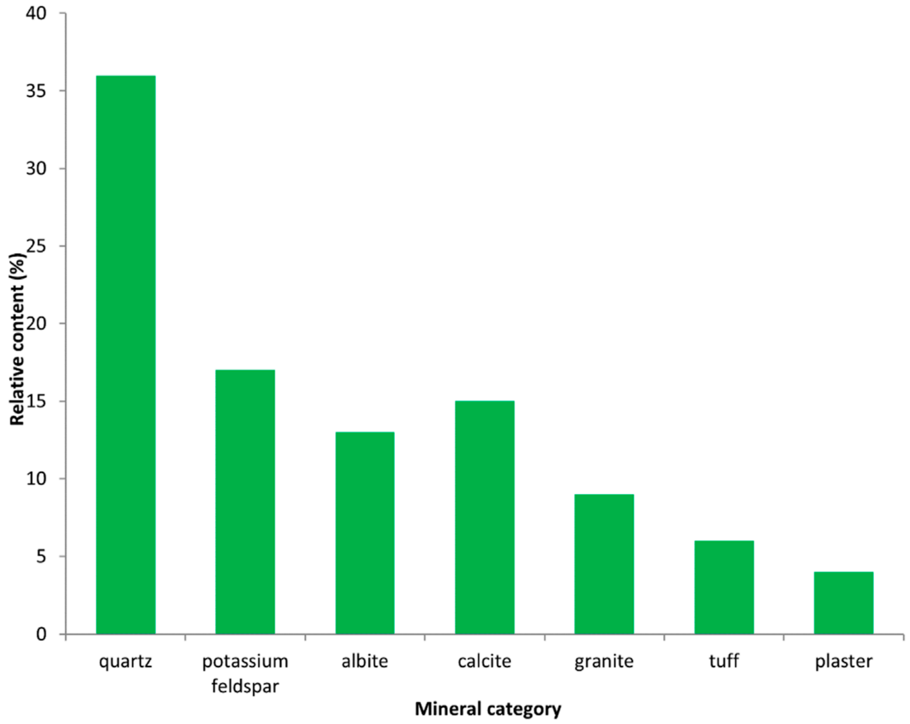

FIGURE 2
Relative contents of minerals in rock samples.

For the test, it was necessary to use pre-diagenetic minerals as initial rock samples. However, these minerals could not be obtained. To solve this problem, the test created a composition of pre-diagenetic minerals based on the evolution process of reservoir minerals and combined it with the diagenetic sequence and mineral transformation characteristics of the reservoir. The resulting mixture was divided into six parts, water was added, and the mixture was stirred into a viscous liquid, which served as the initial rock sample (Qamar et al., 2023). The samples in this test contained mainly fine mineral powders such as quartz, potassium feldspar, albite, calcite, granite, tuff, and mud. Table 1 shows the particle sizes and contents of these minerals, while Figure 2 illustrates the relative content of each mineral in the rock sample.

During the test, three different types of solutions were utilized: shallow groundwater, deep groundwater, and organic acid. Through on-site sampling investigations, the ion concentrations and chemical substance amounts were calculated for each fluid (Chen et al., 2022). Each solution was prepared separately and injected consecutively during the test, which was divided into six diagenetic stages. Each stage corresponds to specific diagenetic conditions, with a gradual increase in temperature and pressure. Table 2 displays the diagenetic evolution process conditions of the reservoir, while Figure 3 illustrates the temperature and pressure changes throughout the diagenetic evolution.

In the experiment, the thick samples were placed in six high-temperature and high-pressure reactors. The temperature was set to 120°C, and the pressure was set to 110 MPa. A constant confining pressure of 70 MPa was applied to consolidate the samples into columns. Shallow groundwater solutions were injected at a fixed flow rate. On the fifth day, one sample was extracted for testing, and the temperature of the remaining five samples was raised to 130°C, and the pressure increased to 120 MPa. Deep underground water solution was then injected. On the 10th day, one sample was taken out for testing, and the temperature of the remaining four samples was raised to 140°C, and the pressure increased to 130 MPa. Organic acid solution was then continuously

TABLE 2 Conditions of diagenetic evolution process.

Stage number	Diagenetic process	Temperature (°C)	Pressure (MPa)
1	Compaction	120	110
2	Early diagenetic stage	130	120
3	First injection of organic acid	140	130
4	High temperature and high pressure	160	145
5	Secondary injection of organic acid	170	155
6	Late diagenetic stage	180	165

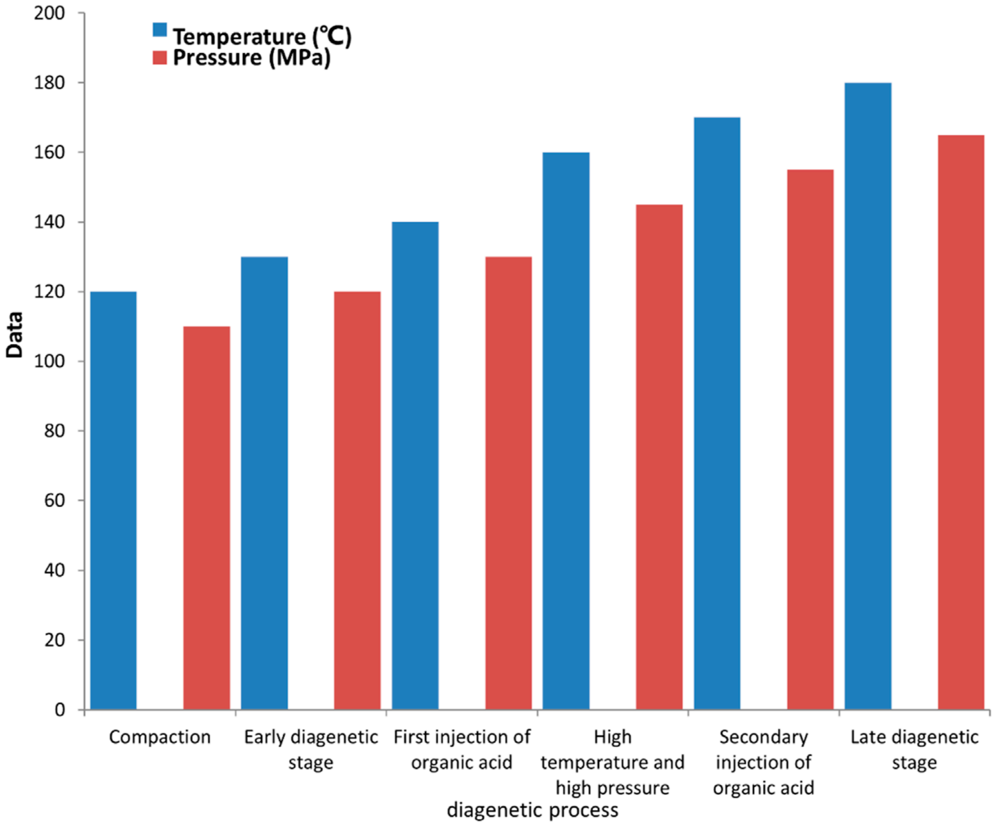

FIGURE 3
Changes of temperature and pressure during diagenetic evolution of reservoir.

injected. This process was repeated, and the last sample was extracted on the 30th day for testing. The changes in temperature, rock-static pressure, and fluid pressure were recorded throughout the experiment.

Through laboratory experiments, we conducted a numerical simulation of the reservoir diagenetic evolution process (Sarhan, 2023). The model consists of 3 grids, each being a cube with a side length of 3.5 cm. The middle grid acts as the simulation grid or the reactor, where it analyzes changes in solution and mineral composition. The upper and lower grids are boundary conditions, with the upper section being the injection end and the lower section being the sampling end. TOUGHREACT was utilized to simulate the static reaction of water and rock. The model is divided into 6 sub-models that correspond to 6 diagenetic stages. The temperature and pressure parameters in the model were set based on the conditions of each diagenetic stage. The physical and chemical characteristics of the sample and solution were determined through actual measurements.

TABLE 3 Content of mineral components in the initial sample.

	Quartz	Calcite	Anorthite	Potassium feldspar	Chlorite	Biotite	Muscovite
Relative content (%)	31	21	18	17	7	4	2

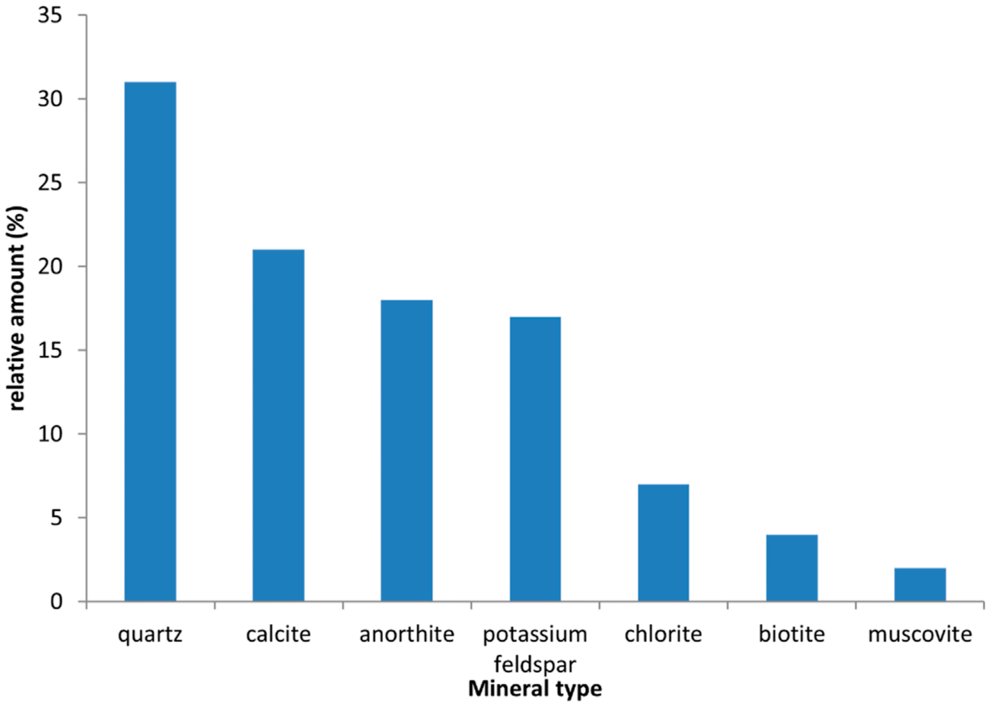

FIGURE 4
Relative content of mineral components in initial samples.

Results

Laboratory test results

To compare the changes in mineral content before and after the test, we used an X-ray spectrometer to test the mineral composition of the samples. Table 3 and Figure 4 show the initial mineral composition content of the samples. From Table 3 and Figure 4, we can see that quartz and feldspar minerals account for 62% of the sample, calcite accounts for 21%, and chlorite and mica account for 13%.

During the first stage, the system's temperature and pressure remained low, and most of the mineral content remained unchanged during the sample compaction process. Only the quartz mineral dissolved, reducing its content to 20%. In the second stage, the injection of deep groundwater solution caused quartz minerals to start precipitating, while calcite and feldspar minerals gradually dissolved, causing the content of potassium feldspar to decrease to 15%.

During the third stage, the mineral dissolution reaction intensified due to the injection of organic acids. Quartz minerals continued to precipitate. In the fourth stage, calcite, chlorite, and feldspar minerals precipitated under high temperature and high pressure conditions, while quartz minerals continuously dissolved. In the fifth stage, the second injection of organic acids caused the amount of quartz precipitation to reach 36%, and the dissolved content of calcite dropped to 2%.

In the last stage, formation water entered the reservoir and diluted the acidic solution in the system. Under alkaline conditions, most minerals precipitated, and their content increased. During the entire test process, the content of chlorite remained basically unchanged, and the content of mica precipitated in the early stage of the test. Its content increased from 6% to 10% and gradually dissolved in the later period.

The porosity of the rock sample was determined using various methods such as scanning electron microscope, X-ray spectrometer and casting thin section at different stages (Sarhan and Selim, 2023). The distribution of pores in the rock sample at different stages is shown in Table 4 and Figure 4. Table 4 and Figure 5 demonstrate that the injection of organic acid led to an increase in porosity to 23.76% as the minerals dissolved. However, with a continuous increase in temperature and pressure, calcite and feldspar minerals precipitated, causing the porosity to decrease to 18.42%. After a second injection of organic acid, the minerals dissolved, and porosity continued to increase, the Zone A of Thebes Formation is the best oil-bearing zone in RE-25 Well in terms of reservoir

TABLE 4 Pore distribution of samples in different diagenetic stages.

Stage	Early shallow burial diagenesis	First organic acid	High temperature and high pressure	Second organic acid	Late deep buried diagenesis
Average pore size (um)	41.42	28.32	34.54	27.91	22.32
Porosity (%)	17.45	23.76	18.42	24.76	15.61

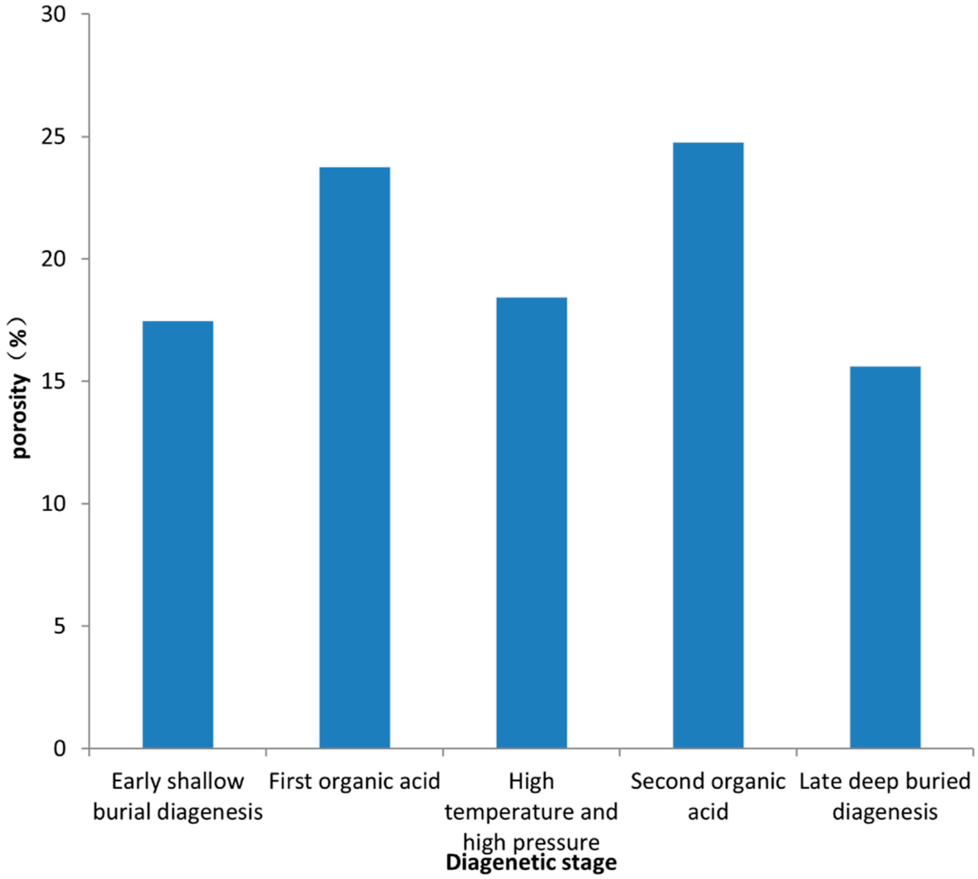

FIGURE 5
Pore distribution of samples in each diagenetic stage.

quality since it exhibits lowest shale volume (0.07), minimum water saturation (0.23) and lowest bulk volume of water (0.03) (Sarhan, 2021). In the final stage of deep burial diagenesis, a significant amount of minerals precipitated under high temperature, high pressure, and alkaline environment, leading to a decrease in porosity to 15.61%.

Numerical simulation results

To accurately model geological processes, numerical models based on laboratory experiments must extend the time frame of each diagenetic stage and apply it to a larger geological time scale. This study's simulation spans 30 million years, with the following diagenetic stages: compaction (30–26 Ma), early shallow burial diagenesis (26–22 Ma), first injection of organic acid (22–18 Ma), high temperature and pressure (18 Ma–14 Ma), second injection of organic acids (14–10 Ma), and late deep burial diagenesis (10 Ma-present).

In the first stage of diagenesis, the sample's porosity is affected by both mechanical and chemical compaction. However, in this paper, only chemical compaction was taken into account. As a result, the porosity decreased from 30.0% to 27.4%. Quantitative petrophysical analysis of the thick limestone interval (Area 1) of Well Dong 22 in Rabeh shows that the interval between 4,569 and 4,595 feet (26 feet thick) is the most promising interval in Area 1. This promising interval reflects good reservoir characteristics, with average oil and gas saturation of 53%, average shale volume of 21%, average total porosity of 20%, average effective porosity of 15% and average water volume of 0.07, The quantitative investigation displays that the examined zone has good petrophysical parameters with 0% shale volume, 9% effective porosity (Sarhan, 2020; Sarhan, 2021). It is worth noting that after mechanical compaction, the porosity of the reservoir was only 20.0%, The calculated "m" for Abu Roash D in the two studied wells are 1.56 and 1.34 for SWQ-21 and SWQ-25; respectively which is indicative of the fractured limestone nature (SarhanBasal and Ibrahim, 2017). In the second stage, calcite and quartz were cemented, but the low temperature and pressure did not cause significant changes in the reservoir's porosity. In the third stage, the injection of organic acid dissolved most of the minerals, leading to a continuous increase in porosity. The porosity eventually reached 23.5%, and the system entered a balanced state. However, the sudden increase in temperature and pressure in the fourth stage destroyed the previous balance. Most of the minerals dissolved in a short period of time, resulting in an increase in porosity. In the fifth stage, the second injection of organic acid had little effect on the reservoir's porosity since most minerals were already in a saturated state. Finally, in the last stage, the continuous entry of formation water diluted the acidic fluid in the reservoir. As a result, most of the minerals gradually precipitated, leading to a drop in porosity from 20.3% to 11.4%.

Conclusion

This study focuses on the formation of carbonate reservoirs in the Tarim Basin and the impact of meteoric water on their diagenetic evolution process. The complex internal mechanism of carbonate reservoirs often hinders their exploration and development. Therefore, the researchers conducted geological surveys, laboratory experiments, theoretical analysis, and numerical simulations to study the impact of meteoric water on carbon at different diagenetic stages.

The research findings suggest that the carbonate reservoirs in the Tarim Basin have high porosity and good permeability. These reservoirs have undergone deposition, compaction, dissolution, and hydrothermal stages, as well as meteoric water effects for a long time. The researchers used indoor experiments to prepare the initial rock sample and analyzed the mineral composition and content at different diagenetic stages. They also conducted numerical simulations of the reservoir diagenetic evolution process using TOUGHREACT.

The results show that the quartz and feldspar minerals accounted for 62%, calcite accounted for 21%, and chlorite and mica accounted for 13%. The quartz content decreased, then increased, and then decreased again throughout the entire stage, while the content of the other minerals remained basically unchanged. The porosity of the reservoir increased with the injection of organic acid but decreased as the temperature and pressure continued to increase.

In summary, the diagenetic evolution of deep carbonate reservoirs can be analyzed more comprehensively by combining laboratory tests and numerical simulation. Laboratory tests can simulate actual geological conditions, obtain experimental data, verify the accuracy of numerical simulation results, and improve the reliability of research. Numerical simulation can quantitatively analyze the effect of atmospheric fresh water and reveal the mechanism and law of diagenetic evolution of deep carbonate reservoirs. However, the combination of indoor test and numerical simulation also has some disadvantages. Indoor test consumes a lot of time and cost, and is limited by experimental conditions, which cannot completely simulate the natural environment. Numerical simulation has certain subjectivity in modeling and parameter selection, and the accuracy of results is affected by the limitations of the model.

When the laboratory test and numerical simulation are used for analysis, the conditions of the laboratory test often cannot completely simulate the deep geological environment, and the obtained data may have certain deviations. Although the numerical simulation can simulate the complex geological process more accurately, the establishment of the model and the selection of parameters will also have some influence on the results. Therefore, it is necessary to fully consider these limitations and conduct comprehensive analysis combined with actual geological survey data to obtain more reliable results of diagenetic evolution.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ZW: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Writing–original draft, Writing–review and editing. YZ: Conceptualization, Formal Analysis, Investigation, Resources, Software, Validation, Visualization, Writing–original draft, Writing–review and editing. XW: Conceptualization, Investigation, Methodology, Resources, Software, Supervision, Validation, Writing–original draft, Writing–review and editing. YL: Conceptualization, Data curation, Investigation, Methodology, Software, Supervision, Writing–original draft, Writing–review and editing. LJ: Conceptualization, Investigation, Resources, Software, Visualization, Writing–original draft, Writing–review and editing. XZ: Methodology, Resources, Software, Visualization, Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

The authors would like to show sincere thanks to those techniques who have contributed to this research.

Conflict of interest

Authors LJ and XZ were employed by PST Service Corp.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Asjad, S., Khan, K. F., Quasim, M. A., Sachan, H. K., and Javed, A. (2023). Microfacies and stable isotope analysis of Kuldhar Member Limestone (Callovian–Oxfordian), Jaisalmer Basin, western Rajasthan: implications for depositional environment and diagenetic evolution. *Carbonates Evaporites* 38 (4), 81. doi:10.1007/s13146-023-00905-6

Chen, X., Wang, M., Inoue, T., Liu, Q., Zhang, L., and Bader, T. (2022). Melting of carbonated pelite at 5.5–15.5 GPa: implications for the origin of alkali-rich carbonatites and the deep water and carbon cycles. *Contributions Mineralogy Petrology* 177 (1), 2. doi:10.1007/s00410-021-01867-5

Chen, Z., Zhu, L., Liu, P., Li, C., Zhou, Y., Li, Y., et al. (2021). Hydrogeochemical evolution mechanism of carbonate geothermal water in SouthwestSouthwest China. *Arabian J. Geosciences* 14, 1310–1318. doi:10.1007/s12517-021-07566-6

da Conceição, F. T., Vasconcelos, P. M., Godoy, L. H., Navarro, G. R., Montibeller, C. C., and Sardinha, D. S. (2022). Water/rock interactions, chemical weathering and erosion, and supergene enrichment in the Tapira and Catalão I alkaline-carbonatite complexes, Brazil. *J. Geochem. Explor.* 237, 106999. doi:10.1016/j.gexplo.2022.106999

Desbarats, A. J., Percival, J. B., Bilot, I., Polivchuk, M. J., and Venance, K. E. (2022). Drainage chemistry of mine tailings from a carbonatite-hosted Nb-REE deposit, Oka, Québec, Canada. *Appl. Geochem.* 138, 105216. doi:10.1016/j.apgeochem.2022.105216

Jiu, B., Huang, W., Mu, N., and Li, Y. (2021). Types and controlling factors of Ordovician paleokarst carbonate reservoirs in the southeastern Ordos Basin, China. *J. Petroleum Sci. Eng.* 198, 108162. doi:10.1016/j.petrol.2020.108162

Khosravi, M. H., Emami Niri, M., and Saberi, M. R. (2023). Effects of diagenetic processes on the velocity evolution in carbonate reservoirs. *Geomechanics Geophys. Geo-Energy Geo-Resources* 9 (1), 147. doi:10.1007/s40948-023-00683-4

Mehrabi, H. (2023). Deposition, diagenesis, and geochemistry of upper cretaceous carbonates (sarvak formation) in the zagros Basin and the Persian gulf, Iran. *Minerals* 13 (8), 1078. doi:10.3390/min13081078

Memon, F. H., Tunio, A. H., Memon, K. R., Mahesar, A. A., and Abbas, G. (2023). Unveiling the diagenetic and mineralogical impact on the carbonate formation of the indus basin, Pakistan: implications for reservoir characterization and quality assessment. *Minerals* 13 (12), 1474. doi:10.3390/min13121474

Qamar, S., Shah, M. M., Janjuhah, H. T., Kontakiotis, G., Shahzad, A., and Besiou, E. (2023). Sedimentological, diagenetic, and sequence stratigraphic controls on the shallow to marginal marine carbonates of the middle jurassic samana suk formation, north Pakistan. *J. Mar. Sci. Eng.* 11 (6), 1230. doi:10.3390/jmse11061230

Rizwan, M., Hanif, M., Ullah, S., and Ishaq, M. (2023). Detailed diagenetic investigation and their impact on the reservoir potential of Upper Cretaceous mixed carbonate-siliciclastic succession, Rakhi Nala Section, Eastern Sulaiman Range, Pakistan. *Carbonates Evaporites* 38 (2), 50. doi:10.1007/s13146-023-00871-z

Sarhan, M. A. (2020). Geophysical appraisal and oil potential for rudeis formation at west hurghada area, southern gulf of suez: detection of stratigraphic trap. *Arabian J. Geosciences* 13 (6), 263–269. doi:10.1007/s12517-020-5277-0

Sarhan, M. A. (2021). *Petrophysical characterization for thebes and mutulla reservoirs in rabeh east field, gulf of suez basin, via well logging interpretation*. Berlin, Germany: Springer International Publishing.

Sarhan, M. A. (2023). "Hydrocarbon potential of carbonate rocks in Egypt," in *The phanerozoic Geology and natural resources of Egypt* (Cham: Springer International Publishing), 675–690.

Sarhan, M. A., and Selim, E. S. (2023). Geophysical appraisal of fractured carbonate reservoirs: a case study of abu roash d member, abu gharadig field, western desert, Egypt. *Euro-Mediterranean J. Environ. Integration* 8, 395–408. doi:10.1007/s41207-023-00365-3

SarhanBasal, M. A. A. M. K., and Ibrahim, I. M. (2017). Integration of seismic interpretation and well logging analysis of abu roash d member, gindi basin, Egypt: implication for detecting and evaluating fractured carbonate reservoirs. *J. Afr. Earth Sci.* 135, 1–13. doi:10.1016/j.jafrearsci.2017.08.010

Shatskiy, A., Podborodnikov, I. V., Arefiev, A. V., Bekhtenova, A., and Litasov, K. D. (2022). Genetic link between saline and carbonatitic mantle fluids: the system NaCl-CaCO3-MgCO3±H2O±Fe0 at 6 GPa. *Geosci. Front.* 13 (6), 101431. doi:10.1016/j.gsf.2022.101431

Xiang, P., Ji, H., Shi, Y., Huang, Y., Sun, Y., and Xu, X. (2023). Characteristics, diagenesis, controlling factors and formation mechanism of deep-burial ordovician carbonate reservoirs in the yangshuiwu area, jizhong depression, bohai bay basin. *Arabian J. Sci. Eng.* 48 (1), 645–663. doi:10.1007/s13369-022-07050-7

Yang, J., Zhang, J., He, Z., Brandano, M., and Wu, C. (2023a). Controlling factors of meteoric diagenesis in karst reservoirs: an example from the majiagou formation, ordos basin, China. *Minerals* 13 (6), 812. doi:10.3390/min13060812

Yang, J. Q., Zhang, J. T., He, Z. L., and Zhang, T. (2023c). Paleoenvironment reconstruction of the middle ordovician thick carbonate from western ordos basin, China. *Petroleum Sci.* 20 (1), 48–59. doi:10.1016/j.petsci.2022.08.027

Yang, L., Chen, D., Hu, J., Meng, X., Liu, J., and Yang, W. (2023b). Understanding the role of sequence stratigraphy and diagenesis on the temporal and spatial distribution of carbonate reservoir quality: a conceptual modeling approach. *Mar. Petroleum Geol.* 147, 106010. doi:10.1016/j.marpetgeo.2022.106010

Yang, L., Yu, L., Chen, D., Liu, K., Yang, P., and Li, X. (2020). Effects of dolomitization on porosity during various sedimentation-diagenesis processes in carbonate reservoirs. *Minerals* 10 (6), 574. doi:10.3390/min10060574

Yousef, I., Morozov, V. P., Kolchugin, A. N., and Leontev, A. (2023). Impact of microfacies and diagenesis on the reservoir quality of upper devonian carbonates in southeast tatarstan, volga-ural basin, Russia. *Petroleum Res.* 8 (3), 386–403. doi:10.1016/j.ptlrs.2022.10.006

Zhang, W. F., Xia, X. P., Su, B. X., Xu, Y. G., Zhang, Y. Q., Yang, Q., et al. (2022). Distinct geochemical behavior of water in olivine between silicate and carbonatite metasomatism. *Minerals* 12 (9), 1090. doi:10.3390/min12091090