Journal of Geoscience and Environment Protection, 2023, 11, 333-350
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Reservoir Characterization of Special Dolomite Rock of Fengcheng Formation in Junggar Basin, China

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How to cite this paper: Huang, F. M., Liu, Y., Pan, C. H., Wang, D. C., Zhang, P., Fu, Y. P., Zhang, H., Su, H. B., Lu, J., Zhong, Z., & Wei, B. (2023). Reservoir Characterization of Special Dolomite Rock of Fengcheng Formation in Junggar Basin, China. *Journal of Geoscience and Environment Protection, 11,* 333-350.
https://doi.org/10.4236/gep.2023.119021

Received: August 12, 2023
Accepted: September 25, 2023
Published: September 28, 2023

Abstract

Dolomites and eruptive rocks are well-developed in the Permian Fengcheng Formation in Junggar Basin in China, in which oil and gas are accumulated extensively. Until now, high-yield industrial oil and gas flows have been obtained in the dolomitic tuff of the second unit of the Fengcheng Formation, which demonstrates the huge exploration potential of the thick layer of massive dolomitic tuff. The lithology of the second unit of the Fengcheng Formation in this area has gradually transformed from the dolomite, dolomitic tuff to siltstone from east to west. Moreover, the well testing shows that the reservoir is oil-saturated, and the production rate mainly depends on the reservoir's physical properties and fracture development. In this study, different types of data including core data, well log and seismic data are used cooperatively to characterize the sedimentary, structure and fracture features of the Fengcheng Formation, and then characterize the promising target zone in the study area. The result indicates that hydrocarbons are most accumulated along the deep fault in the Wu-Xia fault zone, which will be the favorable zone for the next progressive exploration.

Keywords

Junggar Basin, Fengcheng Formation Section II, Paragenesis, Dolomitic Tuff, Fracture

1. Introduction

Carbonate reservoir plays an essential role in global oil and gas exploration, of which reserves account for 60% of the world's conventional oil and gas reserves and production accounting for about 40% (Halbouty, 2003). In terms of regional distribution, two-thirds of the world's total crude oil production comes from the Middle East, where over 80% of oil-bearing formations are carbonate reservoirs. Moreover, half of North America's oil production comes from carbonate reservoirs, which makes carbonate reservoir exploration and development crucial (Tian et al., 2019). Typical carbonate oil and gas reservoirs around the world include the Permian Yates field in West Texas of the USA, Grosmont field in Alberta, Canada, Kharyaga field in the Timan-Pechora Basin in Russia, the Cretaceous Golden Lane field in the Tampico area of Mexico, the Cretaceous Fateh field in Dubai, and the Tarim Basin's Tahe field and Jingbian gas field in the Ordos Basin of China (Akbar et al., 2000; Zeng et al., 2022).

Dolomite-eruptive paragenesis sedimentation distributed widely around the world plays an increasingly important role in sedimentary reservoirs and the exploration and development of oil and gas and has attracted a huge amount of attention from all around the world (Warren, 2000, 2006). The dolomite-eruptive paragenesis is the most favorable source-reservoir-seal association, which can accumulate and save the hydrocarbons simultaneously and show extremely high exploration potential (Allen, 2007). These kinks of sedimentation are widely distributed in Tarim Basin and Junggar Basin in China. Dolomite-eruptive paragenesis sedimentation was formed from endogenously and exogenously mixed sedimentation environment, of which the supply of exogenous materials includes the input supply of terrigenous clastic sediments such as deltas and rivers, as well as the input supply of tuff rocks such as eruptive rocks or volcanic dust; while endogenous material generation mainly develops from dolomitic sandstone or dolomitic tuff with chemical sedimentation as the mainstay in low-energy lagoon environments. Endogenous and exogenous sedimentation is mixed, the relationship of which manifests as the ebb and flow (**Figure 1**).

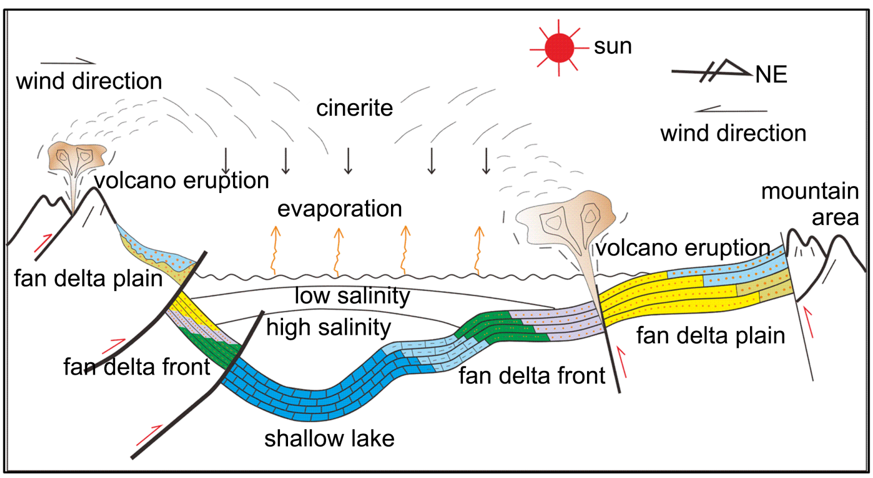


Figure 1. Near-lake terrigenous clastic rocks and stuff sedimentation pattern of endogenously and exogenously mixed sedimentation.

2. Geological Background

The Lower Permian in the research area belongs to the oil-bearing formation, with an obvious thickening trend from the basin to the front edge of the orogenic belt. The Jiamuhe Formation of the Permian is a mixture of intertidal and volcanic facies consisting of variegated tuffaceous and brecciated rocks of purplish-gray, reddish-brown, and grayish-green colors, as well as volcanic rocks, which are widely distributed in this area (Chen et al., 2012). The thickness of the Jiamuhe formation decreases from the orogenic belt to the basin, and it is regionally unconformable with the basement at an angular discordance. The Permian Fengcheng Formation in the Mahu Slope Area of the Junggar Basin has developed a large set of dolomites and eruptive rocks, with complex and diverse lithology (Kuang et al., 2012). The Fengcheng Formation consists of gray and dark gray clouded mudstone, siltstone, muddy limestone, and tuffaceous limestone. It is a residual marine sediment, containing algal fossils and authigenic sea-green stones. Its distribution range is slightly smaller than that of the Jiamuhe Formation, and it shows an obvious west-thickness and east-thinness trend. The thickness of the formation is mainly affected by thrusting and overthrusting in the west, while it is due to erosion by denudation and uplift in the east (**Figure 2**).

The Lower Permian Fengcheng Formation can be divided into three sections from bottom to top: Fengcheng Formation Section I, Fengcheng Formation Section II, and Fengcheng Formation Section III (Kuang et al., 2012). The lithology of the Fengcheng Formation Section I is dominated by volcanic rock sedimentation, and the lithology is dominated by eruptive-mutual-melting welded breccia tuff, and in Fengcheng Formation Section I, high-yield industrial oil and gas flows have been discovered; the lithology of Fengcheng Formation Section II is mainly dark gray laminae dolomite, dolomitic tuff and tuffaceous fine sandstone interbeded banding salt minerals; the lower lithology of Fengcheng Formation Section III is mainly gray-black, gray-green dolomitic mudstone and silty mudstone while the upper part is argillaceous dolomite, and the reservoir is argillaceous dolomite (**Figure 3**).

The Marhu slope area of the Junggar Basin has undergone three major tectonic movements. The Haixi period tectonic transport at the end of the Permian formed the basic outline of the Wu-Xia fault zone (Lei et al., 2017). During the Carboniferous to Permian period, the area was mainly affected by thrust. The Indochinese period was the stereotyping period, and then the fracture basically ceased to be active after the Late Jurassic. Thrusted and overlaid by horizontal stresses in the north-south direction and squeezed in the east-west direction, the fractures are arranged in a tile-like arrangement on the cross-section and spread out in an arc on the plane (**Figure 4**). Affected by multi-stage thrust fault, the strata are ascending from south to north in a stepped manner, meanwhile, the Triassic system in the upper part of the northern structure is eroded layer by layer. The structure of the Mahu slope area is located in the Wuxia fault zone (**Figure 5**).

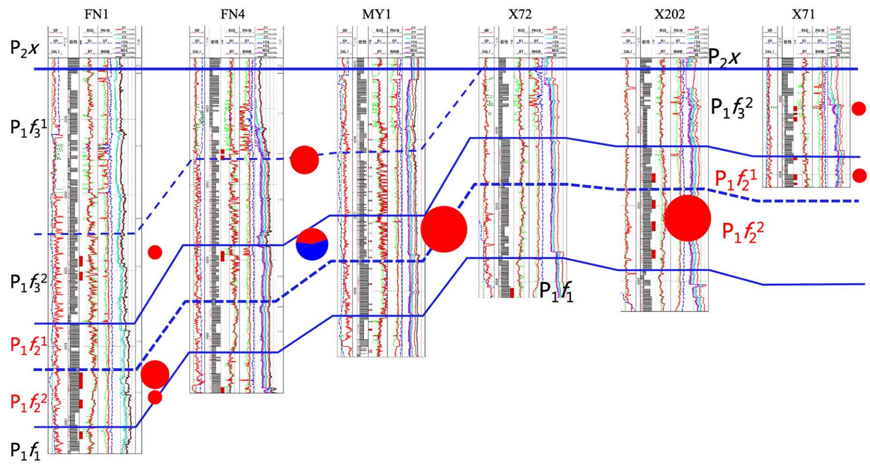


Figure 2. Stratigraphic correlation map of Fengcheng Formation in wells FN1, FN4, MY1, X72, X202 and X71.

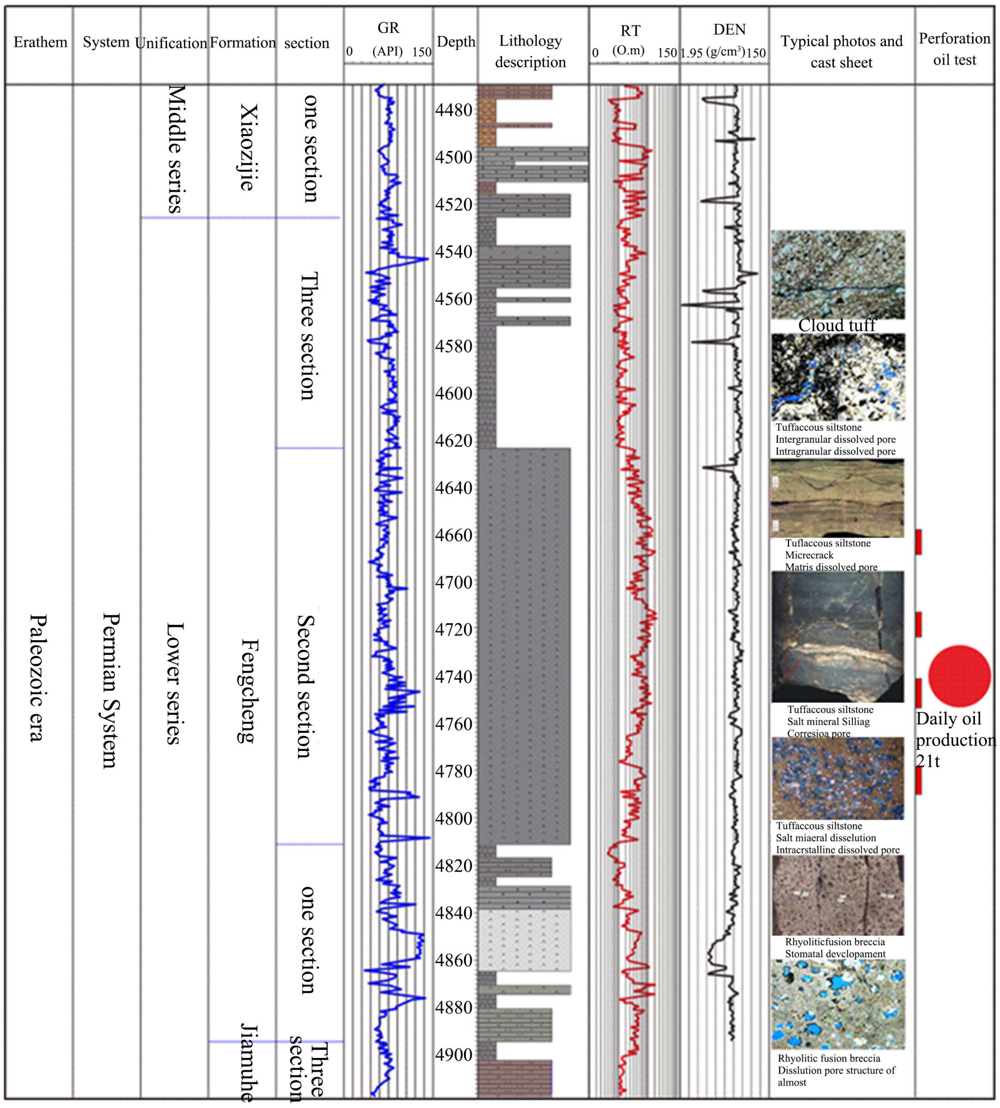


Figure 3. Pattern of Fengcheng Formation lithofacies section.

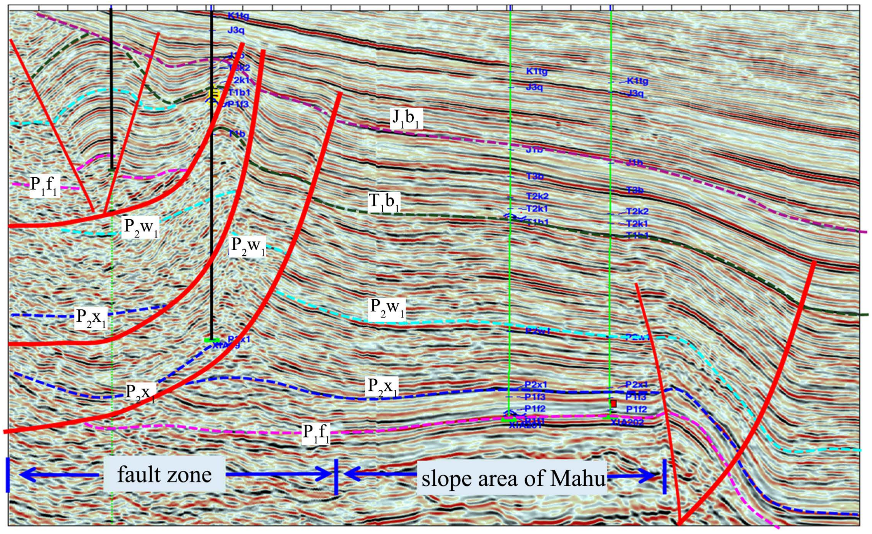


Figure 4. Fengcheng Formation earthquake explanatory section.

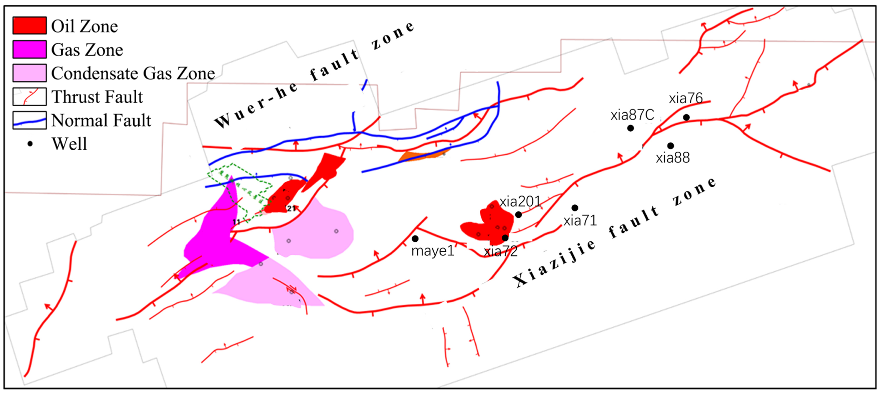


Figure 5. Distribution of Wu-Xia fault zone in Fengcheng Formation, Junggar.

3. Reservoir Characteristics

3.1. Sedimentary Characterization

The Fengcheng Formation in the research area is an important source rock and oil-bearing stratum, which has attracted more and more attention from oil and gas explorers. Discussions on the sedimentary environment of the Fengcheng Formation have been ongoing, and previous studies have proposed various hypotheses, including marsh lakes, saline lakes, residual seas, nearshore lakes, and shallow water lakes. Based on previous research and using various methods such as detailed core observation, thin section analysis, geochemical marker analysis, and authigenic mineral analysis, this study provides a detailed analysis of the sedimentary environment of the Fengcheng Formation in the research area. The comprehensive results suggest that the Fengcheng Formation is a residual marine sedimentary succession. A residual sea refers to an isolated basin far away from the open sea and no longer connected by water. The sedimentary environment of such a basin is similar to that of a lake, but the early water mineral components inherit the characteristics of seawater and gradually shift towards a lake environment. In subsequent discussions, the term “basin” refers to this type of sedimentation in a residual sea.

In the Late Paleozoic, seawater in the northwest gradually shifted to the southeast. According to the stratigraphic analysis of surrounding mountains, marine strata during the Lower Permian are only found within the basin and not in the surrounding mountains, indicating the retreat of seawater. Given the presence of marine strata in the Turpan Basin during the Lower Permian period, it is evident that the seawater had retreated to the Turpan Basin. Combining regional tectonic movement analysis, in the early Permian, the Junggar Basin experienced uplifts and downswings, resulting in the formation of isolated and residual seawater lake basins.

According to drilling data, the sedimentation and subsidence center of the Fengcheng Formation is located in the area from Urho, Fengcheng to Huangyangquan. To the west and south, the strata thin and the lithology coarsens, which is evidently not connected to the seawater at the southern edge of the basin. The Feng 16 well in the northern part of the basin shows continental sedimentation of the Fengcheng Formation, and the Lower Permian in the Bakouquan and Chepaizi areas to the west of the basin indicates continental sedimentation. These observations suggest that during the sedimentation period of the Fengcheng Formation, the research area was a closed inland lake basin.

Through research, it was found that the several major lake periods in the Xinjiang region since the Permian era have a good consistency with the global sea level rise. Some sedimentary evidence related to seawater has even been found in sediments during some high lake level periods, suggesting that the sedimentation period of the Fengcheng Formation in the study area was influenced by marine transgression. At the same time, it is also acknowledged that due to the Himalayan movement, the Tianshan and Kunlun Mountains have undergone strong uplift, and the ancient seawater channels have been destroyed and disappeared, making it difficult to find direct evidence.

The global sea level changes correspond to global tectonic movements, and similarly, the Junggar Basin is also in an active period of tectonic movement. During this phase, the basin uplift and subsidence are relatively intense, resulting in a deepening of the basin water body, but this does not mean that the overall scale of the basin water body has significantly increased. The widespread alluvial fluvial facies in the late Permian can also explain that the influence was not caused by marine transgression. The lithology of the Fengcheng Formation mainly consists of a set of gray and dark gray cloud-type mudstones, cloud-type siltstones, and mudstone and sandstone cloud rocks, with a small amount of fine sandstone and local tuff. Cloud-type mudstones and mudstone cloud rocks often have thin interlayers of organic laminae. The gray and dark gray lithology of the Fengcheng Formation represents a reducing environment, and no exposed features such as mud cracks or rain prints have been found. The development of fine laminations in the cloud-type rocks represents a stable low-energy environment. Based on the lithological characteristics, it can be regarded that the Fengcheng Formation was formed in a stable and deep-low energy water body.

The ancient salinity of the sediment in the Fengcheng Formation was recovered through carbon and oxygen isotopes, and the data indicates that the sediment formation background of the Fengcheng Formation in the study area was a semi-saline to saline environment. The cloud-type rocks developed in the Fengcheng Formation indicate that the water body was rich in calcium magnesium medium. At the same time, a set of evaporite salt combinations such as trona, natron and soda niter, natroalunite and bischofite were found in the Fengcheng Formation, which all indicate that the salinity of the basin water body was high. Typical marine greenstones with particle sizes of 0.05 - 0.1 mm, circular, green, composed of countless small crystals, and exhibiting aggregation polarization characteristics and primary mineral characteristics were found in 9 samples, indicating that the sedimentation of the Fengcheng Formation was connected to seawater.

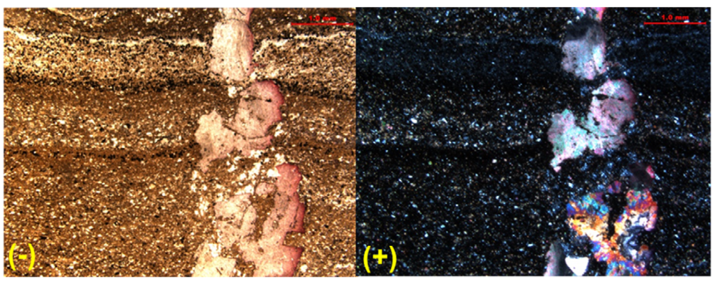
The dolomites in the cloud-type rocks of the Fengcheng Formation can be broadly divided into two types: mud-crystal and powder-crystal, and fine-crystal to medium-crystal self-shaped or semi-self-shaped. The formation of these mud-crystal and powder-crystal structures under rapid crystallization conditions indicates that they were formed under high salinity conditions and are significantly different from the dolomite formed in freshwater lake basins. The fine-crystal to medium-crystal self-shaped or semi-self-shaped dolomite in the Fengcheng Formation has obvious fogged centers, bright edges, individual crystal surface fouling, and typical characteristics of replacive dolomite, which are also significantly different from the clean crystal surface dolomite that forms in freshwater lake basins.

The mudstone cloud rocks in the Fengcheng Formation are often interbedded with layer-like tuff, fully indicating that the sedimentation of the Fengcheng Formation was affected by volcanic activity, and volcanic ash was an important source of material for basin sedimentation. The siliceous aggregates with siliceous bands or lenses in the formation have a close relationship with volcanic material. The surrounding volcanic rocks in the study area are mainly acidic volcanics, which, after leaching and weathering, ultimately transported abundant alkaline water into the basin. In summary, the deep water level and high salinity of the basin water body during the sedimentation period of the Fengcheng Formation are evident from the presence of abundant evaporite salt. The dolomite in the cloud-type rocks of the Fengcheng Formation is different from both marine and freshwater dolomite, which indicates that the sedimentation of the Fengcheng Formation was different from normal marine or freshwater sedimentation, but was still related to seawater sedimentation and volcanic activity.

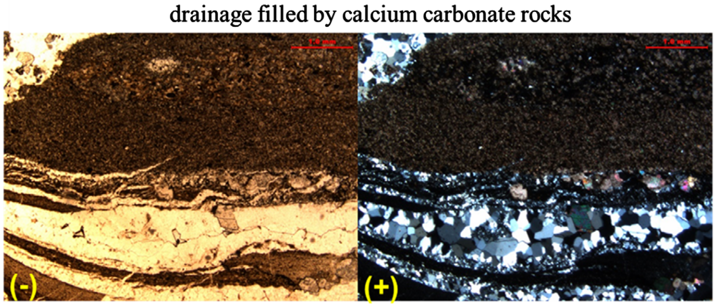
Fengcheng Formation Section II is important source beds and oil pay in the region, having attracted more and more attention from oil and gas explorers. The effective dolomitic rock reservoirs of the Fengcheng Formation in this area comprise a variety of lithology such as dolomitic siltstone, dolomitic mudstone, and argillaceous dolomite. The laminae dolomitic rocks developing in Fengcheng Formation, as well as a set of evaporative salt combinations such as sodalite, sodium bicarbonate, sodium magnesium carbonate and magnesium chloride found in the Fengcheng Formation, indicate that the salinity of the lake basin water body is high, from which can be inferred that the sedimentation of the Fengcheng Formation is to a certain degree related to seawater (**Figure 6**). Banded tuff is often found in the dolomitic rocks, convincingly demonstrating that the sedimentation of the Fengcheng Formation is affected by volcanic activity, while volcanic ash is an important material source for lake basin sedimentation (Liu et al., 2013). Through core observation, cast thin-section observation, geochemical markers analysis, autogenetic mineral analysis and other means, the sedimentary environment of the Fengcheng Formation in this area is analyzed in detail. Its sedimentary environment is equivalent to a lake, but the mineral components of early water bodies inherit the characteristics of seawater and gradually transform into lake environment (**Figure 7**).

3.2. Tectonic Characterization

The northwest edge of the Junggar Basin has undergone three major tectonic movements, including the Hercynian movement at the end of the Permian, which formed the basic outline of the Urwusu-Xia fracture zone. During the Carboniferous to Permian period, the area mainly exhibited thrusting, and the Indosinian period was the time of finalization. After the Late Jurassic, the fault activity basically stopped due to the influence of the horizontal stress in the north-south direction and the compression in the east-west direction. The fault



Xia40,P_1f_2,laminae dolomitized-tuffaceous siltstone, vertical laminae drainage filled by calcium carbonate rocks



Xia40, P_1f_2,laminae dolomitized-tuffaceous siltstone, drainage filled by silicon boron sodium rocks, visible inter-crystalline pores

Figure 6. Analysis and identification of Fengcheng Formation Section II cast-thin sections.

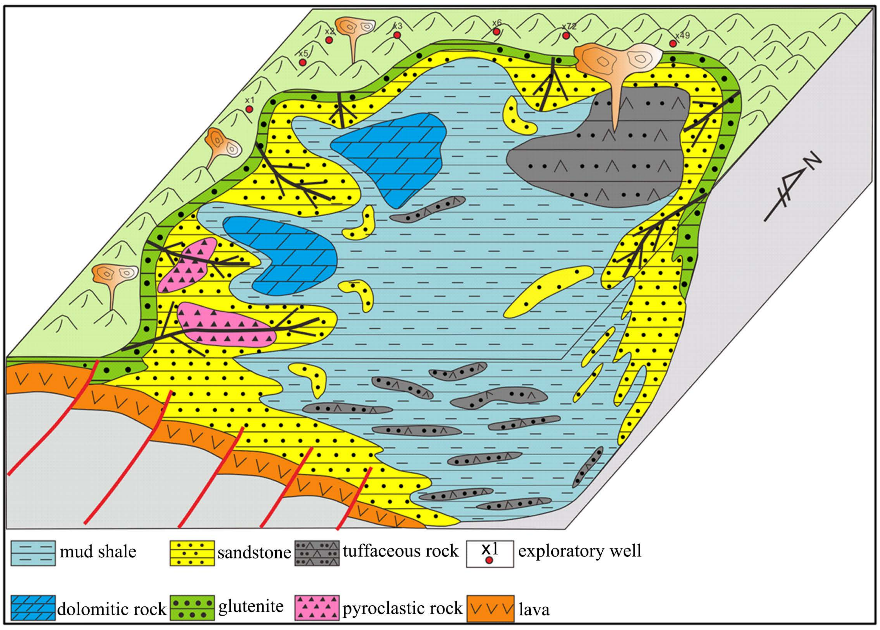


Figure 7. Endogenously and exogenously mixed sedimentary pattern of Fengcheng Formation Section II.

was arranged in a overlapping shape in the cross-section, and it was distributed in an arc shape on the plane because of the multiple retrogressive faults. The strata were uplifted from south to north in a step-like manner, with the Triassic being eroded in the higher positions of the northern structures. The Jurassic was directly deposited on the Permian, and the structure was located in the Urwusu-Xia fracture zone in the western uplift of the Junggar Basin, adjacent to the central depression of the Mahu Sag, and the Xiazijie oilfield area was located on the eastern section of the Urwusu-Xia fracture zone in the northwest of the Junggar Basin.

During the short-term extensional volcanic activity stage of the foreland basin (early Permian), the end of the Carboniferous marine strata represented the complete end of the ocean development stage in the northwest edge of the Junggar Basin and entered the stage of continental collision. However, the subduction and cutting movement of the oceanic crust in the deep Earth's crust was still ongoing. In the early Permian, the thrust body was formed, and the Halahaer Mountains were one of the most obvious thrust structures of the time, accompanied by widespread volcanic activity. The Ma Lake area to the south was in a stable and continuous subsidence, which was one of the subsidence centers at that time, and the direction of tectonic compression was still northwest. The early Permian volcanic activity developed a volcanic eruption cycle, while the Fengcheng period of volcanic activity was relatively strong, showing intermittent and curtain-like characteristics. The filling sequence of the Fengcheng period in the Fengcheng area is composed of argillaceous sandstone, argillaceous rock, and argillaceous tuffite. Overall, the volcanic activity gradually weakened. The thick sedimentary strata of the Lower Permian increased rapidly from the basin to the mountain front, appearing like a prism, and the alluvial fan system and volcanic rock system were stacked and interlaced with each other. It is speculated that the early Urwusu-Xia fracture zone's prototype basin was controlled significantly by the Darbut fault.

Seismic data shows that the Urwusu-Xia fault zone is a thin-shell tectonic belt of thrusting and slipping. In the deep Earth's crust, the Darbut fault intersects with the Keerwu fault to form a "Y" structure, and the Zenier Mountain and the Keerwu fault form the upper plate. In the early Permian, the Urwusu-Xia fault zone had the conditions to communicate with the deep Earth's crust through the Darbut fault (Figure 8).

During the foreland basin, the pre-expansion and inversion of a fault and folding stage (middle to late Permian), the deep subduction of the oceanic crust in the middle and late Permian trended towards stabilization and the onset of the stable crustal development stage. At this time, it was also when large sedimentary basins began to form on the continent. The northwest edge of the Junggar Basin entered another development stage dominated by strong compression and thrusting. The foreland basin continued to develop until its peak, typified by the strong activity of inversion faults. The compression and thrusting intensified in the middle and late Permian, and the inversion of faults increased. The reverse faults also developed, and the anticlinal amplitude increased, with obvious differential erosion. From early to late, the intense inversion and thrusting activity gradually migrated from west to east. After the relaxation adjustment from the Jiamuhe period to the Fengcheng period, the inversion and thrusting activity continued to strengthen from the Xiazijie period to the Lower Urho period, and the foreland basin reached its peak in the Upper Urho period, exhibiting a complete foreland basin system and ultimately heading towards extinction.

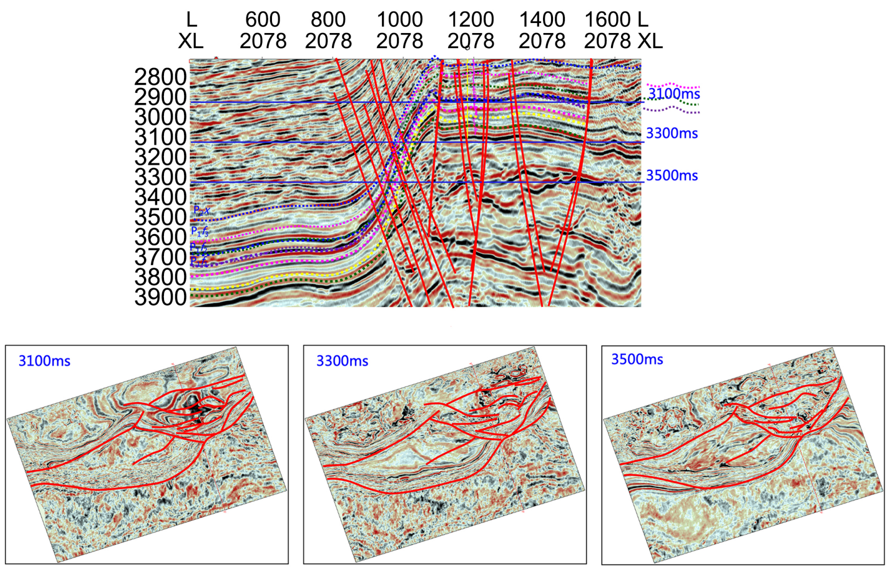


Figure 8. Seismic interpretation section for crossline 2078.

The formation of the Fengcheng-Uranus fault zone occurred in the early Hercynian structural movement of the Permian, and the activity was weak after the Permian, basically stopping after the Jurassic period. During the Hercynian tectonic activity, the main fractures of the structure belt developed in a nearly east-west and northeast direction. At the same time that many secondary faults developed parallel to or obliquely crossed the main faults, these fractures were not only conducive to the migration and accumulation of oil and gas, but also had a great improvement effect on the physical properties of the reservoir cracks formed.

During the hinterland depression, the pre-expansion and inversion of a fault and folding stage (Triassic) were characterized by inversion faults that were the main structural deformation characteristics of the Fengcheng-Uranus fault belt and folds, including the Wuhu fault nose, Fengcheng anticline, and Fengnan fault nose. These folds were all developed under the activity of the Wunan fault, Baiwu fault, and Fengnanjing fault, and the tops of the cores were severely eroded. The Fengcheng hidden anticline was formed during the Triassic period, with thrusting and overturning forming in the Carboniferous and Permian strata, with a northeastward distribution, gradually converging to the east near Xiazijie. The Wuhu fault nose was distributed in an arc shape with a northeastward trend and sinking on both ends. The lower part was a fault-disseminated folding band developed in the Carboniferous and Permian strata, namely, the lower part of the Wuhu West anticline belt. From entering the Mesozoic era, the Junggar Basin uplifted as a unified inland basin, with the development of large shallow lake basins as a sign. The Tethys movement was the main period of tectonic activity in the Triassic era. The thrusting and inversion activity basically maintained its previous tectonic style and developed inheritably. It acted in stages, and the northern section of the orogenic belt advanced intermittently from north to south. However, the thrusting force became weaker, leading to a steeper fault plane and showing a "plowing" feature. The main controlling fault had torsional properties. In the Late Triassic, the strong north-south compression and tectonic deformation occurred, and it was the present-day Halahaer Mountain. The top of the back folds that developed and the mountain front area suffered severe erosion. From this tectonic activity, the structural deformation of the Permian and Triassic was basically finalized.

3.3. Fracture Characterization

Micro-fractures are the major reservoir space of Fengcheng Formation Section II in this area. The active Wu-Xia overthrust fault and secondary fault in this area provide an effective geological condition for the development of micro-fractures. In the process of tectonic evolution, the stress direction changed, so that fractures of a variety of trends and complex fracture combinations develop in Fengcheng Formation Section II in this area. The contribution of microcracks to the reservoir is not only in improving the reservoir storage space, but also in providing a channel for fluid transport for dissolution. Inter-crystalline pores often develop in microcracks and drain channels (Chen et al., 2012). This means that dolomitization can effectively enlarge the Inter-crystalline pores. The Inter-crystalline pores are mainly the quartz inter-crystalline pores as well as salt mineral Inter-crystalline pores in the drainage channel and in the cracks. In the process of diagenesis, salt minerals such as sodium carbonate precipitated along interlayer seams, drainage channels and surroundings, and later dissolution occurred along the cracks and surrounding parts, forming various dissolved pores (**Figure 9**). FMI logging imaging shows that some wells in the Permian Fengcheng Formation in the Mahu slope area slightly develop, mainly oblique angles, and the direction is more chaotic, and holes develop in some wells (**Figure 10**). Through the study of reservoir space in oil pay reservoirs, it is found that microcrack communications are required when dissolved pores improve oil and gas reservoirs.

According to the cast-thin sections, the reservoir type of the Ma 131-Xia 72 well area is the pore-fracture dual medium type (Jiang, 2017). The storage space is mainly dominated by secondary pores, in which dissolved pores, dissolved joints and tectonic seams develop. The dissolved pores are mainly intragranular dissolved pores and matrix dissolved pores, followed by phenocryst dissolved pores. Under the structural stress, the reservoir cracks develop more, which are mainly filling seams, low-angle seams and micro-seams. The overall degree of crack development is high, but the proportion of invalid joints such as filling joints is large (**Figure 11**).

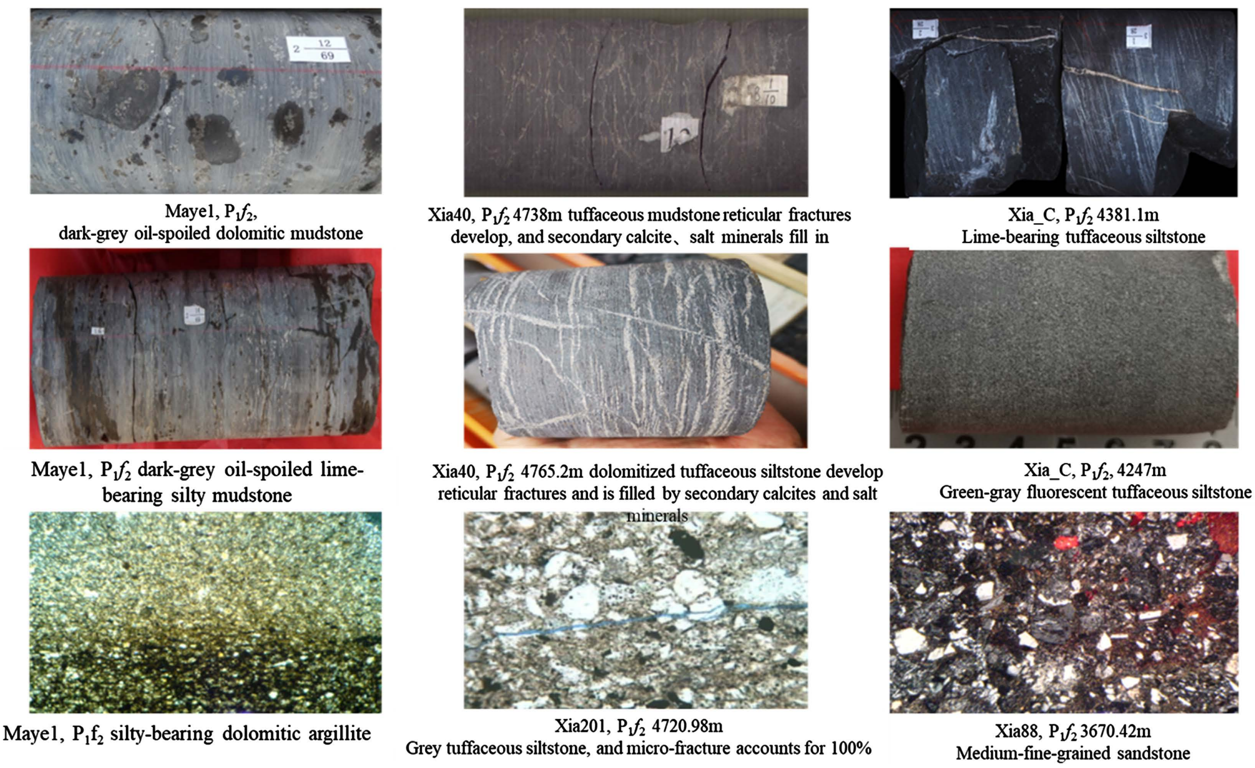


Figure 9. Core fracture and cast-thin sections of dolomitic rock zone, tuffaceous rock zone and conventional arenaceous.

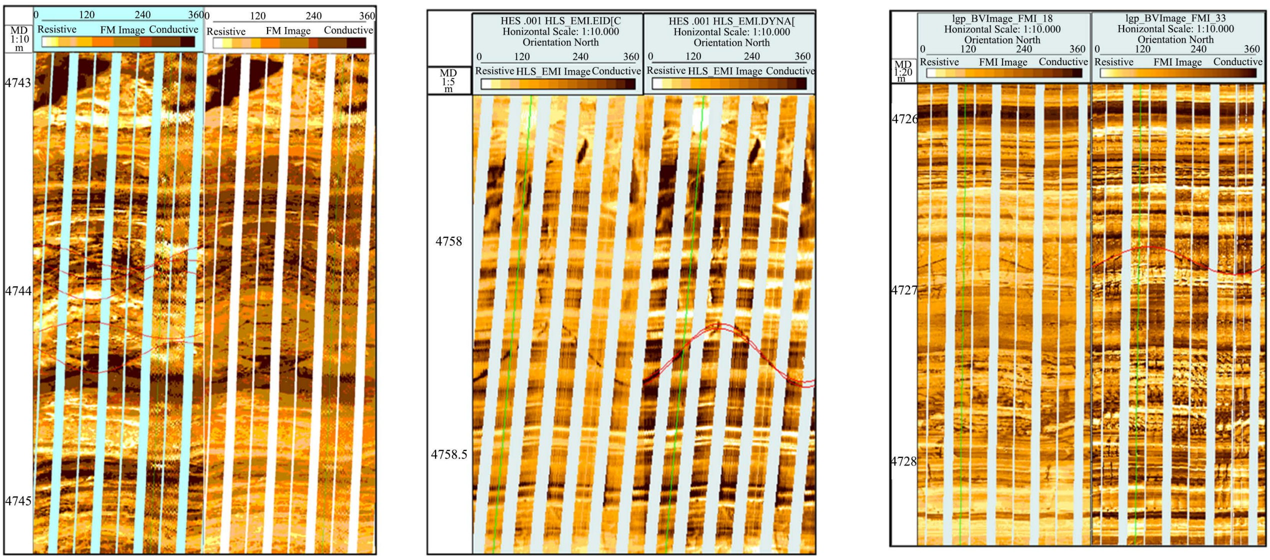


Figure 10. Fracture identification of Xia201 well, Xia202 well in Permian Fengcheng Formation Section II.

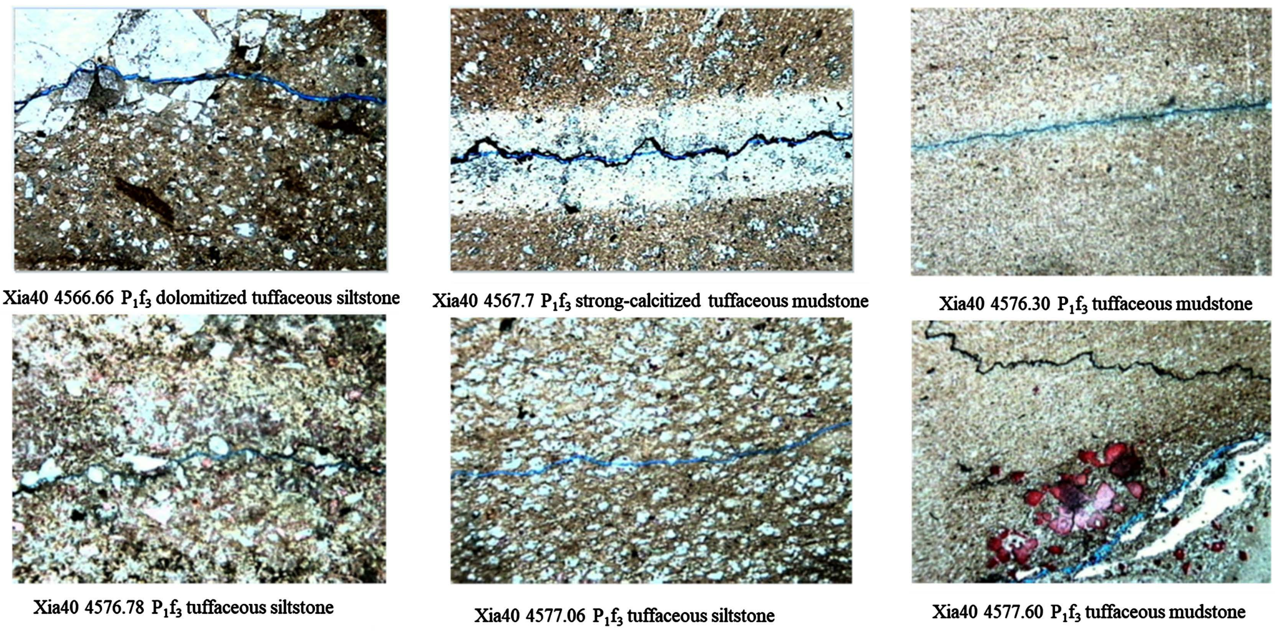


Figure 11. P1f2 core fracture of Xia40 well in Permian Fengcheng formation.

The crack development position was tested by Ant-tracking attribute volume. It shows that seismic axis usually staggers, twists, or suddenly wave-forms, with a characteristic of crack response. Ant-tracking attribute volume bands have a certain correlation with imaging logging in explaining fractures. Ant-tracking attribute volume is large at the position where fracture development is located. Ant-tracking attribute volume can be used to well identify fracture development concentration section. Fengcheng Formation Section II in this area has a large thickness in the "sweet spots", crack development, and good crude oil properties, which contributes to an overall hydrocarbon accumulation potential (**Figure 12**).

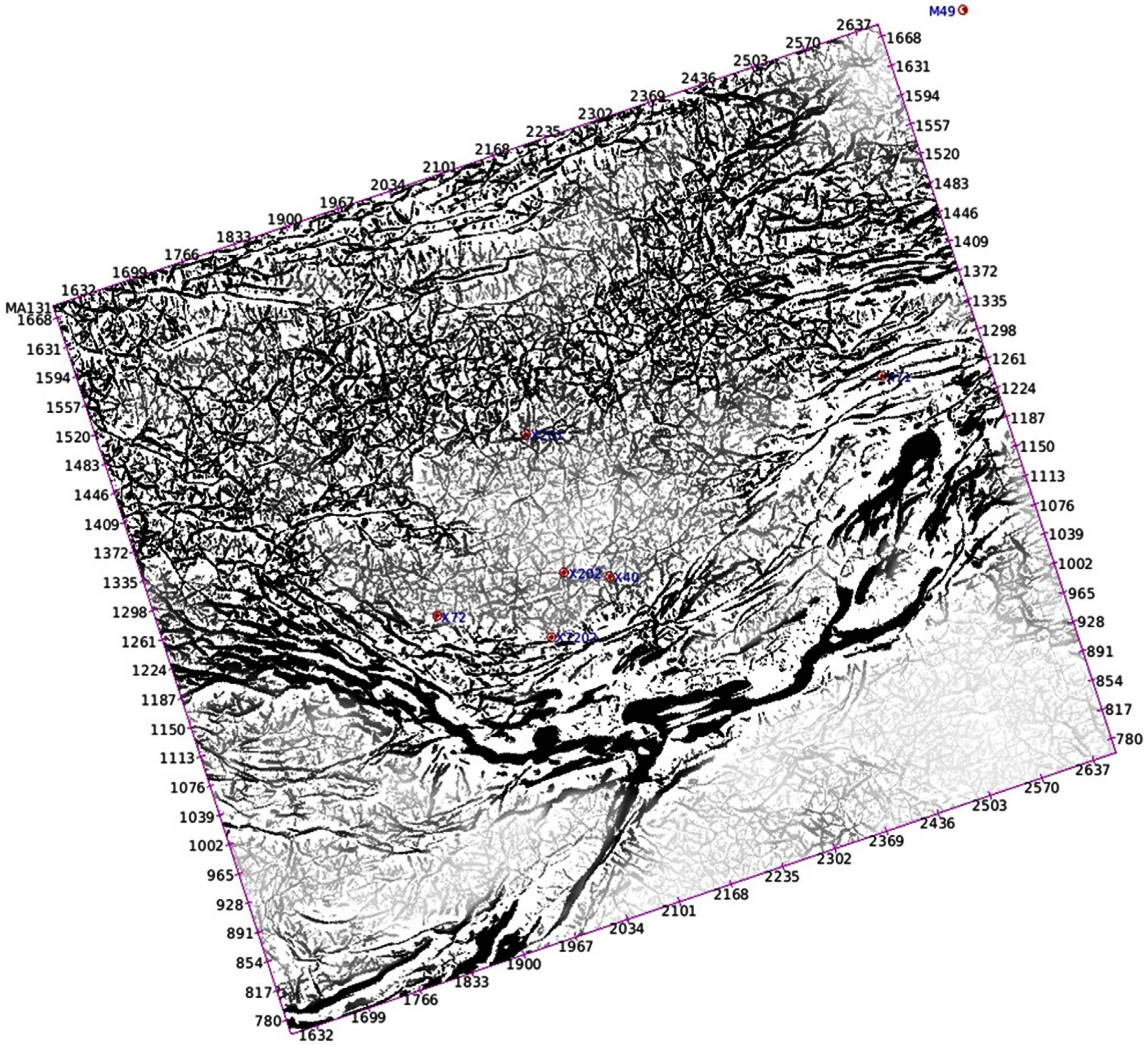


Figure 12. Ant-tracking attribute volume of X40 well in Permian Fengcheng Formation Section II.

4. Result

With logging data of single wells, the conventional impedance, time difference impedance and density impedance are analyzed, and the sensitive curve suitable for the second stage of the Fengcheng Formation Section II is preferred. The analysis results show that the time difference impedance has a good response to the reservoir, that the time difference of the reservoir section is small, that the impedance of the reservoir section is low, that the responding gas test value is high, and that dolomitic sandstone and tuff both develop in the oil layer (Zhang et al., 2018). The analysis results show that the time difference between different lithological sound waves is small, and the resistivity difference is large. The resistivity pseudo-acoustic wave inversion was adopted this time. Top of Fengcheng Formation Section II put as a boundary, the effective reservoir distribution was extracted and the lithological results were explained by logging of single wells and then corrected. With a low-frequency and weak amplitude reflection on the earthquake, as well as medium-impedance, the tuff development in Fengcheng Formation Section II of the Ma 131-Xia 72 well area is different from high-impedance dolomitic rock, low-impedance sand conglomerate, having a wide distribution area and great potential for progressive evaluation (Figure 13). Combined with the forecast of seismic favorable reservoir and the flat distribution extracted from average amplitude attributes, the dolomitic rock and tuff reservoirs in the North-Ma area have developed extensively, whose estimated area is 285.76 km^2. Meanwhile, the preliminary estimated geological reserves have reached the level of 100 million tons (Figure 14).

The dolomitic rocks of the Fengcheng Formation were formed in a sedimentary environment with high salinity. The stratum is rich in salt minerals that have positive significance for the generation and storage of oil and gas. At present, there are many oil and gas-bearing basins with industrial value in the world, of which there are 85 layered or lentic evaporative salt minerals. Besides, in the basins where oil and salt coexist, oil and gas are mainly produced in the lower or upper parts of the salt formation, which has the same characteristics as the oil and gas distribution of the Fengcheng Formation (Figure 15). First of all, the

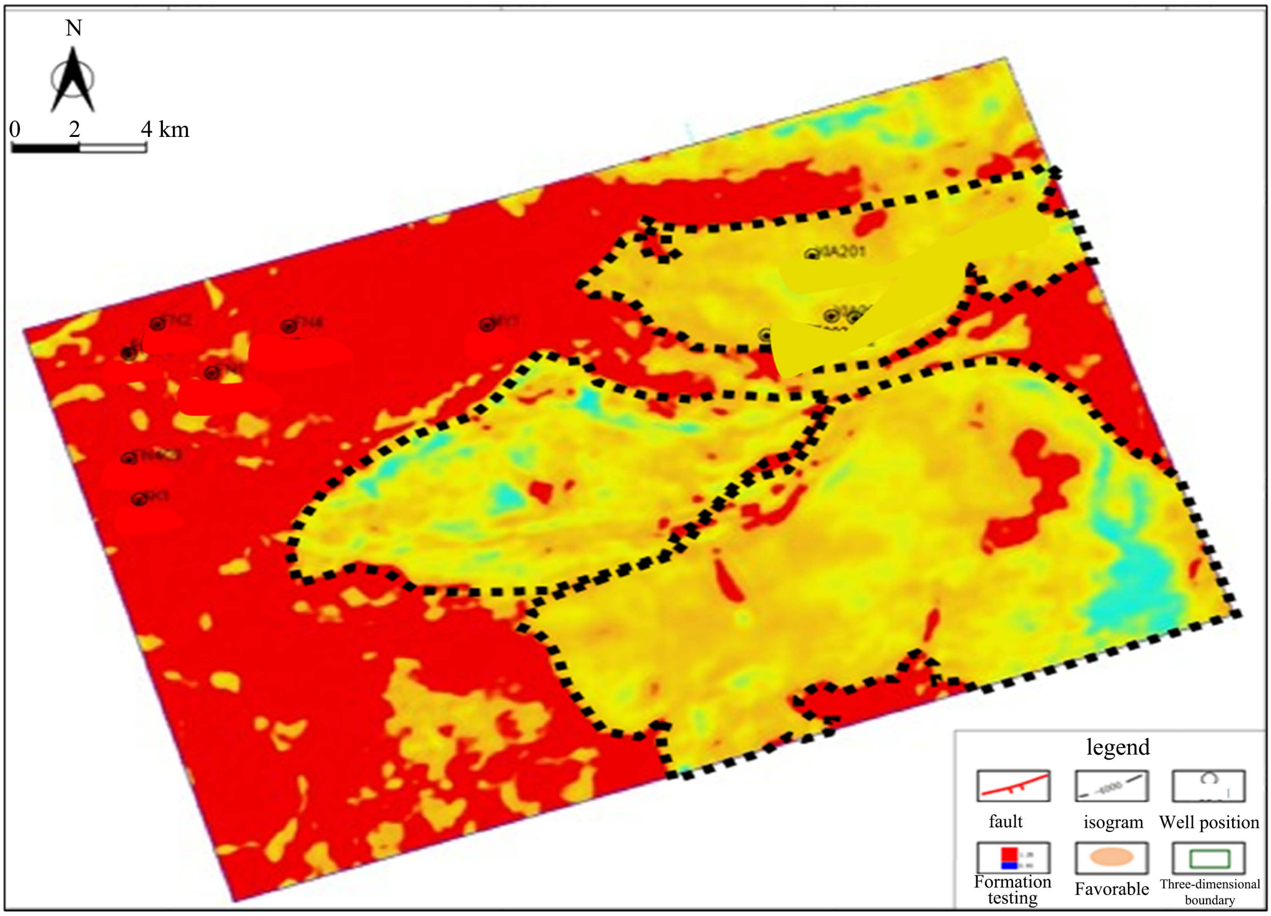


Figure 13. Inversive plane of Fengcheng Formation Section II.

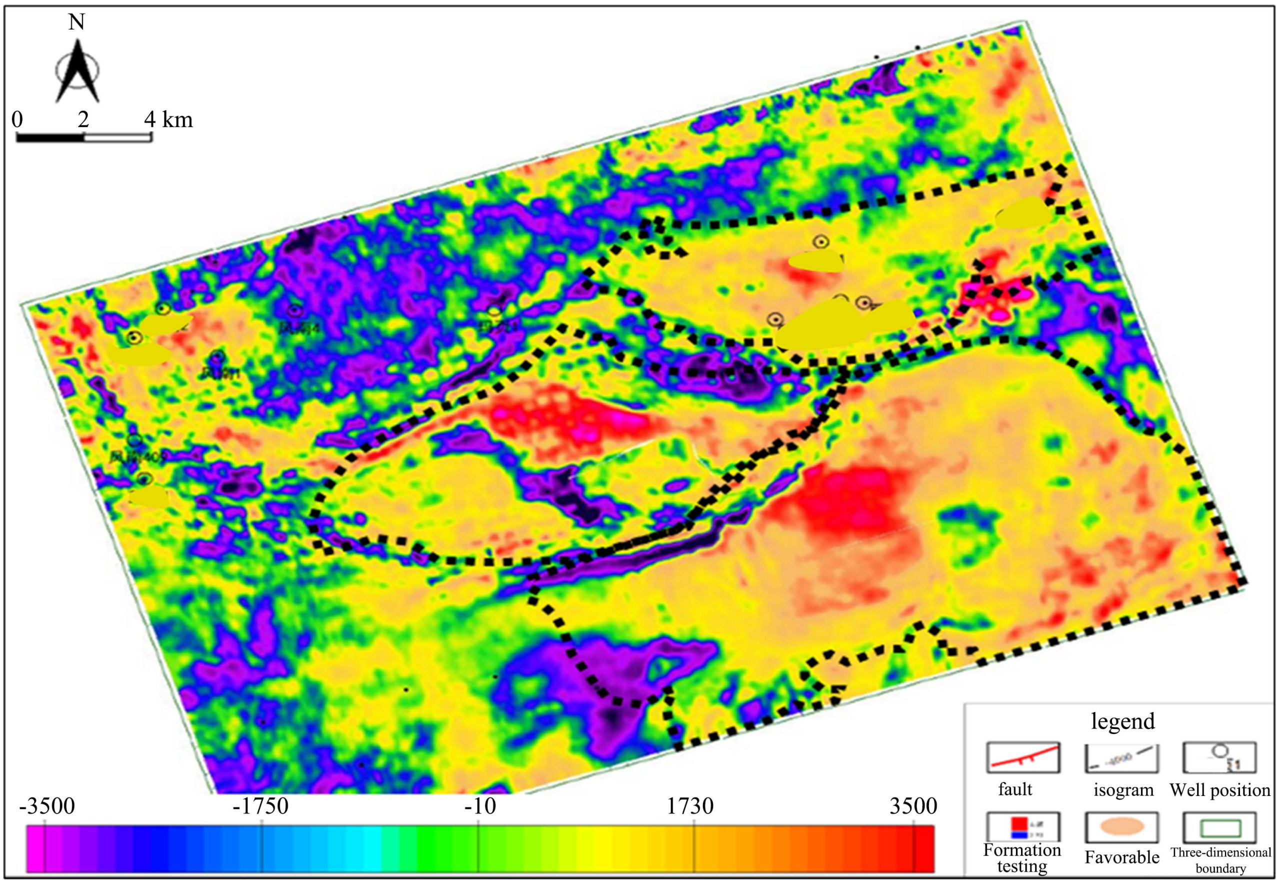


Figure 14. Average amplitude attribute plane of Fengcheng Formation Section II.

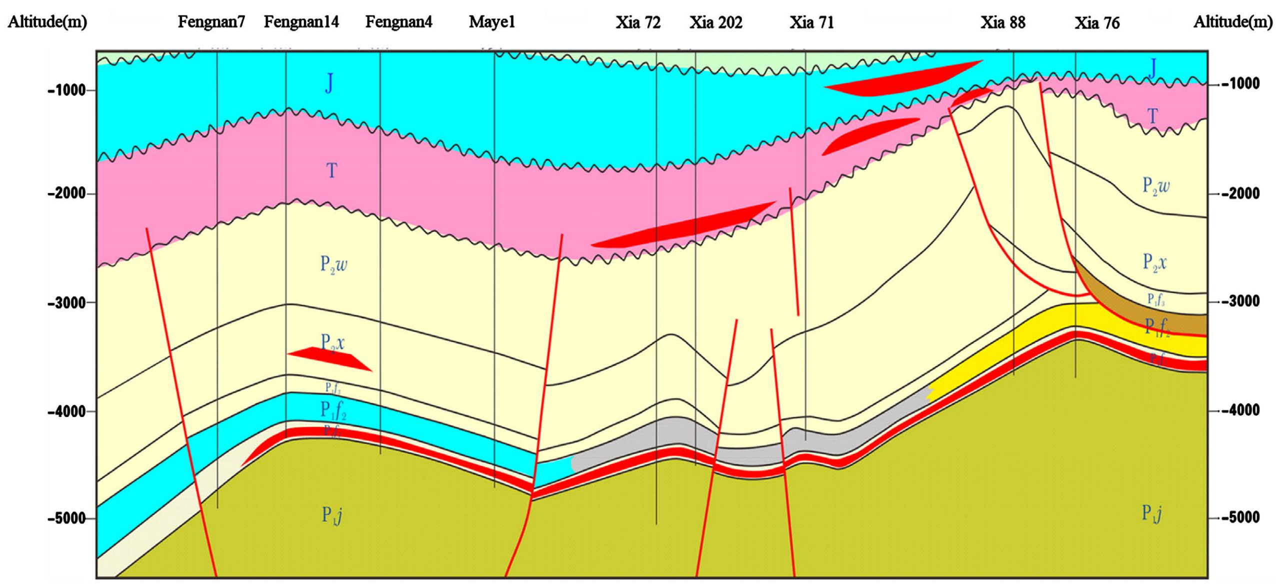


Figure 15. Reservoir pattern of Fengcheng Formation Section II.

sedimentary environment with high salinity also indicates the corresponding enrichment of nutrients needed by organisms (Zeng et al., 2020). It is also very conducive to the reproduction and survival of organic matter, while the production of organic deposits requires several conditions. One is that a favorable ecological environment can produce a sufficient amount of organic matter; the other is a condition conducive to the preservation of sedimentary organic matter (Zhang et al., 2012). The fault development zone and the nose-like uplifts in the West Slope of Mahu have an obvious causal relationship, and the fault not only controls the development of the structure, but also controls the transportation and enrichment of oil and gas. Judging from the previous drilling results, the exploration results of the tectonic background and fault development zone of nose-like uplift belt are good. In addition, the nose-like uplift tectonic belt is a favorable pointing area for oil and gas transport and aggregation. Meanwhile, it is an important control factor for the plane distribution of oil and gas, while the fault plays the role of oil and gas transport channel, and is the key element in controlling oil and gas accumulation. Furthermore, these two factors are related to the high yield of the Fengcheng Well of the Permian Fengcheng Formation and the Fengchengnan Well of Permian Fengcheng Formation. And the formation test of Xia 202 well in Fengcheng Formation Section II has obtained a high yield of more than 20 tons of oil per day, the development effect of which is good.

5. Conclusion

1) The Fengcheng Formation Section II in the west slope of Mahu is the paragenesis sedimentation of dolomite-eruptive rock, and is formed by endogenously and exogenously mixed sediments, of which the supply of exogenous materials is the dual input supply of clastic terrigenous sediments from delta, eruptive rocks and tuff like volcanic dust; the endogenous materials that are mainly dolomites dominated by chemical sediments, are mainly from low-energy lagoon environments.

2) The Fengcheng Formation Section II on the west slope of Mahu Lake is subject to the dual action of tectonics and dolomitization, and the faults not only control the development of the structure, but also control the transportation and enrichment of oil and gas.

3) All kinds of lithology in the Fengcheng Formation Section II of the West Slope of Mahu are oily. It is overall oil-bearing of local enrichment and high yield. Furthermore, the Fengcheng Formation Section II in the West Slope of Mahu is extruded, pushed and cut into different oil-containing faults. The longitudinal and flat body of the “sweet spot” is concentrated and stable, and the reserve scale is huge.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Akbar, M., Vissapragada, B., Alghamdi, A. H., Allen, D., Herron, M., Carnegie, A., Dutta, D., Olesen, J. R., Chourasiya, R. D., Logan, D., & Stief, D. (2000). A Snapshot of Carbonate Reservoir Evaluation. *Oilfield Review, 12,* 20-21.

Allen, P. A. (2007). The Huqf Supergroup of Oman: Basin Development and Context for Neoproterozoic Glaciations. *Earth-Science Reviews, 84,* 139-185. https://doi.org/10.1016/j.earscirev.2007.06.005

Chen, L., Ding, J., Pan, W. Q., Chen, T., & Jiang, J. (2012). Characteristics and Controlling Factors of High-Quality Dolomite Reservoir in Permian Fengcheng Formation in West Slope of Mahu Sag, Junggar Basin. *China Petroleum Exploration, No. 3,* 8-11, 7.

Halbouty, M. T. (2003). Giant Oil and Gas Fields of the 1990s: An Introduction. In M. T. Halbouty (Ed.), *Giant Oil and Gas Fields of the Decade 1990-1999* (pp. 1-13). American Association of Petroleum Geologists. https://doi.org/10.1306/M78834C1

Jiang, Y. Q. (2017). *Characteristics and Causes and Reservoir Control Factors of Dolomitic Rocks of Permian Fengcheng Formation of the Research Area in Junggar Basin* (pp. 45-48). Ph.D. Dissertation, Northwest University. (In Chinese)

Kuang, L. C., Tang, Y., Lei, W. D. et al. (2012). Formation Conditions and Exploration Potential of Tight Oil in the Permian Saline Lacustrine Dolomitic Rock, Junggar Basin, NW China. *Petroleum Exploration and Development, 39,* 700-711. https://doi.org/10.1016/S1876-3804(12)60095-0

Lei, W. D., Chen, G. Q., Liu, H. L. et al. (2017). Study on the Forming Conditions and Exploration Fields of the Mahu Giant Oil (Gas) Province, Junggar Basin. *Acta Geologica Sinica, 91,* 1604-1619.

Liu, M., Zhang, S. C., Kong, Y. H. et al. (2013). Study on the Diagenesis Facies of the Permian Fengcheng Formation in the Northwest Edge of Junggar Basin. *Xinjiang Dizhi, No. 3,* 189-201. (In Chinese)

Tian, F., Di, Q., Jin, Q. et al. (2019). Multiscale Geological-Geophysical Characterization of the Epigenic Origin and Deeply Buried Paleokarst System in Tahe Oilfield, Tarim Basin. *Marine and Petroleum Geology, 102,* 16-32. https://doi.org/10.1016/j.marpetgeo.2018.12.029

Warren, J. (2000). Dolomite: Occurrence, Evolution and Economically Important Associations. *Earth-Science Reviews, 52,* 1-81. https://doi.org/10.1016/S0012-8252(00)00022-2

Warren, J. K. (2006). *Evaporites: Sediments, Resources and Hydrocarbons*. Springer. https://doi.org/10.1007/3-540-32344-9

Zeng, L., Keshavarz, A., Xie, Q., & Iglauer, S. (2022). Hydrogen Storage in Majiagou Carbonate Reservoir in China: Geochemical Modelling on Carbonate Dissolution and Hydrogen Loss. *International Journal of Hydrogen Energy, 47,* 24861-24870. https://doi.org/10.1016/j.ijhydene.2022.05.247

Zeng, Z. P., Wang, J. D., Wang, G. Z. et al. (2020). Research on the Process of Tight Reservoir in the Lucaogou Formation in the South Edge of Junggar Basin. *Journal of Xi'an Shiyou University (Natural Science Edition), No. 1,* 329-335.

Zhang, J., He, Z., Xu, H. B. et al. (2012). Petrological Characteristics and Origin of Permian Fengcheng Formation Dolomitic Rocks in Wuerhe-Fengcheng Area, Junggar Basin. *Acta Sedimentologica Sinica, 30,* 859-867.

Zhang, S., Liu, Y. Q., Jiao, X. et al. (2018). Sedimentary Environment and Formation Mechanism of Dolomitic Rocks in the Middle Permian Lucaogou Formation, Jimusar Depress, Junggar Basin. *Journal of Palaeogeography, No. 1,* 321-330.