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Relationship between the later strong gas-charging and the improvement of the reservoir capacity in deep Ordovician carbonate reservoir in Tazhong area, Tarim Basin

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Some large-scale oil-gas fields have recently been discovered in marine carbonate in China, especially the significant discoveries in deep reservoir that reveals a favorable exploration prospect. Tazhong area is the first-order tectonic unit in Tarim Basin, where there are nearly trillion cubic meters of natural gas resources in the Ordovician limestone reef flat complex in Lianglitage Formation. The reservoir is shelf edge reef flat complex, characterized by ultra-low porosity, low permeability and strong heterogeneous, with a current burial depth of 4500—6500 m. Studies find that the formation and distribution of deep reservoir of the Lianglitage Formation were controlled not only by the early high-energy sedimentary facies and corrosion, but the fracture network formed by the strong gas-charging process since the Himalayan epoch, which played an important role in optimizing and improving reservoir properties. This paper discusses the relationship between the strong later gas-charging and the improvement of the reservoir capacity in deep Ordovician carbonate reservoir, and also builts the corresponding mechanisms and modes, which is favorable for the prediction and evaluation of the advantageous exploration targets.

fracture, high-quality carbonate reservoir, deep reservoir, Ordovician, Tazhong No.1 fault zone, Tarim Basin

The marine sedimentary basins in China are mainly developed in the Paleozoic, and there abundant oil and gas resources are deposited. The multi-circle superimposed alteration formed the extremely complicated oil and gas distribution[1−9], especially, the carbonate reservoirs are now generally deep buried, strongly densified, intensely heterogeneous, and difficult to predict, so the pace of the petroleum exploration in marine carbonate reservoir has been restrained[10,11]. Recently, a series of large-scale carbonate oil and gas fields have been discovered with the development of exploration technique and research reinforcement, and at the same time, the high-quality deep reservoirs have been revealed[12−20]. All of these findings bring a new hope for China's marine carbonate hydrocarbon exploration, exhibit its great exploration potential, and make the Palaeozoic deep marine strata a hotspot for petroleum exploration and a focus for scholars.

The discoveries of the large-scale marine carbonate oil and gas fields benefited from the new advancements of the reservoir theoretical research: the further study on the temporal and special distribution, the development pattern of the diagenesis in the oil-gas-bearing basin, the

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mechanism and distribution of the interaction of fluid and rock, the classification of the diagenesis system and temporal and special framework of the diagenesis, the combination of the diagenetic trap and hydrocarbon generating evolution and other basic research work[21−34]. All of the findings greatly broaden the petroleum exploration range and the forecast precision of the effective reservoir, and supported the recent carbonate oil and gas exploration powerfully. Especially the discovery of large acreage petroleum within carbonate reef flat complex in Upper Ordovician in the Tazhong area (mainly around No. 1 faulted zone) demonstrated the great importance of reservoir study. The reservoir heterogeneity is strong in the limestone reservoir in the Lianglitage Formation and the effective reservoir was controlled by many factors, so it is difficult to predict after superimposing. Many scholars have done effective research[35−44], and have drawn the conclusion that the distribution of effective reservoir was mainly controlled by high-energy sedimentary facies and the reservoir was also strongly modified by diagenesis, of which the karstification was the most important constructive diagenesis (Well Tazhong 45 was a typical burial hydrothermal karst reservoir[45]), the last is the faults and fractures formed by later tectonic deformation, which improved the reservoir properties and formed the pore-hole-fracture system. The combination of the three aspects can determine the favorable distribution range of the effective reservoir. These opinions directed the petroleum exploration in the Tazhong area, and they are the main reasons for the high success rate of the exploratory well.

The tectonic movement played an important role in the development of cracks and fractures as an important power source. Since the Himalayan movement (the Himalayan), the structure has been relatively stable, and no fault could be identified from seism. In addition, the Tazhong No. 1 fault has stopped acting since the Hercynian period. Therefore, the fracture development in the Himalayan period might not be initiated by tectonization. Studies show that storage capability of the Ordovician reservoir of the Lianglitage Formation was relatively poor before the Himalayan. There was no large-scale storage space and only a small amount of oil and gas was charged. And no asphalt is discovered in most of the early pores, so the oil and gas filling-up is mainly in the Himalayan period. During this period, The Tarim Basin subsided rapidly, and crude oil cracking gas came into being in the depressed area. Although the Tazhong No.1 fault has been a dead fault, it could still transport natural gas because of the different sedimentary lithology and the tectonic location between both sides of the No.1 fault zone. The reservoir of the Lianglitage Formation was poor for oil storage and migration, but it is still good for gas migration. Therefore, plenty of high-mature natural gas migrated upward along the Tazhong No.1 fault zone. With the gas going ahead, the previous micro-cracks expanded or extended or the rock broke to form new micro-fissures, forcing the cracks to develop further along the No.1 fault zone, which is the main reason for the abundant gas reservoirs along the Tazhong No. 1 fault zone.

1 The petroleum geological background in the Tazhong area

The Ordovician is the key petroleum exploration strata in the Tarim Basin. The Ordovician carbonate exploration began in 1989, and on the basis of the three-dimenional seismic researches and comprehensive geology[12], the large-scale condensate gas field of the Ordovician carbonate reservoir was discovered in the No.1 slope- break zone in 2005.

The Tazhong area belongs to the Tazhong low uplift in the middle section of the central uplift, and it is a large-scale anticline composed of several sub-tectonic belts. The Tazhong No.1 fault belt is a strip-shaped tectonic belt in the northern part, and locates at the cutting belt between Tazhong low uplift and Manjiaer depression, a complex tectonic belt of NWW trend, more than 260 km long and in the form of near anti-“S” type (Figure 1). The Tazhong No.1 fault is the main fault that controls the formation and development of the Tazhong anteclise and the second-order faults which have a certain angular relationship with the Tazhong No.1 fault and converge towards the Tazhong No.1 fault, showing a NEE distribution laterally (Figure 1).

The Tazhong No. 1 fault was developed in the Caledonian period, strongly activated in the early-Hercynian period and stopped acting in the middle-late Hercynian period. Then it became a relatively stable subsiding zone without large displacement of faults. The Tazhong No. 1 fault zone controls the tectonic pattern and sedimentary evolution of Upper-Ordovician shelf edge reef flat complex. The Lianglitage Formation developed along the Tazhong No. 1 fault zone is 200 km long and 3－10 km

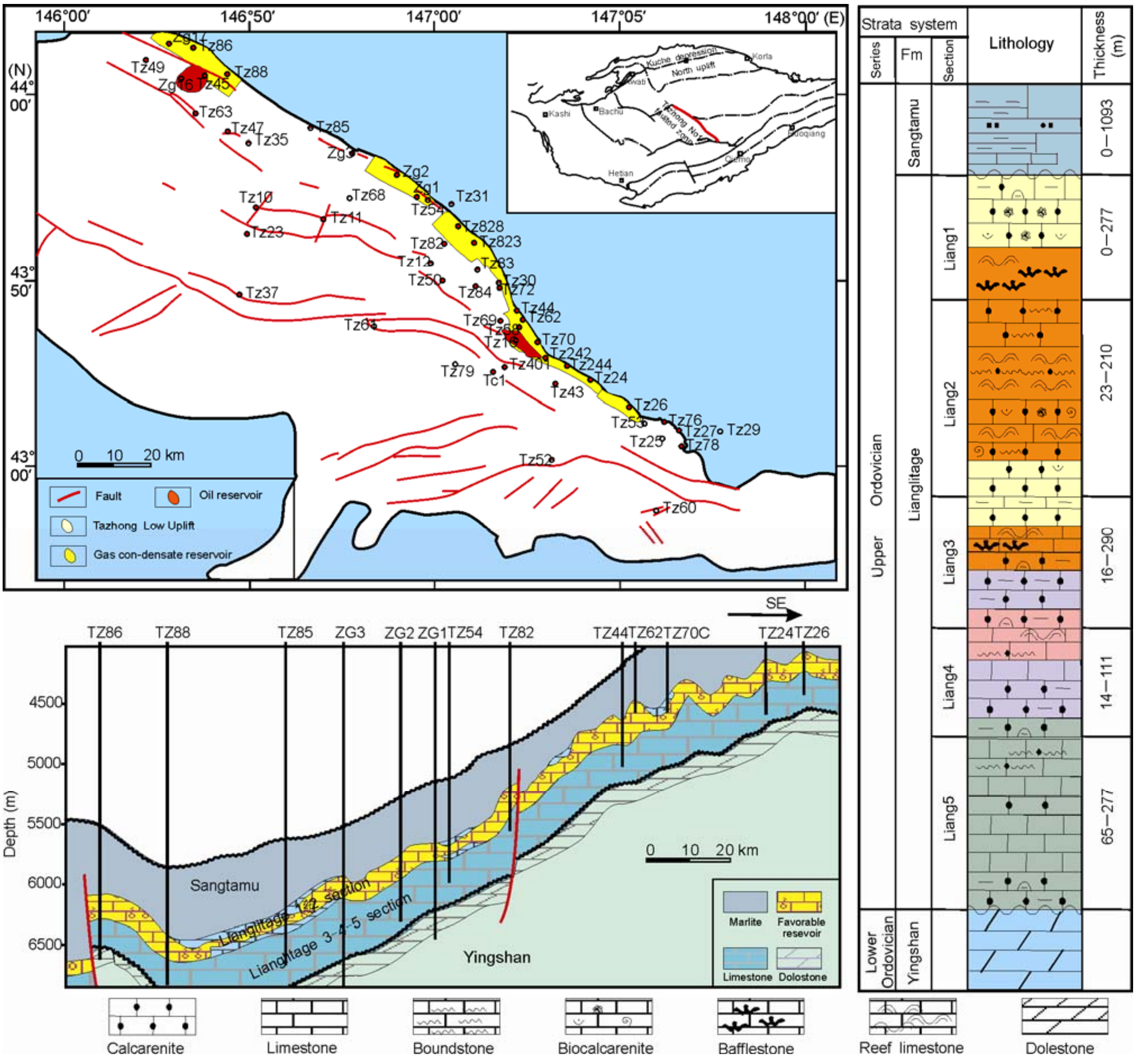

Figure 1 The petroleum distribution and lithologic assemblages in the Tazhong area, Tarim Basin.

wide, and with an area of more than 1000 km^2 (Figure 1). Currently, the Tazhong No.1 shelf edge-reef complex is the largest favorable reef complex reservoir found in the Tarim Basin and the richest petroleum zone of Ordovician carbonte in the Tazhong area.

The Ordovician of Tazhong No.1 fault zone can be divided into Upper Ordovician including the Sangtamu Formation and the Lianglitage Formation, and the Lower Ordovician including the Yingshan Formation and the Penglaiba Formation from top to bottom (Figure 1). Unconformable contacts existed among the upper Ordovician, Silurian, and lower Ordovician. The carbonate platform margin sedimentary system was developed on the west side of Tazhong No.1 fault when the Lianglitage Formation deposited. The Lianglitage Formation can be divided into 5 Members: Liang 1—Liang 5 Members (Figure 1). Cryptite, argillaceous limestone and algal biosparite of the open platform facies were developed at the early deposition stage of Lianglitage Formation (Liang 4—Liang 5 Members), the reef flat complex, biohermal complex, biogenetic limestone and grain limestone, with a thickness of 80—300 m, were developed at the middle-late stages (Liang 1—Liang 3 Members), and flat (reef knoll), marine pelsparite, grain limestone and pelsparite were also developed locally, which are important reservoirs with a thickness of 30—38 m.

2 Reservoir diagenetic evolution and petroleum charging

2.1 Reservoir characteristics

The shelf-slope-basin depositional system was developed in the Tazhong area in the late Ordovician. The reef flat complex was mainly developed in the platform margin on the west side of the No 1 fault zone, and was strictly controlled by the sedimentary environment. Three main reservoir types were found through the thin-section analysis, that is pore-type, cave-type and fracture-type reservoirs. and pore-cave reservoir was mainly related to the dissolution. The reservoir space mainly includes intragranular dissolved pore, mould pore, intergranular dissolved pore, intercrystal dissolved pore, organic visceral foramen, organic framework pore, ultra-large type dissolved pore and cavity, etc. A large number of core property data show that the porosity is in the range of 0.24% and 6.2%, averaging 1.45%, the average lateral permeability is 2.96×10^{-3} μm^2, The average vertical permeability is about 1/7 of the radial permeability, reflecting the contribution of vertical fracture or high angle fracture on the permeability[35]. The fracture increases and the permeability gets better if the porosity does not change. So fractures can improve the reservoir property effectively.

2.2 Reservoir diagenetic evolution

It is obvious that the formation of the favorable reservoir of the Lianglitage Formation is controlled by the high-energy depositional environment, dissolution and tectonic disruption**,** and especially, the eogenetic meteoric corrosion and burial dissolution are important to the improvement of the reservoir porosity and permeability. The meteoric corrosion stage mainly includes the syndiagenesis meteoric corrosion stage and the late Lianglitage meteoric corrosion stage. The primary pores such as reef flat skeleton body holes and intergranular pores are developed, and its porosity is in the range of 25%—40% (Figure 2). The cementation happened before the meteoric corrosion action and fibrous calcite grew around the edge of particles to form comb-shaped shell cement ring, resulting in the reducing of the original intergranular pore (the porosity reduced to 5%—15%). With the relative falling of sea level, the grain bank was exposed to the meteoric diagenetic environment and selective dissolution occurred to form interparticle dissolved pores, intragranular pores, modle pores, ultra-large dissolved pores and caves. Although some dissolved pores and caves were filled or partly filled by silt sand, argillaceous or microcrystalline calcite, the residual dissolved pores enlarged the porosity by 10%—20% (Figure 2). There were different scales of karst zones under the denudation surface, where different sizes of dissolved pores were developed, which were filled or partly filled by argillation and microcrystalline calcite, and although highly filled, there was still a certain distribution of the residual holes. Burial diagenetic compaction and cementation destroyed the reservoir, and the particles contacted well when there was strong compaction. With the overlaying pressure increasing, the compaction action gradually changed into pressure solution, and in the deep burial environment, the high angle stylolite was partly filled by the insoluble organic matter and argillation. There are high angle stylolite and solution phenomena along high angle stylolite within grain limestone.

Thus, the reef-flat complex of the Lianglitage Formation experienced multi-phase cementation, dissolution and disruption and had a complicated diagenesis due to the multi-type and multi-phase deformation and superimposition. So the reservoir performance got worse because the constructive diagenisis was smaller than the destructive cementation and compaction. But the fractures formed in the Himalayan period greatly improved the reservoir performance.

2.3 The hydrocarbon charging period

There are three important hydrocarbon charging periods in the Tazhong area, and the first two are mainly oil charging periods (Figure 2). However, most of the reef-flat complex reservoir of the Lianglitage Formation failed to fully capture the oil, and only some biomarkers confirmed the existence of the two charging periods, the reason might be that the reservoir or the charging path was not available. The geochemical characteristics, biomarkers and fluid inclusion data proved that the large-scale hydrocarbon charging was started from the Himalayan period. The micro-pore structure showed that reservoir asphalt was not well developed in the early dissolved pore, and most pores were filled or partly filled, but the residual pores were relatively clean. The fracture formed in the early time was filled by subidiomorphic-allotriomorphic fine, powder calcite, so the intercrystalline dissolved pore was rarely discovered. Therefore, it is certain that most of the reef flat did not

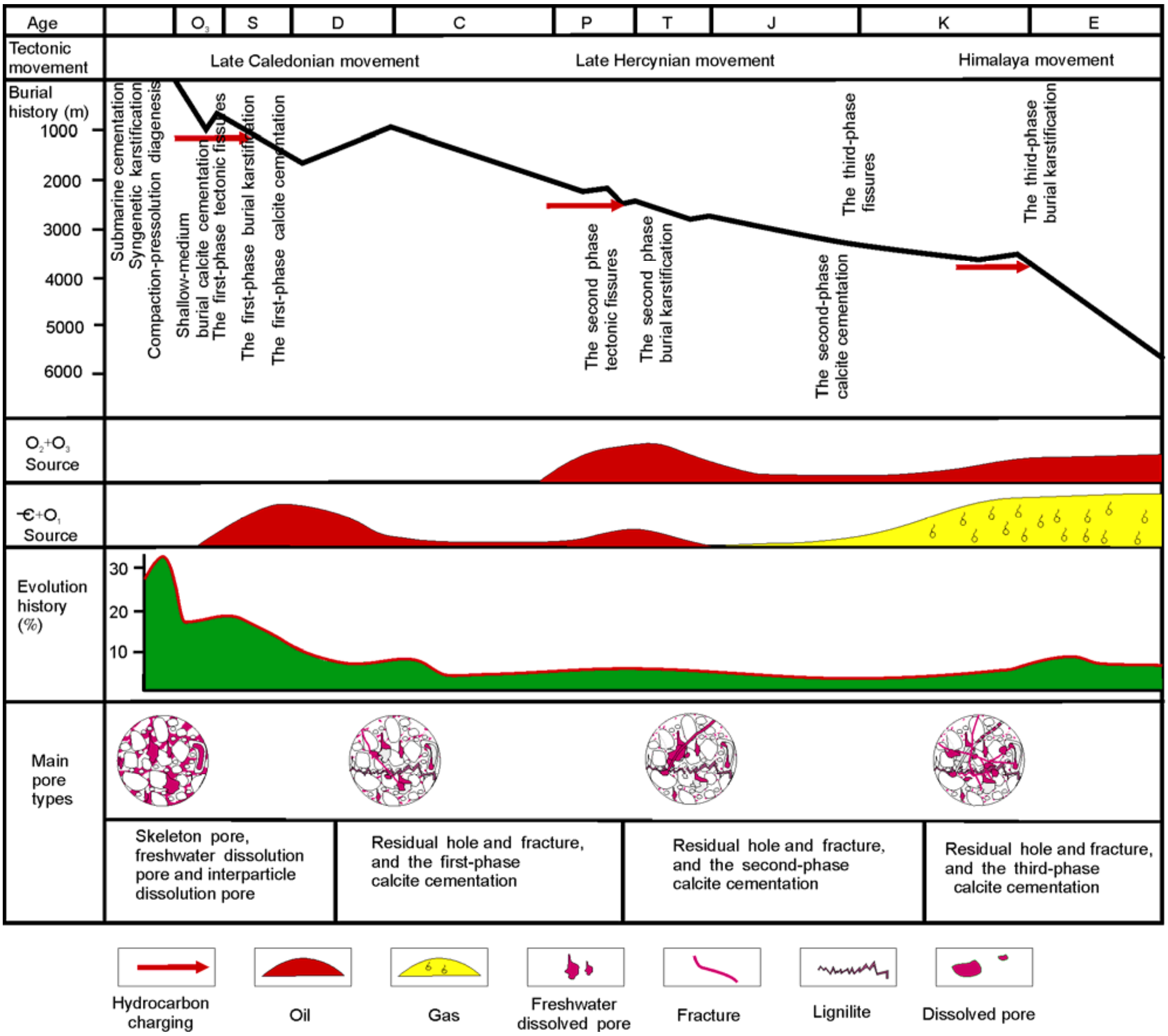

Figure 2 The schematic diagram of diagenetic evolution, porosity evolution, and petroleum charging period of the Lianglitage Formation in the Tazhong area.

catch the first two stages of the oil and gas charging. The abundant available effective network fractures were formed relatively late, mainly at the Himalayan period. And it is characterized by that the dissolution and expansion effect is apparent, the bearing trend was relatively long, and there were many pinhole dissolved pores and small-medium-sized cave along the fractures, only light oil, natural gas or formation water were filled in the fractures. Therefore, the charging process and the organic acid dissolution were the most important burial dissolution effect, and it was also an important factor for the formation of the effective reservoir. The dissolution was relatively strong in the reef flat of platform margin, and the string beadlike dissolved pores and fractures formed by the dissolution action of the organic acid or the other fluid enlarged the reef flat connectivity, the hydrocarbon pore volume and fluid ability.

3 The hydrocarbon distribution and geochemical characteristics of the natural gas

3.1 The hydrocarbon distribution characteristics

The distribution and geochemical characteristics of hydrocarbon is gradually changing from east to west along the Tazhong No. 1 fault belt. The high-yield gas wells cling to the No. 1 fault zone, and the production gets smaller inward. The daily output is more than 500000 m^3 in the Tazhong 86-Zhonggu 17 block in the north of the Tazhong No.1 fault zone, and the Tazhong 82 block in the central zone (Figure 3). Judging from the contour map of gas oil ratio, the high gas oil ratio is regularly distributed along the No.1 fault zone, usually over 2000, while the ratio is low when the well is far from the fault (Figure 4), which shows that the Tazhong No. 1 fault zone is an important hydrocarbon migration pathway, especially in the late gas charging process. So the Tazhong No. 1 fault zone is an important gas source fault.

From the geochemical characteristics of natural gas in the Tazhong No. 1 fault zone, the gas charging is found strong and the displacement phenomenon caused by the late natural gas pushing in the earlier-stage natural gas is obvious. It is clear that the gas oil ratio is small in the inner zone of the Tazhong No.1 fault zone, and the gas is dry near the fault, judging from the contour map of aridity coefficient (Figure 5), which indicates that the gas charging is later near the No. 1 fault zone.

3.2 The geochemical characteristic and genesis of natural gas

The carbon isotope gets light from east to west (Figure 6) (the methane carbon isotope is lighter in the Tazhong 45 area, and it has a complicated genesis, so the contour map of the methane carbon isotope is not shown in this article) in the contour map of the carbon isotope of methane, ethane, propane and other hydrocarbon. The carbon isotope is heavy and the natural gas is dry near the No.1 fault belt, which shows the high maturity of the natural gas. So the big charging intensity and the high moving speed reflect that the Tazhong No.1 fault is an important pathway for the natural gas migration since the Himalayan period. However, the small charging intensity and migration distance along the Tazhong No.1 fault zone make it difficult to judge what is the main controlling factor, the reservoir or the transportation system, that leads to the regular and limited gas distribution.

The natural gas in the Tazhong No. 1 fault zone is

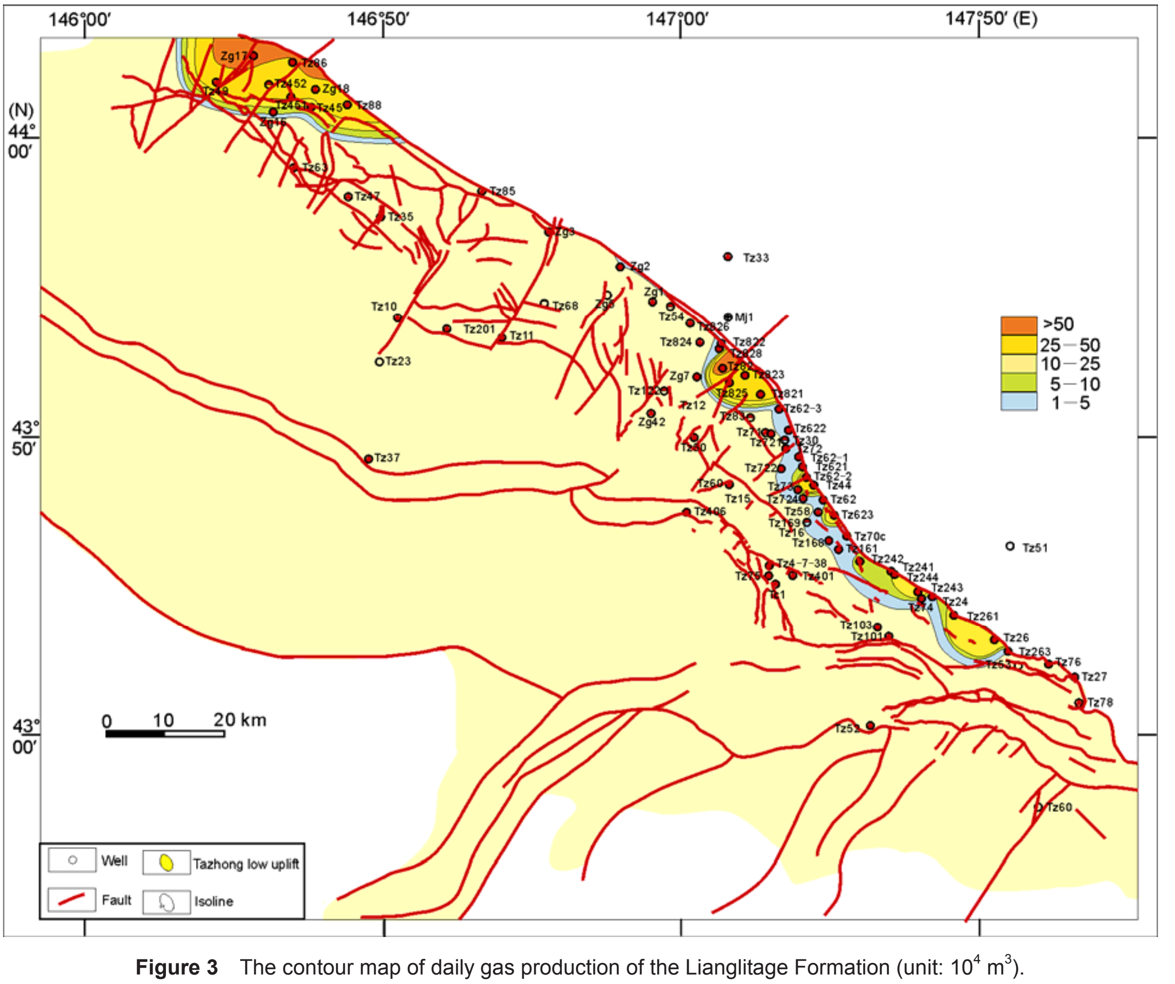

Figure 3 The contour map of daily gas production of the Lianglitage Formation (unit: 10^4 m^3).

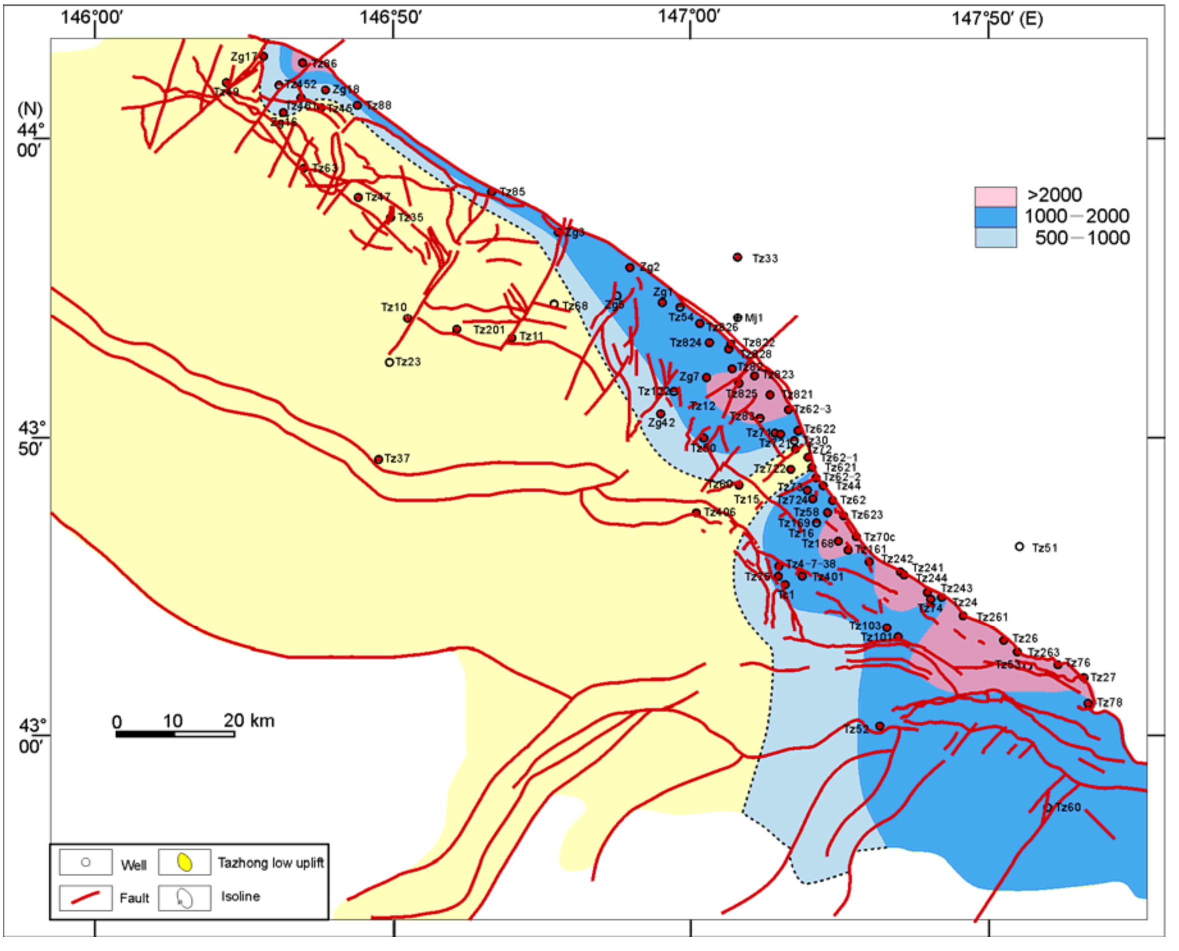

Figure 4 The contour map of gas oil ratio of the Lianglitage Formation (unit: m^3/m^3).

crude oil cracking gas. The range of methane carbon isotope ($\delta^{13}C_1$) is comparatively stable, mainly within the range of −39‰ and −37‰ (except the Tazhong 45 area), the ethane carbon isotope ($\delta^{13}C_2$) is within the range of −37‰ and −32‰, and propane carbon isotope is from −34‰ and −30‰, which indicates that the natural gas came mainly from high-quality hydrocarbon source rock. The normal sequence of $\delta^{13}C_1-\delta^{13}C_2-\delta^{13}C_3-\delta^{13}C_4$ indicates that natural gas is of organic origin (Figure 7).

The natural gas might mainly come from Cambrian-middle Ordovician source rock, because this set of source rock has a high quality and wide distribution, and its thermal evolution has got into the gas generation stage[46–49]. The Ordovician reservoir temperature was generally lower than 140℃ in the Tazhong area, lower than temperature threshold of crude oil cracking, so the natural gas was possibly migrated from other area and accumulated here. According to inclusion data and analysis of the burial history, the charging period of the natural gas in the Lianglitage Formation in the Tazhong No. 1 fault zone is Himalayan.

4 The gas charging and formation mechanism of effective fracture

4.1 The natural gas charging intensity

The large-scale Cambrian and middle-lower Ordovician source rocks began to generate gas since the Late Yanshan-Himalayan period. And the total gas resource volume in the platform is more than 5 trillion cubic meters according to the resource assessment. The proven gas reserves and daily gas production of single well can also prove the strong charging intensity and charging power (mainly the Tabei and Tazhong area). Take the Lunnan area of Tabei in Tarim Basin as an example, the migration pathway (more than 60 km) is mainly carbonate weathering crust and the gas can reach Mesozoic and Cainozoic group through the vertical fault, all of the

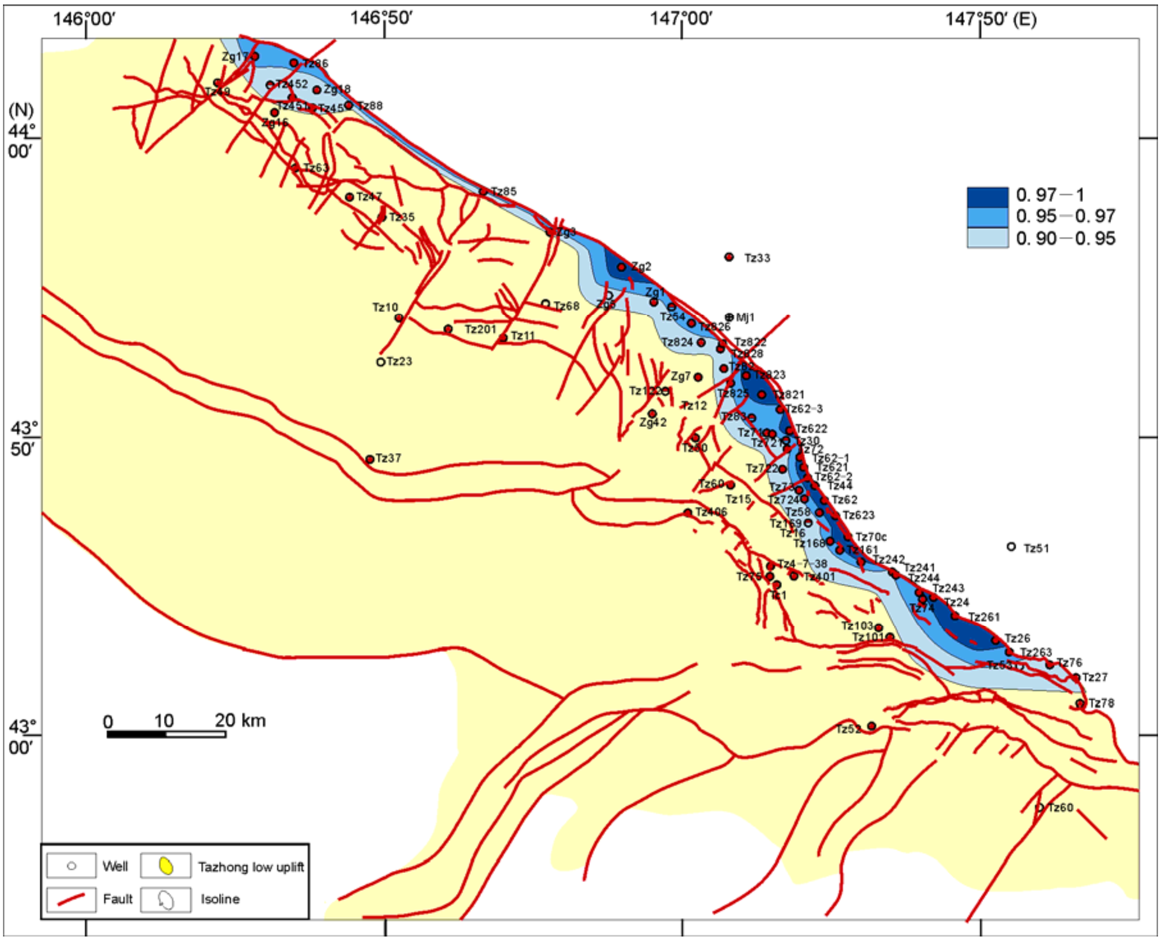

Figure 5 The contour map of aridity coefficient of the Lianglitage Formation.

above proven gas of Yanshan-Himalayan period has strong charging ability. The Tazhong area has a similar charging condition, but it can only migrate several kilometers, even within 5 km. Such great difference may be related to the migrating conditions.

4.2 The development characteristic of fracture and the formation time of effective fracture in the Tazhong area

The reservoir of the platform margin reef flat of the Lianglitage Formation in the Tazhong No. 1 fault zone is composed of pore, cave and fracture, but without fracture, there is hydrocarbon charging, which illustrates the importance of fracture on improving reservoir property. Although the Ordovician fracture of the Lianglitage Formation has the characteristics of multistage genesis, multistage modification and multistage filling[35,36,39,40], according to the fracture types, crosscutting relationship, filling ingredients, the precedence of diagenesis through the observation of the cores and microscopy, the main forming periods are as follows:

(1) Tiny high-angle fractures with straight regular walls were developed in the Caledonian epoch, which were interspersed by later formed cracks and were filled with subidiomorphic-allotriomorphic calcite. The fractures formed in this period have no reservoir capacity, so they were ineffective (Figure 8).

(2) Tensional fractures with irregular walls were developed in the late Hercynian-Indosinian period, which were filled by coarse-grained calcite, fluorite, and other materials, most of them were filled, and only a few has the enlarged corrosion phenomenon.

(3) Fractures formed in the Himalayan epoch have a high distribution density, not filled, but the fractures have small size, short length, narrow silt, generally straight silt surface, enlarged corrosion, showing oblique crossing shaped, branch shaped, horizontal, and netted fracture. The needle-like dissolved pores and small or medium-sized pores are distributed around the cracks or along the extension direction of the fractures, and the

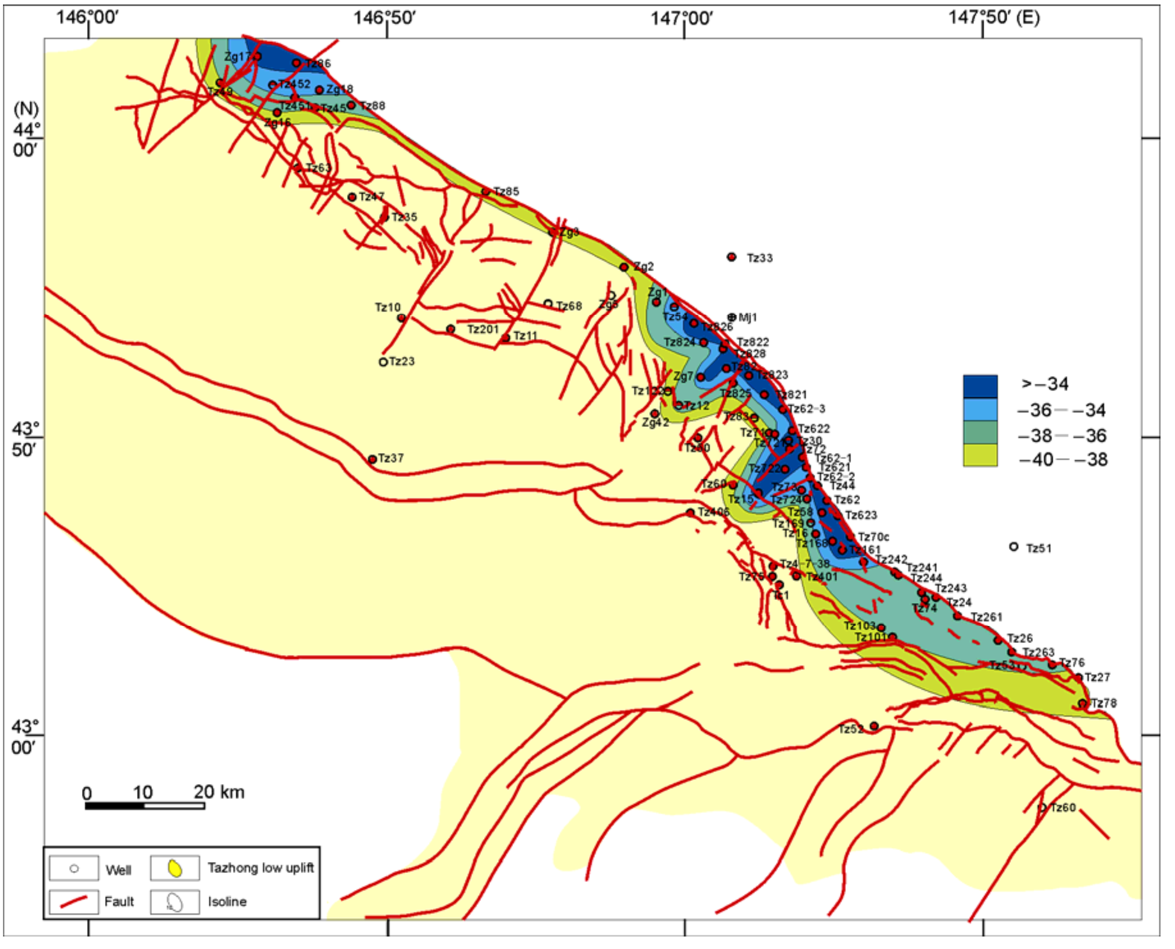

Figure 6 The contour map of ethane carbon isotope of the Lianglitage Formation (unit: ‰).

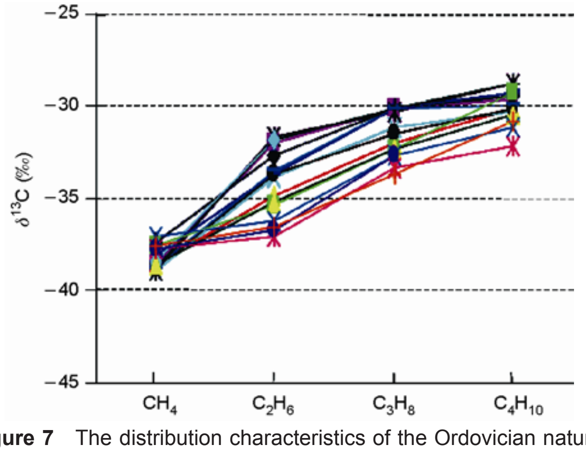

Figure 7 The distribution characteristics of the Ordovician natural gas carbon isotope in the Tazhong area (unit: ‰).

fractures are filled with light oil, natural gas and formation water.

According to the tectonic studies[39], the fault deformation period during the tectonic evolution of the Tazhong uplift are as follows: the first period was the late Caledonian-early Hercynian, when the Tazhong No. 1 fault and associated fault system were formed; the second stage was the late Hercynian, when the Tazhong 4 fault and the Tazhong 11 fault and other fault systems were formed. In the Cenozoic period, the tectonic movement mainly occurred in the Tabei and Kuche areas, and was not associated with the Tazhong area. So no fault was formed in the Tazhong area since the Himalayan epoch, and probably the new fracture system was not caused by the tectonic movement.

4.3 The microstructure of the fractures in Tazhong area

The fractures and cavities within the platform reef-flat complex reservoir of the Lianglitage Formation in the Tazhong No. 1 fault zone were well developed through observations of the cores. However, most tiny fractures could not be observed by our naked eyes. Observations under ultraviolet light revealed that fractures were well developed in the third period (the Himalayan epoch), clean and not filled, and there were many branches,

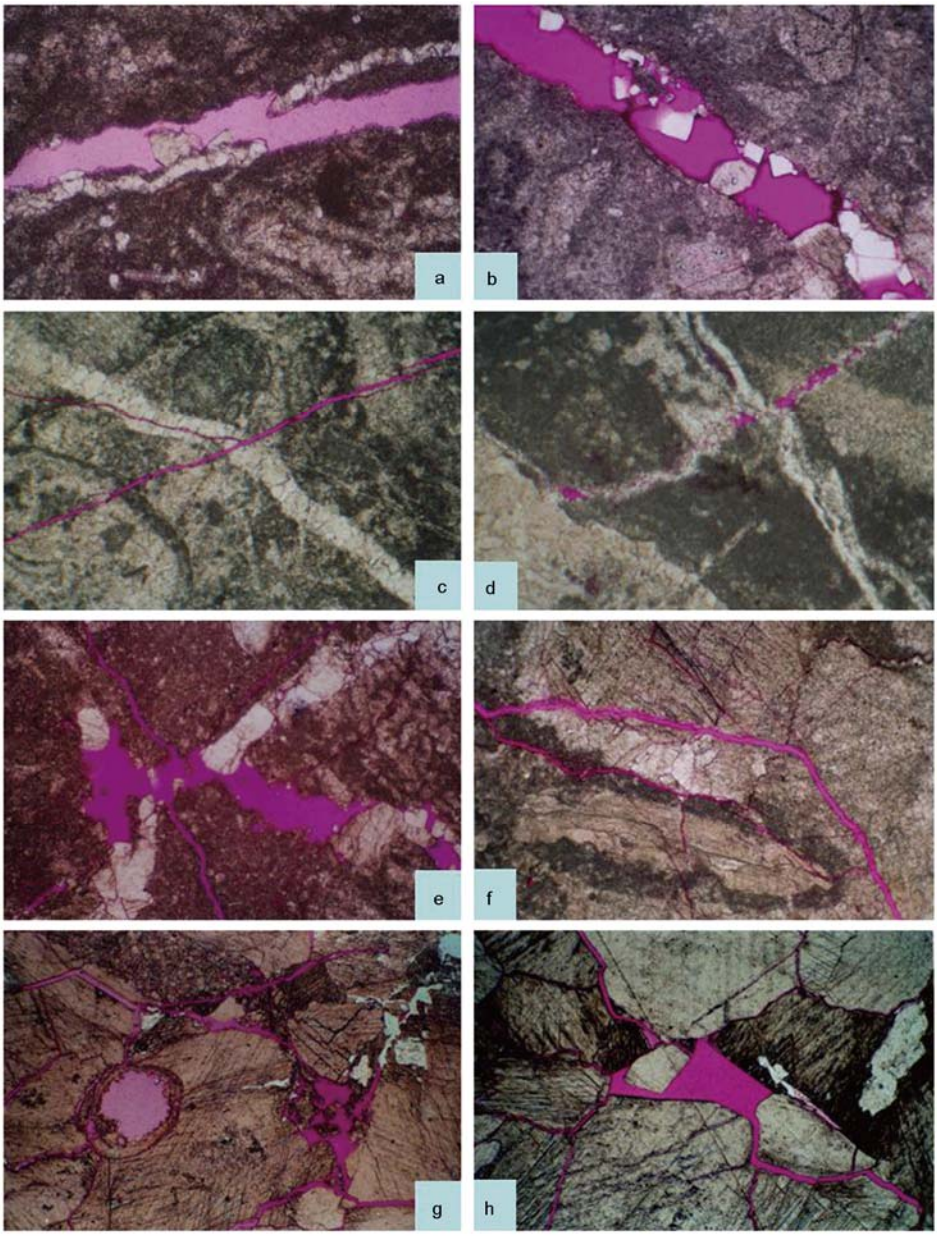

Figure 8 The microscopic features of multistage fractures of the Lianglitage Formation in the Tazhong area.

showing branch-shaped microfractures and intergranular fractures (Figure 9). These branch-shaped fractures were clean and no filled. The silt, crystal gap and interface gap constituted a network and connected with the calcite pinhole through the observations under the fluorescence microscope (Figure 9). Substantial thin-section observations show that the fractures are more developed, with higher density in the wells near the No. 1 fault, but not developed far away from the fault.

4.4 The formation mechanism of the fractures

Judging from the lateral distribution of effective fractures of the platform margin reef-flat complex of the Lianglitage Formation, the effective reservoirs are more developed and the density of the fractures is larger near the gas source. According to the analysis of micro-resistivity imaging logging, most of the trends of the fractures are found to be intersected with the Tazhong No. 1 fault zone with a high angle, spreading from northeast to southwest (while trends of the most early fractures filled by calcite were parallel to the Tazhong No. 1 fault zone), including the erective slip jointings, erective compound fractures, erective extension frac- tures, horizontal fractures, etc. The formation of these fractures is likely to be

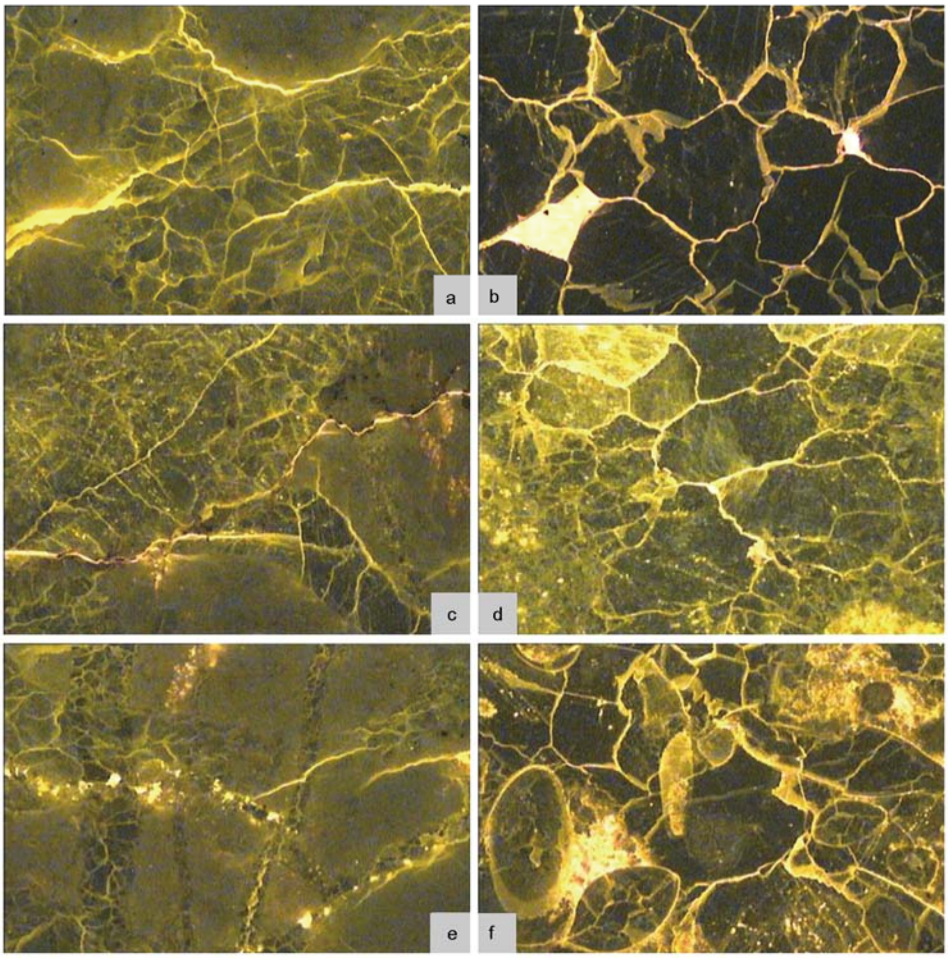

Figure 9 The ultraviolet photos of micro-fracture and intercrystal fracture of the Lianglitage Formation in the Tazhong area (the yellow color represents gas-bearing fractures and pores).

micro fracture systems caused by the breakdown of internal organization structure of limestone in the strong gas charging process. So the development degree of the fractures is related to the force, and the closer to the No. 1 fault zone, the stronger the gas charging, the more developed the fractures and the greater the thickness of the fractured reservoir (Figure 10). In addition, the cracking of the early filled organic matter is also very important to the formation of the post-fractures, because the heterogeneity increases when the fracture develops.

Gas can move more easily than oil because the molecular diameter of gas is much smaller than that of oil, some fractures are only effective for gas migration, but oil cannot pass. The reef-flat complex reservoir of the Lianglitage Formation in the Tazhong No. 1 fault zone has low permeability and low porosity, it is bad reservoir for oil, but good for gas. The previous micro-fractures became wide and extended further, and more micro-fractures were developed around the bigger fractures during the gas moving process driven by the pressure difference. With the reducing of the charging force, the stress power, fracture density, and fracture width reduces gradually, and at last gas cannot pass the fractures again. That is the reason why the natural gas is distributed horizontally along the Tazhong No.1 fault zone at present.

5 The improvement of the reservoir

The fracture forming process, induced by the strong gas charging, is very important to the improvement of the carbonate reservoir. These fracture networks not only connected the pore and fracture, but improved the permeability of the reservoir (Figure 11), and meanwhile they promoted the activity of oil, gas, water and other fluids, also the further development of corrosion holes, and finally the carbonate pore-hole-fracture system was formed. The Ordovician gas in the Tazhong area was

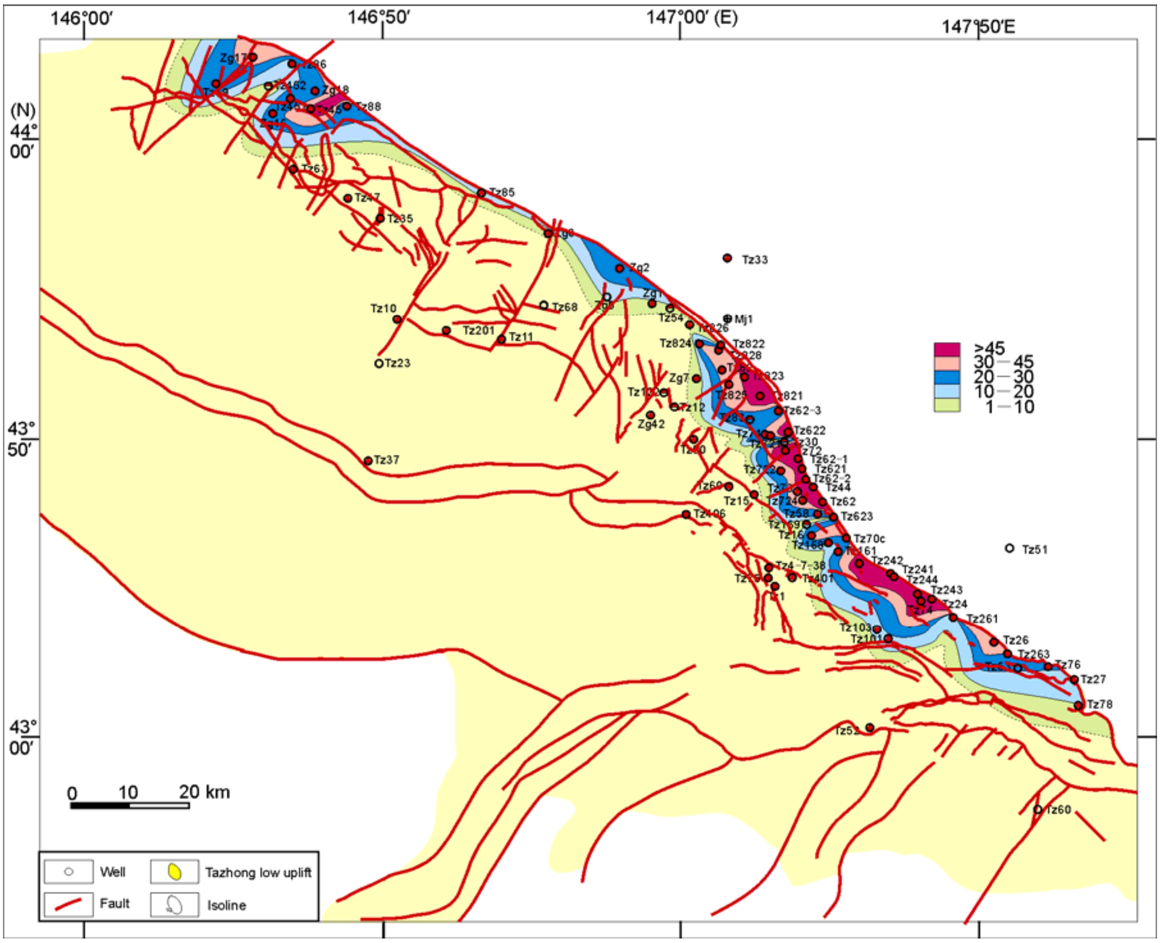

Figure 10 The map of the thickness contours of the effective reservoir of the Lianglitage Formation in the Tazhong No. 1 fault zone (unit: m).

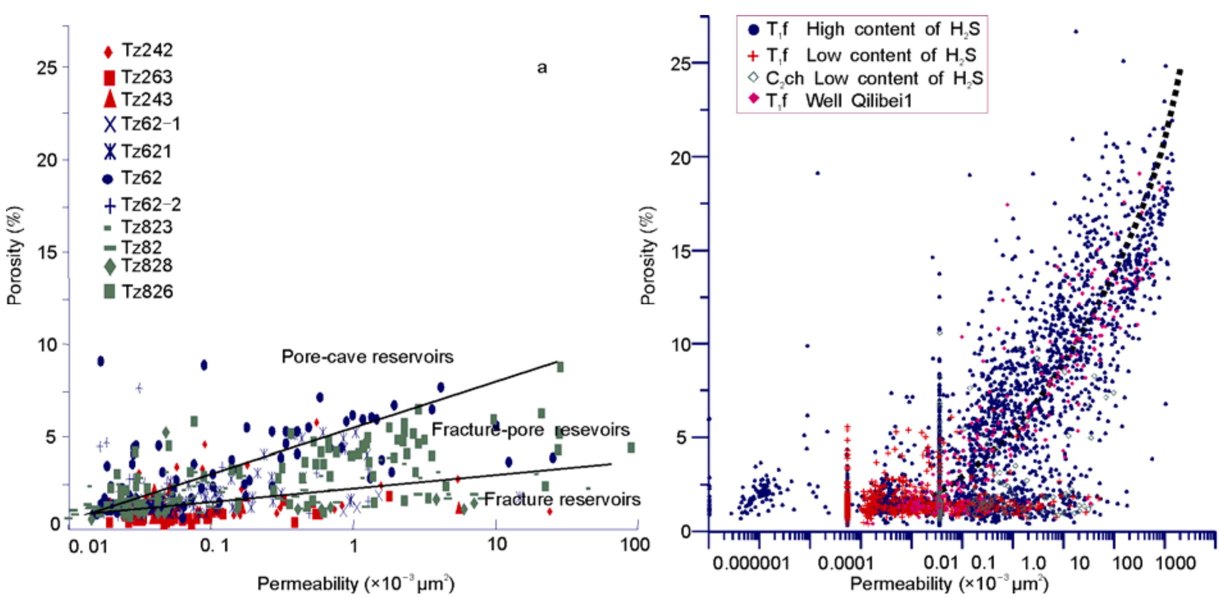

Figure 11 The relationship diagram of the porosity and permeability of the reservoir.

rich in H_2S, and TSR genesis (thermochemical sulfate reduction)[50–52], similar to that in the northeast Sichuan Basin. TSR and hydrogen sulfide formed by TSR played an important role for the dissolution and transformation of the reservoir after they dissolved in formation water[20], and they also could form new dissolved pores.

Therefore, the pore-hole-fracture system connected by the fractures had a great dissolution effect under the interaction of acidic fluid of water-rock. Take the Tazhong 82 area as an example, the interparticle dissolved pores, intragranular pores and intercrystal solution pores are well developed around the fractures observed under the microscope, which formed very late, and were accompanied by beadlike dissolved pores and fractures, etc.

The formation of the cavern is related to the sedimentary facies and erosion, and the later fault was more important for the reservoir transformation. The average porosity of reef-flat complex of the Lianglitage Formation is 0.4% higher in the cores with well-developed fractures than in those with fractures not developed. The average permeability of the former is twice the later, so the formation of the fractures greatly improves the permeability and reservoir property of reef-flat reservoir of the Lianglitage Formation, which play a key role in the formation of the effective reservoirs. That is the reason why the porosity and permeability get better towards the Tazhong No.1 fault zone.

Thus, the fracture network system of the Lianglitege Formation, induced by the strong gas charging since the Himalayan epoch, is very important to the mass gas migration and accumulation. And most important, the pore-hole-fracture integrated system composed of fracture networks and some isolated pore systems greatly improved the reservoir and expanded the reservoir performance. So the pore-hole-fracture integrated system is an important factor for the formation of the large-scale gas condensate fields.

6 Conclusions

The formation and distribution of the reef flat complex of the favorable carbonate reservoir of the Lianglitage Formation is obviously controlled by high-energy sedimentary environment, dissolution and tectonic disruption.

The gas was mainly cracked from the Cambrian, middle-lower Ordovician source rock, and migrated strongly inward along the Tazhong No. 1 fault in the Himalayan epoch. The powerful driving force made the original micro-fractures expanded or extended to form new micro-fractures, that is, the gas charging made the small fractures larger, short ones longer, and even expanded into new ones to form network systems with greater density, which greatly improved the reservoir property. These fracture networks and the isolated pore-hole-fracture systems formed integrated pore-hole-fracture system, which promoted the water-rock interaction and the dissolution, and greatly improved the reservoir performance. The integrated pore-hole-fracture system is an important factor for the gas accumulation of reef-flat complex of the Lianglitage Formation.

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