Reservoir characteristics and genesis of high-porosity and high-permeability reservoirs in Tarim Basin

GU Jiayu, JIA Jinhua & FANG Hui

Research Institute of Petroleum Exploration and Development, PetroChina, Beijing 100083, China;
Correspondence should be addressed to Gu Jiayu (e-mail: gujy@petrochina.com.cn)

Abstract **Based on detailed studies, this paper proposes that in the Tarim Basin, hydrocarbon reservoirs widespread either in vertical sequences or in plane and high-porosity and high-permeability reservoirs are developed all over the basin. However, obvious difference and heterogeneity exist among different kinds of reservoirs. The lithologic characteristics, reservoir space types and reservoir properties in various strata have been probed. The result indicates that although the Paleozoic carbonates have been deeply buried for a long period, high-quality reservoirs with the porosity of up to 5%—8% (12% as the maximum) and the permeability of 10×10^{-3}—100×10^{-3} μm^2 (1000×10^{-3} μm^2 as the maximum) can be found in certain areas. These include the area with the development of reefs and carbonate beaches, the weathered-crust buried-hill belts that have undergone the long-term exposure, weathering and leaching, the area with the development of dolomitization, and those areas that have experienced the resolution of carbonic acid and organic acid generated by the maturity of the organic matter. Finally, the genesis of the high-porosity and high-permeability reservoirs in deep-buried conditions (with the depth more than 3500 m) have been investigated thoroughly.**

Keywords: Tarim Basin, clastic rocks, carbonate rocks, high-porosity and high-permeability reservoirs, control factors.

The Tarim Basin is the largest inner-continental basin of China with an area of 56×10^4 km^2, which bears abundant petroleum resources with oil reserves of 1.09×10^{10} t and gas reserves of 8.3×10^{10} m^3. The strata of the Sinian period to the Quaternary period are well developed in this basin. The Tarim Basin is an important petroleum-replacing strategic area of China and a key basis of the West-East gas transportation project where 10 strata systems from the Sinian system to the Quaternary system have been found to be hydrocarbon bearing. As the basis of hydrocarbon exploration, although the reservoir study has experienced many stages[1—6], former investigations concentrated mainly on the outcrop along the boundary of the Tarim Basin and on the Mesozoic and Cenozoic as a result of technologic limitation. The reservoir of the Paleozoic covered by the desert in the central basin has seldom been concerned. Especially, it is unbelievable that those reservoirs buried down to 5000 m and even 6200 m in depth are of high-porosity and high-permeability. Different supposes have been proposed about the genesis of the pore types and high-porosity and high-permeability reservoirs. Through detailed outcrop investigation, core observation, sample analysis, seismic interpretation and well-log analysis, the reservoir characteristics, pore characteristics, and diagenetic evolution in the Tarim Basin have been elaborated to our best. Furthermore, the genesis of the deep-buried high-porosity and high-permeability reservoirs has been probed which will favor the selection of prospecting belts and targets of petroleum exploration and the increase of the rate of successive exploration.

1 Reservoir characteristics

In the strata from the Cambrian to the Triassic, the lithologic diversity present as a result of the depositional facies diversity, which comprise mainly of carbonate rocks and clastic rocks. Meanwhile, the reservoir type and properties are complex and different largely from each other because of various depositional environments and the large burial depth. The significant feature of reservoirs is that most of their burial depths are more than 3500 m. According to the general practice of the reservoir properties, they should be bad reservoirs or non-reservoirs. However, large amounts of high-quality high-porosity and high-permeability reservoirs are well developed in the Tarim Basin[6,7].

(i) Reservoir space types

The type of reservoir spaces in the Tarim Basin is of diversity. The main reservoir spaces and their characteristics will be introduced as follows[1,2,6—11] (fig. 1).

(1) Reservoir spaces of carbonate reservoirs. Carbonate reservoirs develop mainly in the Cambrian and the Ordovician and secondly in the Carboniferous as some carbonate interbeds. Modified by diagenesis, primary pores have been destroyed to a large extent, which lead to the lack of primary pores. Generally, the matrix porosity of limestone is only 1%—3% and dolomite 5%—7%. The dominating pores are secondary pores.

Intercrystalline pores: They have been found mainly in crystalline dolomite and relict intraclast dolomite. Because of the generally low crystallization degree of the Cambrian and Ordovician dolomite in the Tarim Basin, the pore diameter is small (mainly 0.01—0.15 mm).

Intercrystalline solution pores: They are composed mainly of dolostone intercrystalline pores, calcite intercrystalline pores and anhydrite intercrystalline pores with various diameters (generally 0.05—0.25 mm). The dolostone intercrystalline pores develop mainly in dolosiltite. As the product of the solution of calcite or anhydrite, their distribution is non-even. Most calcite intercrystalline pores are developed in grainstone and packstone, which present as the product of the solution of fine-crystalline calcite cements and fillings of fractures and vugs. Anhydrite intercrystalline pores are developed in the algal-dolomite, lime dolomite or micritic and fine-crystalline dolomite with relatively large proportional change among different reservoir rocks.

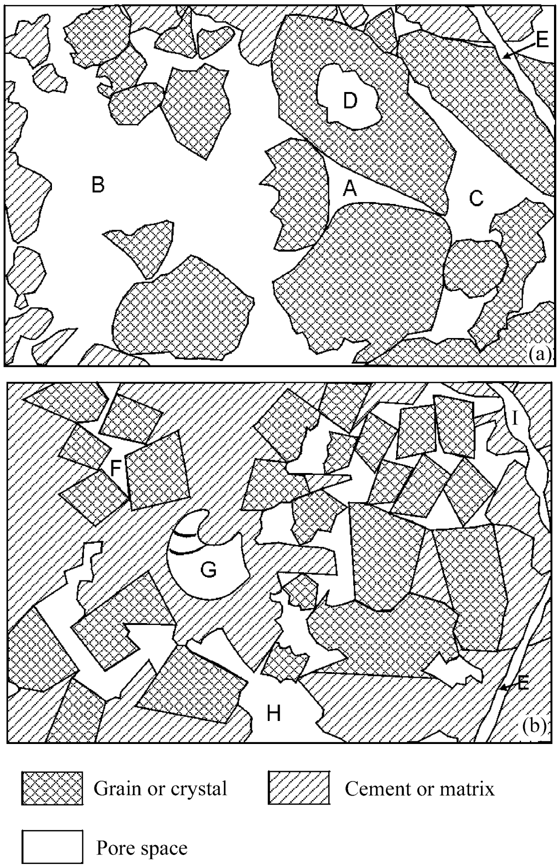

Fig. 1. Sketch map showing main pore spaces of reservoirs in the Tarim Basin. A, Primary pores; B, super-large solution pores; C, intergranular solution pores; D, intragranular solution pores; E, fractures; F, intercrystalline pores; G, moldic pores; H, intercrystalline solution pores; I. fissures.

Moldic pores: They can be subdivided into bio-moldic pores and anhydrite moldic pores. Resulting mainly from the solution of echinoderm and mollusk fragment or whole unit by syngenetic fresh-water leaching, the bio-moldic pores present mainly in dolosiltite, dolarenite, algal-dolomite and dolomitic bioclastic limestone. With relatively large diameter (generally 1—3 mm), they are the dominant pores in bio-clastic beaches. With some anhydrite remains, anhydrite moldic pores in the tabular shape present mainly in micritic and fine-crystalline dolomite of the Carboniferous. In the dolomite of intertidal zone and supratidal zone, they account for 25% of the total pores.

Intergranular and intragranular solution pores: These pores are the most common holding 60%—80% of the total that develop mainly in grainstone, such as ooidal edge solution pores, intraooidal solution pores, algal fragment intragranular solution pores and so on. These pores, in the elongate or irregular shape, are the result of the solution of intergranular matrix, cements, grain's edge and inner, and make the grain's edge in the harbour shape.

Solution caves: These pores are of various shape distributing without fabric selection. Their sizes are different with diameters of several milimeters to several meters. Micro-caves and small caves are dominant in dolomite and relatively large caves in limestone. It is represented by bit drops and mud loss during well drilling. The medium- and small-scale caves are the main contributors to the accumulation of hydrocarbon. Because these caves were formed by the long-term karstification, they always present within 200 m in thickness from the top of weathered crust.

Solution fissures or ditches: They present in pure dolomite and limestone. Having some relationship with the fabric, their shapes are crescent or irregular.

Fractures: They can be subdivided genetically into tectonic fractures and diagenetic fractures. Most diagenetic fractures are filled and only few have been preserved or modified to become the migration way or reservoir spaces of hydrocarbon. Related to the property and orientation of tectonic forces, the tectonic fractures are a perfect migration way of and effective reservoir spaces for hydrocarbon.

(2) Reservoir spaces of the clastic rocks. Reservoirs of the Mesozoic are dominated by primary pores and some secondary pores can also been found. While in the Paleozoic, secondary pores are dominant and primary pores occur to some extent. In some intervals of the Carboniferous, primary pores are relatively well developed.

Primary pores: Primary pores are often intergranular pores that have not been pushed out by the post-depositional compaction. Determined by the contact relationship between grains, their shapes are often triangular, long, irregularly multi-angular, honeycomb-like and so on.

Reservoirs of the Cretaceous and the Tertiary are dominated by primary pores, which account for over 90% of the total porosity. With the increase of the burial depth, the primary pores become gradually less in percentage, 55%—75% in the Triassic-Jurassic and 30%—55% in the Carboniferous. Secondary pores are dominant in the reservoirs of the Silurian. The primary pores change in percentage among different depositional environments. The Silurian oil sands also kept a certain original pore percent.

Secondary pores: With the change of post-depositional physicochemical conditions, such as temperature, acidity, pressure, ion-exchange and so on, secondary pores were formed by dissolution, replacement or carrying away of the rock grains, cements and matrix by formational water. The shape of secondary pores is often irregular with estuary-like, worm-like and pin-brick-like edges. With a large scope of size, the diameter of pores can be less than 0.01 mm and can also be larger than those of clastic grains. Their distribution is uneven with local concentration.

Such secondary pores play a very significant role in the Silurian and Carboniferous reservoirs and also play a certain role in the Triassic and Jurassic. The major characteristics and classification of the secondary pores are described as follows:

1) Intergranular solution pores: They are the pores among grains, which were formed after the matrix, carbonate cements or grain edges, and angles were dissolved or replaced. This kind of pores accounts for a large proportion (generally, 70%—90%) of secondary pores.

2) Intragranular solution pores: These pores were formed partly or completely due to the dissolution or replacement of some internal compositions of the original clastic grains. The dissolution often occurs within the relatively unstable grains, such as feldspar grains and lithic fragments, or occurs along weak texture lineaments, such as joints and microfractures. The intragranular solution pores are commonly distributed cellularly or irregularly and are often connected with the intergranular solution pores. This kind of pores accounts for a small proportion of secondary pores.

3) Super-large moldic pores: When some of the clastic grains were completely dissolved or replaced, there will form moldic pores at the original grain locations. Such pores will keep the shape of their original grains. If the pore space is larger than the original grains, making the grains take a floating shape, the pores can be classified as super-large moldic pores. This kind of pores account for 1%—10% of secondary pores.

4) Solution fissures: Strictly speaking, such pore spaces cannot be classified as secondary pores. However, they were formed by dissolution along some weak lineaments, such as structure fractures and joints. With the width of 0.05—1.0 mm, they can act as conduits for fluids and can also provide fluids for the development of the other pores.

(ii) Reservoir diagenesis and distribution of porosity and permeability

Having formed during the long geological history, the sedimentary sequence in the Tarim Basin has huge thickness and has experienced different kinds of diagenesis.

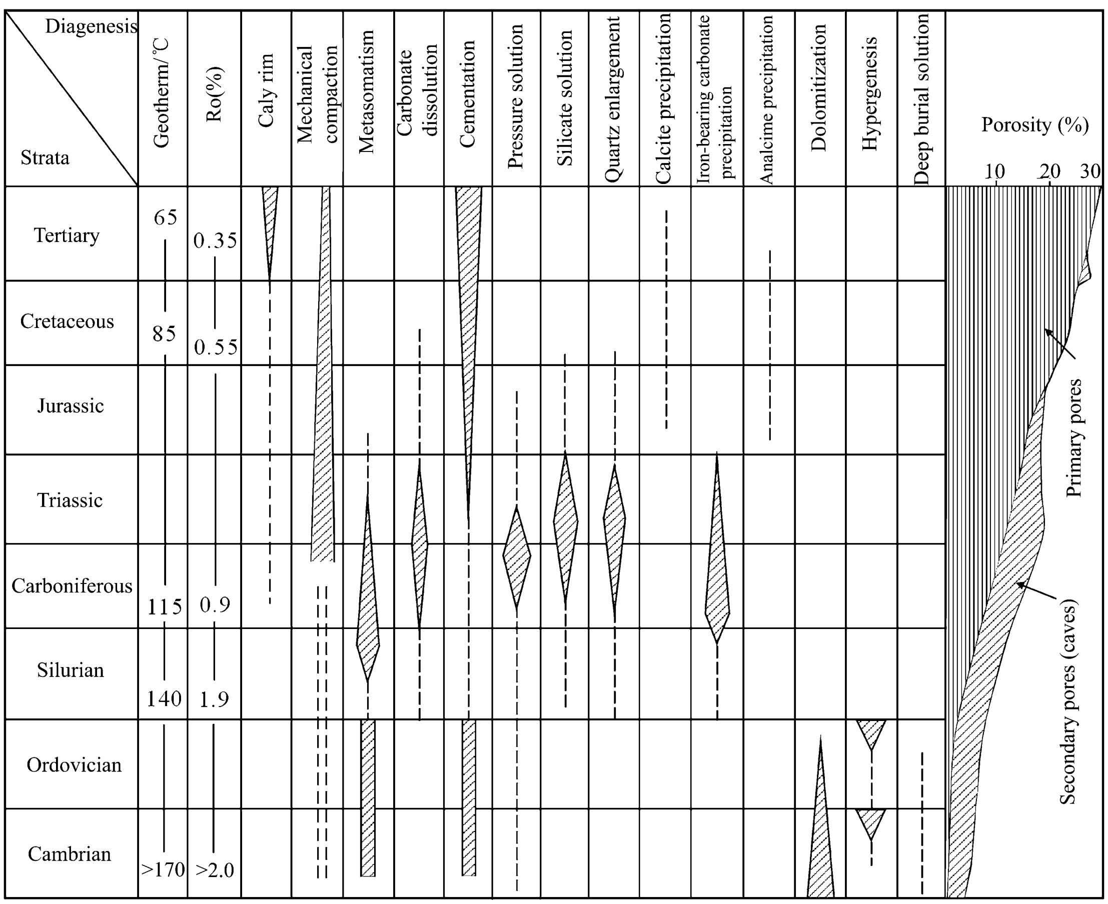

Fig. 2. Main diagenesis and pore evolution of producing strata series in Tarim Basin.

Because of the different diagenesis and pore evolution of different strata (fig. 2), there are obvious differences between the reservoir properties of different strata series.

The dominant rock in the Cambrian and Ordovician are carbonates whose present burial depth is 3500—7200 m. The Cambrian and Lower Ordovician consist mainly of dolomite with abundant intercrystalline and secondary pores. Its porosity is relatively large, 3%—7.6% as the common and up to 5.6%—13.8% sometimes. The permeability of the dolomite member in Tazhong 1 well is 1.13×10^{-3}—14.83×10^{-3} μm^2. The main rock of the Middle and Upper Ordovician is limestone with secondary pores. Its porosity is low, generally ca. 2%, some 4%—5%, few up to 7%. And its permeability is generally below 10×10^{-3} μm^2.

The Silurian sandstone reservoirs have low porosity (mostly 5%—15%) and low permeability (mostly 0.1×10^{-3}—30×10^{-3} μm^2) because they have experienced strong diagenesis[7]. However, reservoir property was improved largely in the sandstone near strata pinch-out line as the result of erosion, weathering and leaching. In Wei 1 well, for example, the porosity is up to 18% and the permeability is up to 40×10^{-3} μm^2 in the interval at 2702.85—2708.25 m, which construct weathered crust reservoir.

From the drilling data, the Devonian sandstone reservoirs have the moderate reservoir property with 10%—20% of porosity and 10×10^{-3}—40×10^{-3} μm^2 of permeability (223×10^{-3} μm^2 as the maximum).

The reservoir types of the Carboniferous are of diversity. According to the rock types, they can be subdivided into clastic rocks and carbonate rocks. The clastic reservoirs formed in the littoral facies, delta facies and tidal beach facies. The Donghetang sandstone of the Carboniferous is foreshore and shoreface sand body comprising of fine-grained quartz sandstone, lithic sandstone and sub-feld-spathic lithic sandstone whose present burial depth is 3200—6120 m. Its reservoir property shows great difference in different regions. The porosity of Donghetang sandstone in the Tazhong region is 16%—21% with the permeability of 100×10^{-3}—1000×10^{-3} μm^2 (3057×10^{-3} μm^2 as the maximum) (fig. 3). However, in the Tabei area, its porosity is 14%—17% with the permeability of 10×10^{-3}—85×10^{-3} μm^2 (150×10^{-3}—714×10^{-3} μm^2 as the maximum). Deltaic sandstone was distributed mainly in the C_1 oil member and around the Tazhong region. It is characterized by the high porosity (19%—24%)

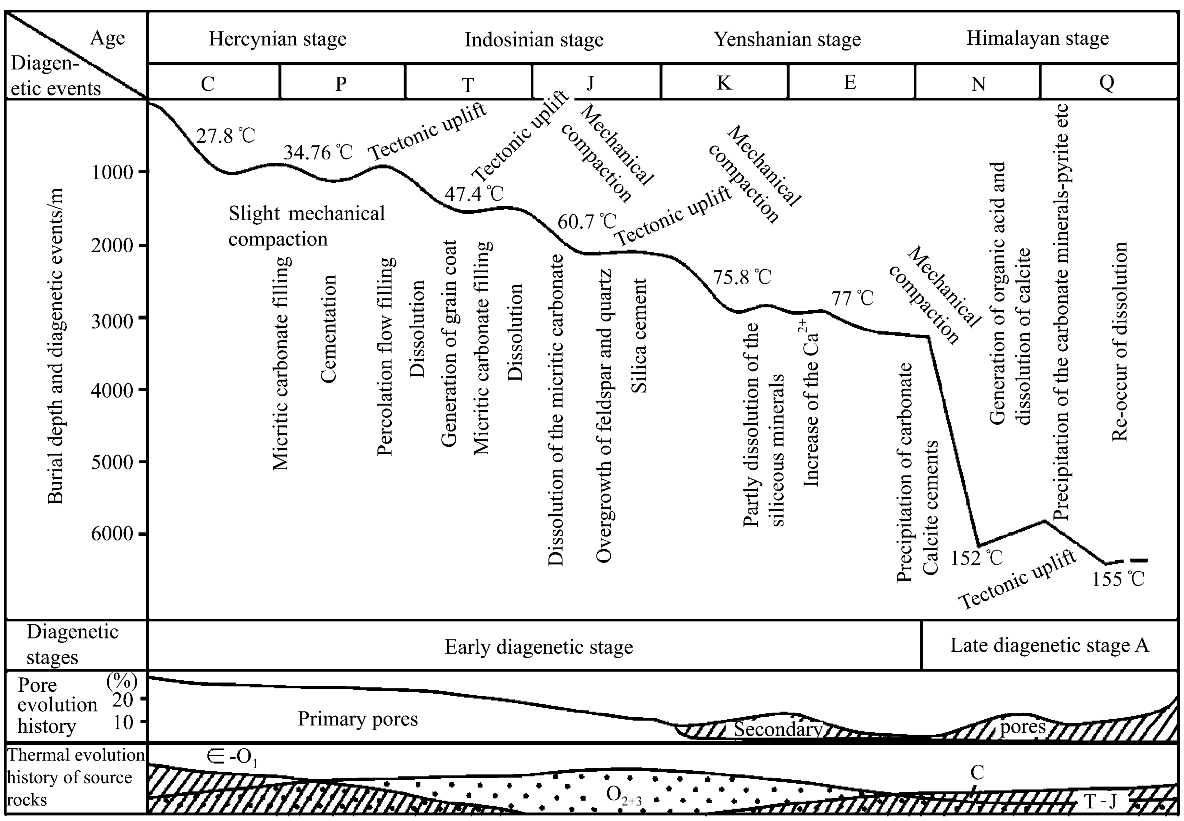

Fig. 3. Pore evolution of the Carboniferous in Donghetang area, Tarim Basin.

and high permeability (100×10^{-3}—6300×10^{-3} μm^2). Tidal beach sandstones were distributed mainly in the C_1 oil set in the Tabei region. It is a set of medium-fine lithic sandstone composed of different sizes of lithic grains and carbonate cements. Its reservoir property depends on the content of carbonate cements and the dissolution degree. The sand body undergone strong dissolution has good reservoir property with the porosity more than 19% and the permeability of 631×10^{-3} μm^2.

The Lower Permian in the western Tarim Basin is of marine deposits and eastern of continental deposits. The algal calcarenite in this area can become reservoirs. But its thickness is small (less than 1.7 m of single bed) and its porosity (11%—12%) and permeability (less than 1×10^{-3} μm^2) is also relatively low.

The Upper Permian in the western Tarim Basin is of lacustrine deposits and in the eastern of braided-river deposits. Relatively good sandstone reservoirs have been found in the shallow lake. The Upper Permian in Manxi 1 well is of braided-river deposits. Because its low-degree sorting and mineral maturity, its plastic deformation was strong during the compaction which leads to the low porosity (less than 16%) and low permeability (less than 20.99×10^{-3} μm^2).

The Triassic and Jurassic sand body in the Tabei and Tazhong regions include braided-delta sand body, fan-delta sand body, fluvial sand body and delta sand body[9,10] whose present burial depth is 4200—5780 m. Generally speaking, their porosities in the Tazhong area are larger than those in the Tabei area. In vertical, because of the coarser grain size and abundant dissolution, the reservoir property of the Jurassic Ⅳ oil set is better than those of Triassic Ⅰ, Ⅱ and Ⅲ oil sets (table 1).

Table 1 Porosity and permeability characteristics of the Triassic and Jurassic in Tarim Basin

Exploration region	Stratohorizon		Type of sandbody	Core porosity (%)	Core permeability ($\times10^{-3}$ μm^2)
	Stratum	Oil sets			
Lunnan—Jielake	J	Ⅰ, Ⅲ	shore sand bar	15.6	19.0
		Ⅳ	subaqueous distributary channel with channel-mouth bar interbeds	18.0	222.5
	T	Ⅰ	subaqueous distributary channel with flat sands and channel-mouth bar interbeds	17.4	138.1
		Ⅱ	subaqueous distributary channel with channel-mouth bar and flat sands interbeds	19.2	254.3
		Ⅲ	subaqueous distributary channel and braided channel	20.02	328.3
Donghetang—Yingmaili	J		shore sand bar and meandering river channel	17.35	51.3
	T		subaqueous distributary channel, channel-mouth bar interbeds, flat sands	19.35	128.5
Manjiaer	J		shore sand bar, delta plain channel sands	26	310
	T		delta subaqueous distributary channel, channel-mouth bar, shore sand bar, alluvial channel sands	21	126
Tazhong	J		alluvial channel sands, shore sand bar	24	120
	T		alluvial plain, flood plain, channel sands	20	10

The Cretaceous reservoirs are widespread with a large proportion in the whole strata. Its present burial depth is 2360—6400 m in the Kuqa depression. The porosity and permeability of the Cretaceous are always high with the porosity of 12.03%—19.7% and the permeability of 0.22×10^{-3}—1365.9×10^{-3} μm^2. Vertically, reservoirs concentrated in the Lower Cretaceous with some random.

The Eogene system is characterized by the development of evaporation marginal-sea deposits with different degrees of anhydritization in the dry climate, such as conglomerate, sandstone, mudstone, micritic limestone, bioclastic limestone and anhydrite. The basal medium-fine conglomerate and fine sandstone were formed in the braided-river channels that were distributed in the flat shape of the fan delta front. The Lower Triassic sandstone in Kela-2 well enjoys the porosity of 3.97%—18.14% and the permeability of 0.03×10^{-3}—202×10^{-3} μm^2. In the Yingmaili tectonic belt, the Eogene sandstone in Yingmai 21 well own the characteristic of high-porosity (18.8%—30.9%) and high-permeability (4.1×10^{-3}—32.9×10^{-3} μm^2). In addition, the dolomite reservoirs in the Kela 2 well district have an average porosity of 11.45% and an average permeability of 3.6×10^{-3} μm^2. Their capillary pressure curves in shape of coarse-skewness indicate that grains are well sorted. So this kind of dolomite is the good reservoir. Of course, the Eogene reservoir property is different in different regions.

2 Genetic analysis of the reservoir with high-porosity and high-permeability

The current hydrocarbon reservoirs in the Tarim Basin are distributed mainly in the Ordovician, Carboniferous, Triassic, Jurassic and Cretaceous. These hydrocarbon reservoirs are at the burial depth over 3500 m, occasionally reaching approximately 6000 m (the Carboniferous Donghetang sandstone in the Donghetang area), the reservoir quality remained very good and can be classified high-porosity and high-permeability reservoirs. For example, the Carboniferous Donghetang sandstone at 6000 m depth has an average porosity of 15% (24% as the maximum) and average permeability of 64.04×10^{-3} μm^2 (1911×10^{-3} μm^2 as the maximum) (according to 178 samples). High hydrocarbon production of 200—400 t per day can be attained in the Ordovician which is at the depth of more than 5000 m.

It is rare in the world petroleum geology history that such good reservoirs can be kept at such a large burial depth. Discussion on the issue will be of important theoretic and practical value.

(i) The low geothermal gradient enables preservation of original pores and meanwhile causes the deep-buried reservoirs still at peak secondary pore developing stage. It is widely accepted that the Tarim Basin is a low geothermal gradient basin, with the average geotemperature gradient ranging from 1.8 to 2.0℃/100 m, with 0.5—1.0℃/100 m lower than the other basins of China (table 2). Due to the low thermal gradient and the high anti-compaction capacity of the quartzite sandstone, the quartz grains underwent a very weak pressure solution and still kept being point contacted with each other even at so deep a burial depth over 5700 m. This enables the preservation of primary pores in the reservoirs. On the other hand, although the burial depth had reached over 5000 m due to the low thermal gradient, the geotemperature is about 100℃, belonging to the B substage of the early diagenetic stage or A substage of the later diagenetic stage. So the organic matters remained at the maturation stage. A large volume of organic acid and carbon dioxide generated from the organic matters can dissolve part of the early-formed cements, matrixes or even mineral grains, forming some secondary pores and keeping the rocks a high porosity[7].

Table 2 Geothermal comparison at different depths in different large-medium scale basins of China

		Songliao Basin	Huabei Basin	Ordos Basin	Sichuan Basin	Tarim Basin
Geotemperature/℃	1000 m	40—50	40—45	35—40	35—45	30—40
	2000 m	70—80	70—80	60—70	60—70	50—65
	3000 m	90—110	90—100	90—100	90—100	75—90
Geothermal gradient (℃/100m)		3.5—4.0	3.4—3.5	2.8—3.0	2.4—2.5	1.8—2.0

(ii) Long-term shallow burial and rapid short-term deep burial enable preservation of primary pores.

According to the tectonic evolution analysis, since the Cambrian, the Tabei, Tazhong and Bachu uplifts had experienced several stages of tectonic rising. The rapid deep burial did not occur until the Neogene, about 23.3 Ma ago. For example, the Carboniferous sediments of the Lunnan area kept a burial depth of 1400—1800 m during the 257 Ma from the deposition to the end of the Paleogene. They were deeply buried over 5000 m after the 3300—3600-m-thick sediments of the Neogene were deposited during 23.3 Ma from the Neogene to the present. Because the deep burial time is short and the geothermal gradient is low, the original pores can be kept within the high maturity rocks[7,12].

(iii) Dissolution of part of the cements of mineral grains by acidic formational water increases the porosity.

In the terrigenous clastic sediments, the carbonate rocks or grains moving in from outside met dissolution after the water media changed, and when the formational water reached carbonate saturation, the carbonate began the precipitation, forming syngenetic micritic carbonate cements. With the increase of the burial depth, and when the formational temperature reached 85—135℃, corresponding to the B sub-stage of the early diagenesis stage ——the A sub-stage of the late diagenesis stage, a great amount of generated organic acid made the feldspar strongly dissolved[1,6], with the Ca^{2+} and Al^{3+} moving away in complex solution[8,13,14]. This led to the porosity increase by 6.0%—8.0%. On the other hand, the authigenic kaolinite dispersed among the rock grains, with less influence on the porosity and permeability, and formed a clay film over the quartz grains, prohibiting the quartz grains from overgrowth. This is benefit for the preservation of reservoir pores[15].

(iv) Modification of the diagenetic system by unconformity and structural faults improves the reservoir property. The Tarim Basin has experienced several stages of tectonic movements, forming 7 large unconformities and several fault systems of different ages. The unconformities and fault systems acted as hydrocarbon migration pathways, and meanwhile, the unconformities underwent the long-term weathering and leaching. Therefore, the organic acid concentration reaches the highest along the unconformities and faults. In the Donghe-2 well, for example, the organic acid concentration reaches 873×10^{-6} at the unconformity between the Jurassic and the Carboniferous. Meanwhile, along the unconformities, kaolinite obviously increased due to dissolution of the feldspar, and leaching as a result, the reservoirs along the unconformities and the neighboring intervals were obviously improved. Generally, the unconformities are 2%—5% higher in porosity than the original rocks or the original non-fractured rocks[12,16].

The influence of tectonic fracturing on carbonate reservoirs is more obvious. Carbonate rocks are so brittle to fracture. So carbonates can form fractures easily with the action of tectonic movements, which build up fracture-type reservoirs with improved reservoir spaces and permeability. Meanwhile, fractures provided pathways for the dissolution fluid. For example, three-stage tectonic fractures in the Tazhong area play a important role in the formation of high-porosity and high-permeability reservoirs.

(ⅴ) Favorable sedimentary facies provided a basis for the deep buried high-porosity and high-permeability reservoirs to develop. The study indicates that the sedimentary facies is a basis for controlling the high-quality reservoirs development. In the marine sediments, the beach subfacies and subtidal marine sediments, the delta front facies, the fan delta front sub-water braided facies and the shallow beach facies of the lacustrine sediments are all of high energy during the deposition and are long lasting, and as a result, the sediments in these facies are of high matrurity, with low matrix content. The quartz grains within the sediments have a high anti-compaction capacity and are difficult to dissolve, and thus favorable for primary pores to preserve[4,6,7,10,12,17]. The pure sandstone has very less authigenic minerals formed during the diagenesis process because there are very less mudstone intervening within it. The low content authigeneic minerals dispersed in the sediments, favoring pores to preserve and with less influence on the permeability.

(ⅵ) Charge of hydrocarbon. Large amount of pore water could be pushed out by the charge of hydrocarbon into pores. The cementation became weak or ceased, which has preserved reservoir pores and formed high porosity[18—22]. According to the fluid-inclusion homogenization temperature analysis of limestone cements of the Ordovician in the Tazhong region, the temperatures of the third-epoch calcite cements in reef caves are of two-segment distribution. In the absent of 100—110℃, the low values are distributed between 80—100℃ and the high values between 110—120℃. In the hydrocarbon-inclusions homogenization temperatures of the calcite filled in Hercynian fractures are distributed between 80—120℃, most concentrating between 100—110℃. Therefore, we proposed that the temperature scope of the migration and accumulation of Hercynian hydrocarbon is 100—110℃ and the charge of the Hercynian hydrocarbon prevented the deepening of cementation. For example, the porosity of the oil-containing cores is obviously higher than that of adjoining cores in Tazhong 161 well.

(ⅶ) Dolomitization. It is believed that dolomitization can improve the reservoir property for the following reasons: 1) Because dolomite has greater ability of anti-compaction and anti-pressure solution than limestone, the declining speed of porosity with the increase of the burial depth in dolomite is much smaller than that of limestone. 2) Without the input of external Mg^{2+}, when Ca^{2+}-rich dolomite reformed into more stable dolomite, the excessive $CaCO_3$ should be taken away, which would generate relatively large amounts of intercrystalline pores. 3) Under the same condition, dolomites can form fractures more easily than limestone. 4) When dedolomitization and the selected dissolution happened in dolomites, intercrystalline solution pores should be generated easily along the original intercrystalline fissures. Dolomitization is well developed in the Lower Paleozoic of the Tarim Basin, which could form high-quality reservoirs[2,5,6]. According to the porosity and permeability analysis of small-diameter samples, the Lower Ordovician dolomites in the Tazhong region have a porosity distribution of 0.3%—8.63% with the mean porosity of 1.759% and the mean permeability of 2.256×10^{-3} μm^2, while the limestone of the same stratum has a porosity distribution of 0.2%—3.66% with the mean porosity of 1.087% and the mean permeability of 1.721×10^{-3} μm^2. Obviously, the reservoir property of the dolomite is better than that of the limestone.

(ⅷ) Paleokarstification. After the deposition of the Ordovician in the Tarim Basin, the Caledonian, Hercynian, Indosinian and Himalayan orogenies had uplifted the Ordovician in Tabei and Tazhong regions to the long-term weathering and erosion, that is, the weathered crust karstification. Paleokarstification can be subdivided into the limestone karstification and dolomite karstification. The limestone karstification distributed mainly in the Lunnan region and secondly in Yingmaili and Tazhong regions. The dolomite karstification was distributed mainly in the Yingmaili and Tazhong regions. The effective reservoir spaces generated by karstification are characterized as semi-filled or none-filled large-scale caves, medium- and small-scale solution pores or caves, fractures in the top of caves, intergravel pores and inherited solution fissures. The dolomite karstification generated intercrystalline solution pores which are small and compactly distributed without fillings of mud and sands, whose reservoir property is better. The reservoir property of limestone had been improved with the generation of solution caves and fissures by the paleokarstification. Moreover, the paleokarsitfication provided a good basis for the formation of tectonic fractures, burial dissolution and effective pores[23—25].

3 Conclusions

In the Tarim Basin, hydrocarbon reservoirs are widespread either in vertical sequences or in the plane. Although reservoirs are developed in different series of strata, serious difference and heterogeneity exist among different kinds of reservoirs. The rock type of reservoirs is of diversity including limestone, dolomite and various clastic rocks. The reservervoir spaces are also of diversity including dominantly secondary pores and secondly few primary pores. The main secondary pores are intercrystalline pores, intercrystalline solution pores, moldic pores, intergranular pores and solution pores, solution caves and fractures. The reservoir spaces of clastic rocks comprise mainly primary pores and secondly of some secondary pores. The main reservoir spaces are primary pores, intergranular solution pores, intragranular solution pores, moldic solution pores, super-large solution pores and solution fissures. Obvious reservoir property difference exists between clastic rocks and carbonate rocks. Most carbonate reservoirs are geologically old-aged and have experienced complex diagenesis with relatively low porosity of up to 5%—8% (12% as the maximum) and permeability of 10×10^{-3}—100×10^{-3} μm^2 (1000×10^{-3} μm^2 as the maximum). High-porosity and high-permeability reservoirs are well developed upon the Devonian with the porosity of 14%—20% in common (30% as the maximum) and permeability of more than 100×10^{-3} μm^2 (1000×10^{-3} μm^2 as the maximum). The main reasons of the formation of these high-porosity and high-permeability reservoirs are as follows: The long-term low geothermal gradient enabled the preservation of primary pores. The long-term shallow burial and rapid short-term deep burial slow down the decrease speed of primary pores. Dissolution of some cements and grains by acidic formational water improved the reservoir property. Paleokarstification and tectonic fracturing generated large amounts of secondary pores in carbonate reservoirs. Dolomitization enlarged intercrystalline pores which had increased the porosity. The charge of hydrocarbon could prevent or slow down the diagenesis, which had preserved and increased the reservoir pore spaces. Favorable depositional facies provided a basis for the development of high-porosity and high-permeability reservoirs in the Tarim Basin.

References

1. Chen Guojun, Ma Baolin, The diagenesis and secondary pores of the Lower Permian of Keping areas in the northwestern edge of Tarim Basin, Acta Sedimentologica Sinica (in Chinese), 1990, 8(1): 91.
2. Shi Ji'an, The origin of dolostone and its reservoir characteristics of Sinian and Paleozoic, northwestern margin of Tarim Basin, Acta Sedimentologica Sinica (in Chinese), 1993, 11(2): 43.
3. Ye Desheng, Deep dissolution of Cambrian-Ordovician carbonate in the northern Tarim Basin, Acta Sedimentologica Sinica (in Chinese), 1994, 12(1): 66.
4. Gu Jiayu, He Bin, Study on Triassic fan delta sedimentation and reservoir in Lunnan area, Tarim Basin, Acta Sedimentologica Sinica (in Chinese), 1994, 12(2): 54.
5. Guo Jianhua, Shen Zhaoguo, Li Jianming, Dolomitization of Lower Ordovician in eastern sector of North Tarim region, Oil and Gas Geology (in Chinese), 1994, 15(1): 51.
6. Chen Yongwu, Reservoirs and Hydrocarbon, Beijing: Petroleum Industry Press, 1994, 198—227.
7. Gu Jiayu, Ling Congqian, Jia Jinhua, High-quality reservoir features and genetic analysis of clastic rocks in Tarim Basin, Geological Review (in Chinese), 1998, 44(1): 83.
8. Wang Shaoyi, Zhu Guohua, Yao Genshun, Pore assemblage types and genesis of clastic reservoirs in eastern Tarim Basin, New Development of Petroleum Geology study in Tarim Basin (eds. Tong Xiaoguang, Liang Digang, Jia Chenzao) (in Chinese), Beijing: Science Press, 1996, 399—405.
9. Wang Zhengyun, Wang Fangping, Lin Xiaoyun et al., Pore types and origin of secondary pores of Triassic and Jurassic in north Tarim Basin, Oil and Gas Geology (in Chinese), 1995, 16(3): 203.
10. Wang Fangping, Wang Zhengyun, Lin Xiaoyun et al., Characteristics of Triassic-Jurassic reservoirs in Tabei Uplift, Oil and Gas Geology (in Chinese), 1995, 16(3): 277.
11. Zhai Yonghong, Liu Shengguo, Guo Jianhua et al., Diagenesis and pore evolution of Carboniferous clastic rocks in Central Tarim Basin, Oil and Gas Geology (in Chinese), 1995, 16(3): 252.
12. Gu Jiayu, Sedimentary environment and reservoir characteristic of the Carboniferous Donghe sandstone in Tarim Basin, Acta Geologica Sinica (in Chinese), 1996, 70(2): 153.
13. Barth, T., Organic acids from source rock maturation: generation potential transport mechanisms and relevance from mineral diagenesis, Applied Geochemistry, 1993, 8: 325.
14. Cai Chunfang, Mei Bowen, Ma Ting, The source, distribution of organic acids in oilfield waters and their effects on mineral diagenesis in Tarim Basin, Acta Sedimentologica Sinica (in Chinese), 1997, 15(3): 103.
15. Aase, N. E., Bjφrlykke, P. A., Nadeau, P. H., The effect of grain-coating micro-quartz on preservation of reservoir porosity, AAPG Bulletin, 1996, 80: 1654.
16. Sun Yushan, Yang Fan, Rediscussion on pore genesis of Donghe sandstone——an example from Tazhong area, Acta Sedimentologica Sinica (in Chinese), 1997, 17(supp.): 699.
17. Gu Jiayu, Fang Hui, Jia Jinhua, Diagenesis and reservoir characteristics of Cretaceous braided delta sandbody in Kuqa Depression, Tarim Basin, Acta Sedimentologica Sinica (in Chinese), 2001, 19(4): 517.
18. Nedkvitne, T., Karlsen, D. A., Bjφrlykke, K. et al., Relationship between reservoir diagenetic evolution and petroleum emplacement in the Ula Field, North Sea, Marine and Petroleum Geology, 1993, 10: 255.
19. Wang Qi, Shi Ji'an, Xue Lianhua et al., Characteristics of fluid-rock interaction in clastic reservoir controlled by evolution of diagenetic environment, Acta Sedimentologica Sinica (in Chinese), 1999, 17(4): 584.
20. Wang Qi, Shi Ji'an, Xiao Lixing et al., Influence of oil emplacement on diagenetic sequence of the clastic reservoir rock and it's relationship to the porosity evolution——taking the Carboniferous quartz sandstone in Southeast Tarim Depression as an example, Acta Sedimentologica Sinica (in Chinese), 1998, 16(3): 97.
21. Cai Chunfang, Gu Jiayu, Cai Hongmei, Effect of hydrocarbon emplacement on diagenesis of Silurian sandstone of Central Tarim Basin, Acta Sedimentologica Sinica (in Chinese), 2001, 19(1): 60.
22. Cai Chunfang, Mei Bowen, Ma Ting et al., Diagenetic reaction of Jurassic-Triassic system in North Tarim Basin, Oil and Gas Geology (in Chinese), 1995, 16(3): 259.
23. Guo Jianhua, Buried hill paleokarst and its controlled reservoir heterogeneity in Ordovician, Lunnan region of Tarim Basin, Acta Sedimentologica Sinica (in Chinese), 1993, 11(1): 56.
24. Wang Jinqi, Reservoir prospect of the Ordovician karst reservoirs in Tarim Basin, Oil and Gas Geology (in Chinese), 1999, 20(4): 305.
25. Wang Qi, Shi Ji'an, Chen Guojun et al., Characteristics of diagenesis environments of carbonate rocks in western Tarim Basin and their controls on the reservoir property, Acta Sedimentologica Sinica (in Chinese), 2001, 19(4): 548.

(Received August 9, 2002)