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# Main controlling factors of distribution and genetics of marine reservoirs in China

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**Marine reservoirs are mainly made up of clastics and carbonate reservoirs, which are distributed widely in central Tarim, Sichuan, Ordos basins from the Pre-Cambrian to Cenozoic, mainly in Palaeozoic. Marine clastic reservoirs are developed in foreshore and nearshore, tidal flat and delta environment. The sedimentary facies are important controlling factors for reservoir quality. Compaction, pressolution and cementation are factors of decreasing porosity, and low palaeo-temperature gradient, early emplacement of oil and gas and dissolution are favorable for preservation of pore. Carbonate reservoirs are divided into reef and bank, karst, dolomite and fracture reservoirs. Dolomitization, dissolution, TSR and fracture are important factors of controlling carbonate reservoirs' quality.**

marine, carbonate reservoir, clastic reservoir, genetics

Marine reservoirs are distributed widely from the Precambrian to Cenozoic in China, which are mainly made up of clastic and carbonate reservoirs, and also marine volcanic and volcaniclastic reservoirs. Compared with other countries' marine reservoirs in the Palaeozoic, the marine reservoirs in China have some distinct characters: 1) mainly develop carbonate karst reservoir in the Lower Palaeozoic; 2) mainly develop porous clastic and carbonate reservoir in the Upper Palaeozoic; 3) the types of the carbonate reservoirs are various with strong anisotropy and deep burial depth; and 4) unconventional reservoirs account for large proportion, and reef reservoir is undeveloped[1].

According to the statistics of C&C Company, oil and gas reserves in carbonate rocks account for 38% of the whole oil and gas reserves in the world, and marine carbonate reservoirs approximately account for 60% of the whole reserves in large oil and gas fields. So the marine carbonates are important exploration territory for oil and gas. Since the beginning of 1990s, marine oil and gas exploration in China has been the hotspot that drew much attention of many large petroleum companies and scholars and obtained many important breakthroughs, for example, many carbonate oil and gas fields were found, such as Lunlan-Tahe Ordovician oil field, Puguang Triassic gas field in Feixianguan Formation, Ordovician oil and gas field in the central Tarim, central gas field in the Ordos Basin, and also the Hadexun oil field, the first marine clastic oil field with hundred million ton reserves. But the whole extent of marine oil and gas exploration is very low, owing to the complex geology. In order to improve the exploration of the reserves of marine oil and gas, and relieve the contradiction between supply and demand of oil and gas, it is necessary to enhance theory research about the enrichment and distribution rule of marine oil and gas, and also exploration technology, among which the efficient hydrocarbon rock, the reservoir bed and the preservation condition are very important[1,2].

Scholars at home and abroad have made many researches and discussions about the distribution and genetics mechanism of marine reservoir. For marine clastic reservoir, Surdam et al. [3,4] researched the relationship

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between reservoir diagenesis and secondary pore genetics and evolution in the 1980s. Others also discussed the main factors of high quality reservoirs developed in marine clastic rocks, including sedimentary environment, geothermal field, early oil and gas emplacement, chlorite coatings, micrite quartz coatings, abnormal high pressure and secondary pore, etc.[5−13]. The main factors of reservoir genetics in marine carbonate rock include favorable sedimentary facies, dolomitization, different stages dissolution, tectonic disruption, sulphate thermal reduction, and early hydrocarbons emplacement, etc.[14−21].

This paper discusses the main controlling factors of reservoirs developed in marine clastic and carbonate rocks in China, providing some basic geology data for marine oil and gas exploration in China.

## 1 The main controlling factors of formation and distribution of reservoirs in marine clastic rocks

### 1.1 The distribution characters of reservoirs in marine clastic rocks in China

Marine clastic reservoirs are mainly developed in foreshore, nearshore, shallow sandbar, continental shelf sand, tidal sandbar, tidal channel, sand flat, delta distributary channel, and mouth bar sedimentary environment. Shoreline-shallow continental shelf reservoirs are mainly developed in Kepingtage Formation of the lower Silurian, Donghe sandstone of the upper-Devonian and lower-Carboniferous, mudstone in the Carboniferous in the Tarim Basin, and the Silurian in the Sichuan Basin, the Carboniferous in north China platform. Tidal flat reservoirs are mainly distributed in sand-mud stone in the Silurian and Carboniferous in the Tarim Basin, the Carboniferous in north China platform and Hexi district. Delta reservoirs are mainly developed in the Permian-Carboniferous in north China platform and Hexi district, sand-mud stone in the Silurian and Carboniferous in the Tarim Basin, and Silurian in the Sichuan Basin (see Table 1)[22−26].

### 1.2 The main formation controlling factors of reservoirs in marine clastic rocks

The main controlling factors of reservoirs' quality in marine clastic rocks include sedimentary environment, diagenesis, etc. There are usually one or several factors of sedimentary environment and diagenesis making function in one area (Figure 1).

The detrital component, grain size grade, separation and mud content in matrix, etc. controlled by sedimentary facies are very important to reservoirs' quality. For example, the porosity and permeability of beach sand, shallow sandbar and continental shelf sandbody are better than that of subtidal zone sandbody of Silurian in the central Tarim Basin (Figure 2)[10,23].

The compaction, pressolution and cementation also have important influence on reservoir. According to the compaction percentage statistics of Donghe sandstone in the Tarim Basin, the whole compaction is weak. For example, the compaction of Donghe sandstone is mid-high in Donghetang, and the sum of porosity loss owing to carbonate cementing and compaction is about 26%. The porosity loss of Donghe sandstone owing to compaction is about 15%—22% when buried at 5600 m, and is 20%—25% when buried below 6000 m. The porosity loss of Donghe sandstone in central Tarim is 13%—26% when buried between 3500—3700 m, which compaction is equivalent with that of Donghe sandstone buried at 5600 m in Donghetang, illuminating that the compaction in Donghetang is far weaker than that in central Tarim under the same condition. This maybe related with the shallow burial depth and early carbonate cementation lasting from Permian to the end of Triassic in the area.

Dissolution is the key factor of high quality Donghe sandstone reservoir developed in the Tarim Basin, which is related with carbonate cementation dissolution, migration and deallocation caused by acid fluid when oil and gas emplace. The dissolution materials mainly are instability grain (e.g. feldspar and debris), carbonate cementation (e.g. calcite and ferroan calcite), halite and gypsum, etc. The carbonate cementation loss by solution can be 15% in the early diagenesis stage, even to 20%. The most important influence on reservoir is the late stage corrosion, which improves porosity about 2%[9,12]. But Zhu et al.[22] considered that carbonate cementation dissolution had little contribution to accumulate scope.

The early emplacement of oil and gas and geothermal, etc. also have important influence on diagenesis evolution and reservoirs' pore conservation[11]. For example,

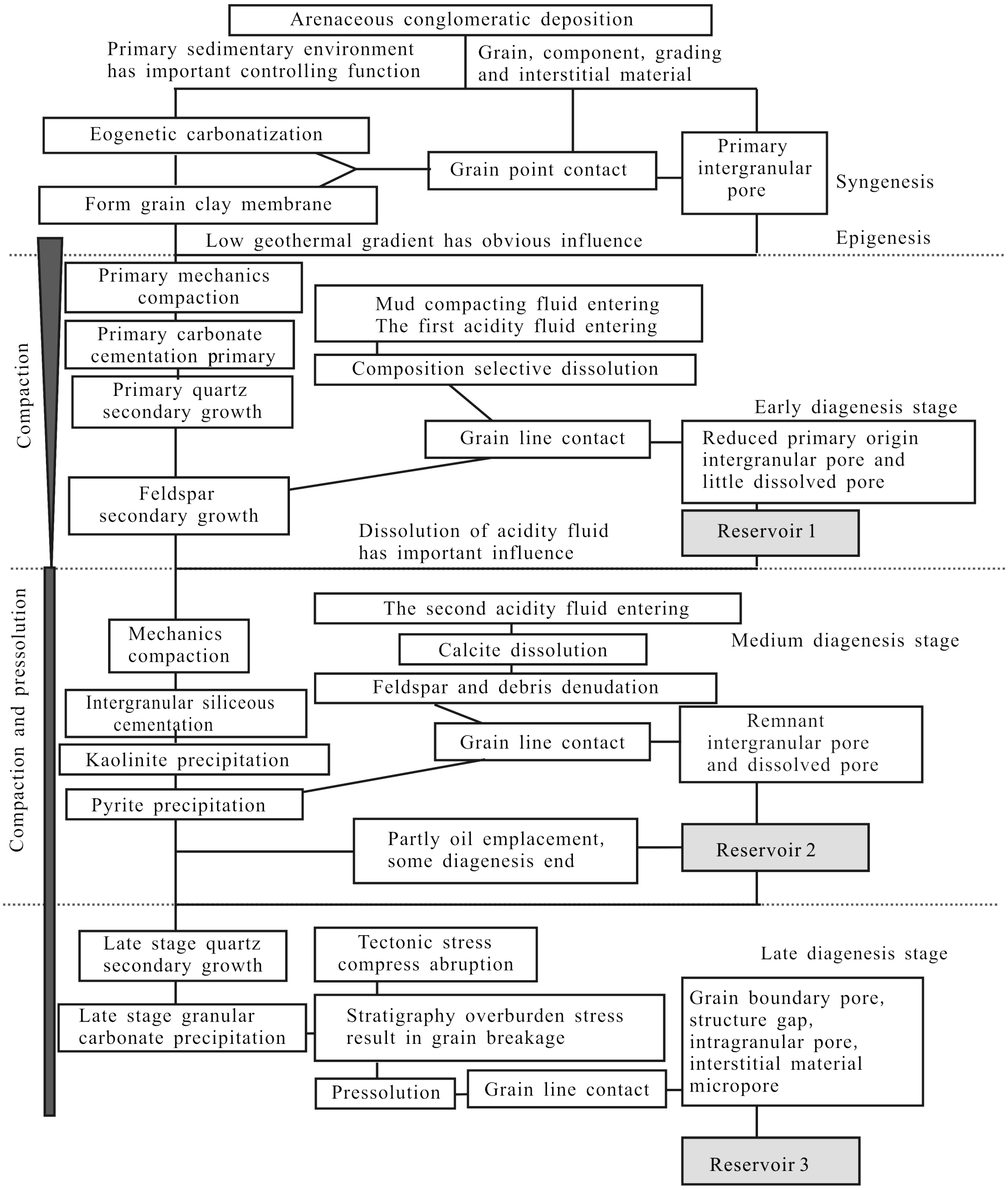


**Figure 1** The model of diagenesis and pore evolution of marine clastic reservoirs.

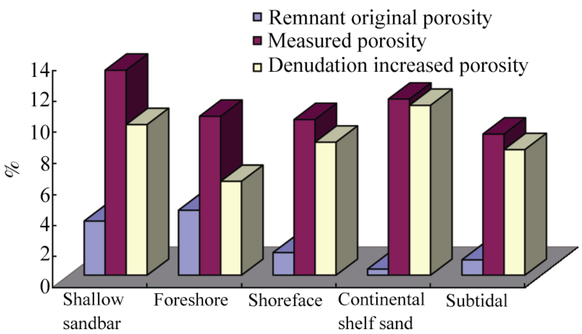


**Figure 2** Remnant original porosity and increased porosity by dissolution in different sedimentary microfacies.

the Tarim Basin became a "cold basin" in the late Palaeozoic, in which geothermal gradient is very low, e.g. the average geothermal gradient is about 2.16℃/100 m in the central Tarim uplift district. At present, though the Silurian reservoir buried between 4000—5000 m, the highest geothermal it experienced is just about 105—120℃. This background of geothermal field resulted in the fact that the Silurian reservoir is just in A2 sub-stage of mid-diagenesis stage, which is beneficial to pore conservation of Silurian reservoir[10,25].

**Table 1** The characteristic comparison of marine clastic reservoirs in China

| | Shoreline-shallow continental shelf system | | | Delta system | |
|---|---|---|---|---|---|
| The type of sandbody | shoreline sandbody | tidal flat sandbody | continental shelf sandbody | braided river delta sandbody | shallow delta sandbody |
| The composition of sandstone | cleanly, well-sorted, fine sand | cleanly, well-sorted, very fine sand | well-sorted, fine sand, silty sand | pebbled medium-coarse sand | medium-coarse sand, lag deposition |
| The texture of size grading | inverse graded | normal graded | composite graded | normal, inverse graded | normal, inverse graded |
| Sedimentary structure | swash bedding, paralleling and wavy bedding, little burrow | small-medium high angle cross-bedding, partly inverse cross bedding, little burrow | low angle diagonal bedding, cross bedding | bottom erosion, large trough cross bedding, parallel bedding and wavy bedding | tabular and trough cross bedding, parallel bedding |
| The character of grain size | medium-fine grain, $\sigma$<0.7 | Fine grain, silty sand, 0.8<$\sigma$<1.4 | medium-fine grain, silty sand 0.5<$\sigma$<0.8 | medium-coarse grain | medium-coarse grain |
| Log face | smooth curve, infundibular | ragged curve, mainly campaniform | smooth curve, arciform, infundibular | box-like, campaniform, infundibular | campaniform, infundibular |
| The character of facies | typical swash bedding in foreshore | typical tidal bedding in intertidal zone | typical interlayered with continental shelf mud | the bottom of sandbody is flat with large thickness, large trough cross stratification developed | usually interlayered with coal and limestone |
| Strike and distribution of sandbodies | parallel to sedimentary strike | elongate limited belt of nearly perpendicular to sedimentary strike | parallel or diagonal cross to sedimentary strike | nearly parallel to sedimentary strike, and the front sandbar nearly perpendicular to sedimentary strike | nearly parallel to sedimentary strike, and the front sandbar nearly perpendicular to sedimentary strike |
| The type of rocks | medium-fine grain sandstone, mainly debris quartz sandstone and quartz sandstone | siltstone and fine grain litharenite | fine grain quartz sandstone, feldspathic litharenite and fine grain litharenite | medium-fine grain, medium-coarse grain litharenite | pebbled coarse-medium quartzarenite, medium-coarse quartzarenite , litharenite , fine-medium lithic quartzarenite |
| Reservoir scope | relic primary intergranular pore, intergranular dissolved pore, intragranular dissolved pore, large pore, pore in matrix | secondary pore, primary-secondary pore, micropore | relic primary intergranular pore, intergranular dissolved pore, intragranular dissolved pore | remnant primary intergranular pore, grain dissolved pore, intergranular dissolved pore and micropore | relic intergranular pore, large scale pore, intragranular dissolved pore, micropore and dissolved pore |
| Reservoirs' ability | average $\Phi$: 3.4%-17% Average $K$: (0.403–385.6)×$10^{-3}$ $\mu m^2$ | ($\Phi$:1.09%–11.55%)4.27% $K$:(0.05–87.293) ×$10^{-3}$ $\mu m^2$ | ($\Phi$:3.05%–19.9%)12.05% $K$:(0.10–29.5/5.36) ×$10^{-3}$ $\mu m^2$ | ($\Phi$:3.76%–14.53%)7.83% $K$:(0.03–21.4) ×$10^{-3}$ $\mu m^2$ | average $\Phi$:9.1%-%10.2% Average $K$(0.48–1.02) ×$10^{-3}$ $\mu m^2$ |
| Distribution | Donghe sandstone of Devonian-Carboniferous in Tarim Basin, Kepingtage Formation of Silurian in north Tarim Basin | Tataaiertage Formation of Silurian in the Tarim Basin | mid-lower part of Kepingtage Formation of Silurian in the Tarim Basin | silurian in the east of the Tarim Basin | carboniferous-Permian in the Ordos Basin |

## 2 The main controlling factors of formation and distribution of reservoirs in marine carbonate rocks

### 2.1 The distribution characters of reservoirs in marine carbonate rocks in China

Compared with clastic reservoirs, carbonate reservoirs in China are more complex and diversified. The age of carbonate reservoirs in China is old with complex geological history. During the formation and evolution of carbonate reservoirs, the background of areal structure is the most controlling essential factor of the type of carbonate accumulates body, but in a specific condition and a particular stage of diagenesis, different reservoirs have different pore evolution history[14−21,27−30]. According to the sedimentary facies belt, diagenesis and lithology of carbonate reservoirs, the authors divide marine carbonate reservoirs in China into four types: reef and bank reservoir, karst reservoir, dolomite reservoir and fracture reservoir (Table 2). Marine organic reef reservoir in China is most representative in Changxing Formation, the Upper Permian in the Sichuan Basin, which is an important natural gas pay formation[30]. Oolitic bank reservoir is most representative in Feixianguan Forma-

**Table 2** The characters and genetics types of marine carbonate rock reservoirs in China[a)]

| Genetics character | | | Reef, bank reservoir | Karst reservoir | Dolomite reservoir | Fracture reservoir |
|---|---|---|---|---|---|---|
| Geology environment | | | sedimentary environment, thermal evolution and dissolution | multiphase tectonic activity, deposition break and epi-diagenesis | sedimentary environment, thermal evolution and dissolution | partly tectonic disruption and buried diagenesis |
| Main lithology | | | bioclastic limestone(dolomite), reef limestone(dolomite), oolite limestone(dolomite) | all kinds of limestone and dolomites | dolomite, grain dolomite and algae dolomite | all kinds of limestone and dolomites |
| Main sedimentary facies | | | reef and bank | all kinds of environments | tidal flat, restricted evaporate platform | all kinds of environments |
| Reservoir pore | | | pore | fracture-pore, pore-fracture | pore | fracture-dissolved pore |
| Combination of reservoir pore | | | intergranular pore-intergranular dissolved pore | combination of dissolved pore-cave-fracture | combination of intercrystal pore-intercrystal dissolved pore | combination of Sature-micropore-fracture |
| Significance of fracture | | | no function | the fracture mainly link up the pores and caves which determine deliverability | | fracture not only passageway of percolation, but also reservoir scope |
| Pore evolution | Eogenetic stage | penecontemporaneous | + + | + | + + | – |
| | | Shallow buried | + + | + or – | + + | – |
| | Late diagnetic stage | Deep buried | + or / | + or – | + | + or - |
| | Epigenesis stage | | + or / | + + | + | + + |
| Main diagenesis | | | compaction, cementation, dolomitization and dissolution | multiple phase percolation and dissolution | early dolomitiziation and dissolution | tectonic disruption and late dissolution |
| Typical examples | | | $T_1f$ in Sichuan, $O_{2+3}$ in central Tarim | O in Lunnan-Tahe and Ordos, Z-O in north China | $T_1$j, C in Sichuan | $T_1j$, C, P in Sichuan |

a) + +, On behalf of intense activity; +, on behalf of medium activity; /, on behalf of poorly activity; –, on behalf of no activity.

tion, the Triassic in the east Sichuan Basin[16−18,29]. Bioclastic and sand bank reservoir is most representative in biogenic limestone part, the Carboniferous in the Tarim Basin. Reef and bank composite reservoir is most representative in the Mid-Upper Ordovician in the central Tarim Basin. Patina karst reservoir is most representative in the Cambrian-Ordovician of Lunnan-Tahe oil field in the Tarim Basin, Sinian-Palaeozoic in the Sichuan Basin, the Ordovician in the Ordos Basin and the Sinian-Ordovician in the Bohai Bay Basin[15,27,28]. Dolomite reservoirs distribute widely, such as Sinian-Ordovician, Leikoupo and Jialingjiang Formation of the Low-Mid Triassic in the Sichuan Basin, Sinian- Ordovician in the Tarim Basin, Ordovician in the Erduosi Basin, and Sinian in the Bohai Bay Basin. Fracture reservoirs distribute in many basins, such as Feixianguan Formation of the Lower Triassic, Permian, Carboniferous in the Sichuan Basin and Ordovician of Lunnan-Tahe oil field in the Tarim Basin.

## 2.2 The main formation controlling factors of reservoirs in marine carbonate rocks

There are many factors controlling the carbonate reservoirs' ability, among which the types of rocks, sedimentary facies and time are the basement, and the dolomitization and dissolution are important to carbonate reservoirs. To the carbonate reservoirs in multicycle basins of the Palaeozoic, the dissolution and tectonic disruption are very important (Figure 3).

The sedimentary facies belt provide lithology base for reservoir pore. The sedimentary facies control the texture and lithology of rocks, so they can control the development degree of original pores in rocks, and have important influence on development of dissolution pore. Although reservoir pores are mainly second dissolution pore, the existing of original pores is just the necessary condition of dissolution. From the analysis of organic reef reservoir of Changxing stage, Permian in the northeast Sichuan Basin, it is found that the reservoirs' ability of grain dolomite and reef-dolomite in platform edge are the best.

Cementation and compaction are the main factors to decrease porosity in carbonate reservoirs. Cementation happened in the environment of sea floor diagenesis, atmosphere fresh water diagenesis and burial diagenesis. Compaction mainly happened in the environment of burial diagenesis, and can be divided into two types of

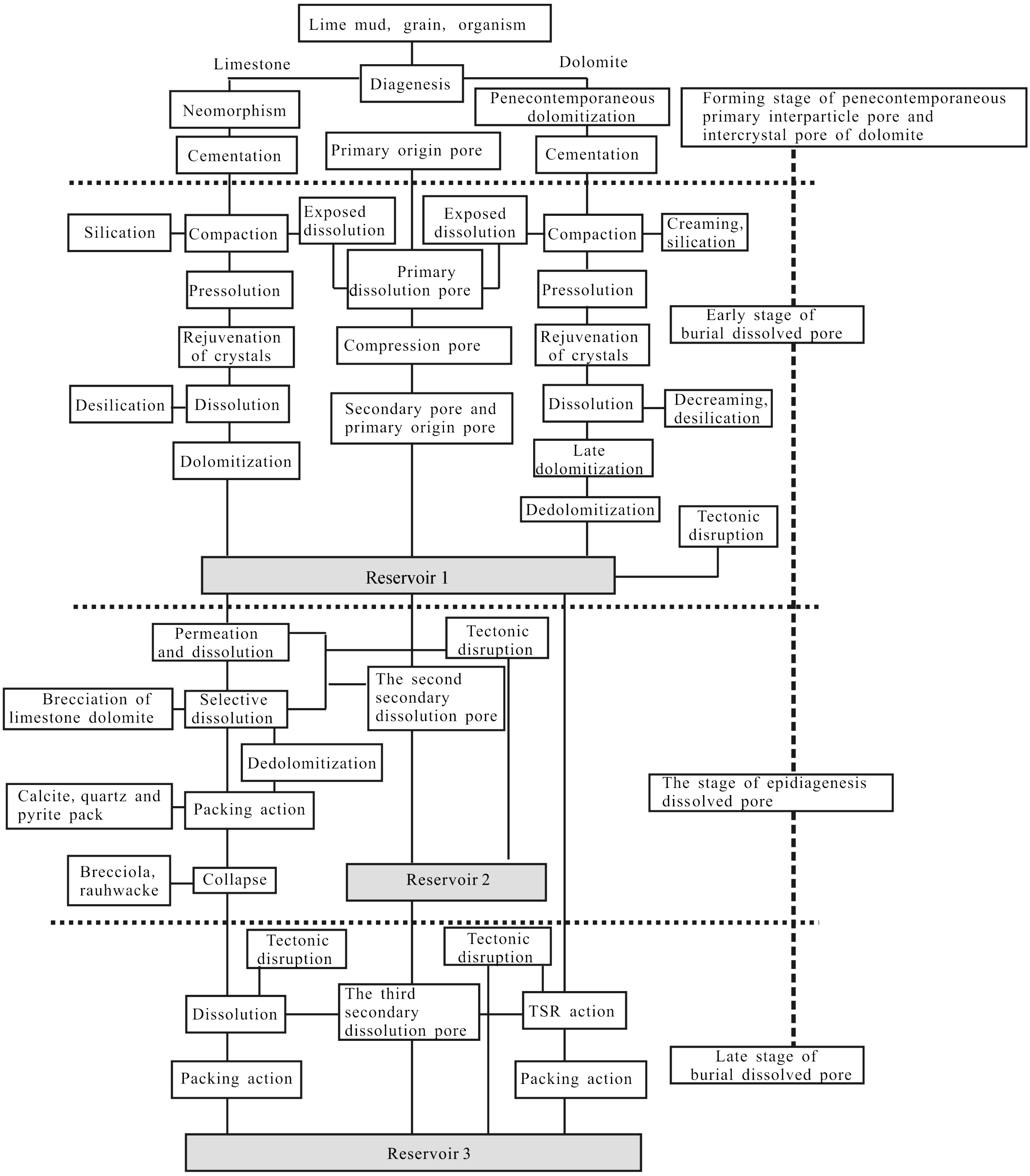


**Figure 3** The model of diagenesis and pore evolution of marine carbonate reservoirs.

mechanic and chemical compaction. To the carbonate reservoirs, they are destructive, which decrease porosity and reduce permeability[17,18,20,21,28].

Dolomitization is the important factor to improve reservoirs' quality. According to the characters of oolith bank gas reservoir of Feixianguan Formation in the northeast Sichuan Basin, mid-large gas reservoirs are dolomite. Dolomitization form a mass of intergranular pores, which intergranular porosity can be above 10%, but with the incrassation of autogenic edge of dolomite, intergranular pores gradually reduce, some pores even completely disappeared and inset dolomite formed[17,18,20,21,29,30]. Dissolution is the fundamental reason of high quality reservoir developed. The dissolution of carbonate deposition can happen in any stage of the history of deposition buried, which usually increase pore scope. The paleokarst can be divided into two types of epidiagenetic stage and buried diagenetic stage. The epidiagenetic stage paleokarst can be further divided into syndiagenetic stage interstratal karst and exposure patina karst. The buried diagenetic stage paleokarst can be further divided into mid-deep buried outwater karst and deep buried stage hot water karst[27]. Buried dissolution mainly connected with organic matter diagenesis, deep fluid flow in basin and sulphate organic and (or) heat chemistry deoxidization. For example, it can be seen that gypsum and anhydrite concretion are partly metasomatosed by calcite and syngenesis with sulphur, some completely be metasomatosed, some just metasomatosed in outer leaving internal still be gypsum and anhydrite. That indicates that sulphate deoxidization did happen[16], the porosity can be 5%—15%, partly reaches 25%.

## 3 Conclusions

(1) Marine reservoirs in China are distributed widely. The Lower Palaeozoic mainly develops carbonate reservoirs, and the Upper Palaeozoic mainly develops clastic and carbonate reservoirs.

(2) The genetic model of marine clastic reservoirs in China is established. The sedimentary environment has important controlling function to clastic reservoir attributes. Compaction, pressolution and cementation are the important factors to decrease porosity. The low geothermal background, early oil and gas injection, dissolution are beneficial to conserve reservoir pore.

(3) The genetic model of marine carbonate reservoirs in China is established. Dolomitization, dissolution, TSR function and tectonic disruption are the important control factors to reservoir equality of carbonate rocks.


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