Effect of Diagenesis on Reservoir Distribution in a Sequence Stratigraphic Framework: Evidence from the Feixianguan Formation (Triassic) in Tieshan District of Northeastern Sichuan, China

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Abstract. By integrating diagenesis and sequence stratigraphy, the effect of sedimentary-diagenetic reformation on reservoir quality and distribution was investigated with in a sequence stratigraphic framework. Based on the petrological characteristics, sedimentary microfacies and logs analysis, 2 third-order sequences and 5 system tracts are distinguished in the Feixianguan Formation, as well as a stratigraphic framework has been established. Besides, the diagenetic processes of Feixianguan Formation contain compaction, pressure-solution, cementation, dolomitization and dissolution. A analysis reveals that cementation is the major cause of porosity-loss for primary and secondary porosity. Contrary to the adverse impact of cementation on reservoir space, polygenetic dolomitization and dissolution greatly improve the carbonate rocks reservoir and permeability. Sequence stratigraphic framework constrains the distribution of diagenesis, which result that dolomitization is most evident in transgressive system tract (TST) and below maximum flooding surfaces (MFS) in Sq1, and locally occur in lower part of the highstand system tract (HST). And it is also proved that the dolomitic reservoir shows high porosity in TST of Sq1 and moderate quality in HST of Sq1.

Introduction

Feixianguan Formation was deposited in the northeastern Sichuan basin during the Early Triassic, when the sedimentary features basically inherited the characteristics of the Late Permian, with transgression continuing. The study area is located in Tieshan district, the platform margin belt on the west side of Kaijiang Liangping trough, and topography and structure is complex here. There are regional differences in sedimentary thickness, lithology and structure as the beach and shallow marine facies stratum transitionally evolve both in vertical and horizontal directions. Oolitic limestone in beach face can turn into oolitic dolomite by diagenesis, while marine stratum manly contains micrite limestone and silty-fine limestone [1-6]. The reservoir in the study area is a kind of typical facies-controlled reservoir which is also greatly transformed by various diageneses [7-10]. Playing a key role in carbonate reservoir, diagenesis determines the formation and distribution of effective reservoir indirectly. It is a worthy concern that similarities and differences between diagenesis distributions of different rocks are related to the formation and evolution of carbonate reservoir [11]. This paper therefore selects some typical single wells to establish a stratigraphic framework with the combination of lithology, sedimentary facies and logs analysis. By means of microscopic identification and carbon oxygen isotope analysis, the relation between diagenesis and sequence boundary, as well as the influence of diagenesis on the development of reservoir space are analyzed.

1. Sequence Stratigraphy

Feixianguan Formation spread continuously in study area, its underlying strata is upper Permian Changxing Formation and Lower Triassic Jialingjiang formation is the overlying strata. On account of being a typical basin (trough) to platform depositional system [1, 2, and 4], the sedimentary facies for this region are as follows: slope-trough face, platform margin face, open platform face, evaporate-restricted platform face and including six sedimentary microfacies (Fig. 1). The oolitic beach facies in platform margin and in open platform are favorable microfacies that may help to form high-quality reservoirs.

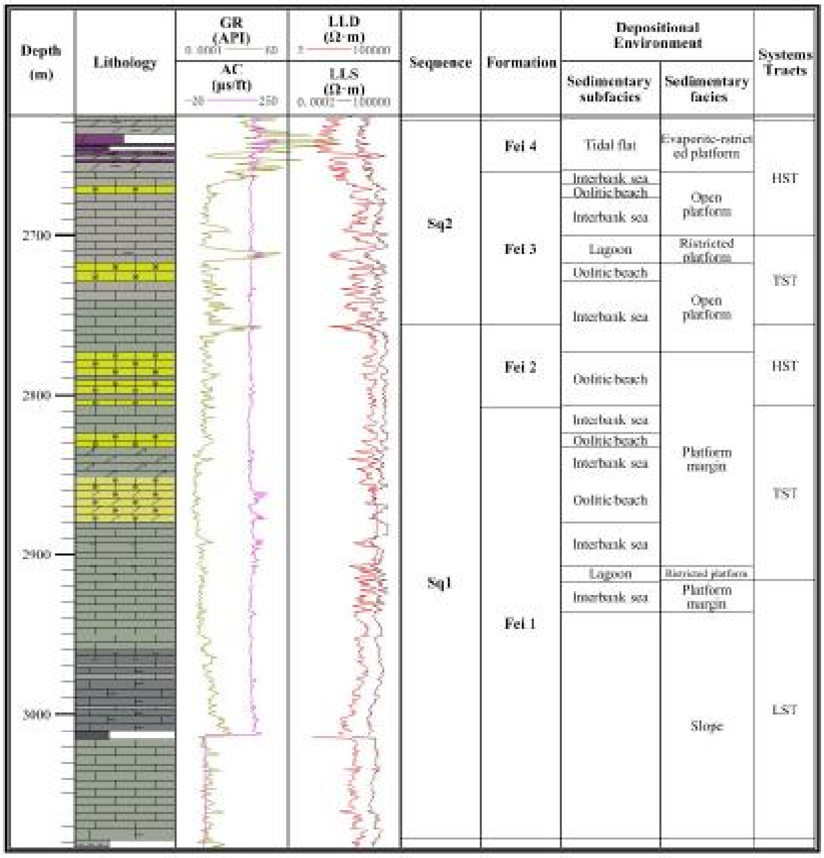

Fig. 1 Sedimentary facies and sequence stratigraphy of T5 well Feixianguan Formation

Early Triassic Feixianguan period is a process when the relative sea level rose from rapid to slow, and it is considered as an upward shallowing sedimentary sequence. On the basis of sequence variation on petrology and logs, a paleokarst surface with strongly exposure is recognized as a type I sequence boundary between the bottom of Feixianguan formation and Upper Permian Changxing formation [4]. A transformational surface of sedimentary facies is identified as a type II sequence boundary between Fei 2 (2th segment of Feixianguan Formation) and Fei 3 (3th segment of Feixianguan Formation). The maximum flooding surfacies (MFS) occurs in the bottom of Fei 2 and middle part of Fei 3. In terms of the research above, two third order sequences and five system tracts are recognized in Feixianguan Formation. Sequence 1 (Sq1) is composed of a lowstand system tract (LST), a transgressive system tract (TST) and a highstand system tract (HST). While sequence 2 (Sq2) consists of a transgressive system tract (TST) and a highstand system tract (HST) (Fig. 1and Fig. 4).

LST of Sq1 contains limestones, marlstones and dolomitic limestones deposited in the bottom of Fei 1.Locally, thin layers of dolomites may distribute in the top of Fei 1below a transgressive surface (TS). The transgressive surface marks the end of LST and beginning of TST [12]. TST of Sq1 is located in the top of Fei containing abundant dolomites, platform-margin oolitic dolomites, oolitic limestones and dolomites with pinpoint pores. With the increasing of thickness from south to north, platform continually aggrade to shelf area. HST of Sq1 is situated in full segment of Fei 2, in which sea level dramatically falls and platform deposits extensively spread with light oolitic dolomites.

Similar to TST of Sq1, TST of Sq2 situated in middle and lower segment of Fei 3 consists of dolomites, limestones, marlsones and little oolitic limestones. Since sea level rises beyond the deposition velocity, TST of Sq2 is not as large in thickness as TST of Sq1. Fei 4 and upper part of Fei 3 constitute HST of Sq2, which may deposit in evaporate and restricted platform with oolitic limestones locally occurs in lower part and a thin layer of gypsolyte and dolomicrites in the top.

2. Carbonate Diagenesis

2.1 Compaction and pressure solution

Compaction may cause the decrease of the porosity of carbonate sediments and the decline of the total volume of rocks, which usually occurs in shallow burial environment without any effect on early cements. Particles are common to exhibit as constrictively mosaic contact, deformation, particle breakage and displacement (Fig. 2A).

Pressure solution generally in the medium-deep burial environment, following compaction, forms carbonate cements in the limestone which may result in reducing the porosity and thickness. It arise a further deterioration following compaction. Stylolite structure and little corrosion occur with asphalt and insoluble residue filled in, which shows most of the stylolite structures have become the reservoir spaces and migration pathways of oil and gas (Fig. 2B).

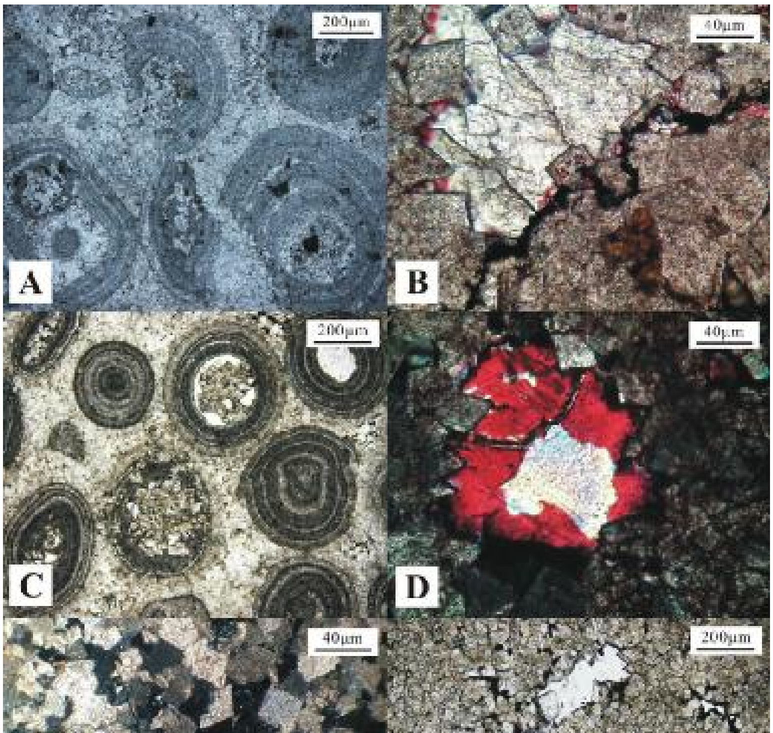

Fig. 2 A) Optical photomicrograph showing the rupture of oolitic grains and dislocation of concentric strias caused by compaction. B) Optical photomicrograph with dolomitic limestones showing stylolite structure caused by pressure dis-

solution. Late stage dolomitization occurring along the stylolite structure which is filled with asphalt later. C) Optical photomicrograph with sparry oolitic limestones showing rim cementation of the first-phase micrite and foliated calcite cements. The second-phase subhedral cements growing along the first-phase cements and incomplete filling up dissolved pores and fractures. D) Optical photomicrograph with dolomitic limestones, the third-phase aotomorphic sparry calcite cements inlaid in the pore between two phases of dolomites. E) Saccharoidal medium-grained dolomite with zonal structure. F) Close-up view of intergranular pores and expansive dissolved pores in saccharoidal fine-grained dolomites, residual dolomites and a little bitumen are displayed.

2.2 Calcite cementation

The studies we carried out demonstrated that three phases of calcite cementation occur in Feixianguan Formation, which cause the disappearance of primary intergranular pores of oolitic limestone.

The first-phase calcite cements are mainly micrite with leaf-like and fiber-bar shape, which fill the porosity surrounding the particle. Generally it occurs between intertidal and subtidal zone of marine phreatic environment in syngenetic diagenetic period. Enriched in magnesium, media in pore water may cause a selective lateral growth of crystals, then this kind of calcite cements often displays as a ciliated columnar cement-ring in early marine. Prone to dolomitization, it is common to see leaf-shaped dolomite rings in late stage (Fig. 2C).

The second-phase calcite cements are hypidiomorphic granular, growing along the calcite cements of the first period and the dissolution pores and fractures, and fill in primary intergranular pores, which may result in greatly porosity-loss (Fig. 2C). Such cementation occurs in the early diagenetic stage, in shallow to medium buried diagenetic environments or meteoric freshwater environment, and calcite cements in this phase are susceptible to selectively dissolved.

Calcite cements of the third-phase are idiomorphic grain or massive sparry calcites, filling residual pores or larger intergranular pores with monocrystalline and poikilitic structures (Fig. 2D). The cementation generally occurs in the medium-deep burial environment, of middle and late diagenesis. Since liquid hydrocarbon inclusions are common in this phase, it is revealed that calcite cementation and migration of liquid hydrocarbon happen at the same time.

2.3 Dolomitization

2.3.1 Mixed water dolomitization

Mixed water dolomitization are usually situated in platform marginal oolitic dolomites. Due to the ancient topographic uplift and rapid aggradation of carbonates, oolitic beach were often exposed above sea level under the influence of meteoric freshwater and sea water, which caused mixed water dolomitization. Intergranular pores and intercrystalline pores are the main reservoir spaces in mixed-water oolitic dolomites (Fig. 2C). Isotopes analysis of platform marginal oolitic dolomites samples reveals a wide range of $\delta^{18}O_{PDB}$ from -3.5‰ to -6.5‰, $\delta^{13}C_{PDB}$ from 0.5‰ to 2.5‰ (Fig. 3). In terms of sedimentary background, platform marginal oolitic sediments may be frequently exposed above sea level, which results $\delta^{18}O_{PDB}$ values turning into the negative ones under the impact of meteoric freshwater. It is the vast amounts of gas in dolomite reservoirs that $\delta^{13}C_{PDB}$ got a positive value.

2.3.2 Seepage-reflux dolomitization

Seepage reflux dolomitization often occurs in the evaporate-restricted platform. According to microelement analysis based on the samples of well T5 and T11, the various amounts of Sr, Na and FeO indicate saline-reductive environment of dolomites forming (Table1). Isotopes analysis of open platform oolitic dolomites samples reveals a wide range of $\delta^{18}O_{PDB}$ from -2.5‰ to -4‰, $\delta^{13}C_{PDB}$ from -2.5‰ to 0.5‰, which indicates dolomitization is related to evaporation and low contents of gas resulting from dense lithology(Fig.3). Seepage-reflux dolomicrites often interbed with gypsolyte, and intergranulars are also filled of gypsolyte.

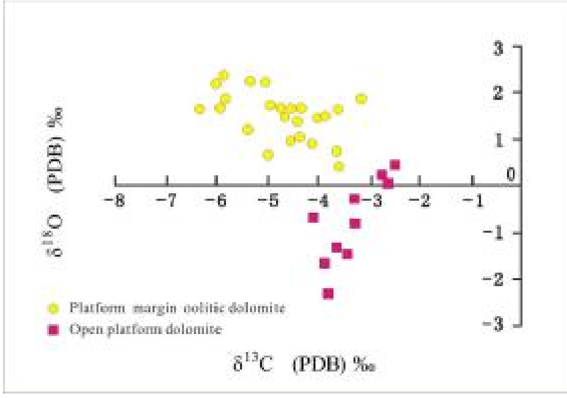

Fig. 3 Carbon and oxygen isotope distribution of the dolomites in samples

Table.1 Microelements analysis of carbonates in different environments

Dolomitization	Sedimentary facies	Microelement%			
		Na_2O	SrO	MnO	FeO
Mixed water dolomitization	Platform marginal oolitic beach	0.002~0.02	0.001~0.04	0.01~0.06	0.005~0.1
Seepage-reflux dolomitization	Platform lagoon and oolitic beach	0.03~0.07	0.09~0.2	0.002~0.02	0.1~0.17
Burial dolomitization	Platform marginal (oolitic beach)	0.01~0.03	0.03~0.08	0.01~0.08	0.02~0.04

2.3.3 Burial dolomitization

With great impact on limestones, burial dolomitization is often superimposed with mixed water dolomitization in platform margin. The burial dolomites show idomorphic or hypidiomorphic saccharoidal structures, and it is common that dolomites selectively replace the oolitics or distribute along the fractures and stylolite structures (Fig. 2B, 2E). In terms of chemical composition, the various amounts of MnO indicate the origin of dolomitization referring to burial origin.

2.4 Dissolution

Dissolution is another key factor for the formation of carbonate reservoir in Feixianguan Formation, which contains penecontemporaneous dissolution, shallow to medium burial dissolution and medium to deep burial dissolution.

2.4.1 Penecontemporaneous dissolution

This kind of dissolution is caused by meteoric freshwater selectively dissolving particles. It helps to form the medical pores, intragranular dissolved pores and intracrystalline pores, etc. (Fig. 2C). Since the most pores have been filled with calcites and seepage matters, the pores remain poor permeable abilities.

2.4.2 Shallow to medium burial dissolution

It is ascertained that the origin of shallow to medium burial dissolution is related to acid water activity which is associated with liquid hydrocarbon maturation period and enriched in organic acid [10]. Shallow to medium burial dissolution occurs between second-phase granulous calcite cements and third-phase coarse sparry calcite cements. Along the pores formed by penecontemporaneous dissolution, this kind of dissolution does not contribute to new spaces in reservoir. Asphalt incomplete filling in large pores along the edges and complete filling in fine pores both demonstrate that these pores caused by Shallow to medium burial dissolution forms before asphalt emplacement, and are regarded as the major reservoir spaces of liquid hydrocarbon.

2.4.3 Medium to deep burial dissolution

Occurring in medium to deep burial period, this kind of burial dissolution is concerned with cracking of liquid hydrocarbon [10]. Saccharoidal dolomites and coarse sparry calcites are often selected to be dissolved, as well as dissolution expands along the intracrystalline pores of dolomites and calcites or cleavage crack of coarse sparry calcites (Fig. 2F).

3. Distribution of Diagenetic Carbonates in a Sequence Stratigraphic Framework

Diagenesis has a positive impact on reservoir development as polygenetic dolomitization and dissolution helping to improve the reservoir spaces. On the basis of diagenetic mineralogy and lithology and geochemical characteristics, linked to sequence stratigraphy, distribution of reservoir and regional positive diageneses is clarified (Fig.4). Development of reservoir in Feixianguan Formation displays strongly heterogeneity both in vertical and horizontal directions.

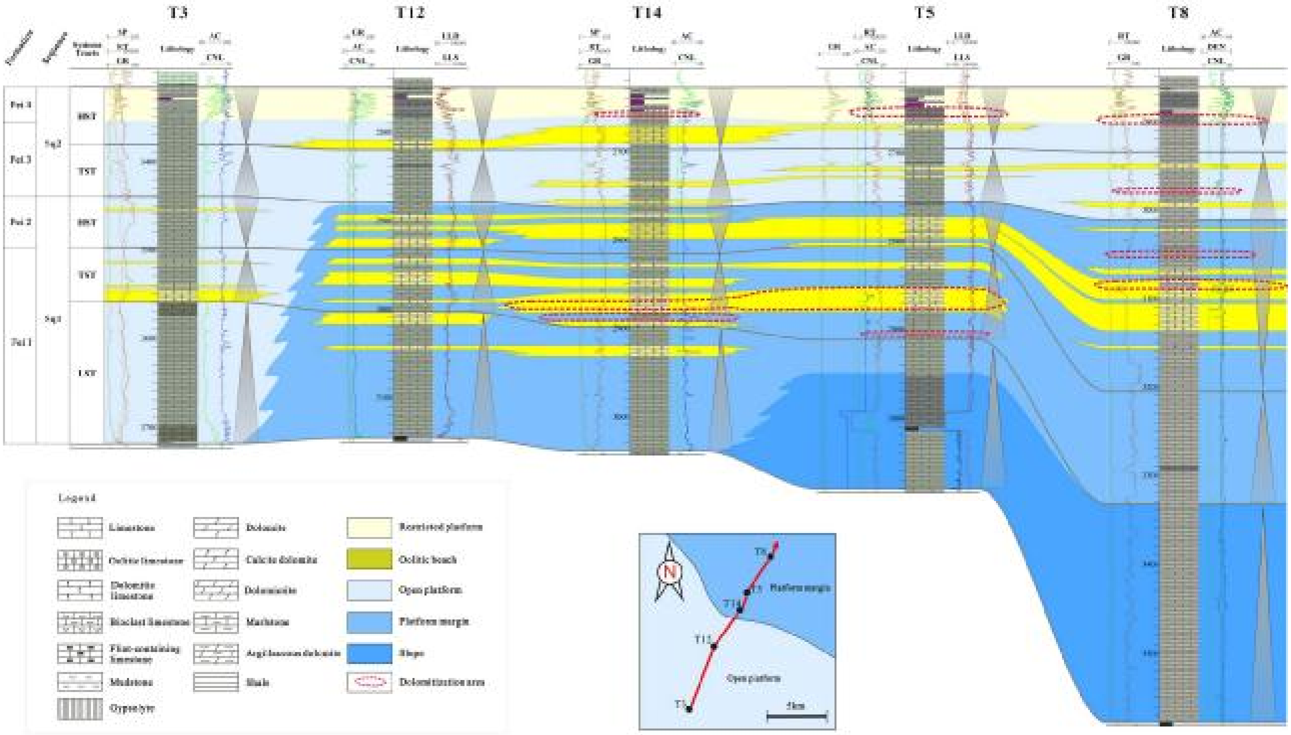

Fig. 4 Correlation and general sequence stratigraphic framework with dolomitization distribution

Long-period situated in platform margin deposit, reservoir in Feixianguan Formation has been rebuilt a lot by dolomitization, multilayered and large thickness, and contains massive dissolved pores. The largest thickness of reservoirs occurs in T14, T5 and T8 well area, gradually reducing from platform to northeastern slope and trough (Fig. 4). As potential effective reservoir, oolitic beaches nearly spread in each cycle of Sq1 and Sq2, and are mainly developed in oolitic dolomites and oolitic limestones in transgressive system tract (TST) and highstand system tract (HST) of Sq1(Fig. 4). Oolitic beach reservoirs continually distribute with big lenticular shapes in vertical and the sediments' sorting becomes better. Within the sequence stratigraphic framework, dolomitization is constrained to develop in limited area (TST and HST in Sq1), which has strong effect on oolitic beach reservoirs. A mass of dissolved pores, fractures and holes can be observed under microscope, and porosity values range from 2.5% to 9.6%. With the aggradation from platform to trough, oolitic beach reservoirs distribute in a higher area in Sq2 and locally display as small lenticular shapes. But dolomitization occurs little in each cycle of Sq2 which cause a poorer reservoir capacity compared to that in Sq1. Although fractures and intercrystalline dissolved pores can still be observed under microscope, areal porosity remains relatively low.

Sequence boundaries have impact on positive diagenesis, and especially restrict the distribution of dolomitization in short sea level rising cycle and the bottom of upward shallowing cycle. Statistical analysis shows that as long as rebuilt by dolomitization, the reservoir can be given priority to form a favorable one. Hence, Effective reservoirs are mainly located in platform margin and open platform oolitic beaches in both middle and upper part of Sq1.

Conclusion

Two third order sequences and five system tracts are recognized in Feixianguan Formation of Tieshan district. Sq1 is composed of Fei 1 and Fei 2 and Sq2 consists of Fei 3 and Fei 4.Oolitic beach reservoir space development and distribution is under the controlling of diagenesis. Reservoir quality commonly deteriorates as primary pores and secondary pores are filled with cements from calcite cementation. Polygenetic dolomitization plays a key role in forming a favorable oolitic reservoir and greatly improves reservoir capacity so as to provide effective reservoir spaces and migrant pathways. Constrained by sequence stratigraphic framework, dolomitization is mainly located in cycles from slowly transgression to slowly regression which is conductive to distribution of effective reservoir. With platform margin oolitic beaches distributing along high-steep slope break belt, T14, T5 and T8 well area in TST and HST of Sq1 is a favorable region for effective reservoir.

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