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Research on Sedimentary Facies Characteristics of Carbonate Reservoirs -----Taking NT Complex Carbonate Reservoirs in the Pre-Caspian Basin as an Example

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Abstract: Accurate characterization of reservoirs is a great difficulty in the study of carbonate reservoirs. Characterization of reservoirs shall be firstly based on the geological recognition of carbonate reservoirs, including multiple reservoir quality-related geologic features such as structure evolution, sedimentary diagenesis environment, reservoir rock types, etc. Taking NT oilfield in the east margin of the Pre-Caspian Basin as an example and starting with the characteristics of carbonate sedimentary facies and sedimentary microfacies, this paper has determined the sedimentary facies characteristics of all layers of carbonate reservoirs in the research area. The lower KT-Ii reservoir in the oilfield mainly belongs to open platform deposits, where intraplatform beach microfacies, algal reef microfacies and interbank sea microfacies are developed. The middle MKT reservoir belongs to a shallow sea shelf environment, where about 400m thick clasolite formation has been deposited. Because of frequent tectogenesis and large sedimentary environment variation, the upper KT-I reservoir includes B layer belonging to open platform deposits, Б layer mainly belonging to open platform depositions and restricted platform deposits, and A layer belonging to restricted platform deposits and evaporative platform deposits from bottom to top, where grained clastic beach, dolomitic flat, limestone flat, gypsum salt lake and lagoon microfacies are mainly developed.

Oilfield Overview

NT oilfield is located on the slope structure belt in the east margin of the Pre-Caspian Basin, and the geotectonic location belongs to the southeast part of Eastern European Platform. On the east of the basin is Ural Hercynian fold mountain system. The hydrocarbon bearing series are Carboniferous carbonate reservoirs, including two sets of platform facies carbonate reservoirs such as KT-I and KT-II. The MKT clastic barrier with high shale content is located in the middle of the reservoirs. The lower KT-II is divided into two reservoir groups such as Г and Д and subdivided into totally 9 layers such as Г1-Г6 and Д1-Д3. The upper KT-I is divided into two reservoir groups

such as A, Б and B and subdivided into totally 9 layers such as A2-A3, Б1-Б2 and B1-B5. A1 is lost in the research area.

Sedimentary Environment and Classification of Carbonate Reservoirs

In the Carboniferous Period, the research area was located in the east margin of Eastern European Platform, belonged to a normal seawater sedimentation environment under low-altitude tropical or subtropical humid climate conditions, and had plentiful marine organisms. According to the statistical slice data of 6 coring wells, the average content of particles is 69.25% in KT-I and 80.72% in KT-II, and the average content of bio-particles is 41.80% in KT-I and 76.29% in KT-II, indicating that the area is a shallow sea environment favorable for biological growth. The thickness of granular carbonate rock formations (including non-biological particles) is over 90% of the total thickness of carbonate rock formations in the area, reflecting a shallow sea environment with turbulent water bodies, strong energy, sufficient sunlight and abundant nutrients at that time.

According to the sedimentary features of Carboniferous System as well as the lithologic description data, core analysis data (e.g. slice appraisal, geochemical analysis, paleontology, etc.), logging data and mud logging data of the coring wells, the identification marks of lithofacies and logging facies have been analyzed and studied, and the sedimentary environment and sedimentary facies of all single wells have been identified and divided. Through single well facies analysis, totally 4 types of subfacies such as evaporative platform, restricted platform, open platform and shelf and 10 types of microfacies have been identified in the research area.

Characteristics of Sedimentary Subfacies and Microfacies

Shelf subfacies

Shelf facies is the transitional sedimentary facies between deepwater basin and carbonate platform. Shelf subfacies is located below the normal wave base and near the oxidation interface has a water depth ranging from dozens of meters to 200 meters; except large wind wave and stormy wave impacts, the water bodies are calm on the whole and the energy of seawater is low. For instance, B5 layer of wells 5555 and CT-4 belongs to shelf subfacies.

Tidal zone and energy: low energy below the wave base.

Color: off-white, gray, light gray, dark gray, bluish gray, grayish black, mauve, brown, and brownish red. Biological assemblage: planktonic foraminifera, bivalve, lamellibranch. Rock assemblage: bioclastic micritic limestone, micritic limestone, argillaceous strip marlite, mudstone, silty mudstone, siltstone, limy mudstone, argillaceous limestone, and varicolored breccia. Rock structure: particle content <10%, micritic structure. Sedimentary structure: horizontal bedding, bioturbation, dwelling burrow, burrow. Distribution horizons: B5, MKT.

Open platform subfacies

The facies belt is located on the inner side of the high energy beach body in the platform margin beach, the water bodies are shallow and have a depth ranging from several meters to dozens of meters and good connectedness with the open sea, and the seawater is circulated smoothly and has normal salinity, being suitable for biological growth. The subfacies includes intraplatform beach, algal reef and interbank sea microfacies.

① Intraplatform beach microfacies

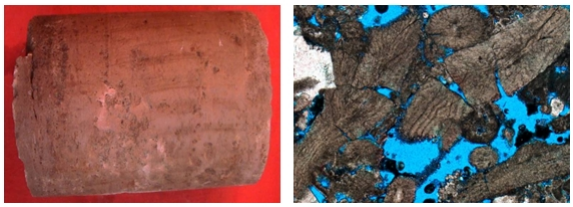
The microfacies is formed in a shallow high energy or relatively high energy environment controlled by tidal action or wave action and located above the intertidal-normal wave base. The

microfacies is favorable for accumulation of plentiful allopatric carbonate particles and bioclasts lies inside the carbonate platform, and has different scales. For example, Г3 layer of well 5598 belongs to intraplatform beach microfacies.

Tidal zone and energy: intertidal-subtidal high energy. Color: gray, off-white, light gray, light grayish brown. Biological assemblage: green alga, red alga and foraminifer predominate; others include brachiopoda, echinodermata, gastropods, lamellibranch, spongia and spicule, solitary coral, etc.; there are many biological categories, and the total biomass is high. Rock assemblage: foraminifer green alga limestone, foraminifer algal lump limestone, algal lump foraminifer limestone, foraminifer limestone, foraminifer red alga limestone, algal limestone, arenaceous foraminifer (fusulinida) limestone (as shown in Fig.1), foraminifer calcarenite, fusulinida tuberiform limestone, etc. Rock structure: particle content >70%; algae predominate; others include bioclast, algal clast, algal lump, onkoid, sandy clast, superficial ooid, and radial ooid, which are mainly sparry-cemented and partly filled by micrite. Sedimentary structure: massive structure, cross bedding. Distribution horizons: В1-В4, Г1-Г6, Д1-Д3.

Grayish brown calcarenite — Sparry psammitic foraminiferal limestone

Fig.1 Intraplatform microfacies of open platform subfacies in well 5555



Limestone — Sparry red alga framework limestone

Fig.2 Algal reef microfacies of open platform subfacies in well CT-4

② Algal reef microfacies:

An environment suitable for algal reef development is formed in the part with strong hydrodynamic force and appropriate water depth inside the open platform. The algal reef bodies in the area have different distribution scales on plane but small thickness, which is only several meters in general. For example, Г4 layer of well CT-4 belongs to algal reef microfacies.

Tidal zone and energy: intertidal-subtidal high energy. Color: gray, off-white, light gray. Biological assemblage: green alga and red alga predominate, thus forming an alga framework; others include a large quantity of adnascent foraminifer, brachiopoda, echinodermata, gastropods, lamellibranch, spongia and spicule, solitary coral, etc. Rock assemblage: algal framework limestone (as shown in Fig.2), algal limestone, foraminiferal limestone. Rock structure: particle content >80%; algae predominate; others include algal lump, onkoid, foraminifer, sparry cementing matters. Sedimentary structure: algal framework, massive structure. Distribution horizons: В3, Г2-Г6, Д1-Д3.

③ Interbank sea microfacies

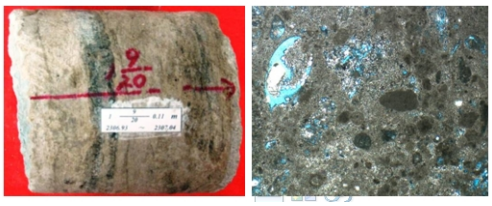
The microfacies is located between intraplatform beach bodies and has a water depth ranging from several meters to dozens of meters, belonging to a subtidal still water low-energy environment; water bodies are circulated smoothly, the salinity is normal, sunlight and nutrients are sufficient, organisms are developed, there are many types of organisms, and bioturbation is strong. For example, Г1 layer of well CT-41 belongs to interbank sea microfacies.

Tidal zone and energy: subtidal low energy. Color: light gray, dark gray, light brownish gray. Biological assemblage:thin-shell ostracoda, bivalve, planktonic foraminifera, gastropods. Rock

assemblage:(bioclast-bearing) bioclastic micritic limestone, micritic limestone (as shown in Fig.3), argillaceous limestone, limy mudstone. Rock structure: particle content <80%, micritic structure, bioclast-bearing micritic structure. Sedimentary structure: horizontal bedding, bioturbation, dwelling burrow, burrow. Distribution horizons: B1-B4, Г1-Г6, Д1-Д3.

Micritic limestone　　Lamellar micritic limestone

Fig.3　Interbank sea microfacies of open platform subfacies in well CT-4



Lamellar structure　　Residual foraminifer micritic dolomite

Fig.4　Dolomitic flat microfacies of restricted platform subfacies in well 55555

Restricted platform subfacies

The facies belt is located after barrier islands or large shoals and extends to the evaporative platform. Seawater is not circulated smoothly, water bodies are extremely shallow, the energy is low, and various exposed sedimentary marks are developed. Dolomitic flat microfacies, limestone flat microfacies, grained clastic beach microfacies and lagoon microfacies are mainly developed in the facies belt.

① Dolomitic flat microfacies

The microfacies is located in supratidal zones, has even topography and belongs to a low-energy exposed environment. Marl is of dolomitization into dolomite because of evaporation. For example, A3 layer of well CT-41 belongs to the dolomitic flat microfacies of restricted platform subfacies.

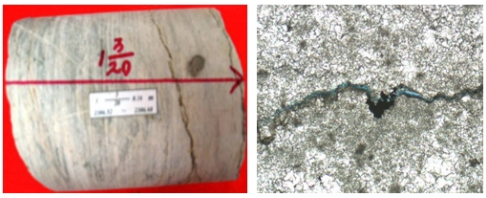
Tidal zone and energy: supratidal low energy.Color: brown, gray. Biological assemblage: cyanobacteria, foraminifer, fusulinida, calthrop, bryozoa, trilobite, thin-shell organism, echinodermata, thin-shell ostracod individual, gastropods, and lamellibranch; there are many biological categories, the biomass is small, and biofraction is strong. Rock assemblage: residual foraminiferal micritic (fine-crystalline) dolomite (as shown in Fig.4), residual fine-crystalline fusulinida dolomite, residual tergorhabdites fine-crystalline dolomite, residual bioclastic micritic fine-crystalline dolomite, micritic breccia dolomite, micritic fine-crystalline dolomite, micritic dolomite, psammitic micritic dolomite, fine-crystalline limy dolomite, and dolomitic limestone. Rock structure: metasomatic relict texture; particle content <60%, mainly various bioclasts, a small quantity of arene, micritic support. Sedimentary structure: drying crack, bird’s eye, cryptomonas lamina, syngenetic breccia; plate-column shaped and needlelike gypsum pseudomorph. Distribution horizons: A2, A3.

② Limestone flat microfacies

The microfacies is located in the upper part of the supratidal~ intertidal zone, belonging a periodical exposure environment, where marl is mainly deposited and there are part bioclasts. For example, Б1 layer of well CT-41 belongs to the limestone flat microfacies of restricted platform subfacies.

Tidal zone and energy: supratidal~ intertidal low energy. Color: gray, light gray. Biological assemblage: cyanobacteria, foraminifer, fusulinida, calthrop, bryozoa, trilobite, thin-shell organism, echinodermata, thin-shell ostracod individual, gastropods, and lamellibranch. Rock assemblage: micritic limestone (as shown in Fig.5), particle-containing micritic limestone, pelletoidal fine

crystalline limestone. Rock structure: particle content <20%; mainly various bioclasts, a small quantity of arene, marl support. Sedimentary structure: cyanobacteria bonded lamina, greenish gray argillaceous strip, alga bonded lamina, bioturbation, burrow.



Lamellar micritic limestone — Pelletoidal fine crystal limestone

Fig.5 Limestone flat microfacies of restricted platform subfacies in well 5555

Limestone — Sparry foraminiferal limestone

Fig.6 Grained clastic beach microfacies of restricted platform subfacies in well CT-4

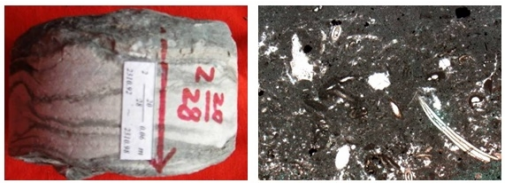
③ Grained clastic beach microfacies

The microfacies is formed in the topographically high part of the restricted platform and located in the intertidal~ subtidal zone with strong hydrodynamic force, belonging to a medium-high energy environment. For example, A2 layer of well CT-22 belongs to the grained clastic beach microfacies of restricted platform subfacies.

Tidal zone and energy: intertidal-subtidal medium to high energy. Color: brown, off-white, gray. Biological assemblage: mainly foraminifer and fusulinida; a small quantity of alga, bryozoa, ostracod, brachiopoda, gastropods, echinodermata, coral; strong biofraction. Rock assemblage: sparry green algal foraminiferal limestone, sparry foraminiferal limestone (as shown in Fig.6), micritic bioclasitc limestone, calcrudite. Rock structure: particle content >70%; bioclast, arene, silt-sized grain, algal lump; sparry cementing matter, or micritic filling. Sedimentary structure: cross bedding. Distribution horizons: A2, A3, Б1, Б2, B3, B4.

④ Lagoon microfacies

The microfacies is developed after the platform shoal and restricted by underwater uplifts or shoals, where seawater is not circulate smoothly, and the energy of water bodies is low, belonging to a low-energy shallow water environment. Sweater is slightly saline, the salinity is slightly high, and euryhaline organisms can be developed, but organisms are scanty and monotonous. For example, B3 layer of well 5555 belongs to lagoon microfacies.



Micritic limestone — Bioclastic micritic limy dolomite

Fig.7 Lagoon microfacies of restricted platform subfacies in well 5555

Gray mudstone — Asphaltene nodular limestone

Fig.8 Lagoon microfacies of restricted platform subfacies

Tidal zone and energy: subtidal low energy. Color: gray, grayish black, brown, bluish gray, dark gray. Biological assemblage: bioclast, strong biofraction; many biological categories but small total biomass; trilobite, bryozoa, brachiopoda, echinodermata, spicule, etc.; thin-shell organisms reflecting a still-water low energy environment. Rock assemblage: bioclastic micritic limy dolomite

(as shown in Fig.7), micritic limestone, gray argillaceous limestone, dark gray mudstone (as shown in Fig.8), bauxitic mudstone, silty mudstone, grayish black nodular limestone (as shown in Fig.8). Rock structure: micritic structure and particle-containing structure; particle content <25%, micritic support. Sedimentary structure: horizontal lamina, nodular limestone; plate shaped and columnar gypsum pseudomorph. Distribution horizons: A2, A3, Б1, Б2, B3, B4.

Evaporative platform subfacies

The evaporative platform belongs to a shallow water environment. The evaporative platform has poor connectedness with the open sea water and belongs to a supratidal low energy zone, where seawater is circulated poorly, water bodies are evaporated strongly, and salinity is high. The lithology is alternate layers of gypsum rock and gypsum-containing limy mudstone with micritic fine crystalline dolomite; organisms are extremely sparse, but cyanobacteria are developed relatively, and alga mats, alga turfs and alga lamina are formed. The bird's eye structure, gypsum salt pseudomorph, tent structure etc. formed from exposure and evaporation have been found. The subfacies can be subdivided into 2 microfacies such as gypsum salt lake and gypsodolomite flat, e.g. gypsum salt lake and gypsodolomite flat microfacies of evaporative platform subfacies in well A-22.

① Gypsum salt lake microfacies

The supratidal zone is located in an exposed evaporative dry environment for long, and gypsum salt lake microfacies is formed in the partial lowland. The lithology is gray, light gray and off-white gypsum rock, argillaceous gypsum rock, micritic fine crystalline gypsum dolomite, micritic fine crystalline dolomite, etc., doesn't contain fossils and can contain terrigenous clastic quartz, feldspar and mica.

Tidal zone and energy: supratidal low energy. Color: gray, light gray. Biological assemblage: not containing fossils. Rock assemblage: gypsum rock, argillaceous gypsum rock, gypsum salt rock, gypsum (gypsum-containing) mudstone, and gypsum-containing silty fine sandstone. Rock structure: micritic structure, crystal grain structure. Sedimentary structure: horizontal lamina, drying crack, bird's eye, coop iron wire, enterolithic structure, lump, concretionary structure, tent structure. Distribution horizons: the northeast of A2 and A3.

② Gypsodolomite flat microfacies

Gypsodolomite flat microfacies belongs to a supratidal low energy zone, and the lithology is gypsum rock sandwiched with thin bedded mudstone, micritic fine crystalline dolomite and argillaceous dolomite.

Tidal zone and energy: supratidal low energy. Color: gray, light gray. Biological assemblage: containing a small quantity of fossils and cyanobacteria. Rock assemblage: gypsum rock, argillaceous gypsum rock, micritic dolomite. Rock structure: micritic structure. Sedimentary structure: horizontal lamina, drying crack, bird's eye, coop iron wire, enterolithic structure, lump, concretionary structure, tent structure. Distribution horizons: the northeast of A2 and A3.

Sedimentary Facies Characteristics of All Layers

The Carboniferous structural unit in the east margin of the Pre-Caspian Basin is located in the platform margin sag belt. To the west of the unit is the intraplatform uplift belt; further to the west is the central depression area; on the east side is Ural geosyncline. The Carboniferous sedimentary pattern and sedimentary facies distribution in the research area are controlled by structural unit

evolution. This paper describes the sedimentary characteristics of all layers from bottom to top in the research area.

Д3-Д1 layers belong to a “strip shaped carbonate platform” environment. The west of the research area is the sea, and its east is Ural Ocean. “Lower carbonate formation” has been deposited in the research area. The research area is far away from the ancient land, the supply of terrigenous substances is limited, and the main sedimentary facies types include intraplatform beach microfacies, algal reef microfacies and interbank sea microfacies of the open platform subfacies.

In the sedimentation period of Г6-Г1 layers, the “strip shaped uplift belt” was disintegrated, the east earth crust subsided and accepted transgression, thus forming a shallow sea carbonate platform environment and depositing Moscow lower substage biogenic limestone. Г6-Г2 layers are mainly the deposits of intraplatform beach microfacies, algal reef microfacies and interbank sea microfacies of the open platform subfacies.

In the sedimentation period (“geosyncline activity” period) of МКТ and В5 layers, the thrust front belt migrated further westwards, the platform margin depression area became the remote end part of the front land depression, thus forming a shallow sea shelf environment; in addition, the provenance directly came from the east thrust belt, and about 400m thick classic rock formations were deposited. The main lithology is mudstone, limy mudstone, gray fine to medium grained feldspar lithic sandstone partially sandwiched with breccia rock formations.

В4-В1 layers were in the “geosyncline quiet” period again, and because of lacking the injection of terrigenous clastic substances, the platform margin depression area became a shallow sea carbonate platform environment and “biological carbonate formation” was deposited.

Because of aggravation of east continental crust subduction and the forming of Ural orogenic belt in the early stage of Б2-Б1 layers, the earth crust in the area was uplifted, and Б2 layer of restricted platform subfacies and open platform subfacies and Б1 layer of restricted platform subfacies were deposited.

Because of earth crust uplifting, sea level drop, arider and hotter climate and stronger evaporation, restricted platform subfacies and evaporative platform subfacies were deposited in А3-А2 layers.

Conclusions

The two sets of carboniferous carbonate reservoirs in NT oilfield in the east margin of the Pre-Caspian Basin belong to shallow sea platform facies deposits, including shallow sea shelf, open platform, restricted platform and restricted platform deposits, totaling 10 types of microfacies. The lower KT-II reservoir mainly belongs to open platform deposits, where intraplatform beach microfacies, algal reef microfacies and interbank sea microfacies are developed. The middle MKT reservoir belongs to a shallow sea shelf environment, where about 400m thick clasolite formation has been deposited. Because of frequent tectogenesis and large sedimentary environment variation, the upper KT-I reservoir includes open platform deposits, restricted platform deposits and evaporative platform deposits from bottom to top, where grained clastic beach, dolomitic flat, limestone flat, gypsum salt lake and lagoon microfacies are mainly developed.

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