Reservoir fracture cave characteristics of middle - lower Ordovician carbonate rocks in Tahe oilfield in Tarim Basin, China

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Different carbonate types found in Tahe Oilfield and their petrological characteristics are analyzed. Primary rock types include sandy limestone, bamboo-like limestone, sandy limestone, dolomitic micrite, particle limestone, limestone containing organic matter, micrite, and siliceous fine crystalline dolomite containing calcite, in which cracks or fissures are mainly or locally developed. The main reservoir space types are also studied. Intergranular or intragranular dissolved pores constitute the main pore types in the study area, with intergranular holes and intergranular dissolved pores playing a secondary role.

[Key words: Tahe Oilfield, carbonate reservoir, fractured-vuggy system]

Introduction

Tahe Oilfield is an important oil production basement in Tarim Basin. Oil mainly comes from middle-lower Ordovician carbonate rocks, whose reservoir space includes pores, fractures, and caves1-4. The distributions of reservoir fracture body were affected by the factors such as long-term structural movement and dissolution5-6, and the structure of reservoir space is very complex at the same time. In order to increase production, several important uncertainties should be resolved, such as macro- and micro-space types and their spatial characteristics, and the fluid distribution characteristics within the reservoir. Considerable research has been conducted to characterize the structural features of reservoir space for the middle-lower Ordovician in Tahe Oilfield7-15, with the results focused on well logging, processing, and analysis of seismic data15-18. However, there exists relatively little analysis and study of microscopic features, greatly impacting the accuracy of reservoir characterization and reservoir modeling. In order to improve the accuracy of reservoir geology modeling, and to fully characterize the spatial features and structural model of the fractured reservoir body, the microscale reservoir characteristics should be researched and analyzed18. Concurrently, the micro reservoir space types and spatial structure characteristics should be suitably summarized with regard to the study area. These results have practical significance for further analysis of the spatial structure of the carbonate reservoirs in the study area, summary of the fracture structural mode, and enhancement of oil and gas production.
Materials and Methods

Tahe Oilfield is located in the north of Tarim Basin, south-central of Akekule, and west of Grass Lake depression. To the east of Tahe Oilfield is Halahatang sag, and to the north of Tahe Oilfield is Manjiaer hydrocarbon depression. Its tectonic position is located along the southwest slope of Tarim basin within Shaya uplift Akekule projections, which is west of Grass Lake depression, in the north of Shuntuuguole upheaval and Manjiaer depression. Manjiaer depression is west of Halahatang hollow and north of Yakela uplift (Fig. 1). Tahe Oilfield has undergone two major sedimentary evolution periods: the development stage of the Paleozoic cratonic basin and the evolution of the Cenozoic foreland basin. Stratigraphic boundaries such as those of the Ordovician Sangtamu Group, Lianglitage Group, Qiaerbake Group, and Yijianfang Group thin out stepwise from upsection to downsection, from west to east, from south to north, and from the southwest to the northeast. New drilling has revealed the lower Ordovician Series Penglaiba Group, middle-lower Ordovician Series Yingshan Group, middle Ordovician Yijianfang Group, upper Ordovician Qiaerbake Group, Lianglitage Group, Sanggemu Group, and so on. Lower-middle Ordovician rocks are composed of restricted platform-open platform facies, micrite, particle microcrystalline limestone, and local tableland reef facies surrounded by tidal flat algal boundstone facies (Fig. 2).

Fig. 1 Tahe Oilfield regional location map and distribution of well drillings
Results and Discussion

Petrology

There are many types of carbonate rocks in the research area. Typical types include sandy intraclast limestone, wormkalk, sandy limestone, dolomitic intramicrite, grainstone, intraclast limestone containing organic matter, intramicrite, and fine-grained siliceous dolomite containing calcite. Fissures or seam holes are well developed mainly in sandy intraclast limestone, wormkalk, dolomitic intramicrite, sandy limestone, grainstone, innerclastic limestone containing organic matter, etc. Voids and cracks are locally developed in other rock types.

Sandy intraclast limestone

Voids and cracks are developed in sandy intraclast limestone (Fig.3). These are filled with organic matter to varying degrees, and are locally filled with oil shape or cloud organic matter (Fig.3). The rock is composed of clastic quartz granules having different sizes and shapes. Most are sub-rounded with a grain size of about 2-15 mm. The mineral composition includes micritic calcite lump or sparry calcite lump, micritization calcite pellets, and sparry calcite cement. Some compositions have internal biological bone structure calcite that presents as irregular granular. Intraclast granule content is about 25-50%. Fillings composed of quartz and calcite occupy about 50%. Among the minerals, subangular quartz granules with particle size about 0.2 mm comprise about 10-20%, and calcite—mainly micritic calcite and crystal powder calcite—comprises about 25%. Locally occurring pyrite, bound up inside carbonate particles, comprises about 3-5%. Organic matter content is about 5-10%, existing partly inside the cracks. Around micrite lump it appears reddish brown or black.
Wormkalks

A few wormkals can be found, with the rocks having an intraclastic grain structure. Pores and fissures exist and are filled with organic matter. Intraclasts are irregular brecciform micritic breccia or spherulite micritic brecciaform intraclasts composed entirely of calcite. Most particles are angular and have a shape resembling bamboo leaves (Fig.4), with particle sizes ranging from 3-10 mm. Most of the fillings are grey-black cements of micritic calcite with little sparry calcite, showing an irregular filling among breccias with a content of about 20-30%.

Sandy limestone

Sandy limestone is a common type in the study area. Cracks and porosity up to 15-25% are developed in sandy limestone rocks, and are infilled with organic matter in some pores. Rocks have a quartz grain structure, with subangular or irregularly-shaped quartz particles. Particle size is about 0.2 mm, and their content is about 20-40%. The carbonate mineral is calcite with a content of 45-75%, showing subhedral diamond, square, or xenomorphic-granular texture. Most calcites are sparry calcite filling up the quartz particles, as shown by Alizarin Red staining. Abundant pyrite is developed in the limestone with a content of 3-15%. A small amount of green glauconite (Fig.5) is distributed among quartz and calcite grains, with fine granular aggregates.

Dolomitic micrite

A small amount of fractures developed in the rock mass of the micrite contain dolomite which is filled with organic matter, iron oxides or dolomite crystals (Fig.6). These rocks have an intraclastic granular structure. Spherical (Fig.6) or ellipsoidal intraclasts are mainly micritic, powder crystal calcite or xenomorphic calcite particles, with a size between 1-15 mm. Calcite presents as irregular granular, subhedral diamond or square, and its content is about 45-60%. Cement content is about 10-25%, and is mainly composed of micritic calcite, organic mineral particles, and micritic calcite. These cements have a crystal-dependent structure, filling between dolomite and intraclast extremely irregularly. Alizarin Red staining showed that dolomite is mainly hypidiomorphic irregular diamond, saddle-shaped, or granular crystals, with a content of about 15-20%. Dark brown organic matter is distributed along the calcite cement or infills.
between cracks in the debris, showing a disseminated or crumby structure, and has a content of about 5-10%.

![Fig.6 dolomitic micrite, well S64, layer O1, depth 5535.36m, single polarization, 5x10](image)

**Particle limestone**

In the study area, particle limestone mainly can be divided into two types: particle limestone containing dolomite, and sandy particle limestone containing organic matter. The voids and cavities between mineral grains developed in particle limestone containing dolomite (Fig.7) are partly filled by organic matter or micritic calcite. The rock presents a grain pattern comprised of carbonate innerclastics and quartz grains. The intraclasts have different shapes and range from 3-10 mm in size, with a content of about 50-55%. Micritic calcite and crystalline grain have a mosaic structure inset internally. The matrix consists of quartz, calcite, and dolomite. Quartz grains show a subangular or irregular round shape, with a size of about 0.2 mm and content of about 15%. The calcite is composed of micritic calcite or calcite grains, whose content is about 20-25%. The dolomite exists in innerclastic grains and in the matrix. It mainly shows subhedral diamond, quadrangular fine grain, although some show a saddle shape. Dolomite grains are 0.1-0.2 mm in size and have a content of about 8-10%. Bicrystals are very rare. The Alizarin Red dye test shows that the content of dolomite is about 10%. Pyrite is black and opaque, with a content of about 5%.

![Fig.7 Particle limestone with dolomite, well T615, layer O1, depth 5525.58m, single polarization, 5x10](image)

The voids, cavities, and cracks developed in the sandy particle limestone containing organic matter (Fig.8) are mainly filled by the organic matter. The rock presents a grain pattern comprised of carbonate innerclastics and quartz grains. The intraclasts mainly consist of calcite which has a nearly isometric granular structure and is evenly distributed. Grain size is typically 0.1-0.2 mm, and the content is about 40%. The quartz grains are well sorted but have low psephicity. Their shape is subangular or irregular round, with a size about 0.2 mm and content of about 8-12%. The matrix mainly is calcite, whose content is about 28-32%. Reddish brown or brown-black organic matter with a content of about 20% fills in voids and cavities between calcite grains.

![Fig.8 Grainy limestone with sandy and organic matter, well T615, layer O1, depth 5533.52m, single polarization, 5x10](image)
Limestone containing organic matter

Innerclastic limestone containing organic matter mainly consists of calc sparite, partly colored reddish brown because of organic matter (Fig.9). There are large gaps between calcite grains, whose content is about 15%. The rock presents an innerclastic grain pattern. The cavities and cracks of the rock are well developed, and the porosity is about 16-25%. Innerclastic grains are colorless and transparent calcite briquette having a granular shape. Cracks between briquettes are well developed, and briquettes have a content of about 75-80%. Bronze-colored organic matter with a content of 10-15% appears as a cloud shape symbiotically with calcite, or partly filling in cavities and cracks.

Fig.9 Micrite with organic matter, well LHK, layer O2, single polarization, 5×10

Micrite

Local rocks have fractures which are filled with organic matter and red-brown iron minerals. Rocks present a particle-micritic structure, with locally developed fractures (Fig.10). Rocks contain some particles, mainly spheroidal-, ellipsoidal- and irregularly-shaped intraclasts whose internal minerals are mostly composed of calcite particles. Calcite granularity is coarse powder-fine grain, showing irregular graininess, or hypidiomorphic diamond or square granules, with a content of about 20%. Micritic calcite is very fine and has a content of about 75%. The little dolomite grain that is present is hypidiomorphic irregular, diamond-shaped, or saddle-shaped. The results of Alizarin Red staining show that dolomite content is about 3-5%. Pyrite has a content of about 3% and presents irregular granularity. It is black under single polarized light, and bright yellow under reflected light. Although pyrite is visible in the late carbonate veins, the vein body is mainly composed of hypidiomorphic granular calcite crystal.

Fig.10 Micrite, well T403, layer O1, depth 5486.11 m, single polarization, 5×10

Siliceous fine-grained dolomite containing calcite

Siliceous dolomite containing calcite has a fine-grained structure comprised of dolomite grains (Fig.11). The grains are hypidiomorphic diamond, square or granular crystals, some shaped like a saddle. A few particles show visible rhombohedral cleavage, and no twin development. Particle sizes are between 0.05-0.2 mm, and have a content of about 45-55%. The results of Alizarin Red staining are consistent with the observational analysis. Calcite grains show an irregular granular or rhombic shape, with a content of about 15-20%. Siliceous sediments are uniformly distributed with a content of about 15-25%, and coexist with the carbonate deposits. Organic matter exists as brown plaque, size 0.1-0.4 mm, with an uneven distribution in dolomite, calcite, and intergranular siliceous sediments. Its content is about 4-8%. Pores and fractures that have been filled with organic matter to different degrees can be found locally.
Types of reservoir space

On the basis of summarizing previous results about fractured-vuggy types and characteristics of reservoir system in reservoir space in carbonate rocks of early Ordovician in Tahe Oilfield, the authors found that secondary pores are the major type because primary porosity almost disappeared during diagenetic evolution involving a series of Ordovician-age karstification and burial events in the study area. Secondary pores include intergranular pores, inter- and intragranular dissolved pores, intercrystalline pores, and other types with apertures ranging from a few microns to tens of microns. Cast thin section and scanning electron microscopy analysis show that intergranular dissolved pores and intragranular dissolved pores are the main pore types, followed by intercrystalline pores and intercrystalline dissolved pores. The spatial distribution of intragranular dissolved pores is controlled by the lithology and facies, as these were the syngenetic corrosion products of atmospheric fresh water. Hence, it is common to see grainstones and algal bryozoan boundstones in Yijianfang Formation.

Intergranular pores

Intergranular pores are original spaces between debris unfilled with matrix and cement in carbonate rocks. Primary porosity is the space formed by grain support during carbonate debris accumulation, and represents an effective storage space. Its mechanical origin was mainly controlled by lithology and diagenesis in the study area (Fig. 12).

Intergranular dissolved pores

Intergranular dissolved pores are secondary pores formed by transformation of primary intergranular pores. These can be seen as irregular vugular pores, solution cavities, corroded hollows, karrens, and sutures in carbonate rocks under the microscope (Fig. 13).

Intragranular dissolved pores

Intragranular dissolved pores were formed in dissolution pores inside carbonate rocks. These pores are always filled with calcite in the study area because of selective carbonate dissolution (Fig. 14).
Intercrystalline pores and cement denudation pores

The pores were mainly formed by penecontemporaneous dolomitization and recrystallization, mostly within porphyritic dolomite limestone, and characterized by residual calcilutite between dolomite crystals, internal plaque, and corrosion at the edge of dolomite crystals. These pores were not completely filled and contain spaces for hydrocarbon preservation. Intercrystalline pores and cement denudation pores are commonly distributed in crystalline limestone, dolomite, dolomite plaque, and spaces between calcite and dolomite in cracks, dissolution pores, and karst caves. Pore diameters are typically 0.001-0.01 mm (Fig. 15). Intercrystalline denudation pores often have irregular shapes and the majority are less than 1 mm, being formed by corrosion and distributed along skeletal pores and within gaps between crystals. The dissolved minerals are calcite and dolomite.

Solution pores

Solution pores can be identified in cores with no selectivity of fabric (Fig. 16), in all kinds of limestone and even along internal boundaries of silicified structures that are big enough to be seen by unaided eyes. With a diameter of 5-100 mm, these pores are distributed along cracks and weathering fissures separately, and are partially filled with calcite, carbonate clastics of silt mud grade, or both, leaving the effective space occupied by crude oil.

Intergranular hole, well T403, layer O1-2y, depth 5541.96m, single polarization, 2×10

Fig.14 Intragranular solution openings, well T403, layer O1-2y, depth 5541.96m, single polarization, 2×10

Fillings in large scale solution cave, composition dominated by grayish-green sand, clay, mixed with gray matter. Plaques and stripes, well T615, layer O1, depth 5521.57m

Solution pores

Fig.15 Intergranular hole, well S65, layer O1, depth 5535.36m, single polarization, 2×10

Structure fractures

The efficient structure fractures in the Ordovician carbonate formation of Tahe Oilfield

Fig.16 Fillings in large scale solution cave, composition dominated by grayish-green sand, clay, mixed with gray matter. Plaques and stripes, well T615, layer O1, depth 5521.57m

Fig.17 Plaster filling in the fractures of high angle, black siliceous in the microfracture, well T403, layer O1-2y, depth 5486.11m

Structure fractures

The efficient structure fractures in the Ordovician carbonate formation of Tahe Oilfield
were divided into two types: (1) Partially-filled or half-filled structure fracture, which is well developed in the rock core and is always represented by a high angle oblique bedding surface. The width of the cracks is relatively large. The fracture is partially filled with granular sparry calcite (euhedral calcite). The surplus space may be connected to the crack, or distributed like beads. (2) Unfilled structure fracture, developed in the lower Ordovician core (Fig17), featured as vertical to level, parallel or parallel-pinnate and straight distribution, narrow in width, unfilled with diagenetic mierals or crude oil.

Conclusions

The middle and lower Ordovician carbonate rock types of Tahe Oilfield are sandy intraclast calcareous rock, wormkalk, sandy limestone with dolomite mud crystal within debris limestone, particles of limestone within the clastic limestone containing organic matter, micritic limestone containing debris within and micritic limestone containing fine-grained siliceous dolomite calcite. Cracks or seam holes mainly include sandy intraclast calcareous rock, wormkalk, sandy limestone with dolomite mud crystal within debris limestone, particles of limestone containing organic matter, limestone sand particles of organic matter and so on. Holes and crevasses may develop partially in other rock types.

Original pore spaces have disappeared at the middle and lower Ordovician carbonate rock storage layer of Tahe, and the secondary porosity has now become the main reservoir space. This reservoir space includes intergranular dissolved pores, intragranular dissolved pores, intergranular pores, dissolution pores among grains in surface residual products, solution pores, structural fractures, etc. Among them, intergranular dissolved pores, intergranular dissolved pores, and intragranular dissolved pores are the main types of microscopic pores in the study area, with intergranular pores and intergranular dissolved pores being of secondary importance.

Microscopic observation showed that micro-fissures and secondary corrosion holes are the main micro-seamless hole features of the middle and lower Ordovician carbonate rock storage layer in the study area, but their proportion and function during the accumulation of oil and gas still need further study.

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