PETROLEUM EXPLORATION AND DEVELOPMENT
Volume 43, Issue 4, August 2016
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: PETROL. EXPLOR. DEVELOP., 2016, 43(4): 655–662.

RESEARCH PAPER

Features and classified hierarchical modeling of carbonate fracture-cavity reservoirs

LI Yang[1], HOU Jiagen[2,*], LI Yongqiang[2]

1. China Petroleum & Chemical Corporation, Beijing 100728, China;
2. China University of Petroleum, Beijing 102249, China

Abstract: Taking the Ordovician fracture-cavity carbonate reservoir of Tahe oilfield, Tarim Basin as an example, the fracture-cavity reservoir has been classified according to the type and size of reservoir space, and a 3-D geological model of fracture-cavity reservoirs was built according to their types and classes. Based on core, drilling, logging and seismic data, the fracture-cavity reservoir was divided into four types, namely cave, dissolved pore, fracture and Matrix block types, in which the cave was subdivided into two subtypes, large cave and small cave; and the fracture was subdivided into four subtypes, large scale fracture, meso-scale fracture, small scale fracture and microfracture. The large cave model was established using deterministic method via seismic truncation and pattern modification. The small cave model was built using the method of multiple-point geostatistical simulation with large cave model as the training image. The dissolved pore model was built using sequential Gaussian simulation. The large scale fracture model was established using the deterministic method of manual interpretation, meso-scale fracture model was built using deterministic method of ant tracking, the small scale fracture model was built using stochastic object-based modeling. The micro-fracture and Matrix block have no discrete distribution model established because of their poor storage quality. Then the different types of reservoir space models were merged into one model to get the discrete distribution model of typical fracture-cavity unit. The application in Tahe blocks 6 and 7 showed that this classified hierarchical modeling improved the reservoir model precision, guided the water-flooding effectively and advanced the development efficiency.

Key words: fracture-cavity reservoir; reservoir type; classified hierarchical modeling; Tahe oilfield; Ordovician

Introduction

Carbonate fracture-cavity reservoirs take a considerable proportion of discovered reservoirs worldwide and contain huge potential for exploration and development. In the Tarim Basin, the Ordovician carbonate rocks experienced multi-phase tectonic activities, karstification processes and hydrocarbon accumulations; thus various types of fractures and caves with greatly different scales and irregular geometries scatter randomly in reservoir rocks[1–3]. Different types of reservoirs have storage space with large differences, which leads to complicated reservoir development performance. On account of large difference in reservoirs scales and representation accuracy of seismic, log and core data used in reservoir modeling, it is necessary to build a 3D geologic model with carbonate fracture-cavity reservoirs of different types and scales characterized quantitatively for refining reserve distribution, so as to enhance the recovery efficiency.

For the Ordovician carbonate fracture-cavity reservoirs in Tahe oilfield that have been developed for years, recent reservoir characterization has mainly focused on the heterogeneity description of fracture-cavity units[4], seismic attribute constraints prediction using such as wave impedance and root-mean-square (RMS) amplitude[5–10], and multivariate modeling for multi-type multi-scale reservoirs[11–13], etc. However, there is no quantitative criterion and method for fracture-cavity reservoir classification. In this study, outcrop, drilling, log, seismic, core and production performance data were used to classify the Ordovician carbonate fracture-cavity reservoirs by type and scale, and the methodology of classified modeling was then used to establish the 3D geologic model of the fracture-cavity reservoirs.

1. Carbonate fracture-cavity reservoir features

The carbonate fracture-cavity reservoirs contain various types of reservoir space, including dissolved pores, caves and fractures. Dissolved pores, usually in micrometer to millimeter

---

Received date: 10 Aug. 2015; **Revised date:** 15 Apr. 2016.

* **Corresponding author.** E-mail: houjg63@cup.edu.cn

Foundation item: Supported by the National Key Basic Research and Development Program (973 Program), China (2011CB201003); China National Science and Technology Major Project (2016ZX05014-002).

scale, can only be observed using microscope and petrofabric related. Caves refer to interconnected dissolved pores larger than 2 mm, which are macroscopic and in various sizes. Fractures include cracks and fissures[14–17].

The classification of carbonate reservoir space has various schemes owing to its complexity. As per the most classic one presented by Choquette et al.[18] based on texture origins, two pore groups can be recognized, i.e. fabric selective and non-fabric selective. The former includes the pore types of interparticle, intraparticle, fenestral, shelter, growth framework, intercrystal and moldic, which are primary or secondary pores within or between depositional texture. The latter includes dissolved cave, pore, channel and fracture, which are secondary pores without specific relation with depositional texture. Lucia[19] proposed another scheme based on Archie's classification[20] and jointed petrophysical properties (porosity, permeability and saturation) with petrofabric elements (intergranular and dissolved pores) to relate carbonate rocks fabrics with distribution of pores sizes, in which, dissolution pores were grouped into two categories: isolated ones, including moldic pores, complex moldic pores, organic chamber pores, and intragranular micropores which are not interconnected with each other; and interconnected ones, including caves, breccia pores, dissolved pores, fractures, dissolved fractures and fenestral pores.

Typically, the carbonate reservoir space consists of a small percentage of traditional pores, but a large number of dissolved caves, dissolved pores, dissolved fractures and fractures which leads to markedly different scales and large scales reservoirs.

2. Carbonate fracture-cavity reservoir classification

The Ordovician carbonate reservoirs in the Tarim Basin are typical fracture-cavity reservoirs, in which the reservoir space is composed of dissolved caverns (caves), dissolved pores, matrix pores and fractures. According to reservoir space types and their contribution of production in oil and gas wells, the fracture-cavity reservoirs are grouped into four types: cave, dissolved pore, fracture, and matrix rock.

2.1. Cave reservoir

A cave is early equiaxial and equal to or greater than 0.5 m in diameter. As per conventional log data responses, the minimum cave recognized in Tahe oilfield is 0.5 m in height and the maximum cave which has been filled is 66 m in height (Fig. 1) (Well T403, depth interval 5 488–5 554 m); the maximum cave identified by imaging logging data is 30 m high (Well TK471X, depth interval 5 540–5 570 m). As per production performance, the caves contribute most to the reservoir space, and present the characteristics of high initial production, a stable or fairly stable long production, long period of production etc. Cave reservoirs contribute more than 95% of productivity in those blocks put into development in Tahe oilfield[21]. This field has 3D high-precision seismic data (with a sampling interval of 1 ms and grid size of 15 m×15 m) and abundant outcrop, core, drilling, log and production data, so there are various possible ways to identify the cave reservoirs.

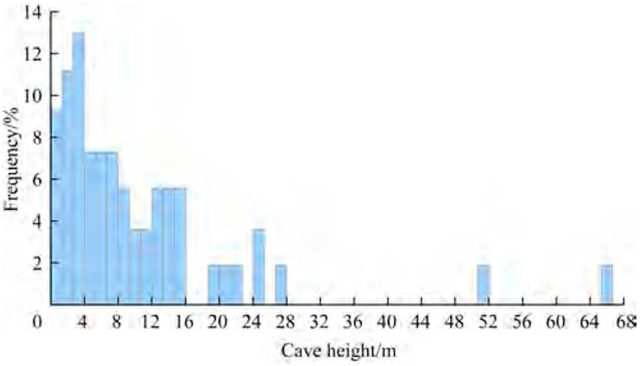

Fig. 1. Distribution histogram of cave height by conventional logging.

Caves can be further grouped into large caves and small caves based on the identification accuracy of seismic data. The former can be clearly identified by seismic data, and are generally higher than 5.0 m in view of seismic resolution in Tahe oilfield (Fig. 2). No core can be acquired from an unfilled cave and a filled cave may be deterministic identification by the observation of the fillings. The existence of a large cave may cause drilling break, severe circulation loss, well kick, and drilling tool drop, etc. which leads to finished drilling ahead of schedule, possible failure of well logging, fragmented cores or even failure of coring. Caves are shown as conventional log curve distortion at the unfilled interval. Some of the sections of caves could get the qualified log curve, presenting clearly log characteristics, extremely low drilling time, low resistivity, low density, low neutron porosity and high acoustic time, and dark shadows or patches on imaging log. Their typical identification feature on seismic profiles is the bead reflection in wave attribute, including entire bead-string reflection, top weak reflection with inner beadlike reflection, and low impedance and etc.[6] A major way affecting the reservoir space in caves is collapse. The type and filling degree of fillings inside caves may affect the identification characteristics in log and seismic responses of the caves[22].

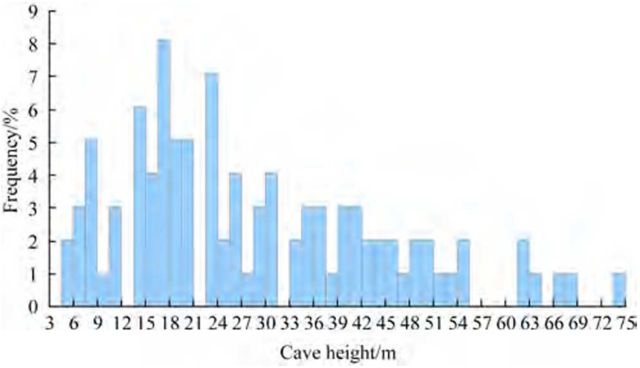

Fig. 2. Distribution histogram of cave height by seismic interpretation.