# Characteristics of Hydrocarbon Accumulation and Distribution of Tight Oil in China: An Example of Jurassic Tight Oil in Sichuan Basin*

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## Abstract

Not only tight gas, but also tight oil is well developed and widely distributed in China. The center of a large lacustrine depression basin is a favorable place for tight oil. Shallow-water delta and lacustrine carbonate are the foundation of continuous petroleum accumulation. Taking Jurassic of Sichuan Basin as an example, it is found that the Jurassic in Sichuan Basin shares the similar hydrocarbon accumulation conditions and reservoir characteristics with the Eagle Ford and Bakken tight oil, and it is possible to borrow the ideas of tight oil exploration and development methods from abroad.

## Basic Overview

The tight oil became another strategic breakthrough field in succession to the success of shale gas in North America. Borrowing the techniques from the shale gas development, Bakken tight oil achieved a huge success by using the under-balanced horizontal well drilling techniques, acidizing and fracturing techniques, etc., which pave a new way to explore and develop the tight oil. The Jurassic in Sichuan Basin, having hydrocarbon shows in each layer, was problematic in that each well had oil but no commercial oil flow, similar to the initial exploration of tight oil in other countries.

The most dominant petroliferous layers in central Sichuan Basin are Daanzhai Limestone Member of the Lianggaoshan Formation, and sandstone in the Shaximiao Formation. 1810 wells were drilled in the basin and 5 hydrocarbon bearing zones were discovered within the Jurassic stratum. In all those wells, 863 discovery wells and appraisal wells were completed, in which 455 wells are

commercial hydrocarbon wells; there are also 339 development wells of which 271 wells are commercial hydrocarbon wells. The proved reserves in Sichuan Basin is $5.97\times10^8$ bbl.

The hydrocarbon in the Jurassic is characterized by low permeability, low abundance and low production, while most of the porosity is 0.1% to 5.9%, and permeability between 0.03 mD to 0.97 mD, with the average permeability below 0.5 mD. The current annual production is $7.35\times10^5$ bbl; annual production reached a peak of $1.59\times10^6$ bbl in 1997. The proved reserves abundance is $4.41\times10^5$ bbl/km$^2$, and the recovery rate is 6.6%. The oil API is 70° to 100°, belonging to the light oil category.

It was originally thought that Jurassic sediments in Sichuan Bain were super-low permeability and super-low porosity, characterized by gentle structure, disseminated hydrocarbon and low aggregation. The reservoir was regarded as a fractured reservoir and having a natural production decline. Based on a fractured-structural reservoir model, the reservoir was explored under the principle of drilling on highland, aiming at fractures, with big fracture causing high production. But the latest research results show that the limestone and sandstone reservoirs in Jurassic satisfy the fundamental requirements of forming large scale tight oil.

## Reservoir Characteristics

The Jurassic stratum in Sichuan Basin is lacustrine, floodplain and fluvial-delta deposition, which could be divided into 3 formations, namely Ziliujing Formation, Lianggaoshan Formation and Shaximiao Formation in ascending order. Ziliujing Formation consists mainly of interbedded lacustrine shale and shaly limestone in unequal thickness (Figure 1) which could form tight limestone oil or shale oil. Lianggaoshan Formation is composed of grey white sandstone and shale deposited by floodplains and fluvial-deltas. Shaximiao Formation (Figure 2) shares similar sedimentary characteristics with the Lianggaoshan Formation in that its bottom is grey white sandstone and middle-top layer is a thick set of light red brown to light brown sandstone.

Two kinds and three sets of reservoirs which are widely distributed are developed in central Sichuan Basin. Daanzhai shaly limestone, covering an area of approximately $6\times10^4$ km$^2$ (Figure 1), is 10 to 60 m thick and its porosity and permeability are 1~2%, 0.0001~0.3 mD respectively. Lianggaoshan sandstone covers an area of $10\times10^4$ km$^2$ and its thickness ranges from 30 to 130 m. The porosity is 2% to 4%, and permeability is 0.001~0.4 mD. The Shaximiao sandstone distribution area is $12\times10^4$ km$^2$ and its thickness is 80~230 m. The porosity and permeability are 3~5% and 0.001~0.5 mD, respectively. Under optical microscope, Jurassic reservoirs are founded to develop a fracture-porosity duel system.

## Accumulation Conditions

Two sets of excellent source rocks, widely distributed, are developed in Lianggaoshan Formation and Daanzhai Member of the Jurassic, but the potential resources need to be re-evaluated. The area of upper Lianggaoshan source rock is $8\times10^4$ km$^2$ and 80 to 160 m thick. The TOC ranges from 0.8% to 3.5% and Ro is about 0.6 to 1.3. The source rock of the Daanzhai Member has a distribution area of $7\times10^4$ km$^2$, 60 to 160 m thickness, TOC is 0.7~2.8% and Ro is 0.7~1.4. These data reveal huge potential resources.

Two types of plays are developed in the research area. They are within oil-source play type (self-generation and self-storage), and near-source play type (lower-generation and upper-reservoiring). The close relationship between source rock and reservoir provides a great advantage to form continuous oil reservoirs. The hydrocarbon accumulation pattern needs to be rebuilt according to the new model of commercial hydrocarbon accumulating in non-structural traps.

There is no obvious corresponding relationship between hydrocarbon distribution and structural relief in the central Sichuan Basin. Oil can be found in anticline, slope and syncline settings. Trap boundaries are not very distinct and reservoirs have special flow phases. Nearly all the reservoirs lack edge and bottom water, and have basic geologic characteristics of continuous tight oil, which are large-scale, continuous, integrated and diffusive distributed.

## Prospects

The favorable reservoir distribution area of the Jurassic with thickness of 10 to 40 m covers nearly $10\times10^4$ km$^2$ and has huge potential. Both the fractures and porosity that is well developed in the tight sandstone reservoirs contain oil. The oil in the porosity is the main guarantee of a long period of stable producing and naturally flowing wells. These provide necessary conditions for forming a large scale continuous distributed tight oil reservoir which has huge potential resources.

Compared with Eagle Ford tight oil and Bakken tight oil in North America, the hydrocarbon accumulation conditions and reservoir characteristics of the Jurassic in Sichuan Basin are quite similar, which makes it possible to borrow the ideas of horizontal well fracturing and other tight oil exploration principles and development methods from abroad.

As exploration and research continues, the Research Institute of Petroleum Exploration & Development gradually turns its attention from structural traps and stratigraphic traps towards tight oil. And the proven reserves make up more than 50% of the total proved reserves.

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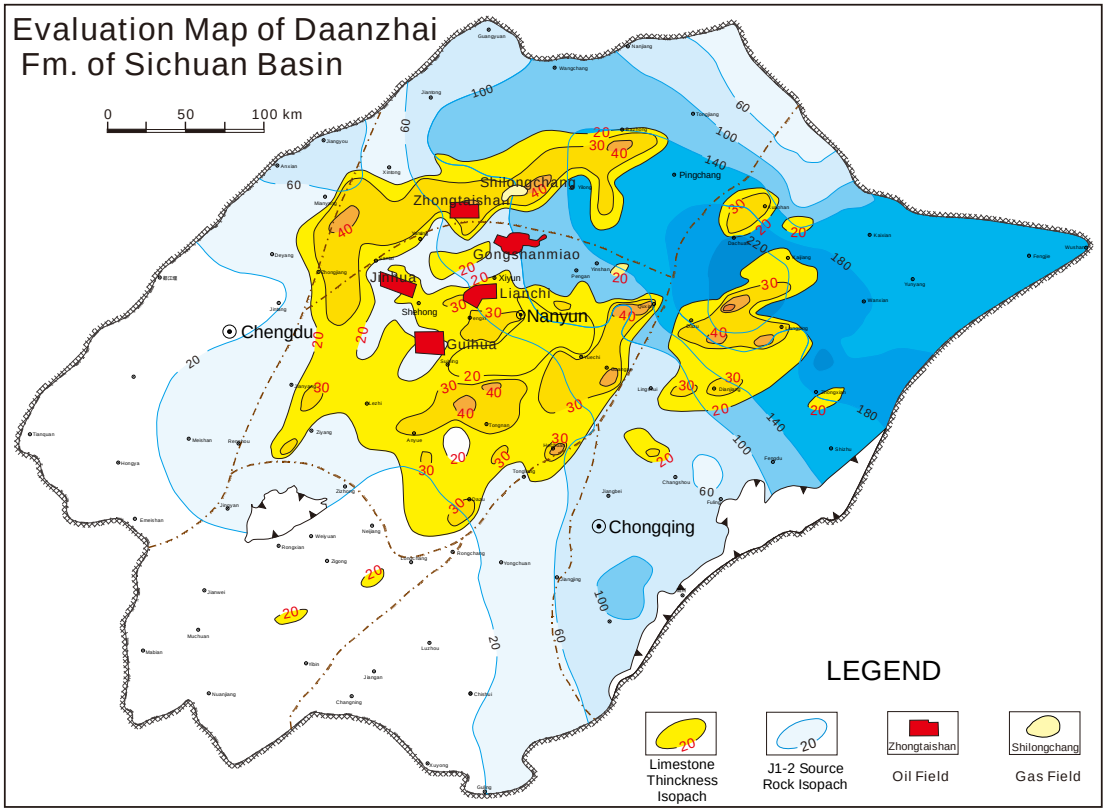


Figure 1. Comprehensive assessment map of Daanzhai Member in Jurassic, Sichuan Basin.

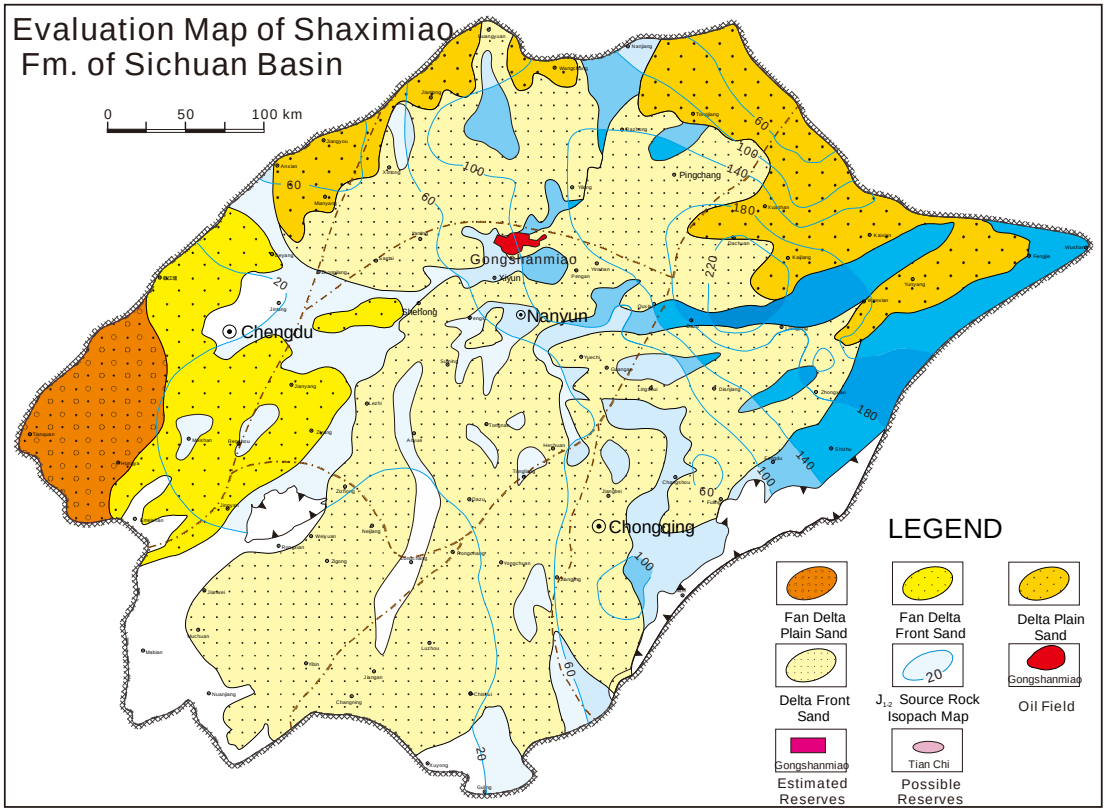


Figure 2. Comprehensive assessment map of Shaximiao Formation in Jurassic, Sichuan Basin.