Structural characteristics and its exploration significance of Wufeng-Longmaxi formation in LaiFeng-Xianfeng Shale gas block, Hubei province

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Abstract. Laifeng-Xianfeng Block whose licensee of exploration belongs to China Huadian Corporation, is located in the west of Hubei province, the eastern edge of the Sichuan Basin and close to the eastern Sichuan high steep fold belt. This block is a mountain landform, in which the geology conditions are complicated. Thus, this paper focuses on 11 two-dimension seismic data and one discovery well in this block. By jointing logging to seismic, the bottom interface of shale gas reservoir in Wufeng-Longmaxi Formation are determined precisely and this type of Formation is characterized by low frequency, strong dual phases, stable distribution, and can be traced in the full-region. Finally, the structure style and distribution of target formations are identified, on the basis of which the integrated evaluation of preservation conditions for shale gas syncline structure is carried out, leading to a selection of Lianghekou Syncline for the best exploration area, which lays a foundation for the future exploration and deployment of shale gas.

1. Block overview
Laifeng-Xianfeng Block which is located in the southwest flank of Yidu-Hefeng anticlinorium, the central of the Yangtze plate, partly on the Huaguoping synclinorium, is adjacent to Sichuan Basin in the west, Qinling-Dabie Orogen in the north, and the Jiangnan-Xuefeng Orogen in the east\textsuperscript{[1-4]}. There are all stratigraphic strata from the Sinian to Triassic, however, the strata above the Jurassic is absent. The oldest formations outcropped are the Lower Cambrian Tianheban Formation, while the latest formations outcropped are the Lower Triassic Daye Formation (Figure 1.). Wufeng-Longmaxi Formations, as the major exploration targets in this block, are composed mainly of black shale, locally intercalated with muddy siltstone. The total thickness of this sequence of strata is about 50 m. In this paper, the spatial distribution and structural characteristics of organic rich shale in the area are defined, through all kind of data including sections of geological investigations, 2D seismic and wells data. Therefore, this can provide an important technical support for shale gas exploration and deployment.

2 Structural characteristics
Application of geophysical data for fine structure interpretation is one of the cores of regional prediction and resources assessment\textsuperscript{[5-6]}. Based on field geological survey, the research of 2D seismic and drilling data, using multiple methods of the synthetic seismogram calibration, the field outcrop and seismic forward modeling, etc., the seismic reflection characteristics of Wufeng-Longmaxi formation bottom boundary (TS\textsubscript{1}) have been determined. On the basis of the interpretation model, the fine structure interpretation and analysis of the structure characteristics have been carried out, using the average speed model and regional data to correct it and to make the time-depth conversion, thus
obtaining the structure map and buried depth map of the target layer bottom boundary.

2.1 Seismic reflection characteristics
Seismic geologic horizon calibration is both the prerequisite and key for the structure interpretation, and it is also a bridge which connects the seismic reflection phase axis with the geological horizon. Based on the comparison between field measured outcrop geological survey mapping and seismic profile in terms of equal proportion, along with comparative analysis and calibration of synthetic record of Laidi1 well and the seismic section features in the adjacent region, the lithology of Wufeng-Longmaxi Formation interface consists of the overlying Silurian black shale containing muddy siltstone with the underlying Ordovician carbonate rocks, that is to say, the contact interface of the mud shale and limestone. Synthetic records show that the reflection characteristic is 1-2 strong phase with middle and low frequency (Figure 2a.). On the field outcrop horizon calibration section of LF-113, we can observe the good corresponding relationship between the seismic reflection (TS1l) and the geological field outcrops, where the reflection has the characteristics of 1-2 strong phase, intermediate frequency, good continuity, and stable distribution (Figure 2b.).

2.2 Tectonic style
According to characteristic analysis of structure, sedimentary and tectonic stress field in the west block of Hunan and Hubei, the tectonic style of this area is divided into three basic types: extrusion fault block, stretch fault block, and thrust fold (Suyong, etc.). Based on the investigated results on
tectonic style, combing with work area skeleton seismic section interpretation, the tectonic styles of this studied area contain basement-involved type and capping-sliding type. The former can be subdivided into the hedge and rushed back. On the other hand, the latter can be subdivided into imbricate fan, broken exhibition anticline and normal fault combination (Figure 3.).

![Figure 3. Tectonic style section of Laifeng-Xiangfeng block (LF-107).](image)

Structural configuration in this area is mainly divided into three types: two of these, Yangdong fault, Xianfeng-Yanhe fault, are large thrust fault, which controls the structure configuration of the whole block. Whereas the remaining Lianghekou syncline axis fault is a compression-shear fault, which have the properties of dextral strike-slip to control the structure configuration of the Lianghekou syncline. Within these major faults are a series of ramp adjusting faults.

2.3 Tectonic characteristics

In this area, the combination of Xianfeng-Yanhe thrust fault and late reverse fault forms the “one uplift-two sag” structural pattern Yangdong syncline is located on the west of Xianfeng-Yanhe fault zone, Xianfeng anticline and Lianghekou syncline in the east. In addition, there are cataclastic and breccias on the Xianfeng-Yanhe fault zone, which the direction is from north east to 40 °, southeast dip, an angle of 60 degrees, approximately 0.5 km spreading width, along with fault escarpment occurring in local area (Figure 4.).

![Figure 4a. Fault breccia in Guiziyan. Figure 4b. Fault escarpment in Chenjiayan.](image)

Through the fine structure interpretation, the tectonic characteristics of Longmaxi formation is believed to be “two sag intercalated with one uplift”, where the faults of Yangdong syncline in the west are well developed and show the complex structures, in the middle part, a north east trending Xianfeng single-faulted anticline, there is a denudation area of 12 km long and 5-6 km wide, in the east, the Lianghekou syncline spreads in the north-eastern direction, indicating a asymmetric south-east dipping, which is gentle in the east flank and is steep in the west flank, 9 km long, 3-8 km wide (Figure 5.).

3 The discussion of significance of shale gas exploration

Currently, there are more wells drilled in Wufeng-Longmaxi Member of Lower Silurian, which has better shale gas shows due to good preservation conditions. At this stage, the main factors of the shale gas preservation contain the roof and floor plate conditions, tectonic deformation characteristics, hydrocarbon generating-expelling history and hydrologic geology conditions. however, the core is the differences in tectonic conditions and sealing conditions [7]. Based on the data of field geological survey and drilled-wells, the 2D seismic data being interpreted and analyzed as precisely as possible,
this paper evaluates the preservation conditions of the three structural units in Laifeng-xianfeng Block from two basic perspectives of 11 relevant parameters (Table 1.).

Through analysis of three structural units in this block, every structural unit has its own characteristics. The emergence strata of Yangdong Syncline, located in the northwest of this block, is of the Permian, 4000m below the target zone, the cap rocks in this area mainly consist of the overlying Silurian mudstone and silty mudstone, thickness greater than 100m, on this region, there is a large area and continuous distribution. And the targeted Wufeng-Longmaxi Formations of the Silurian are underlaid by the Ordovician Baota formation of nodular dense limestone as regional floor rocks. Therefore, the sealing condition of targeted-formations in Yangdong Syncline is better. But the structure condition of Yangdong Syncline is just so-so because of its intense deformation, larger-scale and large number fractures. However, in Xianfeng Anticline, due to uplift and erosion, the Silurian strata are worn away while the middle and lower Cambrian strata are exposed, thus causing the tendency of the lateral migration of shale gas in the target zone from both sides, which will have an adverse effect on shale gas accumulation. Compared with Yangdong Syncline, Lianghekou Syncline located in the east of this block has a less sealing condition, as a result of burial depth decrease, even the maximum buried depth of 2350m, the strata of Luoreping and Xintan are exposed in surface, where the cap rocks are composed mainly of mudstone or silty mudstone, thickness larger than 100m, and a continuous distribution. In short, Lianghekou Syncline has a better structure condition than Yangdong Syncline, partly because of fewer faults development in this syncline and the core area being greater than 4km from the outcrop.

**Figure 5.** Structure map of Longmaxi formation bottom in Laifeng-Xianfeng block.

Through comprehensive and comparative study of the blocks that has achieved a breakthrough in developing shale gas at the edge of Sichuan Basin, it is found that the shale gas of Pengshui Block and Zhengan Block occurs in the syncline area, the shale gas of Jiaoshiba Block in the box-type anticline structure. This has fully demonstrated that the syncline is now a good tectonic unit for shale gas accumulation in south China. Simply, the Lianghekou Syncline in Laifeng-Xianfeng Block has the features of simple structure, stable formation distribution, less faults and well-developed strata, which is helpful to the preservation and enrichment of shale gas. In addition, there are good shale gas shows when drilling Laiye1 well. Therefore, the results indicate that Lianghekou Syncline is a favorable target zone for shale gas exploration in this block.
Table 1. The comprehensive evaluation of preservation conditions of Wufeng-Longmaxi Formations

| factor                      | evaluation parameter | block                                  |
|-----------------------------|----------------------|----------------------------------------|
| sealing condition           | the outcrop of the strata | P₁ ∈₁₂                                 |
|                            | type of the regional cap rocks | mudstone, silty mudstone               |
|                            | Shale thickness (m)     | >100                                   |
|                            | burial depth (m)        | 1000~4600                              |
|                            | distribution of the cap rocks | in large area                          |
|                            | conditions of the roof and floor rocks | good                                   |
| structure condition         | tectonic deformation    | intense                                |
|                            | degree of fault growth and evolution | high                                   |
|                            | erosion thickness (m)   | 4000                                   |
|                            | distance to the outcrop (km) | 2.5                                    |
|                            | the comprehensive evaluation | just so-so                            |

4 Conclusions
(1) The reflection characteristics of Wufeng-Longmaxi Formations’ bottom (TS₁l) are clarified by many methods such as well-to-seismic integration, synthetic seismogram, geological-hat mapping, formation comparing to adjacent areas, and seismic forward modeling. And they are considered to be characterized by low frequency and strong dual phase as well as stable distribution.
(2) The structural pattern of this block is composed primarily of "one uplift and two sags", indicating that the Lianghekou Syncline is the most favorable structure unit in this area.
(3) According to the evaluation of capping conditions and construction conditions along with the contrast between three structural units, it suggests that the Lianghekou Syncline has the features of simple structure, stable formation distribution, less faults and well-developed strata, which is helpful to the preservation and enrichment of shale gas in Laifeng-Xianfeng Block.

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