Study on Fault Characteristics of Lower Cretaceous in Lishu Fault Depression of Songliao Basin

Shaodong Qu\textsuperscript{1,2,3,4}

\textsuperscript{1} Shaanxi Provincial Land Engineering Construction Group Co., Ltd.
\textsuperscript{2} Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd.
\textsuperscript{3} Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Natural Resources
\textsuperscript{4} Shaanxi Provincial Land Consolidation Engineering Technology Research Center

Xingtai 7th Street, Weiyang District, Xi'an, China
Email: 331209555@qq.com

Abstract. As one of the most important geological structures, faults are widely developed in the crust, and the formation of faults is closely related to the regional stress field. The study of the fault characteristics can reflect the properties of the regional stress field in different periods. The regional stress field in Lishu fault depression, southeast uplift area of Songliao Basin is analyzed based on the statistical analysis and the study on the strike and length of the faults in different periods. The results illustrated that the Lishu fault depression went through three stages, the NW-SE extension in Huoshiling period, the left-lateral extrusion in Shahezi period, and the NW-SE extension in Yingcheng period, in which research the maximum value of regional stress field. With its special tectonic characteristics, Lishu fault depression reflects and records the tectonic regime and the main stages of innovation, transformation and evolution in geodynamic environment since the Mesozoic of northeast Asia tectonic domain.

1. Introduction

As one of the most important geological structures, faults are widely developed in the crust [1], which controlling the ore deposits and the occurrence and distribution of ore bodies [2]. The important metallogenic belts are formed by magma, hydrothermal solution and ore-bearing solution which invading or filling easily along the fault zone. Metallogenic locations are formed especially at the place where two faults intersected, or the place where the occurrence (strike or tendency) of faults suddenly changed, or the place where a strata (such as carbonate rock) with porous or chemical activities cut through by a fault. Faults are structures formed by the rock destruction caused by strong pressure or tension in crustal movement that exceeds the strength of the strata. Therefore, the formation of faults is closely related to the regional stress field. The relationship between regional stress field and hydrocarbon migration has been concerned by foreign researchers since 1980s [3]. With the increasing need, the relationship between regional stress field and hydrocarbon migration has been studied in recent years in domestic research [4]. The direction and relative size of stress field in geological history can be reflected by researching the strike and length scale of faults. In this research, a theoretical basis for hydrocarbon migration and reservoir formation is provided by the analysis of regional stress field through the statistical study on fault strike in main stages of hydrocarbon generation and expulsion in Lishu depression of Songliao Basin.
2. Geological Background and Brief Introduction

Lishu fault depression is located in the southeast of the southeastern uplift area in Songliao Basin, with an area of 2300 km², which is generally spread in NNE direction. It is a residual half graben rift in early Cretaceous controlled by Sangshuitai fault on the western boundary, which faulted in the west but overlapped in the east [5] (Fig. 1). The sedimentary thickness of the western strata is more than 10,000 meters. The boundary faults on the east side are undeveloped. The strata are overlapped upward, with a thickness thinning, even thinned out [6,7].

Figure 1. Tectonic location and fault depression structure of Lishu fault depression.

Lishu fault depression is a superposed basin composed of fault-subsidence and depression [8,9]. The rifted layers are composed of Huoshiling Formation, Shahezi Formation, Yingcheng Formation, Denglouku Formation, with an average thickness of more than 5 km. The layer of the upper depression is composed of Quantou Formation, Qingshankou Formation and Nenjiang Formation (Fig. 2) [10], with a limited thickness of 2 km. The hydrocarbon exploration began in the 1980s [11]. Five series of hydrocarbon-bearing strata were discovered from bottom to top [12], such as Shahezi Formation (Siwujiazi hydrocarbon reservoir), Yingcheng Formation (Wujiazi hydrocarbon reservoir), Denglouku...
Formation (Xiaochengzi hydrocarbon reservoir), Quantou Formation (Nong’an hydrocarbon reservoir and Yangdachengzi hydrocarbon reservoir). As all the hydrocarbon reservoirs are located in the early Cretaceous, this research mainly analyses the characteristics of regional stress field in the early Cretaceous by focusing on the characteristics of fault strike in top structural layer.

Figure 2. Stratigraphic of Lishu fault depression.

3. Analysis of Fault Characteristics

3.1. Analysis Method.
In this research, the strike and length scale of faults on the top structural layers are mainly considered in fault statistics. 3D seismic acquisition has been carried out in the study area since 1992, which have covered the whole area of Lishu fault depression up to now [13]. In this research, the top-structure maps of Huoshiling -Quantou group in Early Cretaceous, namely the fault distribution maps of T42,T41,T4,T3 and T2, are drew by plotting the structure-corresponded faults interpreted in the 3D seismic profiles on Geoframe workstation to the planar map.

The length scale and strike of each fault can be calculated by self-compiled software through the processing of fault-distribution data counted by the digital processing in Mapjis through five tectonic layers [14].

3.2. Characteristics of Fault Length
The fault lengths of the five main tectonic layers, such as T42, T41, T4, T3 and T2 in Lishu fault depression are analyzed through the above methods, and the following tables are obtained (Table 1).

Table 1. Statistics of fault length scale in T42-T2 layers of Lishu fault depression.

|        | T2  | T3  | T4  | T41 | T42 |
|--------|-----|-----|-----|-----|-----|
| Number of faults | 128 | 247 | 345 | 270 | 153 |
| <4km   | 90  | 169 | 265 | 221 | 106 |
| 4km-8km| 31  | 58  | 56  | 40  | 32  |
| >8km   | 7   | 20  | 24  | 9   | 15  |

Seen from the table above, there are more than 150 faults developed on the top Huoshiling Formation. There are more than 100 faults less than 4 km in length, accounting for nearly 70% of the total number, and 15 faults greater than 8 km, accounting for nearly 10%. On the top Shahezi Formation, the number of faults increases sharply, indicating that the regional stress field begins to increase. The main faults are those less than 4 km in length, and those greater than 8 km only accounting for about 3%. On the top Yingcheng formation, the regional stress field continues to increase, as well as the number of faults. The number of faults with 4-8 km and greater than 8 km is larger than that of top Shahezi Formation. The number of faults on the top Denglouku Formation
begins to decrease, but the number of faults with 4-8 km and greater than 8 km is larger than that of the top Yingcheng Formation. The number of faults on the top Quantou Formation decreases sharply, which indicates that the regional stress field decreases sharply at the end of deposition in Quantou Formation, and the activities in this area are weak. The longest fault is 61 km at the top of Huoshiling Formation, 56 km at the top of Shahezi Formation, 30 km at the top of Yingcheng Formation, 25 km at the top of Denglouku Formation and 11 km at the top of Quantou Formation (Fig. 3).

3.3. Strike Characteristics of Faults
The trend rose diagram of each tectonic layer is drawn by counting the fault strikes in tectonic layers of T42-T2 (Fig. 4). It can be seen from the graph that the fault strikes of top Huoshiling Formation are generally in disorder, mainly in directions of SN and NNE directions, with a small number of NW direction. The direction of the fault strike with a length longer than 8 km is obviously NE. The fault strikes of top Shahezi Formation are mainly in direction of SN and NNE. Compared with top Huoshiling Formation, the number of faults longer than 8 km is less, and the fault strikes are obviously mainly in NE. Compared with the unconformity distribution of the top Shahezi Formation and the NW axis characteristics of folds, it can be seen that the faults in Shahezi period was developed by the inheritance and utilization of Huoshiling faults under the strong activities of NE faults. The directions of fault strikes in top Yingcheng Formation are mainly in SN and NNE, which are similar to top
Shahezi Formation. The number of faults longer than 8 km is obviously larger than that of Shahezi Formation, and mainly in NE direction. The research shows that faults in Yingcheng Formation are further developed on the base of Shahezi faults under the environment of NE-SW extrusion, which combined with the unconformity distribution and the axial direction of NW folds at the top Shahezi Formation. Under the environment of SSE-NNW compressed-structure stress field, most faults of top Denglouku Formation are further developed on the base of Yingcheng Formation, with the main direction of NWW, SN and NNE. The directions of fault strikes are mainly in NW and SN. The directions of stress field are mainly in NW-SE, with an obviously reduced strength. Most fractures are developed from early fractures (Fig. 5).

4. Analysis of Tectonic Evolution in Lishu Fault Depression

During the Huoshiling period, Lishu fault depression was in the environment of dextral tearing under the development of NW-SE extension caused by mantle uplift influenced by the quick closure of Mongolian-Okhotsk Sea [15]. During this period, the NE half graben rift of Qinjiatun was developed, as well as the extensional faulted depression of Sangshutai fault, in which the trachyte dacite volcanic rocks of the Huoshiling Formation was developed.

During the Shahezi period, the study area was under the left-lateral extrusion environment dominated by the NW subduction of Izanagi plate, which was caused by the slow closure of Mongolian-Okhotsk Sea [16]. It resulted in the strong left-lateral extension of the nearly SN Sangshutai fault, and the development of half graben rift. The muddy source rock of thick layer was formed by the stratigraphic overlap of Shahezi Formation controlled by the half graben rift. Qindong Strike-slip fault in the southeast of Lishu fault depression began to form by the uplift and corrosion of Huoshiling deposition in the east of Qinjiatun fault.

During the Yingcheng period, Lishu fault depression was in the environment of dextral tearing under the development of NW-SE extension [17], which was caused by mantle uplift influenced by the quick closure of Mongolian-Okhotsk sea. During this period, the NE half graben rift of Qinjiatun was developed, as well as the dextral-extension faulted depression of Sangshutai fault. It resulted in the deposition of thick muddy source rocks near Sangshutai fracture caused by the graben faulted in the east but overlapped in the west.

During the early period of Denglouku -Quantou, the study area was under the left-lateral extrusion environment dominated by the NW subduction of Izanagi plate, which was caused by the quiet period of Mongolian-Okhotsk Sea. It resulted in the strike-slip extrusion of NE structures in Qinjiatun and Xiaokuange caused by the left-lateral extension of SN Sangshutai major fracture and the cease of volcanic eruption. (Fig. 6).
5. Conclusion

(1) Through the NW-SE extension in Huoshiling period, left-lateral extrusion in Shahezi period, the regional stress field of Lishu fault depression reached the maximum value. The study area was dominated by left-lateral extrusion caused by the NE subduction of Izanagi plate in the early Denglouku-Quantou period.

(2) Lishu fault depression is located in the southeastern part of Northeast Asian tectonic domain, which is in the eastern part of Paleo-Asian Ocean megatectonic domain between Siberia and North China plate in pre-Mesozoic and early Mesozoic. The study area has been obviously compounded, superimposed and reformed by the tectonic activities of the paleo-Pacific-Pacific tectonic domain since the late Mesozoic. The formation and evolution of this area are controlled by the tectonic sitting of region and deep layer, dynamic environment and dynamic evolution. It reflects and records the main stages of reformation, transformation and evolution in tectonic regime and geodynamic.

6. References

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