

## Article

# Genesis of Bedding Fractures in Ordovician to Silurian Marine Shale in Sichuan Basin

Hu Wang<sup>1,2</sup>, Zhiliang He<sup>3,4,\*</sup>, Shu Jiang<sup>1,2,\*</sup>, Yonggui Zhang<sup>3,4</sup>, Haikuan Nie<sup>3,4</sup>, Hanyong Bao<sup>5</sup> and Yuanping Li<sup>1,2</sup>

<sup>1</sup> Key Laboratory of Tectonics and Petroleum Resources, Ministry of Education, China University of Geosciences, Wuhan 430074, China

<sup>2</sup> School of Earth Resources, China University of Geosciences, Wuhan 430074, China

<sup>3</sup> China State Key Laboratory of Shale Oil and Gas Enrichment Mechanisms and Effective Development, Beijing 100083, China

<sup>4</sup> Sinopec Petroleum Exploration and Development Research Institute, Beijing 100083, China

<sup>5</sup> Exploration and Development Research Institute, SINOPEC Jiangnan Oilfield Company, Wuhan 430073, China

\* Correspondence: wanghu0622@cug.edu.cn (Z.H.); jiangsu@cug.edu.cn (S.J.)

**Abstract:** The effective utilization of shale bedding fractures is of great significance to improve shale gas recovery efficiency. Taking the Wufeng–Longmaxi Formation shale in Sichuan Basin as the research object, the formation process and mechanism of bedding fractures in marine shale are discussed, based on field observation and description, high-resolution electron microscope scanning, fluid inclusion detection, and structural subsidence history analysis. The results show that the formation of bedding fractures is jointly controlled by sedimentary characteristics, hydrocarbon generation, and tectonic movement: the development degree of bedding (fractures) is controlled by the content of shale organic matter and brittle minerals, and bedding fractures formed in the layers with high organic matter; tectonic movement created stress environment and space for bedding fractures and promoted the opening of bedding fractures; the time for calcite vein to capture fluid is consistent with the time of oil-gas secondary pyrolysis stage. The formation of the calcite vein is accompanied by the opening of fractures. The acid and oil-gas generated in the hydrocarbon generation process occupied the opening space and maintained the bedding fractures open. The study of the formation process of bedding fractures is helpful to select a suitable method to identify bedding fractures, and then effectively use it to form complex fracture networks in the fracturing process to improve shale oil and gas recovery.

**Keywords:** fractures; complex fracture net; formation of bedding; Fuling area



**Citation:** Wang, H.; He, Z.; Jiang, S.; Zhang, Y.; Nie, H.; Bao, H.; Li, Y. Genesis of Bedding Fractures in Ordovician to Silurian Marine Shale in Sichuan Basin. *Energies* **2022**, *15*, 7738. <https://doi.org/10.3390/en15207738>

Academic Editors: Manoj Khandelwal and Ingo Pecher

Received: 20 June 2022

Accepted: 10 October 2022

Published: 19 October 2022

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## 1. Introduction

At present, shale gas resources are mainly found in Sichuan Basin and Ordos Basin, with an estimated resource volume of 80 trillion m<sup>3</sup>. By December 2020, shale gas production has reached 20.04 billion m<sup>3</sup>; continental shale oil is mainly concentrated in northern China. According to the public data of major oil companies, including 11 basins such as Songliao, Bohai Bay, Junggar, and Ordos, the shale oil resources with medium and high maturity (Ro: 0.7–1.3) are 10 billion tons. It is estimated that by the end of the “15th Five-Year Plan”, the annual output may reach 40 million tons, which will account for 20% of total crude oil production [1].

The production of shale oil and gas is affected by geological and engineering factors. Geological factors are mainly organic matter abundance, the thickness of the sweet section, formation pressure, clay mineral content, fracture development intensity, bedding density, and other factors while engineering factors are mainly the horizontal well length and the number of fracturing section clusters spacing and casing deformation [2–4]. Previous

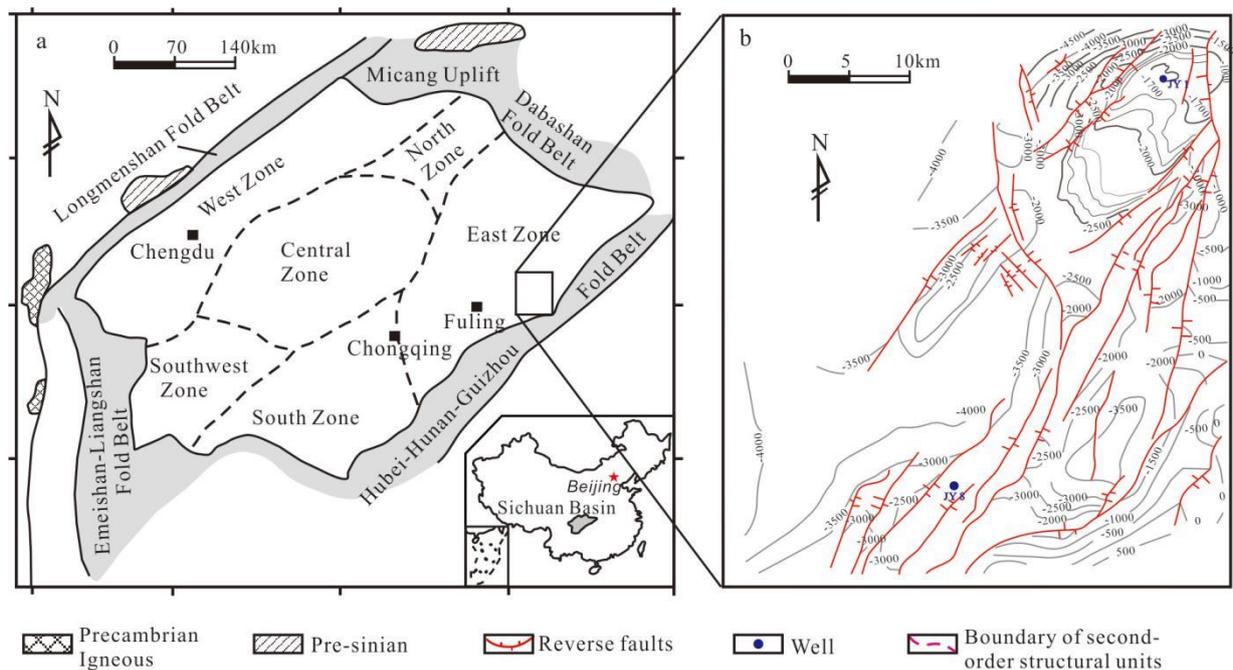
research results believe that bedding controls the distribution of organic matter and brittle minerals to a certain extent, and bedding fractures are important reservoir spaces of the Wufeng–Longmaxi formation shale in the Sichuan Basin [5]. The formation of bedding fractures is generally closely related to the stress field, and the bedding fractures are in multiple scales [6,7]. The late uplift and reconstruction of the Sichuan Basin are of great significance to the formation and activation of fractures [8]. The differences in development intensity and longitudinal stress in weak bedding planes will directly affect the development scale and complexity of fractures in the reservoir after fracturing [9]. The study on shale optimization schemes in Permian basins in North America found that the cluster spacing was shortened to 6.1 m, the complex fracture network produced the largest volume, and the recoverable reserves could be increased by 140% [10]. Generally, the bedding fractures develop in small fracture height, but they will increase the spatial complexity of hydraulic fractures, which is conducive to improving the production and ultimate recovery of a single well [11].

However, most of these studies on bedding fractures are based on the effects and results brought by bedding fractures. There are few studies on the controlling factors of the formation of bedding fractures, which is an urgent need for research on bedding fractures to provide theoretical support for the identification and prediction of bedding fractures. Based on the data of cores and outcrops, this paper attempts to analyse the controlling factors of shale bedding fracture formation by means of rock mineral analysis, scanning electron microscope, and fluid inclusion analysis, so as to provide a geological basis for identifying and characterizing the three-dimensional spatial distribution of bedding fracture, optimize the fracturing network reconstruction scheme, and improve shale oil and gas recovery.

## 2. Geological Background and Data Method

### 2.1. Geological Background

The eastern edge and southern edge of the Sichuan Basin mainly include Chongqing and Sichuan Province, separately. The southeast edge of the basin formed a strongly rising fold belt with a high altitude, where are middle and low mountain areas. The villages and towns in the area are connected by simple roads with inconvenient traffic. The study area is located in the east of the Sichuan Basin, northeast of the Fuling area, Chongqing (Figure 1a). Affected by the central Sichuan uplift, the central Guizhou paleouplift, and the Jiangnan Xuefeng mountain paleouplift, the shale reservoirs of the Wufeng–Longmaxi Formation are mainly distributed in the southeast of the Sichuan Basin and its periphery. In the Chongqing Nanchuan, the shale of the Longmaxi Formation is missing due to the influence of the underwater highlands in the northeast of the central Sichuan paleouplift and the northeast of the central Guizhou paleouplift. The overall thickness of high-quality shale varies from 5 m to 40 m, and the target layer in the study area is just in the area with the largest thickness (Figure 1). During the shale deposition period of the Wufeng Formation, the water was deep, which was also a high-quality section of the shale gas reservoir. The deposition thickness in the target area was 6 m, which was the center of the depression area. The high-quality reservoir section of the Wufeng–Longmaxi Formation was deposited in an oxygen-deficient or anoxic environment and rich in organic matter. However, in the upper Longmaxi Formation, the sedimentary environment changed, resulting in a decrease in organic matter.



**Figure 1.** Location structure of study area. (a) Regional division of Sichuan Basin, (b) Structural plan of Jiaoshiha area.

## 2.2. Data and Experimental Method

### 2.2.1. Data

The core and outcrops samples are mainly collected from the Qijiang Guanyinqiao, Pengshui Lujiao, and Shizhu Qiliao sections and Jiaoshiha shale gas field in Chongqing at the Wufeng Formation of Upper Ordovician and Longmaxi Formation of Lower Silurian, such as Well JY1, Well JY11-4, Well JY41-5, Well Pengye 1, Well Yucan 4, Well Yucan 6, Well Yongye 6, etc. Quartz vein and calcite vein were mainly collected in coring wells, and the depth distribution range of samples is between 2250~2620 m. The 276 km<sup>2</sup> three-dimensional seismic data of the Wufeng–Longmaxi Formation in the Fuling area of the Sichuan Basin were sorted out and interpreted. All experiments were completed in the Key Laboratory of shale oil and gas exploration and development, Wuxi Institute of geology, Sinopec.

### 2.2.2. X-ray Diffraction

The mineral composition analysis of the samples is based on SY/T 5163-2018 “X-ray diffraction analysis method for clay minerals and common non-clay minerals in sedimentary rocks”, using Rigaku Ultima IV X-ray diffractometer (Tokyo, Japan). The maximum rated voltage of the instrument is 60 kV, the maximum rated current is 40 mA, DOPS direct optical positioning system is adopted, and the angle reproducibility is better than  $\pm 0.0001^\circ$ . The test is carried out in an environment of 25 °C, the working voltage is 20–40 Kv, and the scanning current is 10–40 mA. Before XRD analysis, the sample was crushed to 200 mesh.

### 2.2.3. Fluid Inclusion Analysis

In this study, isolated primary brine inclusions and gas-liquid two-phase brine inclusions associated with pure methane inclusions are selected for homogenization temperature test, so that the homogenization temperature of fluid inclusions can accurately reflect the maximum paleogeothermal temperature experienced by shale. The rock samples were made into a double-sided polished fluid inclusion sheet, and the micro temperature measurement of the inclusions in the vein was carried out by using the Axio scope A1 microscope of Zeiss company (Jena, Germany), equipped with the mdsg600 cold and hot

platform of Linkam company (Redhill, UK) and the corresponding cold and hot systems. The temperature measurement accuracy of the hot and cold platforms is  $\pm 0.1$  °C. During the determination of the homogenization temperature of fluid inclusions, the initial heating rate is 15 °C/min, and when the inclusions are close to homogenization, it drops to 2 °C/min.

### 3. Results

#### 3.1. Lithologic Profile

The characteristics of field outcrops can clearly show the abrupt change from the Guanyinqiao shell marl of the Wufeng Formation in Upper Ordovician to the organic rich shale at the bottom of the Silurian Longmaxi Formation, and then the Longmaxi shale gradually became organic poor shale upward. The field outcrop observation and rock mineral, geochemical, and petrophysical tests of the Lujiao section show that Wufeng is siliceous shale, and Guanyinqiao shell limestone cannot be found. The lower part of Longmaxi Formation is rich in organic matter shale, which transits upward to poor organic matter shale and silty shale. It can be seen that lithofacies, geochemistry, and petrophysical heterogeneity are relatively strong. The Qiliao section also has similar heterogeneity in a vertical direction. The Wufeng Formation transits from the lower siliceous shale to the upper marl interlayer and shell limestone. The lower part of Longmaxi shale is organic-rich carbonaceous shale deposited in deep-water shelf or depression on the shelf, and the upper part is deficient organic matter, gray matter, and sandy shale (Figure 2). All organic shale and siliceous shale contain abundant graptolites.

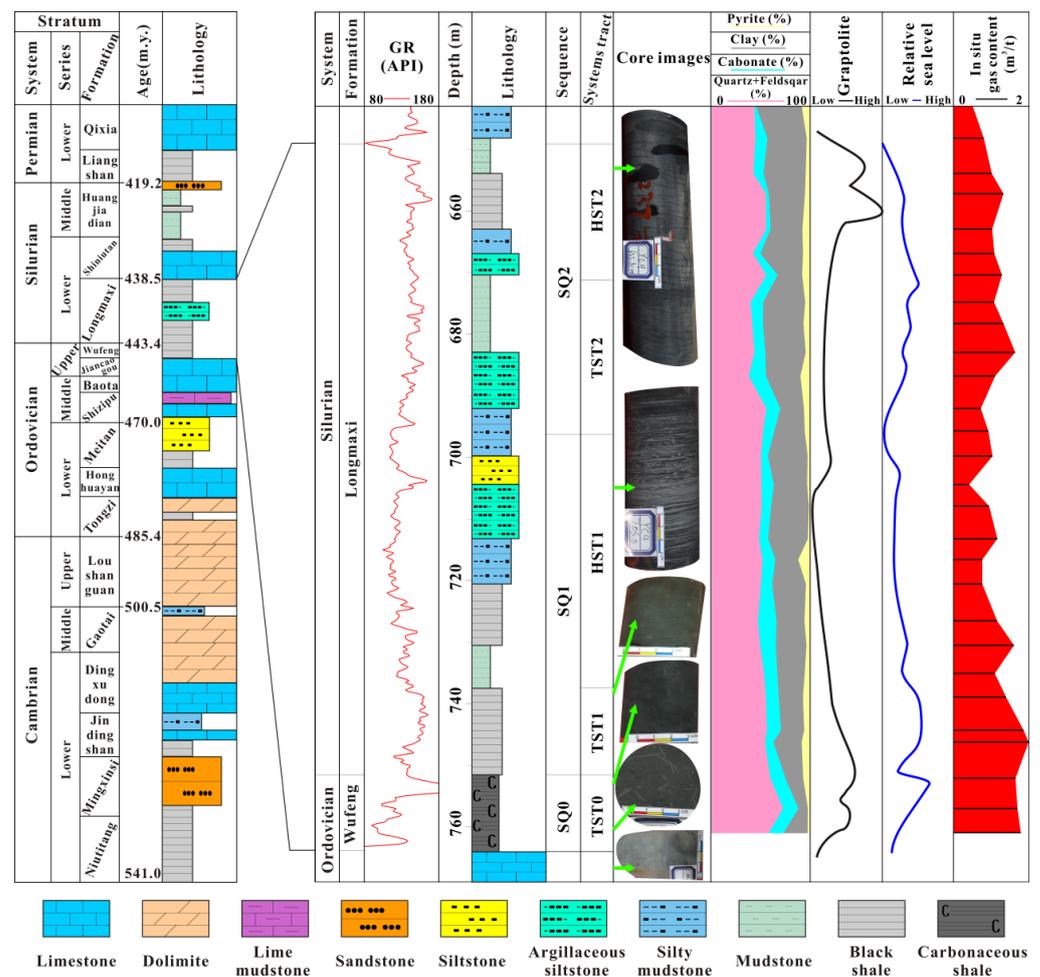
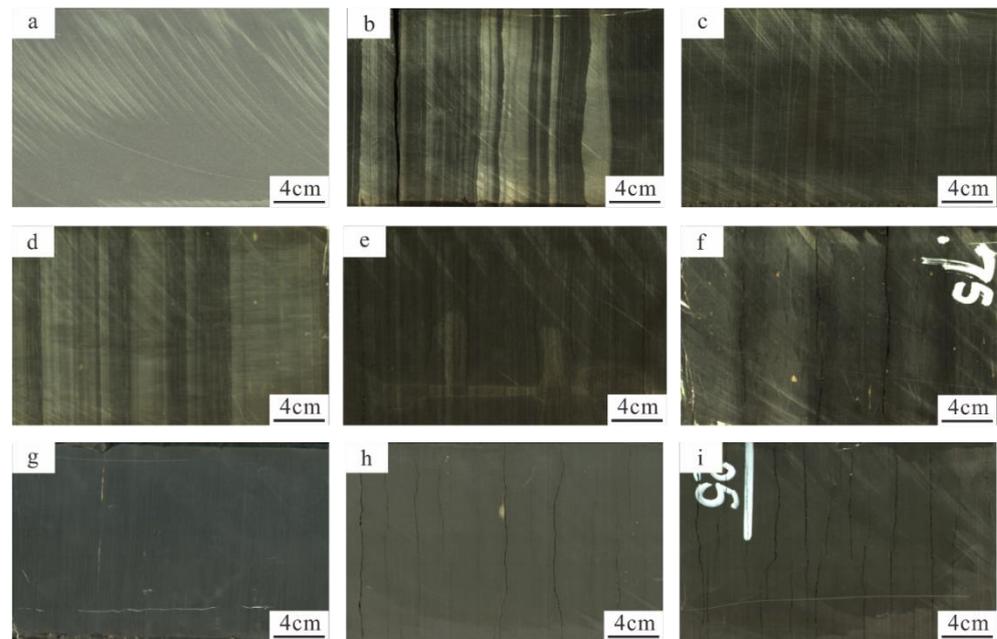


Figure 2. Sedimentary bottom framework of Wufeng–Longmaxi Formation in Sichuan Basin.

### 3.2. Bedding Characteristics

The main types of Longmaxi Formation shale are carbonaceous shale, calcareous shale, and silty shale, which respectively deposited in deep-water, relatively deep-water, and shallow-water environments. The thickness of the strata and the degree of bedding development vary greatly. The thickness of carbonaceous shale varies greatly from 0.1 mm to 10~30 cm. The thickness distribution of silty shale is relatively uniform, generally between 1~30 mm. Calcareous shale is less developed, and its thickness is generally less than 20 mm (Figure 3).



**Figure 3.** Bedding development of shale with different lithology. (a) Grey argillaceous siltstone; (b) Interbedding of grey black carbonaceous shale and grey argillaceous siltstone; (c) Gray black carbonaceous shale; (d) Gray black siliceous shale; (e) Black carbonaceous shale; (f) Gray black carbonaceous shale; (g) Gray black carbonaceous shale; (h) Gray black carbonaceous shale; (i) Gray black carbonaceous shale.

The linear density of bedding (fracture) of shale reservoir varies widely, with at least 127 layers/m (corresponding to 84 bedding fractures/m) and at most 1597 layers/m (corresponding to 480 bedding fractures/m). The quantity of fractures changes frequently. The linear density of bedding of 43 samples fluctuates up and down 14 times with the change of depth. The number of bedding at the bottom of the Wufeng Formation is the largest, and the overall development degree of bedding from the Wufeng Formation to the upper is gradually decreasing (Figure 4). The number of bedding at the bottom of the Wufeng Formation is the most, and the overall development degree of bedding from the Wufeng Formation to the upper is gradually reduced.

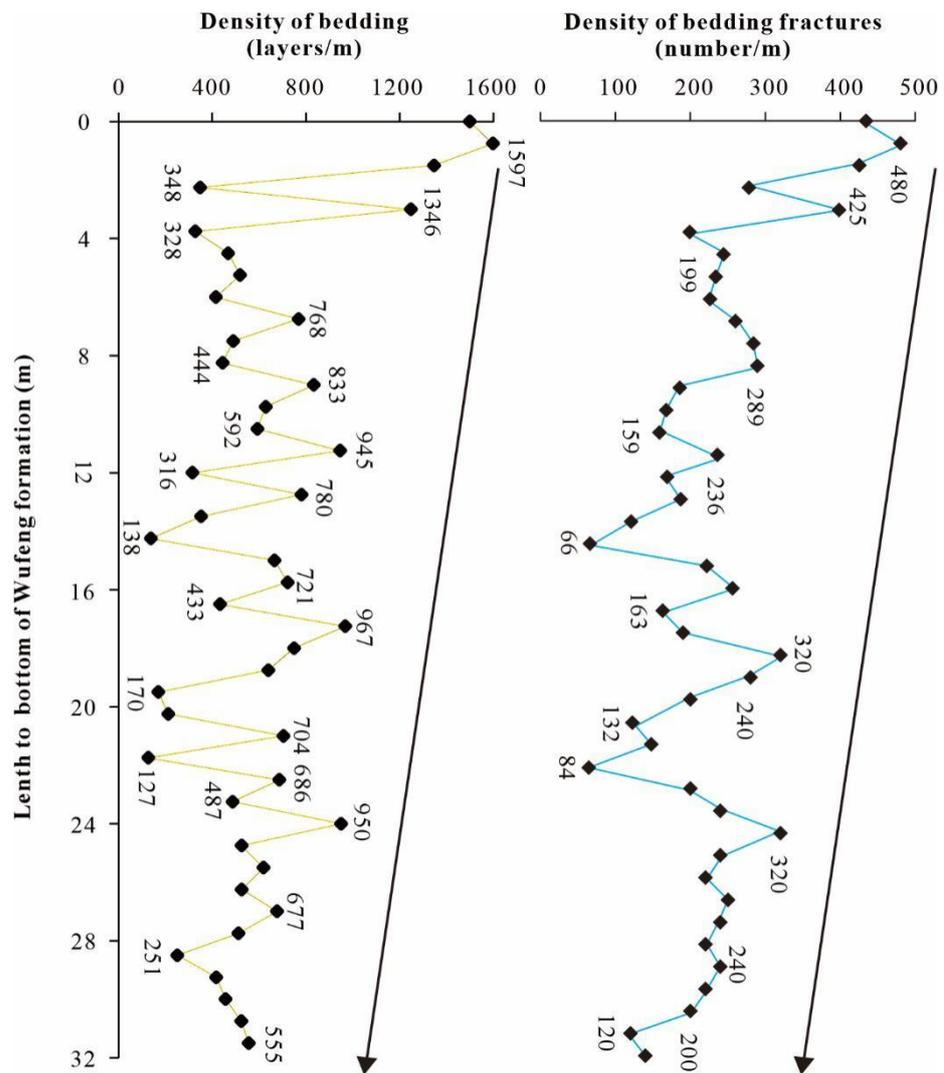
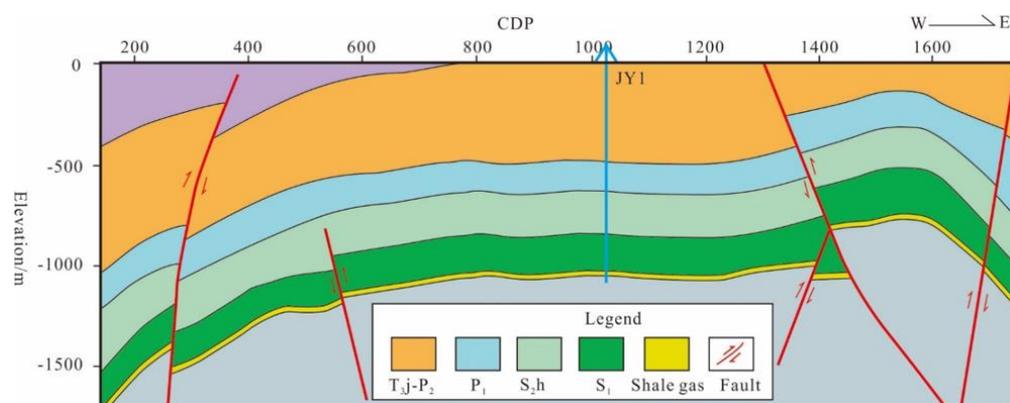


Figure 4. Longitudinal distribution of bedding and fracture density.

### 3.3. Stress Background

The strike of the main large faults in the Fuling gas field is basically in NE, but the faults in the north of Jiaoshiba are obviously biased to the left, and the small NW faults in the west of the internal Wujiang fault and Diaoshuiyan fault were formed in the late stage. It is considered that the NE structure in the study area was formed in the early stage, and was compressed by the NW structure in the late stage to form the NW faults, which transformed the existing NE faults and formed the fault pattern in the current target study area. The study area mainly exists in two groups of northeast and northwest faults, which were formed in the late Yanshan movement and are the result of the East-West compressive stress caused by the subduction of the Pacific plate. The movement of the NE trending fault is larger than that of the NW trending fault. The movement of several large boundary faults is very large, with an extension distance of more than 10 km and a fault displacement of more than 300 m, which penetrated the Cambrian to Triassic strata (Figure 5).



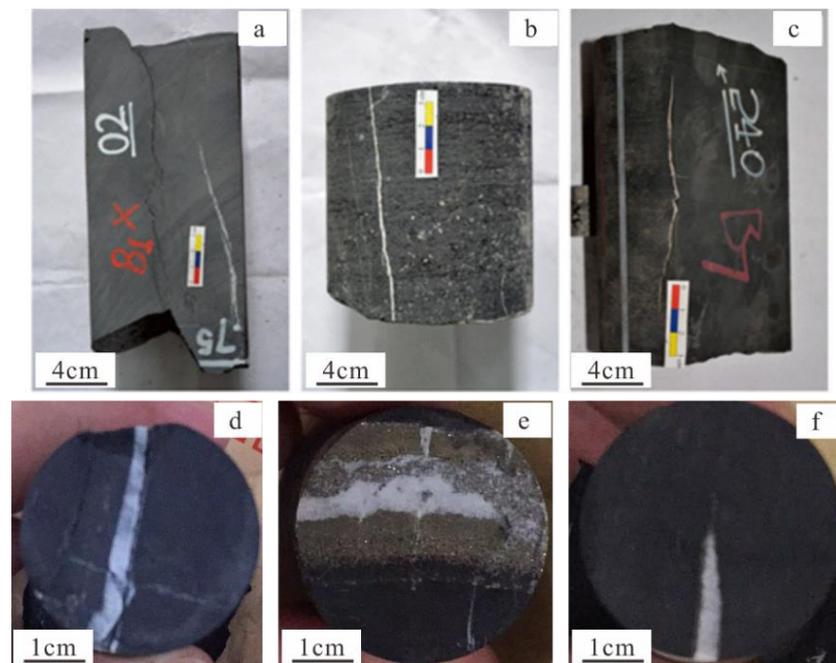
**Figure 5.** Characteristics of EW trending faults in Jiaoshiha block.

The Wufeng–Longmaxi Formation in the Fuling gas field experienced all the tectonic movements since the Caledonian movement. However, according to the analysis of the subsidence history of Well JY1, the whole target strata was in the stage of continuous decline of buried depth before the Hercynian movement, and there was no large tectonic uplift. Until the late Hercynian movement, the target strata in the whole study area began to rise rapidly and transform into the current structural pattern. It is believed that the Yanshan movement played a controlling role in the structure of the target strata in the study area. Further studies have found that Well JY1 experienced three periods of tectonic uplift: Late Yanshanian, late Yanshanian-early Himalayan, and early Himalayan to now. Only the tectonic uplift in late Yanshanian caused strong tectonic deformation in the study area. It is considered that the structural form of the Longmaxi Formation in Wufeng, Fuling District is mainly affected by the early and middle Yanshan tectonic movements. In the early Yanshan movement, the target area was affected by compressive stress, forming a syncline structural form. In the middle Yanshanian period, the target area experienced three deformation stages: basement thrust, cap rock detachment, and left lateral compression and torsion, forming the current anticline structure in the Fuling gas field.

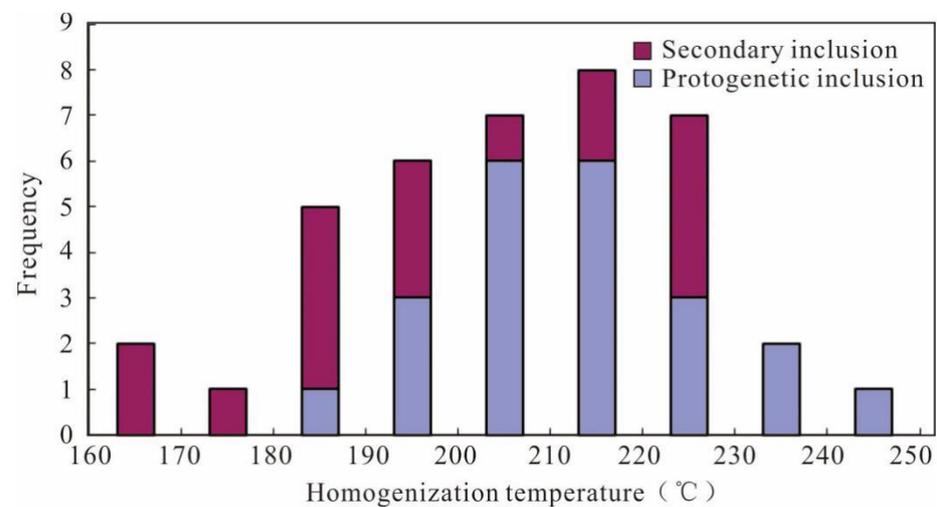
### 3.4. Homogenization Temperature of Fluid Inclusions

Well JY1, JY4, JY5, JY7, JY8, and JY41-5 were selected for fracture inclusion analysis in the Fuling gas field (Figure 6). The results of micro temperature measurement and micro laser Raman spectroscopy show that the types of fluid inclusions captured in the veins are mainly gas-liquid two-phase brine inclusions, single-phase pure methane inclusions, hydrocarbon-containing brine inclusions, asphalt inclusions, etc.

According to the statistics of the homogenization temperature of fracture vein inclusions in six wells of the Fuling gas field, the homogenization temperature of gas-liquid two-phase inclusions in fractured calcite of Wufeng Formation of Well JY1 is distributed at 160–250 °C, concentrated at 160–170 °C and 200–230 °C (Figure 7). The homogenization temperature of calcite inclusions in the Wufeng Formation of Well JY4 is mainly distributed at 150–160 °C and 190–200 °C. The homogenization temperature of quartz inclusions in the upper Longmaxi Formation (2509.3 m) of Well JY41-5 is mainly 210–240 °C. The temperature measured by other wells in the adjacent area is in the range of 110 °C, 140–160 °C, and 180–200 °C, indicating the fluid activity period is more than that in Well JY1, JY4, and JY41-5 areas. Both organic and inorganic genetic mechanisms may generate calcite veins: atmospheric water, primary water, salt water, etc. Gao et al. [12] believed that calcite in the study area formed in a strong water-rock reaction. In the study area, the occurrence of calcite veins has a positive correlation with TOC content in the target interval, and the existence of hydrocarbon inclusions in calcite veins also indicates that calcite veins have a direct relationship with organic matter.



**Figure 6.** Fracture-filled calcite vein shale sample. (a) Longmaxi Formation shale, structural fracture, calcite vein filling; (b) Longmaxi Formation shale, structural fracture, and quartz vein filling; (c) Longmaxi Formation shale, structural fracture, calcite vein filling; (d) Longmaxi Formation shale, calcite vein filling, non-structural fracture; (e) Longmaxi Formation shale, filled with pyrite and calcite veins, non-structural fractures; (f) Longmaxi Formation shale, calcite vein filling, non-structural fracture.



**Figure 7.** Homogenization temperature distribution histogram of fluid inclusions in calcite vein of Well JY1.

#### 4. Discussion

The formation of laminae is due to the periodic or seasonal changes in physical or chemical conditions in a sedimentary environment [13–15]. There is little research on the formation of bedding fractures among beds. From the geological theory, it can be divided into internal and external causes: internal causes mainly include lithofacies and mineral composition characteristics; external factors mainly include regional tectonism, structural location, sedimentary diagenesis, and high abnormal pressure generated during hydrocarbon generation [16–18]. In fact, rock lithofacies and mineral structure are the internal manifestations of sedimentation. From the perspective of sedimentary phenomena,

tectonic background, and hydrocarbon generation evolution process, this paper analyzes the controlling factors for the formation of foliation fractures in the Longmaxi Formation of Sichuan Basin, and puts forward an evolution model of “sedimentary bedding cast foundation, tectonic compression supply space, and hydrocarbon generation process fixation fractures”.

#### 4.1. Sedimentary Bedding Cast Foundation

The change in the sedimentary environment mainly affects the formation of non-structural fractures. For shale reservoirs, the change in the sedimentary environment directly affects the change in lithology. The density of lamina development in shale reservoirs with different lithology varies greatly, which directly determines the number of weak planes of shale reservoirs. It is also the basis for the development of bedding fractures. The bedding in the Longmaxi Formation shale of Jiaoshiba is well developed, which is formed by the interaction of silty, calcareous, and organic carbonaceous mudstone micro-layers, and the bedding thickness is different. Yue et al. [19] through the statistical work on the fracture density on the shale outcrop of the Niutitang Formation, believe that there is a negative correlation between the thickness of the shale reservoir and the fracture density. In addition, the research shows that different sedimentary environments will produce different types of clay minerals, which will have a direct impact on the fractures [20]. Due to the stability of marine sedimentation, the horizontal shale rock type, clay content and bedding development degree in the study area have basically not changed, but the changes in the overall environment of the basin in different periods have resulted in the changes in the bedding thickness, color, and mineral structure of each small layer in the vertical direction. Therefore, it can be inferred that the sedimentary environment is the key factor controlling the degree of bedding development, and the basic characteristics of the large development of organic matter, brittle minerals, and bedding in the Longmaxi Formation shale reservoir have cast a good foundation for the development of bedding fractures (Figure 3).

There is a good positive relationship between the number of cracks and the number of rhythmic segments. The rhythmic sections imply frequent changes in the sedimentary environment; the greater the difference between layers, the easier it is to form bedding contact surfaces with weak mechanical properties (Figure 4).

Through statistical analysis of rock slice and whole rock mineral characteristics of Well JY11-4 and well JY41-5, it is found that small layer 1–9 of the Wufeng–Longmaxi Formation in the Fuling gas field has small horizontal difference and large vertical difference, and the lithological difference is closely related to sea level fluctuation. From the bottom to the top of the study area, comparing layers 4 and 9 with relatively low Young’s modulus and Poisson’s ratio, the 1–3 and 5–8 layers with high Young’s modulus and Poisson’s ratio have high fracture development. This difference has a good correspondence with the change in sea level. Relatively high sea level generally deposits clay rock with high TOC and low brittle minerals, while small layer 1–3 shale has high TOC and brittle minerals, which was controlled by the change of sedimentary environment and diagenetic biogenesis. However, the strength of biogenic silica is consistent with that of all shale, that is, the change in sedimentary environment controls the lithological difference, while the lithological difference controls the difference in TOC and brittle mineral content, resulting in the difference in compressibility and compressive strength of small layers 1–9, which is an important internal factor controlling the development degree of fractures (Figure 8). The development degree of bedding fracture is controlled by the lithology of the shale reservoir. The development degree of micro-fracture in different shale lithology is different and regular. The content of organic matter in the shale reservoir also controls the development degree of shale microfracture. The development degree of microfracture is high in the parts with high content of organic matter.

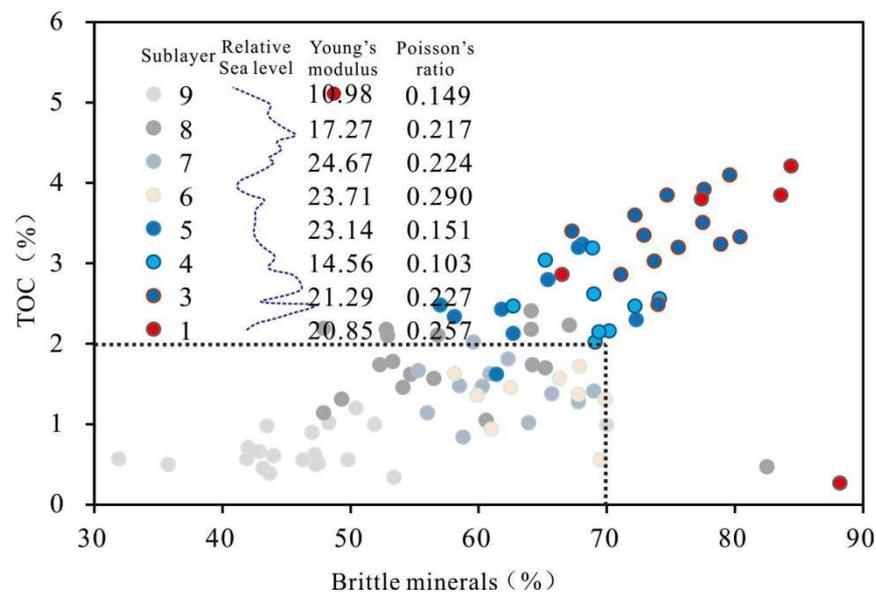


Figure 8. Relationship between TOC, brittle mineral content, and sedimentary environment.

4.2. Structural Extrusion Space

After the hydrocarbon generation peak of the Wufeng–Longmaxi Formation shale, it experienced three major tectonic movements: the Indosinian period, Yanshanian period, and Himalayan period, forming a complex structural style with thrust nappe, strike-slip, and tension multi-stress background. The faults and fractures generated by Indosinian and subsequent structural movements redistribute and readjust oil and gas accumulation. Tectonism is the most important factor affecting fractures, and the types of fractures formed under different tectonic backgrounds are different. It is easy to form low-angle slippage joints, interlayer slippage joints, and interlayer foliation joints under the background of extrusion stress. Tensile cracks are easy to form under the background of tensile stress. In addition to all the above cracks, tensile torsional and compressive torsional cracks can also occur under the strike-slip background [6].

The relationship between structural deformation and cracks was first applied to material mechanics. They believe that materials will be deformed during extrusion, in which cracks will be formed at the bending part of the deformation, and there will be a neutral plane in the middle of the material [21]. This is similar to the anticline, syncline, and fold structures formed by the compression of the strata. Different bending degrees have a direct linear relationship with the development intensity of fractures [22,23]. The thickness, Young’s modulus, Poisson’s ratio, and other parameters of Ordovician Cambrian strata in the Sichuan Basin are collected to calculate the position of the tectonic neutral plane of the strata in this area (Table 1). The results show that the structural neutral plane of the Fuling gas field in the Sichuan Basin is developed in the Cambrian strata at the bottom; that is, the Silurian Longmaxi Formation and Ordovician Wufeng Formation are both located in the upper part of the fold neutral plane, belonging to the compression area, which is easy to form low angle slip fractures, interlayer slip fractures, interlayer foliation fractures, and the changes of structural morphology are directly related to the genesis of fractures.

$$H = \frac{\sum_{i=1}^n \frac{E_i}{1-\mu_i^2} \left| 2h - h_i - 2 \sum_{j=0}^{i-1} h_j \right|}{2 \sum_{i=1}^n \frac{E_i}{1-\mu_i^2} h_i} \tag{1}$$

where,  $h$  is the distance from the neutral surface of the fold to the stratum floor, m;  $H$  is the total thickness of formation, m;  $h_i$  is the thickness of different strata, m;  $E_i$  is Young's modulus of different formations,  $10^4$  pa;  $\mu_i$  is Poisson's ratio of different strata dimensionless.

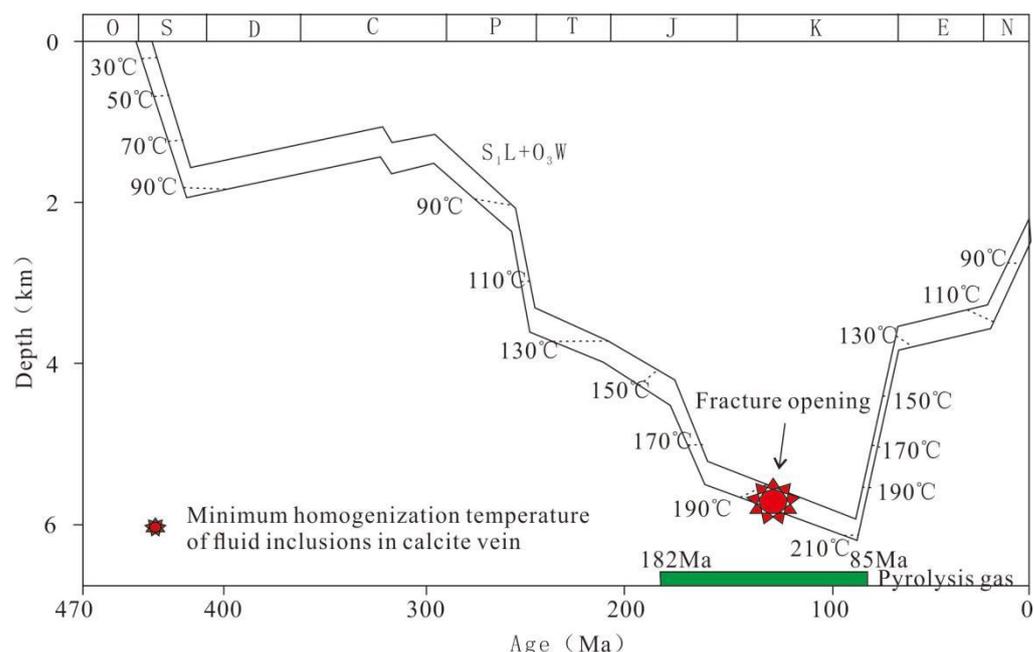
**Table 1.** Statistics of stratigraphic parameters in the southeast edge of Sichuan Basin.

Stratum	Group	Litho	Thickness (m)	Young's Modulus ( $10^4$ Pa)	Poisson's Ratio
Silurian	Hanjiadian	Mudstone	317	3.131	0.23
	Xiaoheba	Siltstone, shale	160	2.658	0.15
	Longmaxi	Shale	488	3.037	0.21
Ordovician	Wufeng	Shale	6	2.449	0.13
	Linxiang	Limestone	20		
	Baota	Limestone	20–25		
	Shizipu	Limestone	20	0.538	0.35
	Dawan	Limestone	50		
	Tongzhi	Dolomite	100	4.522	0.25
Cambrian		Limestone	640	0.538	0.35

#### 4.3. Solid Fracture during Hydrocarbon Generation

The evolution of hydrocarbon and fracture generation in shale reservoirs are well matched in time and space. Immature stage: before the burial depth reaches 1500 m for the first time, 50–60 °C, before the Middle Silurian, which is mainly the stage of organic matter conversion to kerogen and biogenic methane generation with biological activity. This stage is not directly related to the formation of fractures, but the active biological activities and a large number of biological quartz in this stage provide the material basis for the later generation of fractures [24,25]. Plutonic stage: burial depth is gradually from 1500 m to 6000 m, 60–200 °C, Middle Silurian to early Cretaceous, a large amount of organic matter transformed into liquid hydrocarbons, and organic acids precipitated at the same time, resulting in dissolution. After the organic acid is consumed in the later stage, iron calcite and iron dolomite are precipitated to fill the cracks and increase the effectiveness of the fractures [26]. In the middle diagenetic stage, the formation of dissolution pores and fractures by dissolution and the filling of fractures by recrystallization increase the effectiveness of fractures. Metamorphism stage: after the burial depth of 6000 m, after the early Cretaceous, montmorillonite has been completely transformed into illite, hydrocarbon evolution has reached an over-mature stage, and the secondary cracking of oil and asphalt forms dry gas. The formed dry gas forms fluid overpressure, which is conducive to the formation of fractures.

Gao [12,27] et al. believed that through isotope measurement and fluid inclusion analysis, the formation time of calcite vein in the Longmaxi Formation shale reservoir of Well JY1 was  $160 \pm 13$  Ma, and that of the Wufeng Formation was  $133 \pm 15$  Ma. The results of this experiment also have good correspondence. The time for the calcite vein to capture fluid is the same as that of the oil-gas secondary pyrolysis gas stage. The formation time of calcite veins is the same as that of a large amount of secondary pyrolysis gas. The formation of the calcite vein is accompanied by the opening of fractures. It can be seen from the burial history of the reservoir that when the temperature was about 190 °C, the formation was still in the stage of continuous increase with burial depth, and the pressure of the overlying formation was continuously increasing (Figure 9), and the fracture opened at this time, indicating that the opening of the fracture was caused by hydrocarbon generation. This time is 120 Ma earlier than the activity time of the Yanshan movement [28], so it is considered that overpressure is the key factor for fracture opening (Figure 9).



**Figure 9.** Comparison of minimum homogenization temperature and burial history of calcite vein fluid inclusions in Well JY1 (Modified from Gao et al. [12]).

## 5. Conclusions

The sedimentary environment controls the difference in the content of organic matter and brittle minerals in the shale reservoir. The parts with high content of organic matter and brittle minerals in the shale reservoir have a high development degree of microfracture.

According to the principle of material mechanics, the Silurian Longmaxi Formation and Ordovician Wufeng Formation are both located in the middle and lower part of the fold mechanics. Under compressive stress, which are powerful external causes for the formation of shale bedding joints, shale bedding is easy to form low-angle slip joints, interlayer slip joints, and interlayer foliation joints.

The time for the calcite vein to the formation and capture fluid is the same as that of the oil-gas secondary pyrolysis gas stage, which was accompanied by the opening of fractures. The stress analysis of the settlement process infers that the opening of the fracture was caused by hydrocarbon generation.

The formation of bedding fractures is jointly controlled by sedimentation, hydrocarbon generation, and tectonic movement. Sedimentation has formed shale with a complex bedding structure. The tectonic movement has created a stressful environment and space for the bedding fractures and promoted the opening of the bedding fractures. Excess silicon, organic acids, and the oil-gas produced in the hydrocarbon generation process promote and consolidate the bedding fractures.

**Author Contributions:** Conceptualization, Z.H. and S.J.; Methodology, Y.Z.; Project administration, Z.H.; Resources, H.N.; Software, Y.L.; Visualization, H.B.; Writing—review & editing, H.W. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research is sponsored by National Natural Science Foundation of China (No. 41202103, No. 41902127) and China Postdoctoral Science Foundation (No. 2021M703000): Formation mechanism of compressive fracture network constrained by weak surface of shale bedding. Thanks would go to Editor Yong Li, and three anonymous reviewers for their constructive comments and suggestions.

**Acknowledgments:** We thank the Sinopec Exploration Company and the Sinopec Jiangnan Oilfield, for the valuable data and information. We also thank the Sinopec management for permission to publish this work.

**Conflicts of Interest:** The authors declare no conflict of interest.

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