# Study on Stress Sensitivity of Longmaxi Formation Shales in East Sichuan

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**Abstract:** Depletion development is the main way of shale gas reservoir development. The stress sensitivity of shale will have made a great impact on the correct evaluation of shale gas productivity. At the time that the shale gas reservoir in Fuling is on development, the study of stress sensitivity of shale gas reservoir gas formation, Longmaxi formation, will make a great significance to the high efficient development of shale gas reservoir in Fuling even to the shale gas development in our country. This article uses the Longmaxi formation outcrop in east Sichuan and the PDP-200 pulse decay permeameter applied for the evaluation of stress sensitivity of shale permeability. Two different plans, constant confining pressure-decreasing inner pressure test and constant internal pressure-increasing confining test, are adopted to do the permeability experiments of the same core with horizontal bedding. The results show that with the increase of effective stress affected on the shale, the permeability of shale decreases exponentially in tests, and according to decline index that decreasing process is divided into two sections. It respectively embodies the stress sensitivity of shale fracture permeability and shale matrix permeability. At the same time, the tests show permeability hysteresis when compare two tests: constant confining pressure test and constant internal pressure test. And the fracture closing pressure showed in the internal pressure test is lower than the confining pressure test result.

**Keywords:** Longmaxi formation, dual media, stress sensitivity, permeability damage.

## 1. INTRODUCTION

Reservoir stress sensitivity is first proposed according to the permeability damage caused by reducing pressure in the mining development of low permeability reservoir [1-6]. Extensive stress sensitivity experiments of tight sandstone, coal seam and volcanic rocks have been conducted [6-11], including the experiments using man made fracture samples to discover the influence of fracture to the stress sensitivity [12-14, 18]. Resent years, with the greatly exploration of shale gas in China, the stress sensitivity of shale gas has been taken into account. The general understanding is that with the increasing of effective stress, the shale permeability is decreasing exponentially [14-27]. Generally all the research results cannot evaluate the stress sensitivity of shale gas reservoir permeability with natural bedding fracture, especially for the dual media cores, porous-fractured, stress sensitivity researches in Fuling long maxi formation that has been developed for commercial. The single well productivity in Fuling shale reservoir is higher than other shale reservoir of same kind abroad. By comparing the geological conditions of shale reservoir at home and abroad [28], the better developed horizontal bedding fracture of longmaxi formation in Fuling is the main geological factor of high productivity. This paper shows the stress sensitivity evaluation of shale cores with horizontal bedding fracture that sampled in east Sichuan longmaxi formation, by using the PDP-200 pulse decay method permeability instrument of Core Lab.

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## 2. SHALE STRESS SENSITIVITY EXPERIMENTS

By applying the PDP-200 pulse decay method permeability instrument of Core Lab, shale cores that sampled in east Sichuan longmaxi formation have been taken into the stress sensitivity test of shale permeability. By changing the internal pressure and external pressure to have different effective pressure, we can find the variation characteristics of shale permeability.

### 2.1. Characteristic Description of Dual-Media Shale Cores

The experiments used cores are sampled from field outcrop of longmaxi formation in Chongqing shizhu. From Table **1**, we can find that the samples which have significantly horizontal bedding belong to the typical dual media reservoir. So when we evaluate the stress sensitivity, we must chose the standard samples along the horizontal direction because the change of effective stress influenced by fracture permeability and matrix permeability must be different. The basic data officially published in International Conference for Future Petroleum Engineering shows that the shale reservoir permeability is $0.1322\sim0.4991\times10^{-3}\mu m^2$. But the permeability values have great difference with Barnett reservoir and the published shale physical properties papers that magnitude of permeability is about $10^{-3}\times10^{-3}\mu m^2\sim10^{-6}\times10^{-3}\mu m^2$. And the shale reservoir

E-ISSN: 2409-787X/17 

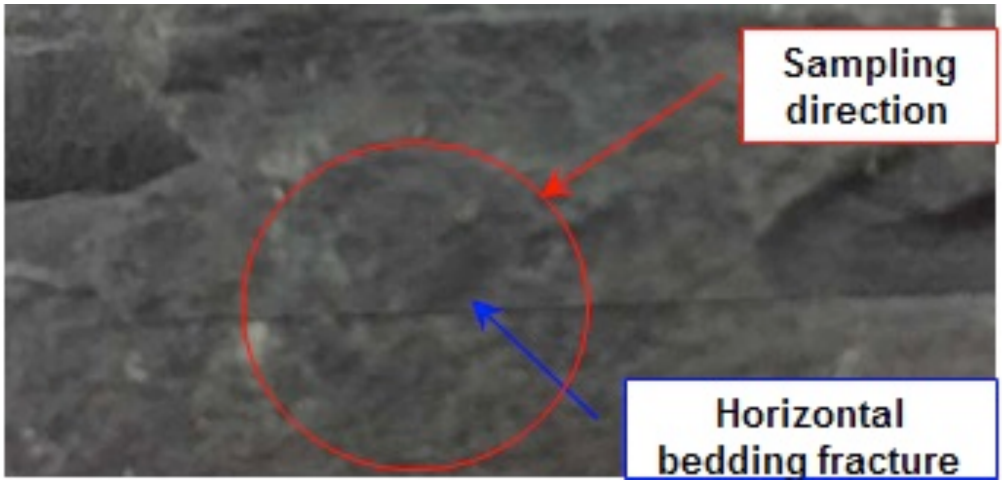


**Figure 1:** The shale outcrop and horizontal bedding of Longmaxi formation in east Sichuan and the sampling direction.

permeability given by the international conference for future Petroleum Engineering may take the shale fracture characteristics into account. According to the production practice, the dual media stress permeability evaluation of shale gas has great significance on the correct evaluation of shale gas productivity.

### 2.2. Experimental Procedures

The test confining pressure can up to 69MPa in PDP-200, but because of the test pressure conducted by booster pump and high pressure gasholder and security consideration, the internal pressure upper limit is 25MPa. There are two test methods: with constant confining pressure, reducing internal pressure and with constant internal pressure, reducing confining pressure. Considering the samples may be not restorative under overburden pressure, it may first keep confining pressure and reduce internal pressure and then keep internal pressure and reduce confining pressure in order to test the change characteristic of shale permeability under different effective pressure. In order to avoid the damage of shale initial permeability from effective stress, the pressure is gradually increased, both the confining pressure and internal pressure. When the confining pressure reaches the test pressure, gradually decrease the internal pressure.

Because of the low success rate of drilling down the shale core with bedding fracture horizontally, this paper use one successful drilling shale cores to do the research. Research plans are shown in Table **1**.

**Table 1: The Plan and Results of Shale Stress Sensitivity Tests with PDP-200**

| Change internal pressure test | | | | Change confining pressure test | | | |
|---|---|---|---|---|---|---|---|
| Confining pressure (MPa) | Internal pressure (MPa) | Effective pressure (MPa) | Permeability ($10^{-3}\mu m^2$) | Confining pressure (MPa) | Internal pressure (MPa) | Effective pressure (MPa) | Permeability ($10^{-3}\mu m^2$) |
| 25.5 | 25 | 0.5 | 0.4845 | 2.8 | 2 | 0.8 | 0.25 |
| 25.5 | 23.45 | 2.05 | 0.2105 | 4.86 | 2 | 2.86 | 0.072 |
| 25.5 | 20.55 | 4.95 | 0.0425 | 7.85 | 2 | 5.85 | 0.016 |
| 25.5 | 17.8 | 7.7 | 0.0089 | 9.65 | 2 | 7.65 | 0.0062 |
| 25.5 | 15.54 | 9.96 | 0.0029 | 12.56 | 2 | 10.56 | 0.0011 |
| 25.5 | 12.62 | 12.88 | 0.00052 | 14.87 | 2 | 12.87 | 0.00038 |
| 25.5 | 10.94 | 14.56 | 0.00021 | 15.76 | 2 | 13.76 | 0.00023 |
| 25.5 | 8.53 | 16.97 | 0.000135 | 19.64 | 2 | 17.64 | 0.000108 |
| 25.5 | 6.26 | 19.24 | 0.000114 | 21.86 | 2 | 19.86 | 0.000098 |
| 25.5 | 4.32 | 21.18 | 0.000101 | 23.68 | 2 | 21.68 | 0.000091 |
| 25.5 | 2.26 | 23.24 | 0.000088 | 25.26 | 2 | 23.26 | 0.000082 |

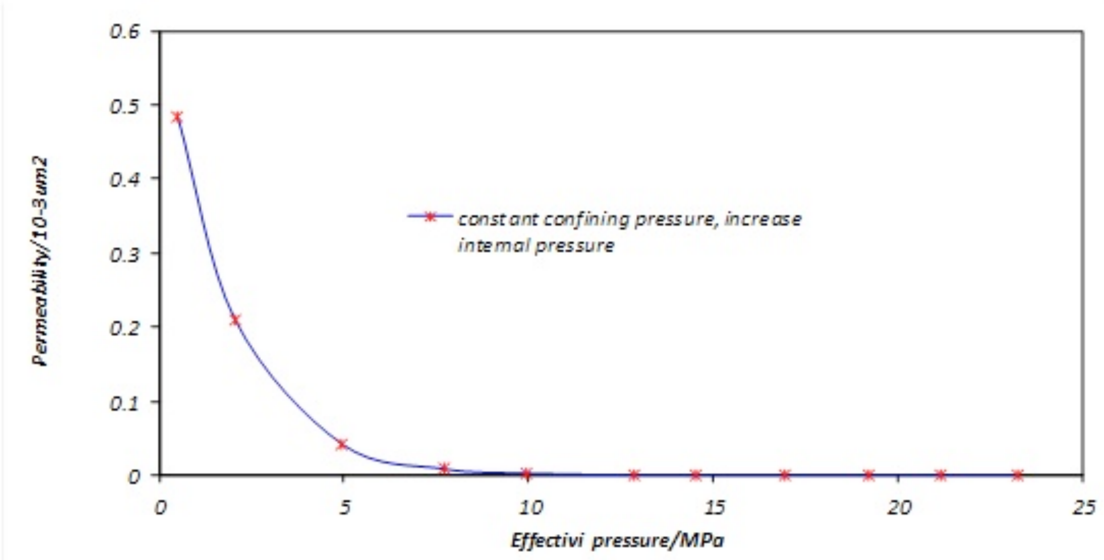


**Figure 2:** The shale permeability curves under constant confining pressure

## 3. RESULTS AND DISCUSSION

### 3.1. Shale Stress Sensitivity under Constant Confining Pressure

First adjust confining pressure to 25.5MPa and internal pressure to 25Mpa of core holder before measuring the initial core permeability. Then decrease the internal pressure in order to increase effective pressure, and measuring the permeability under different effective pressure. The result is shown in Table **1** and Figure **2**. From the results we can know that the initial permeability is $0.4845\times10^{-3}\mu m^2$ which is close to the data given by the conference. After increasing effective pressure, the permeability decrease rapidly and then tend to be stable. The permeability is about $10^{-3}\times10^{-3}\mu m^2$~$10^{-6}\times10^{-3}\mu m^2$ which is consistent to the data of Barnett reservoir and the papers published. The results illustrate that the shale with horizontal bedding has dual–medium characteristic.

On the other hand, the result shows the exponential relationship between permeability and effective stress. Because the change of ultra-low permeability under high effective pressure can hardly be recognized, so change the normal coordinate to semilog coordinate. From Figure **3**, it's obvious to observe linear decrease of core permeability, also be two-segment. Permeability

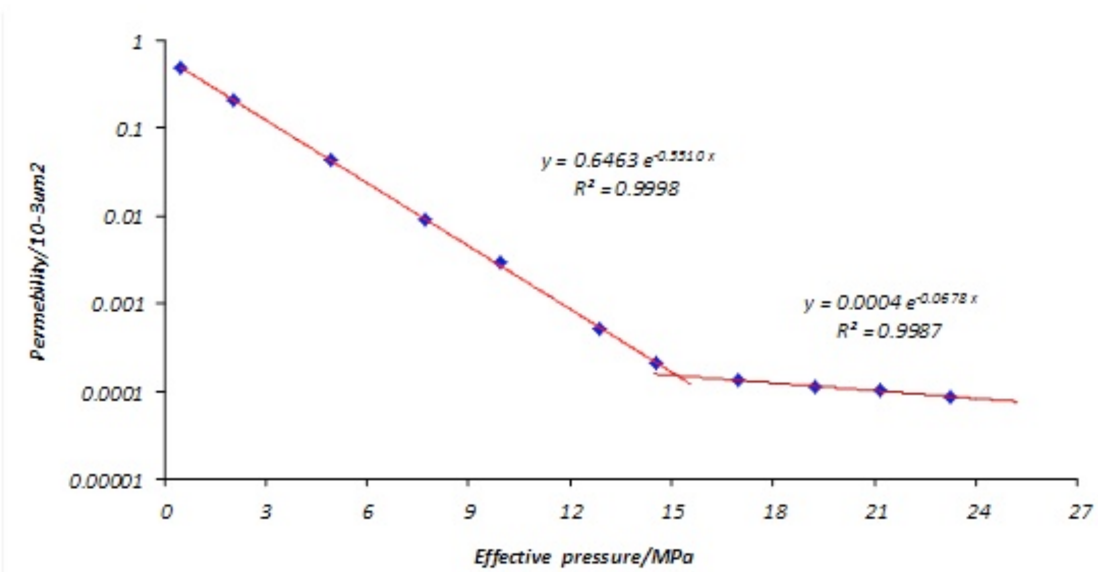


**Figure 3:** The shale permeability curves under constant confining pressure on semilog coordinate.

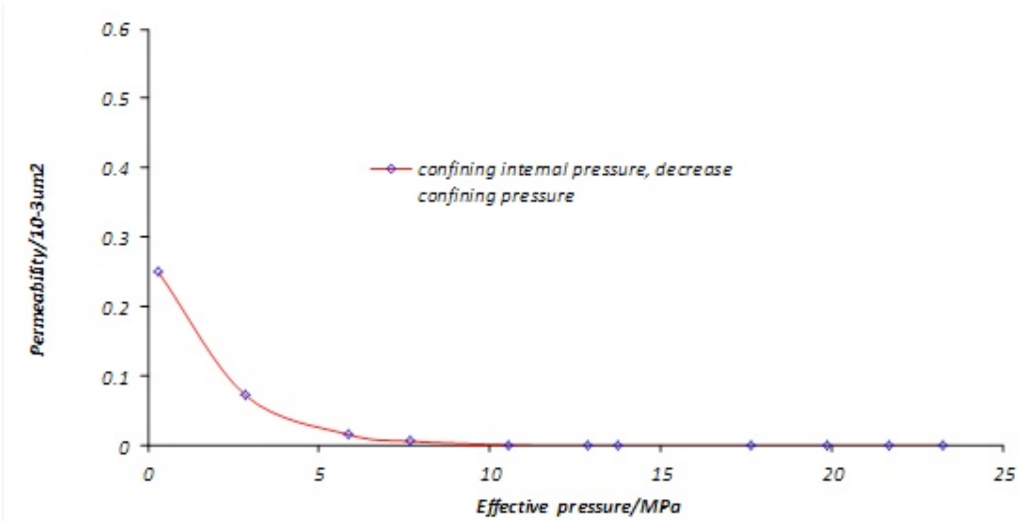


**Figure 4:** The shale permeability curves under constant internal pressure.

reduction speed is relativity higher when effective stress is relativity low. Otherwise, permeability reduction speed is relativity lower when effective stress is high. The demarcation point of two types changing is when the effective stress is about 15.5MPa. From the exponential trend line we can learn the good exponential relationship between permeability and effective stress before and after 15.5MPa. The difference is the different decline index which is 0.551 before 15.5MPa and 0.0678 after 15.5MPa. The results show the dual-medium characteristic of shale core with horizontal bedding. Under low effective stress, the decrease of permeability shows the characteristics of the fracture permeability. However, under high effective stress, the decrease of permeability shows the characteristics of the matrix permeability.

### 3.2. Shale Stress Sensitivity under Constant Internal Pressure

After the above experiment, adjust confining pressure to 2.8MPa and internal pressure to 2Mpa of core holder before measure the initial core permeability. Then increase the confining pressure in order to increase effective pressure, and test the permeability under different effective pressure. The result is shown in Table **1** and Figure **4**. From the results we can know that the initial permeability is $0.25 \times 10^{-3} \mu m^2$ which is close to the result from the above test. After increasing effective pressure, the permeability decrease rapidly and then tend to be stable. The permeability is about $10^{-3} \times 10^{-3} \mu m^2 \sim 10^{-6} \times 10^{-3} \mu m^2$.

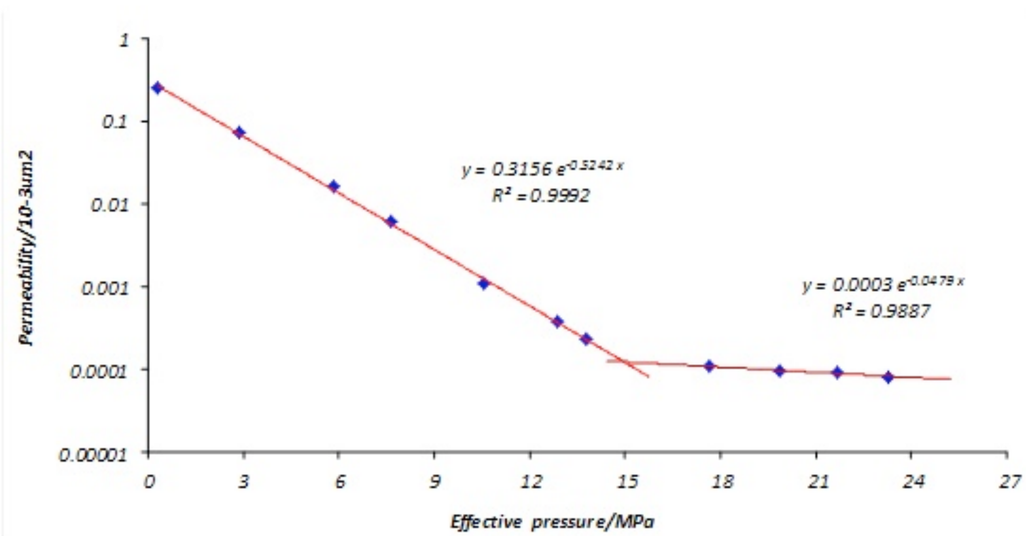


**Figure 5:** The shale permeability curves under constant internal pressure on semilog coordinate.

On the other hand, the results show the exponential relationship between permeability and effective stress. Change the normal coordinate to semi log coordinate. From Figure **5**, it's obvious to observe linear relationship between core permeability and effective stress, also be two-segment. Permeability reduction speed is relativity higher when effective stress is relativity low. Otherwise, permeability reduction speed is relativity lower when effective stress is high. The demarcation point of two types changing is when the effective stress is about 15.0MPa. From the exponential trend line we can learn the good exponential relationship between permeability and effective stress before and after 15.0MPa. The difference is the different decline index, which is 0.5242 before 15.0MPa and 0.0479 after 15.0MPa. The result shows obvious difference between two decline index and the dual-medium characteristic of shale core with horizontal bedding. But the decline index and the demarcation point of effective stress is changing from above test.

### 3.3. The Comparison and Discussion between Two Experiments

From Table **1**, Figures **6** and **7**, the data shows the difference between the results of constant confining pressure and constant pressure experiments. The permeability of constant confining pressure experiment

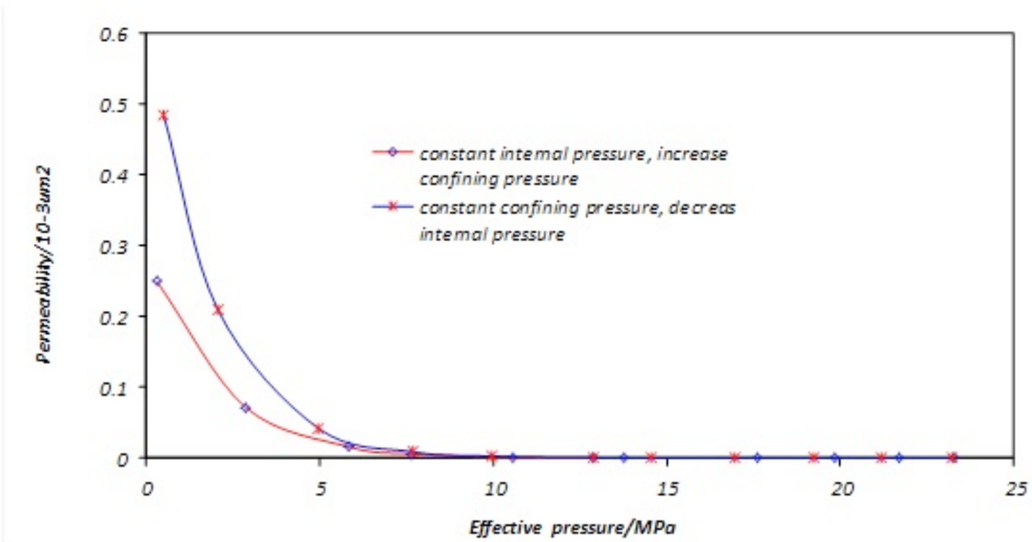


**Figure 6:** The comparison between the permeability curves under constant confining pressure and constant internal pressure.

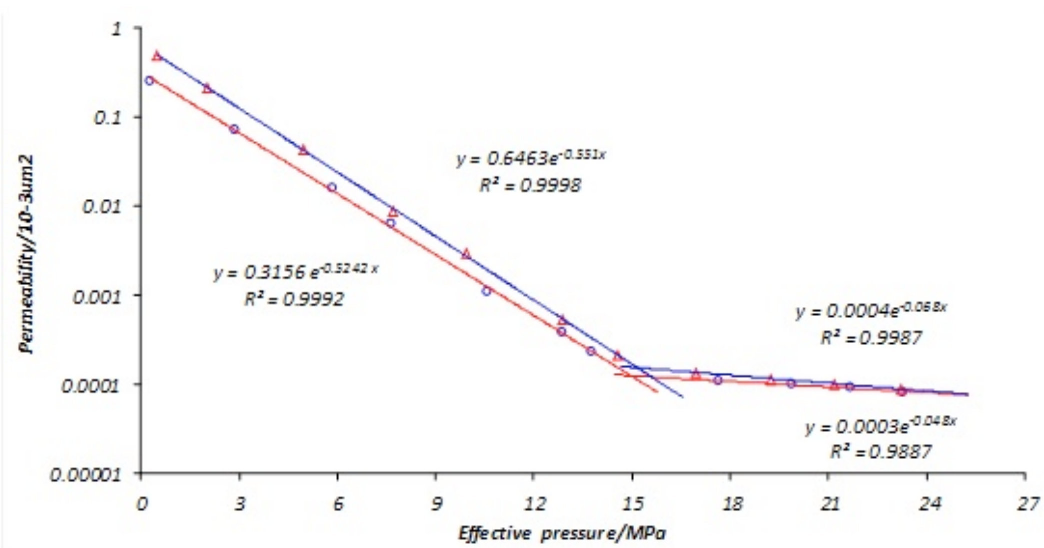


**Figure 7:** The comparison between the permeability curves under constant confining pressure and constant internal pressure on semi log coordinate.

is larger than constant internal pressure experiment, especially obvious in low effective stress. From Figure **7** we can know that the demarcation point of effective stress is changing in different experiments.

Both confining pressure and internal pressure is adjusted to designated value at first when there is no stress damage to shale permeability in constant confining pressure test. The effective pressure starts to increase after decreasing internal pressure. Shale cores can keep elastic deformation within certain limits. But after the effective pressure continually increase, especially after crack closing, shale cores start to have irreversible plastic deformation until increasing to the maximum pressure. These experiments can really reflect the changing law of shale permeability.

The constant internal pressure experiment is proceeding on the basic of the constant confining pressure experiment. After unloading the internal pressure to designated value, irreversible plastic deformation generated in constant confining pressure experiment can't be recovered. So the shale permeability measured in the constant internal pressure test is decreased, and it shows the permeability hysteresis. On the other hand, because of the irreversible plastic deformation caused in previous experiment, the pressure which may lead to crack closing should be decreased. In Figure **7**, it shows the demarcation point of effective stress decreases in constant internal pressure test compared to the constant confining pressure test.

## CONCLUSION

Stress sensitivity experiments of shale outcrop cores taken in east Sichuan longmaxi formation are promoted by using applying PDP-200 pulse decay method permeability instrument. After two experiments, increasing internal pressure and decreasing confining pressure to increase effective pressure, the conclusion is shown as follow:

(1) No matter controlling confining pressure or internal pressure, shale permeability decrease exponentially with the increasing effective pressure. Meanwhile, shale permeability has the decline law with two different decline rates. In lower effective stress, permeability is larger and shows the horizontal bedding permeability characteristic of shale. In higher effective stress, permeability is smaller and shows the matrix permeability characteristic of shale.

(2) Compared to the constant confining pressure experiment, constant internal pressure experiment shows permeability hysteresis phenomenon. And the closing crack pressure is lower than constant confining pressure experiment. It shows the unrecovered damage of permeability when decreasing internal pressure.

The shortage of this paper is that we use the core sampled in outcrop of longmaxi formation, even if it's the same formation to the gas production formation in fuling shale reservoir. It's not the core sampled in production formation. The results may have some deviation from the fact, such as the closing-crack pressure.

## STUDY SUPPORT

This study was supported by the Sichuan East horse Creek formation shale gas accumulation mechanism and its main controlling factors from the National Natural Science Foundation of China (No. 41472122).

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Received on 18-11-2016 Accepted on 06-03-2017 Published on 08-06-2017

DOI: http://dx.doi.org/10.15377/2409-787X.2017.04.01.2