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Short communication

# Anisotropy characteristics of element composition in Upper Triassic "Chang 8" shale in Jiyuan district of Ordos Basin, China: Microscopic evidence for the existence of predominant fracture zone

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ABSTRACT

This study quantified the anisotropy of element composition in Upper Triassic "Chang 8" shale in Jiyuan district of Ordos Basin, China and provided the microscopic evidence for the existence of dominant fracture zone.

Element quantification was carried out ensuring both observational resolution and sample representativeness. Results show that for shale slices in two directions which are 45° (225°) and 0° (180°/360°), the distribution of elements is significantly different from that in other directions. The minimum of element contents often occurs in 45° (225°) and the maximum of element contents often occurs in 0° (180°/360°). The brittleness parameter value stays at a high level from 0° (180°/360°) to 22.5° (202.5°). The maximum value occurs in 0° (180°/360°), and the minimum value occurs in 45° (225°) which has obvious significance in shale stimulation.

The conclusion proved that the existence of predominant fracture zone in shale has the microscopic evidence in micro-scale brittle minerals.

## 1. Introduction

The physical and chemical fields of unconventional reservoirs are generally stable during the whole geological history from formation to diagenetic transformation. However, since human beings began to involve in reservoir development, especially secondary and tertiary oil recovery, underground physical and chemical fields have been disturbed to varying degrees in a short period of time, which can be found from many years of field practice. Due to the injection of external fluids, the production of internal fluids and the filling of proppants, the natural reservoirs gradually change to "artificial reservoirs" [1–5].

With the development, taking an infinitesimal unit as the research object, the stress state of underground rock will undergo unsteady changes at all times, which will mainly cause two kinds of secondary fractures: hydraulic fractures and dynamic fractures in the development process. Among them, hydraulic fractures are mainly caused by external forces which break the rock matrix and form cracks, which is the most important to form effective diversion. Dynamic fracture is formed in the normal development process with the instability of reservoir stress state, instead of directly intervening by external force. By analogy with the influence of structural fracture on hydrocarbon accumulation, the influence of dynamic fracture on reservoir development should also be viewed dialectically. On the one hand, the formation of dynamic fracture communicates with the rock matrix, which enhances the conductivity to a certain extent, and may have a positive impact on the productivity; on the other hand, the generation of dynamic fracture may make the communication between oil wells and water wells, forming flooding, water channeling, and ultimately leading to water injection failure (Zou et al., 2015; Huang et al.,2017 and 2019; Shen et al., 2017 and 2019) [6–12].

In fact, based on the assumption of continuum medium, for an infinitesimal unit, skeleton minerals or fillings are composed of a variety of single minerals or their mixtures at the mesoscopic scale [13–17]. The mechanical properties of this combination will be strictly

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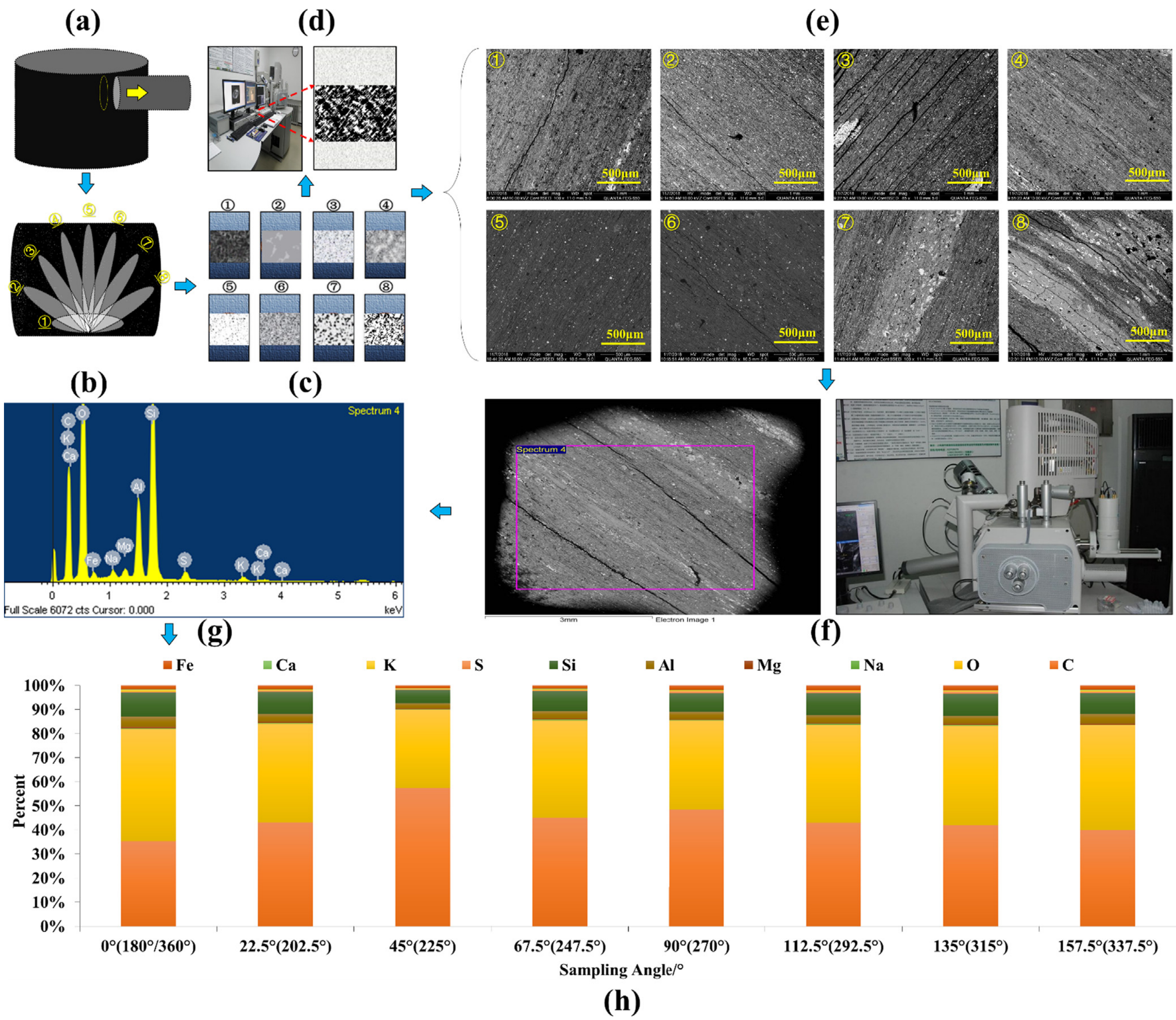


**Fig. 1.** Technical process of anisotropy characterization on element composition (Modified from Du et al. [18,19]).

controlled by factors such as mineral arrangement, mineral species and mineral content, and the properties of the unit cannot be fully expressed without the use of unified mechanical attribute values.

Therefore, for shale, finding the micro-evidence of dominant fracture rupture should be based on minerals. However, this part of the research work is still very little, and we need to explore it urgently.

## 2. Materials and methods

Du et al proposed the "Umbrella Deconstruction" method in 2018 to characterize pore-mineral heterogeneity of unconventional reservoirs in large scale, which reduced the contradiction between observation resolution and scale to a certain extent [18,19]. The technical process is shown in Fig. 1. Using this, we characterized the anisotropic element components of the unconventional hydrocarbon reservoir effectively and flexibly.

First, sampling from the full diameter core of shale (Fig. 1a).
Second, cutting the core column of shale every 22.5°according to the labels (Fig. 1b).
Third, making eight thin sections cutting from eight angles (Fig. 1c).
Fourth, carrying out the FE-SEM characterization (Fig. 1d, e).
Fifth, carrying out EDS determination to analyze the element distribution of eight thin sections cutting from eight angles. Seventh, drawing the figure of the element change with angels (Fig. 1f, g).
Finally, quantifying the microscopic anisotropy of shale (Fig. 1h).

## 3. Application

### 3.1. EDS determination

Direct quantification of anisotropic distribution of element in shale from Upper Triassic "Chang 8" shale in Jiyuan district of Ordos Basin, China was carried out. The initial determination results and the statistics of the element in each angel were shown in Figs. 2–4. We also carried out the content ranks statistics of elements in eight sections and the result could be shown in Table 1. The purpose of this ranking is to clearly show the changing characteristics of each element in each direction, so that we can quickly judge its engineering significance.

The sample size of the element testing can reach 5 mm multiple 5 mm, which is much larger than which of X-ray diffraction, which can accurately measure the sample size (about 40 μm), and its observation resolution can reach micron level, which can fully meet the recognition accuracy of mineral particles.

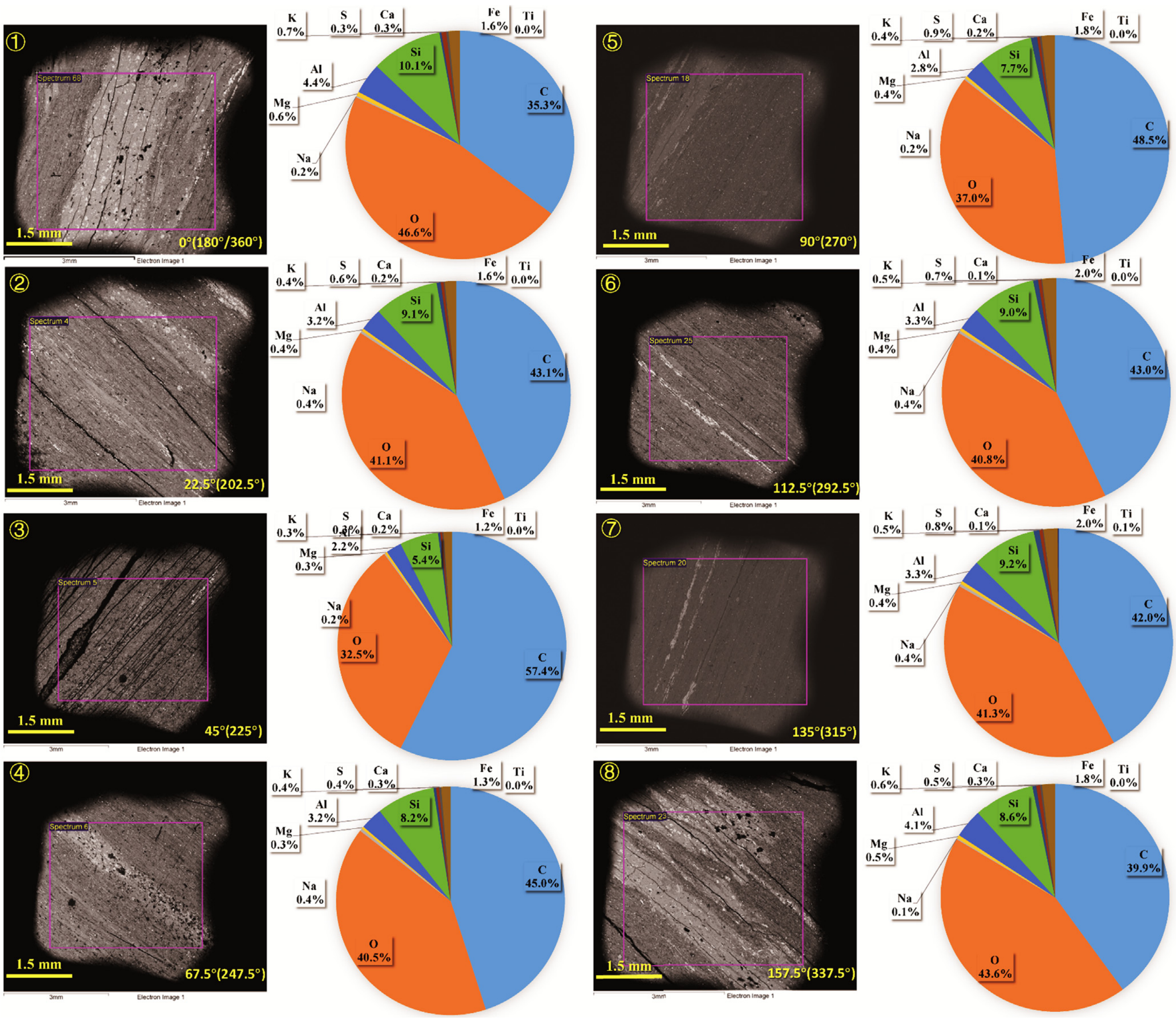


**Fig. 2.** Determination of anisotropic distribution of element in shale from the Triassic Yanchang formation in the Jiyuan district, Ordos Basin China.

At the same time, we can clearly see a very interesting phenomenon (Figs. 2–4 and Table 1). For slices in 45° (225°) and 0° (180°/360°), the distribution of elements is significantly different from that in other directions. The minimum of element contents often occur in 45° (225°) and the maximum of element contents often occur in 0° (180°/360°). The phenomenon is obvious enough to attract our attention.

Among them, for the shale slice in 45° (225°), the content of six elements including oxygen, magnesium, aluminum, silicon, potassium, iron is the lowest. On the contrary, for 0° (180°/360°), the contents of five elements including oxygen, magnesium, aluminum, silicon and potassium are the highest. It seems that there is an internal mechanism that needs to be further explored.

As to the four elements consists of oxygen (O), silicon (Si), aluminum (Al), and potassium (K), they are all the most important elements of potassium feldspar. The contents of above four elements in the 0° (180°/360°) is about 1.4 times, 1.8 times, 2 times, 2.5 times that in 45° (225°) respectively, mainly due to the content difference of K-feldspar containing those four elements between these two directions. As the feldspar is belong to the brittle minerals, so it is also a noteworthy micro-evidence for shale stimulation.

As to the element of magnesium (Mg), as we see the clay mineral content is relatively low in the sample, it is the main element of the mineral represented by dolomite in this sample. Magnesium content in the 0° (180°/360°) is about 2 times that in45° (225°), mainly due to the content difference of dolomite containing magnesium between these two directions. This is also a noteworthy micro-evidence for shale stimulation.

As to the element of iron (Fe), it is the main element of pyrite and typical clay minerals such as chlorite. It has the lowest content in 45° (225°) mainly due to the low content of typical clay minerals such as chlorite in the this direction.

### *3.2. The scientific and practical significance of element anisotropy*

As we know, as the content of silica and calcareous represents the level of brittle minerals, the relative content of silica and calcareous minerals is generally regarded as an important basis for quantitative evaluation and comparison of shale fracturability in academic circles when studying shale fracturability [20,21]. Therefore, the relative content of silicon and calcium in each direction was added together as a quantitative evaluation parameter of brittleness degree, and the trend of this parameter with the direction of “umbrella section” was also drawn (Fig. 5).

The direction with large parameter values represents the direction

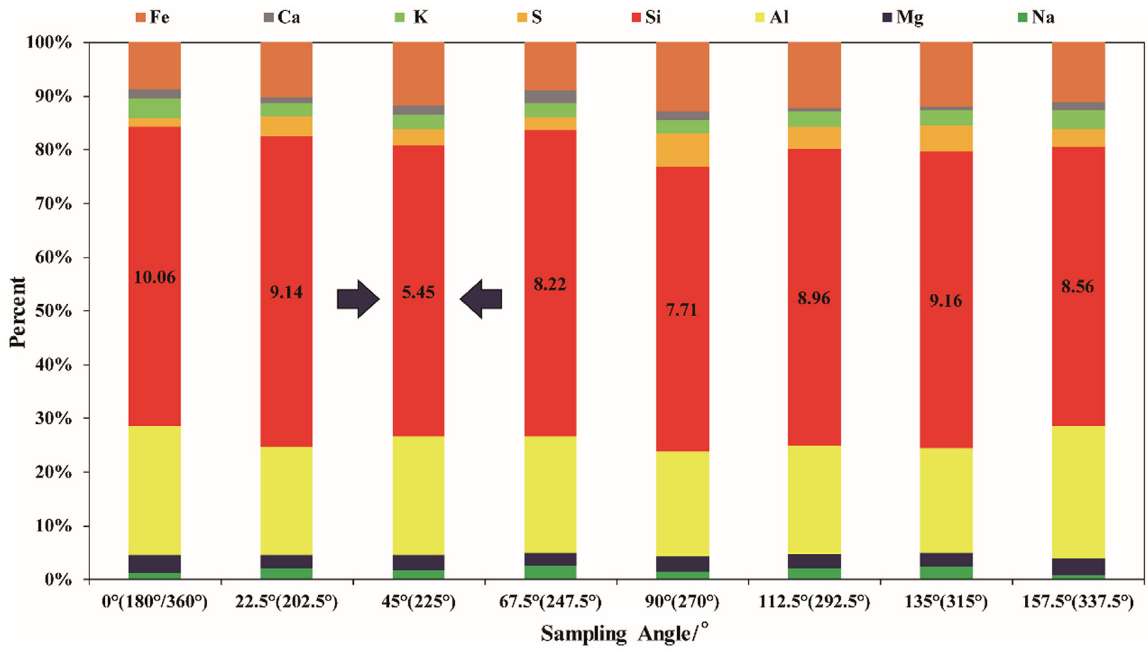


**Fig. 3.** Statistics of the anisotropic distribution of elements in shale from the Triassic Yanchang formation in the Jiyuan district (except for "C" and "O").

of strong brittleness, and is also the dominant direction of fracture in the process of fracturing, while the other direction is weak brittleness or non-brittleness. From Fig. 5, we can see that the parameter value stays at a high level from 0° (180°/360°) to 22.5° (202.5°). The maximum value occurs in 0° (180°/360°), and the minimum value occurs in 45° (225°).

## 4. Conclusion

For the Upper Triassic "Chang 8" shale in Jiyuan district of Ordos Basin, the predominant fracture direction of shale reservoir is an area, in which the best predominant fracture direction can be found, not only along a single direction. It coincides with the phenomenon that the macroscopic distribution of structural fault zone extends along a certain range, and the formation of predominant fracture would also extends in a certain angle range during the fracturing process.

Further research is needed to solve the contradiction between observation resolution and sample representativeness.

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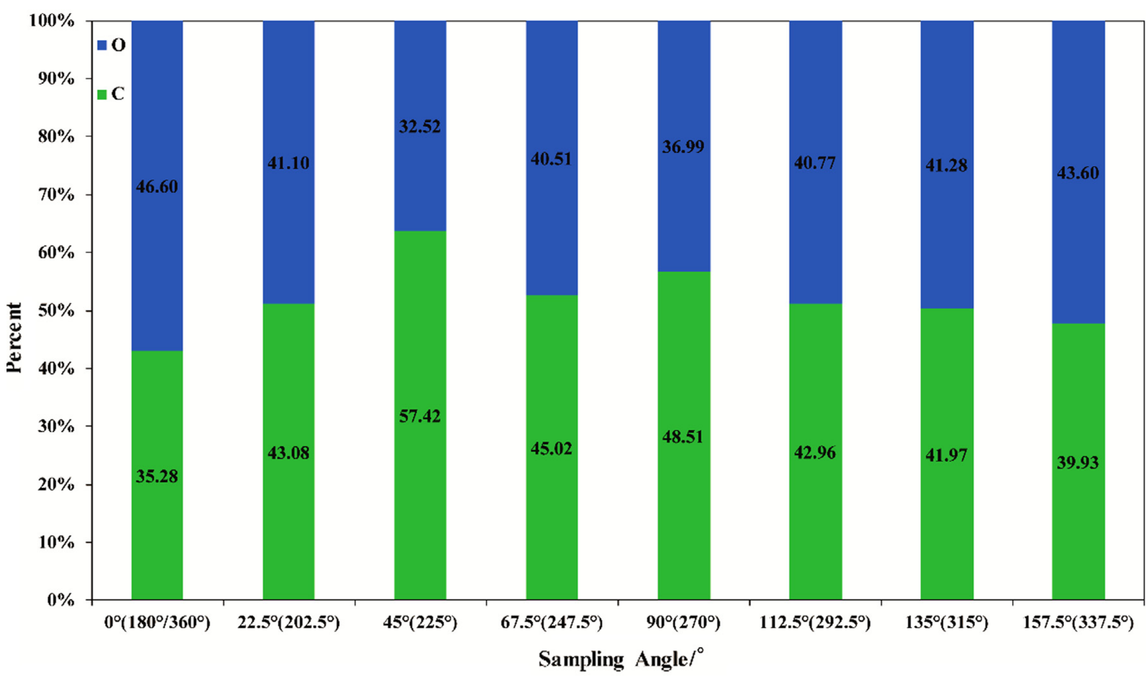


**Fig. 4.** Statistics of the anisotropic distribution of "C" and "O" in shale from the Triassic Yanchang formation in the Jiyuan district.

**Table 1**
Content ranks statistics of elements in eight sections (The color of red indicates the section with the angle of 0° (180°/360°) and the color of green indicates the section with the angle of 45° (225°)).

| Content Ranks | C | O | Na | Mg | Al | Si | S | K | Ca | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 45° (225°) | 0° (180°/360°) | 135° (315°) | 0° (180°/360°) | 0° (180°/360°) | 0° (180°/360°) | 90° (270°) | 0° (180°/360°) | 67.5° (247.5°) | 135° (315°) |
| 2 | 90° (270°) | 157.5° (337.5°) | 67.5° (247.5°) | 157.5° (337.5°) | 157.5° (337.5°) | 135° (315°) | 135° (315°) | 157.5° (337.5°) | 0° (180°/360°) | 112.5° (292.5°) |
| 3 | 67.5° (247.5°) | 135° (315°) | 112.5° (292.5°) | 135° (315°) | 112.5° (292.5°) | 22.5° (202.5°) | 112.5° (292.5°) | 135° (315°) | 157.5° (337.5°) | 90° (270°) |
| 4 | 22.5° (202.5°) | 22.5° (202.5°) | 22.5° (202.5°) | 112.5° (292.5°) | 135° (315°) | 112.5° (292.5°) | 22.5° (202.5°) | 112.5° (292.5°) | 90° (270°) | 157.5° (337.5°) |
| 5 | 112.5° (292.5°) | 112.5° (292.5°) | 90° (270°) | 90° (270°) | 22.5° (202.5°) | 157.5° (337.5°) | 157.5° (337.5°) | 22.5° (202.5°) | 45° (225°) | 22.5° (202.5°) |
| 6 | 135° (315°) | 67.5° (247.5°) | 0° (180°/360°) | 22.5° (202.5°) | 67.5° (247.5°) | 67.5° (247.5°) | 67.5° (247.5°) | 67.5° (247.5°) | 22.5° (202.5°) | 0° (180°/360°) |
| 7 | 157.5° (337.5°) | 90° (270°) | 45° (225°) | 67.5° (247.5°) | 90° (270°) | 90° (270°) | 45° (225°) | 90° (270°) | 112.5° (292.5°) | 67.5° (247.5°) |
| 8 | 0° (180°/360°) | 45° (225°) | 157.5° (337.5°) | 45° (225°) | 45° (225°) | 45° (225°) | 0° (180°/360°) | 45° (225°) | 135° (315°) | 45° (225°) |

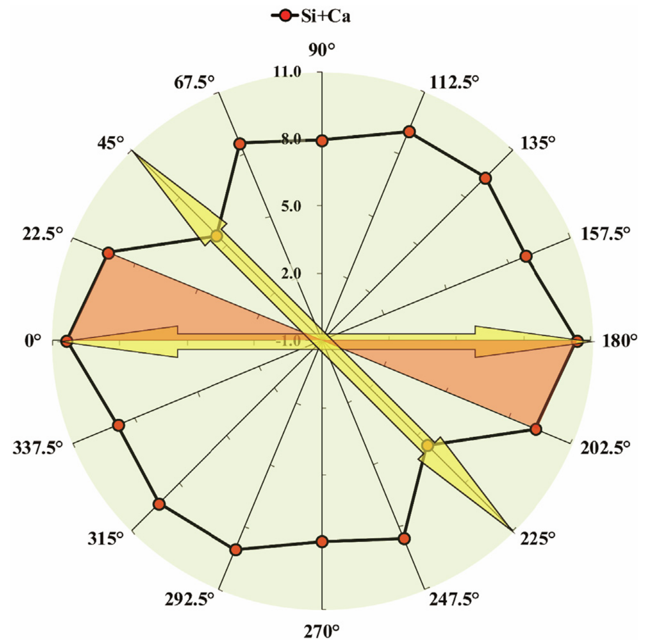


**Fig. 5.** Microscopic identification results of strong brittle zone distribution (fracturing dominant fracture zone). (The angle in the figure is determined by the angle of the umbrella slice.)

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fuel.2019.05.031.

## References


[1] Soeder DJ. The successful development of gas and oil resources from shales in North America. J Petrol Sci Eng 2018;163:399–420.
[2] Hughes JD. Energy: a reality check on the shale revolution. Nature 2013;494(7437):307–8.
[3] Adam Wilson. Economics and technology drive development of unconventional oil and gas reservoirs. J Petrol Technol 2012;64:104–7.
[4] John S, Jeff D, Susana GC, Glenn C, Eric S, Dan B. A completion staging case study in the Barnett Shale using advanced LWD quadrapole sonic and borehole imaging. J Nat Gas Sci Eng 2016;33:1190–200.
[5] Melikoglu M. Shale gas: analysis of its role in the global energy market. Renewable Sustainable Energy Rev 2014;37:460–8.
[6] Zou CN, Yang Z, Zhu RK, Zhang GS, Hou LH, Wu ST, et al. Progress in China's unconventional oil & gas exploration and development and theoretical technologies. J Geol 2015;6:979–1007.
[7] Shen WH, Zhao YP. Quasi-static crack growth under symmetrical loads in hydraulic fracturing. J Appl Mech-T ASME 2017;84(8):081009.
[8] Huang XF, Zhao YP. Characterization of pore structure, gas adsorption, and spontaneous imbibition in shale gas reservoirs. J Petrol Sci Eng 2017;159:197–204.
[9] Chen Y, Jin Y, Chen M, Yi ZC, Zheng XJ. Quantitative evaluation of rock brittleness based on the energy dissipation principle, an application to type II mode crack. J Nat Gas Sci Eng 2017;45:527–36.
[10] Guo TK, Zhang SC, Qu ZQ, Zhou T, Xiao YS, Gao J. Experimental study of hydraulic fracturing for shale by stimulated reservoir volume. Fuel 2014;128:373–80.
[11] Jin Y, Chen KP, Chen M. Analytical solution and mechanisms of fluid production from hydraulically fractured wells with finite fracture conductivity. J Eng Math 2015;92(1):103–22.
[12] Jiang JM, Younis RM. A multimechanistic multicontinuum model for simulating shale gas reservoir with complex fractured system. Fuel 2015;161:333–44.
[13] Cai YD, Liu DM, Pan ZJ, Yao YB, Li CC. Mineral occurrence and its impact on

fracture generation in selected Qinshui Basin coals: an experimental perspective. Int J Coal Geol 2015;150–151(4):35–50.
[14] Kruhl Jörn H. Fractal-geometry techniques in the quantification of complex rock structures: a special view on scaling regimes, inhomogeneity and anisotropy. J Struct Geol 2013;46(46):2–21.
[15] Wang ZZ, Pan JN, Hou QL, Yu BS, Li M, Niu QH. Anisotropic characteristics of lowrank coal fractures in the Fukang mining area, China. Fuel 2018;211:182–93.
[16] Ge XM, Liu JY, Fan YR, Xing DH. Laboratory investigation into the formation and dissociation process of gas hydrate by low field NMR technique. J Geophys Res-Sol Earth 2018;123(8):3339–46.
[17] Ge XM, Fan YR, Li JT, Muhammad AZ. Pore structure characterization and classification using multifractal theory- an application in tight reservoir of Santanghu basin in Western China. J Petrol Sci Eng 2015;127:297–304.
[18] Du SH, Pang S, Shi YM. A new and more precise experiment method for characterizing the mineralogical heterogeneity of unconventional hydrocarbon reservoirs. Fuel 2018;232:666–71.
[19] Du SH, Pang S, Shi YM. Quantitative characterization on the microscopic pore heterogeneity of tight oil sandstone reservoir by considering both the resolution and representativeness. J Petrol Sci Eng 2018;169:388–92.
[20] Du SH. Prediction of permeability and its anisotropy of tight oil reservoir via precise pore-throat tortuosity characterization and “umbrella deconstruction” method. J Petrol Sci Eng 2019;178:1018–28.
[21] Du SH, Shi GX, Yue XJ, Kou G, Zhou B, Shi YM. Imaging-based characterization of perthite in the upper triassic yanchang formation tight sandstone of the ordos basin, China. Acta Geol Sin-Engl 2019;93(2):373–85.