Lithofacies composition and geological significance of black rock series: a case study from the lower Cambrian Qiongzhusi Formation in Huize area, eastern Yunnan province

Yong Cheng1,2, Ping Lu1*, Qi Nie1*, Zhennan Liu1, Cong Liu1, Yiming Wen1, Yufeng Guo1 and Shili Wu1
1Kunming Metallurgy College, Kunming, Yunnan, 650033, China
2Faculty of Land and Resource Engineering, Kunming University of Science and Technology, Kunming, Yunnan, 650093, China
*Corresponding author’s e-mail: 70461393@qq.com; kiki158961326@163.com

Abstract. Lithofacies is an important basis for the characterization of source rocks, shale oil and tight oil reservoirs and the evaluation of oil and gas reservoirs. In this study, a well-developed Qiongzhusi Formation section in Huize area was selected to study the lithofacies features and their evolution and the following conclusions are obtained. In the geological section, the lower part of the Qiongzhusi Formation black rock series is mainly composed of felsic fine-grained sedimentary rock (I) and dolomite or limestone (II). The middle part of the section is clayey felsic fine-grained sedimentary rock (I2), and the upper part is felsic clay rock (III2). Lithologic changes in Qiongzhusi Formation were controlled by terrigenous debris supply, hydrodynamic conditions and water depth. The felsic fine-grained sedimentary rocks formed when the water body was relatively deep in the early stage and the felsic clay rocks deposited when the terrigenous clastic supply was weakened in the middle to late stage have a high content of original organic matter, which is a favourable site for the evaluation of shale gas reservoirs.

1. Introduction
The rock types of the black rock series are various, which refers to a set of gray or black rock combinations, mainly including mud shale, siliceous rock, carbonate rock, sedimentary tuff and metamorphic rock [1]. The black rock series are rich in non-ferrous metal elements (Pb, Zn, Cu, Sb, etc.), heavy metal elements (Au, Ag, Pt, Pd, etc.), rare elements (V, Mo, W, Hg, etc.), dispersed elements (Ce, Re, Se, B, Cd, Tl, etc.), radioactive elements (U, Ra, etc.) and rare earth elements, and are important economic value [2]. In addition, the black rock series contains a large amount of organic matter, which is not only a good source rock, but also a hot research topic today -- the target zone of shale oil and gas [3, 4], and has set off a revolution in the global energy field [5, 6]. From the current domestic and foreign examples of shale oil and gas development, the lithology is not pure and homogeneous shale, but mud shale containing a large number of siltstones, silty mudstone lamination [7]. The rock fabric of shale oil and gas development formation is complex, and there are various lithofacies types and assemblage characteristics [8]. Lithofacies, as the types and combinations of rocks formed in a certain sedimentary environment, not only directly affect the diagenesis and the development of porosity and permeability, but also directly determine the strength, brittleness and stress anisotropy of rocks [9]. It is an important basis for the characterization of source rocks, shale oil and tight oil reservoirs and the evaluation of oil and gas reservoirs. Lower Cambrian Qiongzhusi formation in eastern Yunnan is an important formation...
for shale gas exploration and development, and some exploratory studies have been done before [10-12]. However, the Qiongzhusi Formation in this area is obviously insufficient in the study, and the lithofacies division is rough, which does not reveal the rule of the longitudinal evolution of the lithofacies and restricts the exploration and development of shale gas. In this study, a well-developed Qiongzhusi Formation section in Huize area was selected to study the lithofacies features and their evolution, in order to provide some geological basis for the evaluation of shale gas selection in this area.

2. Geological setting
The study area is located in the southwest margin of the Yangtze block, to the north of the Mile-Shizong fault and to the west of the Xiaojiang fault [11]. This area belonged to platform or quasi-platform from Sinian to Jurassic, and uplifted and denuded in Yanshanian and Xishanian. The strata are developed from Proterozoic to Neozoic, lacking Cretaceous, and have the dual structure of middle Proterozoic Kunyang group fold basement and Sinian to Neozoic sedimentary cover. During Qiongzhusi stage in early Cambrian, the depocenter of eastern Yunnan was located in the area of Huize - Qujing - Malone, and the black rock series composed of black-grey-green shale, silty shale, carbonaceous shale and argillaceous siltstone were deposited [12].

3. Samples
Samples were collected from Dahai township, Huize county. The Qiongzhusi formation outcrop section is well developed with few coverings. According to the colour, structure and structure of the rock, 21 samples were collected from bottom to top for study.

4. Lithofacies classification
4.1. Classification scheme
Due to the limitation of data mastery and description methods, there is no uniform standard for lithofacies classification of fine sedimentary rocks at home and abroad [13]. The essence of the existing scheme is to divide the lithofacies by a combination of one or more indicators in the factors such as colour, grain size, mineral composition, sedimentary structure, biological fossils, organic matter content and geochemistry. There are some problems in these schemes, such as expanding the lithology range of "shale", lacking quantitative constraints on the discriminant index, and not establishing a reasonable discriminant process. In this study, the lithofacies of the black rock series were divided based on the XRD analysis data, and the scheme was referred to reference [14] (Figure 1A). The results of lithofacies division are shown in Figure 1B.

![Figure 1. Lithofacies classification scheme (A) and classification result (B)](image)

4.2. Classification results
According to facies classification results, the lithofacies of Qiongzhusi Formation black rock series
mainly develop felsic clay rock (Ⅲ2) and clayey felsic fine-grained sedimentary rock (Ⅰ3), a small amount of dolomite/limestone (Ⅱ1), felsic fine-grained sedimentary rock (Ⅰ1), Dolomitic fine-grained sedimentary rock (Ⅰ2), Felsic dolostone (Ⅱ2) and dolomitic mixed fine-grained sedimentary rock (Ⅳ2). Their characteristics are shown in figure 2.

5. Discussion
The lithofacies composition and variation of black rock series are the comprehensive reflection of the specific sedimentary environment, paleodepth, hydrodynamic and hydrochemical conditions, and provenance supply [15]. The presence of a large number of clay minerals in shale formations usually indicates weak hydrodynamic conditions relative to deep water at the time of deposition. The content of clastic minerals such as quartz and feldspar can be used as an indicator to analyze the input of terrigenous clasts. However, the developed carbonate minerals in the sedimentary period often means that the concentration of calcium ions and carbonate ions in the water is relatively high and is closely related to the relatively shallow water environment.

In the geological section, the lower part of the Qiongzhusi Formation black rock series is mainly composed of felsic fine-grained sedimentary rock (I) and dolomite or limestone (II). The middle part of the section is clayey felsic fine-grained sedimentary rock (I2), and the upper part is felsic clay rock (III2) (Figure 3). This reflects that the change of water depth in Qiongzhusi Formation at the early sedimentation stage is corresponding to the supply of terrigenous debris, and the content of original organic matter is also high or low. In the middle period, the water became deeper and the terrigenous clastic supply was strengthened, and a set of extremely thick clayey feldspathic fine-grained sedimentary rocks was deposited, and the content of original organic matter was reduced. However, in the late period, the terrigenous clastic supply was weakened, and felsic clay rocks were mainly developed, and the content of original organic matter was increased.

To sum up, the felsic fine-grained sedimentary rocks formed when the water body was relatively deep in the early stage and the felsic clay rocks deposited when the terrigenous clastic supply was weakened in the middle to late stage have a high content of original organic matter, which is a favorable site for the evaluation of shale gas reservoirs.
Figure 2. Lithofacies characteristics of Qiongzhusi Formation

A. Felsic fine-grained sedimentary rock, black, blocky structure (I1); B. Dolomitic fine-grained sedimentary rock, ash black, blocky structure (I2); C. Clayey fine-grained sedimentary rock, dark gray, horizontal bedding developed (I3); D. The microscopic characteristics of the clayey fine-grained sedimentary rock, mainly composed of feldspatic minerals and a small amount of clay minerals, cross-polarized light (I3); E. Dolostone, grayish black with inconspicuous undulate lamina (II1); F. The microscopic characteristics of the limestone, developed a large number of calcites, cross-polarized light (II1); G. Felsic dolostone, ash black, blocky structure (II2); H. The microscopic characteristics of the felsic dolostone, dolomite dominated, followed by felsic minerals, a small amount of clay minerals, cross-polarized light (II2); I. Felsic clay rock, gray-black, horizontal bedding visible (III2); J. The microscopic characteristics of the felsic clay rock, mainly clay deposits followed by felsic minerals (III2); K. Dolomitic mixed fine-grained sedimentary rock, gray-black, horizontal bedding visible (IV2); L. The microscopic characteristics of the dolomitic mixed fine-grained sedimentary rock, a large amount of dolomite, followed by felspatic minerals, a small amount of clay minerals, single polarized light (IV2).
6. Conclusion
In the geological section, the lower part of the Qiongzhusi Formation black rock series is mainly composed of felsic fine-grained sedimentary rock (I) and dolomite or limestone (II). The middle part of the section is clayey felsic fine-grained sedimentary rock (I₂), and the upper part is felsic clay rock (III₂). Lithologic changes in Qiongzhusi Formation were controlled by terrigenous debris supply, hydrodynamic conditions and water depth. The felsic fine-grained sedimentary rocks formed when the water body was relatively deep in the early stage and the felsic clay rocks deposited when the terrigenous clastic supply was weakened in the middle to late stage have a high content of original organic matter, which is a favorable site for the evaluation of shale gas reservoirs.

Acknowledgments
This work was financially supported by the Scientific Research Fund of Yunnan Education Department (2020J0771), Science and Technology Planning Project of Yunnan Province (2017FD129) and Scientific Research Fund of Kunming Metallurgy College (2019XJZK08, 2019XJZK03).

References
[1] Shi C.H., Cao J., Hu K., Bian L.Z., Han S.C., Yao S.P. (2013). A review of origins of mineral deposits hosted in black rock series and the mineralizing functions of their sea water, hydrothermal fluid and bio-organics. Earth Science Frontiers, 20(1): 19-31.
[2] Zhang S.H., Pei J.L., Hu G.H., Zhang Q.Q., Shui G.H., Zhao Y. (2019). Genetic link between large igneous provinces and large volumes of black shale deposition and its implications. Journal of Geomechanics, 25(5): 920-931.

[3] Zou C.N., Pan S.Q., Jing Z.H., Gao J.L., Yang Z., Wu S.T., Zhao Q. (2020). Shale oil and gas revolution and its impact. Acta Petrolei Sinica, 41(1): 1-12.

[4] Wang S.Q. (2017). Shale gas exploitation: Status, issues and prospects. Natural Gas Industry, 37(6): 115-130.

[5] Cheng Y., Guo Y.F., Chen G.D., Yang W.L., Wang F.L. (2017). On resource potential, distribution and characteristics of shale gas in china. Journal of Kunming Metallurgy College, 33(5): 17-24.

[6] Cheng Y., Chen G.D., Yin Q., Xia C.X., Wang F.L., Zhou L., Lu P., Ma L. (2017). Exploration and development status of shale gas in china and enlightenment from north american prosperous shale gas. Journal of Kunming Metallurgy College, 33 (1): 16-24.

[7] Zou C. N., Zhao Q., Dong D. Z., Yang Z., Qiu Z., Liang F., Wang N., Huang Y., Duan A. X., Zhang Q., Hu Z.M. (2017). Geological characteristics, main challenges and future prospect of shale gas. Natural Gas Geoscience, 28(12): 1781-1796.

[8] Ju Y. W., Qi Y., Fang L. Z., Zhu H. J., Wang G. C., Wang G. L. (2016). China Shale gas reservoir types and its controlling factors. Advances in Earth Science, 31(8): 782-799.

[9] Dong D. Z., Wang Y. M.n, Li X. J., Zou C. N., Guan Q. Z., Zhang C. C., Huang J. L., Wang S. F., Wang H. Y., Liu H. L., Bai W. H., Liang F., Lin W., Zhao Q., Liu D. X., Qiu Z. (2016). Breakthrough and prospect of shale gas exploration and development in China. Natural Gas Industry, 36(1): 19-32.

[10] Zhang C., Bao S. J., Shi D. S., Hu L., Yuan K. (2017). Geological Conditions for Shale Gas Accumulation and Favorable Area Prediction in Qujing of Eastern Yunnan. Marine Origin Petroleum Geology, 22(1): 69-74.

[11] Cheng Y., Nie Q., Xia J.B., Gu H.Y., Wen Y.M., Lu P., Liu C. (2018). Formation environment and distribution of organic-rich shales in Yunnan Province. Geology and Resources, 27(06): 514-521.

[12] Cheng Y., Hu Y.Z., Li P.Y., Lu P. (2019). The geochemical characteristics of trace elements and paleoenvironmental evolution of black rock series in the lower Cambrian Qiongzhusi Formation from Huize area,eastern Yunnan province. Contributions to Geology and Mineral Resources Research, 34(3): 416-422.

[13] Ran B., Liu S. G. Sun W., Ye Y. H., Qiu J. W. Zhang J., Yang D. (2016). Lithofacies classification of shales of the Lower Paleozoic Wufeng-Longmaxi Formations in the Sichuan Basin and its surrounding areas, China. Earth Science Frontiers, 23(2): 96-107.

[14] Cheng Y., Wen Y.M., Xia J.B., Liu C., Chang L.T. (2020). Lithofacies classification of fine-grained sedimentary rocks in the early Cambrian Qiongzhusi formation of Huize area, Eastern Yunnan Province. IOP Conference Series: Earth and Environmental Science, 295(4): 042124.

[15] Chen K.L., Zhang T.S., Liang X., Zhang Z., Wang G.C. (2018). Analysis of Shale Lithofacies and Sedimentary Environment on Wufeng Formation-Lower Longmaxi Formation in Dianqianbei Depression. Acta Sedimentologica Sinica, 36(4): 743-755.