Structural characteristics and prospecting direction of coal-based graphite deposits in Feng county area, China

Yunxun Wei ¹, Lushi Lv ² and Congcong Li ², *

¹ China National Administration of Coal Geology, Beijing, China
² Aerophotogrammetrical Surveying and Remote Sensing Bureau, CNACG, Xi’an, China

*Corresponding author e-mail: weiyunxun@163.com

Abstract. The Fengxian coal-based graphite deposit in Shaanxi province is located in the southern western section of the Northern Qinling Massif in Shaanxi Province and is an important graphite metallogenic belt in the Qinling massif. The results show that the main structural styles of the graphite deposit in Fengxian county, Shaanxi province are "S" - type folds, nappe structure and superimposed fold. After mineralization, it has experienced at least two strong tectonic movements. In the early stage, the compressive stress is dominated by near-NS direction, while in the later stage, the compressive stress is dominated by NWW direction, which is superimposed with the near-East-west fold. Combined with the characteristics of structural ore control, it is found that the focus of ore prospecting in the study area lies in the 5th and 6th strata of Caoliangyi Formation, east of Laochang.

1. Introduction
Coal-measure graphite is formed by thermal contact metamorphism and tectonic metamorphism of coal and coal-measure carbonaceous shale, etc. It is mostly cryptocrystalline graphite [1] and belongs to coal metamorphic graphite deposits. Mineralization is mainly coal seams in the construction of coal contained in the tectono-magmatic belt, and recrystallization occurs through medium-acid magmatic hydrothermal contact metamorphism [2]. Coal-measure graphite has the characteristics of "concentrated ore body, high grade and easy development" and is an important part of graphite mineral. It is a strategic emerging mineral [3-6]. The study area is located in the western southern section of the North Qinling Mountains and the conversion site of the East and West Qinling (Fig. 1). It belongs to the North Qinling Imbricating thrust nappe tectonic belt [7-9] in the Qinling block.
In the past 30 years, there has been little research on the structural characteristics and graphite deposits of the Caliangyi Formation, and some scholars believe that the west of laochang formation is coal mine and the east of Laochang formation is graphite ore [10].

The study area is located in the southern margin of the North China plate, namely between the Loran-Luanchuan thrust nappe fault and Shangdan suture zone (SF1), and belongs to the North Qinling structure. The strata involved are mainly quaternary, Carboniferous Caliangyi formation and Ordovician Zhangjiazhuang formation. The distribution line is nearly east-west, the surface of the sizes lenticular rock in different level scale, nature and type of fracture as skeleton, actual it is in the southern margin of the north China plate groove of the Qinling tectonic plate, arc, basin, based on the active continental margin, north China and Yangtze, successively subduction of the Qinling plate collision split, and superposition of Cenozoic intracontinental orogenic structure and form of a complex of split belt and superposition of multiphase composite structural belt [11].

2. Structural deformation characteristics
Under the influence of multi-stage tectonic stress, the structure in the study area is developed. The eastern part of the study area is a South inclined monoclinic structure, and the western part is a west inclined syncline structure, which is composed of caoliangyi formation, with an extension length of about 2km and an axial direction close to EW. It is an asymmetric syncline. The North Wing stratum attitude is $160^\circ \sim 220^\circ \angle 20^\circ \sim 40^\circ$, the south wing stratum attitude is $314^\circ \sim 10^\circ \angle 30^\circ \sim 40^\circ$, and the hinge attitude is $270^\circ \angle 40^\circ$. Near the North Wing F2 fault, the stratum dip angle becomes larger, even vertical. Influenced by the small fold, the attitude of the stratum changes greatly.

The North-South boundary of the caoliangyi formation is mainly bounded by faults, the south boundary is F1 fault, the west boundary is F2 fault, and the source bed is held by two faults.

3. Main structural style and ore-controlling structure

3.1. "S" - type folds
The Xujiashan-Huayuansi syncline in western China is affected by two periods of strong tectonic movement. The plane shape is "S" - type, the axial direction is nearly EW, the core is steep, the two wings are wide and slow, and the two wings are mostly composed of small compound folds: Hub occurrence$270^\circ \angle 40^\circ$. The north wing is close to fault F2, and the stratum dip angle increases or even stands upright. Small east-west thrust faults are developed, with occasional right-lateral shear strike slip.
According to the stress field analysis of the syncline structure (Fig.2), the maximum principal stress direction that controls the syncline structure shape is NNW direction. Meanwhile, the axis trace of the north eastern section deflected to the east, while the axis trace of the south western section deflected to the west, forming a slow and unique "S" - type folds combination with the property of right strike-slip.

Figure 2. The “S” fold and the analysis of tectonic stress field

3.2. Superimposed fold
Superimposed fold is the result of the tectonic deformation of multiphase, overlay structure in the study area is mainly development in the midwest, by nearly EW to fold and superposition of NNE and SN to fold, generally of 70 ~ 90, two groups of fold axis show large Angle intersection or right across the stack. After stacking, EW to fold axial plane generally affected by the deformation is small, while the hub was forced to fold by NWW or nearly EW , regular ground wave shaped ups and downs, and eventually form a series of dome basin tectonic superposition of two period antiformal place to form a dome structure, forming tectonic basin superposition of two period to formWhen the late antiform crosses the early antiform, the antiform hub leans, and the antiform hub is raised, forming a saddle structure [12-13].

3.3. Stress analysis
Through statistical analysis of joint occurrence in the study area [14], it is found that there are two sets of conjugate shear joints in the area, one of which has a NNW NNE orientation and the other has an NWW near EW orientation. The formation of the former is earlier and the latter is later, which is basically consistent with regional tectonic stress changes.

Before a joint influence restriction after a joint, a joint after the former truncation stagger the effects of a joint, a joint development is superior to the first according to the handover relationship, before the judge a conjugate shear joint formed earlier than after a joint system, namely the extrusion of NNW direction to developing earlier in the extrusion direction of tectonic stress is NWW to tectonic stress,,in accordance with the basic regional research results [7], [11], [15].

Through joint stress analysis, the carboniferous in the area after experienced at least two strong tectonic movement, the early stage of the near NS compression stress is given priority to, nearly east-west fold thrust fault development, later with a NWW compression stress is given priority to, development of NNE to small fold thrust, and compared with previous nearly east-west fold superposition, basically formed the modern form in the study area.

3.4. Structural ore control
The graphite deposit in the study area is the common result of tectono-thermal action. It is not only a physical action, but also a geochemical action, which promotes the change of macromolecular structure of coal (ore source rock). Meanwhile, in addition to generating heat energy, magmatic thermal action can also transfer stress relatively uniformly through tectonism.

The study area is dominated by the compressed structural style, and the fold is the main ore-controlling structure, which controls the occurrence form of the graphite stratum and the graphite ore
layer. At the same time, it can cause the inter-layer slip or intra-layer flow of graphite and affect the migration of the graphite ore body.

Under the strong south-north compressive stress, each monolayer of rock and ore produces fold deformation of different sizes and shapes according to their own internal characteristics, and the deformation is concentrated in the non-uniformity of medium, which causes the non-uniformity of deformation. Thick sandstone forms large scale and slow fold. In the process of folding, it is obviously not in accordance with the upper and lower direct roof. In a plastic state, it extrudes into various peel holes or structural weak surfaces to form downward tooth bifurcation ore bodies and saddle ore bodies, etc.

A series of north-dipping thrusting napping faults of Hualisi-Indo-Chinese and Yanshanian developed in the study area. At the same time, under the influence of dynamic metamorphism, graphitization can be observed on the fracture surface, but it is usually of low grade and very small thickness, with little industrial value. If the fracture hole is filled by coal metamorphized graphite, industrial ore body can be formed.

4. Prediction of prospecting potential

Coal-series associated graphite has proven reserves of 50 million tons. The deposit is in great scale, metallogenic geological conditions are good, and the grade is high, but attention has not been paid to [16].

4.1. Ore characteristics

The coal-based graphite in the study area is steel-gray and gray-black, with dense block, soil-like, lamellar and patchy structure. It is cryptocrystalline graphite or semi-graphite [2]. Scanning electron microscopy showed that cryptocrystalline graphite particles were irregular flake (Figure 3), and most of the particle sizes were 2 ~ 3 m. The graphite crystal is flake with clear boundary. XRD test shows that the mineral composition is mainly graphitic quartz chlorite illite.

![Graphite particles under the SEM](image)

Figure 3. Graphite particles under the SEM

4.2. Prediction of favorable blocks

The author found in recent years’ geological survey work summary, Fengxian county in penetration groove - old factory - coal coal graphite metallogenic belt is the carboniferous coal seam by the Yanshan period magma thermal and tectonic thermal metamorphism, and through ore body towards a continuous, buried depth, generally 300 ~ 500 m, according to drilling and old adit of the sample test result analysis, the eastern metallogenic belt (laochang to Guangou) has much orebodies and ore quality is better, the fixed carbon content of whic is generally 68% ~ 89% (table 1);The ore quality in western China is slightly poor, and that in the coal gully west of Jialing River is the worst, which is inseparable from the duration of magmatic activity and the strength of tectonic stress. Therefore, the prospecting focus of coal-measure graphite in the study area is located in the 5th and 6th section of the Caliangyi Formation to the east of Laochang.
Table 1. Grade characteristics of samples

| sample     | ore body | A (%) | V (%) | CGD (%) |
|------------|----------|-------|-------|---------|
| YP3-1      | I        | 28.01 | 3.33  | 68.66   |
| YP3-2      | I        | 16.75 | 3.42  | 79.83   |
| YP4-1      | I        | 16.79 | 3.88  | 79.33   |
| YP9-2      | I        | 15.25 | 3.84  | 89.19   |
| YP20-1     | III      | 24.35 | 3.08  | 72.57   |
| YP20-3     | III      | 28.85 | 3.22  | 67.93   |

5. Conclusion
The coal-based graphite deposit in Fengxian, Shaanxi is affected by multi-period tectonic stress. The deformation and transformation of the carboniferous system in the source layer are relatively large, and the main structural styles are S-type fold, nappe structure and superimposed fold.

Through stress analysis, it is found that the area experienced at least two strong tectonic movements after the Carboniferous period, with near-NS compressive stress as the main stress in the early stage and NWW compressive stress in the late stage, superimposed with near-EAST-west fold in the early stage.

Fold structure affects the migration of graphite ore body; At the same time, the grade of the graphite layer is affected.

Combined with the investigation work and the characteristics of structural ore control, it is found that in the eastern part of the study area (from laochang to Guangou), there are many graphite ore bodies of coal measures and the ore quality is good, while the ore quality in the western part is slightly poor. Therefore, the prospecting emphasis of coal-based graphite in the research area should focus on the fifth and sixth stage stratum of Caliangyi Formation to the east of Laochang.

References
[1] Qian Chengxin. Mineral processing and application of graphite [J]. Foreign Metal Ore processing, 1993(12):12-13.
[2] Mo Rujue, Liu Shaobin, Huang Cuirong, et al. Geology of graphite deposits in China [M]. Beijing: China Building Industry Press, 1989:26-84.
[3] Cao Daiyong, Zhang He, Dong Shi, et al. Research status and key direction of coal measure graphite mineral geology [J]. Geoscience Front, 2016, 23:1-11.
[4] Sun Shenglin, Wu Guoqiang, Cao Dayong, et al. Coal measure mineral resources and its development trend [J]. Coal Geology of China, 2014, 26(11):1-11.
[5] LIU Qinfu, YUAN Liang, LI Kuo, et al. Structure characteristics of different metamorphic grade coal-based graphites[J]. Earth Science, 2018, 43(5):1663-1669.
[6] WANG Lu, CAO Daiyong, PENG Yangwen, et al. Strain-induced graphitization mechanism of coal-based graphite from Lutang, Hunan Province, China[J]. Minerals, 2019, 9:617.
[7] Zhang Guowei. Formation and tectonic evolution of the Qinling orogenic belt [M]. Xi ‘an: Northwest University Press, 1987:126-134.
[8] Song Chuanzhong, Zhang Guowei, Ren Shenglian, et al. Characteristics and significance of several important tectonic belts in the Qinling-Dabei orogenic belt [J]. Journal of Northwest University (Natural Science edition), 2009, 39(3): 368-380.
[9] Zhang Guowei, Zhang Benren, Yuan Xuecheng. Qinling orogenic belt and continental dynamics [M]. Beijing: Science Press, 2001:117-119.
[10] Chen Erhu, Zhang Xungu, Liu Ping. Development and utilization status of graphite ore in Baoji area and its peripheral prospecting potential [J]. Gansu Metallurgy, 2013, 35(5): 88-92.
[11] Zhang Guowei, Meng Qingren, Yu Zaiping, et al. Orogenic process and dynamic characteristics of the Qinling orogenic belt [J]. Scientia Sinica (D), 1996, 26(3): 193-200.
[12] Ramsay J G. Rock folding and fracture [M]. Beijing: Geological Press, 1985:355-379. (in Chinese)
[13] Ramsay J G, Huber M I. Modern structural geological methods (Vol. 2 folds and Fractures) [M].
[14] Chen Qingxuan, Wang Weixiang, Sun Ye, et al. Rock mechanics and structural stress field analysis [M]. Beijing: Geological Press, 1998:118-129.

[15] Li Jiahao. Study on tectonic deformation and Dynamics in the North Qinling Mountains [D]. Hefei: Hefei University of Technology, 2013.

[16] Yan Dayu. Overview of coal measure associated mineral resources in China and significance of development and Utilization [J]. Coal Processing and Comprehensive Utilization, 2004(6) : 44-47.