2011 Xi’an International Conference on Fine Geological Exploration and Groundwater & Gas Hazards Control in Coal Mines

Styles and Coal-Controlling Effects of Detachment Structure in Some Coalfields of Southeast China

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Abstract

Coal-scarcity provinces of southeast China, such as Jiangxi, Guangxi, Guangdong, and so on, have successively experienced the effects of paleo and modern Pacific geodynamic system, resulting in multilevel and multi-phase detachment structure developed broadly. According to the geodynamic characteristics, the detachment structure styles in study area are divided into nappe-type, gliding nappe-type and superimposed type, and subdivided into eight second-order structure styles, with analyzing their coal-controlling effects. The results show that: detachment structure is the main controlling factor of the structural reform of coal-bearing stratum and the preservation condition of coal resource, and among them, the superimposed type is the most principal coal-controlling structure style. Based on regularizing structure styles by means of anew examining and verifying fault point combination, to discover coal under nappe and gliding nappe is an important direction of coal resource exploration and exploitation.

Keywords: Detachment Structure; Structure Style; Tectonic Control of Coal; Southeast China

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Selection and peer-review under responsibility of China Coal Society

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1. Introduction

In economically developed provinces such as Hubei, Hunan, Guangdong, Guangxi, Jiangxi, Zhejiang, Fujian, coal consumption is huge, but coal resource is lacking due to bad coal-forming conditions and later violent structural deformation. To discover new resource bases is a very urgent task because that the resource has approximately verged on exhaustion in many coal mining areas and there is little reserve base. The coal geological research for many years shows that multilevel and multi-phase detachment structure is the main controlling factor of the structural reconstruction of coal-bearing stratum and the preservation condition of coal recourses. Analyzing the coal-controlling structure style and summarizing the regular pattern of tectonic control of coal (Huang Ke-xing, et al, 1991) are vital for guiding further coal resource exploration in this area.

2. Regional geological setting

The provinces aforementioned locate in the southeastern of South China block, adjacent to Pacific Plate, being a part of eastern Asia moving continental margin (Ma Wen-Pu, 1992). The areas have successively experienced the effects of paleo and modern Pacific geodynamic system, therefore the coalfield structure deformation is violent since middle-late Triassic (Xia Yu-cheng, et al, 1996), and characterized by multilevel and multi-phase detachment structure developed broadly.

In the wake of the westward subduction of paleo-Pacific Plate began in the middle-late Triassic, the east margin type of Asian continent changed from Atlantic type to Andes type, and the squeezing action in the east part of South China block became more and more strong. Under the action of paleo-Pacific geodynamic system, the eastern part of South China block gradually uplifted from east to west, accompanying with the development of fold and overthrust. The structural deformation characteristics in the research area formed in Indosinian-Yanshanian period are as follows: (1) thrust nappe structures develop broadly extending eastward from Hunan and Guangxi to Fujian and Zhejiang coastal; (2) imbricate nappes thrust up from southeast to northwest, and the tectonic deformation developed from east to west; (3) tectonic deformation intensity strengthens gradual from east to west.

Since late Early Cretaceous Epoch, the paleo-tectonic stress fields changed from northwestward compression during Indosinian-Yanshanian period to southeastward tension. The eastern China has been involved into a new geodynamic system that is the modern-Pacific system, on the whole, which is a chasmic-extension geodynamic system. Under the action of the modern-Pacific geodynamic system, the extensional and compressive movements alternatively occur in the eastern part of South China block during Cenozoic, but the extensional gliding nappe and gravity sliding structure are the main intracontinental deformation styles.

3. Styles of detachment structure

3.1. Detachment structure and structural styles

Detachment structure is composed of detachment surface, overlying system (detachment body) and underlying system (Wang Gui-liang, et al, 1992). In compressive tectonic stress field, the thrust nappe structure originated from thrust upward of the overlying system along a nearly horizontal detachment surface. In tensional stress field, the extensional gliding nappe structure resulted from the overlying system moving down along the detachment surface. Because gravity plays an important part in extensional gliding process, the detachment structure originated from extensional gliding nappe and gravity sliding is called gliding nappe structure.
The structure style, a concept put forward by Harding in 1979, is the structure combination in the same structure deformation phase or the same tectonic stress filed, which is obviously different from other structure in characteristics and style. In 1993, the structure style was defined as the structure combination with era and local character by Liu He-fu. The coal-controlling structure style is the structure style controlling preservation condition of coal-bearing stratum and coal seams (Cao Dai-yong, 2007). The objective of studying structure style is to reveal geological structure development regularity, and to establish geological structure pattern for structure prediction (Cao Dai-yong, et al, 2010; Cheng Ai-guo, et al, 2010).

3.2. Structure styles in study area

Detachment structure develops broadly in southeast of China, which is the main geological factor reform the structure of coal-bearing stratum and controlling the preservation state of coal resources. The structure styles of detachment structure in study area can be divided into three types of first-order styles according to theirs geodynamic characteristics, including nappe-type, gliding nappe-type and superimposed type, and can be subdivided into eight types of second-order styles, as listed in Table 1.

4. Detachment structure and coal preservation

4.1. Nappe structure

4.1.1. Basement-involved thrust nappe structure

The main involved strata are the basement composed of metamorphic rocks formed before Devonian (including intrusive bodies of Caledonian and Indosinian epoch in the rock), and late Paleozoic and Mesozoic strata. It is characterized by metamorphic basement with upper-Devonian thrusting up late Paleozoic and Mesozoic strata. The coal-bearing stratum nearby the fault zone has been mightily extrusion crumpled, the part rock nearby the fault surface shows intensively extruding and rumples deformation. The styles of basement thrust nappe structure can be subdivided as follows:

- Thrust sheet (klippe): Huge “sheet” or “klippe” is trusted up on a gentle detachment surface. After the ground denudation, the intersecting line of detachment surface and ground appears in snake-bending, harbor, close circle or irregular shapes. The detachment surface is steeper at upper location. For example, in the south of Fujian, the klippe composed of Mesoproterozoic Lengjiaxi Group and Sinian, Devonian, Carboniferous Systems, widely thrust up the new stratum, Permian and Triassic. The similar klippes are also found in some exploration areas of Hunan, such as Jiangjiang, Feijiang, Lijiang, and so on.

- Thrust geologic window (fenestra): The underlying system of a basement thrust nappe structure outcrops in the low-lying parts of the ground, forming fenestra varying in size, because the overlying system has been denuded. For example, the lower-middle Jurassic strata is bared in fenestra in southwest Fujian; in some coal mining areas of Hunan, such as Wenjiashi, Zhangjiachong, Chengtianjiang-Shihuiichong, and so on, Longtan coal-bearing series of Permian and upper Triassic are also outcropping in geologic window.

- Concealed trust sheet: After nappe structure formation, nappe has been subjected to weathering and denudation, and then had received new deposits of Mesozoic, resulting to the strata sequence of new stratum-thrust sheet -coal-bearing series, from top to bottom. Showed as in Fig.1, the stratigraphic sequence is exposed by drill ZK7 in southwest of Fujian.
Table 1. Classification of coal-controlling structure styles in study area

| Geodynamic characteristics | First-order | Second-order | Features | Examples |
|----------------------------|-------------|--------------|----------|----------|
| Basement-involved thrust   | Thrust sheet (klippe) | Southwest area of Fujian, Jiangjiang in Hunan, and so on. |
| Compression Nappe type     | Thrust geologic window (fenestra) | Southwest area of Fujian, Wenjia in Hunan, and so on. |
| Concealed thrust sheet     | Shuijingkeng mine filed in Fujian |
| Cover-involved thrust      | Thrust sheet | Chenlei coalfield in Hunan |
|                           | Imbricate thrust | Eastern margin of Xuefengshan in Hunan |
|                           | Duplex thrust | Lianshao coalfield in Hunan |
|                           | Ramp thrust | Lianyang coalfield in Guangdong |
|                           | Back thrust | Lianyang coalfield in Guangdong |
| Gliding | Gliding overlying system gliding down | Xingmei coalfield in Guangdong |
| Multi-phase compression and/or extension | Multi-level nappe | A series of nappes superimpose together | Longyan coal mine area in Fujian |
|                           | Multi-level gliding | A series of gliding nappes superimpose together | Pingxiang coal mine area in Jiangxi |
|                           | Nappe-gliding superimposition | Gliding after thrusting | Tangbian coalfield in Yongding, Fujian |
|                           | Gliding-nappe superimposition | Thrusting after gliding | Jiangjiang exploration area in Hunan |
|                           | Fold-gliding-nappe superimposition | Thrusting after gliding through fold | Yonglei coal mine area in Hunan |

Lots of coal resources are usually found under Basement-involved thrust structures. For example, in Guangping of Fujian, the nappe is composed of Lingdou rock body of pre-Indosinian and metamorphic rock of pre-Devonian, whose north-south length is 20km, the east-west width is 5km and the total area is about 100km². In recent years of exploration, concealed coal resources have been found under the basement-involved thrust structure in many areas, such as Suqiao, Yuansha, Shuijingkeng, and so on. In the Shaoshan and Chenlei coalfields in eastern Hunan, the coal resources have also been found under the old strata.

4.1.2. Cover-involved thrust structure

The main involved strata of cover-involved thrust structure are Upper Paleozoic and Mesozoic, whose development scale is relatively small, and distribution is sporadic, discontinuous but general in the South
China. According to the space combination and geodynamic characteristics, the cover-involved thrust structure can be divided into several styles:

- **Thrust sheet style**: owing to detachment surface is laid into cover rock, the coal-bearing strata is upper and lower overlaid. As it is showed in the Fig. 2, F9 is a large nappe fault in Longyan of Fujian. Basing on borehole data, the relatively complete coal measure is preserved under the nappe, including two mining coal seam and one local mining coal seam, whose total resource is considerable. In the exploration process, the coal-bearing strata are considered to be cut by a ground of thrust fault, and the coal mine structure is concluded as “sheet”, including a ground of coal-bearing strata, napped above another “double building structure”, and the better continuity coal resources have been discovered.

- **Imbricate thrust style**: it is composed of a series of thrust faults, whose occurrence is similar and interval is uniform. The thrust fault converges to the main detachment surface in deep. According to fault activity series, imbricate thrust styles are subdivided as follows:
  1. **Front expansion style**: The above thrust fault has been developed early, and then inferior one is developed later, such as the imbricate thrust structure in east Xufengshan of Hunan, Daxiongshan forest farm.
  2. **Back expansion style**: The inferior thrust fault is developed early, and then above one is developed later.

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**Fig. 1** Geological section of line 10 Shuijingkeng mining field
- D3mn: Nanjing group of Mid-upper Devonian Series;
- P2w: Wenbishan Fm of Middle Permian;
- P3t1: first section of Tongziyan Fm of Middle Permian;
- P3t2: second section of Tongziyan Fm of Middle Permian;
- J3c: Upper Jurassic Changlin Fm

**Fig. 2** Geological section of Xinji coal mining area in Xinluo, Longyan
- P2t: Tongziyan Fm of Middle Permian;
- P3t1: first section of Tongziyan Fm;
- P3t2: second section of Tongziyan Fm;
- P3t3: third section of Tongziyan Fm;
- P3cp: Cuipingshan Fm of Upper Permian;
- T1x: Lower Triassic Xikou Fm;
- K2s: Upper Cretaceous Shaxian Fm

**Fig. 3** Geological section of Lianyang coal mine in Guangdong
- D: Devonian;
- C: Carboniferous;
- P: Permian
Fig. 4 Seven line geological section of Xiejiabang exploration area

D-C. Devonian-Carboniferous; P_{2q}. Xixia Fm of Middle Permian; P_{2t}. Tongziyan Fm of Middle Permian; P_{2t1}. first section of Tongziyan Fm in Middle Permian; P_{2t3}. second section of Tongziyan Fm in Middle Permian; P_{3cp}. Cuipingshan Fm of Upper Permian

such as the imbricate fan in the northeast of Hunan.

- Duplex thrust style: according to the measuring water coal system in the middle of north section of Lianshao coal mine in Hunan, double thrust structure is composed of top thrust fault, lower thrust fault, imbricate fan and fault block.

- Ramp thrust style: thrust fault dip is contrary to the thrust. In the middle of north section of Chenzhou coal mine in Hunan, the opposite thrust style, developing in two wings of Donglongshan, extends and inclines back to back, and intersects in regional detachment surface between late Paleozoic strata and early Paleozoic strata. The opposite thrust structure is developed broadly in south area of Yongan-Jinjiang fault.

- Back thrust style: it mainly develops in these sites where are influenced by the strong structure extrusion stress, such as between Chengtangjiang and Louqian, and the uplifted side between two thrust fault groups whose dips are opposite, lifts shallowed.

As is showed in Fig.3, typical opposite thrust style and typical back thrust style are found in Lianyang coal mine in Guangdong.

If the main detachment surface of nappe structure locates under the coal measure, coal seam, occurred in thrust structure, would been strongly destroyed and deformed, such as Wangren-Shanghuang nappe structure in Huangshi of Hubei. If the main detachment surface of nappe structure is cut by coal measures, the coal seam would be lose mining vault, and the coal seam under the detachment surface is useful, such as Xianju nappe structure and Huangshi-Lishihai nappe structure in Jingmen of Hubei.

4.2 Gliding nappe detachment structure

In the effect of extensive stress field and gravity, gliding nappe structure is originated from overlying rock moved from top to button along lubricated surface. The main gliding detachment structures in South China are formed in Himalayan since late Cretaceous. In the southwestern of Fujian, the detachment surface, in the largest scale and of most widely distributed, develope in contact zone between Wenhishan Fm, Chuanshan Fm and Xixia Fm which is under the Tongziyan Fm. The NW trending fold structure mainly develops in the Xingmei coal mine of Guangdong, gravity gilding structure is resulted from the development of the slipping form anticline wing to syncline show. In Majiawan mine field of Xiangyong coal mine in Hunan. Owing to the effect of concealed rock, Longwangling is lifted, leading to terrain height different, and many small nappe structures develop in the function of gravity. The structure style is found in two sides of the Xuefengshan.
If detachment surface of gliding structure is above coal measures, overlying rock strata would be thinning and even disappears because of slipping cut. The underlie coal seam is protected well and relatively shallow, which is beneficial to exploration. In many coal mines such as in Huangshi of Hubei, Yonglei of Hubei, Shilishan, Matian, and so on. Due to the gliding structure, the old strata are lost, and the new strata directly cover above coal-bearing strata, which are called as “new strata stressing coal”. If the detachment surface of gliding structure is under coal measures, the coal seam would be damaged because of being involved into gliding structure, and there isn’t coal under detachment surface, such as Huangshi coal mine, sliding mass in Caijiashan and Weishan, and so on.

4.3. Superimposed detachment structure

The detachment structure style with different horizons, different periods, different characteristics are superimposed together; the styles of superimposed detachment structure are as follows.

- **Multi-level superimposed nappe style**

  According to the geologic section of the seventh line in Xiejiabang exploration area in east Longyan in Fujian, showed in Fig.4, there are three levels nappe structures: the top detachment fault (F02) develops between upper Permian Cuiplingshan series and the first section of middle Permian Tongziyan Fm, the interlayer detachment fault (F01) locates in the third section and the first section of middle Permian Tongziyan Fm. The detachment fault (F0) locates in the second section of middle Permian Tongziyan Fm and middle Permian Xixia series Fm. The interlayer detachment fault (F01) leads to the loss of the second section of Tongziyan Fm, coal-rich belts are generally occurred under the underlying system (P2t1). The detachment fault in laminates, developed between the upper sub-member (P2t3-3) and lower sub-member (P2t3-1) of the third section of Tongziyan Fm, results in the loss of middle sub-member of the third section of Tongziyan Fm. The coal-rich belts are generally occurred in the underlying system (P2t1). The top detachment fault (F02) leads to the strata loss between upper sub-member of the third section of Tongziyan Fm and basal conglomerate of Cuiplingshan Fm, the coal seam of underlying system is better perseverated. In the Yangmeishan coal mine there is two or many thrust sheets superimposed together.

- **Multi-level slipping nappe structure**

  In the Huangtang of Pingxiang, Jiangxi, The slipping structure, showed as Fig.5, locates in eastern of Juyuan mine field and Huangtang.” Three building structure” is resulted from slipping nappe along upper and lower detachment surfaces, developing from ground to deep underground. The Maokou Fm of Permian (P2m), the basement of Anyuan coal measures (T3a), repeatedly appears three time in limestone. In Matian coal mine and Aiheshan mine field, double slipping superimposed structure is composed of two

![Fig. 5 Geological section of gliding nappe in Pingxiang coal mine](image-url)
nappe structure groups. In Daxiongshan and Zhenshang, multi-level slipping superimposed structure is composed of many nappe structure groups.

- **Gilding-nappe superimposed style**

  In the Douling coal mine in Hunan, the gilding-nappe superimposed structure is originated from the nappe in which develops a slipping fault, whose dip is the same with thrust fault, but the moving direction is contrary. As it is showed in the Fig 6, the coal seam is lifted and thinned in wedge-shaped thrust tectonics, this is beneficial for exploration; but when the two-side coal seam locates in downthrown side of fault, this is unbeneﬁcial for exploration because of the increasing buried depth, such as in the Huangshi coal mine in Hubei.

- **Gliding-nappe structure**

  In the Yongdingtang mine field in the middle of south coal-bearing area of southwest Fujian, is showed in the Fig.7. According to borehole data, the upper strata of Tongziyan series is under cover rock strata of Cuipingshan Fm and the limestone is found under the upper strata of Tongziyan Fm, whose thickness is about 100m. And the coal-bearing strata are under the limestone.

- **Nappe-gilding style**

  This style develops broadly in most coal mine in Hunan. For example, in the Jiangjiang exploration area in Hunan, the pre-developing gilding structure in the coal-bearing strata is cut by late-developing nappe structure.

- **Fold slipping-nappe structure**

  In Yonglei coal mine in Hunan, the NS-trending fold developed in Indosinian epoch, and then the anticline slipped to syncline, in the later the fold slipping-nappe structure develops from EW-trending thrust nappe structure.

5. Conclusions

- In and during the coal-accumulating period, the tectonic activities, in coal-scarcity provinces of southeast China are frequent and strong, the coal mines’ structure is complex, multi-level and multi-stages detachment structures have developed broadly, which are the main controlling geological factors of the structure reform of coal-bearing strata and the occurrence state of coal recourses.

- In research area, the styles of detachment structure are divided into three first-order structure styles, including nappe-type, slipping nappe-type and superimposed type, and eight second-order structure styles, such as basement-involved thrust, cover-involved thrust, gliding nappe, multi-stage nappe, multi-stage gliding, nappe-gliding structure, gliding-nappe structure, fold slipping-nappe structure, and so on. The main style of tectonic control of coal is superimposed type.
In the South China, the coal occurrence is controlled by detachment structure. “Double building structure”, even “tree building structure” are found in coal-bearing strata in the effect of multi-level and multi-stages detachment structure. So coal-exploration under the nappes and slipping nappes is an important direction of coal resource development, basing on renewably auditing fault point combination and accurately redefining structure styles.

Acknowledgment

The paper is finished basing on the massive related basement works conducted by researchers in many geological bureaus, such as Hubei, Hunan, Guangdong, Guangxi, Jiangxi, Zhejiang, Fujian. Sincerely thanks for the related units and individuals, and the authors of references.

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