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Analysis of Ore-Controlling Structures of the Xincheng-Hexi Gold Deposit, Shandong Province, China

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Abstract Based on quantitative and semi-quantitative mathematical and mechanical analysis of the shape, motion, structural factors, stress field and deformation field of the ore-hosting faults in the Xincheng-Hexi gold deposit, the ore-controlling features of faults and mineralization mechanism are discussed. It is concluded that the mineralization is controlled by the main faults, subsidiary fractures, joint density, mechanical features and deformation of the faults. The ore bodies are mainly located in the lower part of the convex crest and upper part of the concave trough of the main undulating fault surface. Mineralization is positively correlated to the development of subsidiary fractures and joints, which correspond to zones of low internal stress and high body strain and shear strain. They are favourable positions for mineralization and alteration.

Key words Shandong, gold deposit, ore-controlling structure

1 Introduction

In recent years, with the extensive application of computers to geological problems, methods for the research on ore-controlling structures have been rapidly developed. A series of mature mathematical and mechanical theories have been introduced into structural geology. Research methods of ore-controlling structures have developed gradually from the descriptive to semi-quantitative and quantitative one (Li et al., 1994; Lü et al., 1996). Great achievements have been obtained in all aspects of structural geology. Ore-controlling faults and mechanical characteristics of ore-formation are discussed through semi-quantitative and quantitative mathematical and mechanical analysis of ore-hosting structural systems, fault shapes, fault activity, structural factors, stress field and deformational field.

2 Basic Characteristics of Faulted Structures

The Xincheng-Hexi gold mine is located in the northern Zhan-Ye gold belt and the centre of the Jiaojia gold field controlled by the Jiaojia fault belt (Fig. 1). Rocks exposed in the mine area are simply Mesozoic Linglong granite with some Archean gneiss and schist. Fault structures (mainly NE-ENE-trending) are well developed. Faults of different orders, scales and directions include the Jiaojia fault and the associated Houjia, Wangershan, Hexi and Houxi faults, which form the ore-controlling fault system in the Xincheng-Hexi gold deposit and control the distribution of three large deposits, i.e. the Xincheng, Hexi and Houxi deposits. Up to now, the explored metal reserves amount to about 70 tons.

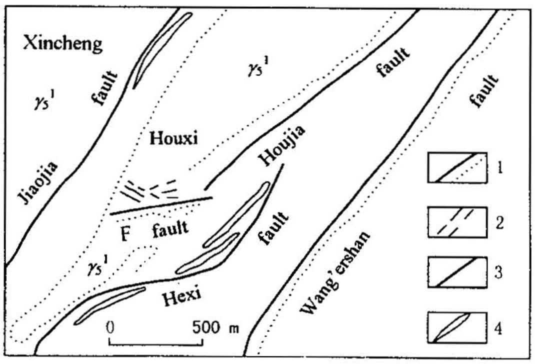


Fig. 1. Schematic Geologic map of the Xincheng-Hexi Gold Field.

γ_5^1-Mesozoic granite; 1. fractured alteration belt; 2. alteration-mineralization-fracture belt; 3. main fault; 4. ore body.

2.1 Jiaojia fault

The Jiaojia fault is the middle part of the Huanghu fault, which is the largest regional fracture in the Jiaojia gold field, 70 km long and 100–200 m wide. The main fault plane with gently wave-like surface strikes NE 20–55° and dips NW at angles of 30–45°. The faults control the general distribution of the Jiaojia gold field.

Not only the two super-large Jiaojia and Xincheng gold deposits are confined to the altered fracture zone, but also the Hexi and Houxi gold deposits are controlled by the ENE-trending subsidiary fault and NW-trending fracture belt on the footwall. The Jiaojia fault formed earlier with obvious features of multi-stage inherited activity. In addition, a series of NE-trending faults are present. Among them, the comparatively large Wangershan fault and Houjia fault are the secondary fractures parallel to the Jiaojia fault.

2.2 Hexi fault

As a comparatively large subsidiary ENE-trending fault of the Jiaojia fault, the Hexi fault, 2.5 km long and 30–60 m wide, appears in a reverse "S" shape on surface, and the Hexi gold deposit occurs in its altered fracture belt. The fault dips 330–340° at angles of 20–50° in the eastern part and dips 310–320° at angles of 40–50° in the western part. The fault was probably formed along with the NE-trending and ENE-trending secondary faults and was multi-periodically active for a long time. An ENE-trending fault parallel to the Hexi fault in the gold mine area is an ore-hosting structure discovered by the author in 1990.

2.3 NW-trending fracture belt in Houxi

The NW-trending fracture belt is situated on the footwall of the Jiaojia fault, extending NW and including a series of low-grade and low-order small fractures and joints. The ore-hosting fracture belt is mainly NW-trending in the west, E-W-trending in the middle and mainly NE- and E-W-trending in the east, as shown in a density diagram of mineralized fractures. In plan view these fractures converge towards the NE and splay towards the SW like a broom. This fissure belt, 300 m long and 60–150 m wide, controls the emplacement of the ore bodies of the Houxi gold deposit.

3 Mathematical Analysis of Structural Control of Ore

The Xincheng-Hexi gold field includes three main gold deposits, the Xincheng, Hexi and Houxi deposits. According to different main ore-controlling factors, different mathematical analysis methods are adopted for different deposits.

3.1 Ore-locating analysis for the Xincheng and Hexi deposits

The Xincheng-Hexi gold deposit is controlled by the Jiaojia and Hexi faults. The ore lodes occur in the footwalls and hanging walls and are closely related to the formation of the main fracture belt. To discuss the characteristics of the ore-controlling faults, the mathematical analytical method of fault shape was utilized. In other words, by using the data from drilling and underground workings, the trend of the main fault plane and the total gold content of the ore bodies on the footwalls and hanging walls of the mineralization-alteration belt are analysed. A first-trend residual diagram of the main fault section in the Xincheng gold mine was plotted (Fig. 2). The fitting goodness of the first trend surface is 99% (with 115 controlling points), which reveals that the main fault plane of the Jiaojia fault in Xincheng is basically an oblique surface with evident convex and concave. Fig. 3 presents the contours of the longitudinal projection of the total gold content. By comparison it with Fig. 2 it is seen that the ore bodies of the Xincheng gold mine occur on the footwall in the convex section of the main fault and no ore bodies in the concave. The spatial location and lateral-dip direction of the convex and small wave crest are consistent with those of the main ore bodies and lateral ore lodes. The dominant Hexi fault has a wavy fault plane. The fitting goodness of the first trend surface is only 84% (with 182 controlling points). The ore lodes in the Hexi gold deposit are located in the main concave section on the hanging wall with extensive distribution and wide mineralized zones. The lateral dip direction of the ore lodes is in agreement with that of the wave trough. While in Hongbu, the ore lode is at the wave crest on the foot-

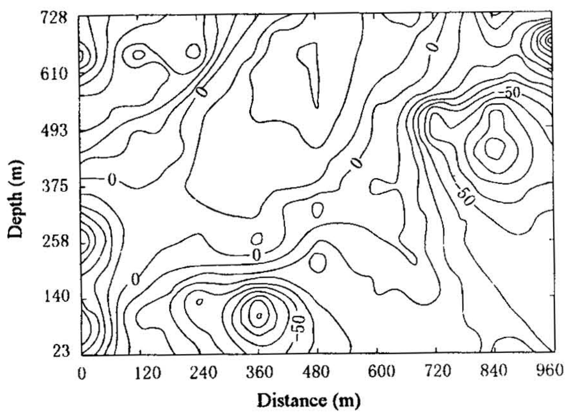


Fig. 2. Contour map of first trend residual of the main fault section on the vertical profile between Line 143 and Line 207 in the Xincheng gold deposit.

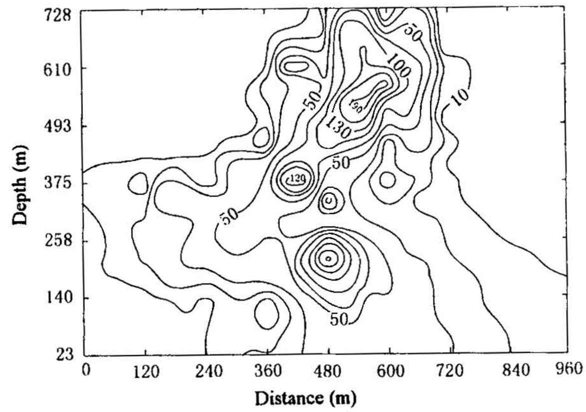


Fig. 3. Contour map of the total gold content on the vertical profile between Line 143 and Line 207 in the Xincheng gold deposit.

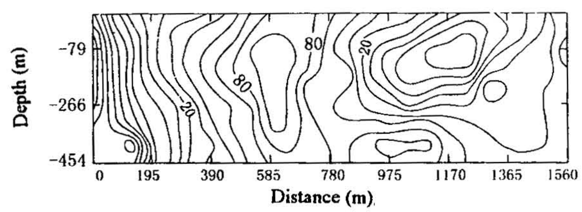


Fig. 4. Contour map of the first trend residual of the Hexi fault on the vertical profile between Line 36 and Line 140.

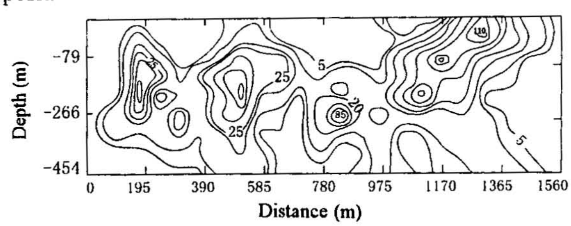


Fig. 5. Contour map of the total gold content on the vertical profile between Line 36 and Line 140.

wall of the main fault, distributed along the main wave crest (Figs. 4 and 5).

The above trend surface analysis of the shape of the main fault section shows that the location of gold ore is obviously controlled by the shape of the main fault plane. The wave crest on the footwall and the wave trough on the hanging wall of the main fault plane are the preferential ore-forming sites and enrichment loci of the gold deposit. The lateral-dip direction of the ore lode is limited especially to that of the wave trough.

3.2 Statistical analysis of structural factors in the Houxi gold deposit

Ore bodies in the Houxi gold deposit are controlled by small fractures and joints. The chief fracture belt is not well developed. To study the ore enrichment and spatial distribution of ore bodies, a stepwise regression analysis of mineralization intensity and structural factors was performed.

3.3 Selection of structural factors and data source

The NW-striking ore lodes have been disclosed at three levels and the second is the best. Based on all eight transverse drifts on level 2 and two transverse drifts on level 3, eight structural factors and one mineralization intensity factor were selected: (a) the width of the faulted clay-breccia belt (in centimetre); (b) the width of the cataclastic belt; (c) thickness of residual blocks; (d) the width of the altered zone; (these four structural factors are the statistically accumulated widths in all transverse drifts) (e) the number of small faults (width exceeding 10 m); (f) product of density and width of mineralized joints; (g) the strike of chief faults (in degree) and (h) the average dip angle of the main fault. The factor of mineralization intensity is the total gold content of all samples from transverse drifts with gold content exceeding 0.5×10^{-6}, yielding a matrix of 10×9 primary data.

3.4 Statistical analysis and results

Step 1: normalization of data to eliminate the effect of the unit and magnitude on the result.

Step 2: stepwise regression analysis.

The low critical value for checking the significance of variables was selected as follows:

The number of samples is 10. Of all the eight variables, four were selected into the stepwise regression equation. Then the first freedom should be 1 and the second freedom is (10–4–1)=5. If the confidence level is chosen as 0.1, the critical value is 4.06 by consulting the F distributive table.

Regression equation: $1 = -0.3837 + 0.3768B + 0.6847E + 0.4382F$

The complex relative coefficient is 0.98 and the F statistical value equals to 59.5288 ($F_{0.05}$ 0.36 check critical value equals 0.976).

That the F statistical value is far larger than the check critical value indicates that the regression equation is highly significant. From the above one can see that the mineralization intensity is positively related to the number of small fractures, the product of the density and width of joints and the width of fractured belts (cataclastic and joints belts). This result is consistent with the geological observation in tunnels.

4 Mechanical Analysis of Structural Control of Ore

The faults in the Xincheng-Hexi gold deposit have experienced an evolutional process from ductile to brittle deformation, which is divided into two periods composed of four stages according to structural deformation and intersecting relations. During the first period, the ore district was in the mid-deep crust and ductile deformation was dominant. N-S compression resulted in the formation of the NE-trending Jiaojia, Houjia, Wangershan ductile-shear belts, followed by a series of secondary shear belts (the Hexi Fault in Houxi). In the Mesozoic, the subduction of the Pacific plate under the Eurasian plate led to NW-SE compression and the uplifting of the crust. The NE- and NNE-trending ductile faults were reactivated as brittle fractures. A series of small attendant secondary NW-trending faults and fissures gave rise to the ore-controlling structural system in the gold district. In the late Mesozoic, severe uplifting of the crust in eastern Shandong converted the tectonic force from compressional to extensional (Hu et al., 1987). At the same time, extension and shearing of the NE-trending faults and attendant ENE-trending and WNW-tending accompanying fissures yielded dilatant space that became preferential sites for the enrichment and deposition of ore materials.

To discuss the relationship between the faulting and gold mineralization, the stress field and deformational field were simulated on the computer by means of programs SAP84 and SAP84-1 of the finite element method.

By comparing a number of simulation results, a simulation scheme for the fault stress field and deformational field shown in Fig. 6 was adopted. This is a linear elastic model. The physical parameters of every finite element were conditionally chosen on the basis of survey and previous experimental data in attempt to meet the actual situation. Owing to less consideration of fault and fracture belt and the easy slipping deformation, the elastic modules were lower than the usual, generally by one order of magnitude or so, while the Poisson ratio was relatively higher (Table 1) (Wang et al., 1979).

Table 1 Physical parameters

Rock	Elastic module (kg/cm^2)	Poisson ratio
Granite	5.5×10^5	0.2
Rocks in fractured belt	5.5×10^4	0.4
Mylonitized granite (anisotropic)	5.5×10^5 3.5×10^5	0.3

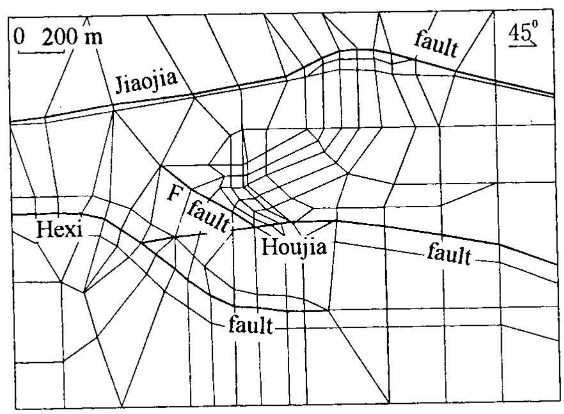


Fig. 6. Diagram showing the element distribution in the Xincheng-Hexi area.

As the simulation was semi-quantitative, only the actual pressure direction induced by the external force on the model was considered, namely the NNE extension during the ore formation. (In the Xincheng-Houxi deposit, the statistics on 10 mineralization joints shows that the maximum tensional stress direction is 175–205°∠40–55° and the mainly concentrated at

198–205°∠42–45°). The simulation results are as follows:

(1) The main stress direction in the NE-trending fault belt deviate and the minor main stress deviate to N-NNE.

(2) Both normal stress and deviatoric stress in the structural belt decrease, giving rise to a zone of marked low stresses (Figs. 7 and 8).

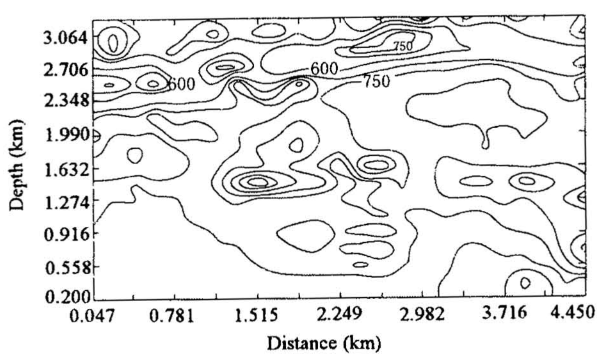
(3) The body strain and maximum shear strain both increase sharply, which suggests that the structural belt is a dilatant and high-value area of maximum shear offset under tensional stresses in the ore-forming period (Figs. 9 and 10), supplying a favourable site for ore formation.

(4) Some faults, such as the Houxi fault, are zones of high body strain and maximum shear strain.

(5) In different parts of the same fault, the body strain and shear strain are evidently different. For example, the intensive body strain and shear strain at the apex and the right of the arc curve of the Jiaojia fault in Xincheng shows that this part is a large-scale dilatancy in the ore-forming period and a favourable site for enrichment of ore materials. The above simulation result is completely consistent with the actual ore-hosting location in Xincheng. The body scale and the intensity of body strain and maximum shear strain of the Hexi fault in the Hexi area are greater than those in the Hongbu area (Figs. 9 and 10), so Hexi is more favourable than Hongbu for the enrichment and gold ore formation, which is consistent with the fact that large-scale gold deposits formed in Hexi and small ones in Hongbu.

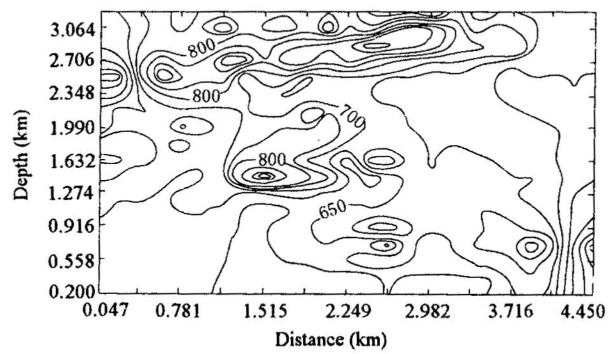
(6) As shown in Figs. 9 and 10, in areas east of Houxi the body strain and maximum shear strain in the NW-trending ore bodies in Houjia are relatively low, which is in agreement with the actual situation of weak mineralization.

(7) That the body strain and maximum shear strain in the NW-trending fracture belt in Houxi exceed those in the Jiaojia and Houxi faults reveals that small fissures and cleavages in the NW-trending fissure belt have strong dilatancy ability, which facilitates free



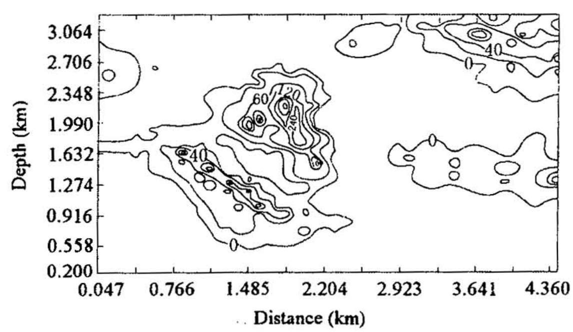
$(\sigma_1+\sigma_2)$

Fig. 7. Contour map of normal stress in the study area.



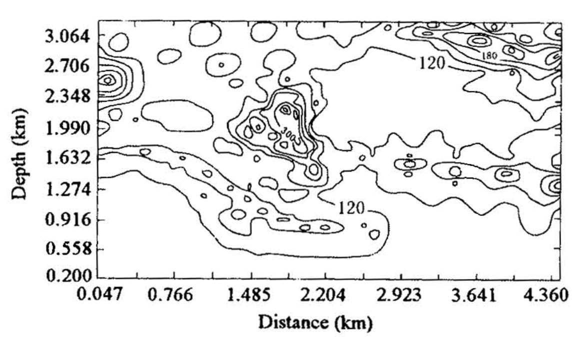
$(\sigma_1-\sigma_2)$

Fig. 8. Contour map of deviatoric stress in the study area.



$(\varepsilon_1+\varepsilon_2)\times10^4$

Fig. 9. Map of relative contours of body strain in the study area.



$(\varepsilon_1-\varepsilon_2)\times10^4$

Fig. 10. Map of relative contours of maximum shear strain in the study area.

space for vein-filling ore lodes. While in the Jiaojia fault and Hexi belt, the body strain and maximum shear strain are small, which is not favourable for the formation of free space. Disseminated deposits related to altered rocks were formed mainly by penetration, diffusion and metasomatism.

The mathematical and mechanical analyses of the main ore-controlling faults in the Hexi-Xincheng area show that the deposits and ore lodes are confined to fault structures. (1) In the faults developing in the main fracture belt, the shape of the main fault has a close connection with the location of gold deposits and ore lodes. The ore lodes spread chiefly in the convex on the footwall and concave on the hanging wall of the main fault plane. While in the Houxi gold deposit the main fractured belt is not well developed, small faults and cleavages are the chief factor controlling ore distribution. The occurrence of workable ore lodes, the width of ore body and the degree of mineralization and enrichment depend on the density of small faults and mineralized joints. (2) Computer simulation by the finite-element method indicates that the favourable loci for gold ore deposits are zones of low structural stress and high body strain (showing dilatancy capability) and maximum shear strain (showing shear deformation capability). The mineralization type has a close relationship with the body strain and maximum shear strain. Higher values of the strains are more favourable for the formation of vein-filling ore bodies and extensional breccia type deposits, while lower values are more favourable for deposits related to fractured altered rocks.

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References

Hu Jiajie, Cao Xingnan, Cheng Xiaojiu and Gong Runtan, 1987. Fault and ore-body forecasting of Hexi gold deposit, east of Shandong. *Geological Science*, (5): 551–557 (in Chinese with English abstract).

Li Hanlin, Zhao Yongjun and Zha Ming, 1994. Statistical classification and optimization for indexes of oil and gas surface geochemical exploration. *Geological Review*, 40(sup.): 33–45 (in Chinese with English abstract).

Lü Guxian, Kong Qingcun, Deng Jun and Li Xiaobo, 1996. Study and estimate of depths of the formation of the Linglong and Jiaojia gold deposits, Shandong. *Geological Review*, 42(6): 550–559 (in Chinese with English abstract).

Wang Ren et al., 1979. *Foundation of Solid Mechanics*. Beijing: Geological Publishing House, 360 (in Chinese).

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