Appendix II:

CHINESE CARLIN-TYPE GOLD DEPOSIT EXAMPLES:

II-1. Geologic features, metallogenic process and prospect on the Lannigou gold deposit, Zhengfang County, Guizhou Province, P.R. China.

II-2. A New Type Gold Deposit, the Greatwall -- Its Characteristics and Potential in Eastern Hebei Province, P.R. China

Appendix II-1.

GEOLOGICAL CHARACTERISTICS, FORMING MECHANISM AND PROSPECT ON THE LANNIGOU GOLD DEPOSIT IN ZHENGFENG COUNTY, GUIZHOU PROVINCE

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INTRODUCTION

The Lannigou gold deposit is located on the bank of the Beipanjang River in southeast Zhengfeng County, Guizhou Province. It was originally an orpiment prospect discovered by the Regional Geological Survey Team, Bureau of Geology of Guizhou Province, *in* 1986, and was evaluated by the 117th Geological Team of the Bureau. This deposit has been listed as one of the “892 National Plan” projects because its orebodies are thick and rich, having significant economic potential. Through exploration, the Lannigou gold deposit has become one of the largest deposits in the Dian-Qian-Gui area in the past six years (1987 to 1992). The No. 1 orebody, located in the Huang-Chang-Gou block, has been proven to be large in size, while the deposit as a whole is extra-large in size. This deposit is considered to be mineable because of its uniform thickness, even grade, good hydrogeology, metallurgy of the ore and suitability for open pit mining.

This paper attempts to build a geological model of the deposit through understanding of the geological characteristics, structure-metallogeny processes, and mechanism of formation in the Lannigou gold deposit, then, will discuss prospecting directions and criterion for further exploration and development. Discussion of new ideas about ore-formation theory and how it would be helpful to find other structure-related gold deposits, such as the Lannigou deposit, *in* the Dian-Qian-Gui area. Some mistakes or misunderstanding may be found in this paper because of time and reference limitations. However, the author welcomes any comments and suggestions from readers. The author would like to thank the many colleagues who are working on this deposit for allowing me to cite portions of their exploration data in this paper.

REGIONAL GEOLOGICAL SETTING

The Lannigou gold deposit is located at the southwest margin of the Yangtze Craton, *in* the northern Nanpanjang orogenic fold zone, at the joint area of the Tethyan-Hemalayan and Pacific Ocean tectonic plates. Regionally, tectonic

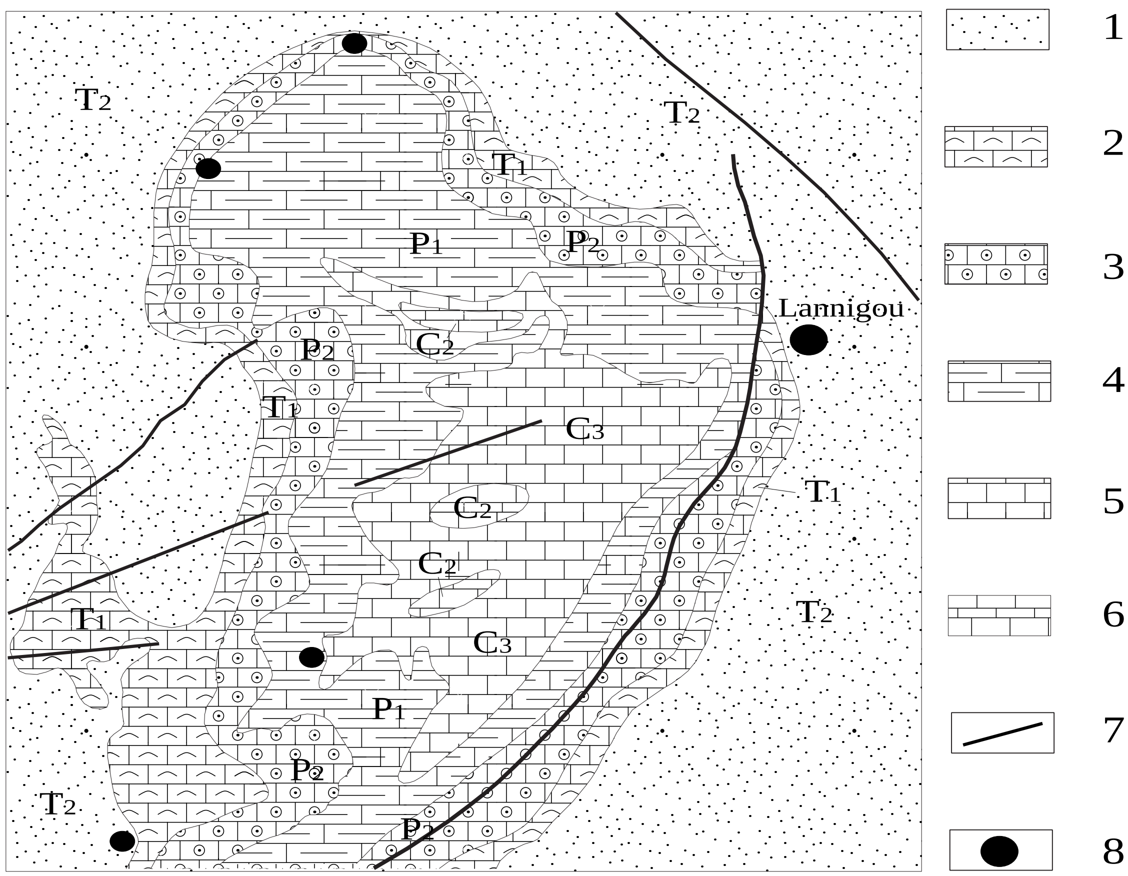

Figure 3-1-1. Laizishan short-axial anticline structure
1, 2-the Triassic stratigraphy (T2b, T1l), which are located on the east-west flanks; 3, 4, 5,6-Carbonaceous to Permian limestone, bioclastic limestone located in the core; 7-Faults surrounding the fold are related to Carlin-type gold mineralization such as the Lannigou deposit; 8-Gold deposit.

units belong to the northwest-trending Wangmei deformation zone, which is a triangular-shaped area surrounded by NNE-, NW-, and EW-striking structural zones.

Along the tectonic boundary from Leiping – Xingyi – Zhengfeng – Anshun, sedimentation was controlled by a paleo-tectonic environment, which differed from the late Paleozoic to the early Mesozoic. In the northwestern area of the basin, sediments developed in a broader, restricted platform environment, locally a tidal flat in the early Triassic. Resultant stratigraphic units, from lower to higher, are the Huanglong group (Middle to upper Carbonaceous) and Maping group (upper Carbonaceous), consisting of light gray massive limestone and bioclastic limestone; the Qixia and Maokou groups (lower Permian) consisting of cherty limestone, limestone, and bioclastic limestone, and argillite and tuffaceous argillite in "the Dachang Layer"; the Wujiaping group (upper Permian) consisting of limestone and reef limestone; the Yielang and Anshun groups (Triassic) consisting principally of argillite, limestone, and dolomite. Brittle deformation, such as faults and joints, are better developed in these rocks, and often form a grid-shaped structural pattern, developed by the intersection of N-S, NE and NW trending faults.

By contrast, sediments formed in the southeastern area developed in a chasm basin environment, resulting in a set of thick detrital materials of terrigenous origin. Also, the structural style in this area is characterized by ductile deformation, such as tight folds and thrust structures. Most of the thrust structures trend to northwest and some, north to south. Northeast-striking faults are present as shear-faults cutting the thrust structures. The fold axes of this area trend mainly northwest and east- west, and a few northeast. Recumbent folds are usually associated with the thrust structures.

Structures observed are typical of "thin skin" deformation, and are the products of the Indosinian-Yanshanian Orogeny. Structures can be roughly divided into four stages on the basis of field observations of structural pattern and determination of the regional stress field, which varied from north-south, east-west, northeast-southwest, and northwest-southeast (Zheng, 1989). The specific structural pattern observed in the Lannigou orefield was formed by a multiple and varied stress field, from which the Laizishan short-axial anticline and Banchang thrust fault that played an important role in the evolution of the deposit, were formed (fig. 1).

The Laizishan short-axial anticline is 25 km long and 12 km wide and generally trends to the NNE. Its core consists of middle-upper Carbonaceous to Permian limestone, bioclastic limestone, and reef limestone, and argillite, tuffceous argillite of the "Dachang Layer" which is interbedded between lower and upper Permian strata. Total thickness of the strata in the core is about 1,300 m. Triassic strata is exposed mainly on the east and west limbs of the fold. The west limb consists principally of platform carbonate rocks, while fine-grained clastic rocks, formed in shelf-chasm facies, are present on the east limb. Total thickness of the strata is about 1,000 m. The two limbs of this fold are asymmetric; the dip angle of the eastern limb is around 20° to 40°, and 5° to 20° on the western limb. Well developed, arc-shaped faults surround the anticline and are often associated with Au, As, Hg and Sb mineralization.

The Banchang thrust is located 3 km northeast of the gold deposit, along a line from the Baiceng to Banchang and Pingbe. It is about 60 km long and 1 to 13 km wide, and consists of four parts; the front fold zone; the upper nappe system; the lower nappe system; and the thrust decrement zone (Chen, 1992). The associated fault breccia zone, is about 30 to 100 m wide and filled with compression breccia, mud, oval structural lenses [phacoids] and associated, strong silicification. Minimum horizontal movement of this structure is 1.5 km, and about 800 m vertical. Direction of thrusting

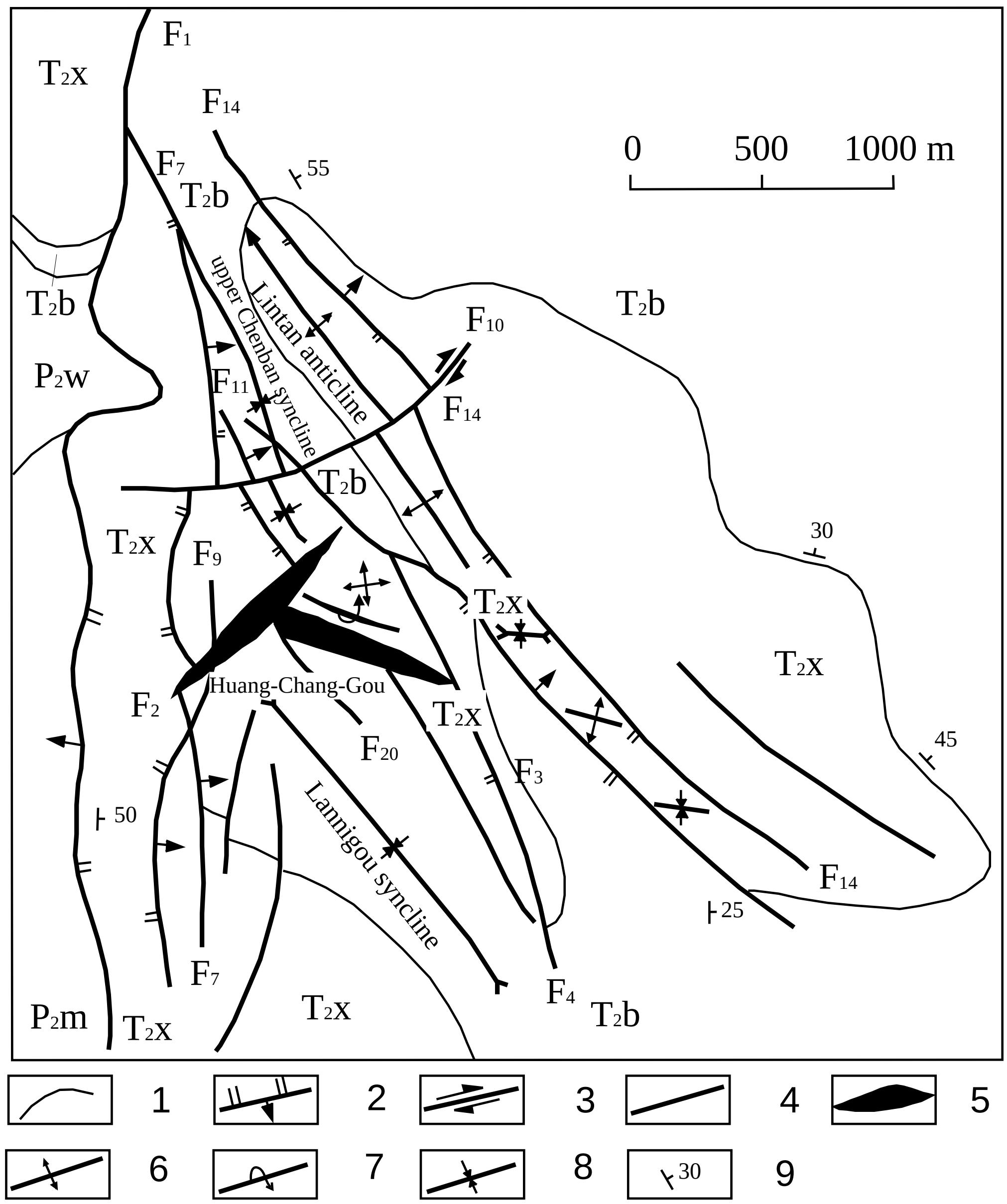

Figure 3-1-2. Geological map of the Lannigou gold deposit

T2b - Bianyang group; T2x - Xinyuan group; T1l - Luolou group; P2w - Wujiaping group; P1m - Maokou group. 1 - Boundary of stratigraphy; 2 - compression fault; 3 - shearing fault; 4 - undefined fault; 5 - ore-control fault; 6 - axial of anticline; 7 - axial of over-turned anticline; 8 - axial of syncline; 9 - dip and angle.

was northeast to southwest with a sinistral shear component.

Igneous rocks are limited in this area, except for a few small alkalic, ultramafic intrusions (porphyry cascadite, fasinite, and cuselite) exposed in Zhengfang to Baiceng about 27 km northeast of the deposit.

The Lannigou, Bannian, Yangyou, Banqi and Yata deposits, *in* addition to the Pegao and Loudong gold prospects, as well as the Qingping and Tangxinzhai gold anomalies and other As, Sb, Hg mineralization present in this area, all surround the Laizishan short-axial anticline. The principal type of mineralization found is sedimentary rock-hosted disseminated gold along with associated metals.

GENERAL GEOLOGY OF THE OREFIELD

Stratigraphy

Two distinct sets of Triassic sedimentary rocks host the ore deposits. Upper Triassic rocks are exposed in the western limb of the Laizishan short-axial anticline and are shallow sea carbonate rocks formed in a continental shelf environment of the Yangtze craton. Early to Middle Triassic rocks are exposed in the eastern limb and host the main ore block of the deposit. They are up to 1,000 m thick terrigenous clastic rocks, such as flyschoid, calcitite, and turbidite formed in an abyssal environment of the Youjang rift basin. Stratigraphic units involved include the Luolou group, the Xinyun (Xuman) and the Bianyang groups (fig. 3-1-2).

Middle Triassic

(1) **Bianyang** group (T_2b) consists of thin- to medium-thick layered, fine-grained sandstone, siltstone that are interbedded with argillite or alternating beds of sandstone and argillite. The sandstone has a fine granular texture, while the argillite displays a microcrystalline texture. The principal clastic component of the sandstone is quartz, which is well sorted and round, forming about 80% of the rock. Hydromica clay minerals, calcium and silica are present in the sandstone as porous cement, forming about 10 to 20%, the remaining detrital fraction of the rock contains clastic debris, feldspar, anatase, rutile and other minerals. Bouma turbidite sequences observed include, B-C, B-D, D-E as well as A, D and E segments. Some sedimentary features such as flute groove casts, load structures, and evenly, oblique, and convoluted bedding are also present in the rocks. Bivalve fossils and fossil fragments are often present in the argillite and silty argillite. The thickness of the Bianyang group is about 268.73 m, and is conformable with underlying strata.

All of the main orebodies of the Lannigou deposits occur in these rocks, the bottom of this group being most favorable for hosting gold orebodies.

(2) **Xinyuan** group (T_2x) is divided into four segments (**Formations?)** based on their lithology, from top to bottom they are:

Fourth segment (T_2x^4, 10 to 46.56 m thick) consists of thin to medium-thick gray, dark gray argillite, *in* which there is a significant component of bivalve fossils and fragments. Limestone or marl, about 0 to 10 m thick, is interbedded within the middle of this segment [Formation].

Third segment (T_2x^3) include three members:

3rd member (T_2x^{3-3}, 30 to 109.78 m thick) is composed of thick or massive, light colored or gray, fine-grained sandstone and less argillaceous siltstone, and is often interbedded with thin to laminated argillite. The sandstone contains coarse cubic pyrite, and scattered pelletal pyrite. Strong gold mineralization is associated the F_3 fault that cuts through this stratigraphic unit.

2nd member (T_2x^{3-2}, 50 to 209.99 m thick) consists of argillite and interbedded lenses of fine-siltstone.

1st member (T_2x^{3-1}, 20 to 67.44 m thick) is made up of sandstone in the upper part, and alternating beds of argillite and sandstone in lower and middle parts.

Second segment (T_2x^2, 0 to 121.78 m thick) is composed of argillite, argillaceous siltstone interbedded with fine-grained sandstone which contains a plethra of bivalve fossils and fragments.

First segment (T_2x^1, 0 to 147.46 m thick) consists mainly of thin to medium-thick argillite, thin micritic limestone, and limestone with an argillaceous interbed. Fine-grained sandstone is present in both upper and bottom segments of this unit.

The Xinyuan group tends to decrease their thickness or disappear to the west (in Huang-Chang-Gou area), while increasing their thickness to the east (Lannigou and Lintan area). It is unconformable with the underlying strata.

Lower Triassic

(1) Luolou group (T_1l, 0 to 76.25 m thick) is distributed in the northern area of the Chenban block in the deposit, and consists of gray to dark gray limestone, *in*terbedded with some argillite and tuffceous argillite. Many ammonite fossils are found in this unit.

(2) Lixue limestone (Lx) is located in the southern orefield, and composed chiefly of calcirudite, limestone breccia, micritic limestone, and bioclastic limestone.

Permian

Wujiaping group (P_2w) is comprised of bioclastic limestone and reef limestone.

Structure and Mineralization

The Lannigou gold deposit is located on the western side of the Banchang thrust structure, at the protruding nose-like portion of the eastern limb of the Laizishan short-axial anticline (fig. 3-1-2). Structures in the orefield are similar to the regional structural grain. As a result of this influence, the two main structures are north-south-trending in the western orefield, while northwest-trending structures are present in the eastern orefield. Another two sets of structures, trending WNW and NE, are present in the central orefield (fig. 3-1-2). Different orientation, ranks of alteration, and breccia in fault zones, control gold mineralization (orebodies). The No. 1 orebody, host of most of the reserve in the deposits, is controlled by the F_3 fault, the most important host-structure in the Huang-Chang-Gou block. The F_2 fault controls the No. 2 orebody and the F_{11} NNW fault in the Chenban block, and the F_{14} NW fault in the Lintan block, are also important ore-control structures.

North-South Structures include the F_1, F_7, and F9 faults, which are present in western part of the orefield. These faults are compressional and are components of the thrust structure. Of these, F_1, the largest fault crossing through the whole orefield, is 8,000 m long, 5 m wide, has a low to medium dip angle to the west. This fault is filled with well-developed tectonite, and is locally associated with gold mineralization and alteration. F_1 is considered to be a thrust fault, and part of the Peping giant thrust structure, of which, Permian carbonate is an outlier sitting on Triassic clastic rocks. The F_7 fault, about 3,000 m long, is associated with strong alteration and mineralization in the Huang-Chang-Gou block, is present on the eastern side of the F_1, and usually dips east with a medium dip angle. The F_9 is a small fault with associated weak alteration and mineralization (fig. 3-1-2).

Northwest Structures include the Lannigou syncline, Lintan anticline and the F_{14}, F_5, F_4, F_{11} faults. These structures formed by lateral compression along a northeast-southwest direction. Length of the axial line in the folds is from 200 to 3,500 m, and about 400 to 1,000 m wide across the limbs. All the folds have gentle-dipping southwest limbs and steeply-dipping northeast limbs. The core of the anticline consists of the third segment of the Xinyuan group strata, while the Bianyang group is exposed in the core of the synclinal structure. The F_{14} fault, which roughly traces the axis of the Lintan anticline, is about 4,000 m long, and dips 60° to the northeast. This fault cuts the northwest end of the Lintan anticline, and is associated with orebody mineralization. The mineralized zone is about 200 m long, 2 to 3 m thick, containing high grade up to 30 ppm Au from individual samples. The F_5 fault is present in the southwest, and is similar to the F_{14} fault in scale and occurrence, but has been found to contain only weak alteration and no gold mineralization. The F_4 fault, with related weak gold mineralization, dips 45° to the northeast, is located to the west of the F_5 fault and cuts F_5 at its north end. The F_{11} fault to the east of F_7, and intersects F_7 at its north end, and also cuts F_2 in its south end, but is offset by the F_{10} fault in the middle. This fault has NNW strike, ENE dip direction, 55° to 75° dip angle, 4 to 10 m wide fault zone, and is associated with strong silicification and pyritization. It is another important ore-control structure in the deposit. The present proven mineralized zone is about 300 m long, with large thickness and large prospect potential (figs. 3-1-2, 3-1-3, 3-1-4).

Northeast Structures comprise a group of shear faults, which include the F_2 fault in the Huang-Chang-Gou and the F_{10} fault in the northern end of this area. Of these, the F_2 fault is a ore-control fault.

The F_2 fault is located on the west slope of the Huang-Chang-Gou block, is 500 m long, 5 m wide, up to 10 m wide at the intersection with the F_3. It dips 45° to 80° southwest, with inverse dip directions to the northwest on the surface. Highly round tectonic lenses [phacoids] fill parts of this fault, but no not show evidence of tension. The F_2 fault has offset the F_3 fault, according to their relationship and the arrangement of the tectonic lenses, and shows a dextral shear sense. The No. 2 orebody, 270 m long, occurs in the F_2 fault, and has a consistent occurrence within the fault. This orebody has a large thickness and is high grade at the intersection of the F_2 and F_3 faults. However, the ore zone thins and disappears away from this intersection towards the northeast and southwest along the strike of the F_2 fault. The No. 2 orebody is controlled by both the F_2 fault and the F_3 fault (fig. 3), and is currently the second largest orebody in the deposit.

WNW Structures are well developed in the Huang-Chang-Gou block, and are also present in the northern end of the orefield (i.e. the F_{80} fault).

The F_3 fault, *in* general, trends 290^o, dips varying between 55^o to 85^o to the NNE. The F_3fault has been proven to be at least 700 m long, from where its western end joins with the F_2 fault, its eastern end still open. The depth, *in* dip direction, is about 570 m, and still open. The F_3 fault has an "S"-shape both in horizontal and vertical planes, illustrated in the western part to the 2^{nd} exploration line. Its dip becomes more planer with depth to the NNE in the lower part of the section (fig. 4).

More detailed field research shows that the F_3 fault actually is a strongly strained structural deformation zone, as

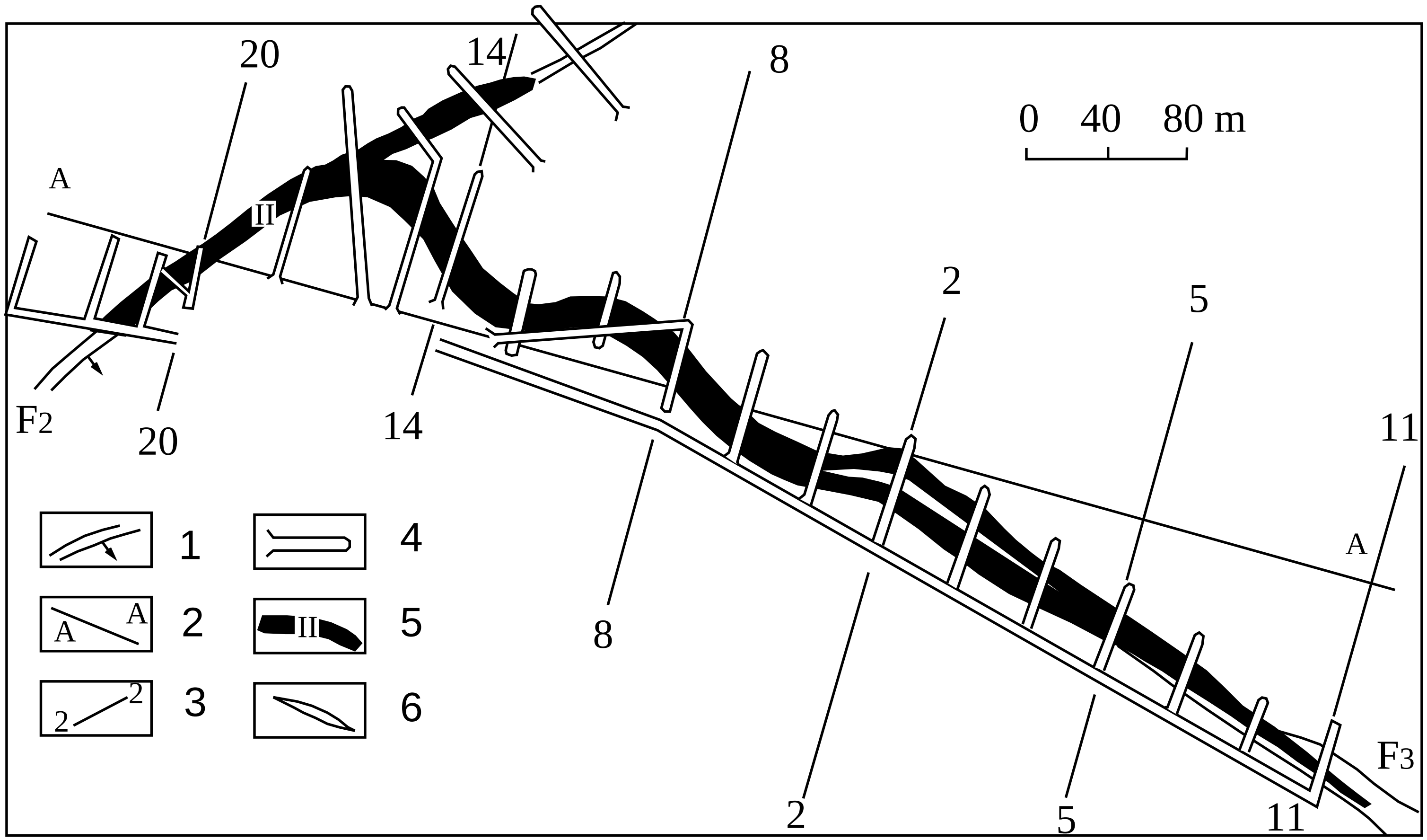

Figure 3-1-3. 4th level map (600 m) of the Huang-Chang-Gou block in the Lannigou gold deposit

1- ore-control fault; 2 - strike line; 3 - exploration line; 4 - tunnel; 5 - orebody; 6 - stone in the orebody.

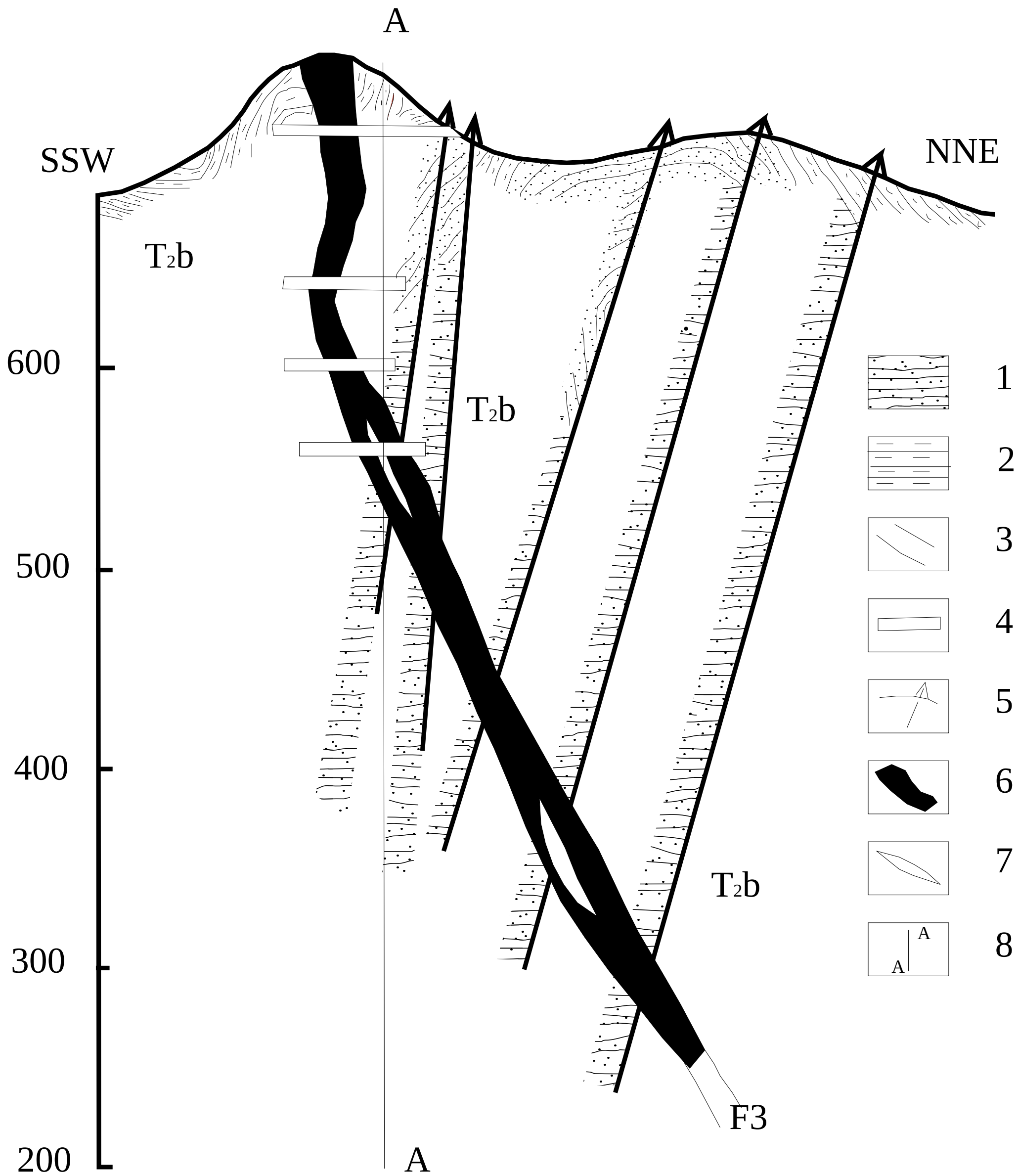

Figure 3-1-4. Exploration section of the Hunag-Chang-Gou block in the Lannigou gold deposit

T2b - Bianyang group of the middle Triassic: 1 - sandstone; 2 argillite; 3 - fault zone; 4 - strike-tunnel; 5 - drill hole; 6 - gold orebody; 7 - stone in the orebody; 9 - center line.

well as a strong mineralization zone. Both boundaries of this strained zone (fault plane) are similar. The width of the fault zone is about 8 to 20 m, maximum up to 30 m, and varies along both strike and dip. Rocks in the fault zone have undergone strong deformation, and different kinds of tectonites, such as tensional breccia, compression cataclastic rocks, and mylonite. Hard rocks, such as sandstone, were deformed into lenses or phacoidal bodies, and are en echelon in the fault zone, while soft rocks, such as argillite, became foliated schist, mud and fill into the fractures of the lenses, or wrap around them. The size of the sandstone lenses, dependent upon the thickness of the original rocks, varies from several centimeter to 1 meter, the maximum long axis is about 3 to 4 m. These structural lenses have medium roundness and a smooth surface. Additionally, sliding, splitting, and joint planes, which have the same occurrence as those sandstone lenses, are well-developed in the fault zone, which combine into a group of conjugate joints (fig. 3-1-5). The rocks in the strongly strained structural zone have undergone both dynamic and dynamo-hydrothermal metamorphism.

The strata on the both the footwall and hangingwall are complete except for some weak silicification or striped pyrite along bedding. Many small drag folds are present in the strata, and in general, drag synclines are present in the hangingwall, while the drag anticlines occur in the footwall (fig. 3-1-6). These drag folds indicate that the fault is dextral with a tensional component.

The structures in the orefield are typical "thin skin" tectonics, and have a complicated pattern. Each group of these structures has been identified as either hosting a gold orebody or gold mineralization. They may have been formed in the Yanshanion Orogeny according to the analysis of the structural characteristics of the regional structures.

GEOLOGIC CHARACTERISTICS OF THE ORE DEPOSITS

Shape, Occurrence and Size

The No. 1 orebody, which is controlled by the F_3 fault in the Huang-Chang-Gou block, has a slaty shape, similar in occurrence to the fault zone, and in general, trends 299° and dips to the NNE at 55° to 85°, with local inverse of dip direction. The orebody has an "S"-shape in map view in the western part of the 2nd line. It also shows an "S"-shape cross section above the 560-meter elevation, but becomes more planer and dips to NNE below that elevation.

The topographic expression of the outcrop of the No. 1 orebody about 155 m long, and extends along the east-west dividing range in the eastern part to the 2nd line. The orebody is situated high on a central upland surrounded by a low valley and is amenable to channel exploration and open-pit mining. The No. 1 orebody is exposed for 500 m along strike on the surface, and joins the No. 2 orebody on its West End, while the east part of the orebody, to the 11th line is not exposed on the surface (fig. 3-1-7). The controlled maximum strike length of the orebody is 680 m, and 570 m down dip, and is still open to depth and to the east.

Factors controlling grade and thickness of the No. 1 orebody

(1) **Strain-Intensity of the Structure**: The strain intensity in the F_3 fault is not uniform so that the mineralization intensity is different from place to place. The types of tectonites in the F_3 fault include mylonite (rare), different-sized cataclasite and local whole sandstone, argillite blocks with bedding (about 3 m thick) that form unmineralized phacoids in the orebody. Highly strained, small fragmental cataclasti**c** rocks, usually are associated with rich orebodies, while large-fragmental cataclastic rocks are present in

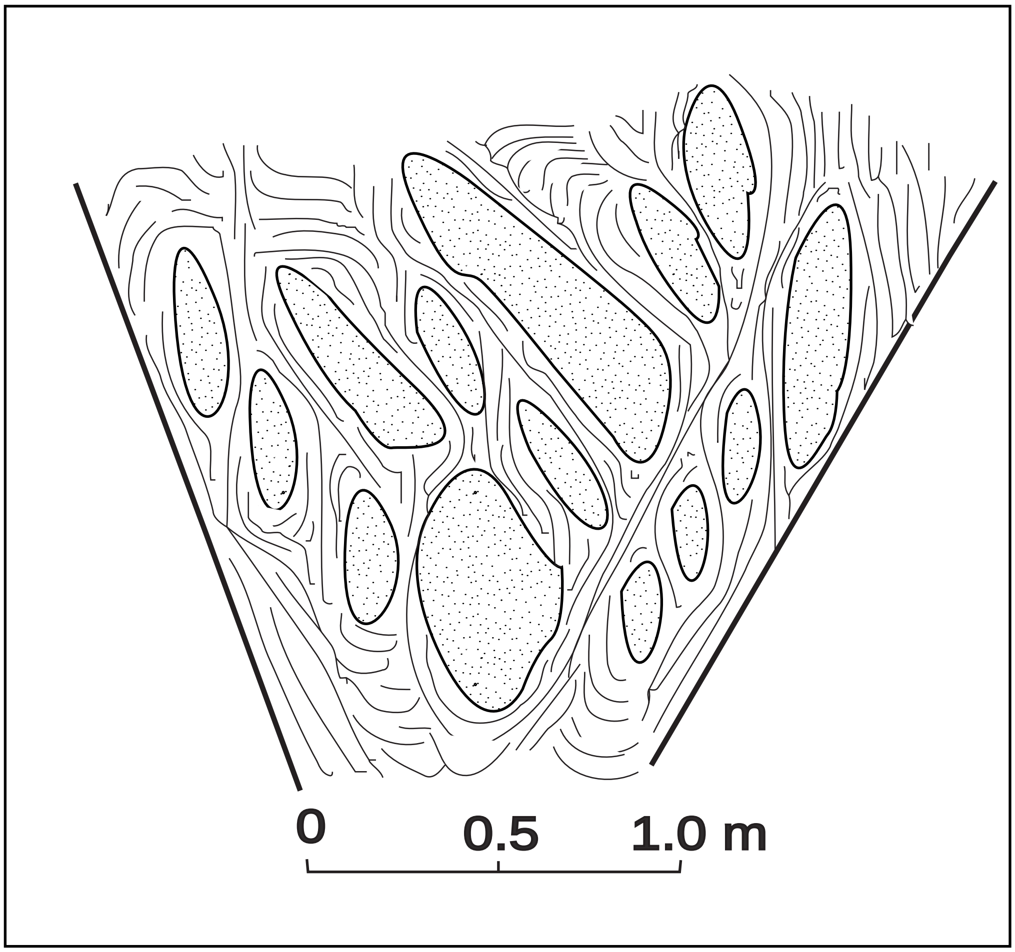

Figure 3-1-5. Phacoid development in main No. 1 shear zone of the Lannigou deposit.

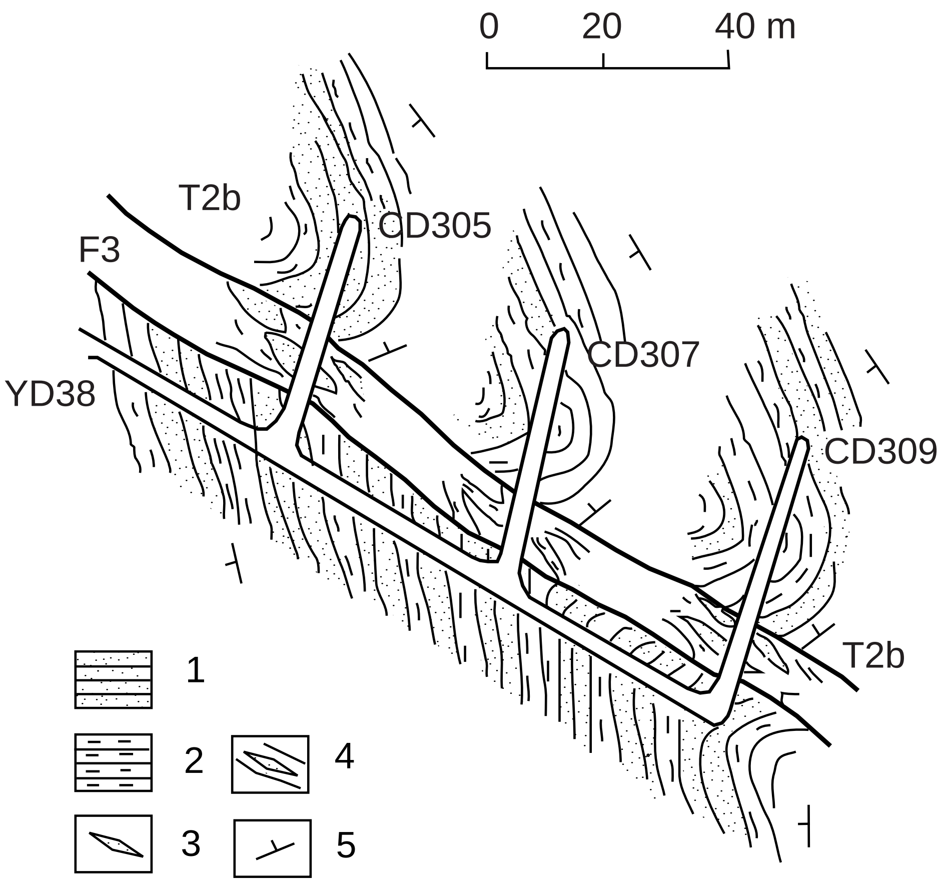

Figure 3-1-6. Part of 3^{th} level map (640 m) of the Huang-Chang-Gou block in the Lannigou gold deposit.

T2b - Bianyang group of middle Triassic: 1 - sandstone; 2 - argillite; 3 - structural lenses; 4 - fault; 5 - occurrence of stratigraphy. YD38 - strike-tunnel; CD307 - cross tunnel.

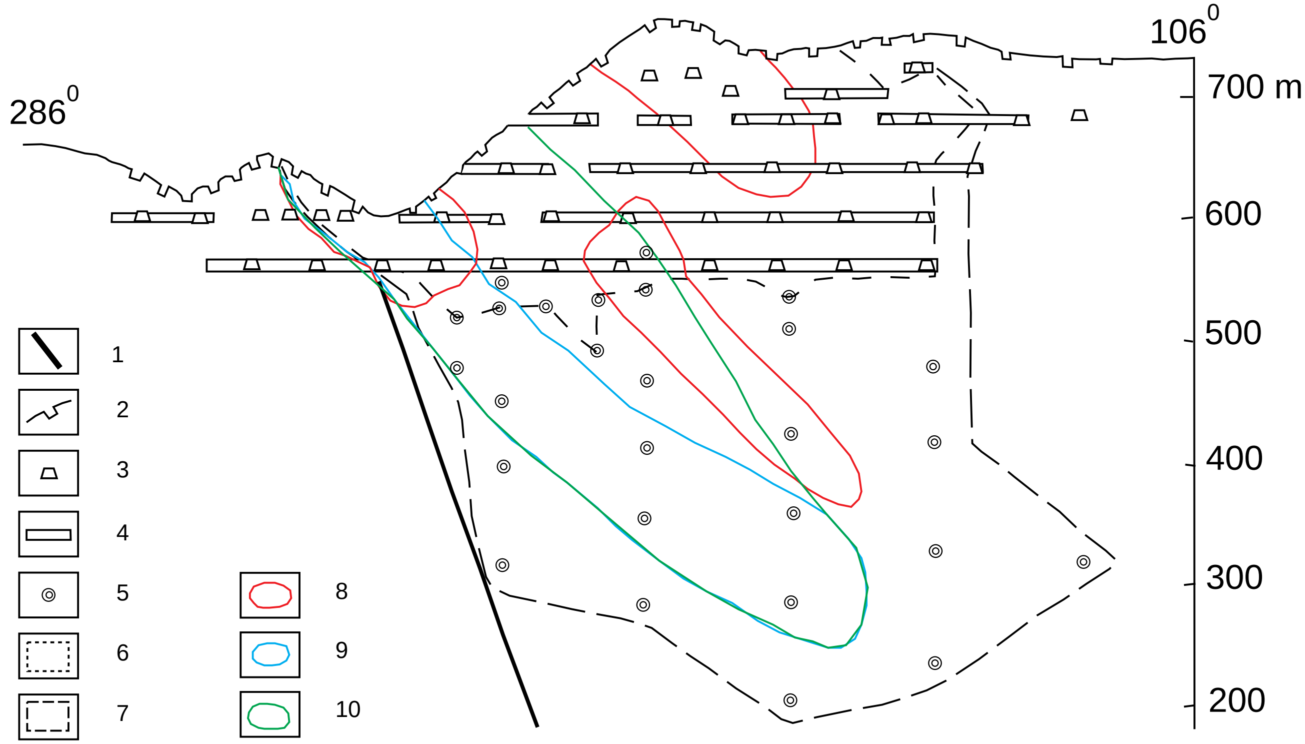

Figure 3-1-7. Projection of the No.1 orebody of the Huang-Chang-Gou block in the Lannigou gold deposit

1 - the intersection line of F2 and F3; 2 - trench; 3 - cross tunnel; 4 - strike-tunnel; 5 - drill hole; 6 - C-reserve block; 7 - D-reserve block; 8 - Au-enriching zone; 9 - As-bearing zone; 10 - Hg-bearing zone.

poor orebody blocks. In general, the tensional portions of the F_3 fault usually host rich, thick gold orebodies, and also represent the location of large areas of strain intensity within the structure. A positive correlation exists between the type of tectonite and grade of mineralization. The syndeformational relation between the gold grades and strain is also identifiable on the microscopic level. Au-bearing pyrite and arsenopyrite are concentrated in or near joints and fractures, and diminish away from these structural planes. Larger strain intensity has produced more joints and fractures with resultant strong mineralization and higher gold grade.

(2) **Lithology**: Gold mineralization in the F_3 fault occurs preferentially with specific lithology. Thin to medium-thick, fine-grained sandstone, siltstone and argillite. These observations are further verified where the F_3 fault extends to the east into the T_2x^{3-3} single massive sandstone or T_2x^4 single argillite, gold mineralization rapidly weakens or disappears. Furthermore, mineralization and alteration is very strong in some favorable rock units outside of the F_3, even in areas where the host-rock is weakly tectonized. The ore-fluid was concentrated within 3 m of the fault, where both the width of the fault and thickness of the orebody are large. The author considers that this resulted from structure-metallogenic processes, resulting from sealing of the F_3 fault and formation of an aquiclude. If the fault was formed before the orebodies and ore-fluid moved along the fault, then it is hard to imagine the ore-fluid becoming “effluent” out of the fault. However, if the fault and orebodies were formed at almost same time, the ore-forming system would still be in an open state, and the above could result.

(3) **Alteration**: hydrothermally generated pyrite and arsenic rich pyrite are important gold-hosting minerals. Gold assays of up to 123.05 ppm have been obtained from pure pyrite samples. However, not all pyrites contain gold based on SEM and TEM analyses, and observations of crystal morphology and size. Part of the orebody in the F_3 fault contain less gold in areas consisting mostly of pyrite, however, other parts of the orebody containing a combination of pyrite, orpiment, realgar, cinnabar, and stibnite have high gold concentrations. This situation holds true for the other minerals as well. Pure cinnabar contains less gold, while pure orpiment, realgar, and stibnite contain almost no gold. This phenomenon indicates that the Au-bearing pyrite was formed together with cinnabar, orpiment, realgar, and stibnite. On the other hand, the rich orebodies were formed by overprints of multiple metallogenic processes.

The No. 1 orebody has an average thickness of 10.70 m, and varies from 5.77 m to 19.77 m, up to 33.01 m; gold assay values average 7.01 ppm, with variation coefficient in grade of 81%, and varies from 4.01 to 11.01 ppm Au, up to 13.82 ppm Au. There are three gold-rich blocks in the No. 1 orebody (fig. 3-1-7). The first one, #Au-1, is present at the west end of the orebody adjacent to the junction of the F_2, F_3 faults, and is 15.80 m thick (average), with 8.46 (average) ppm Au grade, and a higher As and Hg trace element content. The second one, #Au-2, which is in the center of the No. 1 orebody, is 21.83 m (average) thick, with an average grade of 8.53 ppm Au. Most of this zone is overlain with high grade Hg zones. The third one, #Au-3, located to the east of the No. 1 orebody, is 19.14 m (average) thick and 9.20 ppm Au (average) in grade. The thickness of the three gold-rich blocks are 5.10 to 11.13 m larger than the average thickness (10.70 m) of the No. 1 orebody, and the grades are 1.45 to 1.29 ppm (Au) higher than its average gold grade (7.01 ppm). Based on a rough calculated result, the total area of these three gold-rich blocks forms only 16% of the whole No. 1 orebody, but their reserves form about 40% of its total. Most of the unmineralized phacoids are present outside of these gold-rich blocks.

The No. 1 orebody also contains anomalous As, Hg, and C. Their amounts in the ore are, As 0.12 to 1.10% (average 0.53%), Hg: 10 to 1000 ppm (average 108 ppm), and C: 1 to 2% (average 1.55%). As, Hg, and C are unevenly distributed in the orebody, of these, As and Hg are concentrated in a block (fig. 3-1-7), *in* which the amount of As and Hg is 3 times higher than the average of the whole orebody. Carbon mainly is enriched near the hangingwall and footwall and decreases in the center. Additionally, the orebody contains S: 1.35% (average), and Sb: (0.004%).

All the gold-rich blocks, As-Hg-rich block and the whole No. 1 orebody rake to east at about 45°.

Beside the No. 1 orebody, the No. 2 orebody is another important orebody in the deposit, and there also are several small orebodies, which are controlled by secondary structures, and present at the junction of the F_2, F_3 faults or the footwall and hanging wall of the orebody. These small orebodies only take a small percentage in the total reserve of the deposit.

Quality of the Ore

Composition of the Ore

(1) Chemical Composition: The result of element analyses of the ore is shown in table 1. The ores contain anomalous amounts of As, Hg, C, and S beside Au; Ag, Cu, Pb, and Zn are minor trace elements in the ores.

Table 1. Chemical composition of the ores

Element	**SiO_2**	**Fe(Tot)**	**Al_2O_3**	**CaO**	**MgO**	**K_2O**	**Na_2O**	**TiO_2**
%	65.80	3.40	10.20	4.88	1.80	2.44	0.45	0.45
Element	P_2O_5	Au	Ag	As	S	C(Tot)	Sb	Hg
%	0.24	5.80*	0.68*	0.43	1.67	1.84	0.0036	0.034
Element	Pb	Zn	Cu	LOI				
%	0.0053	0.01	0.0009	8.10				

* ppm; Analysis by the Metallurgical Design Institute of Guizhou Province

Table 2. Mineral composition of the ore

Mineral	**Quartz**	**Clay minerals**	**Carbonate minerals**	**Pyrite**	**Arsenopyrite**
%	54.25	21.80	13.58	3.20	0.62
Mineral	Carbon	Orpiment and Realgar	Other sulfide	Other mineral	
%	0.36	0.10	0.07	6.02	

(2) Mineral Composition: Mineral Composition of the ores is shown on Table 2. Ore minerals form about 4% of the ores, of these pyrite forms about 80% of ore minerals. Quartz is the principal non-ore mineral, others include clay and carbonate minerals.

Texture and Distribution of the Ore

(1) Texture: Pyrite, cinnabar, and orpiment (realgar) are often present in the ore with euhedral, sub-euhedral, and granular textures; part of these ore minerals are disseminated in the ore as xenomorphic grains.

Poikilitic textures are formed by clay minerals and quartz enclosing the ore minerals; the margin of pyrites are often altered into a girdle-band texture by arsenopyrite [ARSENIAN-PYRITE]; the earlier pyrites usually have a cataclastic texture.

(2) Distribution of the ore: Ore minerals are disseminated through the orebody and are classified into star-disseminated, open-disseminated, and thickly-disseminated, according the percentage of ore minerals. Ore with star-disseminated structure contains few minerals such as pyrite, arsenopyrite, and cinnabar; open-disseminated ore consists mainly of pyrite and arsenopyrite; thickening-disseminated ore contains cluster pyrite.

Additionally, some veinlets of pyrite, cinnabar, stibnite, orpiment (realgar) are present in or near the joints and fractures planes.

Metallurgical Property of the Ore

There are four characteristics of ore in the Lannigou deposit. The first, 81.89% of the gold is enclosed in pyrite and arsenopyrite, and the rest of the gold is present in the interspace between minerals. Pyrite contains 123.05 ppm Au; arsenopyrite contains 115.32 ppm Au, of these, 52.46% is submicroscopic gold. Second, only gold is currently of interest, but if the preparation methods are improved, As, Hg, C, and S may be beneficiated. Third, most ores are refractory with little oxide. Fourth, most gold is native gold, with a fineness greater than 90%. Based on these characteristics, ore-type of the Lannigou deposit is classified as As-bearing, low sulfide, refractory ore.

The Metallurgical Design Institute of Guizhou Province and The Changchun Institute of Gold have completed the bench-scale experiments, and recommend that the following metallurgical processes should be taken in the Lannigou gold deposit:

Preparation + concentrate ore furnacing + clinker leaching. The index for this process will be:

Floating recovery rate: 93.74% (Assay of tailings ore is 0.43 ppm Au)

Leaching recovery rate of clinker: 89.19%

Exchange rate: 99.98%

Total recovery: 83.59%.

Alteration

A combination of epithermal alteration is typical in the Lannigou gold deposit, and closely associated with gold mineralization. The width of the alteration zones is large, but they are basically distributed along and within the fault zones. Silicification and pyritization are the most important alteration types, and arseno-pyritization, carbonatization, and argillitization are also significant in the deposit. Some alteration associated with cinnabar, orpiment (realgar) is locally present in the deposit.

Silicification

Three periods of silicification are identified in the deposit. The earliest event consists of fine-grained quartz together with chalcedony, and is usually present as veinlets in fractures, which often are associated with some pyrite, arsenopyrite, carbonate, and illite. Middle-period silicification is characterized by a network structure that is made up of 1–mm-wide quartz veinlets, and co-exists with significant pyrite, arsenopyrite, carbonate, and illite. Late silicification is identified as coarse quartz crystals with clean crystal planes, coexisting with carbonate, orpiment (realgar), cinnabar, stibnite, and less sphalerite minerals.

Pyritization

The amount of pyrite usually varies from 1% to 3% in poor ore and 8% to 10% in rich ore. Argillaceous siltstone contains an average 3.20% pyrite, and up to 20%. Pyrites are mainly disseminated in the ore within the fault zone. Corresponding to the three periods of silicification, pyrites were also formed in three stages. Pyrites are classified as As-bearing or non-arsenian pyrite according to the SEM analyses. Gold is predominantly related to As-bearing pyrite, and Au assays have a positive relationship to the As content in the pyrite. Most As-bearing pyrites have girdle-banded texture, this texture being observed on a number of morphological shapes of crystals including pentagonal dodecahedron, octahedron, and cubic as well as round granular shapes. Their grain size is typically 0.01 to 0.5 mm, although some pyrites, which are enclosed by quartz and clay, are less than 0.01 mm. Pyrites are unevenly distributed in the orebody, but usually concentrate in fractures or joint planes, and become less concentrated away from these structural planes. Pyrites clearly increase their size and rank of crystal shape outside of the fault, and are present as veins in the fractures or as strips along the host rocks.

Arsenopyrite

Arsenopyrite is one of the primary ore minerals in the deposit, and is also an important gold-hosting mineral. Their size are smaller than pyrite, and vary from 0.005 mm to 0.074 mm, but their crystals are usually better developed than pyrite, being present as euhedral and sub-euhedral prisms, needle-shape, radiating aggregates, and rarely in granular shape. A crystal intergrowth of arsenopyrite and pyrite has been found in this deposit.

Carbonatization

Carbonatization (carbon introduction) includes dolomitization (ankerite) and calcite introduction. The earlier is dolomitization; the later is calcite introduction, which is associated with cinnabar, stibnite, orpiment and realgar.

Argillization

Argillization is largely illite. The illite or illite-quartz veins usually are associated with pyrite and arsenopyrite.

Geochemistry

Secondary Halo

Based on the analysis of the soil samples, 34 elements were detected. They are Si, Fe, K, Ca, Al, Mg, Na, Ti, As, Sn, Cr, V, Ba, Zr, P, Mn, Mo, Pb, Sb, Cu, Ni, Co, Sc, Zn, Y, Ga, Sr, Be, Ag, Yb, Nb, W, Au, Ag, Hg. Of these elements, Au values varied from 1 ppb to larger than 3,000 ppb, averaging 1.26 ppb; standard deviation 4.13 and variation coefficient 328%.

As calculated, the background value for gold in soil in the orefield is 1.26 ppb (the average Au value for sediments of the drainage system, which are within the whole southwest Guizhou province, a total area of 31128 km^2, is 2.1 ppb; Zhang, 1989). Seventeen (17) anomalies were defined using 20 ppb as the low anomaly value (fig. 3-1-8), of these the Au5 anomaly is 2.14 km^2, average 104.7 ppb Au, maximum 3000 ppb Au.

Geological field work confirms that the distribution of Au anomalies corresponds with the main fault zones, and their size is controlled by these structures. For instance, the Au5 anomaly, which has a large size, high value, tidy shape, and complete elemental assembly, results from ore-controlling faults. These are the WNW F_3, NNE F_2 faults in the Huang-Chang-Gou, and the NNW F_{11} fault in the Chenban, and the NW F_{14} fault in the Lintan blocks. Additionally, gold mineralization or orebodies have been found in the structures that correspond to the Au3, Au10, Au12, Au14, Au15 anomalies.

Primary Halo

In order to study the primary geochemistry halo, 12 elements (Au, As, Sb, Hg, Ba, Ag, U, Tl, Cu, Pb, Zn, and Cr) have been analyzed. The variation of Au, As, Sb, Hg, Tl, Ag seem to follow some rules in the orebodies, host rocks of the hangingwall and footwall. For instance, As, Sb, Hg are similar to Au lower in the host rocks of the hanging and foot-wall. However, the values of As, Sb, and Hg in the hangingwall are clearly larger than the footwall, that is, it shows the properties of a head geochemical halo. The values of Ba and U are just the opposite.

Correlation analysis shows that As, Tl, and Cr have a clear positive relationship with Au; Ba, U, Pb, and Zn have a clear negative relationship with Au, while the relationship between Sb, Hg and Au is not clear. Au-As-Tl-Cr-Cu, an element assemblage similar to the Jinyia gold deposit in the Guangxi District, is defined as the element combination of the Lannigou gold deposit based on the R-cluster analysis method. However, it is different from the Banqi and Yata gold deposits, which contain a Au-As-Sb-Ag-Hg element assembly. The Au-As-Tl-Cr-Cu element combination reflects the characteristics of the fine-grained clastic rocks of terrigenous origin (Zhang, 1992).

DISCUSSION ON THE MECHANISM OF METALLOGENY

Analysis for Stress-deformation of the ore-control faults

The main ore-controlling fault, F_3, shows complicated structural properties. This fault has undergone multiple structural reactivation during its long history. The author applied structural interpretation, stereographic methods to analyze the formation, evolution, stress function, and the deformation pattern for the fault F_3, referring to the regional stress field as background.

Structural interpretation shows that the F_3 fault was formed by tracing and developing a set of extensive joints, which formed as a result of east-west compressional stress. Subsequently, with lateral compression and the regional stress-field turning to the northeast-southwest, the large-scale northwest-trending structural system was formed, which included the Lintan anticline, Lannigou syncline, F_{14}, F_5 faults, a series of compressional structures and northeast shearing structures. Controlled by this regional stress field, the hangingwall of the F_3 fault moved sinistrally upward along a 250° azimuth and dip angle of 60°. The formation of northwest-trending structures caused the boundary conditions to change. Then, the regional stress field changed into northwest-southeast compression. As a result, those existing structures, such as the north-south, northwest, and northeast-southeast structures, were deformed into an "S"-shape. Some northeast compressional structures (folds and faults) were formed at the this time. Driven by this regional stress field, extension and dextral sliding took place on the F_3 fault. Its hangingwall moved along a 90° < 60° structure plane. The last structural movement for the F_3 fault resulted from a local stress field with north-west compression. This stress field also developed a series of WNW-ESE small folds, which overlay each other (fig. 3-2-2). According to the tensile strength and friction sliding theories, differential stress, enough to produce a new fault, is much more than that needed to overcome frictional forces and cause sliding along a pre-existing fault. Therefore, once the fault is formed, friction sliding along the existing fracture plane must be the primary activity of the F_3 under subsequence stress processes.

Based on the structure interpretation above, the F_3 fault must have undergone an evolutionary history of multiple compression, moving and deformation, that is, from sinistral shearing, thrust dextral sliding, extension ⇒ approximately south-north compression.

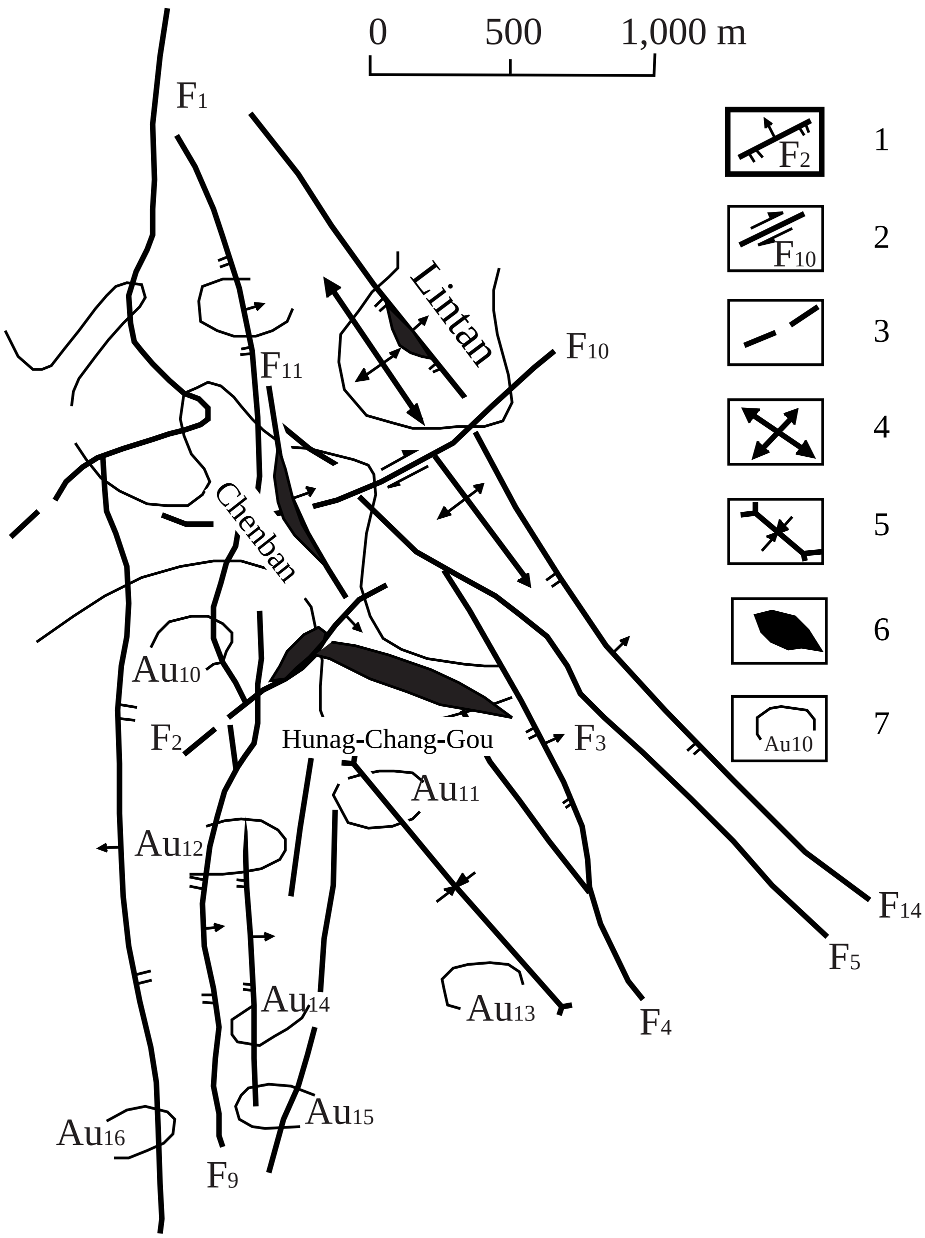

Figure 3-1-8. Distribution of soil geochemical anomaly in the Lannigou gold deposit.

1 - compression fault; 2 - shearing fault; 3 - undefined fault; 4 - axial of anticline; 5 - axial of syncline; 6 - gold

Exploration experience, combined with modern structural theory and experimentation, *in*dicates that structural movement and deformation is not only a simple mechanical process, but also a chemical process. These processes may directly or indirectly affect the formation of ore deposits or alter an existing orebody, which can cause enrichment or impoverishment, and concentrate scattered useful elements in the source strata into an ore deposit (Chen, 1983).

Evidence of Structure-Metallogeny

Relationship between Metallogeny and Structures

(1) Space relation: It is very common to find an orebody controlled by a fault-breccia-alteration zone and the No. 1 orebody in the Huang-Chang-Gou is present along such a zone controlled by the F_3 fault. The thickness of the orebody is subject to the space within the fault zone. Gold content is positively related to fracture spacing. Gold-bearing pyrite and arsenopyrite are concentrated in structural planes in or near the fault zone. Three steps of structural activity correspond to three periods of metallogeny. In the second period of metallogenic process, the main step of ore formation, the orebody occupied positions within the fault zone where pressure reduced and space extended, resulting from dextral sliding and extension. The orebody and its three gold-rich, As-Hg-bearing zones, is the result of both multiple structure movements and metallogenic processes.

(2) Temporal Relations: A metallogenic date of 82.9 ± 6.3 Ma was obtained using the fission-track dating method for the deposit by Professors Yang and Zhang from the Institute of Geochemistry, Chinese Academy of Sciences. This date is directly measured using quartz from a pyrite-quartz vein in the deposit, and considered to be the formation age of both Au-bearing pyrite and the fault-structure-material (hydrothermal quartz). The age belongs to the Yanshanion era, and is almost the same as the formation age of the structures.

(3) Stress Minerals: For specific structural stress processes, macroscopic strains are consistent with microscopic strain (rock, minerals, and crystal deformation). Stress minerals are very common in the deposit, and include stretched crystals or flattening of pyrite, orpiment (realgar), and cinnabar. Earlier hydrothermal quartzes are ground into sugar- or powder-like fragments. Vein quartz exhibits strain-shadow resulting from kinetic crystallization. Comb quartz, perpendicular to the wall, represents extensional conditions; while quartz parallel to the wall indicates a compressional environment. All of these phenomena correspond to the shear, extension and compressional properties of the F_3 fault in multiple structural-metallogenic processes.

(3) Material Resource: The orefield formed in early Permian to middle Triassic sediments developed in a continental slope environment at the margin between the continental platform and deep sea basin. Research on the Au-bearing ability of sedimentary formations formed in a transition environment between margin slope and chasm-basin from early to middle Triassic (especially, the middle Triassic), have been completed by many people. These works include the research on the available Au-bearing potential of the Bouma sequence, on other kinds of rocks in the section, and on the whole stratigraphic package, all resulting in similar conclusions. Zheng and Zhang (1989) indicated that the siltstones in the strata have an average of 20.37 ppb Au, and 17.40 ppb Au in the argillite, much higher than in other rocks, *in*dicating the ore-forming materials already existed in this area prior to structural disruption and hydrothermal alteration.

Suppose a 50-tonne gold deposit were formed if the background value of Au is 20.37 ppb, and 90% of Au were leached out from the host rocks, then, only 1 cubic kilometer of the host rock would be enough to supply the required ore-forming materials for the deposit. Since the strata is over 1,000 m thick in this area, there is a plentiful resource for the metallogeny. On the other hand, the

Nanpanjang orogenic fold zone has undergone regional metamorphism and light metamorphic rocks may exist in this area (Zhang, 1992). Therefore, with such a strong and widely regional metamorphic thermal event, it is possible for gold in the sedimentary formation to be remobilized, transported and precipitated in favorable structures, forming ore deposits. The ore-forming temperature of the Lannigou deposit varied between 172° to 265°, about the lower limit of metamorphic rocks. Therefore, the regional structure and thermal event are the heat-resource, and have provided the ore-forming environment for the deposit, and the F_3 fault, which slid with extension, producing pressure-reduced and space-extended zones, provided the space for hosting the orebody.

Discussion on the Mechanism of Structure-Metallogeny

The Lannigou gold deposit is considered to have been formed by structure-metallogenic processes. In other words, the structural process and metallogenic process took place at almost the same time and place, and started by the same mechanism and co-developed. Structural movement is the proposed driving mechanism, which produced the fault and fault zones, while strong mechanical energy was transferred into thermal energy, heating groundwater into hydrothermal fluid. The power from the structural movement drove the hydrothermal fluid, moving and leaching Au from the host rocks, concentrating on favorable structures, such as the F_3 fault, which had pressure-reduced and space-extended [dilated] zones within them, where minerals were precipitated and the orebodies finally formed. Multiple periods of structural activity resulted in the overprinting of gold metallogeny, which was also a key factor in the development of the orebodies, as it allowed them to thicken, enrich, and become uniform.

There is an indication of gold in all of the strata from middle and upper Xinyuan group to lower Bianyang group in the orefield, and the width of the Au-host strata is large in the orefield. Gold mineralization of orebodies also is present in all of the N-S, NW, NWW, and NE faults zones, *in*dicating multiple periods and simultaneous nature of structure-metallogeny.

PROSPECT DIRECTION AND CRITERION

Prospect Direction

Sedimentary environment, structural background, host rocks, alteration, and mineral assemblages are important factors when exploring for this type of gold deposit. It is necessary to emphasize that sedimentary facies and structural background are the basis for prospecting this type of gold deposit.

Specific Sedimentary Facies

According to conclusions from a former researcher, there are three sedimentary environments (or facies) with high gold value. The first one is early to late Permian argillite and tuffceous argillites, which were formed in a littoral-tidal-flat-lagoon environment (Dachang group or equivalent), with an average gold value >36 ppb. The second is a set of argillite, siltstone, and marl formed in the tidal-flat or sub-tidal shallow sea in the late Permian (Changxing group) and tidal flat environment in the early Triassic (Yielong group), with average Au grade of 8 ppb. The third one is the sedimentary strata formed at the margin of the continental slope, of these, siltstone contains 20.37 ppb Au and argillite contains 17.40 ppb Au. The statistical geochemical data from the known deposits and prospects show that the host rocks are the same as the resource strata. Therefore, it is important to prospect in these three sedimentary facies.

Specific Structure Background:

The principal structures, namely the short-axial anticline and dome structures, combined with the arc faults that surround them, control the distribution of gold fields (zones). This structural pattern is considered to be the ore-forming and ore-control structural model in the Dian-Qian-Gui area. For instance, the Gaolong gold deposit is controlled by the Gaolong short-axial anticline that is associated with a set of arc faults such as the F_3, F_4, F_9, F_{12}, F_{20} faults. The Gedang gold deposit is controlled by bedding parallel faults in the two limbs of the Jiusai dome. The Naban dome and the F_1 fault in its south limb, control the Banqi gold deposit; while the Zimudang gold deposit is controlled by the Huijiapu anticline and faults parallel to its north limb. Therefore, recognition of these specific structures is extremely important toward exploration of this region.

As a typical prospect example, the close relation between sedimentary facies and ore-control structures in the Laizishan short-axial anticline will be illustrated as follows, and their lithology, structural pattern and deformation features are much different in its both limbs.

(1) Lithology Difference: The western limb of the anticline consists of carbonate rocks (local argillite, siltstone), while the eastern limb is composed of clastic turbidites of terrigenous origin.

(2) Structure Pattern: Northeast-trending faults are well-developed in the western limb, and also a few of NW and N-S faults. In the eastern limb, northwest faults are the main structure, and less so the N-S and NE faults.

(3) Deformation Difference: The principal deformation style encountered in the western limb is brittle, and is associated with the intersection of different groups of faults. As a result, a grid-like structural patterns were formed in this limb. Ductile deformation is shown as both folds and fractures in the eastern limb; linear structures are present as structural zones.

However, there are two commonalties found on both limbs; first, both of them contain Au-bearing sedimentary rocks, secondly, both sides of the Laizishan anticline have a similar structural background. Ore-forming materials were remobilized, moved, and concentrated in the favorable structures. As a result, the Lannigou, Bannian, Ceyang, and Pogao gold deposits (prospects) are present surrounding the Laizishan anticline. In general, ore-forming material (resource beds) and the ore-forming environment are the two most important factors for prospecting for similar gold deposits.

Prospect Criterion

Prospect criterion include macroscopic and microscopic structures, alteration minerals, and geochemistry.

Structure Criterion

The close relation between gold deposits and structure imply that they are genetically related to each other. Structural activities and hydrothermal activities are derived from the same mechanism, and have undergone similar evolutionary processes. Experience shows that the potential for a gold occurrence in a fault with multiple activity stages is significantly greater than that of a fault with a single stage of activity.

(2) Alteration Criterion: Wide spread hydrothermal alteration in the host rocks is another important feature in disseminated type gold deposits. Silicification and pyritization are common however, if they co-existed with stibnite, orpiment (realgar), cinnabar or one or two of them, the possibility of finding a gold deposit is significantly enhanced. On the surface, silicification is associated with strong limonitization.

(3) Minerals Criterion: Hydrothermal quartz and pyrite are the most common minerals in these deposits. Hydrothermal quartz is usually present in different sized veins, which often intersect each other, and commonly appear with a cataclastic texture or are ground into powder-like grains. They have undulatory extinction in thin section and often enclose sulfide minerals. Pyrites usually are present as fine-grained, xenomorphic grains, or as idiomorphic crystals with pentagonal dodecahedron, octahedron and cubic morphologies, that often appear to have a girdle-band in microscopic view. SEM analyses show these pyrites contain As, and their Au grades are positively related to the amount of As. Arsenopyrite is another important gold-host mineral, it is characterized by its euhedral crystals, which form needle and prism shapes. Additionally, ankerite and calcite often co-existed with the gold-host minerals of pyrite and arsenopyrite.

CONCLUSION

The large Lannigou gold deposit, Zhengfeng County of Guizhou Province, is tectonically located at the eastern limb of the Laizishan short-axial anticline, which is part of the Yiadu-Ziyun northwest-trending structural zone. Sediments hosting gold mineralization are divided into two facies formed in the early to middle Triassic, the first is a continental slope facies formed between the margin of a platform and a deep rift basin, the second is a group of clastic rocks of terrigenous origin. These rocks not only host the ore but are also the resource strata for the ore-forming materials. The orebodies are clearly controlled by structures. Both structures and gold mineralization are consistent not only in space but also in time and are likely coeval. That is, deposits are formed by the structure-metallogeny process. In general, ore-controlling structures, typical epithermal alteration and mineral assemblies are the common features of these disseminated type gold deposits, and also are the prospective criterion.

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