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## The Zonation of Ore-forming Elements and Its Formation Mechanism Analysis of Gacun Silver-polymetallic Ore Deposit in Sichuan Province

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### 1 Introduction

The Gacun deposit is a superlarge gold-bearing and silver-rich polymetallic deposit in “Sanjiang” area (Lv et al., 2001), which is a typical deposit of the Volcanic Hosted Massive Sulfide (VHMS) (Ye et al., 1991; Hou et al., 1991a, 1991b, 2001; Li et al., 2001; Zhu et al., 2001b). Since the 1980s, many geologists have done a lot of research about the deposit, so a great deal of information has been accumulated; at the same time, as the increasing of exploitation degree, a better condition can be provided for researchers to observe and get samples for analysing. After summarizing and analysing the research achievements of the previous studies systematically, and based on the observation of geological field, indoor microscopic study and the test analysis of ore-forming elements, the authors discovered that the Cu, Ag, Au and other elements selectively enriched in the upper stratiform orebody. Therefore, this article will describe in detail for the zonation of these elements and analyze its genetic mechanism.

### 2 The Discovery of The Ore-forming Elements Zonation

#### 2.1 Geology of the deposit

The Gacun deposit is located in the east of Baiyu County of the western plateau of Sichuan, occurs in the Changtai volcanic-sedimentary basin of the Yidun arc rift generated during late Triassic. The orebodies present on the top of the marine acidic volcanic rocks, the series of volcanic rocks named Gacun group, which formed in Upper Triassic (Ye et al., 1991; Hou et al., 1995, 1996, 2001; Zhu et al., 2001b; Lv et al., 2001). The orebodies can be divided into upper layer stratiform orebody and lower vein-stockwork orebody, with the typical “double-layer structure” (Hou et al., 1991a, 1996, 2001, 2003; Bie

et al., 2000).

#### 2.2 Ore characteristics

Field trips and observation for hand specimens show that the main metallic minerals of the deposit are pyrite, sphalerite, galena and chalcopyrite. Pyrite, sphalerite, galena can be seen on both stratiform ore and vein-stockwork ore; while a large number of grainy chalcopyrite appear only on the upper stratiform ore, and hasn't been found on the lower vein-stockwork ore.

Four main metallic minerals (pyrite, sphalerite, galena, chalcopyrite) are found by microscope observation, too. A large number of the first three metallic minerals generate in the two types of ore; and chalcopyrite widely distribute in the stratiform ore with the shape of grainy, irregular flakes, but in the vein-stockwork ore only a very small amount of emulsion-shaped chalcopyrite and sphalerite featured by solid solution separation.

#### 2.3 The analysis of ore-formation elements of ore

From the analysis results (table 1) of the ore-formation elements of different ore types, we can find that the content of Cu, Sn, Sb, Au, Ag, Mo of the upper stratiform ore are higher than the lower vein-stockwork ore significantly. The ratios of the content of Cu, Au, Ag of the main mineralizing elements in the upper stratiform ore and the average content of the lower ore are as follows: 273.1, 5.3, 23.1. Zhu (2002) found that Ag mainly enriched in tetrahedrite and bornite of the upper ore, while a small amount occurred in the edges and cracks of the galena. Therefore, either directly from the analysis of data or reasoning from the occurrence mineral of Ag, we can get that the Cu selectively enriches in the upper stratiform ore.

### 3 The Analysis of Ore-forming Elements Zoning Mechanism

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**Table 1 ore-formation elements analysis results of different types of ore**

| serial number | Ore types            | Cu                  | Pb      | Zn      | Sn     | Sb                  | Au     | Ag       | Mo      |
|---------------|----------------------|---------------------|---------|---------|--------|---------------------|--------|----------|---------|
|               |                      | $\omega(B)/10^{-2}$ |         |         |        | $\omega(B)/10^{-6}$ |        |          |         |
| GC1203        | Lower vein ore       | 0.0404              | 16.93   | 26.63   | 0.0402 | 193.5597            | 0.1421 | 68.9875  | 4.773   |
| GC1204        | Lower vein ore       | 0.016               | 7.0166  | 18.02   | 0.0215 | 97.6158             | 0.0846 | 26.8161  | 5.314   |
| GC1212        | Lower vein ore       | 0.0191              | 0.7703  | 1.6975  | 0.002  | 61.0473             | 0.1568 | 9.8014   | 6.038   |
| GC1216        | Lower vein ore       | 0.0083              | 1.4045  | 11.8813 | 0.004  | 44.6375             | 0.0165 | 5.9814   | 6.603   |
| GC1223        | Lower vein ore       | 0.0236              | 0.1333  | 0.3671  | 0.003  | 48.726              | 0.0321 | 2.9384   | 4.231   |
| GC1227        | Upper stratiform ore | 5.8637              | 10.1149 | 8.4574  | 0.1137 | 8158                | 0.457  | 530.4105 | 79.5855 |

Some scholars have found that the Cu, Au, Ag, As, Pb and Zn can be migrated by vapor phase in the form of hydrate species such as  $[MeXm(H_2O)_n]^{gas}$ . When the fluid phase and melt phase separates, all ore-forming elements are preferential access to the fluid phase; but under the condition of sulfur-containing, with the vapor-brine phase separation, Au, As and some other elements usually dissolved in the vapor phase preferentially, as the complex form with  $HS^-$ , meanwhile the Fe, Zn, Pb, Mn, Cs and other elements enriched in the brine phase firstly and as the form of complex with  $Cl^-$ ; moreover, Cu is favorably partitioned into the vapor phase in the sulfur-rich systems, but favorably partitioned into the brine phase in the sulfur-poor system (Heinrich et al., 1999, 2004, 2007; Len et al., 2009).

The exhalite and jet sedimentary rocks widely distribute in the layers where the stratiform ore formed, and a lot of residual fumaroles remain in the top siliceous rocks(Hou et al., 1991a, 2001; Bie et al., 2000); the fluid inclusions in the barite of the upper stratiform ore are rich in gas extremely(Yu et al.,2000); moreover, the lower vein-stockwork ore and the upper layer stratiform ore are both formed by the same hydrothermal system(Hou et al., 1991a; Bie et al., 2000; Yu et al., 2000). Therefore, it is confirmed that the hydrothermal fluids formed the Gacun deposit are volatile-rich, whatever from macro- or micro-view.

In addition, the previous sulfur isotope studies show that the sulfur in the barite of upper orebody is from seawater and the sulfur in the metal sulfides is provided directly by the volcanic magmatic hydrothermal. Moreover, the sulfur of lower vein-stockwork metal sulfides are mainly from volcanic magmatic hydrothermal (Ye et al., 1991; Zhu et al., 2001a). Lead isotope studies have shown that the lead mainly provided by a series of volcanic material, which is continuous transition, and partly come from the underlying basement rocks of the volcanic rocks(Zhu et al., 2001a). Besides, the ore-forming metal elements are migrated by magmatic hydrothermal fluids(Yu et al., 2000; Zhu et al., 2001b).

These confirm that the hydrothermal fluids formed the Gacun deposit are not only carry a large number of metals, but also rich in a great deal of sulfur. Scientific investigation find that when the active volcanoes erupting, not only erupt a large number of volcanic material, but aslo erupt huge amounts of hydrogen sulfide gas with the special smell of rotten-egg. what'more, the density of  $H_2S$  in the black smokers fluids can reach to 12.4m mol/kg  $H_2O$ (Sakai et al., 1990; Hou et al., 1997), which means the volcanic magmatic hydrothermal fluids have a great deal sulfur as the form of  $S^{2-}$ . Generally, the  $Fe^{2+}$ ,  $Pb^{2+}$ ,  $Zn^{2+}$ ,  $Cu^{2+}$  can't coexist in the same hydrothermal system with  $S^{2-}$ , but the nature of the hydrothermal fluids will undergo a major change in the deep environment with high temperature and high pressure. For example: the water in the supercritical state can dissolve a large number of material which is insoluble under normal temperature and pressure condition(Wen and Mao,2002).

From the foregoing discussion, in the volatile-rich and sulfur-rich ore-forming fluids, there are affluent of Fe, Pb, Zn, Cu, Au, Ag. Because the volatile gases gather at the top of the ore-forming fluids selectively, as the vapor brine phase separation, the Cu, Au, Ag also gathering at the top of the ore-forming fluids with the volatile gases firstly, while the Fe, Pb, Zn are dissolved into the brine phase selectivity, riched at the middle or lower part of the ore-forming fluids. Because the upper part of the fluids are priority to participate in the mineralization process of the upper stratiform ore, which result in the Cu, Au, Ag and other elements are significantly enriched in the upper stratiform ore during the mineralization process eventually.

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