A Study on The Tectonic Control and Metallogenic Regularity of The Sanjiang Sanjiang Metallogenic Belt Cobalt Deposit in Yunnan Province

Guoti Xia *, Jianbo Yang, Ligang Fan, Chaoyong Wang

Kunming Geo-exploration Institute of China Metallurgical Geology Bureau, Kunming, 650000, China.

* Corresponding Author Email: xiaguoti@126.com

Abstract. The Sanjiang region of Yunnan is rich in minerals, especially known for gold, copper, lead zinc, and iron ore deposits. There are many genetic types of ore deposits, and most of the ore deposits (points) and anomalies are controlled by the northwest north-south structural belt. The regional tectonic activity is strong and the metallogenic conditions are superior. In this paper, the structural ore-controlling effect and metallogenic regularity of Sanjiang Metallogenic Belt cobalt deposit in Yunnan Province are further studied. The mineralization of the ore belt is most closely related to the Caledonian submarine hydrothermal sedimentation, and after mineralization, it was obviously transformed by Indosinian metamorphism and hydrothermal superposition. Some scholars have carried out relevant research on the geological and geochemical characteristics and genesis of the deposit, and think that the deposit is stratabound-reformed, jet sedimentary, hydrothermal sedimentary-tectonic reformed, etc. However, the chemical properties of ductile rocks are inactive and the permeability is poor, which makes the ore-forming fluid difficult to lose, which is beneficial to the full water-rock reaction between minerals in hydrothermal solution and surrounding rocks flowing through carbonate rocks, resulting in a large number of minerals precipitation and enrichment. When the soft and hard rocks alternate with each other, it is beneficial to form bedding detachment structure to become ore storage space, and it is also beneficial to the precipitation of minerals along the chemical interface and the enrichment of minerals.

Keywords: Keywords Sanjiang Metallogenic Belt, Yunnan, Cobalt ore structure, Ore-controlling effect, Metallogenic regularity.

1. Introduction

The Southwest Three Rivers (Nu River, Lancang River, Jinsha River) region is located in the eastern part of the Tethys tectonic domain at the junction of the Eurasian plate and the Indian plate in terms of tectonic location. Since the Early Paleozoic, this area has undergone a series of tectonic events such as oceanic crust subduction, continental arc collision, and intracontinental convergence, characterized by long-term activity. This area is characterized by frequent and intense tectonic and magmatic activities, superior mineralization conditions, and abundant mineral resources, making it one of the important concentrated distribution areas of non-ferrous and precious metal deposits in China [1]. Large-scale research work in Baiyangping area began in the 1990s, and many scholars have done a lot of work in this research area, deeply discussing its structural characteristics and ore-controlling function. The most important feature of this area is that the Middle Jurassic is directly superimposed and unconformity on the Upper Paleozoic, and the folds in the whole area are strong, belonging to dense linear or synclinal inverted folds [2]. Although it is widely distributed in the earth's crust, its content is very low. Most of the known ore belts with industrial significance in the world are magmatic Cu-Ni sulfide deposits, sandstone-shale copper deposits and associated deposits produced in ferrosilicon construction, and independent ore belts are very rare. In addition to Dahenglu cobalt mine in Jilin and Wubaoshan cobalt mine in Jiangxi, Tuolugou is one of the few hydrothermal sedimentary-hydrothermal superimposed transformation ore belts discovered in recent years [3-4]. Based on the analysis of regional geological, geochemical and geophysical characteristics, it is concluded that the abnormal combination of ore-forming elements is a direct geochemical indicator of cobalt prospecting. All the ore occurrences in the aeromagnetic interpretation area are distributed

in or near the ore-forming geological body, and the occurrence position is controlled by the change of the shape and occurrence of the ore-forming geological body [5]. The mineralization of the ore belt is most closely related to the Caledonian submarine hydrothermal sedimentation, and it was obviously transformed by Indosinian metamorphism and hydrothermal superposition after mineralization [6]. Some scholars have carried out relevant research on the geological and geochemical characteristics and genesis of the deposit, and think that the deposit is stratabound-reformed, jet sedimentary, hydrothermal sedimentary-tectonic reformed, etc. Lancangjiang fault is its main high angle thrust fault. Under the influence of its activity, a series of nappe structures are derived from the western margin of the basin, and the important deposits in the western margin are mainly controlled by thrust faults.

2. Ore control effect

The intrusion and volcanic eruption activities of Sanjiang magma have developed to varying degrees during the Variscan, Indosinian, Yanshan, and Himalayan periods, but are mainly characterized by Indosinian magmatic activity. From north to south, it presents a basic characteristic of gradual evolution from old to new, from basic and ultrabasic to acid-base. In the northernmost Xijin Ulan Yushu mineralization belt, there are records of basic, ultrabasic, neutral acidic magma intrusion activities and volcanic eruptions, spanning the Variscan, Indosinian, Yanshan, and Himalayan periods. The geological evolution history of this area can be divided into 5 stages, where the mineralization systems formed in various tectonic environments at different geological stages are superimposed, resulting in the current complex distribution of minerals. The fault structure in the mining area is very developed, and its distribution direction can be divided into three groups of faults: northwest, nearly east-west, and northeast. Each fault intersects and cuts with each other, forming the basic structural framework of the area. Among them, the northwest trending fault is the main fault in the area, controlling the stratigraphic construction, magmatic activity, and later metamorphic transformation in the area.

2.1. Geological characteristics of ore belt

There are Mesozoic strata exposed in the area, and the strata are complete. vein copper deposit and sandstone copper deposits exist in the whole Mesozoic strata in the area. Among them, the Upper Triassic Maichuqing Formation is the main ore-bearing stratum of the Shuixie copper belt. According to the geometric shape and relationship of sequence units in the tectonic basin, the area can be divided into two tectonic sequences. Structural layer A includes Triassic-Lower Jurassic, which is composed of volcanic rock formation, carbonate formation and variegated clastic rocks, and belongs to post-collision rift basin deposition. The structural layer B belongs to the middle and upper Jurassic-Cretaceous sediments, which are red clastic rocks and belong to the depression basin sediments [7]. Rock types are chlorite sericite slate, sandy slate, phyllite, metamorphic siltstone-sandstone, etc. Volcanic rocks only occur in the Luniujingshan ophiolite melange belt and are mixed in slate and phyllite intercalated with metamorphic siliceous rocks in the form of structural fragments. The geological structure in this area is complex, with faults being the most developed, followed by folds. The directions of tectonic lines are mainly northwest, northwest, northeast, east-west and north-south, among which northwest, northeast and northeast are the main directions. The upper member of Huakaizuo Formation, which is related to ore-bearing, can be divided into two sub-sections: the upper member, with a thickness of 13 ~ 280 m, is yellow-gray and grayish-green shale, mudstone mixed with thin layer of calcareous fine sandstone, calcareous shale and marl lens, with barite, pyrite and discoloring alteration, copper mineralization developed and stable horizon, which can be used as a marker layer [8].

2.2. Genesis of ore belt

The deposit obviously shows the superposition of two different genetic types of mineralization. In the early stage, it was hydrothermal sedimentary cobalt mineralization, and in the late stage, it was local enrichment of cobalt ore and hydrothermal superimposed gold mineralization. Divided into two groups according to fault nature and cutting relationship. North-North-West Formation fault: it is a pre-metallogenic fault, basically consistent with the direction of the main structural line in this area, extending northward to Changjie mining area and then turning northwest. According to the differences in ore-forming elements, mineralization characteristics, structural characteristics and ore-controlling effects, Baiyangping silver polymetallic ore concentration area can be divided into the eastern ore belt distributed along Huachangshan fault and the western ore belt distributed along the fault block sandwiched by Blind Mountain fault and Shangxiazhuang-Sishiliqing fault [9]. The eastern ore belt is closely related to the foreland thrust nappe structural system of Jinshajiang-Ailaoshan orogenic belt, while the western ore belt is closely related to the foreland thrust nappe structural system of Lancang-Changning-Menglian orogenic belt. Under the action of regional tectonic stress, the NE-trending fault gradually turns to nearly N-S direction northward. Generally speaking, it shows that most of the NE and NS faults are cut by EW and NW faults, and most of the NW and NW faults are cut by EW faults. Near-east-west faults are post-mineralization faults, with a length of 500-2,500 m and a fault distance of generally less than 200m, which often cut ore bodies. The main faults are F24 and F27, which tend to the south, with a nearly vertical dip angle and a horizontal dislocation of about 300m [10].

2.3. Characteristics of fluid inclusions

The magma activity in the area is not strong, with only sporadic diabase veins and lamprophyre veins visible. Diabase is produced in the form of rock walls and veins, found on the west side of Shuixie, distributed along fault F111. It is 5500m long and 50-100m wide, with a diabase structure. The main minerals are pyroxene and basic plagioclase, while the secondary minerals are magnetite and star shaped pyrite. The altered minerals include chlorite. At the bottom of the lacustrine deep-water basin in the backarc foreland basin, it gathers in strata such as the Huakai Left Formation, with high background values. In addition, due to the influence of regional tectonic thermal dynamics during the Yanshan period, hot brine further enriched this type of strata, ultimately forming an initial source layer for high background value strata, indicating a close relationship between strata and mineralization. The central part of the rock mass is relatively coarse, reaching medium grained and gradually becoming fine grained outward, with a small amount of later quartz interspersed. The lamprophyre is a cloud slanted lamprophyre, which is found sporadically in areas such as the Monk Mountain, Rice Grain Warehouse, Shuanghe Bridge, and Shuixie Liquor House in the Changjie area.

3. Ore-control regularity

3.1. Fault structural transformation after mineralization

Cobalt ore bodies mainly occur in the interbedded strata of gray green and gray, white quartz sandstone and sandy shale in the Maichuqing Formation, with thin layered quartz sandstone mixed with sandy shale being more favorable, such as the Xiaotuanshan deposit and Zhifanghe deposit. The second is the Yangjiang Formation argillaceous shale, mudstone mixed with quartz feldspar sandstone, such as the Alin ore section. The sandy mudstone with thin layers of fine sandstone in the Huakai Left Formation takes second place, such as the Caiyuanzi copper deposit. In short, the interlayer between quartz sandstone and sandy shale has good copper mineralization, while pure mudstone has poor mineralization. On the side of regional major structures, brittle rocks themselves often develop pores and fractures. From the gas phase composition of the inclusions in Table 1, it can be concluded that the main gas phase composition of the inclusions is H_2O, followed by CO_2. The reduction parameter R (molar ratio) =($CO+CH_4$) has a large range of R changes (0.02~1.36),

indicating that the mineralization environment in the Shuixie mining area is not unique and the degree of mineralization is also different.

Table 1 Gas phase composition of inclusions in Shuixie copper belt

Sample number	Mineral	H_2O	CO_2	CH_4	CO
SX5-2	Quartz	92.12	4.23	0.0754	3.124
SXS-1	Barite	88.23	14.12	0.0356	0.088
SX-5	Barite	84.48	16.25	0.168	-

When influenced by the regional structure, the rock breaks to form a large interlayer fracture zone, which is beneficial to the migration and enrichment of ore liquid and is a good ore storage space. The detachment fracture zone and interlayer fracture zone formed by the side of fold structure are related to mineralization. Therefore, after the early structural transformation, the deposit was subjected to the second deformation and transformation due to the influence of near-north-south compression in the later period, and several near-north-south normal faults were formed, which cut through the ore-bearing geological body, and the Tuolugou deposit was divided into three ore segments with similar characteristics due to differential uplift. It is of great guiding significance for mineral exploration to study this ore-controlling law and three-dimensional spatial distribution characteristics of ore bodies.

3.2. Stratigraphic characteristics

The nearly north-south trending fault zone controls the distribution and morphology of ore bodies, and the occurrence of ore bodies varies with the change of fault occurrence. All copper cobalt ore bodies discovered so far, without exception, occur in this group of fault zones. During the enrichment and mineralization process of ore bearing hydrothermal fluids, the bedding detachment structure plays a favorable role in the bedding penetration and migration of hydrothermal fluids. At the same time, carbonate rocks in brittle rocks have active chemical properties and are prone to mineralization through metasomatism. However, the chemical properties of ductile rocks are not active and have poor permeability. As an impermeable layer, they effectively shield the migration of ore-bearing hydrothermal fluids along the layer, making it difficult for ore-forming fluids to escape. This is conducive to sufficient water rock reactions between the mineral substances in the hydrothermal fluid and the surrounding rocks flowing through carbonate rocks, resulting in a large amount of mineral precipitation and enrichment for mineralization. According to the temperature measurement results of the study inclusions, as shown in Table 2, the mineralization temperature of Shuixie copper cobalt deposit is 142-251 ℃, with an average temperature of 194 ℃, belonging to the medium to low temperature mineralization type.

Table 2 Brief Table of Temperature Measurement of Inclusions in Water Drainage Copper Belt

Mining area	Sample number	Main mineral	Freezing point	Homogenization temperature
Shuixie Copper Cobalt Mine	SK01	Barite	-12.02	171.5
	SK02	Barite	-	162.1
	SX5	Barite	-	251
	SXS-1	Barite	-	142-236

Under the influence of regional stress, brittle rocks in the stratum peel off and break to form a broken zone, which is beneficial to the migration and enrichment of mineral liquid and is a good ore storage space. Secondly, carbonate rocks are active in chemical properties, and when hydrothermal solution flows near this kind of surrounding rock, it is easy to occur metasomatism, resulting in a large number of minerals precipitation and enrichment. When the soft and hard rocks alternate with each other, it is beneficial to form bedding detachment structure to become ore storage space, and it is also beneficial to the precipitation of minerals along the chemical interface and the enrichment of minerals. Ore bodies are strictly controlled by volcanic-sedimentary clastic rocks of Nachitai Group.

In spatial distribution, all kinds of ore bodies are produced in clastic rocks and hydrothermal sedimentary rocks of Halabayigou Formation of Nachitai Group, and the output of ore bodies is obviously controlled by horizons. The ore-bearing host rocks most closely related to ore bodies are siliceous albite, sericite schist and metamorphic sandstone, which are rich in Co, Au and Cu elements. In the process of hydrothermal deposition, a large number of metal sulfides are deposited to form cobalt ore bodies.

4. Conclusions

In recent years, with the development of large-scale resource evaluation and mineral exploration work, the superior geological background and broad prospecting prospects of the northwest section of the "Three Rivers" mineralization belt have gradually emerged and attracted the attention of scholars both domestically and internationally. The research area is located in the Changdu Lanping block in the central southern part of the Qiangtang Sanjiang orogenic system, with strong structural deformation, extremely developed fault folds, and superior geological conditions for mineralization. The main ore-controlling structures are thrust faults in the northwest northwest direction and interlayer fracture zones that slip along the layers, while the northeast trending faults are the main ore-controlling structures. Correspondingly to the level of exploration, the research level of geological and mineral resources in this area is extremely low, and some basic issues related to mineralization and major exploration difficulties have not been identified, which to some extent affects the progress and effectiveness of the work. One of the important ways to achieve breakthroughs in mineral exploration in this area is to combine production with scientific research, theory with exploration practice, strengthen comparative research with neighbors, and establish regional mineralization models and exploration models.

References

[1] Tao S H, Wei G P.Study on ore controlling fault geometry, kinematics and ore controlling law [J].World Nonferrous Metals, 2022, 43(20):10-17.

[2] Xua L, Yin Y, Jin S,et al.CSAMT constraints on the metallogenic mechanism of the Zhaishang gold deposit, West Qinling, China [J].Exploration geophysics, 2022, 4(4):16-23.

[3] WANG,Xiaohu,SONG,et al.Metallogeny of the Baiyangping Lead-Zinc Polymetallic Ore Concentration Area, Northern Lanping Basin of Yunnan Province, China [J].Acta Geologica Sinica, 2022, 31(15):24-29.

[4] Li J, Xu L L, Bi X W,et al.New titanite U–Pb and molybdenite Re–Os ages for a hydrothermal vein-type Cu deposit in the Lanping Basin, Yunnan, SW China: constraints on regional metallogeny and implications for exploration [J].Mineralium Deposita, 2021, 56(3):441-456.

[5] Liu Y, Yang Z, Yue L,et al.The Geological Characteristics and Genesis of the Jiamoshan MVT Pb–Zn Deposit, Sanjiang belt, Tibetan Plateau [J].Acta Geologica Sinica, 2020, 25(3):16-24.

[6] Yan T, Ruizhong H U, Yongyong T,et al.Types of dispersed elements bearing ore-deposits and their enrichment regularity in Southwest China [J].Acta Geologica Sinica, 2019, 23(14):16-23.

[7] Zhang L, Zhang G, Wen H,et al.Genetic implications for the Damajianshan W-Cu-As polymetallic deposit in Lvchun, Southwest China: Constraints from H–O, He–Ar, S, and Pb isotopes[J].Geological Journal, 2021, 26(11):11-15.

[8] C F L A B, C X W B.Geochemical domains and their characteristics in the middle-southern part of the Sanjiang orogenic belt in southwestern China [J].Journal of Geochemical Exploration, 2021, 12(4):9-13.

[9] Xiaohu W, Yucai S, Hongrui Z,et al.Metallogeny of the Baiyangping Lead-Zinc Polymetallic Ore Concentration Area, Northern Lanping Basin of Yunnan Province, China [J].Journal of Geology: English Edition, 2018, 92(4):22-30.

[10] Wang X, Song Y, Zhang H,et al.Metallogeny of the Baiyangping Lead-Zinc Polymetallic Ore Concentration Area, Northern Lanping Basin of Yunnan Province, China [J].Acta Geologica Sinica - English Edition, 2018, 92(4):1486-1507.