A Study on the Geological Characteristics and Genetic Types of Dashipo Andalusite Deposit in Yingjiang County, Yunnan Province

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Abstract. The Dashipo andalusite deposit in Yingjiang County, Yunnan Province is taken as an example in this article to discuss the geological characteristics of andalusite ore occurrence and to analyze the genesis of the deposit. The ore body is mainly found in the middle strata of the Upper segment of the Gaoligongshan Group in the Middle Proterozoic (Pt_2gl^2), with the ore-bearing layers consisting of Andalusite mica schist, Andalusite mica quartz schist, and Andalusite mica quartz schist. The main features of the deposit include its super-large scale, the medium to stable distribution of the ore layer, and the uniform grade changes. Most of the red feldspar in the deposit is composed of self-shaped to semi-self-shaped long columnar metamorphic crystals that are distributed along the schistosity of the ore layer. The ore material has a simple composition with relatively low content of harmful components, making it rare in China. Based on the location of the deposit, characteristics of the ore body, structural features of the ore, mineral associations, and chemical composition of the ore, it is preliminarily believed that the deposit belongs to the regional metamorphic type, which holds great significance for searching for similar types of deposits.

Keywords: Yingjiang County, Dashipo andalusite mine, Geological characteristics, Genetic type.

1. Introduction

Andalusite, an important mineral resource, is not only used as an advanced refractory for smelting but also in the production of high-strength lightweight silicon-aluminum alloys, metal fibers, and guide profiles for supersonic aircraft and spacecraft. The DASHIPO andalusite deposit has been chosen as the subject of this study with the aim of better understanding its formation mechanism and metallogenic potential through a detailed analysis and study of its geological characteristics and genetic types. Through a combination of field geological surveys, rock mineral analysis, and chemical composition testing, a comprehensive understanding of the geological attributes and genetic mechanism of the DASHIPO andalusite deposit will be achieved. This study lays the foundation for further mineral exploration and comprehensive study in the working area and provides a prospecting idea for andalusite deposits in Yunnan Province.

2. 1 Regional geological overview

The Dashipo andalusite deposit in Yingjiang County, Yunnan Province, located in southwestern China at the southernmost point of the Hengduan Mountains valley, is situated within the Bangor Tengchong magnetic arc (IX-1-3) structural unit of the Gangdisc Chayu arc base system (IX-1) of the Gangdisc Himalayan orological system (IX), as per the "Research Report on Metallogenic Geological Background in Yunnan Province" submitted by the Yunnan Geological Survey in 2013. The region's complex geological structure and strata, influenced by multiple tectonic movements and magmatic activities, have resulted in diverse geological conditions that have significantly impacted the formation of the Andalusite deposit.

Firstly, according to the 1:200000 "Regional Geological Survey Report (Tengchong Yingjiang)" and combined with some of the latest large-scale regional geological survey results, the Dashipo area has complex structures, developed fold structures, and a wide distribution of magmatic rocks. The strata have undergone varying degrees of metamorphism, and are divided into basement and cover layers according to their formation time. The basement layer is the Gaoligongshan Group (Pt_2gl) strata of the Middle Proterozoic metamorphic rock series, The cover layer consists of the Paleozoic Devonian Guanshang Formation (D_1g) and the Carboniferous Menghong Group (Cmn), with the exposed strata mainly being the Middle Proterozoic and sporadic exposure during the Paleozoic and Cenozoic eras. The Gaoligongshan Group was named by the Yunnan Regional Survey in 1965. Li Zaihui et al. (2012) believe that its main sedimentary strata may have been formed in the Neoproterozoic and underwent multiple stages of metamorphism and magmatism during the Paleozoic, Mesozoic, and Cenozoic eras.The lower member (Pt_2gl^1) is characterized by gneiss, granulite and amphibolite, and is characterized by the occurrence of more amphibolite rocks, the lower member is characterized by more feldspar-granulite facies than the upper member with less biotite-granulite facies, and the Protolith formation may be a set of sandy argillaceous flysch formations with basic volcanic rocks. The upper member of the Gaoligong Mountains Group (Pt_2gl^2) is characterized by more quartz schists and quartzites. Some of the upper schists contain metamorphic minerals characterized by graphite (1-3%), and some of the middle and lower schists often contain amphiboles, the lower intercalated siliceous rock and crystalline limestone amphibolite are seldom seen, and the degree of migmatization is obviously weaker than the former. From bottom to top, it can be seen from lithology that it represents the marine depositional environment, which is gradually stable since the rapid accumulation, and is the terrigenous construction in the subsidence stage of the riser. Secondly, the geological structures in the Dashipo area are active, such as fault zones and fold zones, which may play a key role in the formation and distribution of mineral deposits. For example, fault zones may provide channels for the migration of mineralized fluids to mineral deposits, while fold zones may affect the deformation of strata and the distribution of mineral deposits. Therefore, we need to conduct in-depth research on these geological structures to understand their impact on the deposit. Taking into account the geological characteristics and structures, the geological conditions in the Dashipo area may have a complex and diverse impact on the formation of andalusite deposits. In order to better understand the genetic mechanism of the deposit, detailed geological surveys and experimental studies are needed to reveal the correlation between geological features and deposit formation.

3. Geological characteristics of mining area

The geological characteristics of the Dashipo andalusite mining area are one of the key focuses of this study, which is crucial for understanding the genetic mechanism and resource potential of the deposit.

Stratigraphic characteristics: The strata in the Dashipo area mainly include the upper part of the Middle Proterozoic Gaoligongshan Group (Pt_2gl^2) and the exposed Quaternary (Q) strata.Geological structure characteristics: The mining area can be divided into northeast-southwest trending faults (arc faults) and northwest-southeast trending faults based on the distribution direction of faults. The northeast-southwest trending faults are compressive and torsional faults formed during the Indosinian movement, and their relationship with the andalusite ore body suggests that they belong to pre-mineralization or contemporaneous faults. On the other hand, the northwest-southeast trending faults are compressive and torsional faults formed during the Yanshan movement, and their relationship with the andalusite ore body indicates that they are post-mineralization faults.

Metamorphism: The Gaoligongshan Group metamorphic rock series of the Middle Proterozoic is the main metamorphic rock series in the mining area. This metamorphic rock belt has undergone multiple stages, multiple times, and multiple types of metamorphism. The metamorphism is mainly caused by low-pressure regional metamorphism, which is superimposed with later migmatization granitization, low-pressure thermal contact metamorphism, and dislocation (fragmentation) metamorphism. However, it is relatively less disturbed by later metamorphism.

(1) low pressure regional metamorphism

Low pressure regional metamorphism is the main metamorphism in the mining area, which is distributed in a plane type. There are certain width of schist, granulite, amphibolite, quartzite, etc., and andalusite characteristic metamorphism minerals, indicating that the regional metamorphism belongs to low pressure type and high temperature. It is the main metamorphism that formed andalusite deposit.

(2) Dislocation (fragmentation) metamorphism mainly manifests in the deformation and fragmentation of minerals in the rock (such as andalusite) under the action of stress.

(3) Contact metamorphism mainly occurs in the outer contact zone of granite bodies and derived vein rocks. It is distributed in a strip shape, roughly consistent with the contact line of the rock mass, and sporadic distribution of skarn and gneiss can be observed.

(4) Migmatization granitization is formed by the metasomatism between granite magma and surrounding rocks. The main manifestation in the mining area is migmatized biotite granite.

Wall rock alteration: Due to regional dynamic thermal flow metamorphism and tectonic hydrothermal activity, the most common wall rock alterations in the mining areas are silicification, hornblende mineralization, sericitization, magnetization, pyrrhotite mineralization, pyrite mineralization, limonitization, followed by kaolinization and skarnization. Silicification is accompanied by silicification in the entire Gaoligongshan metamorphic zone of the mining area, mainly manifested by the development of quartz veins in the form of network veins, veins, and lenses. Hornblende mineralization is mainly concentrated in the top of the andalusite mineralization belt, where plagioclase hornblende and quartz-epidote hornblende-diopside schist formations are found, with hornblende and diopside being the main minerals. Sericitization is primarily concentrated in andalusite mica-quartz schist, exhibiting strong intensity and being a product of andalusite alteration.

4. Geological characteristics of the deposit

4.1. Characteristics of ore bodies

The geological characteristics of the Dashipo red pillar ore deposit in Yingjiang County, Yunnan Province, including the characteristics of the deposit and the ore body, are of great significance to the understanding of the deposit and the development of resources.

(1) Geological characteristics of the deposit: lithology and stratigraphy: The deposit is located in the middle strata of the upper member of the Middle Proterozoic Gaoligongshan Group (Pt_2gl^2), mainly distributed in andalusite mica schist, andalusite quartz mica schist, andalusite mica quartz schist with mica schist, mica quartz schist (Adsch) and other lithologies. These formations are rich in aluminous materials, which provide an ideal material basis for the formation of andalusite.

(2) Characteristics of ore bodies:

The Dashipo andalusite deposit is hosted in the middle strata of the upper section of the Gaoligongshan Group in the Middle Proterozoic. The lithology of the ore-bearing layer consists of andalusite mica schist, andalusite quartz mica schist, andalusite mica quartz schist mixed with mica schist, and mica quartz schist (Adsch). The discontinuity in the lithology of the ore-bearing layer is currently believed to be caused by variations in the chemical composition of the original sediment, which resulted in different lithologies after regional metamorphism. This ultimately led to the discontinuity in the andalusite ore body.Based on the intrusion form of granite, the working area is divided into two ore sections: I and II. The No. 1 ore block comprises three ore bodies, distributed in a northwest-southeast layered to thick-layered manner, with a dip angle of 290° to 320° and an inclination angle of 45° to 85°. This is consistent with the stratigraphic occurrence. The No. II ore block consists of six ore bodies, distributed in a thick layer from northwest to southeast, with an attitude consistent with that of the strata. The dip angle ranges from 290° to 320°, and the inclination angle is between 30° and 80°.In terms of spatial relationship, the I and II ore sections are unfolded in a "one" shape along the direction of 215° to 220°, distributed in strips. The ore bodies of each ore section are not mentioned in the original sentence, so no further information can be provided on this.

4.2. Ore quality

4.2.1. Ore structure and structure

The ore structure of Dashipo andalusite mine in Yingjiang County, Yunnan Province mainly includes seven types.

(1) Granular long columnar structure: The andalusite is in a self shaped or semi self shaped long columnar structure, some of which are granular.

(2) Porphyric metamorphic structure: The fine-grained porphyritic structure composed of andalusite, including biotite, sericite, quartz, carbonaceous, and iron components.

(3) Scaly crystal structure: Biotite is arranged in a scaly manner, with some concentrated at the edges of andalusite.

(4) Ring structure: commonly found in ores, indicating the widespread occurrence of alteration. Sericite surrounds columnar andalusite and sometimes completely metasomatizes with andalusite.

(5) Inclusive structure: The andalusite contains components such as quartz, biotite, pyrrhotite, and carbonaceous matter.

(6) Needle like, fibrous, and bundle like structures: A small amount of amphibole and sillimanite are needle like, fibrous, and usually appear in the form of aggregates.

(7) Fragmented structure: Within the ore body, red pillar stone, magnetite, and other minerals can be seen to exhibit fragmented structures, while hematite may replace magnetite fractures.

The structure of the ore is mainly lamellar, composed primarily of scaly minerals such as biotite, sericite, and Muscovite arranged in a directional manner and filled with quartz particles. In addition, a few banded structures are present, mainly distributed in low-grade ore bodies, consisting of strips containing andalusite and strips without andalusite. Overall, the structure and texture of the ore in this deposit area are relatively simple, but diversity still exists, which is of great significance for understanding the formation and evolution of the andalusite deposit. The mineral composition in the ore is presented in Table 1 and Table 2:

Table 1. Mineral composition of andalusite ore (optical thin section identification)

Mineral name	Andalusite	Biotite	Quartz	Sericite	Muscovite	Magnetite
Mineral content(%)	25	30	15-20	20	5	Small amount

Note: represents the results of rock and mineral identification under the microscope of thin section 01; The data was analyzed and tested by the Testing Center of Kunming Geological Survey Institute of China Metallurgical Geology Administration in May 2013. Unit%

Table 2. Mineral composition of andalusite ore (X-ray diffraction)

Mineral name	Andalusite	Mica	Quartz	Feldspar	Kaolinite	Magnetite	Hornblende
Mineral content(%)	14.9	36.5	29.6	10.5	3.2	4.5	0.5

Note: Statistics of X-ray diffraction results for full hole ore sampling in DZK3902 borehole; The data was analyzed and tested by NexION 300x ICP-MS at Southwest Metallurgical Geological Testing Institute in December 2017. Unit%

4.2.2. Chemical composition of ore

The chemical composition of the andalusite ore in this area depends on the content of alumina in the rock forming minerals (Wang Jiangtao et al., 2002). In addition to the main beneficial components Al_2O_3 and SiO_2, the chemical components of the ore also include K_2O, Na_2O, CaO, MgO, Fe_2O_3, TiO_2, C, S, FeO, P_2O_5, MnO, and other components. The main and common chemical components of the ore in the area are shown in Table 3 below.

Table 3. Chemical Analysis Results Table

Original number	Test item and content(10^{-2})							
	K_2O	Na_2O	CaO	MgO	Al_2O_3	SiO_2	Fe_2O_3	TiO_2
DZK3902-H48	3.74	0.47	0.32	1.30	18.94	61.03	1.69	1.17
DZK3902-H57	2.61	1.10	1.36	1.05	15.45	67.98	1.71	1.09
TC3901-H154	2.57	0.12	<0.03	0.25	16.25	58.65	<1.00	0.26
DZK4703-ZH11	3.58	0.88	0.56	1.07	17.18	66.82	1.10	0.70
DZK4702-ZH13	3.44	0.70	0.66	1.07	16.94	66.27	1.79	0.74
DZK3903-ZH19	3.32	0.94	0.94	1.09	16.16	67.57	1.39	0.70
DZK3902-ZH21	3.74	0.42	0.34	1.23	19.65	62.71	2.44	0.81
Original number	C	S	FeO	P_2O_5	MnO	Loss on ignition	Andalusite (X-ray diffraction analysis)	
DZK3902-H48	0.27	0.34	6.00	0.13	0.11	2.60	23.8	
DZK3902-H57	0.12	0.79	4.51	0.16	0.10	2.51	11.3	
TC3901-H154		0.04	<0.70		0.03		20.1	
DZK4703-ZH11	0.37	0.14	4.87	0.15	0.13	1.56	>5-<10	
DZK4702-ZH13	0.12	0.09	4.72	0.17	0.16	1.96	>10	
DZK3903-ZH19	0.26	0.39	4.53	0.16	0.12	1.31	>5-<10	
DZK3902-ZH21	0.15	0.14	5.10	0.22	0.15	2.13	>10	

(1) Beneficial components: According to the "Experimental Research Report on Comprehensive Utilization Technology of Yunnan Andalusite", Dashipo Andalusite ore contains available beneficial components, mainly including Al_2O_3 (aluminum oxide), SiO_2 (silicon dioxide), and Rb_2O (rubidium oxide).

Although Sc (scandium) in the ore has been preliminarily enriched during the magnetic separation process, its content has not yet reached the standard grade for industrial recovery. Therefore, further research is needed to improve the recovery technology of low-grade scandium while recovering rubidium salts, in order to achieve comprehensive evaluation and utilization to the greatest extent possible. In addition, the total content of rare earth elements in the ore is low and dispersed in various minerals. Through mineral processing, it is possible to enrich a portion of the ore mud (up to 1.7 times the original content), but it has not yet reached the grade standard required for comprehensive utilization.

(2) Harmful components: According to industry standards (YB4032-2010), attention should be paid to the content of harmful components in andalusite raw materials used for steelmaking refractory materials, including K_2O (potassium oxide), Na_2O (sodium oxide), Fe_2O_3 (iron oxide), and TiO_2 (titanium dioxide). The Dashipo andalusite ore has a relatively low content of harmful components. After beneficiation and enrichment, the harmful component content of HJ-55 grade andalusite concentrate is relatively low, with R_2O (K_2O+Na_2O) of 0.355%, Fe_2O_3 of 1.46%, and TiO_2 of 0.11%, respectively. This meets the requirements for refractory material preparation and helps to ensure the quality of the product.

4.3. Ore types

According to the types of useful minerals and the origin of minerals, the industrial type of ore in the area is andalusite ore and the natural type is andalusite schist type.

5. Discussion on genesis and metallogenic age of ore deposit

5.1. Metallogenic genesis

The Dashipo andalusite deposit undergoes regional metamorphism as the main mineralization process, which may be superimposed by thermal contact metamorphism in the later stage. The andalusite in the deposit primarily consists of iron aluminum oxide minerals, typically formed in high-temperature and low-pressure hydrothermal environments. Studies have revealed that the region has experienced numerous geological tectonic movements, including tectonic uplift and fault activity. These movements may create pathways for hydrothermal activity, enabling underground fluids to dissolve and enrich elements such as aluminum and iron, and precipitate under suitable conditions to form andalusite deposits.

5.2. Metallogenic age

The determination of the mineralization era is crucial for understanding the formation history of mineral deposits. According to the LA-ICP-MS dating results of metamorphic sandstone samples from the Gaoligongshan Group collected by Zhou Meiling (2019) in the southwest of Taiping Town, Yingjiang County, the main minerals of the collected samples are similar in composition to the ore minerals in the working area in Table 2, including quartz (30%), plagioclase (30%), biotite (15%), muscovite (15%), and microcline (10%). The measurement of harmonic age is primarily concentrated in three intervals: 382-339 Ma (peak value 359 Ma), 592-517 Ma (peak value 569 Ma), and 1289-1010 Ma (peak value 1162 Ma). The minimum age characteristic peak is 236 Ma, indicating that its maximum sedimentary age is the Triassic period. The main age characteristic peaks of the Cambrian and Triassic systems are ~530 Ma and ~1110 Ma, which can be compared with the detrital zircon age spectrum of the Lhasa terrane in central Tibet. This suggests that the early sedimentary basins of the Tengchong terrane mainly received sedimentary materials from the Australian continent.

In addition, based on regional geological background data, it is estimated that the mineralization age of the Dashipo andalusite deposit should have started during the Triassic period, when plate collisions occurred in the Dashipo area, providing a suitable environment for pressure and temperature for the mineralization of andalusite. The Dashipo andalusite deposit is hosted in the upper part of the Middle Proterozoic Gaoligongshan Group (Pt_2gl^2) andalusite mica quartz schist, surrounded by late Paleogene biotite granite (Li Xinmin et al., 2021). The Gaoligongshan Group is like a large captive body, and the distribution of the ore body is not limited to the vicinity of the rock mass, without direct genetic connection to the granite body. Due to the intrusion of granite, andalusite fractures and bending phenomena were found in the mining area, indicating that the formation of andalusite deposits occurred before the intrusion of Yanshanian granite.

It is speculated that the Dashipo andalusite deposit was formed between the Triassic and Paleogene periods, based on the above information. However, the specific era may require further precise methods such as radioisotope dating to determine. In addition, this view is supported by the geological structure characteristics of the Dashi slope area, as the area experienced numerous tectonic deformations and magmatic activities during this period, providing the necessary geological conditions for the formation of the deposit.

6. Conclusion

In summary, the genesis of the Dashipo andalusite deposit is diverse and complex, The main mineralization is regional metamorphism, which may be related to contact metamorphism caused by magma intrusion. The mineralization era may have spanned from the Triassic to the Paleogene, and further chronological research is needed to determine the exact time range in order to have a more comprehensive understanding of the formation history of the deposit.

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