Study on the Current Situation and Utilization of Titanium Ore Resources in Yunnan

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Abstract—In view of the development and utilization of the titanium industry in Yunnan Province, the paper expounds the current situation and utilization of titanium resources in Yunnan Province, introduces the main mineralization and main element analysis results in central, southern and western Yunnan, and introduces the current development situation of titanium resources in Yunnan Province and puts forward suggestions. Yunnan Province is rich in titanium placer resources, with excellent beneficiation and processing performance and low mining and dressing costs. The construction of a full set of production lines for titanium industry can achieve the goal of making full use of the advantages of titanium resources in Yunnan Province.

1. Introduction

Titanium is one of the most widely distributed and abundant elements in the crust, with high abundance (6.320×10^{-3}) [1], with a conversion rate of 0.58%, is a metal element in the crust, which is second only to aluminum, iron, calcium, sodium, potassium and magnesium. Titanium resource is known as the "third metal" because of its increasing use, second to iron and aluminum.[2] Although the content in the crust is large, it is considered as a rare metal because it is dispersed in nature and difficult to extract. Titanium is easy to combine with oxygen due to its strong activity. There is no simple titanium in nature. Titanium in minerals mainly exists in the form of TiO_2 and titanate, often coexists with iron, forming various minerals. There are more than 140 minerals with TiO_2 content more than 1% alone, of which only 10 are of industrial value, mainly rutile, ilmenite, titanomagnetite, anatase, white titanium, perovskite, etc.[3] According to the U.S. Geological Survey (USGS) "Mineral Commodity Summaries 2019" (U.S. Geological Survey, 2019), the world's titanium resources amount to 2 billion tons (TiO_2), mainly distributed in Australia (reserves accounting for 29.68%), followed by China (24.46%), India (9.83%), South Africa (7.59%), Kenya (7.13%), etc. Among titanium resources, ilmenite accounts for 89% of the total resources, and the rest are rutile and anatase.[4]

Titanium is widely used in aviation, aerospace, petroleum, chemical industry, electric power and other important industrial fields, so it is also known as "modern metal", "space metal", "strategic metal" and "high-tech mineral".[5] It is an indispensable metal raw material for modern industry and cutting-edge science and technology, an important mineral required by China's strategic emerging industries, and plays an important role in the future development of science and technology. Rutile and anatase are almost composed of pure TiO_2, which are high quality raw materials for producing high-end titanium materials. As China's rutile accounts for only 3% of the country's titanium ore resources, the utilization of titanium ore resources has been in a state of "low end titanium ore supply exceeds demand, and high-end titanium ore depends on imports".[4] At the same time, China's natural rutile raw ore TiO_2 has poor resource endowment, low grade, fine particle size, and many kinds of associated minerals, resulting in poor selectivity, low recovery, and difficult to large-scale development and utilization.[6] The import of titanium ore in China is on the rise year by year. In 2021, China's dependence on foreign titanium raw materials will be about 40%.[7] In view of the increasingly tense international political and economic environment, it is bound to affect the international titanium ore trade. It is of great significance to strengthen the understanding of the titanium ore resources in Yunnan Province and strengthen the development and utilization.

2. Overview of titanium ore resources in China

China is a large country of titanium resources, and titanium ores are distributed in 27 provinces and cities. According to the China Mineral Resources Report 2022, by the end of 2021, the proven reserves of titanium ores converted into titanium dioxide will be 224 million tons, a net increase of 22.6713 million tons over the previous year, or 11.27%. Titanium resources are divided into three types: ilmenite placer, ilmenite rock ore and rutile rock ore.

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See Table 1 for the summary of major titanium ore resources in China.

Table 1 Resource profile of major titanium ore deposits of large size and above in China

Mineral land	Main minerals	Reserves (10000 tons of TiO_2)	Grade
Sichuan	Vanadium Titanium Magnetite	7000	4.9~11.8%
Shandong	Rutile	3600	1.4~1.7%
Hebei	Rutile	2900	5%
Yunnan	Ilmenite	2800	9.3~114.3kg/m^3
Shaanxi	Rutile	2200	1.9%
Hubei	Titanomagnetite, Rutile	2100	2.3~5.7%
Guangxi	Ilmenite	1700	21.7~33kg/m^3
Guangdong	Vanadium Titanomagnetite, Titanomagnetite, Ilmenite	1300	5.3~36.1kg/m^3
Hainan	Ilmenite	800	33.5kg/m^3
Henan	Rutile	620	2.2%
Shanxi	Ilmenite, Rutile	560	1.9~2.0%
Inner Mongolia	Anatase, Ilmenite	520	6.9%
Jiangsu	Ilmenite, Rutile	300	2.8~80.7kg/m^3

China is not rich in titanium ore placer resources, ranking sixth in the world according to foreign statistics, and the quality of placer is not as good as foreign countries; The deposits are relatively scattered, and no large placer deposit has been found, which is unfavorable to the development of China's titanium industry.

3. Titanium resources in Yunnan Province

3.1 Basic situation of titanium ore resources in Yunnan Province

There are 30 proven titanium iron deposits in Yunnan Province, including 15 large deposits, 5 medium deposits and 10 small deposits. The proven ilmenite reserves are 55.61 million tons, including 32.65 million tons of high-quality ilmenite reserves, with an average titanium dioxide grade of 5%~12%. The titanium ore reserves measured by TiO_2 are 389,373t, and 390,273t has been found accumulatively. Moreover, the geographical location of mineral deposits is concentrated. The titanium reserves in central Yunnan, represented by Wuding, Lufeng, Luquan and Fumin, account for more than 70% of the province's total.[8-11] It is mainly distributed in 6 large areas, including Wuding, Luquan, Maitreya, Dali, Tengchong, Jinghong and Fumin. Large reserves, high grade, easy to exploit, simple beneficiation process, low production cost, less harmful impurities and good quality of titanium concentrate.

The titanium ores in the central Yunnan Province are mainly eluvial and deluvial titanium placers, which are distributed intensively. A total of 30 million tons of B+C+D titanium placer reserves have been obtained; The metallogenic belt is adjacent to Kunming, with convenient transportation, good external conditions, high titanium ore grade, good mineral washability and fine concentrate quality; The ore body is exposed on the surface, and the mining conditions are superior. It is a "near, shallow, rich and easy" titanium ore resource that can be used in the near future.

Residual slope titanium placers in central Yunnan are concentrated in Wuding, Luquan and Fumin counties. After deducting the amount of mined ores, the titanium placer resource reserves are 16.4 million tons; The average TiO_2 grade is 80 kg/m3, the highest grade is 151 kg/m^3, and the lowest grade is 20 kg/m^3; The average thickness of the ore body is 7~8m, the maximum thickness is more than 10m, and the minimum thickness is 5m; The ore body is buried shallowly.

3.2 Distribution and characteristics of titanium resources in yunnan province

There are three types of ilmenite deposits in Yunnan. The main type is Hercynian gabbro diabase weathering crust laterite type sand deposit; The secondary type is lake river alluvial sand deposit transformed from laterite sand deposit; The third type is the fluvial alluvial zircon, monazite, xenotime and ilmenite comprehensive sand deposit related to the adamellite in the southern part of the Hercynian Indosinian Lincang composite rock body, which has a small titanium resource reserve.

The titanium placer resources in Yunnan are mainly distributed in central, southern and western Yunnan, with the largest titanium reserves in central Yunnan. The titanium sand mineral resources in the central Yunnan region are located in Wuding Luquan area, and in the western mountain area of Kunming Fumin area. The titanium sand mineral resources in southern Yunnan are from Mile Jianshui Shiping, while those in western Yunnan are from Eryuan, Baoshan and Menghai.

3.2.1 Titanium Resources in Central Yunnan

The titanium placer deposits in central Yunnan are weathering crust laterite type placer deposits. The ore

types are mainly slope deposit, eluvial slope deposit sandy soil type placer and slope deposit, eluvial slope deposit laterite type placer. The scale, grade, area and thickness of weathered crust titanium placer deposit are closely related to the thoroughness of laterization. The more complete laterization is, the better the useful minerals will be dissociated, and the less residual rock debris will be, which can form a high grade rich ore that is easy to be mined and selected. In terms of ore type, lateritic placer is rich in grade and relatively few in reserves. The ore is mainly composed of loam, sericite and a small amount of quartz sand, ilmenite and magnetite; Sand type placer is the main body of ilmenite storage, with relatively light color. Its composition is the same as that of laterite type, except that clay is reduced, rock debris is increased, and residual structure of basic rock is occasionally seen.

The reserve statistics of some ilmenite deposits in central Yunnan are shown in Table 2, and the quality of titanium concentrate in some mining areas is shown in Table 3.

Table 2 Reserves statistics of some ilmenite deposits in central Yunnan

Mining area	Grade （kg/m^3）	Reserves （10000 tons）
Wuding	63~111	650
Luquan	56~153	581.4
Fumin	35~110	593

Table 3 Chemical Analysis of Titanium Concentrates in Some Mining Areas in Central Yunnan (%)

Element	TiO_2	ΣFe	CaO	MgO	SiO_2	Al_2O_3	V	P
Wuding	44~48	34~38	<0.05	0.5~1.2	1.2~2.9	0.6~1.1	<0.20	<0.03
Luquan	48~49	35~37	<0.2	0.7~1.0	<1.3	<0.7	<0.12	<0.03
Fumin	49~50	35~37	0.1~0.3	0.9~2.0	0.8~1.5	0.2~0.8	—	0.002~0.023

3.2.2 Titanium resources in southern yunnan

The titanium ore resources in southern Yunnan are mainly distributed in "Maile Jianshui Shiping". The junction area of Maile, Kaiyuan and Jianshui counties is the main occurrence area. Most of the titanium placers are produced in Panjiang Township of Jianshui. The ilmenite deposit in Panjiang mining area belongs to gabbro diabase weathering crust type deposit, and the ore type is consistent with that in central Yunnan. The minable thickness of the ore body is generally 10m, and the maximum is 20m. The reserve of ilmenite in this mining area is about 6 million tons, and the prospective reserve is more than 10 million tons. Ore washability is good, concentrate quality is good, especially calcium and magnesium content is low. See Table 4 for chemical analysis results of titanium concentrate in Jianshui Panjiang mining area.

Table 4 Multi element Analysis Results of Typical Titanium Concentrates in South Yunnan (%)

Element	TiO2	ΣFe	CaO	MgO	SiO2	Al2O3	V	P
Content	47~49	34~36	<0.05	<0.2	0.9~1.1	<0.4	<0.3	<0.05

In addition, titanium placer deposits are also found in Jinping County, southern Yunnan. There are residual slope type titanium placers and alluvial type titanium placers in Funing area, southeast Yunnan. This area has certain resource potential and good prospecting prospects.

3.2.3 Titanium resources in western yunnan

The titanium ore resources in western Yunnan are rich, mainly distributed in Baoshan Banqiao metallogenic belt, Menghai metallogenic belt and Eryuan metallogenic belt. Banqiao metallogenic belt and Menghai metallogenic belt are mainly lacustrine and fluvial alluvial titanium sand deposits transformed from weathering crust type titanium sand deposits. The reserves of titanium resources in Banqiao area are large, and the proven reserves are nearly 6 million tons at present. However, the titanium placer ore is located under the farmland, which is difficult to develop. Moreover, the grade of ilmenite in the whole mining area is low, and it is difficult to use in the short term. The reserves of ilmenite in Menghai metallogenic belt are small, and the B+C+D reserves are only about 150000 tons.

The titanium placer resources with high development and utilization value in western Yunnan are mainly in Dali Prefecture, which belongs to the weathered crust laterite type titanium placer deposit. The ore has good washability, low impurity content of titanium concentrate, and especially low content of CaO and MgO. See Table 5 for multi-element analysis results of typical titanium concentrates in western Yunnan.

Table 5 Multi element Analysis Results of Typical Titanium Concentrate in Western Yunnan (%)

Element	TiO2	ΣFe	CaO	MgO	SiO2	Al2O3	V	P
Content	47~49	36~38	<0.05	<0.06	<0.8	<1.3	<0.2	<0.01

4. Current situation of titanium resources development in yunnan province

Most of the titanium placer resources in Yunnan Province exist on the surface without waste rock overburden, so stripping operation is not required. The mining method of titanium ore is relatively simple, mainly water mining, supplemented by mechanical mining. The stoping process is: water gun flushing - sand pumping, supplemented by vertical deep hole springing blasting for loosening or bulldozer stacking. The mining recovery rate can reach 98%, and the dilution rate is 2%. The titanium placer ore in Yunnan Province has simple mineral properties and is easy to concentrate. The general beneficiation process is multi-stage water washing gravity separation magnetic separation process.

There are more than 100 titanium concentrate manufacturers in Yunnan, mostly small private or private enterprises, with an annual output of about 800000 tons of titanium concentrate. As small-scale miners in Yunnan mainly adopt water mining, the beneficiation technology is backward. The recovery rate of ilmenite is only about 50%. The waste of resources is extremely serious. At the same time, the backward mining and dressing technology has caused serious damage to the ecology. First, the stope has formed a steep slope with a height of 10-20m and more than 70 ° . The weathered crust of the stope is loose and porous, and ground cracks have occurred in many places behind the stope and slope. Second, the tailings dam of mineral processing is simple and crude, which is stacked with sandbags and has poor stability. It has broken many times, causing serious environmental pollution. Third, no vegetation restoration has been carried out after the abandoned stope and the relocation of the concentrator. Effective exploitation and rational utilization need to be strengthened.

5. Conclusion

Yunnan Province is rich in titanium placer resources, with excellent mineral processing performance and low mining and dressing costs. Except for the titanium placers in Guangdong and Guangxi, the quality of Yunnan titanium concentrate is the best. The titanium placer resources in Guangdong and Guangxi are nearly exhausted, and the advantages of Yunnan titanium resources are increasingly prominent. Yunnan Province should become an important production and deep processing base of titanium products in China. However, at present, the development of titanium resources in Yunnan Province only stays at a low level of utilization. Environmental damage and resource waste are very serious, and economic benefits are extremely low.

In order to speed up the development and utilization of titanium resources in Yunnan Province, combined with the advantages of hydropower resources in the province, a full set of production processes of titanium industry from titanium rich materials to titanium dioxide products, as well as sponge titanium products to titanium alloys and titanium materials can be built, so as to vigorously develop the titanium industry and make full use of the advantages of titanium resources in Yunnan Province.

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