Mineralogical characteristics of iron ores in the Panzhihua deposit, Yunnan province, China

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1. Introduction

The Panzhihua deposit belongs to the orthomagmatic type, producing mainly iron. Usually, Banded Iron Formation (BIF) is important economically for the iron resources. However, the orthomagmatic-type iron deposits occur abundantly in China, in particular related to basic～ultrabasic intrusive rocks at the southern part of Yunnan province. All of iron orebodies in this area are characterized by the minor elements of vanadium (V) and titanium (Ti). It is reported that the Panzhihua deposit varies from 20 to 40 in Fe weight %, from 8 to 16 in TiO_2 weight %, and from 0.15 to 0.5 in V_2O_3 weight % (Roskill, 1986; Shu et al., 1989). This chemistry is quite different from the Kiruna-type deposit belonging to orthomagmatic type. The iron ores of the Kiruna-type are relatively rich in SiO_2, Al_2O_3 and P_2O_5. BIF ores are also relatively rich in P_2O_5 contents in contrast to the Panzhihua deposit. The elements of Ti and V are very effective for some of iron and steel products. The geochemistry and distribution of Ti and V of in ores, however, have been not made clear. It suggests strongly that the economically important elements have not completely recovered form the iron ore. In addition, we have a big problem that the geologic pollution originates into the remained elements V and Ti into the wastes. The considerable importance is to define the distribution pattern of V and Ti in ore as well as mineral species.

2. Geology and Ore Deposits

The basic～ultrabasic intrusive rocks distribute widely with more than 150km elongation from north to south at the southern part of Yunnan province. The intrusive rocks accompany a lot of iron deposits with by-products of Ti and V. The Panzhihua deposit is the most representative of all in this area, occurring associated with gabbroic rocks. The gabbroic rock intrudes in Precambrian carbonate rocks and is overlaid by Triassic formations. The gabbroic rock is accompanied by the Indosinian stage granite and syenite. The iron orebodies distribute as a stratiform structure at the basal zone of the gabbroic body.

The gangue minerals of wall rock (gabbroic rock) are composed of primarily hyperthene, plagioclase, hornblende and small amount of quartz, and secondarily chlorite and calcite. The iron ore consists of predominantly ilmenite-hematite system mineral and ulvospinel-magnetite system mineral. Pyrrhotite and rutil occur also pervasively in small amounts. The three species of ilmenite-hematite, ulvospinel-magnetite and pyrrhotite are principally in primary paragenesis and occur in the texture of mutual boundaries. Ilmenite-hematite system mineral also occur very rarely as exsolution lamellae in ulvospinel-magnetite system mineral. Rutil occurs quite in small amount, and occurs necessarily as exsolved products from ilmenite-hematite, and ulvospinel-magnetite system minerals. It is the most important characteristic that almost all of ilmenite-hematite, and ulvospinel-magnetite system minerals are homogeneous under microscopic observation.

3. Chemistry of Ore and Mineral Species

Major chemical compositions of ore specimens vary from 14.5 to 46.3 in Fe_2O_3 wt%, from 6.4 to 7.8 in MgO wt%, from 21.8 to 43.9 in SiO_2 wt%, from 8.4 to 14.2 in Al_2O_3 wt%, from 6.9 to 11.7 in CaO wt%, and 3.0 to 9.7 in TiO_2 wt%, Vanadium (V) as a minor element varies from 3000 to 9000ppm.

Chemical compositions of hyperthene are composed of mainly SiO2, CaO, MgO and FeO* (FeO* is calculated as total Fe). The chemical variations are from 51.2 to 54.6 in SiO_2 wt%, from 1.3 to 22.4 in CaO wt%, from 14.1 to 24.5 in MgO wt%, and from 6.1 to 20.6 in FeO* wt%. Aluminum (Al) is contained in small amounts ranging between 1.0 and 4.6 in Al_2O_3 wt%. V, Ti and chromium (Cr) are nearly free varying up to 0.1 in V_2O_3 wt%, up to 1.7 in TiO_2 wt% and up to 0.2 in Cr_2O_3 wt%. Hornblende is composed of mainly SiO_2, Al2O3, FeO*, MgO, and CaO, MgO. The chemical compositions in weight % vary from 38.8 to 43.8 for SiO_2, from 11.0 to 13.2 in Al_2O_3 wt%, from 12.2 to 14.1 in MgO wt%, and from11.2 to 12.1 in CaO wt%. CaO contents are nearly in unity. TiO_2 and Na_2O contents in weight % are necessary varying from 3.0 to 5.2, and from 2.1 to 3.4, respectively. V_2O_3, Cr_2O_3 and K_2O are nearly free, varying up to 0.3 in V_2O_3 wt%, up to 0.07 in Cr_2O_3 wt%, and from 0.5 to 1.1 in K_2O wt %. Major compositions of plagioclase consist of mainly SiO_2, Al_2O_3, CaO and Na_2O. While, TiO_2 and V2O3 are quite free varying up to 0.08 wt %, and up to 0.04 wt%, respectively. Chlorite is composed of mainly SiO_2, Al_2O_3, FeO*, MgO, CaO and Na_2O. The TiO_2 and V_2O_3 contents are also nearly free, varying up to 0.6 wt % with an exceptional value of 4.8 wt%, and up to 0.16 wt%, respectively.

The chemical compositions of the ilmenite-hematite system mineral consist of mainly TiO_2, FeO*, and MgO. The chemical variations are from 3.4 to 53.4 in TiO2 wt%, from 26.6 to 80.0 in FeO* wt %, and from 0.2 to 18.8 in MgO wt%. Al_2O_3 and MnO are necessary, varying up to 5.8 wt% and from 0.3 to 2.8 wt%, respectively. V_2O_3 variation is ranged between 0.31 and 0.70 wt% with exceptional value of 1.3 wt%. CaO, Na_2O, K_2O and Cr_2O_3 are nearly free. While, the chemical compositions of the ulvospinel-magnetite system mineral consist of TiO_2, Al_2O_3, and FeO*. The chemical variations in weight % are ranged between 4.0 and 15.9 for TiO_2, between 0.5 and 12.1 for Al_2O_3, and between 68.9 and 84.9 for FeO*. MgO is necessary varying up to 4.8 wt%. MnO, CaO, Na_2O, K_2O and Cr_2O_3 are nearly free. V_2O_3 vary from 0.4 to 1.5wt%. The V_2O_3 values seem to be higher than that of the ilmenite-hematite system mineral. On the contrary, pyrrhotite of the Fe-S system mineral does not include Ti and V.

The relationship between TiO_2 and V_2O_3 indicates a positive correlation for the ulvospinel-magnetite system minerals contrary to the ilmenite-hematite system minerals. In addition, the diagram relating TiO_2 to V_2O_3 shows that the values of ulvospinel-magnetite system minerals are plotted in the area higher that the ones of ilmenite-hematite system minerals. The FeO*-V_2O_3 relationship represents a negative correlation for the ulvospinel-magnetite system minerals, while a scattered distribution for the ilmenite-hematite system minerals. In consequence, the relationship of TiO_2 against FeO* indicates a negative relationship for the ulvospinel-magnetite system minerals.

4. The Sold Solution of Ilmenite-Hematite System, and Ulvospinel-Magnetite System

The ilmenite-hematite and ulvospinel-magnetite establish the solid solution in the TiO_2 – FeO - Fe_2O_3 system. In order to discuss the solid solution, it is the most important to determine the ratio of Fe^{2+} to Fe^{3+} based on the total Fe values (FeO*). The ilmenite-hematite system minerals establish the solid solution between FeO • TiO_2 and Fe_2O_3. The chemical formulae suggest that FeO of 1 mol. associates with TiO_2 of 1 mol. Here, the FeO and Fe_2O_3 wt% values are calculated as follows;

$$FeO / wt\% = (TiO_2 / 79.9) \times 71.85$$

$$Fe_2O_3 / wt\% = (FeO^* - FeO) \times (79.85 / 71.85)$$

The ulvospinel-magnetite system minerals establish the solid solution between 2(FeO) • TiO2 and FeO • Fe_2O_3. It is indicated by the chemical formulae that TiO_2 of 1 mol. associates with FeO of 2 mol. Still the 1/3 of the remained Fe is calculated as the ratio of Fe^{2+}. Here, the FeO and Fe_2O_3 wt% values are calculated as follows;

$$FeO / wt\% = (TiO_2/79.9) \times 2 \times 71.85 + \{FeO^*-(TiO_2/79.9) \times 2 \times 71.85\} \times 1/3$$

$$Fe_2O_3 / wt\% = (FeO^* - FeO) \times (79.85/71.85)$$

The chemical compositions of the ilmenite-hematite and ulvospinel-magnetite system minerals, which are calculated by the above-stated formulae, distribute widely between the end members. The values of ilmenite-hematite system minerals are plotted completely between FeO • TiO_2 and Fe_2O_3. The compositional values of ulvospinel-magnetite system minerals are also plotted widely between the end members of 2(FeO)•TiO_2 and FeO•Fe_3O_4. However, the values of ulvospinel-magnetite system minerals tend to occupy the area richer than 45 % in Fe_3O_4 molecule.

5. Distribution of Vanadium and Titanium

Based on microscopic observations and quantitative chemical analyses, it is determined that Ti is concentrated into the ilmenite-hematite and ulvospinel-magnetite system minerals, and rutil. In addition, V has been determined to be concentrated into the ulvospinel-magnetite system minerals and ilmenite-magnetite system minerals. Ti concentrations into ilmenite-hematite system minerals are richer than ulvospinel-magnetite system minerals as mentioned above. On the contrary, V contents of ulvospinel-magnetite system minerals are higher than ilmenite-hematite system minerals. The V concentration pattern is obviously determined with the chemical comparison of paragenetic ilmenite-hematite and ulvospinel-magnetite system minerals.

6. Concluding Remarks: Formation Condition of Iron Ores

The chemical variations, which are plotted on the $FeTiO_3$-Fe_2O_3 and Fe_2TiO_4-Fe_3O_4 system diagram for the ilmenite-hematite minerals as well as ulvospinel-magnetite minerals, indicate that the formation temperatures are approximately more than 700℃ (Lindsley, 1981). The geothermometer determined based on the coexisting ilmenite-hematite system and ulvospinel-magnetite system minerals also suggests that (1) the formation temperatures vary from 600 to 700℃, and (2) the V concentrations into the ulvospinel-magnetite system minerals increase with the decreasing formation temperatures of ores (Spencer and Lindsley, 1981). Pyrrhotite of the Fe-S system mineral occurs in a paragenetic association

with the ilmenite-hematite and ulvospinel-magnetite system minerals. The S content of pyrrhotite indicates the sulfur fugacity of formation condition (Barton and Toulmin, 1966). Coexisting pyrrhotite suggests that V concentrations into ulvospinel-magnetite system minerals increase with the decreasing sulfur fugacity. Consequently, it is concluded that the V concentrations into the ulvospinel-magnetite system minerals are controlled strongly by the formation temperatures and sulfur fugacity of ore formation.

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