Study on process mineralogy of limonite

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Abstract: In this paper, the process mineralogy, such as the composition and content of elements and minerals, and the chemical composition of main minerals, was studied by the method of mineral liberation analyser. The results show that the ore is limonite bearing-zinc ore, the content of the main mineral limonite is 95.982%, most of limonite is monomeric, a few limonite is associated with pyrite and muscovite, with quartz, with sericite and quartz, limonite contains sericite, synbiote of limonite and sericite. Zinc occurs mainly in limonite, a small amount of zinc in the form of sphalerite, smithsonite and hemimorphite. This study will lay a mineralogical foundation for the follow-up development and utilization of this type of ore.

1. Introduction
The study of process mineralogy began in the 1940s. Process Mineralogy is an applied discipline to study the chemical composition, mineral composition, mineral properties and changes of ore and products from ore processing processes. It is a discipline developed between mineralogy and mineral processing, and plays an important role in determining reasonable mineral processing technology, optimizing mineral processing flow structure and improving production index of mining enterprises[1]. Based on scanning electron microscope, the appearance and application of automatic mineral analyzer is a great achievement in the field of process mineralogy in recent years. At present, the main products that have been commercialized are quantitative evaluation of minerals by scanning electronic microscopy, mineral liberation analyzer and advanced mineral identification and characterization system. The systems are mainly composed of different types of scanning electron microscope, X-ray energy spectrum and the corresponding software for automatic mineral identification and data processing, the parameters such as mineral dissociation degree, mineral particle size and relative mineral content can be determined automatically[2-6]. In particular, mineral liberation analyzer is currently the most advanced quantitative analysis system in the world and is used in mining, metallurgy and materials and so on. Therefore, the process mineralogy of the limonite bearing-zinc ore were studied by the method of mineral liberation analyser in this paper.

2. Process mineralogy Analysis and discussion
The ore sample was obtained from a mine in Guangxi. The process of MLA Analysis samples preparation are as following. Firstly, the study ore is crushed to -0.2mm, take up 100g representative
samples after mixing and shrinking. Secondly, the samples were cold setting with epoxy respectively after grading and drying, and were made 30mm diameter photomask. Finally, the pieces were ground and polished to prepare qualified analysis samples for MLA analysis. The total number of particles analyzed was about 280,000. The analysis equipment is FEI MLA650 which analysis test condition parameters are working voltage 20KV, high vacuum mode and BSED probe.

2.1 Element composition and content
The results of element composition and content of the sample are shown in Table 1.

| Element | Al | C  | Ca | Cl | F  | Fe  | H  | K  |
|---------|----|----|----|----|----|-----|----|----|
| Content/% | 0.93 | 0.07 | 0.27 | 0.02 | 0.01 | 56.65 | 1.13 | 0.23 |

| Element | Mg | O  | P  | Pb | S  | Si  | Ti | Zn |
|---------|----|----|----|----|----|-----|----|----|
| Content/% | 0.13 | 36.93 | 0.05 | 0.08 | 0.75 | 2.14 | 0.03 | 0.57 |

2.2 Mineral composition and content
The mineral composition and content of the sample are shown in Table 2. It can be seen from Table 2 that the main minerals are limonite with a content of about 95.982%, followed by small amount of zinc minerals such as sphalerite and smithsonite, and trace amount of hemimorphite. The other sulfides are mainly pyrite and galena with less amount. Gangue minerals are mainly sericite, quartz, dolomite, chlorite and calcite.

| Mineral | Content /% | Content /% | Content /% | Content /% |
|---------|------------|------------|------------|------------|
| limonite | 95.982     | albite     | 0.033      | rutile     | 0.017     |
| sphalerite | 0.079 | sericite | 1.306     | calcite    | 0.146    |
| smithsonite | 0.014 | biotite | 0.004     | dolomite   | 0.392    |
| hemimorphite | 0.002 | hornblende | 0.015 | ankerite | 0.012 |
| pyrite | 0.814 | talcum | 0.001     | gypsum     | 0.004    |
| stibnite | 0.002 | kaolin | 0.067     | diaspore   | 0.005    |
| galena | 0.015 | chlorite | 0.158 | barite | 0.003 |
| quartz | 0.836 | psilomelane | 0.001 | apatite | 0.005 |

2.3 The chemical composition of the major minerals

2.3.1 Limonite
The content of limonite is 95.982%. The composition of limonite was analyzed by SEM in Table 3. As can be seen from Table 3, the limonite generally contains zinc and lead, with an average of Fe60.34%, Zn0.57% and Pb0.03%. SEM BSE images of limonite is shown in Fig.1. It can be seen from Fig.1(a), most of limonite is monomeric. From Fig.1(b), a few limonite is associated with pyrite and muscovite. According to Fig.1(c)–Fig.1(e), limonite is associated with quartz, sericite and quartz, limonite contains sericite, synbiote of limonite and sericite, respectively.
Fig. 1 SEM BSE images of limonite

Table 3 Results of energy spectrum analysis of limonite

| Measuring Point | Chemical composition and content/\% |
|-----------------|-----------------------------------|
|                 | Fe  | Si  | Al  | Zn  | S   | K   | Ca  |
| 1               | 59.82 | 1.19 | 0.62 | 0.52 | 0.48 | 0.13 | 0.09 |
| 2               | 60.45 | 0.90 | 0.17 | 0.76 | 0.32 | 0.00 | 0.13 |
| 3               | 58.10 | 2.87 | 1.56 | 0.23 | 0.00 | 0.33 | 0.15 |
| 4               | 59.81 | 1.18 | 0.60 | 0.33 | 0.33 | 0.19 | 0.07 |
| 5               | 64.90 | 2.12 | 1.32 | 0.33 | 0.39 | 0.19 | 0.13 |
| 6               | 63.99 | 1.60 | 1.07 | 0.31 | 0.31 | 0.28 | 0.13 |
| 7               | 60.34 | 1.09 | 0.45 | 0.22 | 0.31 | 0.20 | 0.15 |
| 8               | 60.05 | 1.78 | 0.82 | 0.52 | 0.23 | 0.13 | 0.14 |
| 9               | 58.49 | 0.99 | 0.12 | 0.58 | 0.68 | 0.02 | 0.05 |
| 10              | 60.68 | 1.02 | 0.55 | 0.42 | 0.23 | 0.10 | 0.14 |
| 11              | 60.48 | 0.74 | 0.24 | 0.42 | 0.44 | 0.06 | 0.08 |
2.3.2 Sphalerite

The content of sphalerite is about 0.079%. The results of multi-point analysis of chemical composition energy spectrum are shown in Table 4. As can be seen from Table 4, the sphalerite contains on average Zn63.97%, Fe2.69% and S33.10%, a small amount of Al and Si impurities, containing Cd and In in very few sphalerite, average content Cd0.06%, In0.04%. Sphalerite is mostly monomeric (Fig.2(a)). It is also associated with limonite and pyrite, and is synclinal or inclusion followed by dolomite and sericite (Fig.2(b)~Fig.2(d)).
Table 4 Results of energy spectrum analysis of sphalerite

| Measuring Point | Chemical composition and content/% |
|-----------------|-----------------------------------|
| Zn  | Fe  | Cd  | In  | Al  | Si  | S   |
| 1   | 64.04 | 2.63 | 0.00 | 0.00 | 0.09 | 0.14 | 33.10 |
| 2   | 63.72 | 3.04 | 0.00 | 0.00 | 0.00 | 0.09 | 33.15 |
| 3   | 64.27 | 2.44 | 0.00 | 0.00 | 0.04 | 0.13 | 33.12 |
| 4   | 64.75 | 2.12 | 0.00 | 0.00 | 0.03 | 0.06 | 33.04 |
| 5   | 65.21 | 1.61 | 0.00 | 0.00 | 0.00 | 0.11 | 33.07 |
| 6   | 63.34 | 3.45 | 0.00 | 0.00 | 0.00 | 0.10 | 33.11 |
| 7   | 61.85 | 4.84 | 0.00 | 0.00 | 0.00 | 0.03 | 33.28 |
| 8   | 64.15 | 2.47 | 0.00 | 0.00 | 0.06 | 0.16 | 33.16 |
| 9   | 64.30 | 2.31 | 0.00 | 0.00 | 0.12 | 0.12 | 33.15 |
| 10  | 64.06 | 1.96 | 0.58 | 0.42 | 0.02 | 0.10 | 32.86 |
| Average | 63.97 | 2.69 | 0.06 | 0.04 | 0.04 | 0.10 | 33.10 |

Fig. 2 SEM BSE images of sphalerite

2.3.3 Smithsonite
The content of smithsonite is 0.014%. The results of multi-point analysis of chemical composition energy spectrum are shown in Table 5. It can be seen from Table 5, the smithsonite contains varying amounts of zinc and other impurities such as Fe, Ca, Al, Si, S, Mn and K, with average ZnO 75.15% and CO₂ 18.04%. From Fig.4, smithsonite is monomeric (Fig. 3(a)). It is associated with limonite, sericite and dolomite (Fig. 3(b)–Fig. 3(d)).
Table 5 Results of energy spectrum analysis of smithsonite

| Measuring Point | ZnO | FeO | MnO | Al₂O₃ | SiO₂ | SO₃ | K₂O | CaO | CO₂ | ZnO |
|-----------------|-----|-----|-----|-------|------|-----|-----|-----|-----|-----|
| 1               | 56.67 | 5.66 | 0.08 | 0.34 | 0.27 | 0.69 | 0.00 | 0.77 | 35.52 | 56.67 |
| 2               | 59.07 | 3.20 | 0.24 | 0.00 | 0.38 | 0.53 | 0.00 | 1.10 | 35.48 | 59.07 |
| 3               | 59.98 | 2.47 | 0.10 | 0.22 | 0.23 | 0.31 | 0.00 | 1.27 | 35.42 | 59.98 |
| 4               | 57.41 | 4.01 | 0.61 | 0.13 | 0.12 | 0.16 | 0.00 | 1.90 | 35.66 | 57.41 |
| 5               | 60.83 | 2.63 | 0.00 | 0.04 | 0.26 | 0.00 | 0.00 | 0.82 | 35.42 | 60.83 |
| 6               | 60.17 | 3.51 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.67 | 35.45 | 60.17 |
| 7               | 57.71 | 3.95 | 0.20 | 0.48 | 0.79 | 0.15 | 0.16 | 1.10 | 35.46 | 57.71 |
| 8               | 62.04 | 2.04 | 0.00 | 0.00 | 0.12 | 0.00 | 0.00 | 0.58 | 35.22 | 62.04 |
| Average         | 59.24 | 3.43 | 0.15 | 0.15 | 0.30 | 0.23 | 0.02 | 1.03 | 35.45 | 59.24 |

Fig. 3 SEM BSE images of smithsonite

2.3.4 Hemimorphite
The content of hemimorphite is very few. The results of multi-point analysis of chemical composition energy spectrum are shown in Table 6. It can be seen from Table 6 that hemimorphite contains a small amount of impurities such as Fe, Al, K and Ti, with an average ZnO63.08% and SiO₂27.17%. As can be seen from Fig.4, hemimorphite is associated with limonite and muscovite.

Table 6 Results of energy spectrum analysis of hemimorphite

| Measuring Point | ZnO | FeO | Al₂O₃ | K₂O | SiO₂ |
|-----------------|-----|-----|-------|-----|------|
| 1               | 67.00 | 4.68 | 0.87  | 0.31 | 27.14  |
| 2               | 59.15 | 11.14 | 2.37 | 0.15 | 27.19  |
| Average         | 63.08 | 7.91 | 1.62 | 0.23 | 27.17  |
3. Conclusions

(1) The ore is limonite bearing-zinc ore, the content of the main mineral limonite is 95.982%, most of limonite is monomeric, a few limonite is associated with pyrite and muscovite, with quartz, with sericite and quartz, limonite contains sericite, synbiote of limonite and sericite.

(2) Zinc occurs mainly in limonite, a small amount of zinc in the form of sphalerite, smithsonite and hemimorphite.

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