

# Research on Mineral Structure and Compositions of Peru Raw Ore



Wen Pan, Lei Liu, Ya-peng Zhang, Xia Zhao and Zhi-xing Zhao

**Abstract** In this study, mineral structures and compositions of Peru raw ore (PRO) were investigated by optical microscope, scanning electron microscope and X-ray diffraction. The results show that PRO is primarily composed of magnetite, haematite, gangue and sulphide. A small amount of chalcopyrite and calcium phosphate also exist in PRO. Gangues are mainly quartz minerals. Sulphides exist as FeS, Fe<sub>2</sub>S<sub>3</sub> and FeS<sub>2</sub>, respectively. Sulphides, most of which accrete with gangues, are embedded among ferrous bodies in the form of banding, schistose, or porphyritic structures. The particle sizes of sulphides and gangues are between 200 and 500 μm. Some of them are over 1000 μm. It can be concluded that high liberation degree of sulphides and gangues will be obtained after crushing. After flotation and magnetic separation in Shougang Jingtang dressing plant, the Fe content of PRO was improved from 56.68 to 65.75%. The sulphur content dropped to 0.48% from 3.44%.

**Keywords** Peru raw ore · Mineral compositions · Microstructure · Beneficiation

Peru is rich of iron ore resources with a reserve of 882 million ton and an average grade of more than 50%, which are mainly distributed in Ica province, Arequipa province and Andes mountains [1]. Shougang Hierro Peru S.A.A, a subsidiary of Shougang group, is the largest Chinese mining investment company in South America. The PRO studied in this paper, with low price and high original grade, were from the iron ore company. Study on the microstructures and mineral compositions of the iron ore was carried out by the mineralogical research methods

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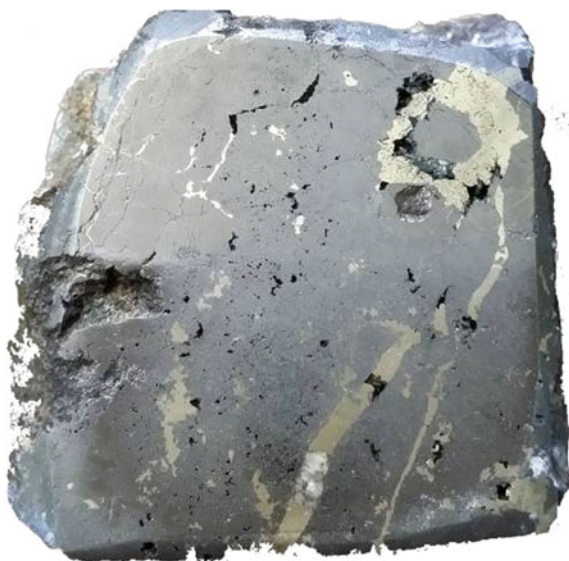
[2–4], which provides technical references for the subsequent usage of the raw iron ore in Shougang Group.

## Samples and Experiments

From the perspective of macroscopic morphology, the PRO was compact. Bright striped, flaky metallic luster minerals were observed scattering in the ore matrix after cutting, rough grinding and polishing, as shown in Fig. 1. Table 1 presents the chemical compositions of PRO. The PRO has relatively high original grade, which is nearly 57%, but it also contains ultra-high sulphur content, which is up to 3.44%.

In order to further understand the internal structure of PRO, the microstructure and mineral compositions of PRO were investigated with optical microscope, scanning electron microscope and X-ray diffraction phase analysis (XRD). The optical microscopy used in the test was the German Leica optical microscopy, the scanning electron microscopy was the Japanese electron jsm-7001f scanning electron microscopy and the XRD analysis was conducted using the German company brock X-ray diffraction instrument.

**Fig. 1** Macro morphology of PRO



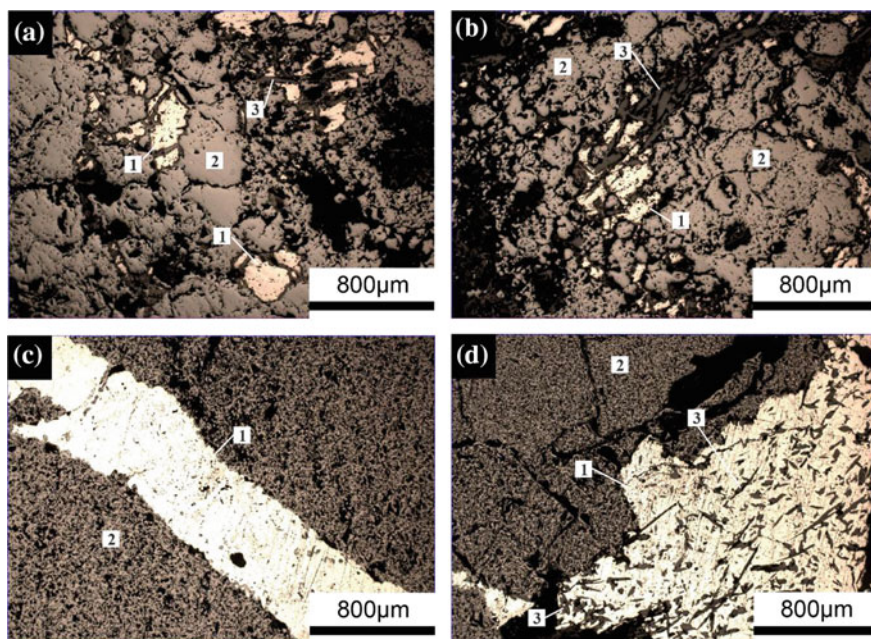
**Table 1** Chemical composition of PRO (wt%)

TFe	SiO <sub>2</sub>	CaO	MgO	Al <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	S	ZnO	LOI
56.68	9.42	2.17	2.98	1.42	0.43	0.19	3.44	0.17	-0.50

## Microstructures of PRO

Figures 2a–d are the microscopic appearance of the PRO under reflected light (50 times) of optical microscopy. It can be seen that PRO is mainly composed of iron-bearing minerals, metallic luster minerals and gangue; among which the metallic luster minerals need to be analysed and identified by scanning electron microscopy and XRD.

Most of the above-mentioned metallic luster minerals are exhibited as porphyric structures, bands or sheets. And most of the grains were between 200 and 500  $\mu\text{m}$ , and a few grains were larger than 1000  $\mu\text{m}$  in diameter. A part of the gangue was clustered between the magnetite grains (Figs. 2a and b), and the other part was patchy and scattered among the metallic luster minerals (Fig. 2d). Both the metallic luster minerals and the gangue minerals are clustered and have a high degree of dissociation. Therefore, the separation of the gangue minerals, the metallic luster minerals and the iron bearing minerals can be realized by crushing the PRO below –90 meshes (180  $\mu\text{m}$ ).



**Fig. 2** Optical microscope images of PRO. 1—Metallic luster minerals; 2—Ferric oxide; 3—Gangue

## Mineralogy Analysis of PRO

Scanning electron microscope and elemental energy spectrum analysis were applied to investigate the mineral types in PRO. The results are shown in Fig. 3.

### *Energy Spectrum Analysis of Mineral Elements*

Figures 4a–d are some scanning electron microscopy photographs of PRO. Combined with the observation results of the optical microscope and the analysis data of elemental energy spectrum, the element compositions of minerals under the scanning electron microscopy were classified and sorted. The results are shown in Table 2, 3, 4, 5 and 6.

#### (A) metallic Luster Minerals

According to the results of energy spectrum analysis in Table 2, the main compositions of metallic luster minerals were iron sulphide which included  $\text{FeS}_2$ ,  $\text{FeS}$  and  $\text{Fe}_2\text{S}_3$ . It can be seen that the Fe/S molar ratio of iron sulphide in PRO was between 0.99 and 1.97. Thus, it can be inferred that the metallic luster minerals in PRO contained all three kinds of iron sulphides. In addition, solid solution of element boron can be occasionally seen in some iron sulphide minerals, as shown in Table 2, position 3.

#### (B) Ferric Oxides

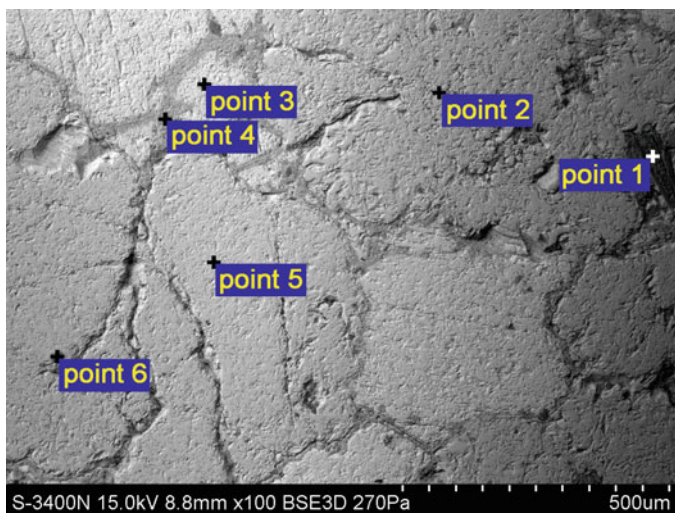
It can be seen from Table 3 that Fe content of iron bearing minerals in PRO was between 60.34 and 71.80%. All the measured points of ferric oxides contain sulphur, and the mass percentage was in the range of 1.0–3.0%.

#### (C) Gangues

According to the results of the energy spectrum analysis of gangue minerals in Table 4, Si, Mg and Fe are the main elements of gangue minerals, which were similar to ferric oxides. All the monitoring points of gangue minerals contain sulphur, and the content range was between 1 and 10%. In addition, Al is present in many of the observation points of gangue minerals with concentration between 0.5 and 4 wt%.

#### (D) D) Unknown mineral #1

A large area of dark grey unknown mineral, called unknown mineral #1, was observed under the scanning electron microscope in PRO. According to the energy spectrum analysis of the elements in Table 5, this mineral was mainly composed of P and Ca elements. The molar fraction ratios of P and Ca elements of the three measurement points are, respectively, 1.50, 1.49 and 1.51, which are very close to



Point	O	Na	Mg	Al	Si	S	Cl	Ca	Fe
Point 1	49.14		10.86	0.58	20.63	2.41		0.32	16.07
Point 2	33.32		0.46		1.26	1.02			63.93
Point 3	9.94	0.48			0.84	31.99			56.74
Point 4	24.71	2.07			1.03	31.09			41.10
Point 5	24.44					1.19			74.37
Point 6	28.90	0.92	1.43		19.48	2.28	1.37		45.61

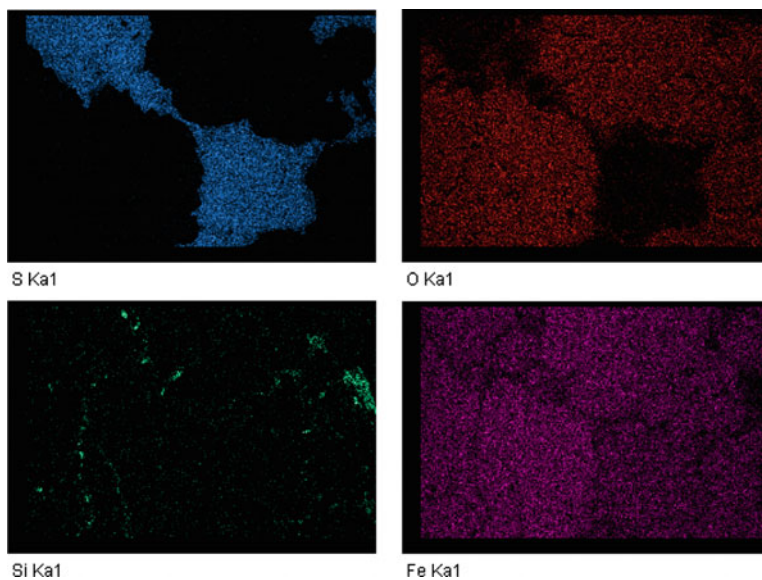
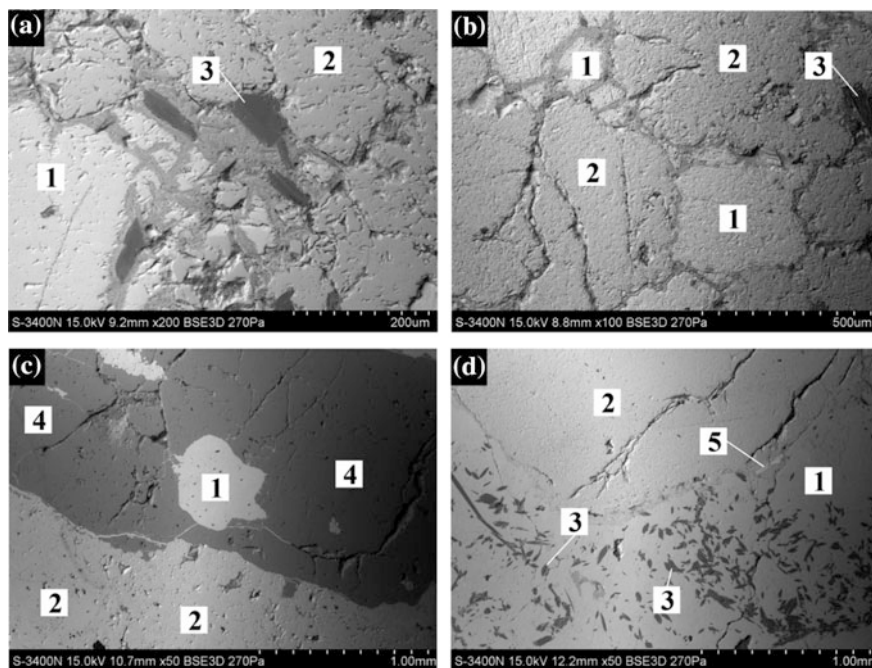


Fig. 3 SEM images and EDS analysis results of PRO



**Fig. 4** SEM images of PRO. 1—metallic luster minerals, 2—ferric oxides, 3—gangue, 4—unknown mineral #1, 5—unknown mineral #2

the molar fraction ratios of P and Ca in  $\text{Ca}_3(\text{PO}_4)_2$  (1.50). Therefore, it was determined that this mineral was calcium phosphate.

#### (E) Unknown mineral #2

The bright sheet unknown minerals, marked as unknown mineral #2, were found in all of the scanning electron microscopy (SEM) photographs of several PROs. According to energy spectrum analysis in Table 6, the mineral was mainly composed of Cu, S and Fe elements. The Fe, Cu, S mole fraction ratio are: 1.93:1.02, 1:1.93:1.20, 1:2.75:3.21 in three points. In addition to point 3, the mole fraction ratios of the other two points were closely to chalcopyrite ( $\text{CuFeS}_2$ ). So, the mineral is presumed to be chalcopyrite

### *Distributions of Main Chemical Elements*

According to the energy spectrum analysis data of the above elements, the distributions of S, Fe, Si, Mg, Ca, Al, Na and K in sulphide, iron oxide, gangue, calcium phosphate and chalcopyrite were calculated.

**Table 2** EDS analysis results of minerals with metallic luster (%)

Position	S	O	Fe	Mg	Si	Ca	Cu	B	Na	K	P	Fe: S (molar fraction)
1	31.99	9.94	56.74		0.84				0.48			1:0.99 (FeS)
2	31.09	24.71	41.10		1.03				2.07			1:1.32 (FeS. Fe <sub>2</sub> S <sub>3</sub> )
3	27.08	23.21	32.77	0.58	1.59	0.46	1.28	12.11	0.58	0.34		1:1.45 (Fe <sub>2</sub> S <sub>3</sub> )
4	34.42	20.84	41.42	0.32	1.80	0.40			0.80			1:1.45 (Fe <sub>2</sub> S <sub>3</sub> )
5	37.78	4.57	57.27		0.39							1:1.15 (FeS)
6	49.75	4.49	45.75									1:1.90 (FeS <sub>2</sub> )
7	47.75	6.15	44.88	0.49	0.74							1:1.86 (FeS <sub>2</sub> )
8	47.07	5.28	41.74			2.32			0.62		1.20	1:1.97 (FeS <sub>2</sub> )
9	46.72	5.55	42.02			2.90					1.08	1:1.95 (FeS <sub>2</sub> )
10	46.41	6.58	47.01									1:1.73 (Fe <sub>2</sub> S <sub>3</sub> . 2FeS <sub>2</sub> )

**Table 3** EDS analysis of ferric oxides (%)

Position	Fe	O	S	Na	Mg	Si	Cl	Ca	K	P
1	63.93	33.32	1.02		0.46	1.26				
2	74.37	24.44	1.19							
3	69.37	28.17	1.82			0.63				
4	63.31	24.97	2.75	4.12	0.57	0.98	1.09	0.63	1.57	
5	69.24	28.99	1.16			0.61				
6	69.65	27.30	1.67	0.60		0.79				
7	70.58	26.02	2.81			0.59				
8	60.34	19.89	1.01	9.68		1.33	6.08	1.00		0.68
9	67.72	31.15	1.13							
10	71.80	27.09	1.11							

## (1) S element

Figure 5 showed the distribution of S elements in various minerals. S elements were widely distributed in all minerals of PRO, and the sequence of content from high to low was as follows: sulphide, chalcopyrite, gangue, calcium phosphate and ferric oxides.

**Table 4** EDS analysis of gangues (%)

Position	Si	Mg	S	O	Fe	Na	Al	Cl	Ca	Cu
1	20.63	10.86	2.41	49.14	16.07		0.58		0.32	
2	19.48	1.43	2.28	28.90	45.61	0.92		1.37		
3	21.74	10.25	3.49	43.08	10.15		1.47		7.51	2.32
4	21.61	11.45	2.38	44.31	13.41		0.55		6.29	
5	19.31	8.85	4.74	43.47	16.42		1.17		6.03	
6	11.03	8.39	1.31	37.96	29.64	3.70	4.00	3.97		
7	19.58	9.69	9.59	39.04	14.84		0.83		6.42	
8	11.48	7.73	5.23	38.33	33.15		4.07			

**Table 5** EDS analysis of unknown mineral #1 (%)

Position	P	Ca	O	S	Na	Si	Cl	Fe	F
1	<b>19.02</b>	36.88	34.79	1.64	0.58	0.49	2.00	4.61	
2	<b>15.33</b>	29.56	35.91	5.04		0.52		9.32	4.32
3	<b>16.58</b>	32.40	39.13	0.70		0.83	0.42	5.54	4.40

**Table 6** EDS analysis of unknown mineral #2 (%)

Position	Cu	S	Fe	O	Mg	Si	Ca	K
1	<b>31.29</b>	30.47	28.11	5.84	1.10	2.07	0.64	0.48
2	<b>30.54</b>	29.70	32.45	6.84		0.46		
3	<b>16.68</b>	23.15	47.26	10.86		2.05		

## (2) Fe element

Figure 6 showed the distribution of Fe in various minerals. Similar to sulphur, Fe was distributed in all minerals, and the content of Fe is successively from low to high: iron oxides, sulphide, chalcocopyrite, gangue and calcium phosphate. The type of ferric oxides was determined by XRD analysis in the following part.

## (3) Si, Mg, Ca, Al

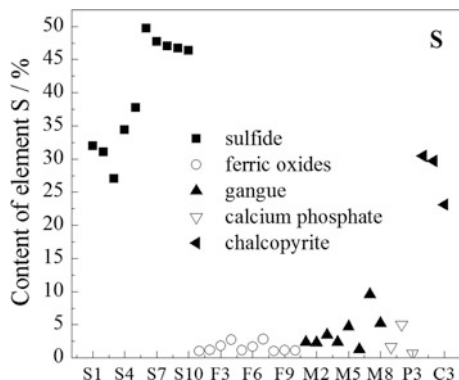
Figures 7a–d, respectively, showed the distribution of Si, Mg, Ca and Al in each mineral. Generally, the above four elements were mainly distributed in gangue minerals, especially Al element. Ca was the highest in calcium phosphate, followed by gangue.

## (4) Na, K

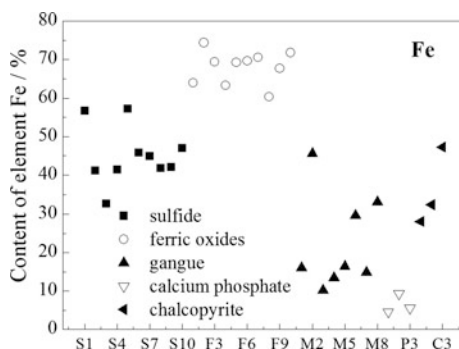
The alkali metal elements Na and K have a small amount of distribution in each mineral, as shown in Figs. 8a and b. In comparison, Na element was more widely



**Fig. 5** Distribution map of element sulphur



**Fig. 6** Distribution map of element ferrum



distributed, existing in all minerals except calcium phosphate, and the contents fluctuated greatly. For example, in ferric oxides, Na content was close to 10% at the highest level and less than 1% at the lowest level. K is only occasionally found in sulphides, ferric oxides and calcium phosphate (less than 2%).

### XRD Analysis of PRO

XRD analysis was carried out to further confirm the mineral species and quantitatively analyse the percentage content of each mineral. The test samples were grinded to -200 meshes. The results were shown in Table 7.

According to the X-ray diffraction results, the ferric oxides in PRO were mainly magnetite and a few haematites. The main mineral in gangue was quartz. However, no sulphide, chalcopyrite and calcium phosphate minerals were found in the X-ray diffraction results of the test samples, mainly because the contents of these three minerals in the sample were lower than the measured range (Fig. 9).

As the sulphide mineral types in PRO cannot be confirmed with the power sample, the sample of PRO used in the optical microscope (See in Fig. 1) was put in

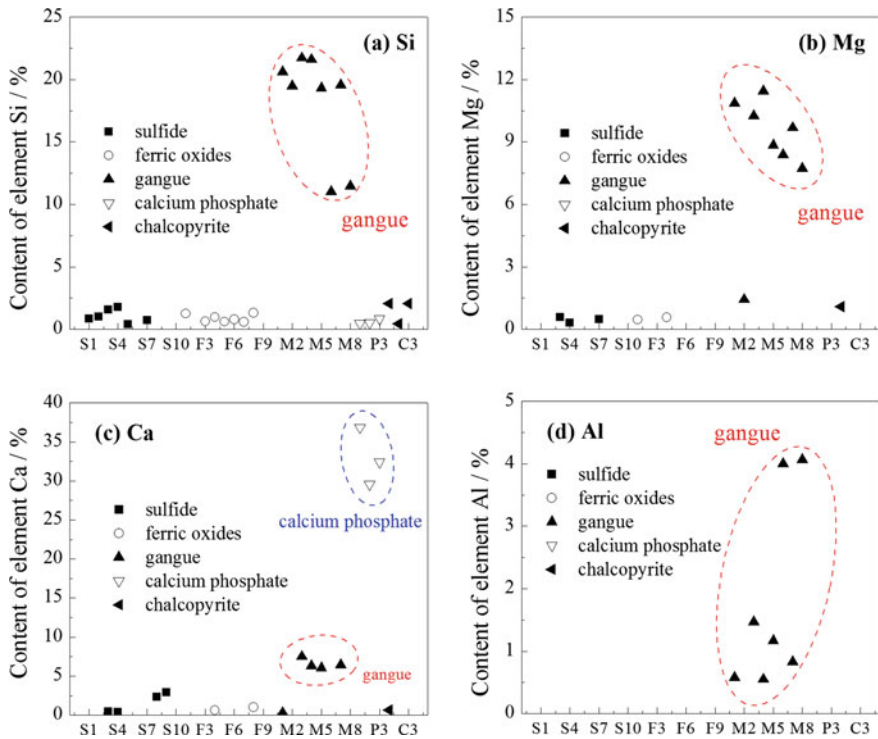


Fig. 7 Distribution map of element Si, Mg, Ca and Al

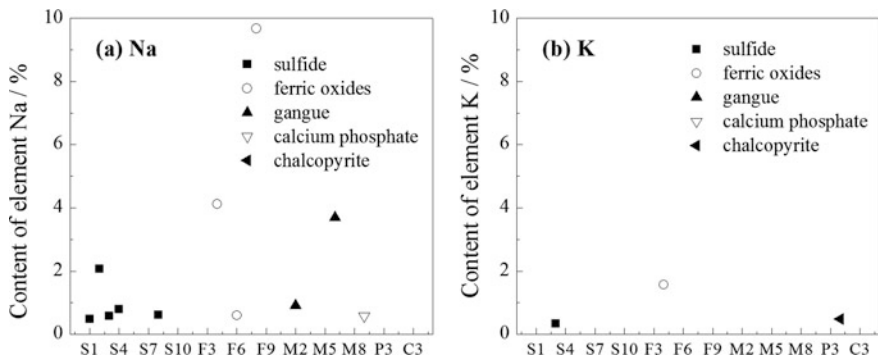


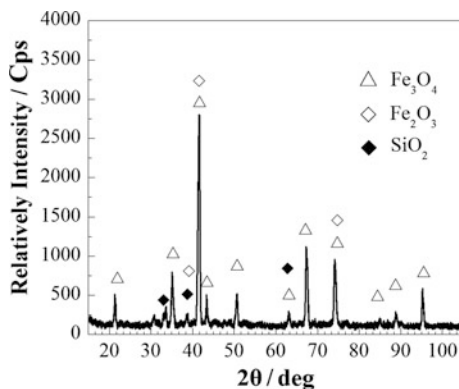
Fig. 8 Distribution map of element Na, K

X-ray scanner. And the X-ray beam was directly located to the sulphide mineral (metallic luster minerals). Two points were selected (See in Fig. 10a and b).

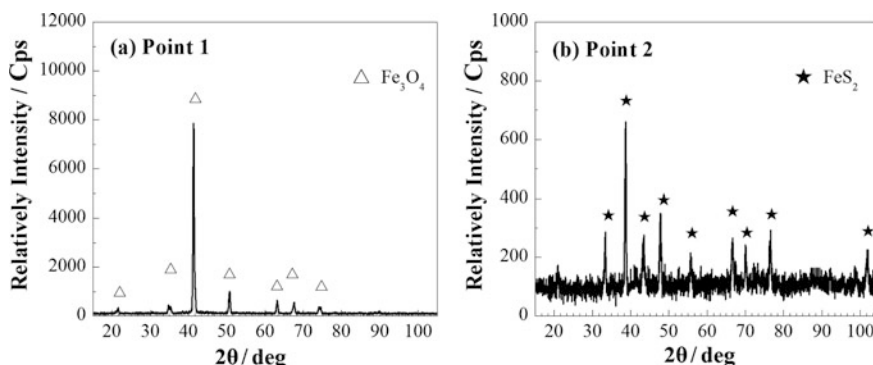
All the mineral types in the scanning area of point 1 were magnetite ( $Fe_3O_4$ ), and the sulphide mineral was still not detected due to the low content of sulphide in the

**Table 7** XRD analysis result of powder PRO (%)

Fe <sub>3</sub> O <sub>4</sub>	Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>
61.7	5.6	32.7



**Fig. 9** X-ray diffraction pattern of PRO



**Fig. 10** X-ray diffraction pattern of lump PRO

region. According to Fig. 10b, the mineral type in the scanning area of measuring point 2 was pyrite (FeS<sub>2</sub>), which was consistent with the conclusions of scanning electron microscopy and energy spectrum analysis above. Therefore, it can be confirmed that pyrite existed in PRO.

**Table 8** Chemical compositions of PRO before and after beneficiation (wt%)

	TFe	SiO <sub>2</sub>	CaO	MgO	Al <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	S	ZnO	LOI
Before	56.68	9.42	2.17	2.98	1.42	0.43	0.19	3.44	0.17	-0.50
After	65.75	4.13	0.47	1.59	0.84	0.16	0.11	0.48	0.01	-1.57

## Industrial Application of PRO

In the case that the load of sintering S is not excessive, a part of PRO was directly broken and then used for sintering by shougang jingtang to take the price advantage of PRO [5].

As the sulphide minerals, gangue minerals and ferric oxides in PRO had a good degree of dissociation, a part of PRO was processed with combined separating technology (flotation and magnetic separation) after breaking and grinding, which would effectively reduce the content of K, Na and some other harmful elements such as zinc, S. Chemical compositions before and after processing were shown in Table 8.

## Conclusions

- (1) The main minerals in PRO were magnetite, haematite, gangue and sulphide, as well as a small amount of chalcopyrite and calcium phosphate. In the gangue, quartz was the main mineral. And the sulphide includes FeS<sub>2</sub>, FeS and Fe<sub>2</sub>S<sub>3</sub>.
- (2) Element S was widely distributed in all minerals of PRO, and the content was in the order from high to low: sulphide, chalcopyrite, gangue, calcium phosphate and ferric oxides.
- (3) Si, Mg, Ca and Al are mainly distributed in gangue minerals, especially Al elements. No Al element was found in other minerals.
- (4) Elements Na and K had a small amount of distribution in each mineral. In comparison, Na elements are more widely distributed and existed in all minerals except calcium phosphate. K was only occasionally found in sulphide, ferric oxides and calcium phosphate, and its content was not high (less than 2%).
- (5) The grains of gangue mineral and sulphide in PRO were between 200 and 500 mm in diameter. There was high degree of dissociation between ferric oxides and gangue, which was easy to separate after crushing.
- (6) After the combined separating processing at Jingtang iron & steel co., ltd. in Shougang Group, the grade of Fe increased from 56.68 to 65.75%, S content decreased from 3.44 to 0.48%, K<sub>2</sub>O content decreased from 0.43 to 0.16%, Na<sub>2</sub>O content decreased from 0.19 to 0.11% and ZnO content decreased from 0.17 to 0.01%.

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