ESM 1

Samples for comminution test work

Tab. A1: Sampled material for comminution test work of the Per Geijer deposits according to ore type. The intervals taken for each ore type including their total weight are expressed as from and to in meters of core. Highlighted samples are described in more detail in the results chapter.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Ore type** | **Drillhole** | **Deposit** | **From [m]** | **To [m]** | **∑weight** |
| **M1a** | **81617** | **Henry-E** | **1091** | **1093** | **7.718** |
| **M1b** | **88325** | **Lapp** | **1087,32** | **1096,91** | **18.282** |
| 81179 | Nukutus | 256 | 265,10 | 14.068 |
| **M2a** | **88325** | **Lapp** | **1216** | **1226,55** | **16.474** |
| **M2b** | **88325** | **Lapp** | **1106,37** | **1115,84** | **13.790** |
| 81179 | Nukutus | 188,20 | 196,80 | 20.956 |
| **HM1b** | 81158 | Rektorn | 312,95 | 321,25 | 15.474 |
| **88325** | **Lapp** | **1057,90** | **1061,24** |  |
| **1071,25** | **1074,64** | **10.768** |
| **HM2a** | 88326 | Lapp | 737,19 | 744,95 | 38.434 |
| **81155** | **Hauki** | **327,55** | **330,20** |  |
| **333** | **335,90** | **11.801** |
| **HM2b** | **81156** | **Rektorn** | **306,80** | **314,80** | **17.494** |
| 81178 | Nukutus | 147,40 | 153,40 |  |
| 161,50 | 164,40 | 17.477 |
| **H1a** | **88326** | **Lapp** | **721,38** | **729,13** | **29.910** |
| **H1b** | **81154** | **Hauki** | **165,15** | **167,60** |  |
| **309,20** | **312,40** |  |
| **315,80** | **318,95** | **17.701** |
| 81177 | Rektorn | 125,25 | 127,75 |  |
| 172,70 | 176,90 | 13.563 |
| **H2a** | 88326 | Lapp | 711,05 | 713,36 |  |
| 716,22 | 721,38 | 15.668 |
| **81165** | **Henry** | **312,90** | **315,90** |  |
| **318,85** | **321,80** | **12.220** |
| **H2b** | 81165 | Henry | 310 | 312,90 |  |
| 315,90 | 318,85 |  |
| 321,80 | 324,80 | 19.249 |
| **81156** | **Rektorn** | **290** | **294,30** | **8.970** |
| **P1** | **81162** | **Henry** | **264,10** | **271,60** | **14.448** |
| 81155 | Hauki | 73,90 | 79,90 |  |
| 79,90 | 84,10 | 9.753 |
| **P2** | 88325 | Lapp | 1038,39 | 1048,27 | 15.874 |
| **81178** | **Nukutus** | **48,10** | **51,70** |  |
| **51,70** | **55,30** |  |
| **72,95** | **75,90** | **21.101** |

ESM 2

Detailed description of the grinding circuit and specification of the grinding media

For the grinding tests all material (69 samples) was weighted to match exactly 2 kg ± 100 g. In the primary grinding step the rods were counted and measured to match the criteria of LKAB’s Malmberget method for comminution (see specifications in Tab. 2).

Tab. A2: Specifications of steel rods used for primary grinding.

|  |  |  |  |
| --- | --- | --- | --- |
| **Diameter (mm)** | **Amount** | **Weight per rod (g)** | **Total weight (g)** |
| 6 | 13 | 55 | 722 |
| 8 | 10 | 98 | 977 |
| 10 | 8 | 151 | 1214 |
| 12.7 | 6 | 250 | 1748 |
| 16 | 5 | 384 | 1919 |
| 18 | 4 | 532 | 2129 |
| 22 | 4 | 713 | 2852 |
| 25.8 | 3 | 970 | 2910 |
|  |  |  | 14213 |

As specified in Table 2, rods were placed into the mill with two kg feed material and 1 liter water. After 10 min of primary grinding the mills were emptied and cleaned with water and all material was collected in a bucket placed beneath the mill. After 24 hours all the material was settled to the bottom of the bucket and most of the water were removed from the bucket with a hose. The material was filtered with a filter press and dried in the oven at 104 °C for at least 12 hours. In the last step the material was sieved and homogenized and filled into bags. The same procedure accounts for secondary grinding with steel balls. Running time of the mills of 25 and 35 minutes, respectively were applied for 23 samples each. The feed used for secondary grinding had undergone primary grinding in advance. According to the Malmberget method, steel balls have a diameter of ca. 15 mm. A total mass of 13100 g ± 50 g of grinding media was used for each secondary grinding circuit. The grinding media was weighted each day before the grinding process.

ESM 3

MLA classification of grinded samples from Per Geijer

Due to the fact that samples had to be measured in several intervals, grey values varied between each individual measurement series. Tab A1 shows samples according to measurement series.

Tab A3: Samples of ore types of the Per Geijer deposits used for MLA analysis according to particle size classes and measurement series.

|  |  |  |  |
| --- | --- | --- | --- |
| 2020\_05\_07 | 2020\_09\_14 | 2020\_09\_16 | 2020\_10\_09 |
| 1C <20 µm | 2C <38 µm | 10C <38 µm | 2C <20 µm |
| 1C <38 µm | 2C <45 µm | 10C <45 µm | 5C <20 µm |
| 1C <45 µm | 2C <63 µm | 13C <20 µm | 5C <38 µm |
| 1C >45 µm | 11C <38 µm | 13C <38 µm | 5C <45 µm |
| 4C <20 µm | 11C <45 µm | 13C <45 µm | 5C <63 µm |
| 4C <38 µm | 11C <63 µm | 13C 63-500 µm | 8C <45 µm |
| 4C <45 µm | 19C <20 µm | 14C <20 µm | 10C <20 µm |
| 4C <63 µm | 19C <38 µm | 14C <38 µm | 10C <63 µm |
| 8C <20 µm | 19C <45 µm | 14C <45 µm | 11C <20 µm |
| 8C <38 µm | 19C <63 µm | 14C <63 µm | 16C <63 µm |
| 8C <63 µm | 20C <20 µm |  | 23C <20 µm |
| 16C <20 µm | 20C <38 µm |  | 23C <38 µm |
| 16C <38 µm | 20C <45 µm |  | 23C <45 µm |
| 16C <45 µm | 20C <63 µm |  | 23C <63 µm |

Based on the heterogeneity of the samples with regards to sample surfaces, beam current fluctuations and variation in mineralogy processing was done according to the following procedure:

1) classify

2020\_05\_07 BSE range Mgt 165-255, Hem 120-164

Spectrum window HemTi 449-453, Apa\_2020 698-643

0.8%-5% 0.5%-1.5%

2020\_09\_14 BSE range Mgt 143-255, Hem 120-142

Spectrum window HemTi 449-453, Apa\_2020 698-643

1.2%-5% 0.5%-1.5%

2020\_09\_16 BSE range Mgt 149-255, Hem 120-148

Spectrum window HemTi 449-453, Apa\_2020 698-643

0.8%-5% 0.5%-1.5%

Apa 0.2%-6.0%

2020\_10\_09 BSE range Mgt 143-255, Hem 120-142

Spectrum window HemTi 449-453, Apa\_2020 698-643

1.2%-5% 0.5%-1.5%

2) touchup BSE overlay unknown to Mgt, Hem, Apa

Unknown 143-255 Mgt

Unknown 120-144 Hem

Unknown 90-100 Apa\_2020

Unknown 91-98 Apa

2a) touchup BSE overlay unknown to minerals

Unknown 55-72 Qtz

2b) touchup BSE overlay Hem to Qtz

Hem 0-120 Qtz

2c) touchup Qtz in Hem

Mineral to Host Qtz in Hem Size < 10 pixels

3) touchup BSE overlay unknown to background

Unknown 0-100 background

4) touchup unknown to any host

Unknown in host Size < 200000 pixels

Mineral to Mineral Apa\_2020 to background Size < 200000 pixels

5) touchup tiny pixels

Touchup Mineral to Mineral Apa to background Size < 50 pixels

Bio to Msk Size < 20 pixels

Ab to Qtz Size < 100 pixels

Msk to Bio Size < 150 pixels

Qtz to background Size < 50 pixels

Touchup Mineral to Host Act in Qtz Size < 100 pixels

Touchup Mineral to Any Host All minerals in Host Size < 1 pixels

6) BSE overlay background

Base Mineral (background) 65-75 Overlay Mineral (low counts)

7) touchup low counts

Mineral to Mineral Low counts to background Size < 200000 pixels

NoXray to background Size < 200000 pixels

8) touchup Qtz in Hem to Hem

Mineral to Host Qtz in Hem Size < 500 pixels

Hem in Qtz Size < 500 pixels

9) automatic deagglomeration tool

10) databasis

ESM 4

MLA data treatment for agglomerates

The classification of the samples follows those described in the ESM 4.

The following procedure was applied in order to treat agglomerates to full separation and is illustrated for one sample (M1a):

For better illustration agglomerates were filtered from the whole sample by applying step 1-2.

1. without any – all but Fe-oxides and unknown, → generates all agglomerates (large and small)
2. sort by area fraction < 80 % Mag,

To only sort and display particles within the P80 range of ore type M1a after 35 min ball mill (26 µm) step 3 was conducted.

1. area > 1352 – number results from the P80 for ore type M1a number = hight x width x pixel2 (here 2).

The now selected agglomerates were saved and all scripts described in ESM 3 were applied. Steps 4-X.

4) touchup BSE overlay unknown to Mgt, Hem, Apa

Unknown 165-255 Mgt

Unknown 100-164 Hem

Unknown 64-73 Qtz

Unknown 102-112 Apa

Unknown 78-84 An

Unknown 81-87 Mus

Unknown 86-94 Bt

Unknown 79-90 Chl

Unknown 118-129 Rt

Unknown 148-159 Alla

5b) touchup BSE overlay Hem to Qtz

Hem 0-120 Qtz

5c) touchup Qtz in Hem

Mineral to Host Qtz in Hem Size < 10 pixels

6) touchup BSE overlay unknown to background

Unknown 0-100 background

7) touchup tiny pixels

Touchup Mineral to Mineral Apa to background Size < 50 pixels

Bio to Msk Size < 20 pixels

Ab to Qtz Size < 100 pixels

Msk to Bio Size < 150 pixels

Qtz to background Size < 50 pixels

Touchup Mineral to Host Act in Qtz Size < 100 pixels

Touchup Mineral to Any Host All minerals in Host Size < 1 pixels

8) touchup hem to background within agglo

Touchup Mineral to Mineral Hem to background Size < 1000 pixels

9) BSE overlay background

Base Mineral (background) 65-75 Overlay Mineral (low counts)

10) touchup low counts

Mineral to Mineral Low counts to background Size < 200000 pixels

NoXray to background Size < 200000 pixels

11) automatic deagglomeration tool

The automatic deagglomeration tool cannot be used directly after classification. This would falsify the results as all particles with cracks

12) databasis

ESM 5

Mass distribution of minerals in the different ore types corresponding to size fractions.

Appendix B5a: Modal mineralogy of magnetite-dominated ore types after comminution.

Tab. A5a: Mass distribution of minerals (modal mineralogy) in different size fractions in magnetite-dominated ore types after comminution.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ore Type | M1a | | | | M1b | | | | M2a | | | | M2b | | | |
| Size fraction | < 20 µm | < 38 µm | < 45 µm | > 45 µm | < 20 µm | < 38 µm | < 45 µm | < 63 µm | < 20 µm | < 38 µm | < 45 µm | < 63 µm | < 20 µm | < 38 µm | < 45 µm | < 63 µm |
| Magnetite | 91.24 | 91.27 | 90.03 | 89.24 | 69.86 | 82.80 | 63.06 | 89.02 | 81.43 | 85.63 | 84.41 | 82.42 | 34.30 | 59.73 | 69.29 | 72.92 |
| Hematite | 3.52 | 2.61 | 2.40 | 2.18 | 8.18 | 1.00 | 30.39 | 0.88 | 4.76 | 5.75 | 5.52 | 5.60 | 2.38 | 2.79 | 1.23 | 0.98 |
| Silicates | 4.56 | 5.26 | 6.15 | 6.84 | 18.64 | 14.26 | 2.72 | 9.08 | 4.45 | 3.22 | 4.05 | 5.48 | 50.12 | 31.24 | 24.99 | 22.28 |
| Phosphates | 0.37 | 0.59 | 0.93 | 1.09 | 1.12 | 0.90 | 3.62 | 0.35 | 8.58 | 5.02 | 5.59 | 5.78 | 2.50 | 3.44 | 2.45 | 2.08 |
| Carbonates | 0.10 | 0.08 | 0.18 | 0.37 | 1.70 | 0.71 | 0.16 | 0.46 | 0.76 | 0.38 | 0.42 | 0.71 | 10.35 | 2.51 | 1.85 | 1.55 |
| Sulfides | 0.01 | 0.01 | 0.03 | 0.06 | 0.14 | 0.12 | 0.04 | 0.06 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Sulfates | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 |
| Halides | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| other Oxides | 0.20 | 0.19 | 0.27 | 0.21 | 0.35 | 0.20 | 0.00 | 0.16 | 0.00 | 0.00 | 0.01 | 0.00 | 0.33 | 0.27 | 0.17 | 0.18 |
| Others | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Tab. A5b: Mass distribution of minerals (modal mineralogy) in different size fractions in hematite-dominated ore types after comminution.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ore Type | H1a | | | | H1b | | | | H2a | | | | H2b | | | |
| Size fraction | < 20 µm | < 38 µm | < 45 µm | 63 - 500 µm | < 20 µm | < 38 µm | < 45 µm | > 45 µm | < 20 µm | < 38 µm | < 45 µm | < 63 µm | < 20 µm | < 38 µm | < 45 µm | < 63 µm |
| Magnetite | 47.85 | 30.43 | 42.84 | 32.83 | 30.77 | 21.95 | 13.97 | 17.11 | 88.66 | 89.10 | 83.42 | 43.40 | 29.10 | 25.82 | 28.09 | 27.08 |
| Hematite | 49.31 | 67.53 | 55.06 | 63.79 | 44.68 | 52.52 | 59.61 | 60.61 | 4.79 | 4.14 | 10.44 | 49.43 | 43.45 | 48.95 | 46.15 | 49.25 |
| Silicates | 2.30 | 1.78 | 1.84 | 3.07 | 23.20 | 24.65 | 25.43 | 21.38 | 4.92 | 5.34 | 5.08 | 6.26 | 19.15 | 20.22 | 21.45 | 20.87 |
| Phosphates | 0.21 | 0.12 | 0.10 | 0.06 | 0.32 | 0.24 | 0.20 | 0.15 | 1.15 | 1.15 | 0.78 | 0.62 | 6.72 | 4.15 | 3.46 | 2.15 |
| Carbonates | 0.21 | 0.08 | 0.10 | 0.16 | 0.99 | 0.60 | 0.65 | 0.70 | 0.42 | 0.25 | 0.23 | 0.27 | 0.97 | 0.44 | 0.45 | 0.36 |
| Sulfides | 0.11 | 0.06 | 0.06 | 0.07 | 0.03 | 0.03 | 0.14 | 0.05 | 0.06 | 0.02 | 0.04 | 0.02 | 0.60 | 0.42 | 0.41 | 0.30 |
| Sulfates | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Halides | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| other Oxides | 0.01 | 0.00 | 0.01 | 0.02 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Others | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |