Magnetite and hematite quartzites - common features and technological differences

V V Ivanchenko, A V Ivanchenko and V V Stetsenko
State Scientific Institution "Center for Problems of Marine Geology, Geocology and Sedimentary Ore Formation of the National Academy of Sciences of Ukraine", 55b Oles Honchar str., Kyiv, 01054, Ukraine
E-mail: vvivanchenko@ukr.net, avi3751@ukr.net, stesenko-4@meta.ua

Abstract. In the process of developing deposits of magnetite quartzites, hematite quartzites are simultaneously involved in mining. But the processing of hematite quartzites is associated with significant difficulties, so they accumulate in warehouses, landfills and spread uncontrollably in the environment. A detailed study of the features of the composition, structure and technological properties of hematite ores made it possible to develop a new method for complex processing in a vortex air-mineral flow. Under laboratory conditions, a number of commercial products were produced from them: iron ore concentrate, sinter ore, clinker ore, mineral paint and quartz sand, without waste accumulation. The formation of magnetic floccules is reduced in the air stream. Therefore, this technology also improves the processing of magnetite ores.

1. Introduction
In the process of developing deposits of magnetite quartzites, hematite quartzites are involved simultaneously with mining. The enrichment of this raw material is associated with significant difficulties [1–4], so it accumulates in warehouses, in dumps and spreads uncontrollably in the surrounding environment. The reserves of hematite quartzites remain insufficiently demanded in many mineral deposits of the world. Therefore, many companies are looking for economical and environmentally friendly technologies for the enrichment of this raw material [5–7].

2. Objects
Magnetite and hematite ferruginous quartzites of the Krivoy Rog iron ore basin. Here, magnetite quartzites (figure 1) are mined by 5 mining and processing plants. At the same time, hematite quartzites (figure 2) are mined along the way and moved to warehouses and mining dumps. In the landscape, these objects form elevated plateaus. Therefore, hematite quartzites spread uncontrollably in the natural environment under the influence of precipitation and wind (figure 3)

Both varieties of quartzite are equally poor iron ores. However, there are important differences between them. They determine a close interest in some ores, and indifference to others. The authors of the article argue the fallacy of both the first and second approaches.

3. Purpose
To show the common features and technological differences between magnetite and hematite quartzites in economic aspect. To assess the possibilities of industrial application of hematite...
Figure 1. Silicate-magnetite quartzites of the Central GOK.

Figure 2. Dump hematite quartzites of the Ingulets GOK.

Figure 3. Hematite quartzites and continental fauna in the alluvium of the Saksagan river.

Figure 4. Hematite quartzites in the fertile soil in the south of the Krivoy Rog basin, microscope, magnification 10X.

quartzites and present ways of their processing.

4. Methodology
Comparative analysis of the composition and technological properties of magnetite and hematite quartzites according to foreign and domestic researchers was used in the research. Under laboratory conditions, a complex processing of magnetite and hematite iron ores was carried out in a vortex air-mineral flow, according to [8].

Processing of magnetite and hematite quartzites was performed under equal conditions and by the same method. The original quartzites were crushed on a jaw crusher to a size of 0-10 mm and sent to the rotary mill of the original design of the authors. It provides one ore and air loading channel and several units for unloading various processed products. The maximum efficiency of the process was ensured by adjusting the rotor speed, air speed flow and gap between the rotor and the walls of the working chamber.

The growth of ore and non-ore mineral growths was carried out by destroying the ore grains by striking the rotor blades, striking the grains against the inner armor of the mill and colliding the
grains with each other. The movement of particles in the working chamber of the mill took place on a toroidal trajectory. The discovered monomineral particles were removed from the working chamber through different unloading units, depending on the size, morphology, hardness and other physical and mechanical properties of the mineral particles. Unopened adhesions continued to circulate in the working chamber until opening into monomineral particles.

After unloading from the rotary mill, the products were divided on sieves into several size classes and cleaned using air separators: magnetic and gravity. Thus achieved significant purity and high quality of the final products of processing of magnetite and hematite quartzites.

5. The results of a comparative analysis of magnetite and hematite quartzites

5.1. Useful components of ores

Magnetite is the only ore mineral in magnetite quartzites that is actually extracted into iron ore concentrate. It is represented by idiomorphic crystals, irregularly shaped grains and intergrowths. It has pronounced magnetic properties and therefore forms floccules in the pulp of enrichment factories. Floccules also capture non-metallic minerals and this makes it difficult to produce high-quality iron ore concentrate (figure 5, figure 6, figure 7, figure 8,).

Figure 5. Idiomorphic crystals and intergrowths of magnetite; binocular microscope. Magnification $25^\times$.

Residual magnetite, hematite (martite, iron mica), goethite and lepidocrocite can potentially be extracted from hematite quartzites into concentrate. However, goethite, hydrogoethite, and hydrohematite contain hydroxyl (OH), SiO2 Al2O3, sometimes Na2O, and other compounds that can reduce the quality of iron ore concentrate (figure 9, figure 10, figure 11, figure 12,).

The total content of iron is higher in hematite quartzites (due to the partial removal of silica), and the magnetic iron content is higher in magnetite ones, due to the oxidation of magnetite under supergene conditions.

5.2. Ballast minerals of magnetite quartzites

Quartz and silicates of metamorphic origin. Quartz is intergrown with magnetite, silicates and contains numerous mineral inclusions (figure 13, figure 14). In hematite quartzites, quartz (including marshalite), sedimentary silicates (hydromicas, kaolinite and other clay minerals) are ballast. Also hydrohematite and limonite. Due to the low content of iron and impurities of alumina, silica, alkalis, these minerals are undesirable in iron ore concentrate, as they reduce its quality.
5.3. **Harmful mineral impurities of magnetite quartzites:** sulfides (figure 15), alkaline silicates, apatite [9]. The composition of hematite quartzites includes sulfates, alkali metal halides (figure 16, figure 17), apatite altered in the weathering crust, close to phosphorite.

5.4. **The anatomy of mineral individuals and aggregates** in magnetite quartzites was formed under hypogene conditions of high pressures and temperatures (amphibolite facies of metamorphism). Their structure is dense. Hematite...
quartzites are dominated by mineral individuals and aggregates formed under supergene conditions of the weathering crust. They are porous, loose and can crumble when squeezed by hand. Therefore, the hardness of minerals, as well as the strength and other physical and mechanical properties of magnetite quartzites are much higher than that of hematite quartzites. These features and differences should be taken into account when choosing a technology for processing magnetite and hematite quartzites.

Many magnetic (including roasting-magnetic, high-gradient), electrostatic, gravity, flotation and mixed technologies for the enrichment of magnetite and hematite ores are described in the literature [1–6, 10–12]. Their analysis indicates a much higher efficiency of enrichment of magnetite quartzites by known methods and technologies. As a result, hematite quartzites were beyond the economic interests of mining companies.

Employees of our institution developed a fundamentally new method for the complex processing of hematite raw materials [8]. It uses a gradient of many physical properties and features of ore and non-metallic minerals: magnetic, density, mechanical, morphological. The separation takes place in the suspended state of mineral particles under the conditions of a vortex air-mineral flow. The laboratory unit consists of a feed unit, a rotary mill, cyclones, magnetic and gravity separators, unloading units and an electronic control unit.

Magnetite and hematite quartzites of the Krivoy Rog iron ore basin were used in the tests.
Iron ore concentrate and enrichment tailings were produced from magnetite quartzites (table 1). Iron ore (goethite-hematite) concentrate, sintering ore, clinker raw materials, mineral pigments, quartz sand were produced from hematite quartzites (figure 18, figure 19, figure 20, figure 21,
Figure 17. Sylvite on the surface of layered silicates in hematite ore of mine production; scanning electron microscopy, microprobe analysis.

All iron ore processing products are dry. They are produced without the participation of water, flotation agents and without heating.

Table 1. Products of enrichment of magnetite and hematite quartzites in a vortex air-mineral flow.

| Product                        | Mass fraction of components, % |
|--------------------------------|---------------------------------|
|                                | $Fe_{total}$ | $SiO_2$ |
| Magnetite quartzites           |                  |        |
| Magnetite quartzite Ingulets deposit | 34,05         | 43,21  |
| Magnetite concentrate          | 66,80           | 7,85   |
| Tailings                       | 9,8             | 73,92  |
| Extraction into useful product, % | 87,2           | 0      |
| Hematite quartzite             |                  |        |
| Hematite quartzite Skelevat deposit | 32,6           | 50,9   |
| Hematite concentrate           | 68,6            | 1,33   |
| Sinter ore                     | 61,4            | 12,1   |
| Clinker ore                    | 48,6            | 29,5   |
| Mineral pigment                | 37,9            | 41,3   |
| Quartz sand                    | 1,3             | 97,6   |
| Extraction into useful product, % | 98,7           | 98,6   |

Complex processing of ferruginous quartzites is based on the use of the above features of the composition, structure and physical and mechanical properties. The initial ore is crushed in the working chamber of the rotary mill in the vortex mode of air blowing. The size of the ore particles is reduced due to self-grinding and impacts on the mill armor. The mineral grains opened from the intergrowths are carried out by the air flow outside the working chamber. Then they are deposited in a series of air cyclones and bag filters, in accordance with the physical
Figure 18. Iron ore (hematite) concentrate: a - general view; b – under a microscope. Magnification 20\(^X\).

Figure 19. Sinter ore: c - general view; d – under a microscope. Magnification 10\(^X\).

properties and morphological features of the particles. Unopened splices remain in the chamber until the splices are destroyed and opened. Opened ore grains are discharged through outlets at the bottom of the mill. The final cleaning of products is carried out using magnetic and gravity separators.

This technology allows disintegrating and separating ore at the same time. In addition, iron ore concentrate and other products remain dry and are sold in this form.

6. Discussion of results and conclusions
From the given data it follows that as a result of the processing of magnetite quartzites, two products are produced: concentrate and enrichment tailings in the form of silicate-quartz finely divided sand. Processing of hematite quartzites in a vortex air-mineral flow allows to produce a larger number of products, and this leads to an increase in their liquidity.

In the dynamic conditions of the working chamber of the installation, where particles collide with each other and with the chamber armor at a high linear speed, magnetic floccules are practically not formed. This increases the efficiency of separation of ore and non-ore particles,
in comparison with the magnetic separators of modern processing plants. In addition, the
magnetic properties of iron oxides in hematite quartzites are much weaker.

In addition to the chemical composition, ore minerals: magnetite, hematite, goethite,
lepidocrocite, hydrogoethite and hydrohematite differ in hardness, specific gravity, and
morphological features. This allows working with hematite raw materials to separate them
into various products. At the same time, the purity and quality of the iron ore concentrate
increases. In its composition, the total content of SiO2 and Al2O3 is no more than 2-3%. This
 corresponds to modern standards of metallurgical companies. And minerals with a lower iron
content are used to produce other marketable product: sinter ore, clinker raw materials, paints,
etc.

The destruction by impact forms a cuboid shape of the newly formed particles. Lamellar
hematite (iron mica) as a result of collisions splits along rhombohedral cleavage planes, acquires
an isometric shape and, as a result of gravitational differentiation in a vortex air-mineral flow,
is unloaded into the iron ore concentrate receiver together with magnetite. In this case, tabular
and lamellar silicate individes are removed from the working chamber into a bag filter.
Thus, the processing of magnetite quartzites by wet magnetic separation is the most energy-intensive and resource-intensive due to the high hardness of the ore, the negative effect of flocculation, the formation of wet polymineral tailings and high losses of magnetite in them. More efficient is the processing of magnetite quartzites in a vortex air-mineral flow. It leads to the formation of dry tailings, which can be used as fillers, for example, in road construction. The most favorable option is the complex separation of hematite quartzites in a vortex air-mineral flow. It ensures maximum savings in electricity and mineral resources, ensures the production of high-quality iron ore concentrate, suitable for the direct reduction of iron and other demanded products. The absence of water, flotation reagents and heating makes the process environmentally friendly and compliant with the principles of the circular economy.

Taking into account the above data, in modern conditions, in the short and long term, the use of hematite quartzites is more promising and should replace the extraction of magnetite quartzites in many deposits of the world.

ORCID iDs
V V Ivanchenko https://orcid.org/0000-0003-4889-8975
V V Stetsenko https://orcid.org/0000-0002-1471-5379
A V Ivanchenko https://orcid.org/0000-0001-7989-7380

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