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Anini iron ore deposit:mineralogy,wet magnetic separation enrichment and metallurgical use

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Abstract
In recent decades, emphasis was on improvement the Algerian mining industry by creating new smelting complexes such as the metallurgical plant in Bellara (Jijel) with a productive capacity of 5 million tons per year to satisfy the increasing demand in steel. The present study was conducted at Anini's iron ore mine to develop its mineral resources in order to use it in the metallurgical industry (Arcelor-Mittal complex of Annaba Algeria).Representative samples were collected from the iron ore mine of Anini in northwestern of Setif. A series of chemical and mineralogical analysis was performed. However, the analysis by (XRD, SEM and XF) shows that this mineral is hematite iron type clay and siliceous gangue. Moreover the mean levels of Fe_2O_3, SiO_2 and Al_2O_3 are 50.52 %, 24.06% and 7.80%. The results obtained with the magnetic separation in wet process reveals significant content of iron ore with 65.11% of Fe_2O_3, 2.46% SiO_2

and 1.73% Al_2O_3.These findings proved the effectiveness of this treatment to provide the criteria imposed by the steel industry. As well as the resulting wastes can be used in the cement industry.
Keywords: ALGERIA, ANINI, IRON ORE, CHARACTERIZATION, PARTICLE SIZE

Introduction

Iron is the most searched and widely used metal over the world due to its utilitarian properties such as hardness, strength and durability. It is used primarily for the development of various kinds of steel which makes it essential across all industries.

In native state, it is a generally dark colored metal, which constitutes about 5% of the crust. This is a very reactive element which oxidizes very readily [1-2].

It takes the form of mineral rocks whose metallic iron can be economically extracted, in nature. Ores are usually rich in iron oxides and vary in color from dark gray, bright yellow, dark violet, to rusted red. Iron is found in the form of magnetite (Fe_3O_4), of hematite (Fe_2O_3), goethite and limonite or siderite [3-4]. Iron ore is the main raw material used for the steel production about 70% irons is intended for blast furnaces. On average, the production of one ton of steel requires 1.6 tons of iron, it occurs in two forms: The first and most common, is magnetite, which requires costly downstream processing, but which counterparty commands a higher price.

Less common, hematite is cheaper to produce and easier to enriched, also known as "natural ore" because it is the most widespread form of rock on the surface of the earth, and also that which is usually employed in industry [1].In eastern Algeria, in the wilaya of Setif, Djebel Anini field is located in the karst cavities in limestones of the cenomano-turonian period;

It consists of the ferriferous mix including a stony complex of loose hematite [5]. Thus, several hematitic lodes about 47m were highlighted with a minimum width of 5 m and a maximum length of 500 m. [6]

Constraints of iron ore enrichment are closely related to two major factors: the first factor is the huge use of fine iron ore amounts, and sludge that are not only a loss in mineral resources, but as a really environmental problem. The second factor is the ore upgrade that is relatively rich in alumina and silica as required the steel standards (blast furnace) [7-8-9].

The ore enrichment technologies are an enhancement of the low content of useful mineral deposits. The ore deposit of Djebel Anini iron does not meet requirements of metallurgy although an iron level is important because its silica content is very high.

By carrying out the chemical analysis of samples crushed and screened, from the studied particle size fractions, it was found that the iron content is changing when the quartz rate decreases or vice versa. For this purpose it would be desirable to conduct a study on the behavior of the ore to recover the iron mass with minimal reduction of silica (quartz), which would qualify by steel consumers. According to specific properties of several ore enrichment processes can be distinguished whose may be mentioned among which the gravity treatment method is one of the most ancient for the iron ore enrichment techniques [10], but it has been replaced through other processes using newest technologies including magnetic separation and flotation [11], although the last method cannot be envisaged for iron ore treatment due to its high cost.

Overview on Anini Iron Deposit

The Djebel Anini iron deposit is located in the northern part of Algeria [12], about 30 km NW of Setif city and 4 km from the municipality of Ain Roua. The perimeters studies are in the southern flank of Djebel Anini (Figure 1). [5]

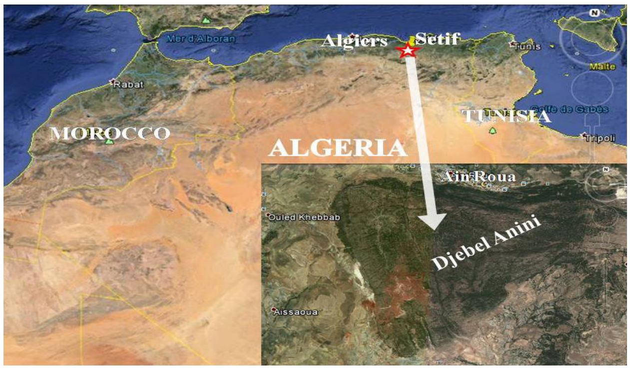

Figure 1. Map of geographical location of the study area (Google Earth)

Cenomanian-Turonian

It constitutes the essential formations Djebel Anini (Mountain Anini). This is a geological formation with a thickness of approximately 300m, the Cenomanian corresponding to rich carbonated mass organizations debris; it consists of crystalline layered sometimes dolomitic limestone massif.

The foundation of this formation contains sparitic massive limestones and zoogenic containing orbitolina of orbitolinaconica kind of crossing and up micritic facies with Nezzazata, to the top of the series, there is cenomanian disappearance of species and the emergence of Hippurites (Figure 2), which indicate the Turonian [13]

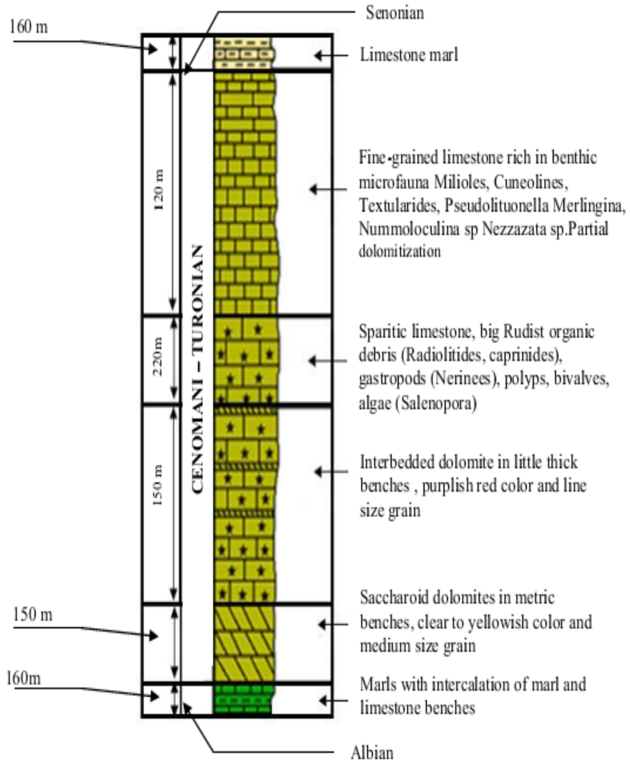

Figure 2. Stratigraphic Log Cenomanian-Turonian of Djebel Anini [14]

Materials and methods

Ore sampling

The purpose of sampling is to allow the most reliable estimate of unknown and inaccessible value of a property of batch from test carried out on a representative sample. [15]

This is the fundamental and decisive step regarding the quality and precision of the results expected from the granulo-chemical and mineralogical characterization of the ore according to the AFNOR (French Association for Standardization), when a sample is representative for a property or properties (which can be measured, it manifests the same characteristics as the material from which it is derived in our case must contain the physico-chemical characteristics of the whole study site. [16]

The collection of an iron sample of 70 kg is carried out on conveying belt, crushed products to (0-250 mm).

Screen chemical testing of iron ore from Anini

Particle size analysis of ore carried out on a sieving Rotap has allowed firstly to determine the% respectively of the different particle size fractions in the sample and secondly, to seek an optimal liberation mesh size iron-bearing minerals in relation to the siliceous gangue (table 1).

Table 1. Results of particle size analysis of the iron ore crushed to 5 mm

Size fractions	Mass (g)	Mass (%)	Fe_2O_3 (%)	Cumulated Refusal (%)
>4	112.65	22.53	50.02	22.53
-4+2	146.55	29.31	52.39	51.84
-2+1	75.30	15.06	48.43	66.90
-1+0.5	65.70	13.14	49.51	80.04
-0.5+0.25	56.45	11.29	53.86	91.33
-0.25+0.125	17.55	3.51	52.64	94.84
-0.125+0.063	13.10	2.62	48.98	97.46
-0,063+0.045	7.90	1.58	53.25	99.04
4<0.045	4.80	0.96	50.73	100
Total	**500**	**100**	**-**	**-**

Chemical Characterization of Mineral Oxides from Anini

The different particle size fractions were analyzed by XRF and the results obtained are summarized in Table 2.

As well, we note that the content of Fe_2O_3 is significant in coarse fractions (50.52%), but excessive-presence of a high content of SiO_2 which sometimes reaches 24.06%, as in the case of Al_2O_3 is 7.80%. Due to high content of silica it excluded its direct use in the steel industry and therefore prior ore enrichment is recommended.

Table 2. Iron ore chemical analysis results of Djebel Anini

d(µm)	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	TiO_2	MnO	P_2O_5
initial	50.52	24.06	7.80	3.30	0.55	0.31	0.09	0.16
>4	50.02	26.04	7.12	3.15	0.34	0.29	0.08	0.13
-4+2	52.39	28.65	7.09	3.20	0.62	0.43	0.09	0.12
-2+1	48.43	22.99	8.49	3.35	0.70	0.33	0.07	0.14
-1+0,5	49.51	24.55	8.61	3.66	1.02	3.38	0.10	0.11
-0,5+0,25	53.86	26.97	9.46	3.46	0.98	1.27	0.09	0.12
-0,25+0,125	52.64	29.64	8.84	3.41	1.01	2.50	0.20	0.11
-0,125+0,063	48.98	23.82	9.42	3.56	0.77	1.80	0.20	0.12
-0,063+0,045	53.25	22.40	7.23	3.12	0.72	2.90	0.35	0.15
<0,045	50.73	24.13	7.11	3.38	0.95	1.25	0.28	0.13

Ore Mineralogical Characterization

Nodular texture infiltrated naturally forms concentric layers of hematite and goethite. Hematite is the central part of the bud or gravitates within it goethite and forms the periphery nodular precipitates (Fig. 3 a). Sometimes we encounter alternating concentric layers of hematite and goethite (Fig.3 b).

Occasionally the central area of the seed is made of massive hematite almost aggregate (i.e. pictures). In the polishing goethite are manifested by good reflections in red-brown shades (Fig.3 e-f). e and f - under crossed nicols

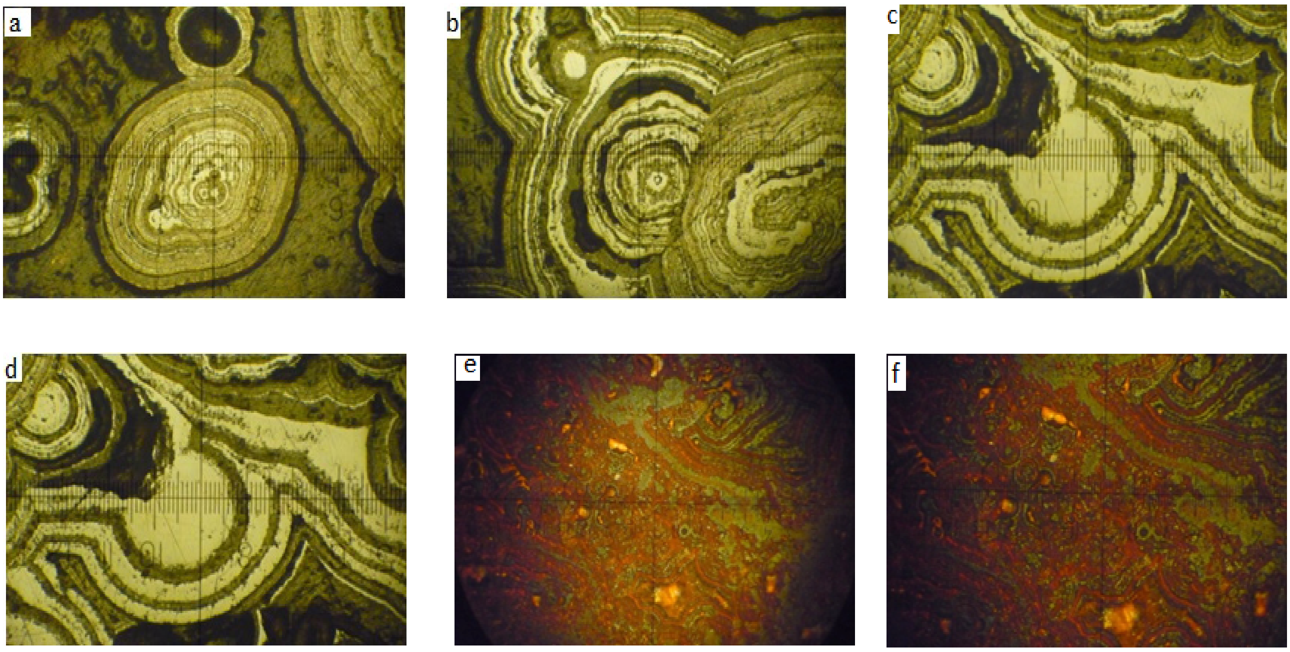

Figure 2. Studied Ore Mineralogical Composition (Polished section No 1)

Over the polishing there is a little more goethite relative to the polished section 1. Further sections contain no hematite (Fig. 3 g and h). The texture is very porous, on some sections. Sometimes the zonal substitution is as straight lines, forming the original triangles (Fig. 3 i to j). Rather, there occurs clogging and replacement of some grains with good facets or, possibly, by filling the pores of regular shape.

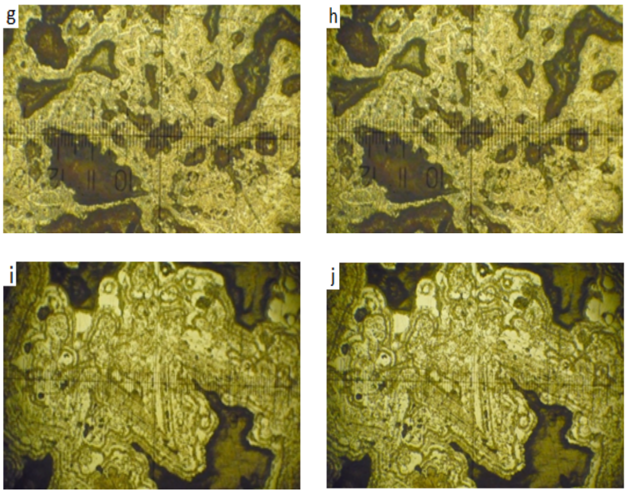

Figure 3. Studied Ore Mineralogical Composition (Polished section No 2)

Analysis by X-ray diffraction (XRD)

The X-ray diffraction is a study technique commonly used to identify mineral species in solid matrix. It allows among other structures of mineral species of the same chemical composition but different crystalline structures such as aragonite and calcite.

However, if the analyzed sample contains an amorphous phase (or vitreous) important XRD analysis will have an incomplete characterization of the solid matrix.

The mineralogical analysis by XRD confirmed the mineralogical composition of this type of ore identified by optical microscope and to specify the nature of minerals. The XRD analyzes were carried out in the laboratory of analysis and characterization of Bejaia University (Algeria).

The results obtained by XRD are represented in the spectrum illustrated in Figure 4. However, we can conclude that the main mineralogical constituents of Anini iron ore are mainly hematite (Fe_2O_3), quartz and clay and some calcite inclusions in the matrix. For this purpose, it is interesting to highlight this type of ore for enrichment by the wet magnetic separation for getting rid of clay and quartz sludge for recovery of ferriferous minerals.

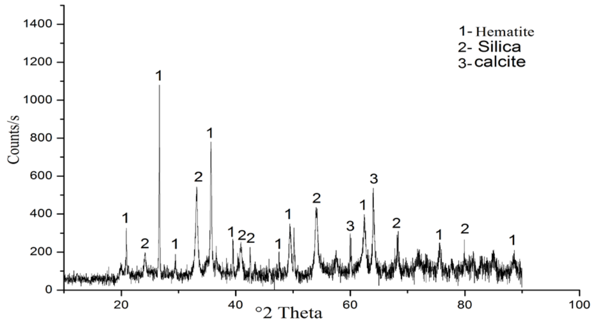

Figure 4. Spectrum of Anini iron ore sample obtained by X-ray diffractometer

Enrichment Tests of Anini Iron Ores by Wet Magnetic Separation

In this research, the equipment used is a high intensity magnetic separator wet magnetic analyzer type. Initially, an iron ore sample of 500 g was prepared, and then the crushing operation using the following devices was carried out:

- Single-toggle jaw crusher with an aperture of 15 mm
- Double jaw crusher effect with an aperture of 05 mm
- Primary roll crusher with an aperture of 1 mm
- Secondary roll crusher with an aperture of 0.5 mm

After completing all the steps of crushing, the sample was divided into two parts of equal parts for each 250 g and then the sieving operation to a particle size of 1 mm was performed.

Iron ore enrichment test was conducted at the laboratory enrichment of minerals of Urals State Mining University - Russia on a high intensity wet magnetic separator (magnetic analyzer) on a sample of 250 g of a size smaller than 1 mm and tested at an optimum intensity of the electric current of 8A.

After magnetic separation method of the concentrate and rejection have undergone through a rigorous drying in a furnace at 105 ° C to reduce moisture content then ground in a disc mill, and finally subjected to chemical analysis by X-ray fluorescence and atomic absorption spectrophotometry XRD.

Results and discussion

According to the obtained results of high intensity magnetic separation (HIMS), we found a significant increase in iron content, and a remarkable decrease in the clay fraction. The Fe_2O_3 content is 65.11%, with an increase of 28.87% compared to the initial content. In addition, levels of silica and alumina experienced a significant decline in 24.06% to 7.80% and 2.46% $Si0_2$ 1.73% Al_20_3.

Calculation of basicity index

The proportions of lime (CaO) and silica (SiO_2) contained in the starting material must be in a CaO / SiO_2, named Basicity, which is generally between 1 and 1.5 which also characterizes the self-fluxing character ore. We often simplify the Global basicity index by calculating the partial basicity index of CaO/ SiO_2

BI = CaO / SiO_2 = 3.30 / 24.06 = 0.13 before magnetic separation

BI = CaO / SiO_2 = 2.89 / 2.46 = 1.17 after magnetic separation

The basicity index calculated [PI = (CaO / SiO_2)] shows that the separated ore responds to metallurgical standards.

Table 3. Results of wet magnetic separation testing of Anini iron ore

Wet Magnetic Separation	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	SO_3	CuO	Pb	P_2O_5
Concentrated	65.11	2.46	1.73	2.89	0.65	0.01	0.01	0.30	0.04
Rejection	7.16	24.55	7.02	3 .50	0.25	0.02	0.04	0.46	0.25

Analysis by X-Ray Diffraction (XRD) After Wet Magnetic Separation

According to spectrum shown in Figure 5, we note that the mineral phase is observed predominantly hematite, and the spectrum in Figure 6 we note that the observed phase is mineral quartz -clay and a few calcite inclusions and hematite.

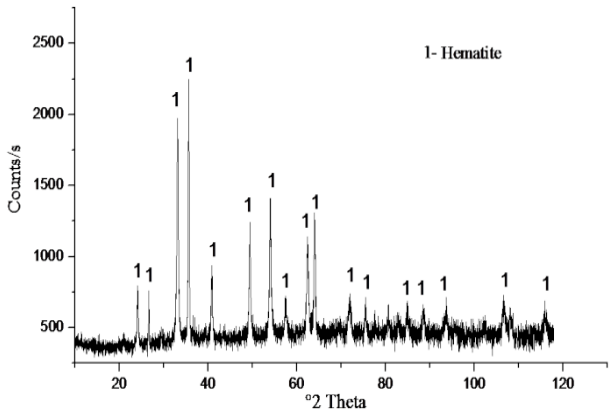

Figure 5. Spectrum of concentrate sample obtained after magnetic separation

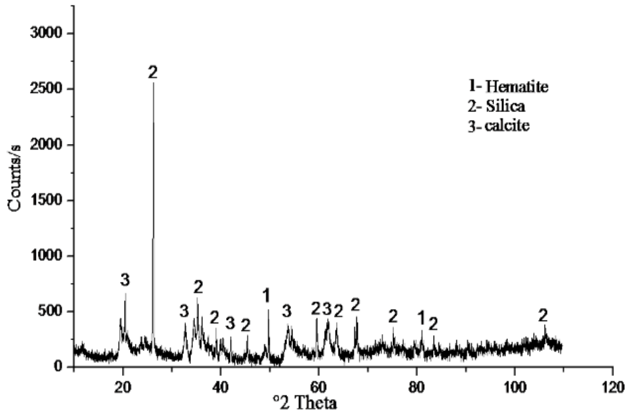

Figure 6. Spectrum of washed sample (rejected)

Diagrams Proposed for Preparation and Processing of Anini Iron Ore by Settling Method

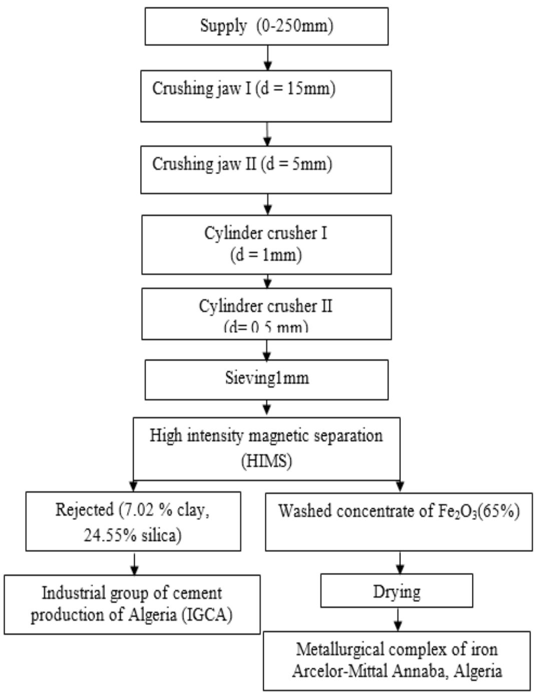

Figure 8. Diagram of Proposed Preparation for Anini's Iron Ore Enrichment

Conclusion

Algeria has significant mining potential, but it is not rationally exploited. The enrichment processes of mineral resources must be developed in order to boost industrial activities related to it, and ensure an increase in yield thereof. To achieve this goal it is necessary to adopt new techniques. According to the study on the characterization of Anini iron ore for enrichment, the conclusions drawn are:

The particle size analysis of a sample crushed to 5 mm reveals that the rich iron ore is significant in fractions of less than 5 mm (are content greater than 50% Fe).

The XRD analysis and thin sections of ore revealed that its mineralogical composition contains mainly hematite, with small quantities of goethite, and trace amounts of calcite.

Chemical analysis of samples shows that the iron ore has an average iron content of 50.52%. However, the contents of SiO_2 and Al_2O_3 are also remarkable, reaching 24.06% and 7.80% respectively. These high contents of quartz and clay classify iron ore, subject of this study as clay-quartz ore.

The application process of wet (HIMS) has allowed firstly increasing the iron content and secondly, to decline significantly the combined fraction of clay and quartz: the content of Fe_2O_3 is 65.11%, with an increase of 28.87% against an initial content 50.52%. In addition, the contents of silica and alumina are respectively decreased by 24.06% to 7.80% and 2.46% to 1.73%.

The importance of the results of this study resides in the process efficiency (HIMS) for ore valorization to make it usable in the steel industry. The rejection from the process can be used in preparation of cement products (SiO_2, Al_2O_3, and Fe_2O_3).

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