Journal of Mining and Geology Vol. 56(1) 2020. pp. 105 - 111 1116-2775

Influence of Sub-Grade Ores on the Cut-Off Grade and Ore Reserve of Itakpe Iron Ore Deposit, North-Central, Nigeria

Nwosu, J.I. and Benard, I.U.
Department of Geology, University of Port Harcourt, Nigeria
Corresponding E-mail: joseph.nwosu@uniport.edu.ng

Abstract
Itakpe iron ore deposit is a multi-grade ore deposit with ore grades varying from 14.8%Fe to 41%Fe in the 25 ore layers. At the point of design of the mine, several low grade ores were deposited in temporary stockpile and a mineable ore reserve of 145mt was established. This paper examines the cut-off grade of Itakpe deposit in view of the current cost of mining, processing and waste removal. It further examines which of the low grade ores in temporary stockpile can now be included in the main ore reserve if the cost of their removal is considered as a credit towards the reduction of the cost of production. Analysis shows that the cut-off grade of Itakpe iron ore deposit without considering the ores currently in temporary stockpile is 26%Fe. It however lowers from 26%Fe to 23%Fe if the cost of production and value of some low grade ores are considered. The resultant effect is that ore reserve increases from 150mt for 26%Fe cut-off grade to 159mt for the cut-off grade of 23%Fe. Thus it becomes justifiable to send the additional 9 million tons whose grades vary from 26%Fe to 23%Fe to the mill especially considering the country's need of iron ore concentrate for steel sector development.

Keywords: *Sub-grade ore, main ore reserve, cut-off grade, value per ton of ore, production cost per ton of ore*

Introduction

Cut-off grade is the grade used to discriminate between what should be mined and what should be regarded as waste (Rendu 2003). However, while the definition of cut-off grade looks clear, cut-off grade policy has been different for various researchers. The earliest cut-off grade is the policy is the breakeven approach. By this approach, the cut-off grade is the grade at which production cost just equals the value per ton of ore (Agabalian 1994). However a different approach was given by Lane (1964) in which cut-off grade was viewed as the grade which provides the maximum net present value (NPV) on the exploitation of mineral deposit. This idea was accepted by a number of authors most who are neither geologists nor mine planners (Lane 1964; Muriuki and Temeng 2018). However, this approach was subjected to criticism by various mine planners and geologists (Arsentiev 1970). The criticism was based on two reasons. First, the methods applied to achieve maximum NPV were purely mathematical and did not reflect patterns of mine development. Secondly, mineral resources are not replenishable and attempt to establish cut-off grade as the grade that maximises the NPV will leave most of the ore reserves untapped. Thus, various authors suggested that the breakeven approach to cut-off grade estimation should be modified so that the value per ton of the cut-off grade ore must provide the production cost per ton of ore and the minimum acceptable rate of return on investment (Alwyn 1991; Nwosu and Okengwu 2009).

Rendu (2003) opined that the breakeven approach does not consider capacity constraints, discounting techniques and opportunity cost. For its simplicity of application he recommends that breakeven concept should be applied at the early life of the pit when most of the input data for NPV application are yet to be known.

Another approach to cut-off grade estimation is that the cut-off grade should not only be based on the main metal of the ore but also must consider the minor metals of the ore (Michelson and Buckley 1973).

Nwosu and Nwankwoala (2009) opined that not only the minor metals should be included in cut-off grade analysis but also that the influence of construction materials within the deposit which can be exploited as profit should be considered as a credit towards reducing the cut-off grade of the main ore.
Any ore body whose grade is lower than the cut-off grade is termed sub-grade ore body. The ore bodies of a mineral deposit are either classified as main grade or sub-grade ores.

After the cut-off grade of a mineral deposit has been established, the sub-grade ores are moved either to the waste dump or to a temporary stockpile, waiting when the production cost will reduce or more especially when price per ton of concentrate will increase to justify the processing of some sub-grade ores.

The current research centres on considering the influence of sub-grade ores on cut-off grade of Itakpe deposit. Over the past 25 years the National Iron Ore Mining Company Itakpe has stockpiled low grade ores in temporary stockpile. Over the past 25 years too, the price per ton of iron ore concentrate has tremendously increased due to industrial revolution in some Asian countries like China and Malaysia. It therefore became necessary to review the influence of the sub-grade ores in temporary stockpile on the cut-off grade of Itakpe mine.

Based on the above discussion, the 25 ore bodies of the Itakpe iron ore deposit will be critically examined to determine which of the 25 ore bodies will be classified as mineable reserve.

Location and Geology of the Deposit

Itakpe iron ore deposit is located within Itakpe hills in Adavi Local Government Area of Kogi State. It is 15km from Okene town. Geographically Itakpe iron ore deposit lies between latitude $7'35^{0}$N - $7'39^{0}$N and longitude $6'15^{0}$- $6'22^{0}$E. The main ores of iron are haematite and magnetite which are intercalated with gneiss, schist, quartzite, and amphibole. The highest point on the hill is 375m above sea level. The iron ore deposit has a proven reserve of 145million tons with average iron content of 36% (NIOMCO 1980). Itakpe deposit is made up of fourteen ore layers with grades varying from 14%Fe – 40.9%Fe.

Currently the deposit is mined using open-pit mining method, with the mine pit being divided into East Pit and West Pit. Most of the rich ore bodies are within the East Pit. The location of Itakpe iron ore deposit in the map of Nigeria is shown below in Fig. 1.

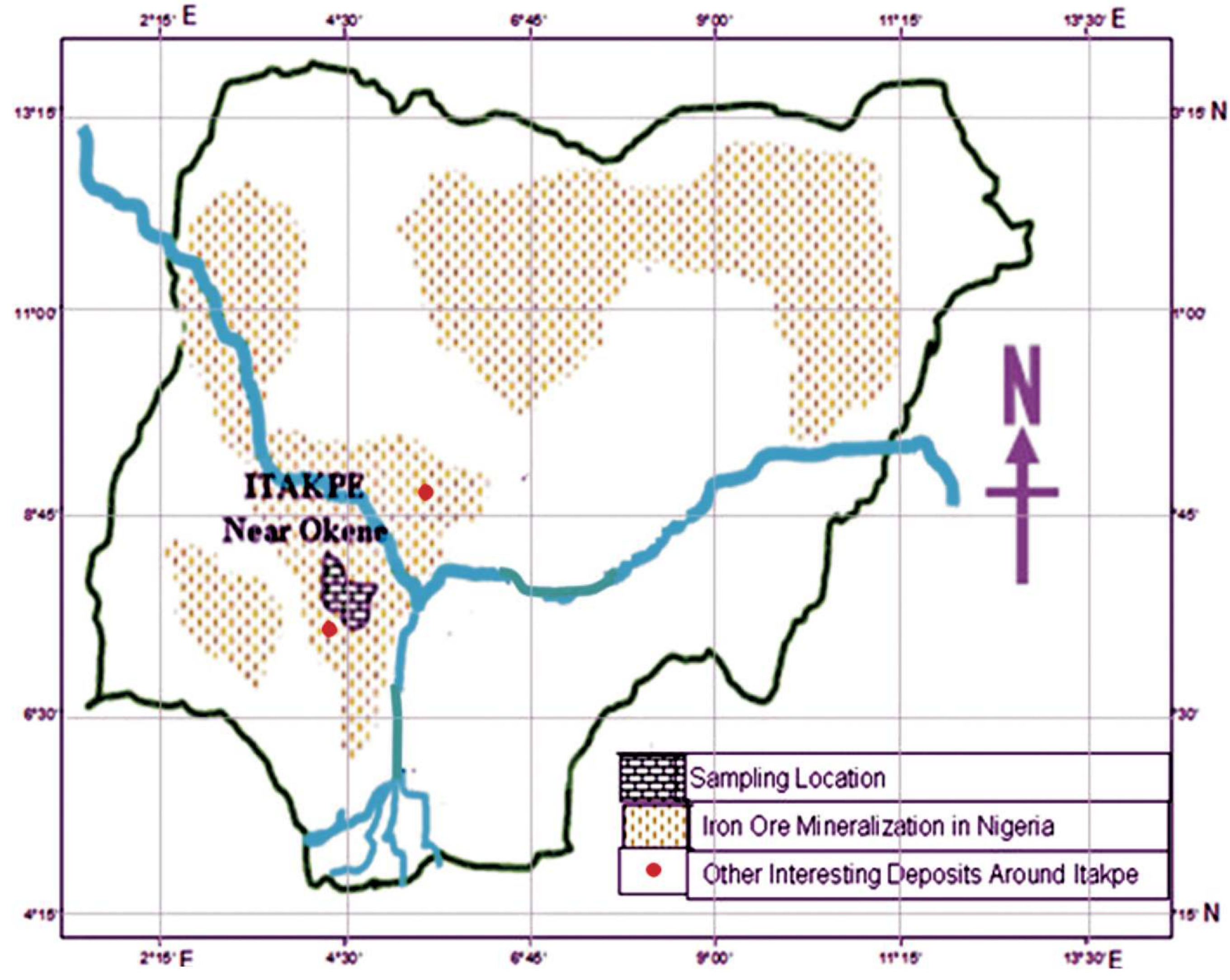

Fig 1: Map of Nigeria Showing Itakpe Deposit (after Onyemaobi, 2001)

Olade (1978) and National Iron Ore Mining Project report of (1980) distinguish four (4) main zones of the ore bodies in Itakpe deposit. The four zones are:

1. The northern ore body zone
2. The southern ore body zone
3. The central ore body zone
4. The intermediate ore body zone

The northern zone is made up of three layers namely; N1 with a grade of 34.19%Fe, N2 with a grade of 37.88%Fe and N3 with a grade of 35.01%Fe content. The southern zone consists of three ore layers namely S1 with a grade of 38.69%Fe, S2 with a grade of 36.45%Fe and S3 with a grade of 24.4%Fe. The central zone comprises of four main ore layers namely C1 with a grade of 40.95%Fe, C2 with a grade of 29.88% Fe, C3 with a grade of 34.12%Fe and C4 with a grade of 37.037%Fe. The intermediate zone consists of 3 ore layers namely I1 with grade of 29.5%Fe, I2 with a grade of 34.95% Fe and I3 with a grade of 36.44%Fe. The 25 ore layers for East Pit and West Pit including their grades and reserves are presented in table 1a and 1b below. Also a cross section of the Itakpe deposit showing the ore layers is shown below in Fig. 2.

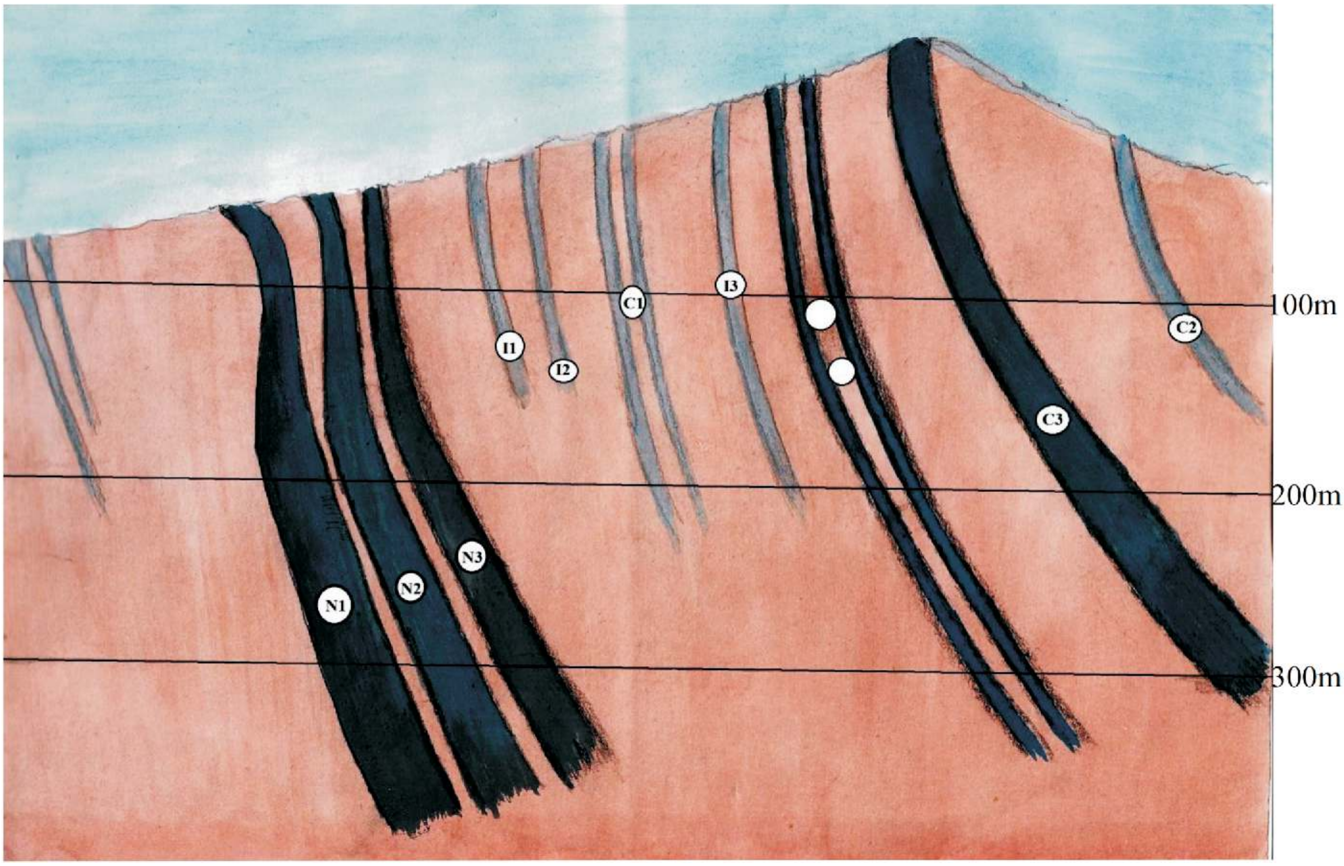

Fig. 2: Cross Section 36 + 50 of the Itakpe iron ore (NIOMCO 1980)

In order to analyse the influence of inclusion of sub-grade ores on the reserve of Itakpe iron ore deposit, the cut-off grade of the deposit was first established using the formula;

$$\mathbf{COG} = \frac{\textbf{Production cost per ton ore}}{\textbf{Value per ton of ore}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

or

$$\mathbf{COG} = \frac{C_m + C_p + S_r C_w}{\gamma p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Considering a minimum acceptable rate of return (r) on investment, formula 2 becomes:

$$\mathrm{COG} = \frac{\left(1+\frac{r}{100}\right)[C_m + C_p + (S_r C_w)]}{\gamma p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where;

COG is the cut-off grade (expressed in fraction or %)
C_m is the cost of mining per ton of ore
C_p is the cost of mineral processing per ton of ore
C_w is the cost of waste removal per ton of waste
S_r is the Stripping ratio

Table 1a: Various ore layers, their tonnages and grades at Itakpe iron ore deposit.

East Pit

Ore layers	Ore layer index	Grade (%)	Tonnage (mt)
Northern	N_1	34.19	15.49
Northern	N_2	37.88	31.58
Northern	N_3	35.01	5.22
Intermediate	I_1	29.5	0.95
Intermediate	I_2	34.95	3.6
Intermediate	I_3	36.44	10.68
Central	C_1	40.95	6.2
Central	C_2	29.88	9.54
Central	C_3	34.42	20.1
Central	C_4	37.037	32
Southern	S_1	38.68	2.8
Southern	S_2	36.45	4.41
Southern	S_3	18.2	3.8
Total reserve of east pit			**147.04mt**

Table 1b: Various ore layers, their tonnage and grades at Itakpe iron ore deposit

West Pit

Ore layers	Ore layer index	Grade (%)	Tonnage (mt)
Northern	N_1	25.3	3.8
Northern	N_2	15.8	2.5
Northern	N_3	14.8	5.6
Intermediate	I_1	15.8	2.8
Intermediate	I_2	20.6	3.6
Intermediate	I_3	34.7	4.5
Central	C_1	20.5	2.27
Central	C_2	18.7	5.6
Central	C_3	17.8	7.6
Southern	S_1	20.8	2.6
Southern	S_2	28.6	3.6
Southern	S_3	24.4	4.6
Total reserve of east pit			**49.27mt**

(Source: NIOMCO Project Report, 1980)

γ is the concentrate yield per ton of ore (ton)
p is the price per ton of concentrate
r is the acceptable rate of return on investment

Based on the value of cut-off grade (COG) obtained from formula 3 above, the ore bodies in tables 1a and 1b are now classified into main grades and sub-grades. Furthermore, the reserve of the main grade and sub-grade are ascertained.

Considering that expenses on the removal of sub-grade is sure to exist whether we send the sub-grade to the mill or not, we now regard the cost of waste removal of the sub-grade as credit towards reducing the cost of mining per ton of the sub-grade ores. Now we convert the cost of mining, processing and value of the sub-grade ores into the main ore equivalent (Michelson and Buckley, 1973), (Arsentiev, 1994). This can be done by developing the following models.

If the cost of removal of sub-grade ore as waste can be considered as a credit towards reducing the cost of mining, now that they are sent to the mill, then the cost of mining the sub-grade ores

$$C_g = C_m - C_w \quad \text{.......(4)}$$

Thus the cost of mining per ton of ore considering the conversion of the sub-grade ores to the main ore equivalent.

$$Z = C_m + \frac{S_g C_g}{S_m} \quad \text{.......(5)}$$

Where;
Z is the cost of mining per ton of ore considering the conversion of the sub-grade ores to the main ore equivalent
C_g is the cost of mining per ton of sub-grade ore
S_m is the reserve of the main ore
C_m is the cost of mining per ton of main ore
S_g is the reserve of the sub-grade ore

Cost of processing per ton of ore considering the sub-grade ore

$$U = C_p + \frac{C_{ps} S_g}{S_m} \quad \text{.......(6)}$$

Where;
U is the cost of processing per ton of ore considering the sub-grade ore
C_p is the cost of processing per ton of the main ore
C_{ps} is the cost of processing per ton of sub-grade ore

Value per ton of ore considering the conversion of sub-grade ore to main ore equivalent can be expressed as;

$$Y = \gamma_m P + \frac{r_s S_g P}{S_m} \quad \text{.......(7)}$$

or

$$Y = P\left(\gamma_m + \frac{\gamma_s S_g}{S_m}\right) \quad \text{.......(8)}$$

Where;

γ = value per ton of ore considering the conversion of sub-grade ores to main ore equivalent

γ_M = concentrate yield of the main ore (ton)

γ_S = concentrate yield of sub-grade ore (ton)

Cost of Waste Removal

Waste removal cost per ton of waste remains the same but the operating stripping ratio changes since the sub-grade ores which were formerly regarded as waste are now regarded as ore. So the operating stripping ratio will be lower than when it was considered as waste.

Results and Discussion

The input data for assessing the influence of sub-grade ores on the cut-off grade and reserve of Itakpe deposit are presented in Tables 1a, 1b and 2.

Table 2: Techno-economic data of Itakpe open-pit mine

Concentrate yield per ton	0.35
Stripping ratio t/t	2.8
Cost of mining per ton of ore US$	3.05
Cost of processing per ton ore US$	2.44
Cost of waste removal per ton of waste US$	1.67
Cost of processing per ton of sub-grade ore	2.93
Price per ton of concentrate US$	120
Acceptable rate of Return On Investment (%)	10

Source: Igbo 2018

Estimation of Cut-Off Grade for the Main Ore

Based on the input data, cut-off grade of Itakpe deposit can be estimated as (equation 3);

$$COG = \frac{\left(1+\frac{r}{100}\right)[C_m+C_p+(S_T C_w)]}{\gamma p}$$

$$\frac{\left(1+\frac{10}{100}\right)[3.05+2.44+(2.8 \times 1.67)]}{0.35 \times 120}$$

$$= 0.26 \quad = 26\%$$

Based on the above COG, the ore reserve in Itakpe is now divided into main grade and sub-grade reserve (Table 3)

Estimation of Cut-Off Grade Considering the Sub-Grade Ore

Now cut-off grade can only be assessed per ton of ore. Consequently in order to incorporate the sub-grade ores into analysis, the reserve and other techno-economic data of the sub-grade ores will have to be expressed per ton of the main ore; that is, they will have to be converted to the main ore equivalent (Michelson and Buckley 1973). Consequently the new cut-off grade considering the influence of the sub-grade ore can be assessed as follows:

Table 3: Reserve of the main grade and the sub-grade of Itakpe deposit.

Ore layer index	Reserve of Economic Grade	Grade %	Ore layer index	Reserve of sub-grade	Grade %
N_1	15.49	34.19	S_3	3.8	18.2
N_2	31.58	37.88	N_1	3.8	25.3
N_3	5.22	35.01	N_2	2.5	15.8
I_1	0.95	29.5	N_3	5.6	14.8
I_2	3.6	34.95	I_1	2.8	15.8
I_3	10.68	36.44	I_2	3.6	20.6
C_1	6.2	40.95	C_1	2.27	20.5
C_2	9.54	29.88	C_2	5.6	18.7
C_3	20.1	34.42	C_3	7.6	17.8
C_4	32	37.037	S_1	2.6	20.8
S_1	2.8	38.68	S_3	4.6	24.4
S_2	4.41	36.45			
I_3	4.5	34.7			
S_2	3.6	28.6			
150.67			**44.97**		

- **Cost of mining per ton ore considering the cost of mining the sub-grade ore (equation 4&5)**

$$C_g = C_m - C_w$$

$$= 3.05 - 1.67$$

$$= \$1.38$$

$$Z = C_m + \frac{S_g C_g}{S_m}$$

or

$$Z = 3.05 + \frac{44.97 \times 1.38}{150.67}$$

$$= US\$3.46$$

- **Cost of processing considering the sub-grade ore (equation 6)**

$$U = C_p + \frac{C_{ps} S_g}{S_m}$$

C_{ps} = **cost to processing the sub-grade**

$$= 2.44 + \frac{44.97 \times 2.93}{150.67}$$

$$= US\$3.31$$

Since some sub-grade ores which were formerly regarded as waste are now regarded as ore, the operating stripping ratio lowers to 2.72.

- **Waste removal per ton of ore**

$$W_c = S'_r \, x \, C_w \quad \text{...(9)}$$

Where ;

is the Waste removal per ton of ore

S'_r is the new stripping ration considering the inclusion of former sub-grade ores into the main reserve.

W_c **= 2.72 x 1.67**

= US$4.54

The total cost of production per ton considering the conversion of sub-grade ore to the main ore equivalent will be

$$\mathbf{T = Z + C_{ps} + W_c} \quad \text{...(10)}$$

= 3.46 + 3.31 + 4.54

= US$11.31

Value per ton of ore considering the sub-grade ore

$$Y = P\left(\gamma_m + \frac{\gamma_s S_g}{S_m}\right) \quad \text{..(8)}$$

$$= 120\left(0.35 + \frac{0.31 \, x \, 44.97}{150.67}\right)$$

= **US$53.10**

New cut-off grade considering the sub-grade ore

$$\text{COG} = \frac{11.31\left(1 + \frac{10}{100}\right)}{53.10}$$

= 0.23 **= 23%**

Thus because of inclusion of sub-grade ores into the main reserve, the COG now reduces to 23% showing the economic justification for this inclusion.

Tables (1a) and (1b) can now be reclassified into main grade and sub-grade reserves in finality (table 4)

From Table 4 below, it can be seen that due to the lowering of cut-off grade from 26%Fe to 23%Fe, the mineable ore reserve of Itakpe iron ore deposit increases from 150.67mt to 159.07mt.

Table 4: Final classification of Itakpe ore reserve into main ore and sub-grade ore reserve.

Ore layer index	Reserve of economic grade	Grade %	Main ore	Ore layer index	Reserve of sub-grade	Grade %	Sub-grade ore
N_1	15.49	34.19	15.49	S_3	3.8	18.2	3.8
N_2	31.58	37.88	31.58	N_2	2.5	15.8	2.5
N_3	5.22	35.01	5.22	N_3	5.6	14.8	5.6
I_1	0.95	29.5	0.95	I_1	2.8	15.8	2.8
I_2	3.6	34.95	3.6	I_2	3.6	20.6	3.6
I_3	10.68	36.44	10.68	C_1	2.27	20.5	2.27
C_1	6.2	40.95	6.2	C_2	5.6	18.7	5.6
C_2	9.54	29.88	9.54	C_3	7.6	17.8	7.6
C_3	20.1	34.42	20.1	S_1	2.6	20.8	2.6
C_4	32	37.037	32				
S_1	2.8	38.68	2.8				
S_2	4.41	36.45	4.41				
I_3	4.5	34.7	3.8				
S_2	3.6	28.6	4.5				
N_1	3.8	25.3	3.6				
S_3	4.6	24.	4.6				
159.07mt				**36.37mt**			

Conclusion

Some of the sub-grade ores stockpiled at temporary stockpile at Itakpe can be profitably processed for the development of the economy of Nigeria.

This is specially so in relation to those ore bodies whose grades are from 23%Fe and above. When this is done, the mineable ore reserve of Itakpe iron ore deposit will increase to about 159mt as against the 145mt currently used for mine planning at the company.

References

Agabalian, U.A. (1994). Optimum Exploitation of Earth Resources: Theory and Practice. Published by Nedra Publishers Moscow p.62-65

Alwyn, E. (1991). Mineral Deposit Evaluation: A Practical Approach. Published by Chapman and Hall, London.

Arsentiev, A.I. (1970). Pit Limit and Production Rate Estimation for Open-pit Mine. Published by Nedra Publishers, Moscow (in Russian).

Igbo S.U. (2018). Estimation of Operation Cost of Mining at Itakpe Iron ore Deposit, Kogi State, Nigeria.

Muriuki, J.W. and Temeng, V.A. (2018). Computer Aided Cut-off Grade Estimation. Ghana Mining Journal Vol. 18 No. 2, Pp 1-8.

Lane, K.F. (1964). Choosing the Optimum Cut-Off Grade, Colorado School of Mines Quarterly, 1964, Vol. 59.Pp 811-829.

Michelson, S.D. and Buckley, R.D. (1973). Influence of Minor Metals or By-products on Pit Planning and Ore Reserve Determination. Mining Engineers Handbook, Edited by A.B. Cummins and I.A. Given, Vol. 2 pp. 19 -21.

National Iron Ore Mining Project [NIOMCO], (1980). Vol. 2 National Iron Ore Mining Company Ltd, Itakpe, Kogi State, Nigeria.

Nwosu J.I. and Nwankwoala, H.O. (2015). Influence of Construction Material on the Cut-Off Grade of an Ore Using Itakpe Iron Ore Mine as a Case Study. *Nat. Journ. of Min. Sci.* Vol.1(2). Pp. 6-11.

Nwosu, J.I. and Okengwu, K.O. (2009). Estimation of Cut-Off Grade of Itakpe Iron Ore Deposit for Open Pit Mining. Integrated Journal of Sciences and Engineering, Vol. 8, No.1 (2009). Pp. 1-5.

Olade, M.A. (1978). General Features of Precambrian Iron Ore Deposit and It's Environment at Itakpe Ridge, Okene Nigeria. Trans. Institute of Mining And Methology, London. Sec. Pp. 87-89.

Rendu, J.M. (2008). An Introduction to Cut-Off Grade Estimation, Society for Mining, Metallurgy and Exploration Inc.