valuation of Alluvial Ore Reserve in an Abandoned Consolidated Tin Mine, Bukuru- Jos Plateau State

Afeni T. B.[1], Lawal A. I. [1] and Omosayin S. J. [2]

1 Department of Mining Engineering, Federal University of Technology Akure, Nigeria.
2 Dangote Cement, Ibese Plant, Ogun State, Nigeria.

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A B S T R A C T

This research work evaluates the ore reserve estimate of the abandoned alluvial tin deposit. The objectives of the research were achieved through visitation, oral interview and internet sourcing. The prospecting plan of the mining lease of the studied Mine (ML.16957, B/Ladi) was also collected and used in the analysis. An abandoned area of the mine was extracted from the prospecting plan of the mining lease; while assay value, drill hole depths were gotten from the prospecting plan. Reserve estimation methods used are the triangle and the polygonal methods. The reserve data analysis revealed that about 121.08 metric tons of cassiterite reserve remained un-mined in the ore block. The average depth of the un-mined area of the block is about 56.99ft (17.37m) as against 15.28ft (4.66m) for the whole block.

1. Introduction

The mineral resources and the subsequent conversion to ore reserves are of key importance to mining operation. Afeni (2007) pointed out that their reliable estimation is critical to both the confidence in feasibility study and the day-today operation of a mine. Mining operation generally over is a capital intensive project and in most cases with a long gestation period, and so the economic outlook of the project in whole at a longer run is a function of the economic decisions made at the early stages of the mining (Botin, 2009). Proper evaluation / re-appraisal is needed in taken a decision on abandoned mine with a view to making an economic decision on whether to re-open the mine or not and what use could the pit be put into if it becomes obvious that re-opening is no longer realistic.

The process of mineral exploitation needs thorough examination and evaluation in the area of its tonnage, grade, technology to be applied, economic viability and future prospect. Therefore, mine valuation is the method of examining all processes and operations (cut-off grade determination in exploration, mine development, mineral extraction, beneficiation and marketing) in detail, in order to discover the best way of carrying out each operation so that optimum result of the best economic estimation with profit is established (Alaster, 2010).). Mine valuation is the basis for mine planning, in that when the best estimations of the ore grade is obtained, it forms the basis for accurate calculation of different mining parameters including production rate, life span, reserve and numbers of equipment needed.

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Correspondence:
E-mail address: tbafeni@futa.edu.ng

While the mine is in operation, evaluation of the production can be made and the past achievements will be fully analyzed with the possibility of future improvement and correction of errors made in the past, so that the targeted plan will be accomplished. The best method of mine reclamation will be arrived at with proper evaluation. This process of mine valuation will help to discover and eliminate unnecessary cost of production and match properly the equipment to different operation (Alaster, 2010). Evaluation which involves critically examining prospecting samples and assay values with the aim of ascertaining the profitability of the deposit taking into consideration the volume, grade, and depth of occurrence will afford the opportunity of establishing viability of any ore reserves (Kwaha, 2004).

1.1 *Description of the Study Area*

Consolidated Tin mines have its administrative headquarters located in Bukuru, the headquarters of Jos South Local Government Area of Plateau State, Nigeria. It has many mining sites spreading across the length and breadth of Jos metropolis and its environs. An abandoned Barinkin Ladi mining site of this company forms the basis of this project. It is located in the Barinkin Ladi local Government Area of Plateau State. It is about 25 km away from the Headquarters of the company along Pankchin road. It lies in the South-East of Bukuru. It is accessible by good road. Figure 1, shows the various Local Government of Plateau State including the study area.

Jos, which is referred to as “Tin city” is the capital of Plateau State. It is geographically located in the north central of Nigeria and covers an area of about 7,000 sq. mile (1814, 400 hectares). It has an altitude of about 1200 m above the sea level. It lies between latitudes 9°55' and10°05' N; longitude 8°45' and 9°10' E (Offiah et al., 2011).

It is bounded by Kaduna State in the North West, Bauchi state in the North, Taraba State in the East, Benue State in the South and Nassarawa state in the South-West.

2.0 Method

2.1 Research Design

This is the plan or blue point which specifies how data relating to the research were collected and analyzed. It provides the procedural outline for the conduct of the investigation. For the success and convenience of this research, the case study research design was therefore applied. The objective assessment of abandoned mined was done with reference to consolidated Tin mines, Bukuru with a particular emphasis on an ore block ML 16957 Barkin Ladi with a view to providing the necessary framework for the research problem.

2.2 Population Sample and Sampling Techniques

The population studied area is an alluvial deposit of Jos, Plateau State. For conveniences a particular mining lease of a company (consolidated Tin mines, Bukuru) was considered. A total number of thirty-two assay values from the mining lease were used. Since the sample values (assay values) can be conveniently handled all the sample values were used to arrive at the tonnage estimation. Random samples were taken for tonnage and grade control.

2.3 Data Collection Techniques

A period of two weeks was used at the research site for the purpose of data collection. Hence the major data collection techniques adopted was personal visit, oral interview and internet sourcing. The prospecting plan of the mining lease of the studied mine (ML.16957, B/Ladi) was also collected, as displayed in Figure 2. The abandoned area of the mine was extracted from the prospecting plan of the mining lease. Data such assay values, drill hole depths (32 of them) were obtained from the prospecting plan for calculations, evaluation and analysis.

Figure 1: Map of Plateau State showing the studied area (source: Offiah et al., 2011)

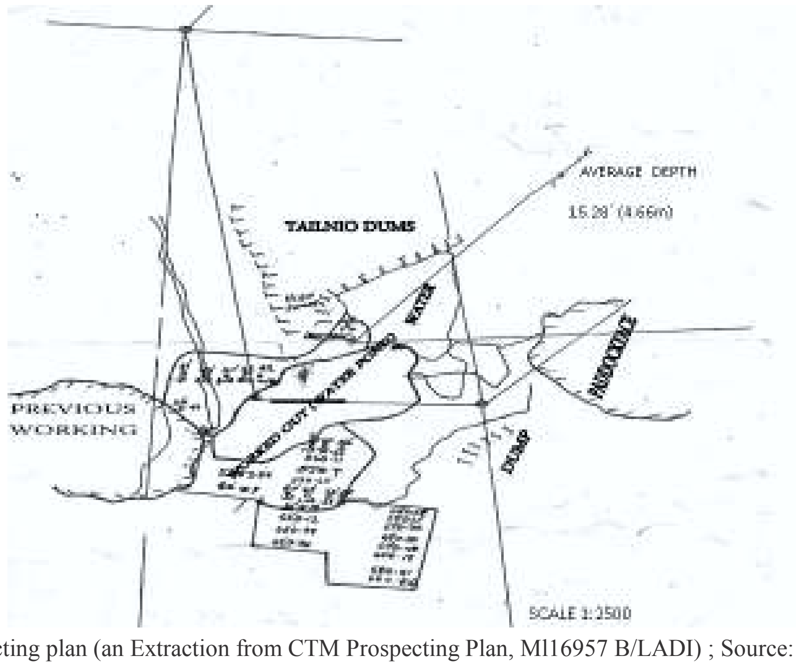

Figure 2: Prospecting plan (an Extraction from CTM Prospecting Plan, Ml16957 B/LADI) ; Source: CTM (2005)

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2.4 Methods and Data Analysis Techniques

The methods used in this work were based on the conventional or classical methods of ore reserve estimation. The basic principles of placer/alluvial sampling and evaluation were used.

The reserve estimation methods used here is the triangular and the polygonal methods. The results from the two methods were compared.

2.4.1 The Triangular Method

The reserve plan was delineated into various triangular prisms (as shown in Figure 3) of surface area, Si and thicknesses, Li. The sampling principles were used to assign assay values and hole depths to the tips of the triangles. One of the unique things about this research work is that the assay points were not chosen originally to reflect triangular patterns. Hence, a deliberate attempt was made by carefully applying alluvial sampling principles in assigning assay values and depths to the tips of the various delineated triangular prisms, that is, the sample hole has influence half way the next hole both in terms of depth and value. The tips of the triangular prisms were assigned the nearest assay hole depths and values. The plan dimensions of the various triangles were measured and converted to the equivalent land dimensions by applying the scale of the plan. The areas of the various triangles were calculated and the volume Vi of each of the triangular prism was found and the average assay valued applied to convert it to tin reserve.

Hero's formula was used to find the area of the triangular prism (Equation 1)

$$S_i = [s(s-a)(s-b)(s-c)]^{1/2}\text{, m}^2 \qquad (1)$$

where $s = a+b+c/2$, and a, b, c are the equivalent land distances of each side of the triangular reserve prisms.

The volume, V_i of prism was determined using Equation 2.

$$V_i = SiLi/3\text{, m}^3 \qquad (2)$$

where $Li = L_1 + L_2 + L_3$, and L_1, L_2 and L_3 are the assay hole depths of the apices of the triangular prisms respectively.

The reserve (Q_i) in each triangular prism was determined in Equation 3.

$$Q_i = V_i G_i \qquad (3)$$

where G_i is average assay value in each triangular prism.

The average value, G_i was calculated in two ways: Using the depth of influence to get the weighted average Equation 4 or arithmetic mean of the assay value Equation 5.

$$Gi = \sum (Ligi) / \sum Li \qquad (4)$$

or

Just arithmetic mean of the assay value,

$$Gi = \sum g_i / 3 \qquad (5)$$

where g_i is the sum of assay value of the apices of the triangular prisms respectively

The reserve in each of the prism is given by

$$Qi = ViGi\text{, kg} \qquad (6)$$

Total reserve, Q is given

$$Q = \sum Qi\text{, kg} \qquad (7)$$

$$\text{Total reserve in metric tons} = \sum Q_i / 1000 \qquad (8)$$

Average assay value (grade) was determined using the equation adapted by Afeni (2007) presented in Equation 8.

$$Qave = \sum Qi / \sum Vi \qquad (9)$$

2.4.2 Polygonal Method

The prospecting plan was split into different shapes (rectangles trapeziums, and triangles) as shown in Figure 4. The plan dimensions of the various shapes were measured and the equivalent land dimensions were obtained by applying the scale of the plan. The area and volume of each shape were found. The following major steps were then taken.

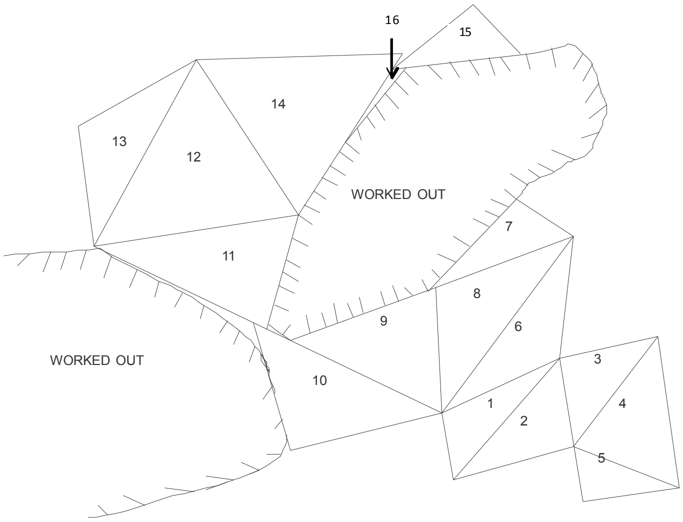

Fig. 3: Ore block divided into different triangle method

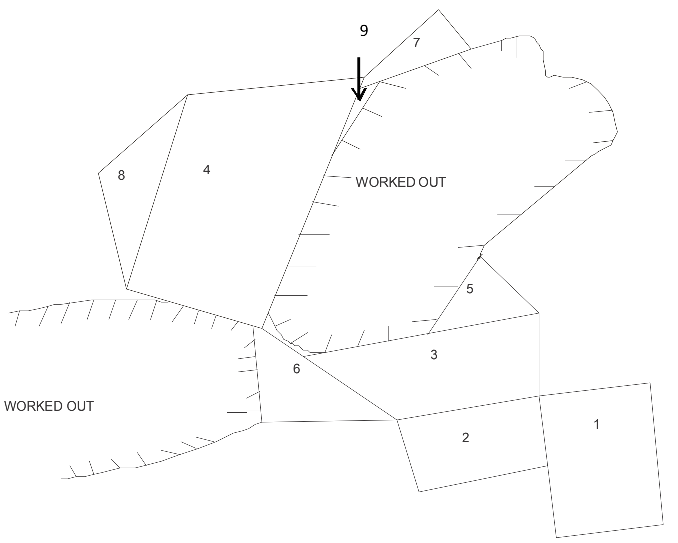

Fig. 4: Ore block divided into different shapes for Polygonal Method

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The volume and average assay value of each shape were found to be V_i and G_i respectively. Ore content in each delineated prism,

$q_i = V_i \times G_i$ kg (10)

Total reserve, $Q = \sum q_i$, kg (11)

Tonnage = Q/1000, metric ton (12)

Total volume, $V = \sum V_{i,}\ m^3$ (13)

$$\text{Average value} = \frac{totalreserve(kg)}{toralvolume(m^3)} = \frac{\sum Q_i}{\sum V_i} \quad \text{in Kg/m}^3$$

2.5 *Dealing with Erratic High Values.*

There are different methods of dealing with erratic high values in an alluvial sampling, but the method used here is the averaging method. The high values are combined with the low values (usually the nil values) around them and the average taken.

3.0 Results

Table 1: Assay value and depth from the prospecting plan

S/N	Depth		Value		Depth x Value	
	(ft)	(m)	(lb/cu.yd)	(kg/m^3)	(ft.lb/cu.yd)	(kg/m^2)
1	68.00	20.73	0.24	0.14	16.32	2.90
2	69.00	21.03	0.21	0.12	14.49	2.52
3	69.00	21.03	0.75	0.44	51.75	9.25
4	69.00	21.03	0.32	0.19	22,08	4.00
5	67.00	20.42	0.40	0.24	26.80	4.90
6	67.00	20.42	0.19	0.11	12.73	2.25
7	68.00	20.73	0.41	0.24	27.88	4.98
8	66.00	20.12	0.44	0.26	29.04	5.23
9	62.00	18.90	0.12	0.07	7.44	1.32
10	66.00	20.12	0.79	0.47	52.14	9.46
11	62.00	18.90	0.74	0.44	45.88	8.32
12	61.00	18.59	0.18	0.11	10.98	2.04
13	58.00	17.68	0.69	0.18	17.98	3.18
14	64.00	19.51	0.61	0.41	44.16	8.00
15	62.00	18.90	1.03	0.61	63.86	11.53
16	61.00	18.50	0.18	0.11	10.98	2.04
17	57.00	17.37	0.37	0.22	21.09	3.82
18	57.00	17.37	0.60	0.36	34.20	6.25
19	60.00	18.29	-	-	-	-
20	57.00	17.37	-	-	-	-
21	56.00	17.07	0.21	0.12	11.76	2.05
22	56.00	17.07	0.67	0.40	37.52	6.83
23	60.00	18.29	0.44	0.26	26.40	4.76
24	53.00	16.15	2.59	1.54	137.27	24.78
25	38.00	11.58	-	-	-	-
26	43.00	13.11	0.45	0.27	19.35	3.54
27	41.00	12.50	0.71	0.42	29.11	5.25
28	43.00	13.11	1.17	0.69	50.31	9.05
29	41.00	12.50	1.15	0.68	47.15	8.50
30	42.00	12.80	0.12	0.07	5,04	0.90
31.	42.00	12.80	0.17	0.10	7.14	1.28
32.	42.00	12.80	1.12	0.66	47.04	8.45
$\sum$	1827	556.79			927.89	167.47

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Table 2: Area of the various triangles from the triangular method.

S/No	Plan Dimension, cm			Equivalent land distance, m			S (m)	A (m^2)
	A	B	C	A	B	C		
1	3.00	2.20	2.3	75.00	55.00	57.50	93.75	1571.36
2	2.00	2.20	3.0	50.00	55.00	75.00	90.00	1374.77
3	2.30	3.00	3.3	57.50	75.00	82.50	107.50	2089.78
4	2.70	3.30	3.6	67.5	82.5	90.00	120.00	2,662.24
5	2.70	2.30	1.4	67.50	57.50	35.00	80.00	1006.23
6	2.20	2.20	3.70	55.00	55.00	92.50	101.25	1376.62
7	2.30	2.70	1.60	57.50	65.00	40.00	18.25	1137.32
8	1.70	3.70	2.10	42.50	92.50	52.50	93.75	497.74
9	2.10	2.10	2.30	52.5	52.5	57.50	81.25	1262.94
10	2.10	2.20	2.30	52.5	55.00	57.50	82.50	1304.44
11	1.90	2.50	1.80	47.5	62.50	45.00	77.5	1064.63
12	1.80	2.2	2.7	45.00	55.00	67.50	83.75	1231.33
13	1.20	1.00	2.10	30.00	25.00	52.50	53.75	214.19
14	2.50	2.60	2.70	62.50	65.00	67.50	97.50	1824.06
15	1.40	2.50	2.80	35.00	62.50	70.00	83.75	1092.22
16	0.30	1.20	1.40	7.50	30.00	35.00	36.25	90.23

Table 3: Volumes of the Various Triangles

S/No	S_i, m^2	L_1		L_2		L_3		$L_{average}$		$V_i = S_i \times L_{average}$	
		ft	m	ft	m	ft	m	ft	m	ft^3	m^3
1	1571.36	58	17.678	60	18.288	62	18.898	60.00	18.288	1013838.69	28737.03
2	1374.78	62	18.898	62	18.898	58	17.678	60.67	18.492	897784.63	25422.43
3	2089.78	58	17.678	62	18.898	68	20.726	62.67	19.102	1409725.45	39,918.98
4	2662.24	62	18.898	68	20.726	66	20.117	65.33	19.914	1872237.05	553,015.85
5	1006.23	62	18.898	62	18.898	66	20.117	63.33	19.304	685961.26	19,424.26
6	1376.62	60	18.288	56	17.069	58	17.678	58.00	17.678	859413.83	24,335.89
7	1137.32	53	16.154	56	17.069	60	18.288	56.33	17.169	689577.13	19526.65
8	497.74	57	17.374	56	17.069	60	18.288	57.67	17.578	308977.55	8749.27
9	1262.94	56	17.069	60	18.288	53	16.154	56.33	17.169	765742.74	21683.42
10	1304.44	60	18.288	60	18.288	53	16.154	57.67	17.578	809745.87	22929.45
11	1064.63	43	13.106	43	13.106	42	12.802	42.67	13.006	488987.35	13846.58
12	1231.33	43	13.106	43	13.106	41	12.497	42.33	12.902	561030.68	15886.62
13	214.19	43	13.106	41	12.497	41	12.497	41.67	12.791	96071.08	2720.43
14	1824.06	43	13.106	41	12.497	42	12.802	42.00	12.802	824654.67	23351.62
15	1092.22	42	12.802	42	12.802	42	12.802	42	12.802	493790.85	13982.60
16	90.23	42	12.802	42	12.802	42	12.802	42	12.802	40792.68	1155.12
∑	19800.11									11818331.51	834686.20

Table 4: Reserve calculation processes using the triangle method

NO	VOLUME, V_i (m^3)	ASSAY VALUE, g_i HOLE 1 Kg/m^3	HOLE 2 Kg/m^3	HOLE 3 Kg/m^3	HOLE DEPTH, m L1	L2	L3	Li=L1+L2+L3	ASSAY VALUE x DEPTH, kg/m^2 HOLE 1	HOLE 2	HOLE 3	$\sum g_i l_i$	AVERAGE VALUE $G_i = \sum g_i l_i / l_i$	$q_i = v_i G_i$	Tonnage = $q_i / 1000$
1.	28737.03	0.41	0.00	0.44	17.69	18.29	19.90	54.87	7.25	0.00	8.32	15.57	0.28	8161.32	8.16
2.	25422.43	0.44	0.44	0.41	18.90	18.90	17.68	55.48	8.32	8.32	7.25	23.89	0.43	10957.07	10.96
3.	39918.98	0.41	0.44	0.14	17.68	18.90	20.73	57.31	7.49	8.32	2.90	18.71	0.33	13173.26	13.17
4.	53015.85	0.44	0.14	0.26	18.90	20.73	20.12	59.75	8.32	2.90	5.23	16.45	0.28	14844.44	14.84
5.	19424.26	0.44	0.44	0.26	18.90	18.90	20.12	57.92	8.32	8.32	5.23	21.87	0.38	7381.22	7.38
6.	24335.89	0.00	0.40	0.41	18.29	17.07	17.68	53.04	0.00	6.83	7.25	14.33	0.27	6574.91	6.57
7.	19526.65	1.54	0.40	0.28	16.15	17.07	18.29	51.51	24.87	6.83	5.12	36.82	0.72	13961.55	13.96
8.	8749.27	0.36	0.40	0.00	17.37	17.07	18.29	52.73	6.15	7.32	0.00	13.47	0.26	2235.02	2.24
9.	21683.42	0.12	0.00	1.54	17.07	18.29	16.15	51.51	2.05	0.00	24.87	26.92	0.52	11332.54	11.33
10.	22929.45	0.00	0.00	1.54	18.29	18.29	16.15	52.73	0.00	0.00	24.87	24.87	0.47	10815.06	10.82
11.	13846.58	0.25	0.25	0.10	13.11	13.11	12.81	39.03	3.28	3.28	1.28	7.84	0.20	2781.38	2.78
12.	15886.62	0.25	0.25	0.42	13.11	13.11	12.50	38.72	3.28	3.28	5.25	11.81	0.31	4845.38	4.85
13.	2720.43	0.25	0.42	0.42	13.11	12.50	12.50	38.42	3.28	5.25	5.25	13.78	0.36	975.73	0.98
14.	23351.62	0.25	0.42	0.06	13.11	12.50	12.81	38.42	3.28	5.25	0.77	9.30	0.24	5651.68	5.65
15.	13982.60	0.66	0.66	0.06	12.81	12.81	12.81	38.43	8.45	8.45	0.77	17.76	0.46	6428.65	6.43
16.	1155.12	0.06	0.06	0.06	12.81	12.81	12.81	38.43	0.77	0.77	0.77	2.31	0.06	69.31	0.07
∑	334678.7														120.19

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Average depth = total volume/total area

=334678.7/19800.11

=16.9m

Average ore value = total reserve (kg)/total volume (m^3)

= 120190/334678.7

=$0.35kg/m^3$

Applying arithmetic mean of the assay value to the volume of the various triangles, the following results were obtained.

Table 5a: Estimation Using the Arithmetic Mean of Assay Values

S/no	Volume	Arithmetic mean value, G_i	$q_i=G_iV_i$, (Kg)	Tonnage, $q_i/1000$ (ton)
1.	28737.03	0.28	8046.37	8.05
2.	25422.43	0.43	10931.64	10.93
3.	39918.98	0.33	13173.24	13.17
4.	53015.85	0.28	14844.44	14.84
5.	19424.26	0.38	7381.22	7.38
6.	24335.89	0.27	6570.69	6.57
7.	19526.65	0.74	14449.72	14.45
8.	8749.27	0.25	2187.32	2.19
9.	21683.42	0.55	11925.88	11.93
10.	22929.45	0.51	11694.02	11.69
11.	13846.58	0.20	2769.32	2.77
12.	15886.62	0.31	4924.85	4.92
13.	2720.43	0.36	979.35	0.98
14.	23351.62	0.24	5604.39	5.60
16.	1155.12	0.06	69.31	0.07
∑	334678.7		121983.8	121.97

Table 5b: Polygonal Method

S/No	Shape	Area, m^2	Average depth(m)	Volume m^3	Average value, kg/m^3	Ore reserve kg	Metric tons
1.	Rectangle	5400.00	20.69	111726	0.22	24579.72	24.58
2.	Rectangle	2956.25	19.13	56553.06	0.27	15269.33	15.27.
3.	Trapezium	3875.00	18.04	69905.00	0.33	23068.65	23.07
4.	Trapezium	4606.25	12.80	58960.00	0.37	21815.20	21.82
5.	Triangle	1137.32	17.68	20107.82	0.37	7439.89	7.44
6.	Triangle	1304.44	17.22	22462.46	0.77	17296.09	17.30
7.	Triangle	1092.22	12.80	13980.42	0.66	9227.08	9.23
8.	Triangle	214.19	12.80	2741.63	0.37	1014.40	1.01
9.	Triangle	90.90.23	12.80	1154.94	0.37	427.30	0.43
		20585.67		357591.33		120137.66	120.15

Average value for the whole ore block = $\frac{\sum q_L}{\sum V_i} = \frac{120137.66}{357591.33}$

$= 0.34kg / m^3$

Average depth = $\frac{V}{A} = \frac{357591.33}{20585.67}$

=17.37m

Table 6: Summary of result from triangle method

S/no	Parameters		Size
1.	No of assay holes		32
2.	No of triangular prism		16
3.	Total areas (m^2)		19,800.07
4.	Total volume (m^3)		606,096.56
5.	Total tonnage (Mt)		121.08
6.	Average depth	m	16.90 ft 55.45
7.	Average value	kg/m^3 0.57	0.34 lb/cu. yd

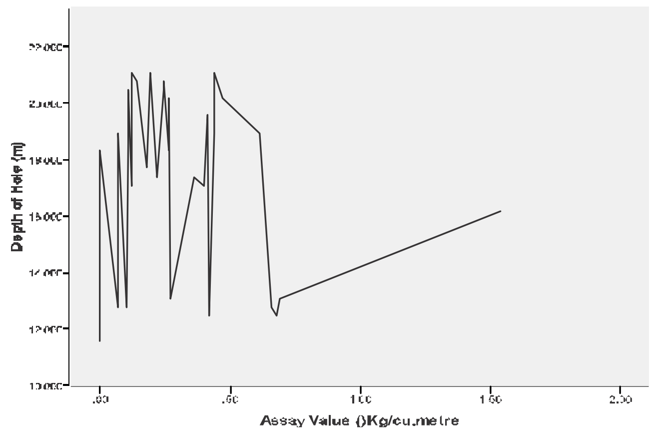

Figure 5: Graph of Depth of Hole against Assay Value.

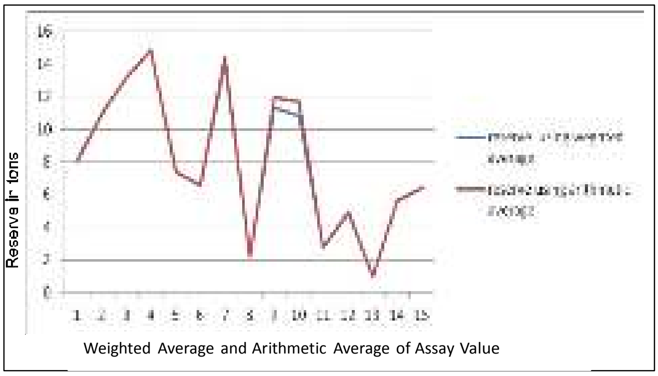

Fig 6: Reserve against Weighted Average and Arithmetic Average

4. Discussion

The average depth of the un-mined area of the block is about 56.99ft (17.37m) as against 15.28ft (4.66m) for the whole block. This means that the shallow and superficial reserve area has been mined leaving behind the relatively deep area. Also, the new average value is 0.57lb ($0.34kg/m^3$) which is higher than the average value of the whole area.

This shows that the deep area has a relatively higher value. The assay hole of nil value was used around the erratic high value zone to harmonize the assay value in order not to have a false estimate of unnecessary high value. The results revealed that there is no significant difference between the reserve got when arithmetic average values were applied and when the weighted average values were applied in the reserve estimation exercise. The result of the

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reserve in each of the triangular prism when considered separately revealed that the southern part of the block has more value than the northern part of the ore block.

Table 2 shows how the various plan dimensions were converted to the equivalent land dimensions and the subsequent calculation of the area of the various triangles. Table 3 shows the conversion of the areas of the various triangles to the equivalent volume. Table 4 shows how the reserves in the various triangles were arrived at and the total reserve obtained from the triangle method shown in Figure 3 explained erratic high value of assay by comparing the various depths with the corresponding assay values. Tables 5a and 5b revealed that there is no significant difference between the results obtained in the triangle method and the polygonal methods.

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The total reserve, average value and depth arrived at in this research were the average value from the various methods applied.

5. Conclusion

The ore block (ML 16957 B/Ladi) has a reserve of about 121.08 metric tons un-mined. Considering the reserve and the relatively cheap method with which the ore can be mined, re-opening could be considered after other detailed economic analysis has been taking into consideration. The average depth of the un-mined area of the block is about 56.99 ft (17.37m) as against 15.28ft (4.66 m) for the whole block.

This means that the shallow area has been mined leaving behind the relatively deep area. Also, the new average value is 0.57 lb (0.3 kg/m^3) which is higher than the average value of the whole area. This shows that the deep area has a relatively higher value. The mining terrain, the land and the method of mining used in consolidated tin mine are inherently advantageous in the post reclamation exercise. Reclamation are done almost concurrently as the mining progresses with excavate over burden materials by dragline and sludge materials from gravel pumps. Conversion of the mine (at the eventual depletion of the ore or at that point when the mine would be consider economically not feasible) to possible land use is essentially an inherent advantage of the characteristics of the mine. The ore (non-corrosive and non poisonous) in addition to the mining method are of great advantage. Such land use may be farming, water pond for fishing and irrigation, domestic water supply, water recycling for further use of the mining.

Above all, periodic re-evaluation and re-appraisal of reserves and mining method should be a standard practice.

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