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Review of exploration data with respect to outliers: experience XXX deposit of NMDC Ltd

A resource estimate (calculation of total tonnes and grade within a deposit) is generally underpinned by a clear understanding of the geometry, orientation and control of mineralization and set of assays with assigned 3D spatial locations. The proper interpretation and handling of outliers in a data set is crucial to estimating a mineral resource that is representative of the deposit. Without a firm understanding of the distribution of metal in a deposit, mine planning, scheduling, process planning and economic analysis will likely be flawed. Three of the most important issues in the mineral resource estimation process are the recognition of outlier values in a data set, the source of the outlier values, and the subsequent handling of these high values. Treatment of outliers in mineral resource estimations is a perplexing problem for which there is no generally accepted solution. Each deposit may have a unique distribution of outlier values which may require multiple methods of treatment to fully understand the issues and their effect on the mineral resource estimate.

Key words: Exploration; resource estimation; ore; outliers; block model

1.0 Introduction

Mineral exploration and development are investigative activities prior to mining. The rewards of successful exploration and development can be large, if a mineral deposit is discovered, evaluated, and developed into a mine. For a mining company, successful exploration and development lead to increased profits. For a local community or nation, successful mineral exploration and development can lead to jobs often well-paying that otherwise would not exist; to new infrastructure, such as roads and electric power supplies, that are catalysts for broader, regional economic development; and to increased government revenues that, in turn, can be invested in social priorities such as education, health care, and poverty alleviation.

International codes such as JORC, NI 43-101 and SAMREC are all based on the notion of transparency together with professional aptitude and experience of the competent persons undertaking the work. These codes are not prescriptive; however they do describe a series of guidelines which professionals must adhere to and they are supported by the possibility of professional censure by the various bodies administering the codes. These guidelines are all aimed at defining the precision and accuracy of the data and to ensure the most appropriate methodologies are used to estimate tonnages and grade which underpin for the majority of investments into a mining venture.

A resource estimate (calculation of total tonnes and grade within a deposit) is generally underpinned by a clear understanding of the geometry, orientation and control of mineralization and set of assays with assigned 3D spatial locations. This exploration data (set of assays) is formed through variable exploration techniques. Typical methods include geologic mapping, diamond drilling from surface or underground, surface trench samples, underground channel sampling, reverse circulation and reverse air blast drilling.

These techniques are performed using a variety of equipment types, which result in varying types of samples being recovered. Samples include drill core (Fig.1) (Sinha et al, 2015b), rock chips, hammer cut and sawed rock. Due to the varying sample types and equipment, sample quality and recovery varies. The quality of the sample and the amount of sample recovered though these methods have a direct relationship to the accuracy of the sample and as such the quality and accuracy of the resource estimate.

The international codes utilized by the international mining community (JORC, NI 43-101, etc.) stipulate that the samples which underpin an estimate must be taken in such a way that they are representative of the interval from which they are taken. A variety of methods which vary in quality can be used to recover the samples; however, every technique has an inherent sample error range and bias which cannot be eliminated. This inherent error can be further amplified if inappropriate equipment, drilling procedures or sampling techniques are employed while collecting, handling and preparing the sample and then determining the grade (assaying) of the samples. The key is to minimize this inherit

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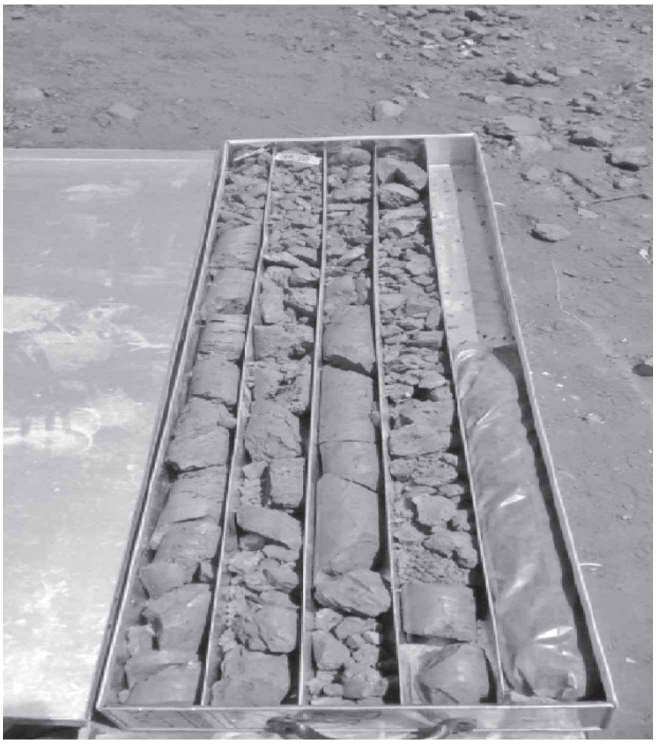

Fig.1 Core recovered during exploration work at Bailadila Deposit -XXX

error, by using well-constructed, methodical procedures, and regularly auditing their use, human caused bias can be minimized.

2.0 Deposit-XXX

Bailadila Iron Ore Deposit-XXX is located in southwest of Kirandul railway station. Kirandul is connected with Raipur by road and to Vishakhapatnam by road and rail by about 470 km. The deposit can be approached by a fair weather road from Kirandul.

Bailadila range trends northsouth and consists of two roughly parallel ridges separated by a valley. These ridges are considered to be synclines and the valley between them is eroded anticline. The Bailadila range is composed of mildly metamorphosed Pre-cambrian rocks. The regional strike of the rocks is more or less persistent in a N-S direction with dips ranging from 50° to 70° towards east. These rocks are considered to be equivalent to iron ore series of Jharkhand and Odisha. The Bailadila iron ore series consists of iron ore, banded iron formation (BIF), ferruginous shales, phyllites, tuffs and quartzites. Metabasaltic traps with tuffs and cherts underlie the above suite of rocks (i.e. Bengpal Series).

On the basis of detailed geological exploration in Dep.XXX, the following local stratigraphic sequence has been established:

Bailadila	Dolerites
Iron ore	Banded iron formations (BIF)
Series	with associated iron ores (ferruginous shale/schist)

The ore body has a NE-SW trend in Dep.XXX with moderately to steep southeasterly dips. The deposit has a strike length of 1600 m and width varies from 120 m to 975 m. The average width is 600 m. Detailed exploration work has indicated surface exposure of ore body up to 930 m RL.

3.0 Exploration works

The Geological Survey of India (GSI) carried out preliminary exploration work in north block (CS N0 to CS N5) of Deposit XXX..

In 1976 NMDC started initial exploration for Deposit-XXX to confirm the grade earlier assessed by GSI. Later on NMDC took up detailed exploration in January 1993 and completed the work in November 1997. Detailed geological mapping, drilling and ore dressing studies have revealed various ore types in Deposit-XXX. Physical and chemical variations in different ore types observed were with regard to degree of surface oxidation, hardness, compactness, granularity, sandy and flaky nature etc. Based on above characteristics ore has been broadly grouped in to six dominant types.

Type - 1 : Steel grey hematite

Type - 2 : Blue grey/blue hematite

Type - 3 : Laminated hematite

Type - 4 : Lateritic/limonitic/re-cemented ore

Type - 5 : Blue dust/flaky ore

Type - 6 : BHQ

For ore type classification the following cut-off criteria has been adopted.

Cut-off %	Ore types
Fe - 55%	For all ore types
SiO_2 - up to 7 %	For blue dust (type-5)
SiO_2 - 7% to 12%	For transition zone ore (type-6).

4.0 Database utilized for geological estimation of Deposit XXX

Total no.93 hole has been utilized for resource estimation. 4537 samples has been prepared. The maximum depth of the hole is 169.25 meter. The details of the database has been given in Tables 1 and 2 below and process flowchart in resource estimation has and been shown in Fig.2 (Sinha S. K., Choudhary B. S. and Sharma R. K. (2015a)).

5.0 Why outliers is important?

The estimation of mineral resources forms the basis for proving the viability of any mining project. While the exploration activities have many steps and extensive data collection to support the resource estimation, it is the

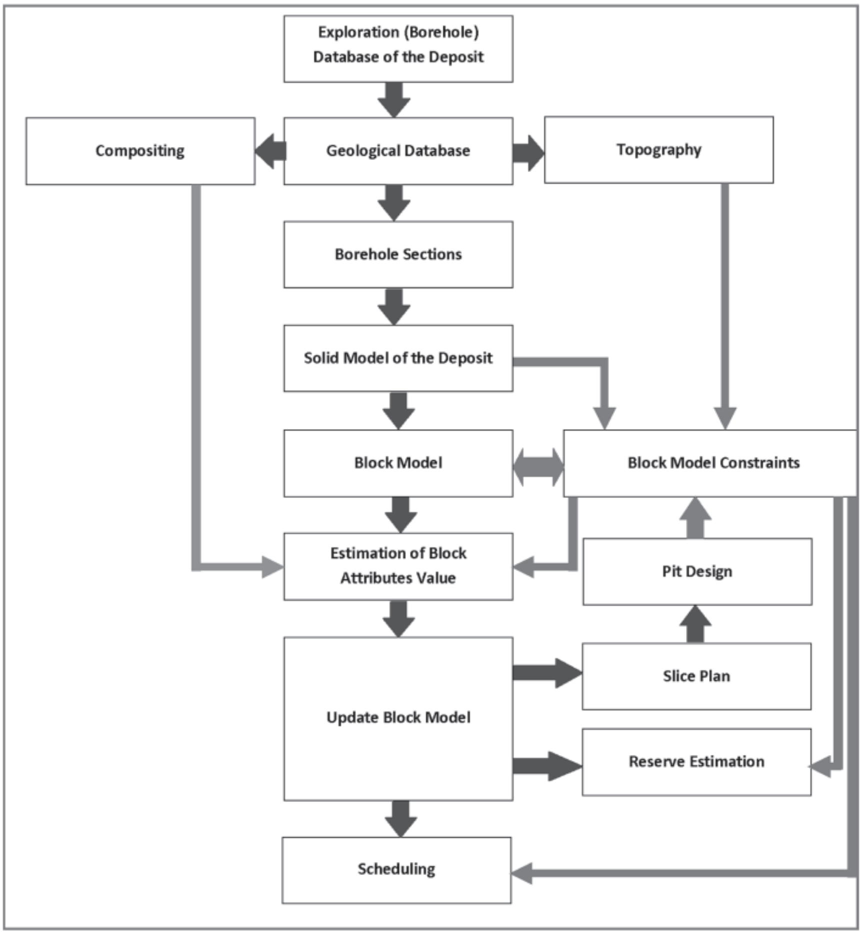

Fig.2 Flow chart of resource estimation

geological and geostatistical interpretation of that data that forms the underpinning of the mineral resource estimate.

Often the upper 10% of the assays represent as much as 90% or more of the metal content, and the upper 1% of the assays may contribute the majority of the metal to the upper 10%. These very high grade values are often referred to as outliers and outlier is an observation that appears to be inconsistent or anomalous with the vast majority of data values (Dagbert, 2008).

The proper interpretation and handling of outliers in a data set is crucial to estimating a mineral resource that is representative of the deposit. Without a firm understanding of the distribution of metal in a deposit, mine planning, scheduling, process planning and economic analysis will likely be flawed. Three of the most important issues in the mineral resource estimation process are the recognition of outlier values in a data set, the source of the outlier values, and the subsequent handling of these high values.

Treatment of outliers in mineral resource estimations is a perplexing problem for which there is no generally accepted solution. Each deposit may have a unique distribution of outlier values which may require multiple methods of treatment to fully understand the issues and their effect on the mineral resource estimate.

Grade estimation is fundamentally a synonym for grade averaging in a spatial context. Averaging means that available sample data are weighted by a scheme. This, in itself, is not an issue nor is it normally a problem, except in the presence of outliers. On the scale of the deposit, using a large number of samples in the interpolation routine, outliers do not impact the mean grade; however, outliers may locally be over-represented in the blocks around the extreme high grades. The outliers generally represent less than 1% of the population (hence less than 1% of the tonnage) but because of their high grade, they may contribute significantly to the global metal content (typically > 10%) (RPM Global.Com/Newletter/Issue no.131 Feb.2016).

TABLE 1: BOREHOLE DATABASE (SUMMARY)

Database: revised_database_2015

Database tables summary

Table name	Data type	Table type	Records
Assay	Interval	Time-independent	4537
Collar			93
Styles			9
Survey			93
Translation			0

TABLE 2: BOREHOLE DATABASE (GEOLOGY)

Database: revised_database_2015

Number of drillholes: 93 Total length drilled: 9068.96

	Hole Id	Northing	Easting	Elevation	Depth
Min. Northing	DXXX/56	-465.84	-3836.18	1041.69	78.2
Max. Northing	DXXX/71	975.1	-4026.7	1061.6	40
Min. Easting	DXXX/67	-240.98	-4287.33	1028.35	23.6
Max. Easting	DXXX/69	914.55	-3030.19	1089.5	88
Min. elevation	DXXX/42	-70.92	-3535.4	946.78	115.5
Max. elevation	DXXX/18	731.21	-3569.39	1212.38	169.25
Min. depth	NBH-3A	882.12	-3192.9	1103.01	13.75
Max. depth	DXXX/18	731.21	-3569.39	1212.38	169.25

6.0 Outlier detection

High values may arise because of sampling errors or may reflect distinct geological sub-environments or domains within a mineral deposit. Effort must be directed to examining these high values and their geological context as soon as is feasible after identification in order to distinguish errors from "real" high grades, investigate their characteristics, and how they relate to the mineral inventory estimates.

Some commonly used techniques to identify possible outliers are (RPM Global.Com/Newletter/Issue no.131 Feb.2016):

A first step is to examine the relationship between sample size and grade because outliers are more likely to be found in small samples than in big ones. The sample lengths should theoretically be standardized by compositing and then capping the grade of composites. Compositing to the smallest consistent support size is a recognized industry practice (this compositing length can be modified later for resource estimation purposes). Furthermore, outliers should be defined on a de-clustered dataset. As the data density increases, the influence of each single sample is better constrained and therefore sample influences decrease (amount of metal at risk declines as well), leading to an increase in the value of the capping threshold (Marinho, 2009.)

Some commonly used techniques to identify possible outliers are:

I. Histograms or log probability plots – It is easy to detect outliers from a sample grade distribution or histogram: they are separated from the rest of the distribution by gaps.

II. There are other less common methods of determining outliers which become quite technical and rely on a good understanding of geostatistics and sampling theory. As this perspective is concerned with basic identification of outliers it will focus on more common techniques of the handling of outliers in the estimation process and will not go into these more complex methods.

8.0 Outliers removal during estimation at Deposit XXX

Once outliers have been identified and confirmed as true outliers, the geologist must make decision as how to handle the outliers in the mineral resource estimation process.

Although outliers may or may not be obvious, a metal risk analysis is recommended as a best industry practice to quantify the metal generated by the highest sample grades in the block model. Commonly, outlier values are geological singularities and have very limited geological continuity relative to lower-grade values. To assume high grades can be extended into neighbouring rock the same distance as low-grade samples can lead to a significant overestimation of mineral resource/reserves.

The statistical analysis report of steel grey hematite (type1) has been given in Table 3 and Fig.3. From the same it can be seen that around 10% of the same is showing a very high value @Fe 69%.

Similarly blue grey hematite (type 2) has been analyzed for all four radicals i.e., Fe, silica, alumina and LOI as shown in the Table 4 and Fig.4.

Histograms or log probability plots made has been applied for all radicals to detect outliers from a sample grade distribution/histogram. Further they are rechecked and subsequently removed from the sample population in order to arrive at a realistic result.

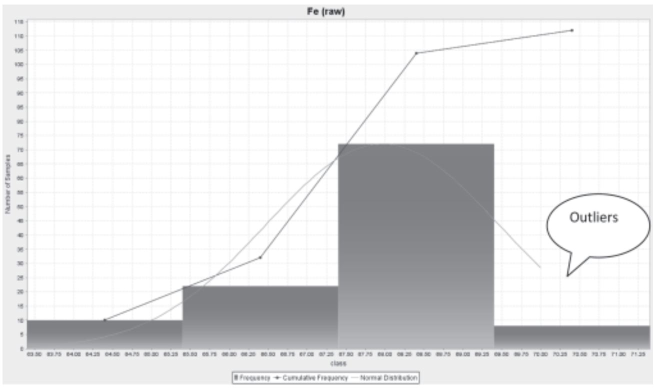

Fig.3: Steel grey hematite (type1) grade distribution curve

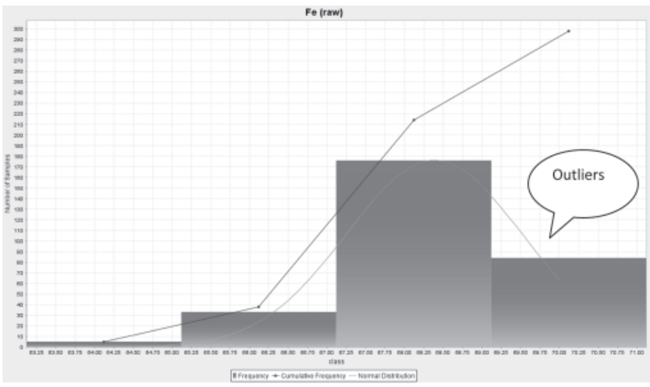

Fig.4 Blue grey hematite (type 2) grade distribution curve

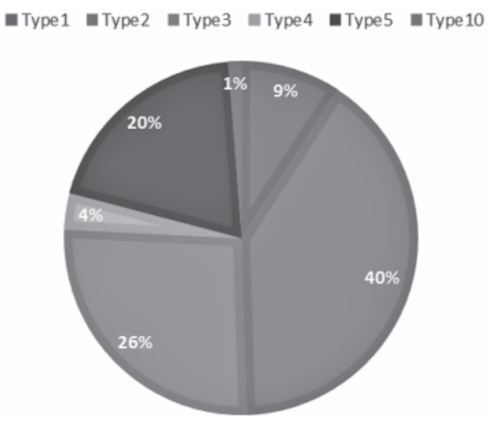

Fig.5 Ore type wise % incidence in Deposit-XXX

TABLE 3: STATISTICAL ANALYSIS REPORT OF STEEL GREY HEMATITE (TYPE1)

Output file name: Type1_Fe	**Mar 03, 2016**			
Statistics report				
File	Composited litho1.str	Composited litho1.str	Composited litho1.str	Composited litho1.str
String range	All	All	All	All
Variable	Silica	Alumina	LOI	Fe
Number of samples	112	112	49	112
Minimum value	0.08	0.01	0.001	63.4
Maximum value	1.998	3.7	0.302	70
	Ungrouped data	Ungrouped data	Ungrouped data	Ungrouped data
Mean	0.38866	0.709087	0.033496	67.966157
Median	0.3115	0.48775	0.0169	68.5669
Geometric mean	0.324362	0.419485	0.013757	67.949442
Variance	0.073737	0.519385	0.002457	2.231217
Standard deviation	0.271545	0.720684	0.049569	1.493726
Coefficient of variation	0.69867	1.016355	1.479864	0.021977
Moment 1 about arithmetic mean	0	0	0	0
Moment 2 about arithmetic mean	0.073737	0.519385	0.002457	2.231217
Moment 3 about arithmetic mean	0.052096	0.727217	0.000445	-3.992707
Moment 4 about arithmetic mean	0.072727	1.955536	0.000114	17.989029
Skewness	2.601821	1.942808	3.651773	-1.197994
Kurtosis	13.376149	7.249146	18.833474	3.613469
Natural log mean	-1.125894	-0.868727	-4.286217	4.218764
Log variance	0.341735	1.310936	2.334102	0.000496
10.0 percentile	0.15	0.10785	0.001	65.5525
20.0 percentile	0.19825	0.17635	0.00435	66.69685
30.0 percentile	0.23885	0.26445	0.008	67.675
40.0 percentile	0.28485	0.35725	0.013	68.233951
50.0 percentile (median)	0.3115	0.48775	0.0169	68.5669
60.0 percentile	0.3775	0.59155	0.0265	68.8116
70.0 percentile	0.43885	0.743451	0.03875	68.98205
80.0 percentile	0.5143	1.1914	0.05105	69.0461
90.0 percentile	0.72965	1.68645	0.066	69.32145
95.0 percentile	0.862	2.115	0.13605	69.49
97.5 percentile	1.07875	2.745	0.235	69.8
Trimean	0.327388	0.524288	0.021575	68.339963
Biweight	0.325806	0.513696	0.021957	68.350646
MAD	0.125806	0.317446	0.018993	0.71
Alpha	-0.048374	0.068413	0.006615	-62.766
Sichel-t	0.384118	0.800282	0.0421	67.966161
Correlation coefficient table	Silica	Alumina	Loi	Fe
Silica	1	0.1371	-0.0767	-0.1857
Alumina	0.1371	1	0.3591	-0.77
LOI	-0.0767	0.3591	1	-0.654
Fe	-0.1857	-0.77	-0.654	1

TABLE 4: STATISTICAL ANALYSIS REPORT OF BLUE GREY HEMATITE (TYPE 2)

Output file name: type2_Fe Mar 03, 2016				
Statistics report				
File	Composited litho2.str	Composited litho2.str	Composited litho2.str	Composited litho2.str
String range	All	All	All	All
Variable	Silica	Alumina	LOI	Fe
Number of samples	298	298	102	298
Minimum value	0.05	0.01	0.001	63.12

Maximum value	3.2067	3.6191	0.2249	70
	Ungrouped data	Ungrouped data	Ungrouped data	Ungrouped data
Mean	0.473432	0.615682	0.030609	68.38383
Median	0.29215	0.4735	0.0211	68.5964
Geometric mean	0.328042	0.427732	0.018319	68.37431
Variance	0.237814	0.301866	0.000981	1.282628
Standard deviation	0.487662	0.549423	0.031317	1.132532
Coefficient of variation	1.030058	0.892381	1.023133	0.016561
Moment 1 about arithmetic mean	0	0	0	0
Moment 2 about arithmetic mean	0.237814	0.301866	0.000981	1.282628
Moment 3 about arithmetic mean	0.290519	0.370799	9.14E-05	-1.83031
Moment 4 about arithmetic mean	0.587276	0.864925	1.59E-05	8.633226
Skewness	2.50506	2.235724	2.977188	-1.26001
Kurtosis	10.38404	9.491848	16.52411	5.247733
Natural log mean	-1.11461	-0.84926	-3.99981	4.224997
Log variance	0.669893	0.880764	1.414046	0.00028
10.0 percentile	0.12	0.15	0.0034	66.99165
20.0 percentile	0.16	0.21825	0.0095	67.60655
30.0 percentile	0.2	0.3	0.01445	68
40.0 percentile	0.2408	0.3913	0.019	68.30895
50.0 percentile (median)	0.29215	0.4735	0.0211	68.5964
60.0 percentile	0.3763	0.57205	0.025	68.8667
70.0 percentile	0.4792	0.6684	0.033	69.09175
80.0 percentile	0.6535	0.83	0.0475	69.374
90.0 percentile	1.08515	1.25115	0.0627	69.66
95.0 percentile	1.5005	1.70895	0.087001	69.755
97.5 percentile	1.96	2.415	0.1003	69.85035
Trimean	0.3276	0.489075	0.0235	68.55128
Biweight	0.318619	0.473391	0.022608	68.55653
MAD	0.158619	0.238141	0.013	0.7167
Alpha	-0.0495	0.080435	0.009708	-62.4888
Sichel-t	0.457873	0.662989	0.036722	68.38386
Correlation coefficient table				
	Silica	Alumina	Loi	Fe
Silica	1	0.3159	-0.0277	-0.5391
Alumina	0.3159	1	0.0098	-0.7284
LOI	-0.0277	0.0098	1	-0.1589
Fe	-0.5391	-0.7284	-0.1589	1

9.0 Conclusions and result

The proper treatment of outliers during the estimation of a mineral resource of Deposit XXX has been demonstrated to be critical for the accurate economic evaluation of a mineral deposit because the tenor and quantity of the mineral resource forms the basis for all further studies.

Geological resource of has been estimated for Deposit-XXX. The incidence % of different ore types is as under (Fig.5):

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