RE-ESTIMATION OF RESERVE FOR AN IRON ORE DEPOSIT - A CASE STUDY

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ABSTRACT

Re-estimation of reserve for a large iron ore operations is a complex and time consuming process. Often the volume of data and the large range of different conditions make the process almost impossible. Up until recently geologists and engineers at these operations would spend hours cutting and pasting data in and out of spread sheets, diligently comparing how resource/reserve models, grade control and survey pick-ups compare to what was actually produced. The implementation of a dedicated re-estimation system required a number of existing practices to be changed. Data sources had to be clarified and validated, terminology had to be standardized, processes needed to be documented and some methodologies needed to be updated. This was a task that required significant effort by mine planning personnel so that the system could be successfully implemented.

This paper provides a case study of the re-estimation system implementation at Deposit-10 of BIOM Bacheli Complex NMDC. This paper outlines the key work carried out like validation of data base, section preparation, preparation of solid & block model of the deposit, estimation of grade, optimization of the pit, scheduling and provides some insights about the benefits that have been gained through the use of a rigorous re-estimation process.

Keywords : *Ore, Resource and Reserves, Iron ore, Reserve modelling, Block modelling, Bore holes.*

Introduction

Mineral exploration is characterized by a number of factors that distinguish it from other resource sectors such as forestry, hydropower, and recreation. Minerals are public resources that are largely hidden from the view those wishing to locate them. Mineral deposits are “where you find them” – they cannot be moved to a location that is more convenient for resource planners. Once a deposit is found, it can develop over time into a “mining camp” The development of the first deposit in an area with its associated infrastructure facilities in the development of additional deposit thereby reducing costs.

Defining an economic mineral deposit is time-consuming, costly, and high risk, requiring the use of advanced technologies such as remote sensing and geophysical methods employed over large areas. Use of discounted cash flow analysis as a first tool in the economics of the mining industry in the last 30 years. It has become common to define an ore reserve as that part of a mineral resource whose exploitation can generate maximum net present value (NPV) or return on investment. The graphical representation of NPV against the tonnage mined or mine life will give the correct trend of the deposit. Management may choose a longer life over the maximum NPV or rate of return. It is because of several reasons like good ore bodies are difficult to find and stakeholders of the company may desire to stay in business long enough to give itself a good chance of replacing a depleting reserves.

Out of 25 Canadian gold projects, only three had lived up to expectations, conclusion being that the main reason for failure was poor reserve estimation. Twenty out of thirty-nine failures of North American gold mines were attributed to reserve issues (Alastair & Garston, 2002). The economic consequences of the errors in reserve estimation can be very serious. A 10 % error in grade estimation is regarded as a minor or small error. If production costs are at least 50 % to 75 % of the mine site revenue, a 10 % decrease in grade can translate to a 20 % to 40 % decrease in cash operation surplus. It can also render a heavily geared project non-viable. There are two reasons most common for poor estimation. They are, poor resource grade estimation and inadequate assessment of dilution and mining losses. The main that causes poor grade estimation are; unreliable data, not enough data, poor geological interpretation and inappropriate estimation methodology. The reserve estimation and associated risks can be minimized by quality of database and proper geological interpretation.

Quality of databases: Research into sampling practice, especially regarding to sample size and representivity continues to improve this aspect of the work as do greater involvement from external expertise by way of audits. Assay methodology and precision have improved in the last 20 or 30 years. It is very important to ensure that, the database is reviewed and audited frequently to ensure its consistency, measure its quality and check its relevancy and completeness. The data shall be collected with future development of a particular deposit in mind and data collectors are properly trained. The resource estimate shall be analyzed, based on enough density of data and if not, the deficiency must be rectified.

Geological interpretation and resource estimation: Geo-statistical resource estimation methods have developed considerably in the last 10-20 years and the mathematical analysis of data by computers has become more powerful. Mathematical techniques of modeling grade variability through a resource on the basis of widely spaced data points have consistently improved. A combination of good database planning and the ability to effectively process that data with powerful computer software contribute to the achievement of the optimum ore reserve. The process of developing an ultimate pit from a resource is effective with the use of computer. Software permits the most effective mine scheduling and in the case of multi-source mining operations, it helps in effective blending for marketing the product. This way, contributes to a better ore reserve estimate (Glacken, and Snowden, 2001).

Objectives of the study

The main objectives of this study was to estimate the reserve of an iron ore deposit and confirm grade and tonnage estimation efficiency.

Field Description

This study was conducted at National Mineral Development Company Limited (NMDC). It is a public sector under the, Ministry of Steel Govt. Of India, expert in developing a mineral industry in a systematic way. Of the projects undertaken by NMDC, Bailadila Mining complex is not only the biggest but also of high importance for mineral industry since it has been implemented against most tough working conditions caused by inaccessibility of the deposits, rugged terrain, heavy rainfall, dense forest etc. BIOM Bacheli complex comprises Deposit 5 and Deposit 10 &11A. Which are developed in the year 1972 and 2002 respectively.

Bailadila range is a group of hill about 40 km in length and 10 km in width occurring in the southern part of Bastar district of Chhattisgarh. In Bailadila range, 14 iron ore deposit occurring mostly along the top of the hills constitute one of the most extensive and richest concentration of Iron ore deposit of the world. For most of its length the range is sharply divided into two north-south trending ridges with a deep valley in between. Deposit nos.1 to 5 occurs in the western ridge and deposit no. 6 to12 occur in the eastern ridge. Deposit no.13 and 14 occur along southern ridge. Rocks of Bailadila iron ore series and metabasaltic Traps / tuffs occupy the Bailadila range. Iron ore bodies are formed as enrichment products mostly of banded iron formation rocks, enrichment occasionally extending to the underlying shale rocks. Major iron ore bodies occur along the top of the range and generally bottom to underlying shale. Iron ore grades enriched in iron formation rocks with depth. The details of NMDC reserve as per UNFC classification is as given in tables 1 &2.

Deposit No. 10 is located in the middle of eastern limb of the folded mountain range of Bailadila iron ore series. Towards north, it is separated from Deposit-8 and towards south from Deposit-11A. Toward east the deposit slopes down steeply to the Bacheli plain and to the west to the Galli valley. The general trend of the ridge is N-S. The country rock dips to the east. Division of the deposit no. 10 has been made in to two blocks on the basis of geology and ore characteristics. North Block (Between CS 1 and CS 9) South Block (Between CS 9 and CS 16). The ore body occurs as an elongated tabloid body 2600 m in length out of which about 1100 m forms the south block between cross section 9 and 16. The average width of the deposit is about 400-500 m and the maximum width of 860 m encountered is at cross section 14. The ore occurs from 1236M above MSL to less than 1000M MSL. The ore concentration is mostly towards the east of central axial line comprising out crops of massive, laminated lateritic ores. The ore body is underlain by flaky ore/blue dust at depth which in turn overlie transition zone and banded hematite quartzites. The boundary of the ore body is limited by shale on western side and Laterite on the eastern side.

Table 1: NMDC mineral reserves as on 31.03.2009 as per UNFC code d*ecleration in NMDC JORC Certifcation Programme*

S. No.	Commodity deposit	Ore type	Measured resource(331)		Indicated resource (332)		Inferred resource (333)		Total resource		Company's percentage interest in mines
		Iron ore	Million of wet metric tonnes	Fe%	Million of wet metric tonnes	Fe%	Million of wet metric tonnes	Fe%	Million of wet metric tonnes	Fe%	
1	Bld. Dep.5	Iron ore	-	-	-	-	49.02	66.34	49.02	66.34	100%
2	Bld. Dep.10	Iron ore	-	-	-	-	55.93	63.60	55.93	63.60	100%
3	Bld. Dep.14	Iron ore	-	-	-	-	27.78	60.85	27.78	60.85	100%
4	Bld. Dep.14 NMZ (11C)	Iron ore	-	-	-	-	0.56	57.11	0.56	57.11	100%
							133.29	64.01	133.29	64.01	
6	Bld. Dep.11 (11B, 11A & part of 11C)	Iron ore	Measured resource(331)		Indicated resource (211)		Inferred resource (333)		Total resource		Company's percentage interest in mines
			Million of wet metric tonnes	Fe%	Million of wet metric tonnes	Fe%	Million of wet metric tonnes	Fe%	Million of wet metric tonnes	Fe%	
	Bld. Dep.11 (11B, 11A & part of 11C)	Iron ore	26.07	64.50	6.23	65.50	2.56	59.44	34.86	64.31	100%

Table 2: NMDC mineral resources as on 31.03.2009 as per UNFC code

S. No.	Commodity deposit	Ore type	Proved ore reserve(111)		Probable ore reserve (122)		Total ore reserve		Reserve life, years	Company's percentage interest in mines
		Iron ore	Million of wet metric tonnes	Fe%	Million of wet metric tonnes	Fe%	Million of wet metric tonnes	Fe%		
1	Bld. Dep.5	Iron ore	43.48	65.39	182.15	66.85	225.63	66.57	24	100%
2	Bld. Dep.10	Iron ore	142.37	65.91	56.46	62.03	198.83	64.81	45	100%
3	Bld. Dep.11	Iron ore	140.65	66.21	10.79	64.56	151.44	66.09	17	100%
4	Bld. Dep.14	Iron ore	132.23	64.68	19.51	64.70	151.74	64.68	27	100%
5	Bld. Dep.14NMZ	Iron ore	63.93	65.81	2.99	65.52	66.92	65.80	9	100%
6	Bld. Dep.13	Iron ore	319.59	67.23	0.00	0.00	319.59	67.23	46	51
7	Donimalai	Iron ore	22.11	66.30	0.00	0.00	22.11	66.30	6	100%
8	Kumaraswamy	Iron ore	130.90	64.00	0.00	0.00	130.90	64.00	19	100%

Details of exploration: Initial exploration was conducted by Geological Survey of India (GSI) in early 1960s. Subsequently Diamond Core (DC) drilling was carried out in 1960-62 by the Indian Bureau of Mines (IBM) with 23 drill holes (19 vertical and 4 angular) over a depth of 1427.25m on 150m x 150m grid. 70 shallow pits and 30 deep pits (1417.07m depth) and 2 adits (219.60m long) were made and a total of 1318 samples were collected and analyzed. Out of the 1318 samples, 612 were drawn from drill holes, 268 from deep pits, 20 from outcrops, 282 from adits and 56 from shallow pits and analyzed for Fe. 14 samples were run for complete chemical analysis consisting of 13 radicals. NMDC explored the deposit during 1978 with 3 vertical drill holes, covering a total length of 150.60m and collected 70 samples for chemical analysis. NMDC subsequently continued drilling with 63 vertical drill holes during 1991 to 1995 with a total length of 6540.35m and collected 3569 samples and analyzed them for Fe, SiO_2, Al_2O_3 and LOI. One in 10 samples was analyzed for Phosphorous. Check samples were collected in the ratio of one in 10 samples and analyzed for Fe, SiO_2, Al_2O_3 and LOI. During the same period, 9 vertical holes with total length of 389.25m were also drilled by NMDC to confirm the area for utilization of dynamic stockpiles. During 2004-05, NMDC drilled 92 vertical drill holes on a 75m x 75m grid with total length of 7712.55m and 5436 samples were analyzed.

Statistical Analysis of the Raw Sample Data

The Normal statistics of the assay table used for re-estimation of the Ore Body of Deposit 10 ML has been given below in Table 3.

The total no. of Boreholes used is 190 having a total length of 16192.49 meter. The Bore Hole sample has been composted to 2 meter length for estimation purpose & around 13000 sample has been prepared using the software. Care has been taken to replace spike sample by applying lower and upper limit.

Table 3: Assay Table Analysis Report

Parameter	Fe	Silica	Alumina	LoI
Number of samples	12182	11808	11808	11808
Minimum	1.00	0.01	0.00	0.00
Maximum	70.90	65.80	56.00	140.60
Mean	60.78	3.49	3.84	5.34
Variance	77.24	49.41	29.38	21.45
Standard deviation	8.79	7.03	5.42	4.63
Skewness	-2.45	4.17	3.01	7.04
Curtosis	10.97	23.18	15.53	187.80
Coefficient of variation	0.14	2.02	1.41	0.87

Table 4: Composited Sample of Type 1 Material

Variable	Fe	Silica	Alumina	LOI
Number of samples	394	297	297	297
Minimum value	62	0.08	0.03	0.06
Maximum value	69.6	4	4	6
Mean	67.139015	0.842757	0.877782	2.079315
Median	67.4	0.58	0.6358	1.68
Geometric Mean	67.120288	0.646398	0.66237	1.534289
Variance	2.47378	0.49073	0.522509	2.450674
Standard Deviation	1.572825	0.700521	0.722848	1.565463
Coefficient of variation	0.023426	0.831225	0.823493	0.752874
Skewness	-0.993976	1.979119	1.832691	1.143533
Kurtosis	3.893601	7.183735	6.247119	3.557873
Natural Log Mean	4.206486	-0.43634	-0.41193	0.428067
Log Variance	0.000563	0.499309	0.577109	0.70183
10.0 Percentile	65.1	0.27365	0.2921	0.54815
20.0 Percentile	66.05	0.36	0.37925	0.71375
30.0 Percentile	66.6	0.43625	0.4475	0.99825
40.0 Percentile	67.0575	0.51	0.53725	1.3435
50.0 Percentile (median)	67.4	0.58	0.6358	1.68
60.0 Percentile	67.67975	0.6874	0.76	2.099
70.0 Percentile	68.0795	0.8864	0.9	2.41295
80.0 Percentile	68.5215	1.21715	1.22655	3.27055
90.0 Percentile	68.81805	1.9068	1.94285	4.31125
95.0 Percentile	69.2	2.335	2.5151	6
97.5 Percentile	69.435	2.850001	3	6

A composite sample data of Type 1 Material i.e. Steel Grey Hematite is shown in Table 4 & the histogram graph with normal distribution curves is shown in Fig.1 to 4. Fig. 1: Normal Fe distribution curve in type 1 sample

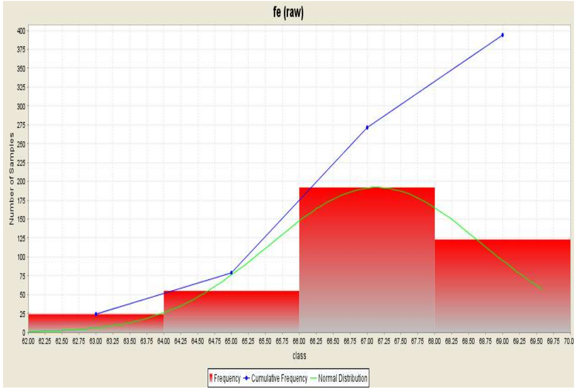


Fig. 2: Normal Silica distribution curve in type 1 sample

Fig. 3: Normal Alumina distribution curve in type 1 sample

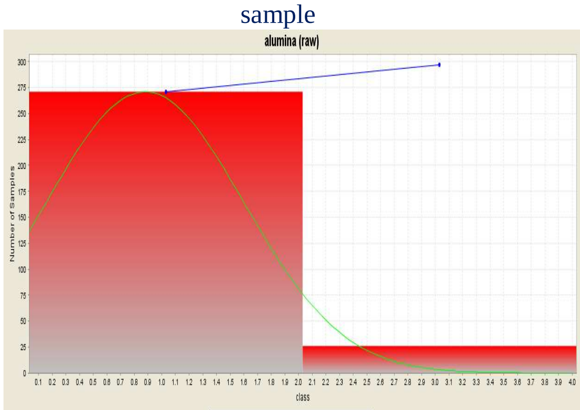
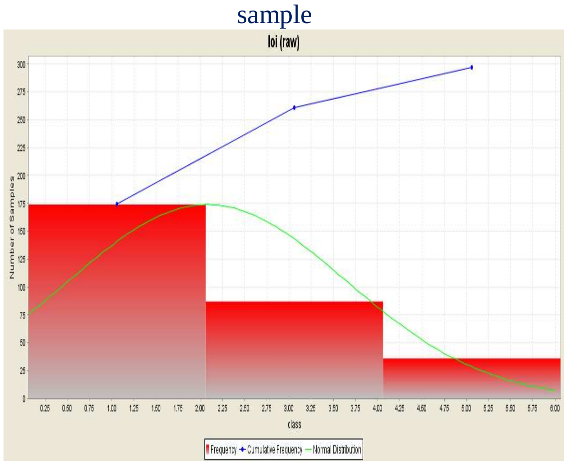


Fig. 4: Normal LOI distribution curve in type 1 sample



Methodology of Work Adopted at Deposit-10

Geological database is the starting point of the mine planning and resource modelling. Various software tools are now available for the specific modelling. Exploration database (i.e., borehole data) is the main input. The database contains geological information obtained in the exploration as topographical, lithological, mineralogical information of the exploration site in specific format.

- Geological database is created in the excel sheet as COLLAR, SURVEY, ASSAY files. These contain exploration information in specific format.
- After the generation of geological database and same is shown in Fig. 5, X sections are prepared as illustrated in Fig.6 and solid model (Fig.7) of the deposit is prepared. From this block model (Fig.8) is generated and value of each attribute is estimated. A block model is a representation or an interpretation of a mineral deposit.

Fig.5: Display of borehole

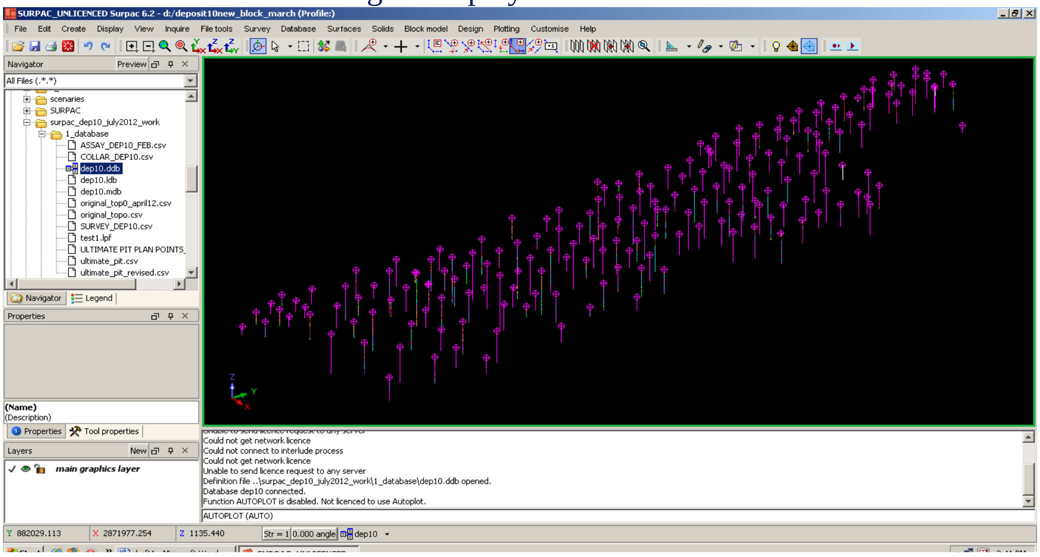


Fig.6: Display of all sections

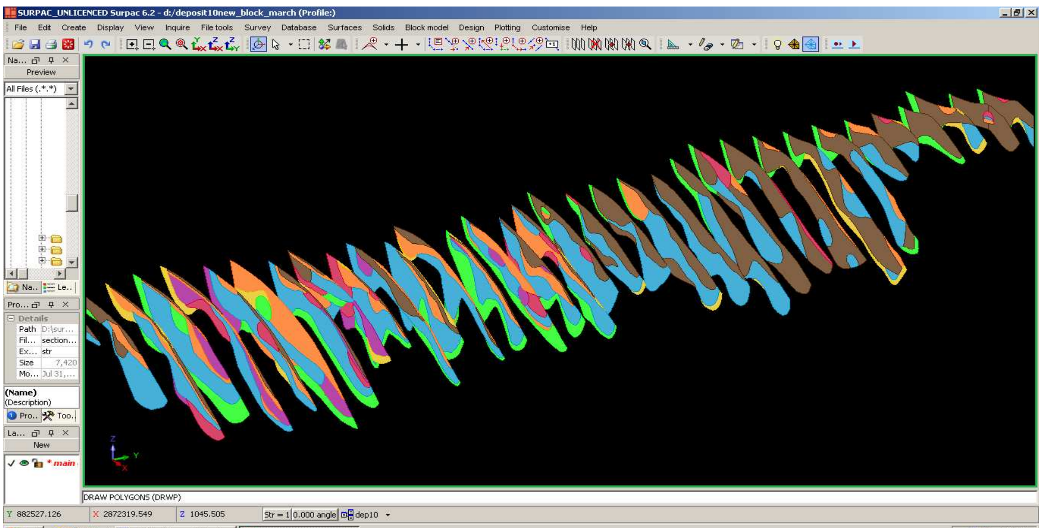


Fig.7: Display of solids

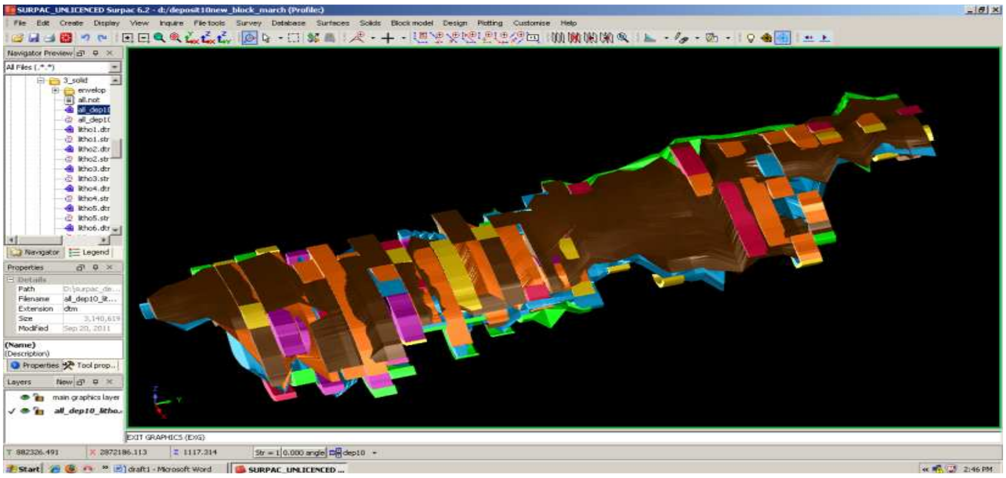
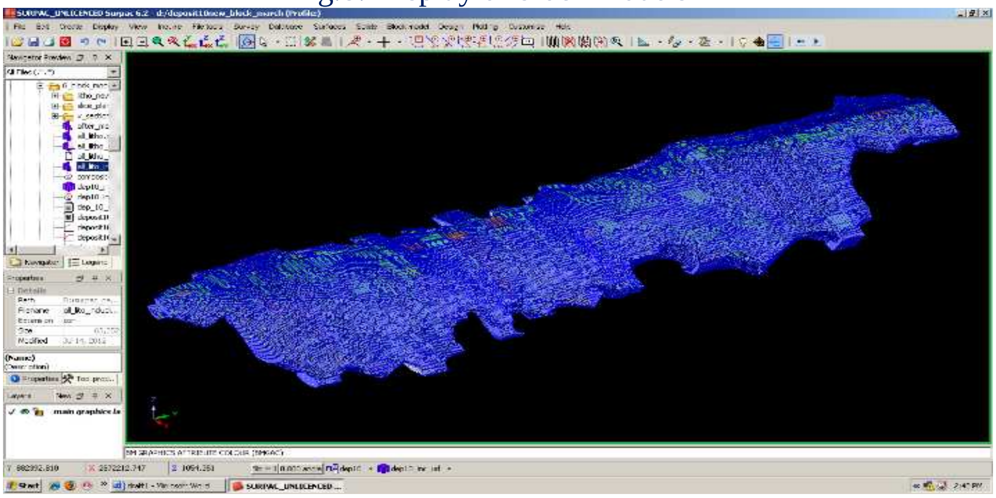


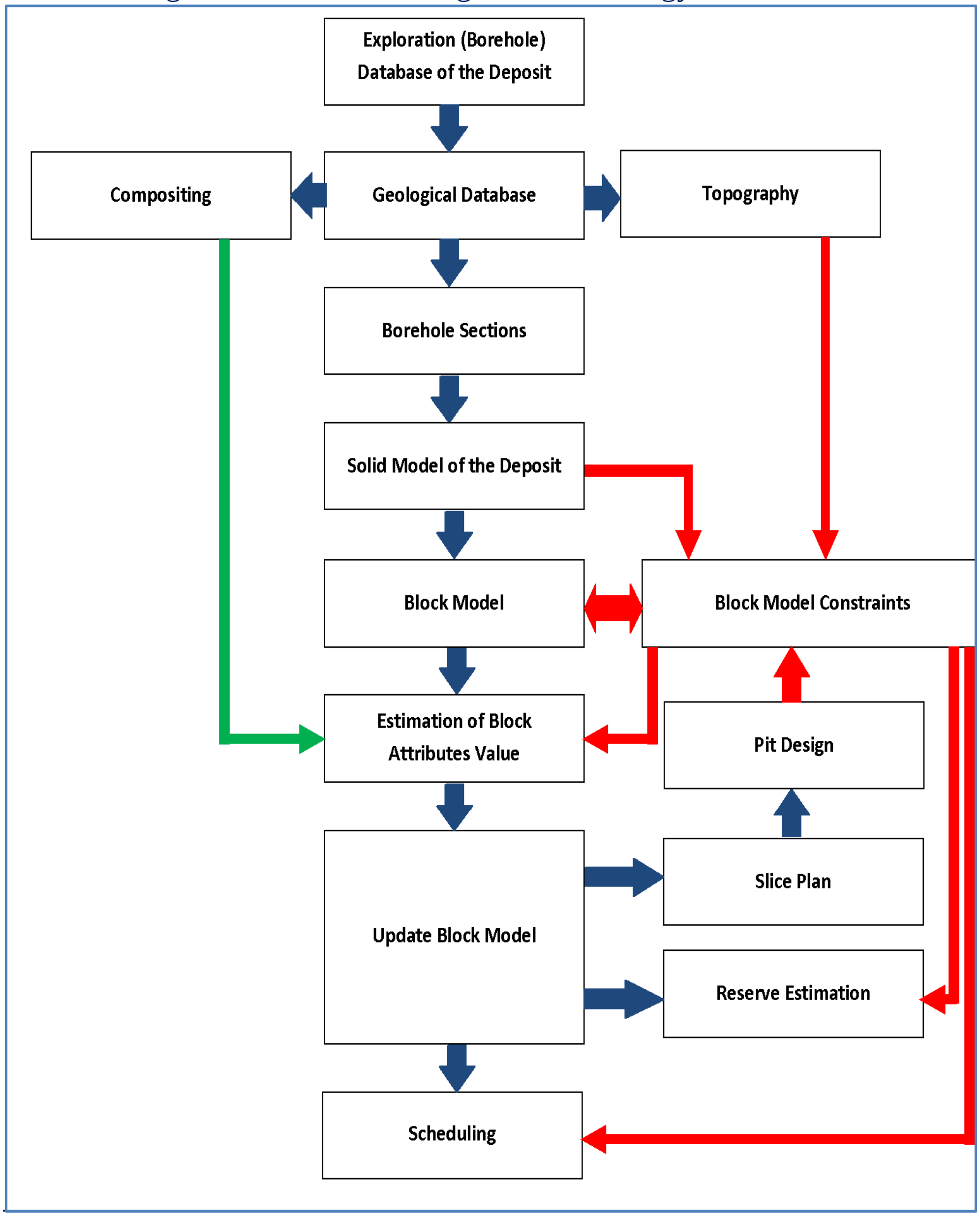
Fig.8: Display of block models



Block model estimation involves detailed variogram analysis and selection of appropriate variogram parameters. The variogram characterizes the spatial continuity or roughness of a data set. Ordinarily two dimensional statistics for two data sets may be nearly identical, but the spatial continuity may be quite different. Variogram analysis consists of the experimental variogramcalculated from the data and the variogram model fitted to the data. The experimental variogram is calculated by averaging one half the difference squared of the z-values over all pairs of observations with the specified separation distance and direction.

The variogram model is chosen from a set of mathematical functions that describe spatial relationships. The appropriate model is chosen by matching the shape of the curve of the experimental variogram to the shape of the curve of the mathematical function. To account for geometric anisotropy (variable spatial continuity in different directions), separate experimental and model variograms can be calculated for different directions in the data set.After the geo-statistical analysis one block model is selected to proceed for the production scheduling. Slice plans are generated from the selected block model which are used for pit designing. Optimum pit is selected using Whitle Software ®.The entire steps of Methodology of work has been explained in the flow chart as shown at Fig.9.

Fig.9: Flow chart showing the methodology of work



Estimation and Classification of Resources

Geological transverse sections were drawn at 75m intervals across the strike by projecting topography, surface features, boreholes, along with the intercepts of various lithological units and their dips, and the assay data for delineating the limits of the ore body envelope and the ore types within it. Slices were extracted at 12m vertical intervals (used the bottom level of the slice for ore type envelopes interpretation) from the geological sections and different ore types in the slices were correlated between section lines. 12m composite values of Fe%, Al_2O_3% and SiO_2% were also drawn for each borehole on the slice plans. The boreholes were drilled at approximately 50m x 50m and 100m x 100m grid intervals both along and across the strike and hence the composite samples plotted on the slice plans are also located at approximately the same grid intervals. Ore body was extrapolated beyond the boreholes both in the transverse sections and slice plans, with definite distance. Similarly, ore body was extrapolated beyond the boreholes at places in the vertical direction, also based on the adjacent borehole data, where the boreholes did not extend beyond the ore body limits. Surpac ® integrated mine planning software was implemented for deposit evaluation and estimation of the mineral resources. Inverse distance square method was deployed for the estimation of Fe, SiO_2, Al_2O_3, LOI and Phosphorous for different ore types separately. The estimation parameters used in the estimation was determined from variography of five radicals.

Discussion / Re-conciliation/Conclusion

The estimates from computerized model have been reconciled with production data for the year 2011-12, as part of internal validation process. The ore tonnage actually produced was 5% lower than the estimated tonnage from the new model, the reason being the change in volumes of ore types. Against the estimated grade of 66.38% Fe, the actual ROM grade was at 65.50% Fe indicating 1.33% error, may be due to dilution, estimation errors etc.

The long term planningefforts culminate in preparing a detailed life of mineplan for the mineral deposit. The level of detail used at this stage of the evaluation was required both by financial institutions for full feasibility studies of new mines and at existing mines to ensure that the long term future mining plan can be used effectively by the short and medium term planners as guidelines for their work. All the above requires a perfect geological model of the ore body hence, a better estimation process. Ore reserve estimation is not only a measure of maximum NPV or return of investment. It also involves other corporate objectives, both quantitative and qualitative. Errors in reserve estimation are still a major source of economic failure in the mining industry. But, computer based analysis can enable an economically better reserve to be defined within a given mineralized resource, especially for more complex ores and for those whose economic value relate significantly to marketing. The main source of errors in reserve estimation, that is resource grade interpolation, is the most difficult to improve (Sinha et al. 2011).

The indicated output of the re-estimation of Deposit-10 is displayed below in Fig. 10 to 11. The proposed ultimate pit design is shown in Fig. 12 and grade tonnage curve is shown in Fig. 13.

Fig. 10: Average Fe for different type of ore

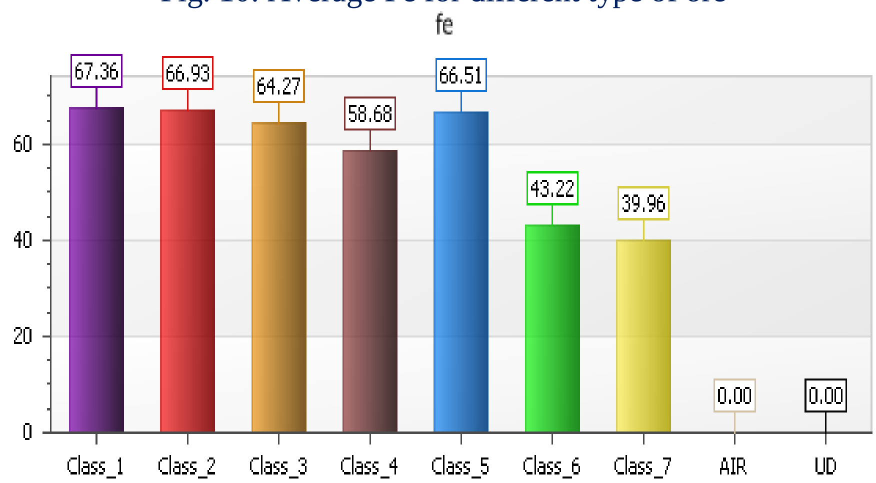


Fig.11: Balance reserves of different ore type

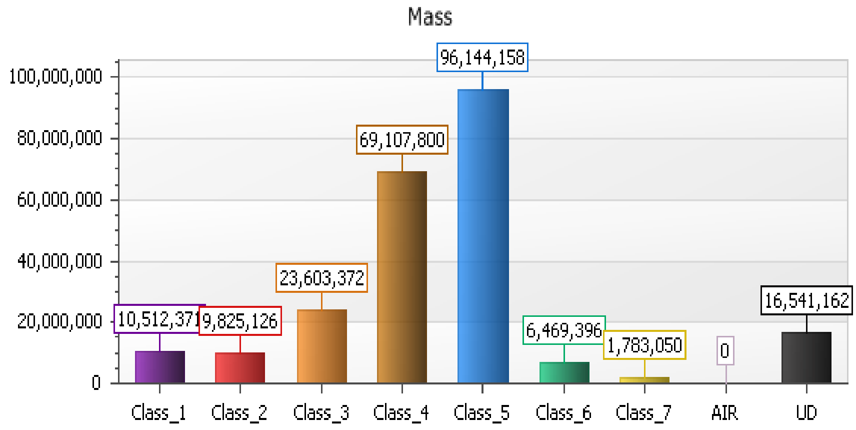


Fig. 12: View of proposed ultimate pit

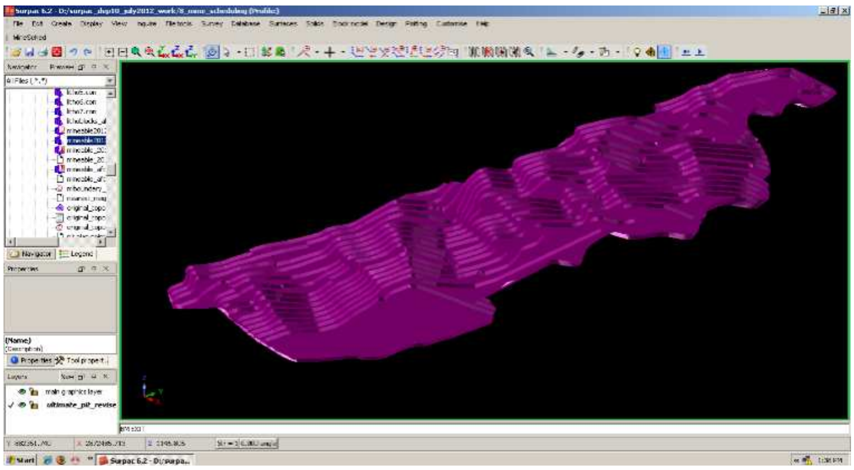
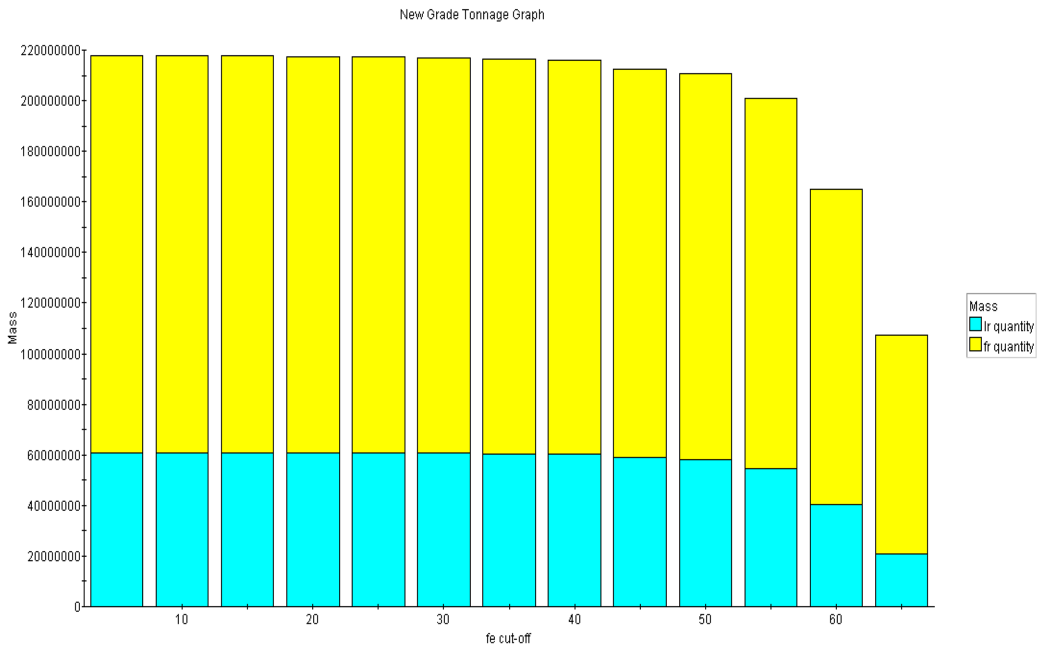


Fig. 13: Grade tonnage graph for the proposed ultimate pit



Acknowledgement

The authors express their gratitude towards the staff and management of NMDC Limited for granting permission to publish the paper. The view expressed in this paper is that of authors and not necessarily of the company they belong to & the result shown is only indicative using the software & may change with time, market scenario, advance exploration work etc.

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