Journal of Mining and Geology Vol. 57(2) 2021. pp. 397 - 406 0022-2763

Predicting the True Reserve of a Steeply Dipping Deposit in a Multi-Deviation Angle Exploration Operation

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Abstract
Borehole deviation is the most precise method of delineating ore bodies in hard rock exploration. In order to achieve a precise delineation and consequently a reliable reserve estimate, borehole trajectories should ideally intercept the ore bodies at 90°. However, because of rock mechanical properties and imperfectness in orientation of borehole trajectories and other factors, borehole trajectories hardly intercept the ore bodies at 90°. Consequently, the ore reserve estimated from borehole data are liable to differ from true values. This in-turn affects the value of the mineral projects and the entire investment profile. In this paper, we have studied the impact of borehole deviation on ore reserve for a range of deviation angles from 10°, 15°, 20°, 25°, 30°; using geometrical modelling. Most importantly, we have been able to develop a mathematical model relating the true reserve to the false reserve through coefficient of variation of the false reserves from their true values. This coefficient has been estimated for various ranges of deviation angles. We have also shown that this coefficient of variation depends on the angle of deviation only and not on ore body thickness or reserve. Consequently, they can be applied to estimate the true reserve from the false reserve for any deposit once the angles of deviation are known.

Keywords: *Angle of deviation, false thickness, true thickness, standard deviation, coefficient of variation, false reserve, true reserve.*

Introduction

When a vertical hole is being drilled and it drifts away from vertical trajectory and becomes inclined, the hole may be said to have deviated from the vertical.

In many circumstances this gives a negative result. However the deviation of hole from the vertical due to varying mechanical properties of rocks and other factors is made use of in mineral exploration (Marjoribanks 1997). Indeed the drill hole is given some inclination so that it deviates to such an extent as to intercept the ore body at 90° and thus depict the true thickness of the ore body. In most circumstances, the hole does not intercept the ore body at 90°. This is also a deviation since the exploratory borehole drifts away from the designed trajectory. This deviation negatively affects the exploration process as it gives a false impression of the ore body thickness and consequently reserve estimate. Dominy et'al (2004) emphasizes that deviation of exploratory holes from the designed trajectory is one of the factors causing uncertainties in reserve estimation which in turn affects the accuracy of mine feasibility. Arsentiev A.I (1972) opines that uncertainties about the reserve of a deposit can lead to underestimation or overestimation of the value of a mineral project depending whether the mine planner in a risk averter or a risk taker.

This research studies how true reserve can be predicted from false reserve caused by hole deviation.

Methodology

Exploratory drilling operations are always associated with deviation of hole trajectories from 90° to the ore bodies, thereby creating false thickness as against the true thickness of the ore bodies which is most desirable for proper estimation of the reserve. The true thickness is the thickness of the ore body when the borehole intersects it at 90° while the false thickness is the thickness when the drill hole intersects the ore body at angle other than 90° and is estimated using formula (1).

$$T_f = \frac{T_r}{\cos \propto} \quad \text{..(1)}$$

Where:
T_f = False thickness caused by deviation.
T_r = True thickness
$\propto$ = Angle of deviation of hole trajectory from 90° to the ore body.

Therefore the result of core measurement and analysis usually provide false thickness and false reserves. With the use of geometrical modelling, the impact of hole deviation on the ore reserve can be studied. This study should be able to show not only the impact of hole deviation on the falsification of ore reserve but also provide a relationship between the falsified ore reserve and the true reserve. In order to study the influence of hole deviation on ore reserve, a geometrical model of ore body was drawn with profiles at 50m interval (fig 2). The total length of ore body along the strike was 1000m..

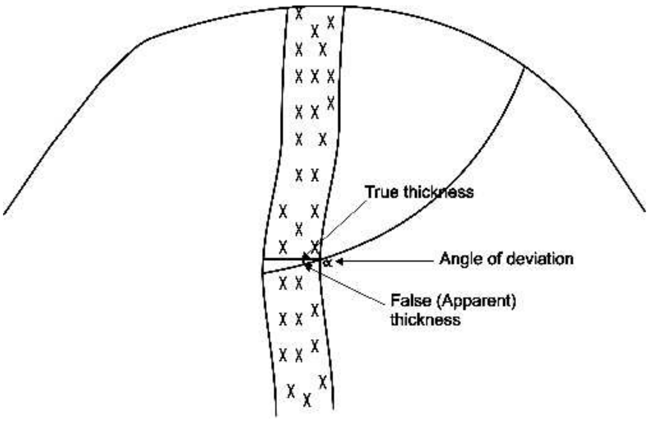

Fig. 1: Deviation of hole trajectory from 90° to the ore body

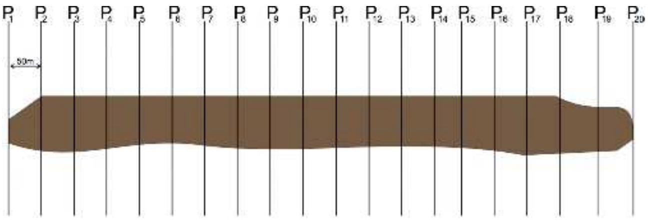

Fig. 2: Profiles along the strike of the ore body.

The ore body was given respective depths at various profile intervals. The thickness of the ore body at the various profiles were measured. Then, the average thickness of ore bodies between profiles was estimated using formula (2). The ore body thicknesses under the influence of various deviation angles 10°, 15°, 20°, 25°, 30° were also estimated using formula (1).

$$\mathbf{T} = \frac{S_i + S_{i+1}\sqrt{S_i S_{i+1}}}{3}$$ (Kajzdan 1985) ....(2)

Where:
T = average thickness of ore body between profiles *i* and *ii*
S_i = the thickness of ore body at profile *I*
S_{i+1} = the thickness of ore body at profile $i+1$

Furthermore, the reserve of the ore body between two profiles was calculated using formula (3)

V = T x L x D ....(3)

Where:
V = Reserve in m^3
T = Average thickness of ore bodies between two profiles
L = Grid interval = 50m
D = Depth of ore body

Thus the volumes of ores between the profiles are summed for the entire deposit and multiplied by the specific gravity to obtain the reserve in tons as usually done in reserve estimation.

The false thicknesses were used to estimate the respective false reserves also.

Both the true thickness and false thicknesses, the true reserve and false reserves estimated from the geometrical model are tabulated for further analysis.

Adjusting the False Reserve to the True Reserve

The problem of adjusting the false reserve to the true reserve could have been most easily solved by dividing the false reserve by the true reserve from the model to obtain an adjustment coefficient or coefficient of adjustment.

$$\mathbf{F} = \frac{\textbf{False reserve}}{\textbf{True reserve}}$$ ....(4)

However, this approach is only applicable when the angle of deviation is constant throughout the deposit. In practical exploration, angle of deviation can vary even along the same grid. So, the angle of deviation in most exploration program vary from grid to grid throughout the entire deposit. In this case, it is best to solve the problem for a range of angles of deviation rather than for a single value of angle of deviation. This can be done by making use of standard deviation of a range of angle of deviation.

The standard deviation of the false reserves from the true reserve under the influence of angles of deviation were estimated using formula (5).
Standard deviation

$$\boldsymbol{S} = \sqrt{\frac{\sum_{i-1}^{N-}(x_i - x)^2}{N}}$$ ....(5)

Where;
S = Standard deviation
x_i = Reserve obtained during the i-th angle of deviation
x = Mean reserve
N = No of deviation angles

In this analysis the true reserve will serve as mean reserve. This is because every member or component of a distribution revolves around the mean just as every false reserve (whether higher or lower than the true reserve) revolves around the true reserve.

The coefficient of variation from the true reserve

$$C_v = \frac{\textbf{Standard deviation}}{\textbf{True reserve}} \quad \text{...(6)}$$

But true reserve + standard deviation = Mean false reserve

From equation (6)

Standard deviation = True reserve x C_v

Let Y be true reserve, consequently

$Y + YC_v$ = Mean false reserve

$Y(1 + C_v)$ = Mean false reserve

Or True reserve $\mathbf{Y} = \frac{\textbf{Mean false reserve}}{1 + C_v}$ ....(7)

The coefficient of variation C_v is estimated using the true reserve from geometrical modelling (table 2) and standard deviation calculated from formula (5).

Results and Discussion

The thickness of the ore body in the geometrical model for each profile was measured and recorded in column 3 of table 1 as the true thickness of ore body. Furthermore, the false thicknesses were calculated for the respective angles of deviation 10°, 15°, 20°, 25°, 30° using formula (1) and recorded in columns 4, 5, 6, 7, 8 of same table. The depths of ore body at each profile were recorded in column 2 of table 1. Average thickness of the ore body between two successive profiles (both for true and false thicknesses) were estimated using formula (2) and recorded in columns 3, 5, 7, 9, 11, 13 of table 2 respectively. The reserve of the ore body between successive profiles were estimated using formula (3) and summed together both for the true and false thicknesses of respective angles of deviation 10°, 15°, 20°, 25°, 30° and recorded in columns 4, 6, 8, 10, 12, 14. The true and false reserves from the model were used to calculate the standard deviation of the false reserves from the true reserve as stated below.

Table 1: Thickness of the ore body in relation to angle of deviation

			Deviation 10°	Deviation 15°	Deviation 20°	Deviation 25°	Deviation 30°
S/N	Depth	True thickness	False thickness	False thickness	False thickness	False thickness	False thickness
1	185	28.53	28.97	29.54	30.36	31.48	32.94
2	190	30.91	31.39	32.00	32.89	34.11	35.69
3	200	32.88	33.39	34.04	34.99	36.28	37.97
4	205	30.48	30.95	31.55	32.44	33.63	35.20
5	195	29.54	30.00	30.58	31.44	32.59	34.11
6	180	28.55	28.99	29.56	30.38	31.50	32.97
7	209	27.07	27.50	28.03	28.81	29.87	31.25
8	214	26.09	26.50	27.01	27.76	28.79	30.13
9	218	26.58	26.99	27.52	28.29	29.33	30.69
10	213	28.06	28.50	29.05	29.86	30.96	32.40
11	217	29.05	29.50	30.01	30.91	32.05	33.54
12	212	29.54	30.00	30.58	31.44	32.59	34.11
13	215	30.52	30.99	31.60	32.48	33.68	35.24
14	219	32.00	32.50	33.13	34.05	35.31	36.95
15	223	30.30	30.77	31.37	32.25	33.43	34.99
16	220	28.36	28.80	29.36	30.18	31.29	32.75
17	225	29.05	29.50	30.01	30.91	32.05	33.54
18	230	27.55	27.98	28.52	29.32	30.40	31.81
19	237	25.11	25.50	26.00	26.72	27.71	28.99
20	232	26.31	26.72	27.24	27.99	29.03	30.38

Standard Deviation of the False Reserves Due to Angle of Deviation of 10°

$$S_1 = \sqrt{\frac{(21.13 - 20.81)^2}{1}} = \mathbf{0.32mt}$$

Coefficient of variation

$$C_v = \frac{\mathbf{0.32}}{\mathbf{20.81}} = 0.02$$

Mean false reserve = 21.13mt

From formula (6)

Table 2: Reserve of the ore body in relation to angles of deviation

S/N	Depth	Deviation 10°				Deviation 15°		Deviation 20°		Deviation 25°		Deviation 30°	
		Average True thickness	True Reserve	Average False thickness	False Reserve	Average False thickness	False Reserve	Average False thickness	False Reserve	Average False thickness	False Reserve	Average False thickness	False Reserve
1	185	29.71	989343	30.17	1004994	30.76	1024308	31.62	1052946	32.79	1091986.6	34.31	1142523
2	190	31.89	1090638	32.38	1107396	33.02	1129284	33.94	1160748	35.19	1203574.6	36.82	1259244
3	200	31.67	1140420	32.16	1157760	32.79	1180440	33.71	1213560	34.96	1258380.4	36.58	1316880
4	205	30.0	1107000	30.47	1124343	31.06	1146114	31.94	1178586	33.11	1221846.5	34.65	1278585
5	195	29.04	1019304	29.49	1035099	30.06	1055106	30.91	1084941	32.05	1124871.2	33.54	1177254
6	180	27.81	901044	28.24	914976	28.79	932796	29.59	958716	30.68	994192.1	32.11	1040364
7	209	26.58	999939.6	27.0	1015740	27.52	1035302.4	28.28	1063893.6	29.33	1103311.3	30.69	1154557.8
8	214	26.33	1014231.6	26.75	1030410	27.27	1050440.4	28.03	1079715.6	29.06	1119293.3	30.41	1171393.2
9	218	27.72	1087732.8	27.74	1088517.6	28.28	1109707.2	29.07	1140706.8	30.14	1182861.7	31.54	1237629.6
10	213	28.55	1094607	29.0	1111860	29.53	1132180.2	30.38	1164769.2	31.51	1207976.7	32.97	1264069.8
11	217	29.29	1144067.4	29.75	1162035	30.30	1183518	31.18	1217890.8	32.32	1262554.2	33.83	1321399.8
12	212	30.0	1144800	30.49	1163498.4	31.09	1186394.4	31.96	1219593.6	33.13	1264410.2	34.67	1323007.2
13	215	31.26	1209762	31.74	1228338	32.36	1252332	33.26	1287162	34.49	1334824.7	36.09	1396683
14	219	31.15	1227933	31.63	1246854.6	32.25	1271295	33.15	1306773	34.37	1354874.2	35.97	1417937.4
15	223	29.32	1176904.8	29.78	1195369.2	30.36	1218650.4	31.21	1252769.4	32.36	1299013.7	33.86	1359140.4
16	220	28.70	1136520	29.15	1154340	29.68	1175328	30.54	1209384	31.67	1254229.5	33.14	1312344
17	225	28.30	1146150	28.74	1163970	29.26	1185030	30.11	1219455	31.23	1264636.6	32.67	1323135
18	230	26.32	1089648	26.73	1106622	27.25	1128150	28.00	1159200	29.05	1202750.3	30.39	1258146
19	237	25.61	1092522.6	26.11	1113852.6	26.62	1135609.2	27.35	1166751	28.37	1210172.3	29.68	1266148.8
20	232												
			20812567.8		**21125975.4**		**21531985.2**		**22137561**		**22955760.1**		**24020442**

$$\text{True reserve} = \frac{\textbf{Mean false reserve}}{1 + C_v} = \frac{21.13}{1+0.02} = 20.72\text{mt}$$

Standard Deviation of the False Reserves Due to Angle of Deviation of 10°, 15°

$$S_2 = \sqrt{\frac{(21.13 - 20.81)^2 + (21.53 - 20.81)^2}{2}} = \mathbf{0.56mt}$$

Coefficient of variation

$$C_v = \frac{0.56}{20.81} = \mathbf{0.03}$$

$$\textbf{Mean false reserve} = \frac{21.13+21.53}{2} = \mathbf{21.33mt}$$

$$\textbf{True reserve} = \frac{\text{Mean false reserve}}{1 + C_v} = \frac{21.33}{1+0.03} = \mathbf{20.71mt}$$

Standard Deviation of the False Reserves Due to Angle of Deviation of 10°, 15°, 20°

$$S_3 = \sqrt{\frac{(21.13 - 20.81)^2 + (21.53 - 20.81)^2 + (22.14 - 20.81)^2}{3}} = \mathbf{0.89mt}$$

Coefficient of variation

$$C_v = \frac{0.89}{20.81} = 0.04$$

$$\textbf{Mean false reserve} = \frac{21.13+21.53+22.14}{3} = \mathbf{21.6mt}$$

$$\textbf{True reserve} = \frac{\text{Mean false reserve}}{1 + C_v} = \frac{21.6}{1+0.04} = \mathbf{20.77mt}$$

Standard Deviation of the False Reserves Due to Angle of Deviation of 10°, 15°, 20°, 25°.

$$S_4 = \sqrt{\frac{(21.13 - 20.81)^2 + (21.53 - 20.81)^2 + (22.14 - 20.81)^2 + (22.96 - 20.81)^2}{4}} = \mathbf{1.32mt}$$

Coefficient of variation

$$C_v = \frac{1.32}{20.81} = \mathbf{0.06}$$

$$\textbf{Mean false reserve} = \frac{21.13+21.53+22.14+22.96}{4} = \mathbf{21.94mt}$$

$$\textbf{True reserve} = \frac{\text{Mean false reserve}}{1 + C_v} = \frac{21.94}{1+0.06} = \mathbf{20.70mt}$$

Standard Deviation of the False Reserves Due to Angle of Deviation of 10°, 15°, 20°, 25°, 30°.

$$S_5 = \sqrt{\frac{(21.13 - 20.81)^2 + (21.53 - 20.81)^2 + (22.14 - 20.81)^2 + (22.96 - 20.81)^2 + (24.02 - 20.81)^2}{5}} = \mathbf{1.86mt}$$

Coefficient of variation

$$C_v = \frac{1.86}{20.81} = \mathbf{0.09}$$

$$\textbf{Mean false reserve} = \frac{21.13+21.53+22.14+22.96+24.02}{5} = \mathbf{22.36mt}$$

$$\textbf{True reserve} = \frac{\text{Mean false reserve}}{1 + C_v} = \frac{22.36}{1+0.09} = \mathbf{20.51mt}$$

The predicted reserve using formula (7) based on respective range of angle of deviation have been presented in table 4. The standard deviation estimated in table 4 shows little dispersion between the true reserve from the geometrical model and the true reserve predicted from the recommended model (formula 7).

Formula (7) can only be applied to any inclined or steeply dipping deposit if it is independent of ore reserve but dependent only on the angle of deviation. To investigate this, ore body models of various thicknesses were used for ore reserve estimation and calculation of coefficient of variation (see appendix 1- 4).

As can be seen from table 3 and fig. (3), the coefficient of variation remains the same for various ore reserves but as can be seen from fig. (5), the coefficient increases as angle of deviation increases showing that the coefficient of variation of false from true reserve is independent of the reserve but solely dependent on angle of deviation. The coefficient presented in table 3 can therefore be applied to any deposit with the same range of angle of deviation. Also the standard deviation increases as angle of deviation increases (fig 4).

A very important property of coefficient of variation is that it is directly proportional or linear when the angle of deviation varies from 10° – 20°. However, beyond 20° the graph is no longer linear (fig 5). This implies that beyond 20° angle of deviation it becomes more difficult to predict the true reserve with good accuracy. Consequently, it is imperative that in exploration program explorationist should endeavour to keep angle of deviation of hole trajectory to the ore body below 20°.

Table 3: Showing ore reserve and coefficient of variation depending on the angle of deviation.

S/N	Reserve (mt)	Angles of Deviation				
		10°	10°, 15°	10°, 15°, 20°	10°, 5°, 20°, 25°	10°, 15°, 20°, 25°, 30°
		Coefficient of Variation				
1	20.81	0.02	0.03	0.04	0.06	0.09
2	22.25	0.02	0.03	0.04	0.06	0.09
3	23.69	0.02	0.03	0.04	0.06	0.09
4	25.13	0.02	0.03	0.04	0.06	0.09
5	26.58	0.02	0.03	0.04	0.06	0.09

Table 4: Showing the predicted reserve and standard deviation from the true reserve.

Range of angle of deviation	10°	10°, 15°	10°, 15°, 20°	10°, 15°, 20°, 25°	10°, 15°, 20°, 25°, 30°
True reserve (mt)	20.81				
Predicted reserve (mt)	20.72	20.71	20.77	20.70	20.51
Standard deviation (mt)	0.09	0.07	0.02	0.06	0.13

Discussion and Conclusion

The coefficient of variation presented in table 3 can be used in formula (7) to obtain the true reserve from any inclined or steeply dipping deposit since the coefficients are independent of the reserve as can be seen in the same table. As can be seen from table 4, the dispersion between the true reserve and the reserve predicted by formula (7) is minimal with standard deviation ranging from 0.02 to 0.13. The suggested method also has the advantage of being based on a range of angle of deviation rather than specific angle of deviation. The

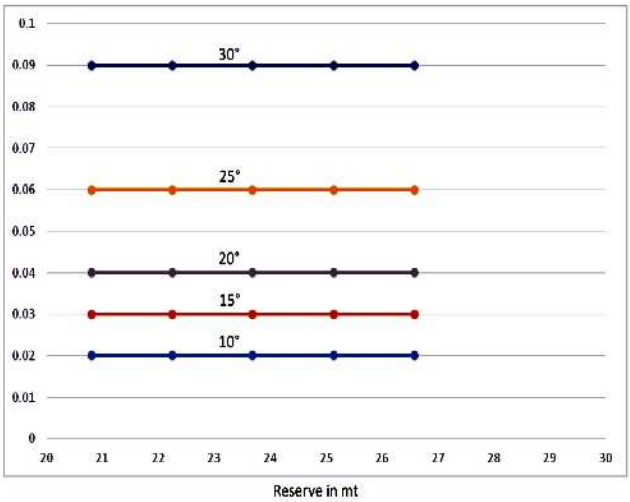

Fig. 3: Graph of reserves versus coefficients of variation

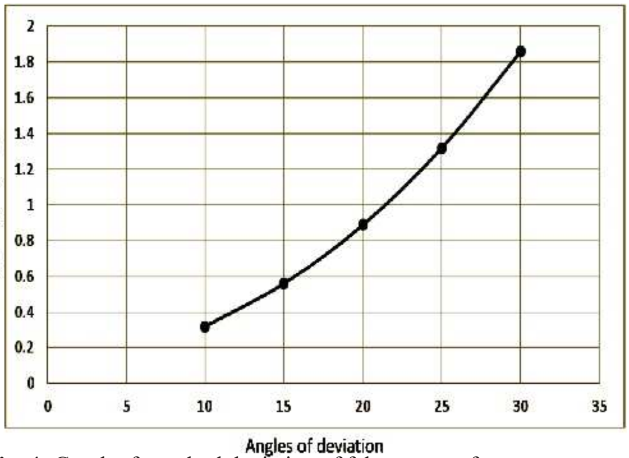

Fig. 4: Graph of standard deviation of false reserve from true reserve depending on range of angle of deviation

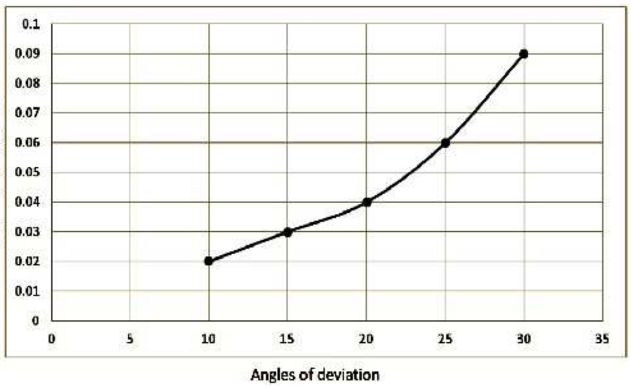

Fig 5: Graph of coefficients of variation versus angles of deviation

study also shows that in order to accurately predict the ore reserve, angle of deviation should as much as possible be kept within 20°. Above 20° the relationship between angle of deviation and coefficient of variation is no longer linear and can introduce errors in predicting the true reserve.

Acknowledgement

This paper is published in loving memory of my supervisor, the Great Russian Mine Planner, Prof. Alexander Ivanovich Arsentiev of St. Petersburg Mining University.

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Appendix

Appendix (1A)

			Deviation 10°	Deviation 15°	Deviation 20°	Deviation 25°	Deviation 30°
S/N	Depth	True thickness	False thickness	False thickness	False thickness	False thickness	False thickness
1	185	30.53	31.00	31.61	32.49	33.69	35.25
2	190	32.91	33.42	34.07	35.02	36.31	38.00
3	200	34.88	35.42	36.11	37.12	38.49	40.28
4	205	32.48	32.98	33.63	34.56	35.84	37.50
5	195	31.54	32.03	32.65	33.56	34.80	36.42
6	180	30.55	31.02	31.63	32.51	33.71	35.28
7	209	29.07	29.52	30.10	30.94	32.08	33.57
8	214	28.09	28.52	29.08	29.89	30.99	32.44
9	218	28.58	29.02	29.59	30.41	31.53	33.00
10	213	30.06	30.52	31.12	31.99	33.17	34.71
11	217	31.05	31.53	32.15	33.04	34.26	35.85
12	212	31.54	32.03	32.65	33.56	34.80	36.42
13	215	32.52	33.02	33.67	34.61	35.88	37.55
14	219	34.00	34.52	35.20	36.18	37.51	39.26
15	223	32.30	32.80	33.44	34.37	35.64	37.30
16	220	30.36	30.83	31.43	32.31	33.50	35.06
17	225	31.05	31.53	32.15	33.04	34.26	35.85
18	230	29.55	30.01	30.59	31.45	32.60	34.12
19	237	27.11	27.53	28.07	28.85	29.91	31.30
20	232	28.31	28.75	29.31	30.13	31.24	32.69

Appendix (1B)

S/N	Depth	Deviation 10°				Deviation 15°		Deviation 20°		Deviation 25°		Deviation 30°	
		Average True thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve
1	185	31.72	1056276.0	32.21	1072570.8	32.84	1093537.4	33.76	1124065.4	35.00	1165471.6	36.63	1219682.5
2	190	33.90	1159209.0	34.42	1177091.7	35.09	1200101.5	36.07	1233604.5	37.40	1279045.6	39.14	1338539.3
3	200	33.68	1212480.0	34.20	1231184.5	34.87	1255251.7	35.84	1290294.3	37.16	1337823.7	38.89	1400051.3
4	205	32.01	1181169.0	32.50	1199390.4	33.14	1222836.1	34.06	1256973.8	35.32	1303275.8	36.96	1363896.5
5	195	31.05	1089679.5	31.52	1106489.6	32.14	1128119.2	33.04	1159612.7	34.25	1202328.3	35.85	1258253.5
6	180	29.81	965844.0	30.27	980743.7	30.86	999915.3	31.72	1027829.7	32.89	1065690.9	34.42	1115260.6
7	209	28.58	1075179.6	29.02	1091766.0	29.59	1113107.8	30.41	1144182.2	31.53	1186329.4	33.00	1241510.5
8	214	28.34	1091464.2	28.77	1108301.8	29.33	1129966.9	30.15	1161511.9	31.26	1204297.5	32.72	1260314.3
9	218	29.32	1150516.8	29.77	1168265.4	30.35	1191102.6	31.20	1224354.4	32.35	1269454.8	33.86	1328502.4
10	213	30.56	1171478.7	31.03	1189550.6	31.63	1212804.0	32.52	1246661.6	33.71	1292583.7	35.28	1352707.1
11	217	31.30	1222382.7	31.78	1241239.9	32.40	1265503.7	33.30	1300832.5	34.53	1348750.1	36.14	1411486.0
12	212	32.03	1222264.8	32.52	1241120.2	33.16	1265381.6	34.09	1300707.0	35.34	1348620.0	36.99	1411349.8
13	215	33.26	1287162.0	33.77	1307018.5	34.43	1332568.2	35.39	1369769.2	36.70	1420226.1	38.41	1486286.7
14	219	33.15	1306773.0	33.66	1326932.1	34.32	1352871.0	35.28	1390638.8	36.58	1441864.5	38.28	1508931.5
15	223	31.33	1257586.2	31.81	1276986.5	32.44	1301949.0	33.34	1338295.3	34.57	1387592.8	36.18	1452135.5
16	220	30.71	1215918.0	31.18	1234675.5	31.79	1258810.9	32.68	1293952.9	33.88	1341617.1	35.46	1404021.2
17	225	30.30	1227150.0	30.77	1246080.8	31.37	1270439.2	32.24	1305905.8	33.43	1354010.2	34.99	1416990.8
18	230	28.33	1172862.0	28.77	1190955.3	29.33	1214236.1	30.15	1248133.7	31.26	1294110.0	32.71	1354304.4
19	237	27.71	1182108.6	28.14	1200344.5	28.69	1223808.9	29.49	1257973.7	30.57	1304312.5	32.00	1364981.4
20	232												
			22247504.1		**22590707.7**		**23032311.1**		**23675299.4**		**24547404.8**		**25689205.0**

Appendix (2A)

			Deviation 10°	Deviation 15°	Deviation 20°	Deviation 25°	Deviation 30°
S/N	Depth	True thickness	False thickness	False thickness	False thickness	False thickness	False thickness
1	185	32.53	33.03	33.68	34.62	35.89	37.56
2	190	34.91	35.45	36.14	37.15	38.52	40.31
3	200	36.88	37.45	38.18	39.25	40.69	42.59
4	205	34.48	35.01	35.70	36.69	38.04	39.81
5	195	33.54	34.06	34.72	35.69	37.01	38.73
6	180	32.55	33.05	33.70	34.64	35.91	37.59
7	209	31.07	31.55	32.17	33.06	34.28	35.88
8	214	30.09	30.55	31.15	32.02	33.20	34.74
9	218	30.58	31.05	31.66	32.54	33.74	35.31
10	213	32.06	32.55	33.19	34.12	35.37	37.02
11	217	33.05	33.56	34.22	35.17	36.47	38.16
12	212	33.54	34.06	34.72	35.69	37.01	38.73
13	215	34.52	35.05	35.74	36.74	38.09	39.86
14	219	36.00	36.56	37.27	38.31	39.72	41.57
15	223	34.30	34.83	35.51	36.50	37.85	39.61
16	220	32.36	32.86	33.50	34.44	35.71	37.37
17	225	33.05	33.56	34.22	35.17	36.47	38.16
18	230	31.55	32.04	32.66	33.57	34.81	36.43
19	237	29.11	29.56	30.14	30.98	32.12	33.61
20	232	30.31	30.78	31.38	32.26	33.44	35.00

Appendix (2B)

S/N	Depth	Deviation 10°				Deviation 15°		Deviation 20°		Deviation 25°		Deviation 30°	
		Average True thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve
1	185	33.72	1122876.0	34.24	1140198.2	34.91	1162486.8	35.88	1194939.7	37.21	1238956.6	38.94	1296585.5
2	190	35,90	1227609,0	36,45	1246546,8	37,16	1270914,4	38,20	1306394,2	39,61	1354516,7	41,45	1417520,8
3	200	35,68	1284480,0	36,23	1304295,2	36,94	1329791,5	37,97	1366915,1	39,37	1417266,9	41,20	1483189,7
4	205	34.01	1254969.0	34.53	1274328.9	35.21	1299239.5	36.19	1335510.1	37.53	1384705.1	39.27	1449113.4
5	195	33.05	1159879.5	33.55	1177772.5	34.21	1200795.6	35.17	1234318.0	36.46	1279785.4	38.16	1339313.5
6	180	31,81	1030644,0	32,30	1046543,3	32,93	1067001,2	33,85	1096788,4	35,10	1137189,8	36,73	1190085,2
7	209	30,58	1150419,6	31,05	1168166,7	31,66	1191002,0	32,54	1224251,0	33,74	1269347,6	35,31	1328390,1
8	214	30.34	1168504.2	30.80	1186530.3	31.41	1209724.6	32.28	1243496.2	33.47	1289301.7	35.03	1349272.4
9	218	31.32	1228996.8	31.80	1247956.1	32.42	1272351.1	33.33	1307871.1	34.56	1356047.9	36.17	1419123.3
10	213	32.56	1248158.7	33.06	1267413.6	33.70	1292189.0	34.64	1328262.7	35.92	1377190.7	37.59	1441249.5
11	217	33,30	1300502,7	33,81	1320565,1	34,47	1346379,5	35,43	1383966,1	36,74	1434946,0	38,45	1501691,2
12	212	34,03	1298584,8	34,55	1318617,6	35,23	1344393,9	36,21	1381925,1	37,55	1432829,8	39,29	1499476,6
13	215	35.26	1364562.0	35.80	1385612.6	36.50	1412698.5	37.52	1452136.5	38.91	1505627.6	40.71	1575660.5
14	219	35.15	1385613.0	35.69	1406988.3	36.39	1434492.1	37.41	1474538.6	38.78	1528854.8	40.59	1599968.1
15	223	33,33	1337866,2	33,84	1358504,9	34,51	1385061,0	35,47	1423727,5	36,78	1476172,0	38,49	1544834,8
16	220	32,71	1295118,0	33,21	1315097,3	33,86	1340804,8	34,80	1378235,8	36,09	1429004,6	37,76	1495473,5
17	225	32.30	1308150.0	32.80	1328330.3	33.44	1354296.5	34.37	1392104.2	35.64	1443383.8	37.30	1510521.5
18	230	30.33	1255662.0	30.80	1275032.6	31.40	1299957.0	32.28	1336247.6	33.47	1385469.7	35.02	1449913.6
19	237	29.71	1267428.6	30.17	1286980.7	30.76	1312138.6	31.62	1348769.3	32.78	1398452.7	34.31	1463500.5
20	232												
			23690024.1		24055480.9		24525717.7		25210397.1		26139049.5		27354883.6

Appendix (3A)

			Deviation 10°	Deviation 15°	Deviation 20°	Deviation 25°	Deviation 30°
S/N	Depth	True thickness	False thickness	False thickness	False thickness	False thickness	False thickness
1	185	34.53	35.06	35.75	36.75	38.10	39.87
2	190	36.91	37.48	38.21	39.28	40.73	42.62
3	200	38.88	39.48	40.25	41.38	42.90	44.89
4	205	36.48	37.04	37.77	38.82	40.25	42.12
5	195	35.54	36.09	36.79	37.82	39.21	41.04
6	180	34.55	35.08	35.77	36.77	38.12	39.89
7	209	33.07	33.58	34.24	35.19	36.49	38.19
8	214	32.09	32.59	33.22	34.15	35.41	37.05
9	218	32.58	33.08	33.73	34.67	35.95	37.62
10	213	34.06	34.59	35.26	36.25	37.58	39.33
11	217	35.05	35.59	36.29	37.30	38.67	40.47
12	212	35.54	36.09	36.79	37.82	39.21	41.04
13	215	36.52	37.08	37.81	38.86	40.30	42.17
14	219	38	38.59	39.34	40.44	41.93	43.88
15	223	36.3	36.86	37.58	38.63	40.05	41.92
16	220	34.36	34.89	35.57	36.57	37.91	39.68
17	225	35.05	35.59	36.29	37.30	38.67	40.47
18	230	33.55	34.07	34.73	35.70	37.02	38.74
19	237	31.11	31.59	32.21	33.11	34.33	35.92
20	232	32.31	32.81	33.45	34.38	35.65	37.31

Appendix (3B)

S/N	Depth	Deviation 10°				Deviation 15°		Deviation 20°		Deviation 25°		Deviation 30°	
		Average True thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve
1	185	35.72	1189476.0	36.27	1207825.6	36.98	1231436.2	38.01	1265813.9	39.41	1312441.6	41.25	1373488.6
2	190	37.90	1296009.0	38.48	1316002.0	39.23	1341727.2	40.33	1379184.0	41.81	1429987.7	43.76	1496502.3
3	200	37.68	1356480.0	38.26	1377405.9	39.01	1404331.4	40.10	1443535.9	41.58	1496710.1	43.51	1566328.2
4	205	36.01	1328769.0	36.57	1349267.4	37.28	1375642.9	38.32	1414046.4	39.73	1466134.4	41.58	1534330.3
5	195	35.05	1230079.5	35.59	1249055.5	36.28	1273472.0	37.29	1309023.3	38.67	1357242.6	40.47	1420373.5
6	180	33.81	1095444.0	34.33	1112343.0	35.00	1134087.1	35.98	1165747.2	37.31	1208688.7	39.04	1264909.8
7	209	32.58	1225659.6	33.08	1244567.4	33.73	1268896.2	34.67	1304319.7	35.95	1352365.7	37.62	1415269.8
8	214	32.34	1245544.2	32.83	1264758.7	33.48	1289482.2	34.41	1325480.5	35.68	1374306.0	37.34	1438230.6
9	218	33.32	1307476.8	33.83	1327646.7	34.50	1353599.6	35.46	1391387.7	36.76	1442641.0	38.47	1509744.2
10	213	34.56	1324838.7	35.09	1345276.5	35.77	1371573.9	36.77	1409863.9	38.13	1461797.8	39.90	1529792.0
11	217	35.30	1378622.7	35.84	1399890.2	36.54	1427255.2	37.56	1467099.6	38.94	1521141.8	40.76	1591896.4
12	212	36.03	1374904.8	36.59	1396114.9	37.30	1423406.2	38.34	1463143.1	39.75	1517039.6	41.60	1587603.3
13	215	37.26	1441962.0	37.83	1464206.6	38.57	1492828.9	39.65	1534503.9	41.11	1591029.0	43.02	1665034.3
14	219	37.15	1464453.0	37.72	1487044.5	38.46	1516113.3	39.53	1558438.3	40.99	1615845.1	42.90	1691004.7
15	223	35.33	1418146.2	35.88	1440023.4	36.58	1468173.0	37.60	1509159.7	38.98	1564751.2	40.80	1637534.2
16	220	34.71	1374318.0	35.24	1395519.1	35.93	1422798.7	36.93	1462518.7	38.29	1516392.1	40.07	1586925.7
17	225	34.30	1389150.0	34.83	1410579.9	35.51	1438153.9	36.50	1478302.6	37.85	1532757.4	39.61	1604052.3
18	230	32.33	1338462.0	32.83	1359109.9	33.47	1385677.8	34.40	1424361.5	35.67	1476829.4	37.33	1545522.8
19	237	31.71	1352748.6	32.20	1373616.9	32.83	1400468.4	33.75	1439565.0	34.99	1492592.9	36.62	1562019.5
20	232												
			25132544.1		**25520254.1**		**26019124.3**		**26745494.8**		**27730694.2**		**29020562.2**

Appendix (4A)

			Deviation 10°	Deviation 15°	Deviation 20°	Deviation 25°	Deviation 30°
S/N	Depth	True thickness	False thickness	False thickness	False thickness	False thickness	False thickness
1	185	36.53	37.09	37.82	38.87	40.31	42.18
2	190	38.91	39.51	40.28	41.41	42.93	44.93
3	200	40.88	41.51	42.32	43.50	45.11	47.20
4	205	38.48	39.07	39.84	40.95	42.46	44.43
5	195	37.54	38.12	38.86	39.95	41.42	43.35
6	180	36.55	37.11	37.84	38.90	40.33	42.20
7	209	35.07	35.61	36.31	37.32	38.70	40.50
8	214	34.09	34.62	35.29	36.28	37.61	39.36
9	218	34.58	35.11	35.80	36.80	38.15	39.93
10	213	36.06	36.62	37.33	38.37	39.79	41.64
11	217	37.05	37.62	38.36	39.43	40.88	42.78
12	212	37.54	38.12	38.86	39.95	41.42	43.35
13	215	38.52	39.11	39.88	40.99	42.50	44.48
14	219	40	40.62	41.41	42.57	44.14	46.19
15	223	38.3	38.89	39.65	40.76	42.26	44.23
16	220	36.36	36.92	37.64	38.69	40.12	41.98
17	225	37.05	37.62	38.36	39.43	40.88	42.78
18	230	35.55	36.10	36.80	37.83	39.23	41.05
19	237	33.11	33.62	34.28	35.23	36.53	38.23
20	232	34.31	34.84	35.52	36.51	37.86	39.62

Appendix (4B)

S/N	Depth	Deviation 10°				Deviation 15°		Deviation 20°		Deviation 25°		Deviation 30°	
		Average True thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve	Average False thickness	Reserve
1	185	37.72	1256076.0	38.30	1275453.0	39.05	1300385.6	40.14	1336688.2	41.62	1385926.5	43.56	1450391.6
2	190	39.90	1364409.0	40.51	1385457.2	41.30	1412540.1	42.46	1451973.7	44.02	1505458.8	46.07	1575483.8
3	200	39.68	1428480.0	40.29	1450516.6	41.08	1478871.3	42.23	1520156.7	43.78	1576153.3	45.82	1649466.6
4	205	38.01	1402569.0	38.60	1424205.9	39.35	1452046.3	40.45	1492582.8	41.94	1547563.7	43.89	1619547.2
5	195	37.05	1300279.5	37.62	1320338.4	38.35	1346148.4	39.42	1383728.5	40.87	1434699.7	42.78	1501433.4
6	180	35.81	1160244.0	36.36	1178142.6	37.07	1201173.0	38.11	1234705.9	39.51	1280187.6	41.35	1339734.4
7	209	34.58	1300899.6	35.11	1320968.1	35.80	1346790.4	36.80	1384388.4	38.15	1435383.9	39.93	1502149.5
8	214	34.34	1322584.2	34.86	1342987.2	35.55	1369239.9	36.54	1407464.7	37.88	1459310.2	39.65	1527188.7
9	218	35.32	1385956.8	35.86	1407337.4	36.57	1434848.1	37.59	1474904.4	38.97	1529234.1	40.78	1600365.1
10	213	36.56	1401518.7	37.12	1423139.4	37.84	1450958.9	38.90	1491465.0	40.33	1546404.8	42.21	1618334.4
11	217	37.30	1456742.7	37.87	1479215.3	38.61	1508131.0	39.69	1550233.2	41.15	1607337.7	43.06	1682101.6
12	212	38.03	1451224.8	38.62	1473612.3	39.37	1502418.5	40.47	1544361.2	41.96	1601249.4	43.91	1675730.1
13	215	39.26	1519362.0	39.87	1542800.6	40.64	1572959.3	41.78	1616871.3	43.32	1676430.5	45.33	1754408.1
14	219	39.15	1543293.0	39.75	1567100.8	40.53	1597734.5	41.66	1642338.1	43.20	1702835.4	45.21	1782041.3
15	223	37.33	1498426.2	37.91	1521541.8	38.65	1551285.0	39.73	1594591.9	41.19	1653330.4	43.10	1730233.5
16	220	36.71	1453518.0	37.27	1475940.9	38.00	1504792.6	39.06	1546801.5	40.50	1603779.7	42.38	1678378.0
17	225	36.30	1470150.0	36.86	1492829.4	37.58	1522011.3	38.63	1564501.0	40.05	1622131.0	41.92	1697583.0
18	230	34.33	1421262.0	34.86	1443187.3	35.54	1471398.7	36.53	1512475.4	37.88	1568189.1	39.64	1641132.0
19	237	33.71	1438068.6	34.23	1460253.1	34.90	1488798.2	35.87	1530360.6	37.19	1586733.1	38.92	1660538.6
20	232												
			26575064.1		**26985027.3**		**27512530.9**		**28280592.5**		**29322338.9**		**30686240.8**