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Predictive Modelling for Iron Ore Exploration Targeting: Case Study: 5-7 Bt Xaudum Iron Ore Exploration Target (Botswana).

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SUMMARY

The principal objective of the research was to determine an exploration target estimate for the Xaudom Iron Ore project. Geophysical data inversion modelling was carried out and the results calibrated against local drill hole interpretation-based geological models. The results compared favourably and enabled a number of correction factors to be established. Subsequent drilling and geological modelling have yielded NI 43-101 compliant resources that are similar to the initial inversion based modelling estimates within optimised pit shells, showing the robustness of the Exploration Target technique. The approach discussed here may be useful for delineating exploration targets for other magnetite-rich iron mineralized areas faced with complex deformational histories.

Key words: Inversion, VPmg, Iron Ore, Botswana, Ground Magnetics.

INTRODUCTION

Xaudom Iron Ore body is situated in NW Ngamiland (Botswana) and stretches over 36.8 km (Figure 1). The potential of this location as an extensive new base-metal field was initially recognised by de Wit (2009). This was subsequently confirmed by de Wit *et al.* (2013) and a joint venture was formed with First Quantum Minerals to explore Zambian Copper belt style copper mineralization (18 April 2013). Further, recent press releases by Tsodilo Resources Limited confirm the presence of a premium grade magnetite exploration target (17 Dec 2013, 22 Jan 2014, see: www.TsodiloResources.com), which was followed up by the Tsodilo Resources maiden NI 43-101 compliant resource – see Mineral Resource Estimate (MRE) report by SRK (Baker, 2014) within Block 1. The paucity of drillhole data covering the entire strike of the ore body, remanent magnetism and complex structural deformation are key challenges that face geophysical modelling and exploration here. Drilling was initially focused in the northern Block 1 area near Shakawe to define the resources in the MRE report mentioned above.

In this study, ground magnetic data was applied to create a series of constrained and unconstrained inversion models. These models were then compared and calibrated against local geological models in terms of volumes. The principal results indicate that the general methodology may be applied as a generic tool for conservative minimum tonnage estimations in regional iron ore exploration programmes. Offsets may need to be recalibrated on a project by project basis, but the underlying principles will remain the same.

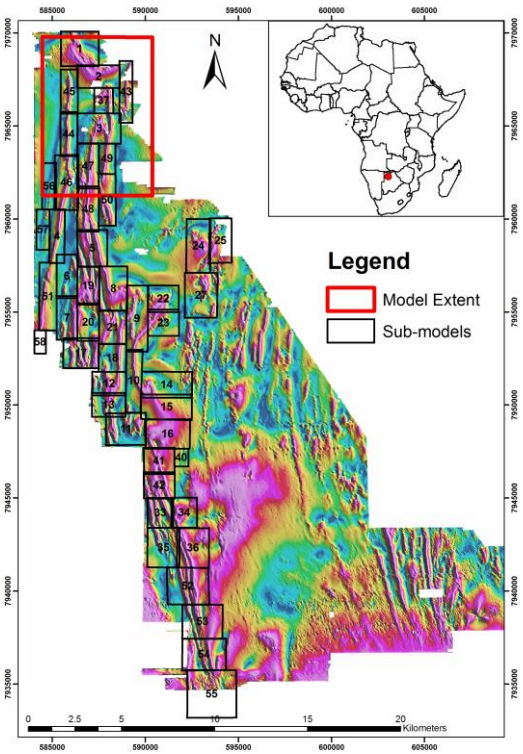

Figure 1 Location map. The ground magnetic data coverage and the sub-models discussed are also shown.

METHOD

The large size of the ore body necessitated the volume of interest be discretized into a number (49) of sub-model regions.

The constrained and unconstrained inversion modelling was carried out by Fuss (2013) following standard Vpmg modelling procedures. These inversion models formed the input for the methodology that was subsequently developed to delineate the current exploration target (Martinez et. al, 2014).

In the methodology outlined below, the constrained block model inversion, based on the Xaudum Iron Formation (XIF) ground magnetic footprint, provides the starting point. This model is initially volume reduced laterally by using the highest magnetic susceptibility value iso-surface derived from the unconstrained model. It is further volume reduced by a base of mineralization offset, which is applied as a base cut-off across the entire model. This volume reduced unconstrained inversion model, is subsequently compared to local drill hole derived models in very localised areas where closely spaced drill hole data was available. From this a set of volume reduction / offset factors are created for each local model. This conservative volume range is then converted to a tonnage range by using an average XIF density value of 3.3 g/cm3. The methodology described above may be summarised as follows (see also Figure 2 and the Tsodilo Resources Limited website for a video with more details).

STEP 1: Create the inversion model from the ground magnetic data using VPmg GOCAD
STEP 2: Smaller volumes are created using high magnetic susceptibility iso-surfaces to create volumes closer to reality due to volume over-sizing in the initial inversion model.
STEP 3: The volumes are further reduced using the drilling data and creation of section models based on this drilling data.
STEP 4: The reduced model volume is compared to the local model volume and offset factors are applied to the whole model to bring the inversion model closer to a reality approximation..
STEP 5: The most conservative volumes are then converted to tonnes by using the average density to create the exploration target tonnage range.

RESULTS

The magnetic susceptibility value (S.I.) that was used when defining the highest iso-surface was based on the unconstrained model and varied from < 0.3 to 1.2 S.I. units depending on the region. The geodomain offset, which reduces the considered volume to that above the banded magnetite geodomain (MBA) base, and section-based calibration minimum and maximum factors were set at 0.566 0.300 and 0.426 respectively. The offsets applied and the estimation results are compared against the calibration models (BK1, BK2 and BK3) in Table 1. The location of these models can be seen in Figure 3.

Tonnages for the entire strike of the ore body, based on the conservative valued calibration factors to ensure conservative estimates, varied from 4.940 to 7.015 Bt (Table2), and were rounded to 5.0 to 7.0 Bt for the exploration target. A limitation of the method is that these estimates are based on local model calibrations.

Geological models based on drillhole data for two regions were then used to test the methodology. The location of the calibration models (BK1-3) are shown relative to these regions in Figure 4. The results of the estimated tonnages are shown in Table 2. Geological model comparisons suggest that these factors are indicative of conservative minimum estimations.

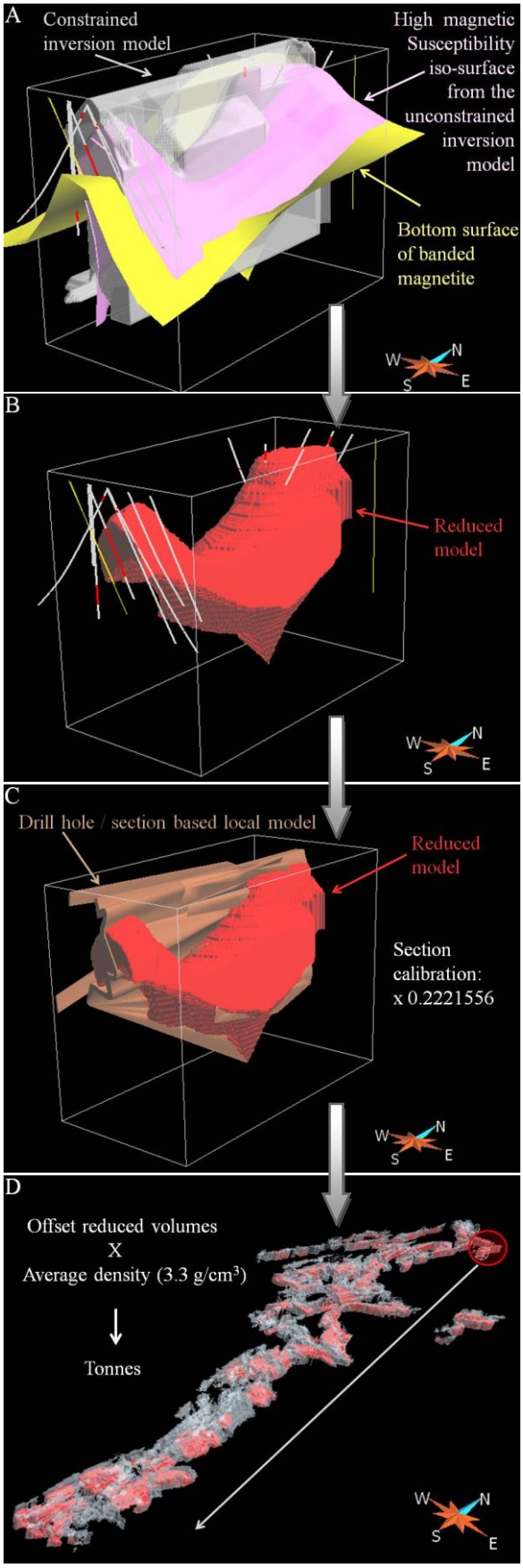

Figure 2. Summary of the methodology. The model box shown (in: A, B, C) has the following dimensions: ΔX = 350 m, ΔY = 700 m, ΔZ = 520 m.

(This was done on purpose by ensuring that the effective offset used was set to about half the lowest applied effective offset.) Figure 4 Regional geological models considered in the initial tonnage estimate comparisons.

	Offsets			Tonnages (Mt)	
Model	Geo	Section	Eff	Section versus Reduced:	
BK1	0.566	0.502	0.284	9.6	9.6
BK2	0.572	0.366	0.209	19.0	19.0
BK3	0.394	1.017	0.401	9.97	9.97
BK3'	0.400	0.833	0.332	9.97	9.97
Ave1	0.483	0.680	0.328		
Ave2	0.569	0.434	0.247		
Used	0.566	0.300	0.170		

Table 1. Minimum value offset factors. Average1 (Ave1: average of all models). (Ave2: average of models 1 and 2). Geo = geodomain offset, Section = section-based offset and Eff = effective offset (i.e. G x S).

	Volume	Min	Max
	m^3x10^3	(Mt)	(Mt)
Total	8816515	4940	7015

Table 2. Tonnages for the entire 36.8 km strike of the exploration target.

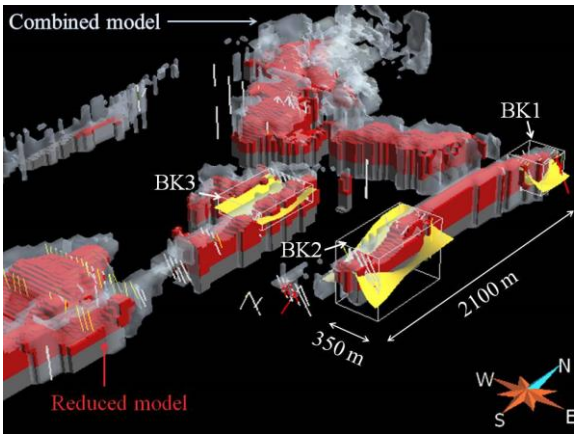

Figure 3. Location of models used to determine offset factors. The combined and reduced models are also shown. The vertical extents of the sub-model blocks are: BK1: 270 m, BK2: 520 m and BK3: 150 m.

Model:		Reduced		Section
	Volume	Min	Max	
Region	m^3x10^3	(Mt)	(Mt)	(Mt)
Region 1	283336	157	223	247
Region 2	92927	52	74	161

Table 3. Results of applying the methodology to estimates tonnages for regions 1 and 2.

COMPARISON OF EXPLORATION TARGET TO NI 43-101 MRE RESOURCES IN BLOCK 1

The NI 43-101 tonnage estimated by SRK for the material inside the optimised pit shell of the geological model for Block 1 (Figure 5), based on geodomains is 441 Mt (Table 4). For more information see the XIF MRE report (Baker, 2014) available on our web site, and www.SEDAR.com.

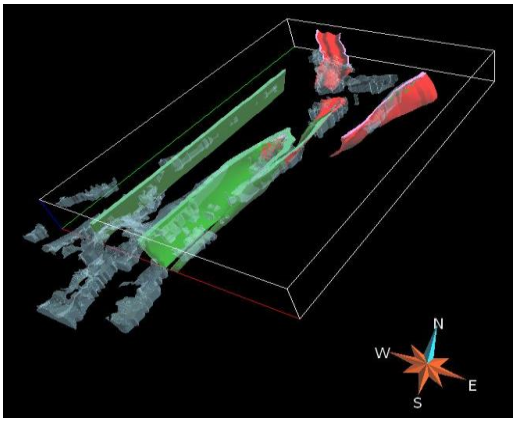

Figure 5. Geological model geodomains MBA (red) and DIM (green) relative to the reduced model (pale blue).

	Tonnage	Grade
Geodomain	(Mt)	Fe (%)
MBA	236	35.6
MBW	21	34.3
DIM	148	20.9
DMW	29	20.5
MGS	7	22.1
Total	441	29.4

Table 4. Tonnages calculated by SRK for the optimised pit shell regions based on the geological model for Block 1. (DMW= weathered DIM, MBW= weathered MBA)

The results based on the method described here are presented in Table 5 (Figure 6). The measured volume was converted to tonnage as follows: [Volume x Geodomain offset (0.566) x Section-based offset x 3.3 (g/cm3) /1000000]. The minimum and maximum estimates are based on section offsets of 0.300 and 0.426 respectively. The results (273 – 388 Mt) are slightly less than the NI 43-101 compliant MRE report resource tonnages (Baker, 2014). However, the results are very close and indicate that the Exploration Target is (as we anticipated) a conservative tonnage estimate for the entire XIF region.

A further useful consequence of the inversion model is that the results have allowed us to hone in on a MBA-type S.I. signature range (see Table 5). This signature is currently being used to help prioritise areas of potential higher grade MBA-like magnetic signature areas DIM magnetic signature areas within

the zones of iron formation as inferred from the 2nd vertical derivative of the magnetic data (Figure 7).

CONCLUSIONS

(1) The Exploration Target methodology detailed here may be applied to obtain conservative minimum tonnage estimates. (2) It is anticipated that the overall methodology is generic, but that the offsets are region / ore body specific. (3) Comparison of the Exploration Target within the same optimised pit shells used for the NI 43-101 compliant XIF MRE report resource figures compare extremely favourably and to the low side. This suggests that the figures for the Exploration Target are as anticipated a conservative estimation of the total tonnages we can expect from the entire XIF region. (4) The S.I. value statistics of the reduced inversion sub-models may be used to target areas of higher iron content such as MBA-like material within the XIF region.

Geodomain	Volume	Min	Max
(All)	m^3x10^3	(Mt)	(Mt)
TOTAL	487637	273	388

Table 5. Tonnage for unconstrained reduced models in the optimised pit shell regions. (DIM+DMW+MBA+MBW)

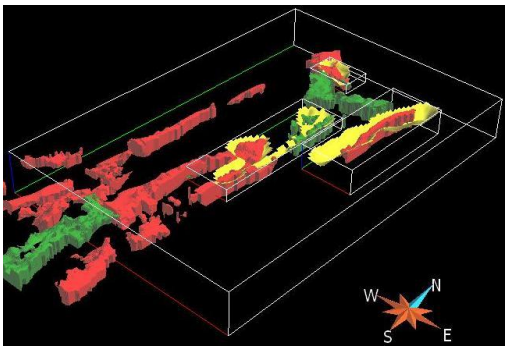

Figure 6. Optimised pit shells (yellow) relative to the reduced inversion model.

S.I.:	Maximum		Used
Model:	Constrained	Unconstrained	K
SM1	1.7	0.8	0.3
SM2	1.7	1.7	0.3
SM3	1.7	2.3	0.8
SM37	1.7	1.6	0.3
SM43	1.7	2.6	0.8

Table 6. Magnetic Susceptibility statistics for MBA sub-models. K: S.I. value used for the ore body iso-surface.

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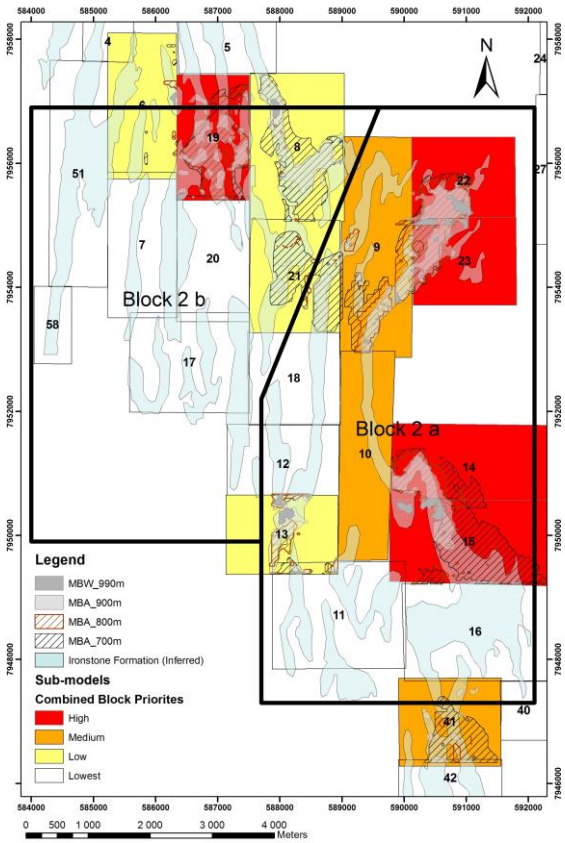

Figure 7. Application of the sub-models to prioritise drill holes with higher iron content.