# Why we should not report unconstrained inversion output in densities or magnetic susceptibilities

**Clive Foss**
*CSIRO Mineral Resources*
*36 Bradfield Road, West Lindfield*
*NSW2070*
*Clive.foss@csiro.au*

**James Austin**
*CSIRO Mineral Resources*
*36 Bradfield Road, West Lindfield*
*NSW2070*
*James.Austin@csiro.au*

## SUMMARY

Unconstrained gravity and magnetic inversions are too readily accepted as justified representations of the ground structure. Reliable estimates from unconstrained inversions are mostly restricted to discrete anomalies which can be reasonably separated from other field variations. Furthermore, for those inversions only the values of total anomalous mass or magnetization and its centre location are reliable. These limitations apply identically to both parametric and voxel inversions. Density and magnetization or magnetic susceptibility values and the details of their distribution are rarely recovered reliably from unconstrained inversions. We suggest that reporting of only those statistics reliably recovered from inversions will enhance the value of inversions even though we are jettisoning much of the apparent detail that is currently accepted.

**Key words:** inversion, unconstrained, parametric, voxel, gravity, magnetic.

## INTRODUCTION

Many gravity and magnetic inversions are of far-field data acquired at an elevation at which there is little or no information about details of the distribution of the subsurface density or magnetization contrasts. Despite this the current practice is to report inversion results which purport to illustrate that distribution with no means to separate what information is reliable from apparent detail which non-uniqueness reduces to be worthless or misleading. Parametric modelling produces geometrical property distributions that are in most cases clearly not geologically acceptable, while voxel inversions report property values across a three-dimensional matrix of subsurface addresses. The apparent information of voxel models can unreasonably be suggested in subsequent discussion of that model to favour particular geological and/or geophysical interpretations. Well-run gravity and magnetic inversions (both parametric and voxel) provide valuable and reliable information, but to maximise the value of the information it must be separated from unjustified aspects of the models. Inversions are only informative when applied to isolated field variations ('anomalies') and in these cases the information that can be reliably recovered is the centre point and total anomalous mass or magnetization causing that anomaly. We propose that these statistics be extracted and presented as the inversion results. The models themselves can then be separately presented as interpretations without the implication that they are favoured or justified by the inversion beyond the fact that they have been shown to be consistent with the data. It is becoming increasingly important to address these issues as the ease of running an inversion is improved, critical evaluation of computer output is relaxed, and methodologies such as artificial intelligence and machine learning further distance interpretation results from the fundamental physics that is the foundation of geophysical methods.

To illustrate reliable recovery of information from unconstrained inversions we selected a simple gravity and a simple magnetic anomaly which can both be reliably separated from their background fields. We classify these inversions as unconstrained because we impose only that the density or magnetization contrasts conform to reasonable geological assumptions. Well-constrained inversions are completely different tasks which include sufficient independent information that they are reduced to advanced interpolation of physical property values (or their controlling geological class). Unconstrained and well-constrained inversions are separated by the third, most-challenging class of partially-constrained inversions which must honour significant constraints but for which the inversion still has to answer significant questions. Our conclusions in this paper apply specifically to unconstrained inversions. We use both voxel and parametric inversions (Oldenburg and Pratt, 2007). These methods represent opposing end-members of assumption that geology consists of discrete units of homogeneous property (parametric models) or diffuse units of continuously variable property variation (voxel models). Neither assumption is ideal but either may be appropriate in particular cases.

## AN UNCONSTRAINED GRAVITY INVERSION

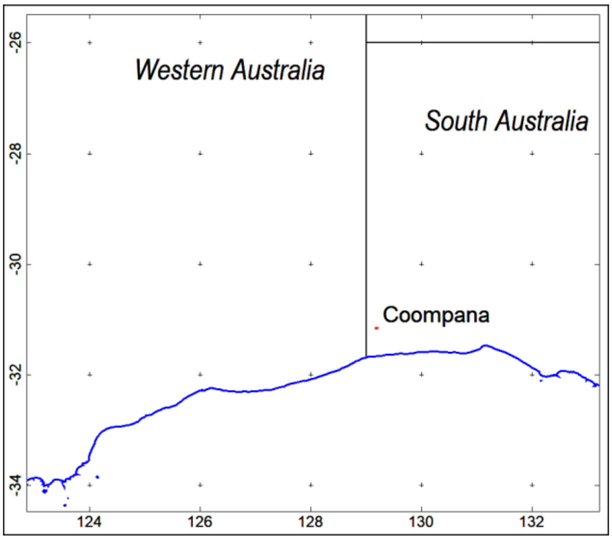


**Figure 1. Location of the gravity anomaly at Coompana.**

Figure 1 shows the location of a positive gravity anomaly of diameter 2 km and peak amplitude 40 μm/s$^2$ in the Coompana region of South Australia. The anomaly defined by a survey with station spacing of 500 metres is believed to be due to a basic to ultrabasic igneous body (expected density 2900 to 3200 kg/m$^3$) intruded into a metamorphic granitoid basement (expected density 2700 to 2800 kg/m$^3$) for a possible density contrast of between 100 to 500 kg/m$^3$. Drilling has established that other nearby bodies extend to the top of basement which in this area is between 50 metres to 200 metres below ground surface. A moderate background field variation introduces slight uncertainty in isolation of the anomaly. We inverted the anomaly with parametric models using ModelVision$^{TM}$ software ( http://www.tensor-research.com.au ) and with voxel models using University of British Columbia Grav3D software (Li and Oldenberg, 1995). A consistent regional-residual anomaly separation was used for all inversions.

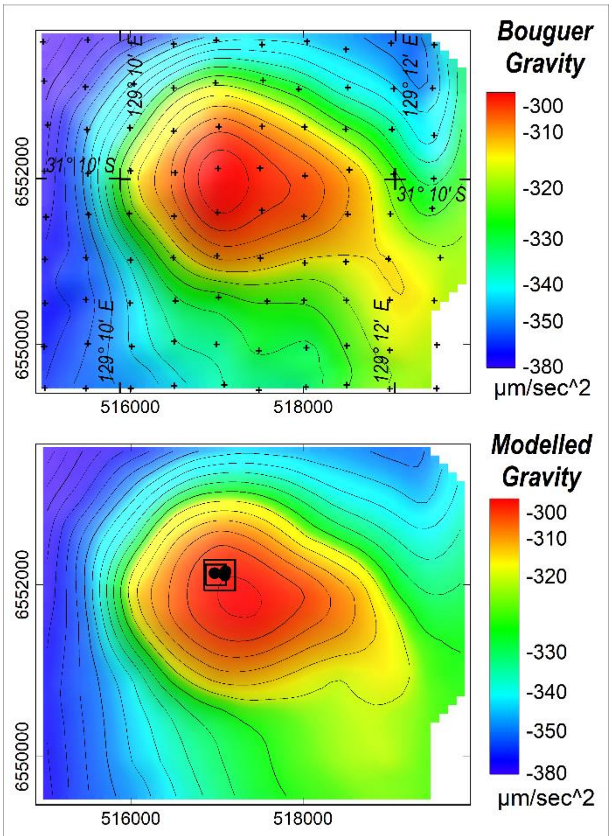


**Figure 2. (top) Bouguer gravity and gravity stations: (bottom) field computed from the polygonal pipe model with model centre points (circles are parametric models, the large square is the full voxel model and the small square is the thresholded voxel model).**

All inversions acceptably match the data and the goodness of fit between the measured and model-computed fields provides no meaningful discrimination between them. Some key model statistics are listed in Table 1. Figure 2 shows the field forward computed from polygonal section pipe model with overlapping estimates of the horizontal centre of each model. Figure 3 shows the ellipsoid and polygonal section pipe model and Figure 4 shows the voxel model. The voxel model has a high-density core with smooth decrease in density outwards and with the top and base of the model at the pre-set limits of the model mesh. The volume of the voxel model depends on the chosen density cut-off, but for the parametric models there is a range in volume by a factor of almost 2.5 and the same (but inverse) range in the density contrast values to give consistent estimates of total anomalous mass (Figure 5). In consequence the total anomalous mass estimate is reliable but the individual volume or density contrast values (and the shape) are not.

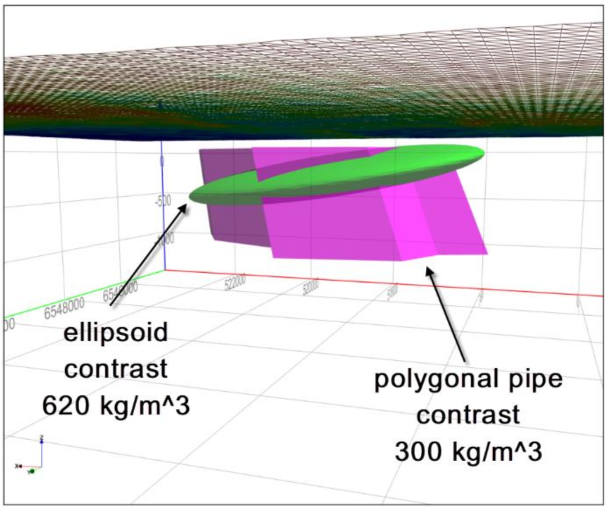


**Figure 3. Ellipsoid (green) and polygonal pipe (magenta) parametric models.**

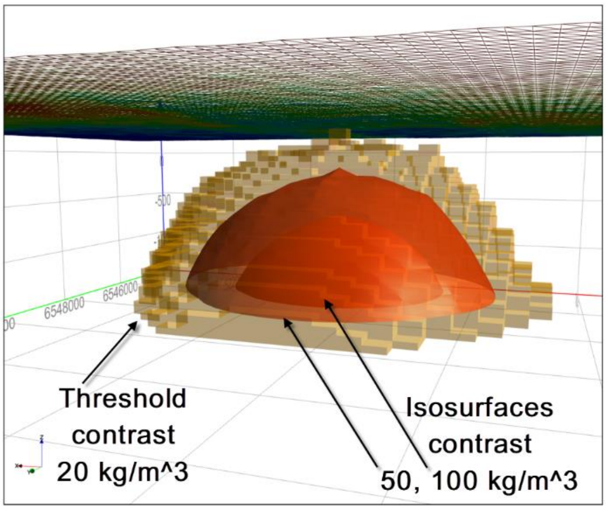


**Figure 4. Voxel inversion model threshold and isosurface.**

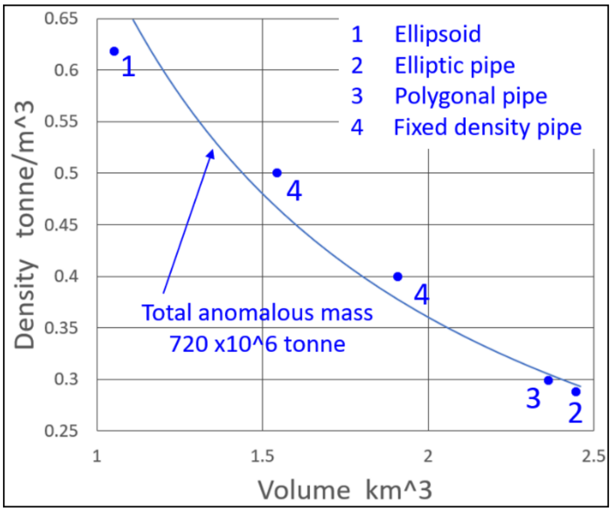


**Figure 5. Inversion model volumes and density contrasts.**

## AN UNCONSTRAINED MAGNETIC INVERSION

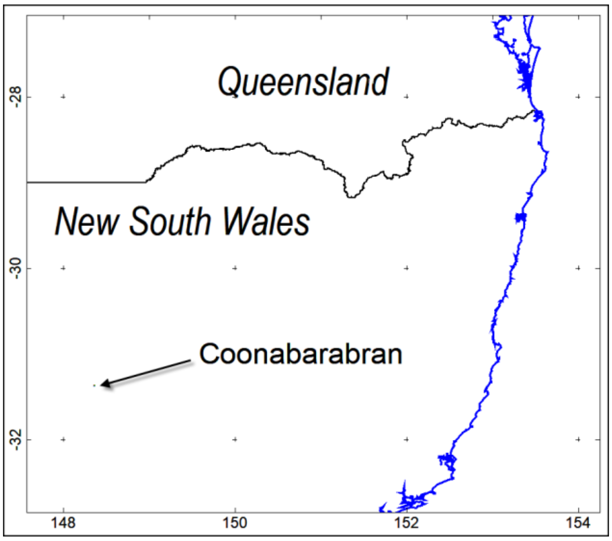


**Figure 6. Location of the Coonabarabran anomaly.**

Figure 6 shows a 430 nT magnetic anomaly of diameter 2 km in the Coonabarabran area of northern NSW. The anomaly is defined on 10 east-west flight-lines flown at a line spacing of 250 metres and a nominal terrain clearance of 60 metres. The more prominent contrast in curvature of the anomaly and background fields compared to the Coompana gravity anomaly provides a more reliable anomaly separation. There is no outcrop of the source body but it is expected to belong to one of a number of volcanic or intrusive units known from limited drilling through cover. We have no petrophysical measurements for this anomaly but in many cases where such measurements are available both induced and remanent magnetizations are found to contribute significantly to magnetic field anomalies. Despite this many magnetic field inversions are undertaken on the assumption of induced-only magnetization. To avoid issues of unknown magnetization direction being incorrectly attributed as the cause of model ambiguity we have deliberately selected an anomaly that by its shape can clearly be explained (correctly or incorrectly) as due only to induced magnetization, and we use only magnetic susceptibility in the inversions. We again used ModelVision$^{TM}$ for the parametric modelling with an identical selection of model geometries. In this case we used the UBC Mag3D software (Li and Oldenberg, 1996) for the voxel inversion. Again, all tested inversions acceptably match the regional-residual separated data. Model details are listed in Table 2. The horizontal model centre points overlap irrespective of model geometry (Figure 7). Two of the parametric models and the voxel model are shown in perspective view in Figures 8 and 9 respectively. The models range of volume by a factor of 3 with an inverse range of 3 in the corresponding magnetic susceptibility values (in this case assumed to be a contrast against a very low background magnetization). All models have similar volume-susceptibility products of .043 km^3 (SI).

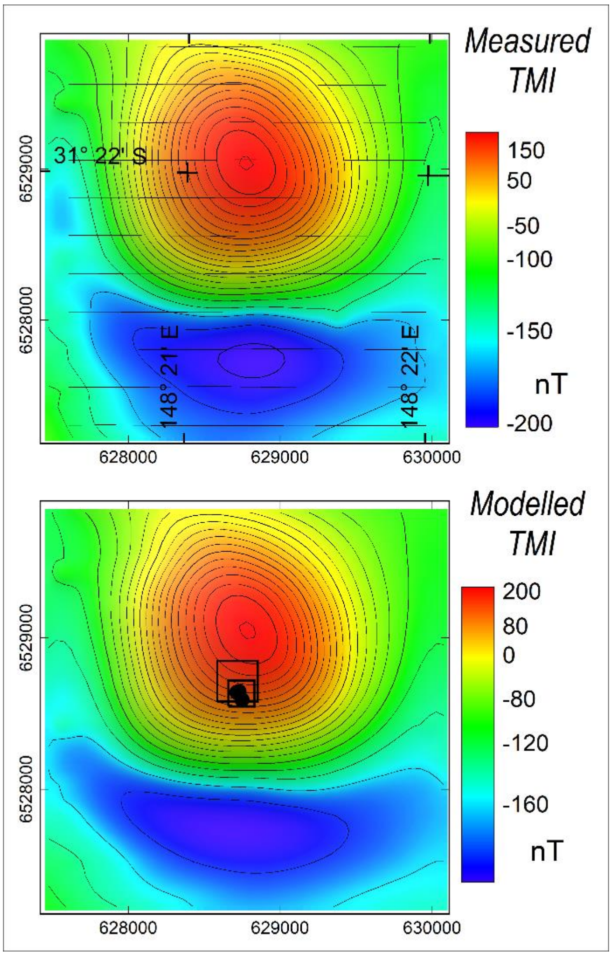


**Figure 7. (top) TMI and (bottom) field computed from the polygonal pipe model with model centre points (circles are parametric models, the large square is the full voxel model and the small square is the thresholded voxel model).**

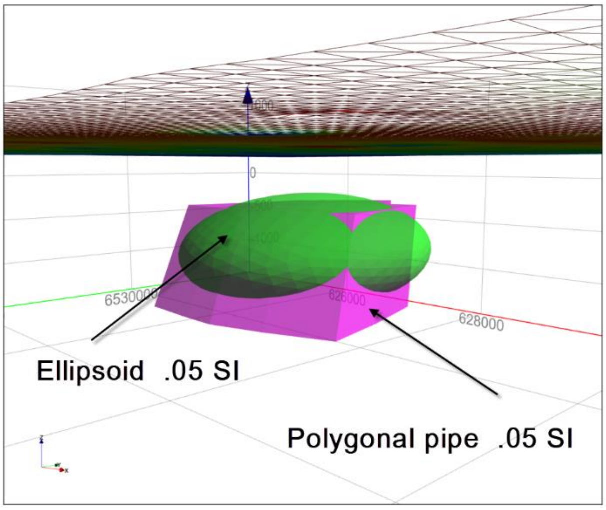


**Figure 8. Ellipsoid (green) and polygonal pipe (magenta) models.**

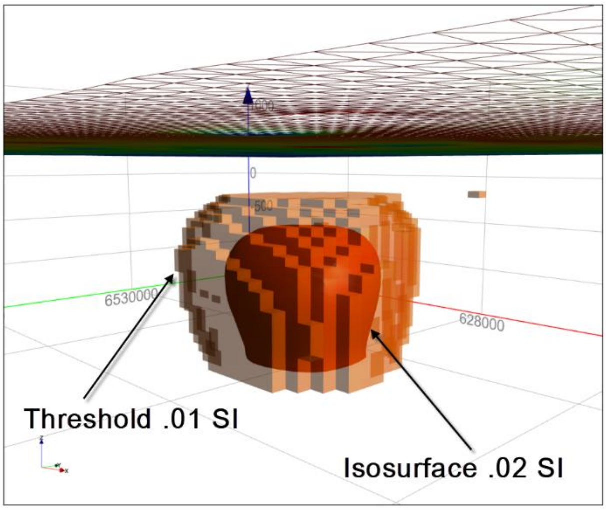


**Figure 9. Voxel inversion model threshold and isosurface.**

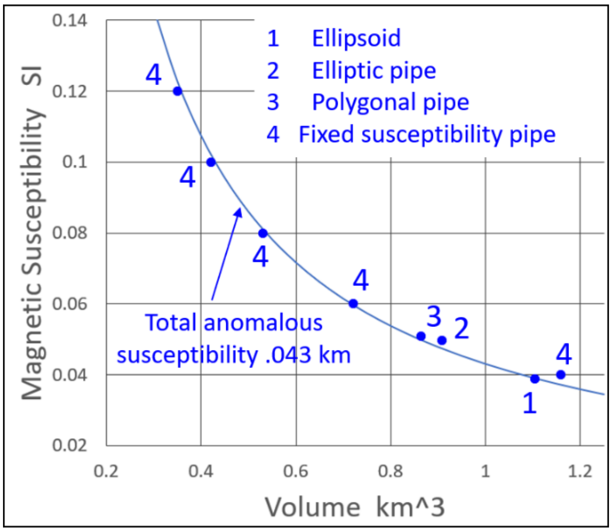


**Figure 10. Inversion model volumes and magnetic susceptibility contrasts.**

## CONCLUSIONS

In unconstrained inversion of both the gravity anomaly at Coompana and the magnetic anomaly at Coonabarabran different parametric and voxel source models can be found to acceptably match the measured fields. We suggest that only key statistics common to all or at least most models be accepted as established by inversion (within its known caveats). Isolated anomalies such as those we investigated here provide the most reliable inversion studies and their most reliable statistics are the total anomalous density and/or magnetization and the horizontal and vertical centre of that property distribution. The anomalous density or magnetization (susceptibility) value, the volume, shallowest depth, and any apparent detail of the shape of the distribution are all statistics of lesser reliability. These and any other ancillary aspects of the inversion models can be presented as interpretational preferences but should not be proposed as having been established or qualified by the inversion. We have not investigated magnetization direction in this study but for well-defined anomalies due to compact magnetizations the vector-mean direction of anomalous magnetization is an additional more-reliable inversion statistic.

## ACKNOWLEDGMENTS

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## REFERENCES


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| model | body | Density contrast kg/m^3 | East centre | North centre | Centre depth below ground | Volume km^3 | Total anomalous mass Tonnes x10^6 |
|---|---|---|---|---|---|---|---|
| 1 | ellipsoid | 618 | 517092 | 6552104 | 285 m | 1.053 | 651 |
| 2 | Elliptic pipe | 288 | 516974 | 6552130 | 393 | 2.447 | 705 |
| 3 | Polygonal pipe | 299 | 517103 | 6552152 | 390 | 2.364 | 707 |
| 4 | UBC voxel model | 13.6 | 517032 | 6552112 | 518 | 44.10 | 600 |

**Table 1. Coompana inversion models statistics.**

| model | body | Susceptibility contrast (SI) | East centre | North centre | Centre depth below ground | Volume km^3 | Total anomalous susceptibility Km(SI) |
|---|---|---|---|---|---|---|---|
| 1 | ellipsoid | .0388 | 628715 | 6528639 | 639 m | 1.104 | .0428 |
| 2 | Elliptic pipe | .0497 | 628748 | 6528590 | 694 | .909 | .0452 |
| 3 | Polygonal pipe | .0508 | 628729 | 6528645 | 620 | .864 | .0439 |
| 4 | UBC voxel model | .0053 | 628718 | 6528631 | 586 | 10.8 | .0573 |

**Table 2. Coonabarabran inversion models statistics.**