

# Enhancing exploration opportunities at Broken Hill with airborne gravity gradiometry

Richard Lane

Paper presented at the NSW Department of Mineral Resources  
"Exploration NSW Geoscience information Release"

Sydney, 3-December-2003

  
**pmd\*CRC**

Enhancing exploration opportunities  
at Broken Hill with airborne gravity  
gradiometry

Richard Lane  
Predictive Mineral Discovery CRC  
(pmd\*CRC)

*p*redictive *m*ineral *d*iscovery



pmd\*CRC (Geoscience Australia)  
GPO Box 378, Canberra, ACT 2601  
richard.lane@ga.gov.au

## List of slides

Slide 1.	Title slide .....	1
Slide 2.	Introduction .....	2
Slide 3.	AGG survey impacts.....	3
Slide 4.	Principal survey products .....	4
Slide 5.	Technical checklist .....	5
Slide 6.	Density.....	7
Slide 7.	Broken Hill ore body model.....	8
Slide 8.	Pre-mining AGG Gdd response .....	9
Slide 9.	Profile across the ore body model.....	10
Slide 10.	Comparison of short wavelengths in ground and AGG data.....	11
Slide 11.	Profile across the ore body model.....	12
Slide 12.	Stacked amphibolite model.....	13
Slide 13.	Low contrast meta-sediment model .....	14
Slide 14.	Outline of granite gneiss bodies on solid geology.....	15
Slide 15.	Overlay of solid geology granite gneiss bodies on Gdd.....	16
Slide 16.	Modified granite gneiss body outlines on Gdd.....	17
Slide 17.	Modified granite gneiss body outlines on solid geology .....	18
Slide 18.	Section through Pasmaenco 3D geological map.....	19
Slide 19.	Ground gravity station spacing .....	20
Slide 20.	Pre-mining Gdd response .....	21
Slide 21.	Targets being followed-up by Gravity Capital Limited .....	22
Slide 22.	Acknowledgments .....	23

Slide 1. Title slide

**pmd\*CRC**

# Enhancing exploration opportunities at Broken Hill with airborne gravity gradiometry

Richard Lane  
Predictive Mineral Discovery CRC  
(pmd\*CRC)

predictive mineral discovery

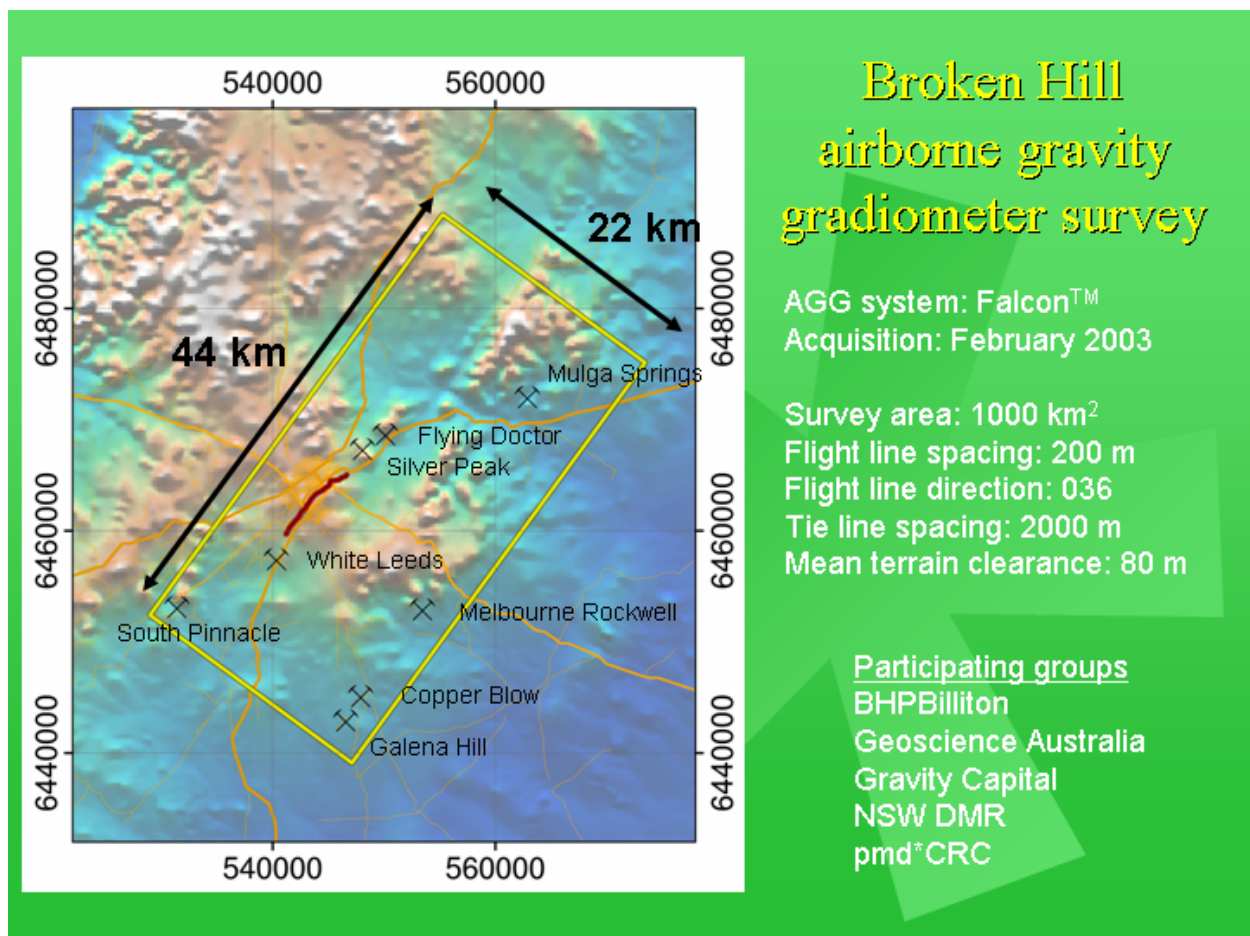
Australian Government  
The University of Melbourne  
MONASH  
THE UNIVERSITY OF  
WESTERN AUSTRALIA  
JCU  
CSIRO  
AMIRA  
INTERNATIONAL

Gravity methods are perhaps the second most widely used geophysical method behind magnetics for regional minerals and petroleum applications. The ranking behind magnetics has more to do with the difficulties of taking measurements than with the usefulness of the results.

Around 10 year ago, the introduction of GPS navigation lowered the costs and increased the speed with which ground gravity data could be acquired. Yet, this improvement is only relative, as ground gravity data are still relatively slow to acquire. The resultant sparse coverage limits the usefulness of the data for mapping in the top kilometre.

With the advent of airborne gravity gradiometer or AGG systems operated for BHPBilliton and Bell Geospace, data can be acquired rapidly from aircraft at a level of detail that approaches that of airborne magnetic data.

## Slide 2. Introduction



An AGG survey was flown over the Broken Hill region in early 2003 (Lane et al., 2003). The survey project was led by the NSW Department of Mineral Resources, with pmd\*CRG and Geoscience Australia as research project sponsors. This is the first AGG survey carried out for Australian government organisations, and the first time that AGG data have been acquired for release to the public.

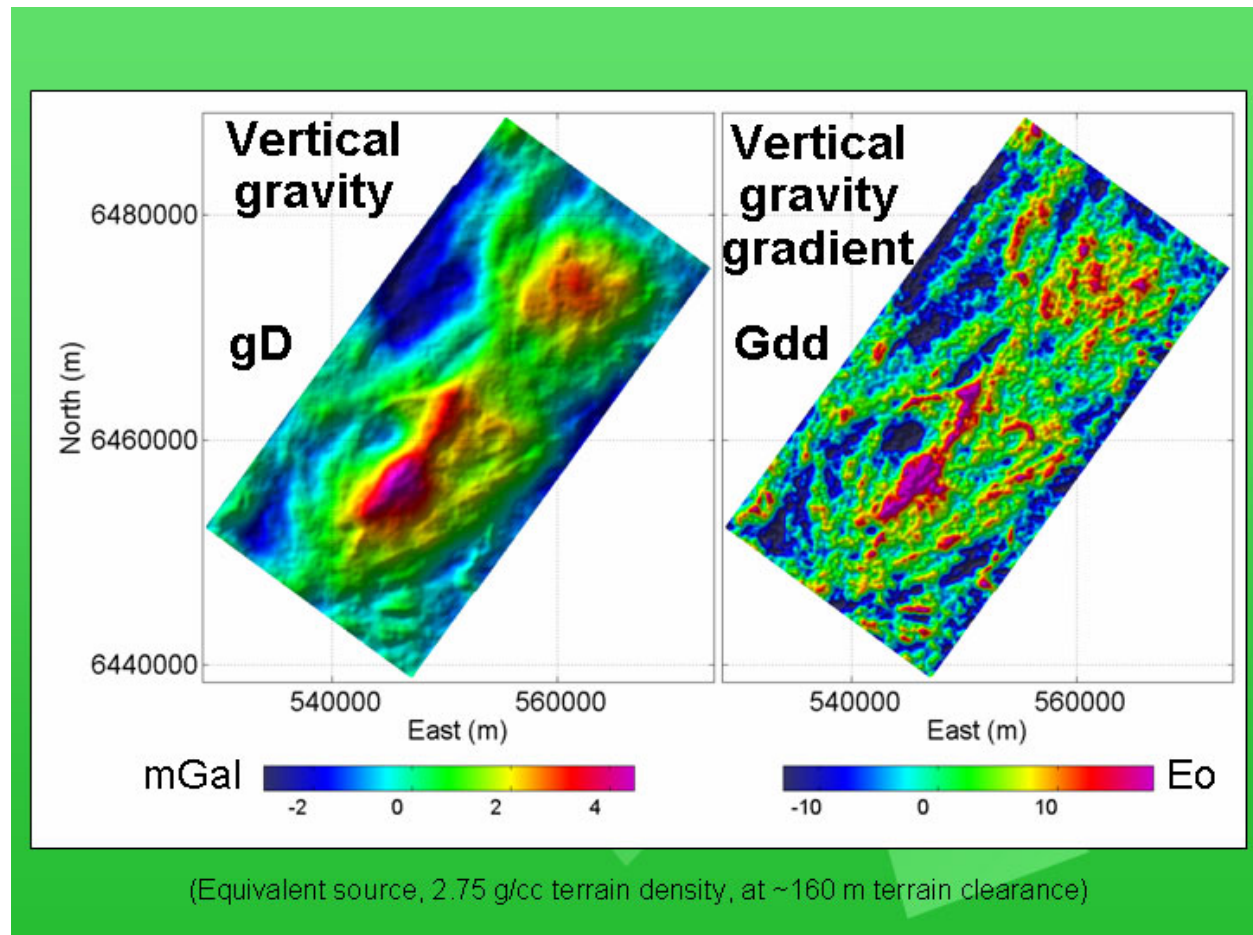
### Slide 3. AGG survey impacts

## Broken Hill AGG Survey impacts

- Increased exploration activity through direct targeting
- Prompting changes to (2D) geological mapping
- Data used to evaluate and refine 3D geological maps (“geological models”) via forward and inverse gravity modeling
- Data from this survey used to evaluate AGG as an option for upgrading the national gravity coverage

This survey has begun to show impact in many quarters. Most directly, the NSW DMR has successfully encouraged a new round of exploration in the survey area. As with aeromagnetic data, the AGG data provide insights that can be used to improve geological mapping. The survey partners, led by pmd\*CRG, are using the data to evaluate and refine 3D geological maps of the Broken Hill district, and to investigate new methods to seed or build such maps. Geoscience Australia has additionally used the survey data as part of an evaluation of airborne and ground gravity options for upgrading the national gravity coverage.

## Slide 4. Principal survey products



The principal survey products are grids of vertical gravity,  $gD$ , and vertical gravity gradient,  $Gdd$ . The latter is simply the first vertical derivative of vertical gravity.

## Slide 5. Technical checklist

### Technical checklist

- Gne & Guv gradients are measured, Gdd and gD are derived by spatial transformation
- Primary output is grid-based
- Different ways of deriving Gdd and gD
- Low pass filtering removes short wavelengths (eg <400m)
- Long wavelengths not recovered (eg >10km)
- Data were acquired at a certain terrain clearance – the output may relate to a different drape surface
- Noise cannot be ignored

I will quickly mention some of the technical aspects of the Broken Hill AGG data which should be kept in mind when interpreting the data.

The Falcon system measures two horizontal gradients, Gne and Guv. Vertical gravity and vertical gravity gradients are derived via spatial transformation, so that the primary outputs are in grid rather than point located format.

There are several methods for deriving Gdd and gD, and different settings that can be used with each of these methods. Hence, there are multiple versions of vertical gravity gradient and vertical gravity available for interpretation.

Low pass filtering is required to remove short wavelength noise. This broadens the anomalies associated with shallow sources and makes them appear to be buried more deeply. This filter needs to be factored into any quantitative interpretation.

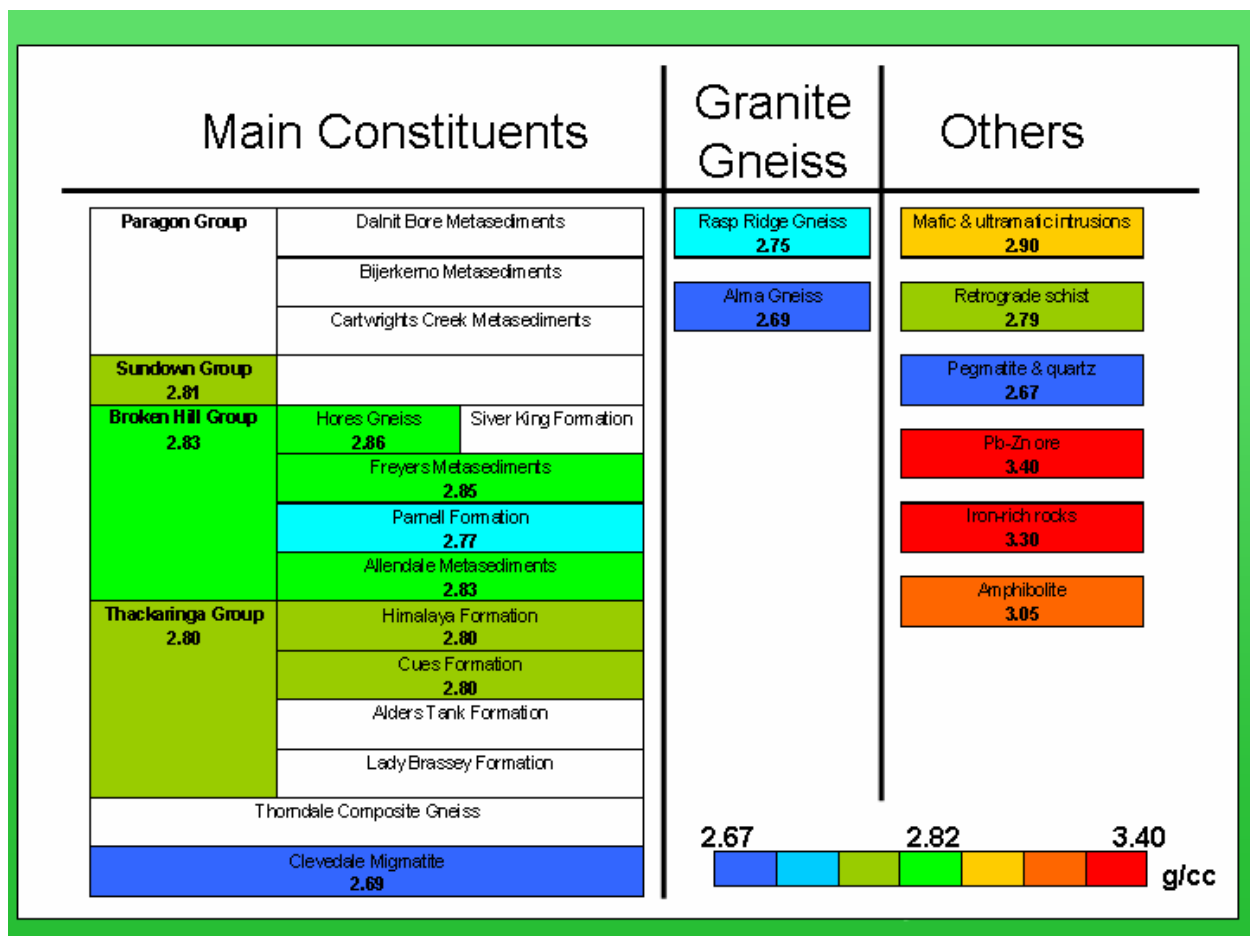
Unlike ground gravity, long wavelengths cannot be recovered from the AGG data, so that only features in the top few kilometres are imaged.

Terrain clearance has a big effect on signal strength, but fortunately, the modest topographic relief in the survey area allowed a terrain clearance of around 80 m to be maintained, except over Broken Hill itself.

Measuring gravity at mineral exploration scales from an aircraft is an impressive technical achievement. However, the residual noise levels in the data are not insignificant and care is required when interpreting low amplitude features.



## Slide 6. Density



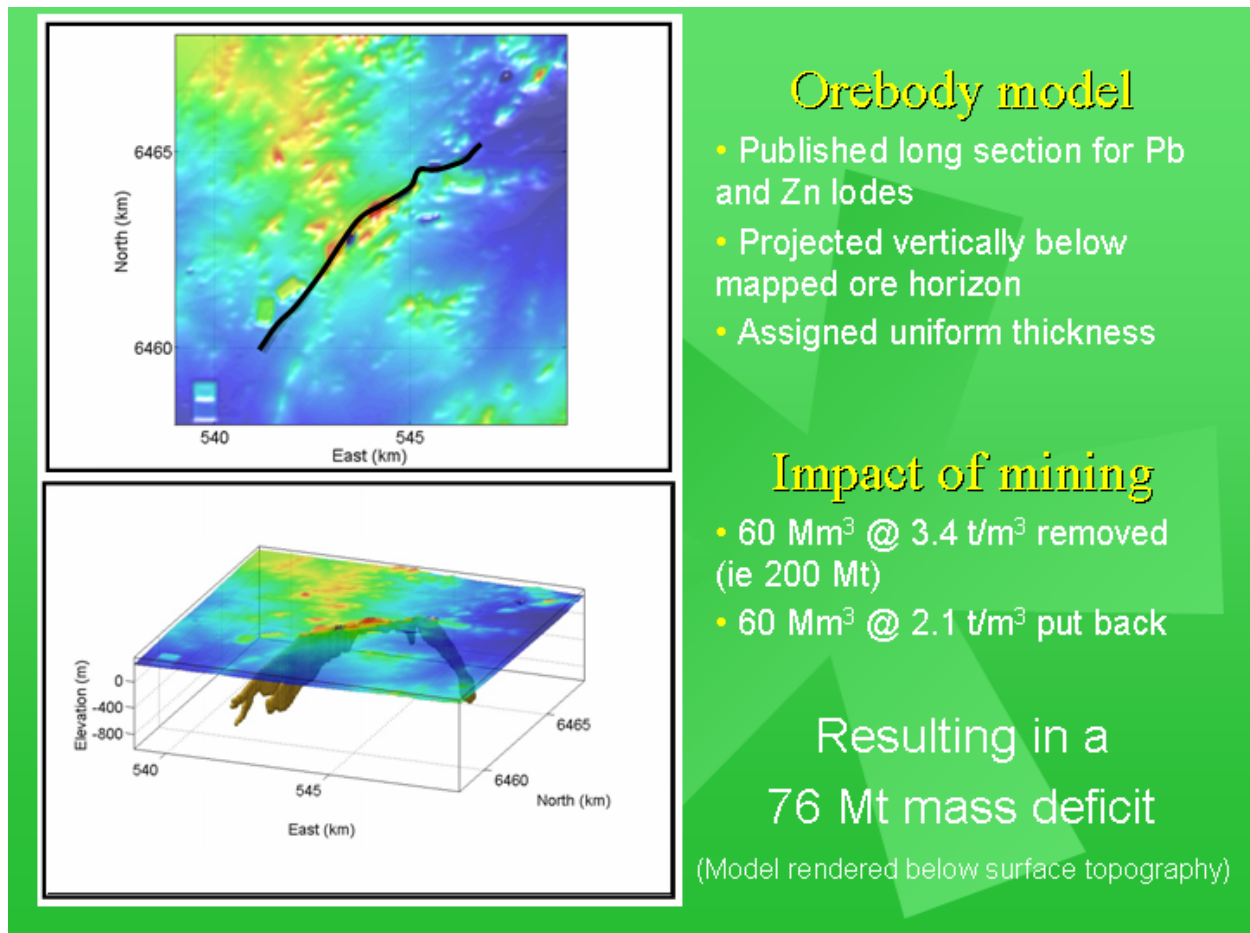
Average density values for various units have been calculated from 750 or so measurements available in the BHEI physical property database.

The majority of the metasediments have density values between 2.8 and 2.85 g/cm<sup>3</sup>. These values are relatively high, reflecting the sediment composition and metamorphic grade.

The average density value of 3.4 g/cm<sup>3</sup> for lead-zinc ore was derived from a very large number of measurements given in student theses, company studies and mining journals. This value is low for base metal ore, reflecting the low concentrations of pyrite and pyrrhotite.

Due to similarities in density and geometry, bodies of amphibolite, banded iron formation, quartz-magnetite rock, and younger mafic and ultramafic intrusions would be expected to have similar gravity anomalies to that of a base metal deposit. Discriminating discrete gravity anomalies due to amphibolite and other sources from those due to base metal mineralisation is likely to be the main challenge for explorers in the immediate follow-up to the survey.

## Slide 7. Broken Hill ore body model



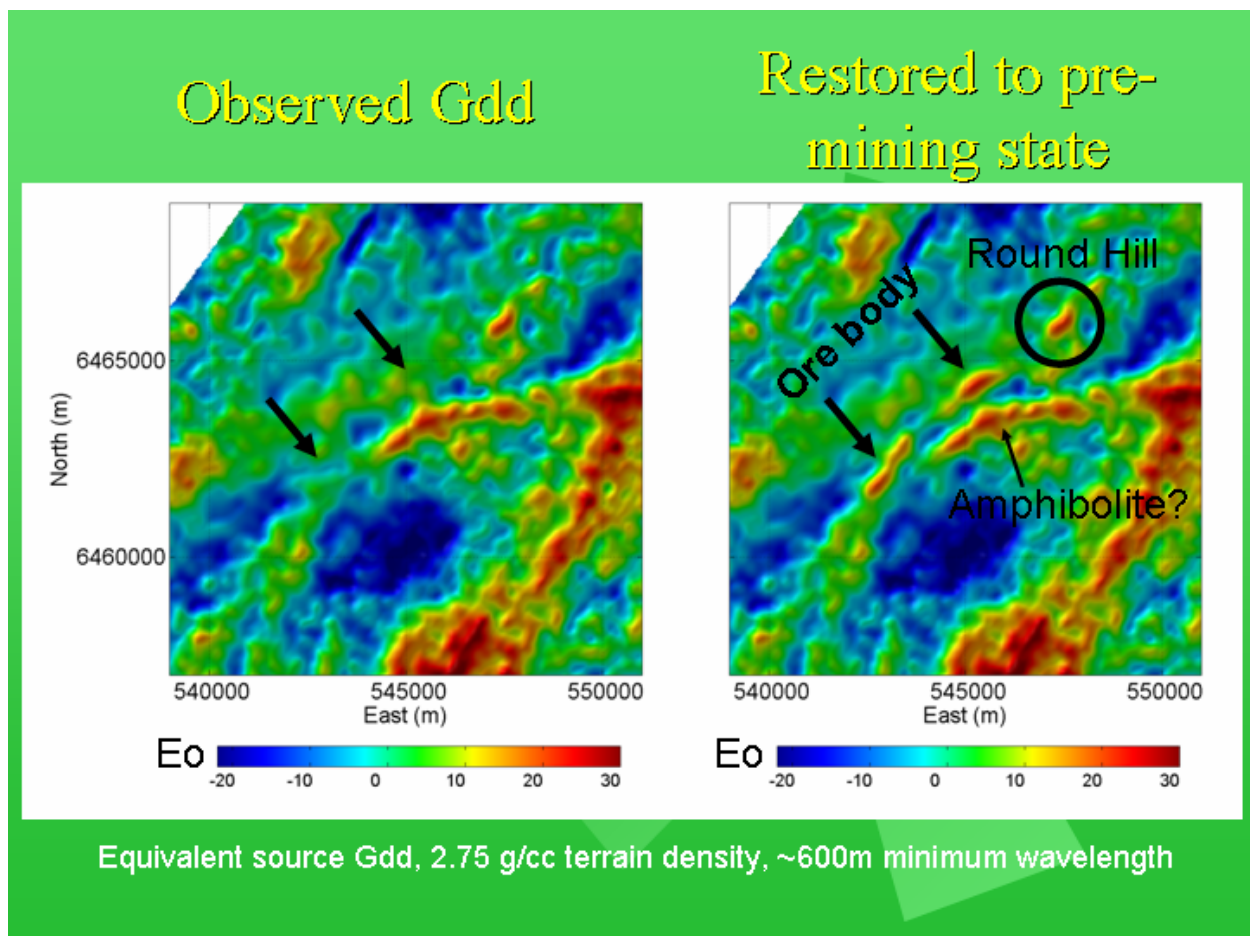
The observed gravity response in the vicinity of the Broken Hill ore body has been substantially modified by changes in mass distribution brought about by mining activities. As a result, there are two nagging questions that surround this gravity survey;

What was the original response of the ore body?  
And, would this response have been detected using this system?

To answer these questions, an estimate of the change in response brought about by mining was made and added to the survey data to produce an image of the pre-mining gravity response.

To do this, a very simple 3D ore body shell was built. The change in mass distribution was estimated assuming that 200 million tonnes of dense ore has been replaced by less dense backfill, and that the changes have occurred evenly across the ore body.

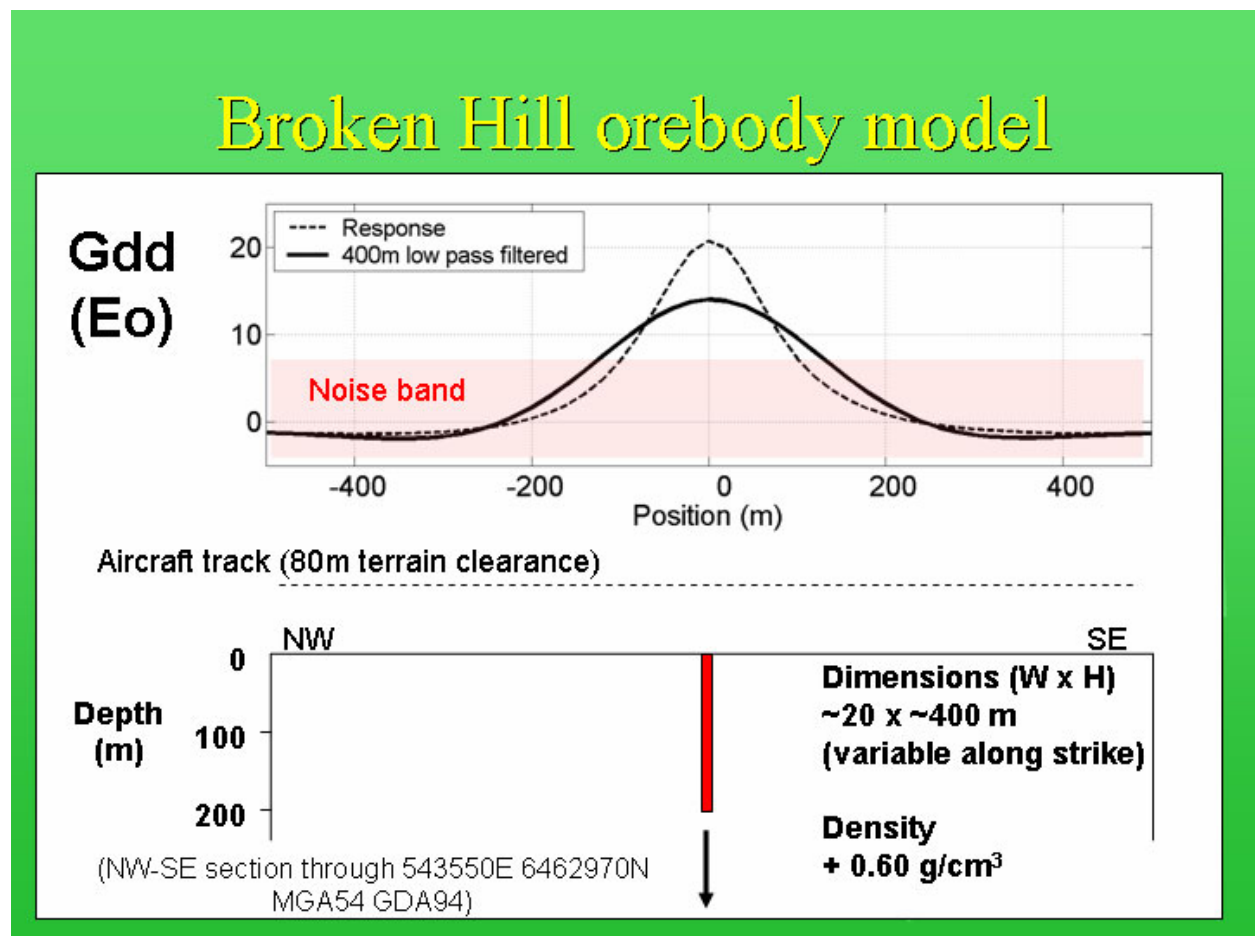
## Slide 8. Pre-mining AGG Gdd response



Vertical gravity gradient data from a portion of the survey is shown on the left. The corrections for mining activities have been calculated and added to the image on the right. There are distinct highs indicated by the arrows over the northern and southern parts of the ore body which hosted the bulk of the reserves.

We can conclude that the AGG survey would have detected an anomalous response from the Broken Hill ore body had the survey been flown prior to mining. However, there are other geological features in the survey area that produce similar anomalies, for example the amphibolite body at Round Hill, and other amphibolite bodies parallel to the Broken Hill ore body.

Slide 9. Profile across the ore body model



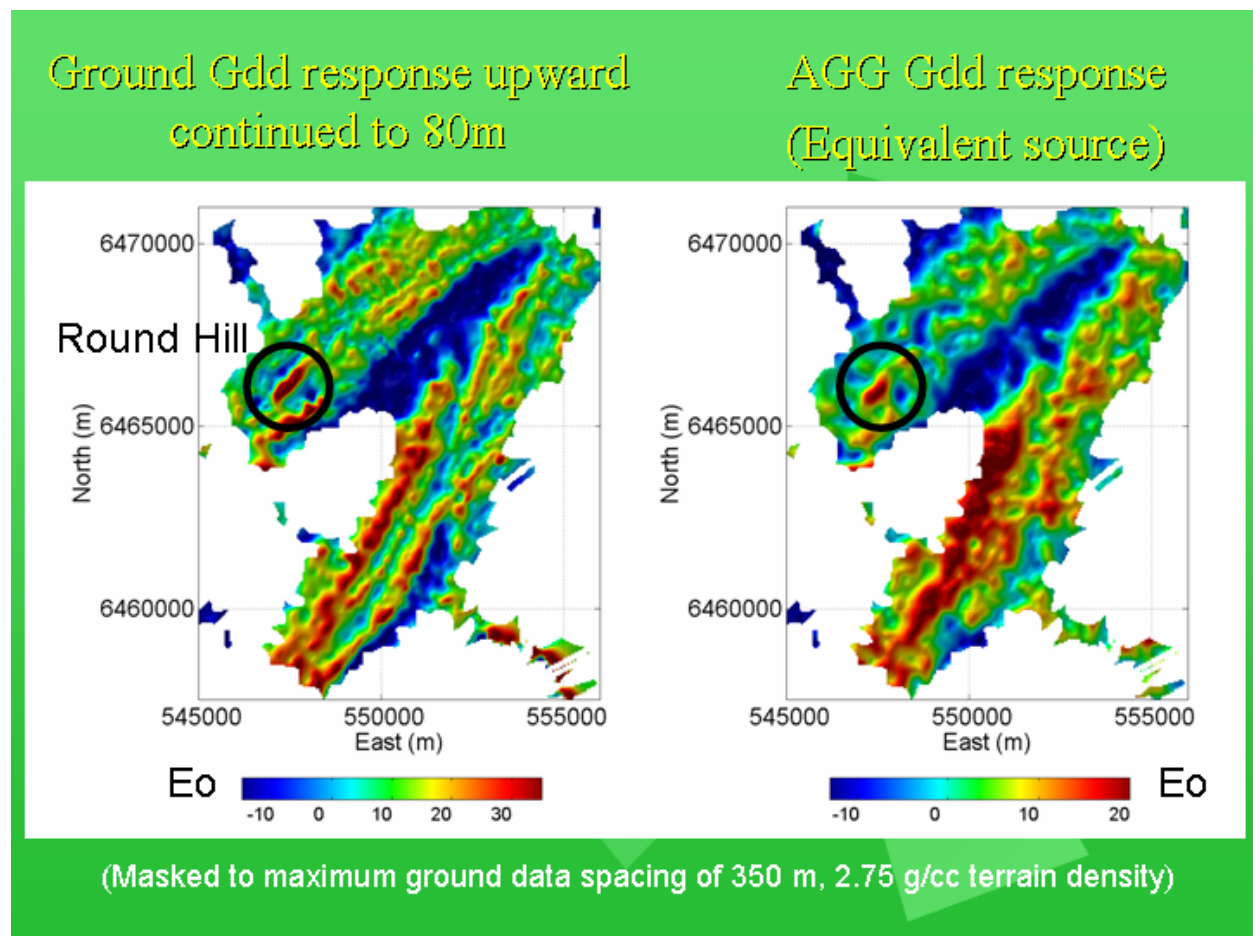
As well as calculating the changes brought about by mining activities, the vertical gravity gradient response of the original ore body was calculated. A profile from north of the Zinc Corp. shaft is shown.

To match the data processing applied to the survey data, a low pass filter has been used on the model response, shown as a dashed line, to produce the response that would have been recorded on this survey, shown as a solid line. This filter reduces the amplitude and broadens the anomaly.

A band corresponding to 1 standard deviation of noise is shown by the red shading. This noise level was estimated from data acquired along a flight line flown multiple times and from comparisons of ground and airborne data.

The ore body response is above the noise level on this particular profile. However, the response from substantially smaller deposits would likely fall below the noise level and be difficult to detect.

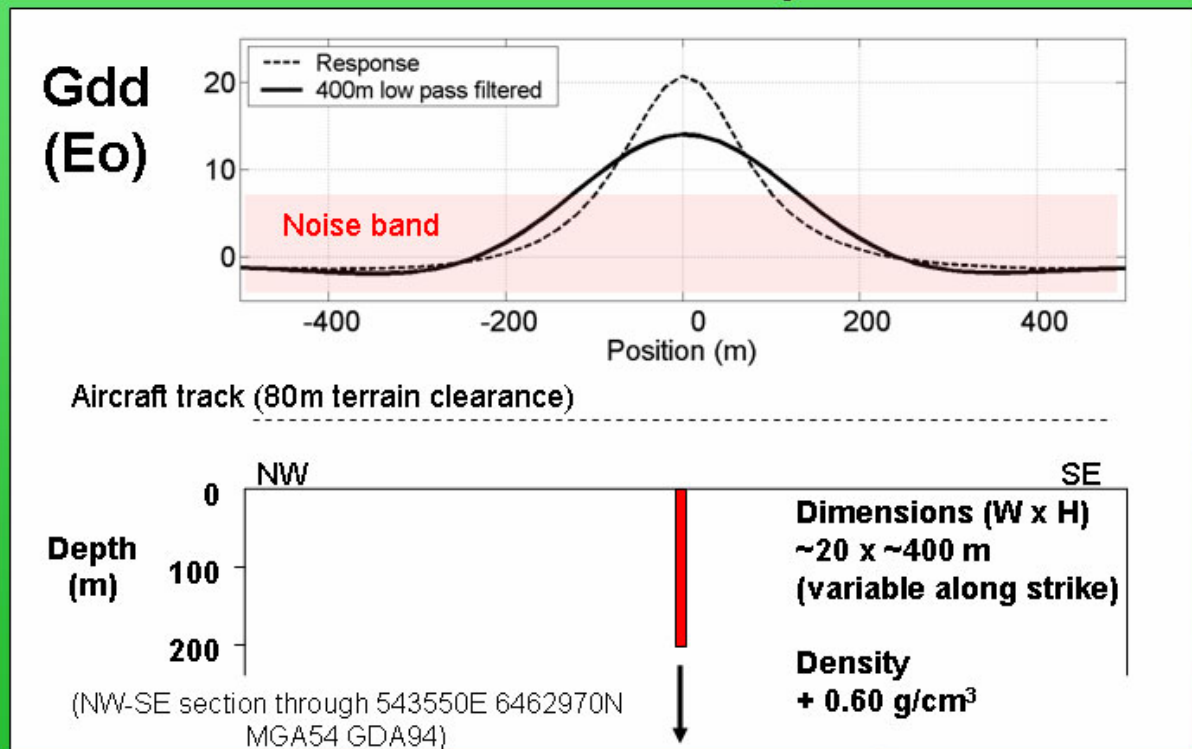
## Slide 10. Comparison of short wavelengths in ground and AGG data



The presence of background noise of 5 to 10 eotvos in the AGG data can be demonstrated using detailed ground data, shown on the left. The image on the right shows airborne data masked to the same outline to facilitate direct comparison. The general features are the same in the two datasets. High amplitude features such as the gravity high at Round Hill are evident in both images. However, many of the fine details such as the curvilinear trends evident in the closely spaced ground data are obscured in the airborne data by background noise.

Slide 11. Profile across the ore body model

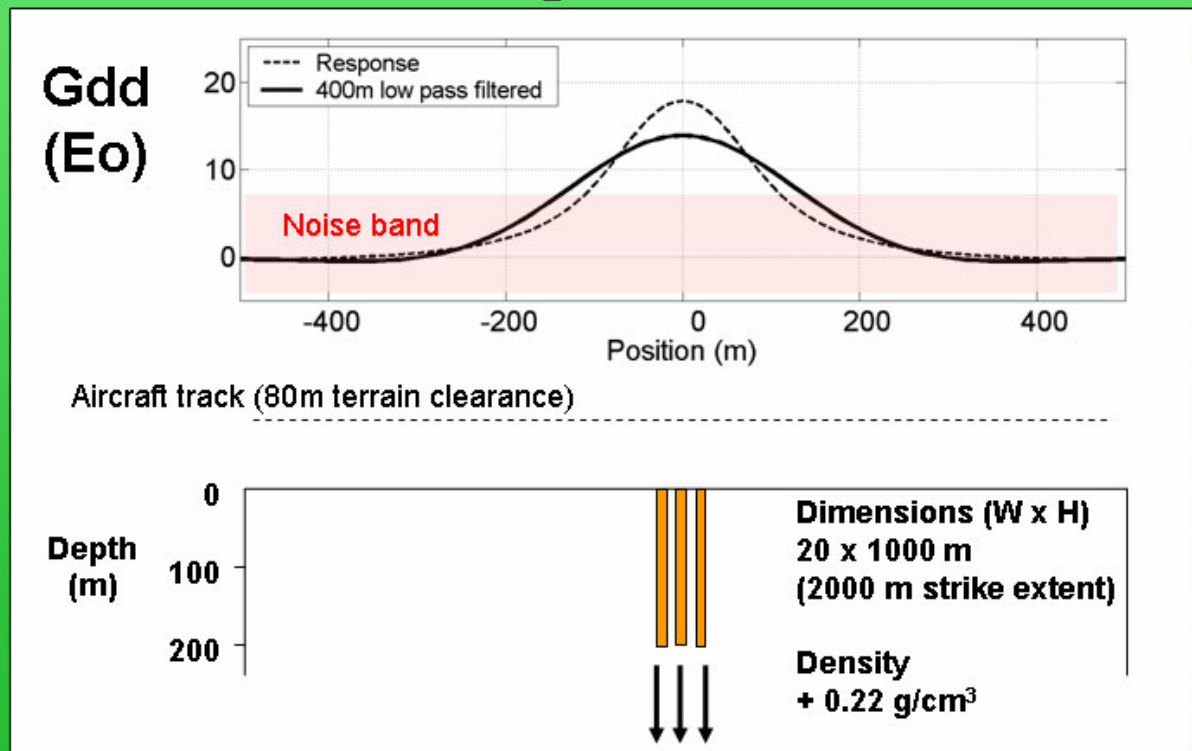
## Broken Hill orebody model



We have seen that the original Broken Hill ore deposit would have produced an anomaly above the noise level. But what other geological features would give rise to similar vertical gravity gradient anomalies?

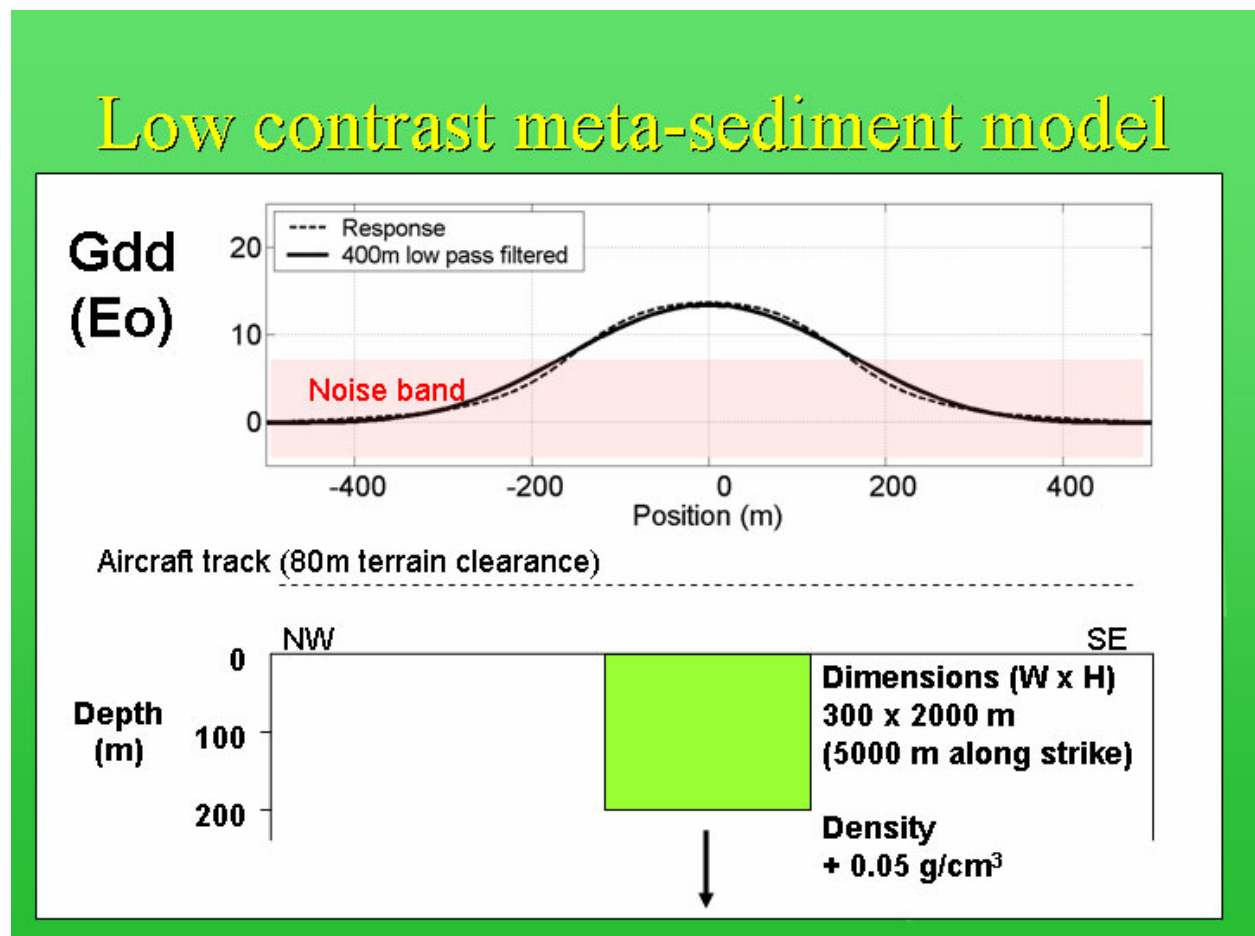
Slide 12. Stacked amphibolite model

## Stacked amphibolite model



There are numerous relatively dense amphibolite horizons in the survey area. A stacked sequence with a combined width of around 60 m would produce a similar anomaly to the ore body.

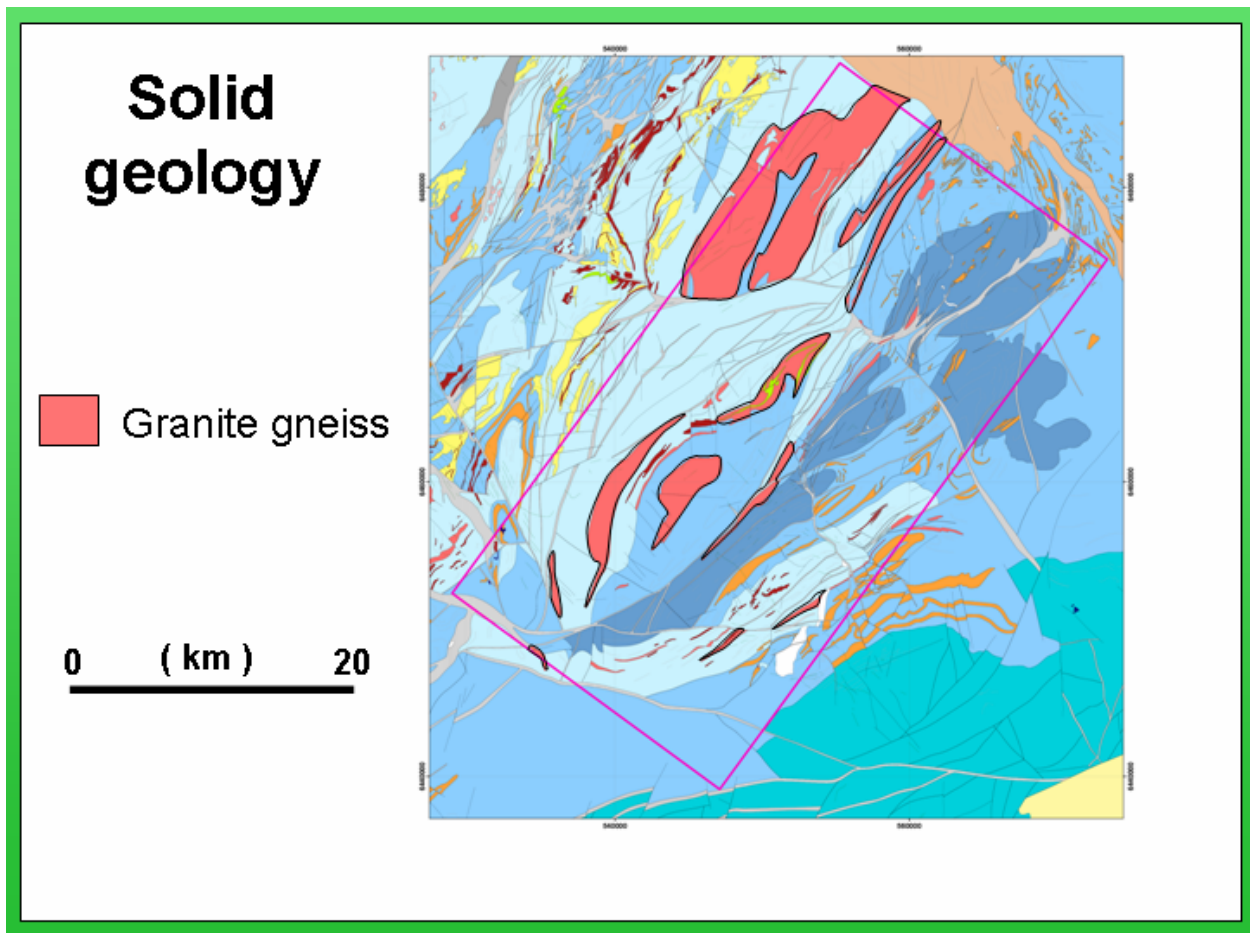
Slide 13. Low contrast meta-sediment model



A 300 m wide meta-sediment unit with density elevated by just  $0.05 \text{ g/cm}^3$  would also give rise to a similar anomaly. Without careful sampling and measurement of density, it would be difficult with this scenario to reconcile drilling results with the source of the anomaly, and an explorer might be left wondering where the dense target disappeared to.



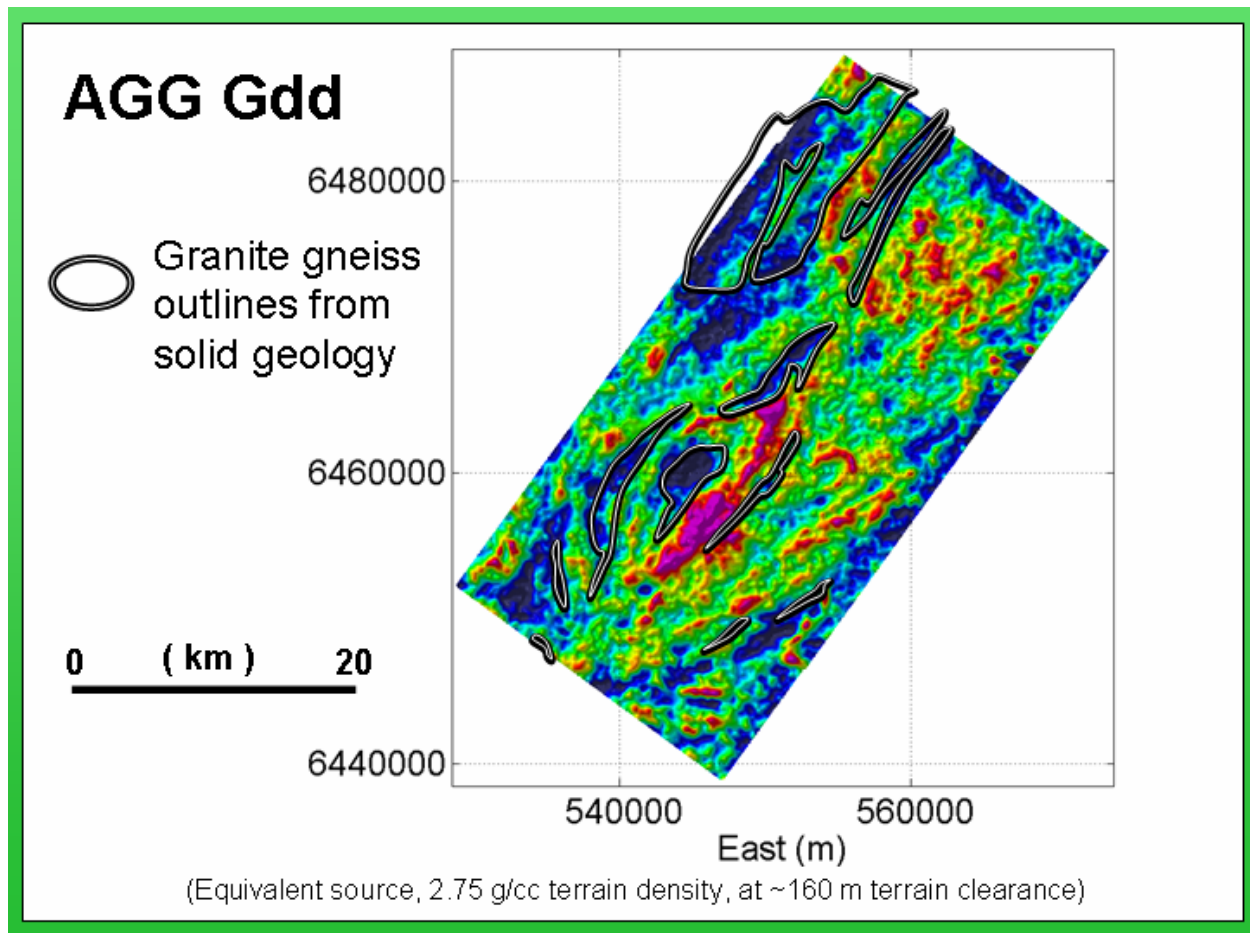
**Slide 14. Outline of granite gneiss bodies on solid geology**



Besides direct targeting, the AGG data are being used to improve the geological mapping and understanding of the Broken Hill region.

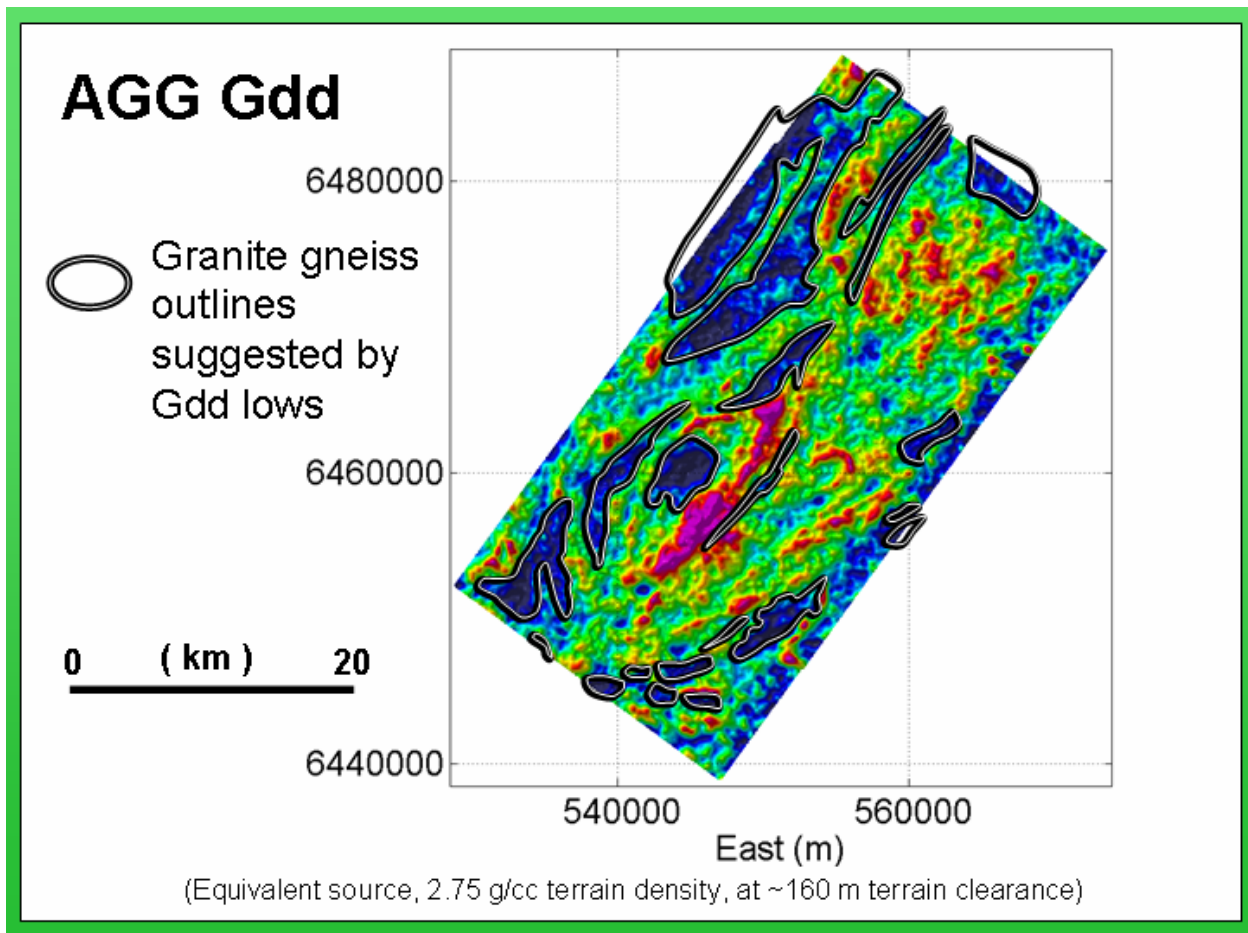
A solid geology interpretation is shown, with the outlines of the larger granite gneiss bodies highlighted.

**Slide 15. Overlay of solid geology granite gneiss bodies on Gdd**



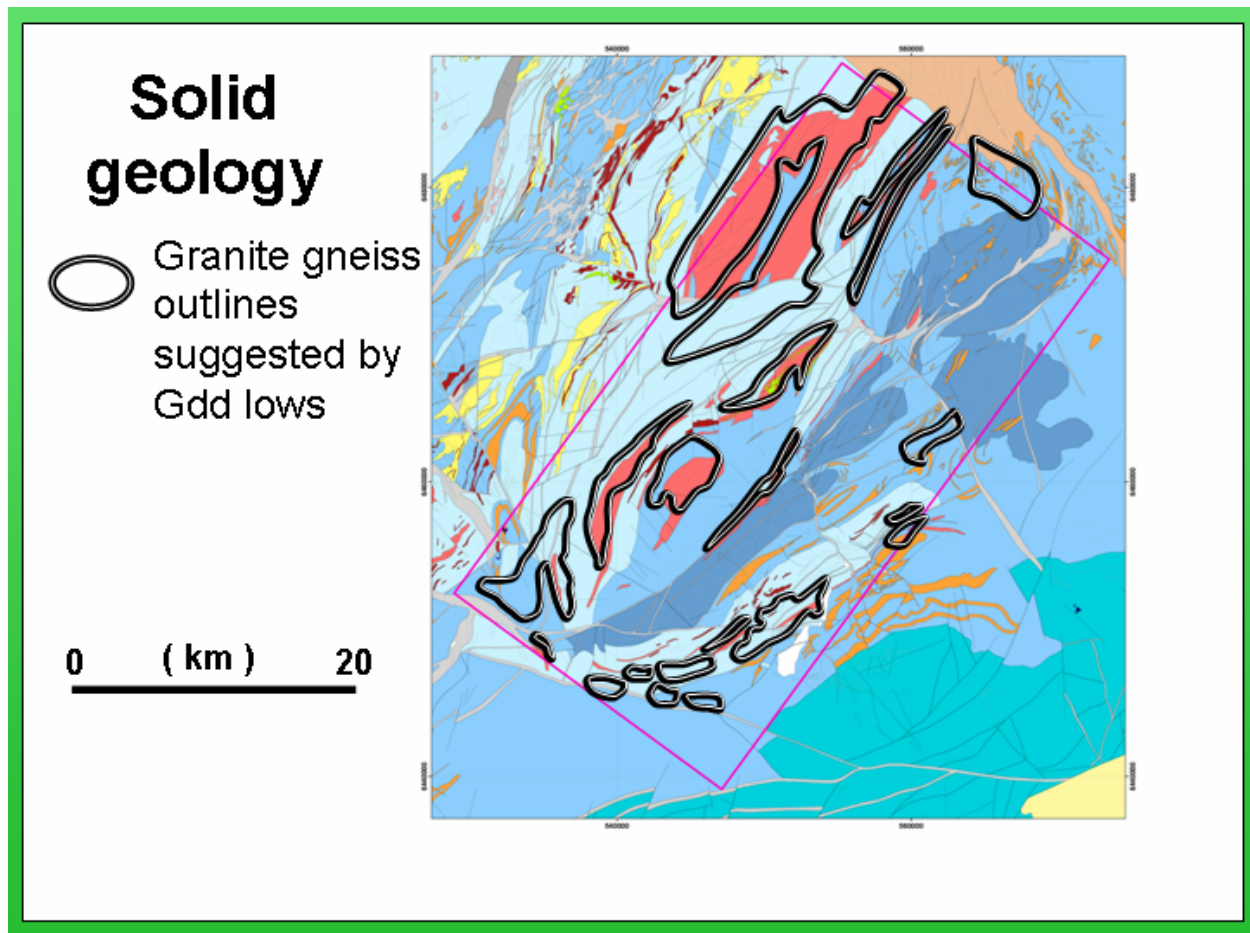
These boundaries have been transferred as an overlay onto a vertical gravity gradient image. As expected from the analysis of density measurements, there is a reasonable correspondence of vertical gravity gradient lows with granite gneiss bodies. However there are also significant discrepancies.

**Slide 16. Modified granite gneiss body outlines on Gdd**



The outlines of granite gneiss on this slide have been modified in accordance with the extent of gravity gradient lows.

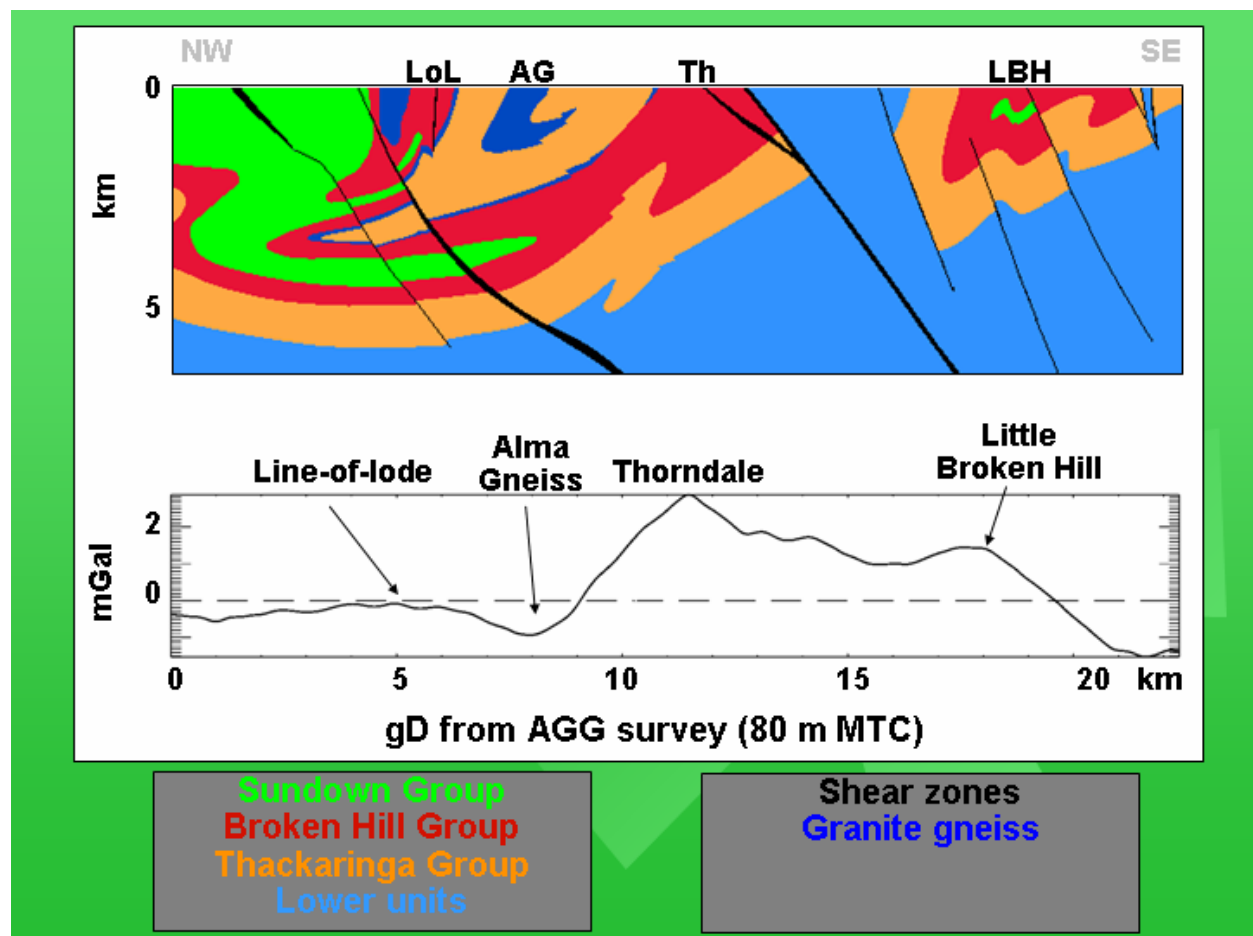
## Slide 17. Modified granite gneiss body outlines on solid geology



These modified boundaries have been transferred back onto the solid geology map. We can see a number of features that have been added or extended; to the north-east of Broken Hill, to the south-west near the Pinnacles, and in the Little Broken Hill region.

Of course, these proposed changes require further investigation before being accepted. Barney Stevens has made some preliminary visits here to the north-east, and confirmed the presence of meta-sediments at surface rather than granite gneiss. It is still possible that the vertical gravity gradient low in this area reflects the presence of granite gneiss at shallow depth.

**Slide 18. Section through Pasmaenco 3D geological map**

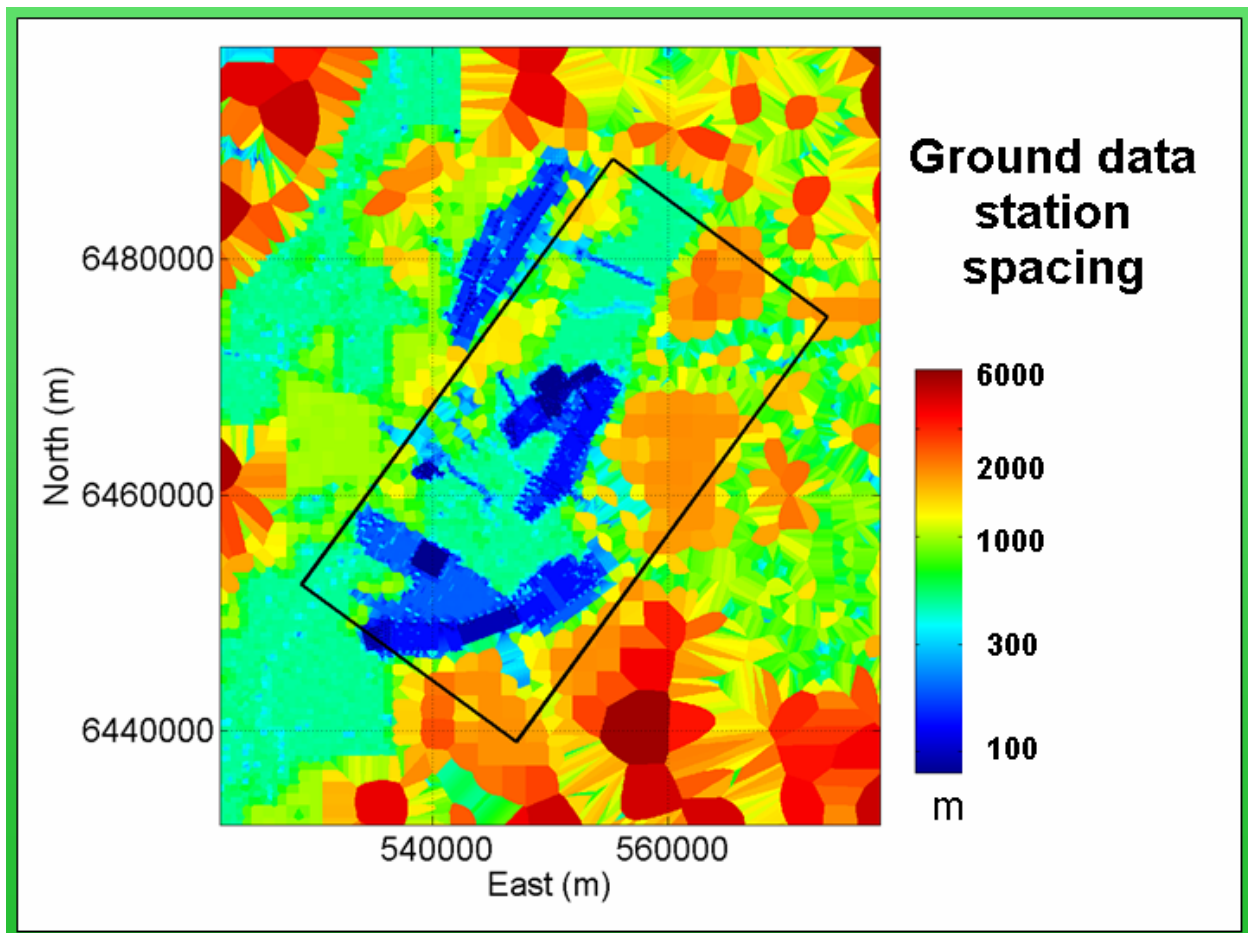


The pmd\*CRC is evaluating the 3D geological map of the Broken Hill region built by Fractal Graphics for Pasmaenco (Mason et al., 2003). A section through the Broken Hill deposit is shown. In this part of the map, the sequence is represented by 4 stratigraphic units, together with granite gneiss bodies and shear zones.

A gravity profile extracted from the AGG data is shown below the geological section.

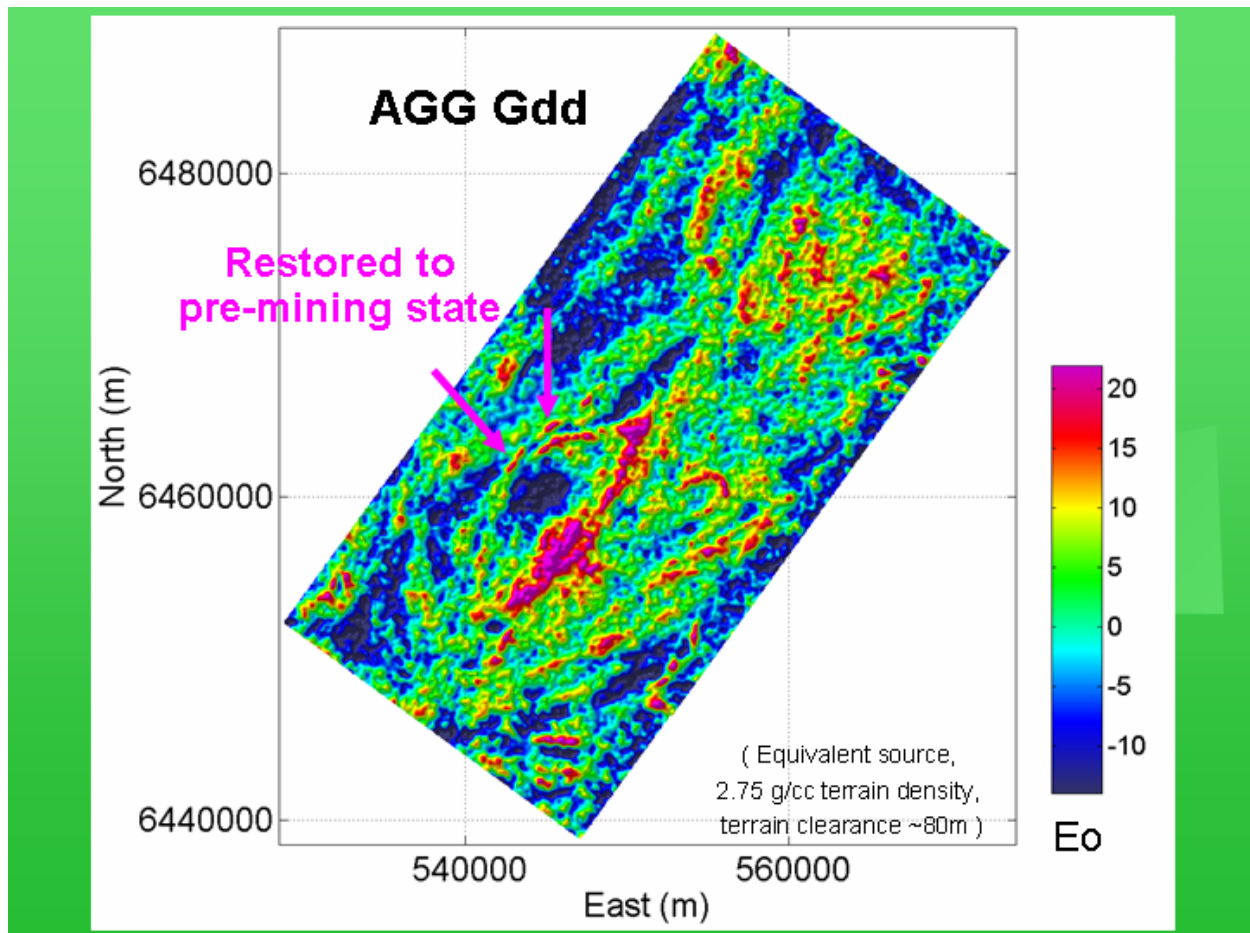
Gravity highs are present at Thorndale and Little Broken Hill where Broken Hill Group rocks, shown in red, are present at the surface. The Alma Gneiss is associated with a gravity low. The absence of a strong positive gravity feature at this scale of observation where there are Broken Hill Group rocks along the line-of-lode is interesting and may be due to compensation for the high density Broken Hill Group rocks by nearby low density granite gneiss units.

## Slide 19. Ground gravity station spacing



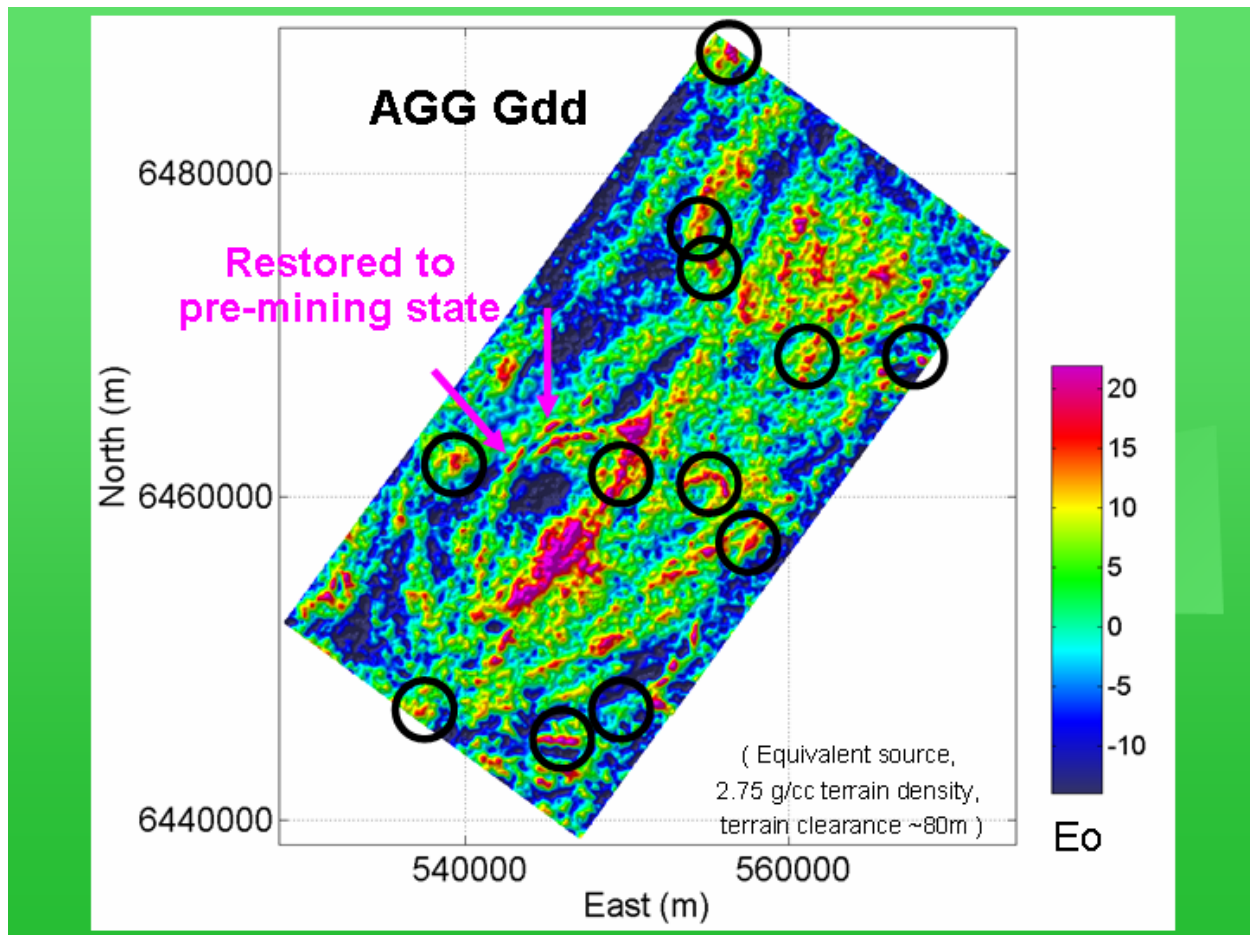
The ground gravity data within the survey area have variable station spacing, from less than 100 m to around 2 km. Except in the areas shown in blue, this coverage lacks the detail to detect features of direct interest for base metal exploration. The AGG survey has revolutionised the level of detail, reducing the effective sample spacing down to a uniform 2 or 3 hundred metres.

## Slide 20. Pre-mining Gdd response



Restoration of the gravity response for the impact of mining indicated that had the survey been flown prior to mining, the Broken Hill ore body would have been detected as a target for follow-up.

## Slide 21. Targets being followed-up by Gravity Capital Limited



The accuracy and sample spacing of the airborne data is sufficient to identify a number of features with geometry and amplitude characteristics that are similar to a prediction of the pre-mining response of the Broken Hill ore body.

The highlighted features are presently being investigated by explorers<sup>1</sup>.

Forward modelling, coupled with an analysis of density measurements has indicated that tabular bodies of amphibolite, iron-rich rocks, younger mafic and ultramafic intrusions and even some metasediment units could give rise to gravity anomalies of similar character to an ore body.

Despite this ambiguity, the Broken Hill ore body would once have been one of the selected gravity targets, so it would be foolhardy to dismiss the possibility that there is a second ore body in the remaining targets.

<sup>1</sup> See Gravity Capital Limited web site (<http://www.gcap.com.au/>)



Slide 22. Acknowledgments

# Acknowledgments

BHPBilliton



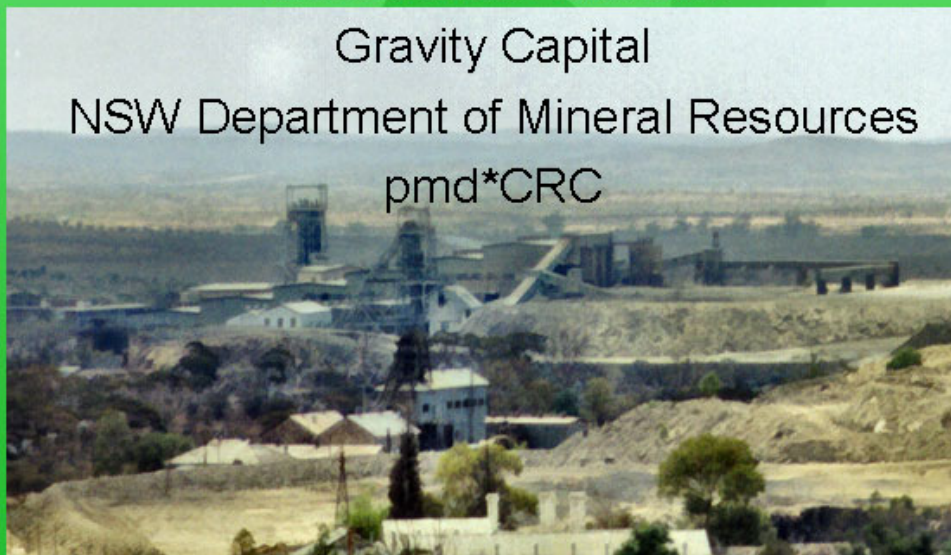
Fugro Airborne Surveys

Geoscience Australia

Gravity Capital

NSW Department of Mineral Resources

pmd\*[CRC](http://www.crc.gov.au)



## References

Lane, R., Milligan, P., and Robson, D., 2003, An airborne gravity gradiometer survey of Broken Hill: *In* Peljo M., (compiler), 2003, Broken Hill Exploration Initiative: Abstracts from the July 2003 conference: Geoscience Australia Record 2003/13, 89-92.

Mason, R.A., Archibald, N.J., Green, T.J., Broome, J.N.M., and Haydon, R.C., 2003, Resolution of the structural geometry of the Line of Lode and the Broken Hill Block: A 3D model: *In* Peljo M., (compiler), 2003, Broken Hill Exploration Initiative: Abstracts from the July 2003 conference: Geoscience Australia Record 2003/13, 112-115.