Development and Implementation of the Sparse Refraction method to exploration for Detrital Fe Deposits

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SUMMARY

The need for a more effective tool to explore for channel hosted detrital iron ore deposits under post mineral cover has led to the development of a novel minimalistic seismic refraction survey method we call 'Sparse Refraction', to map the depth of cover over basement. The survey configuration employs a single source and a single receiver, at a fixed offset. The source-receiver pair are moved progressively along a traverse, and at each station a first break reading is recorded. Gravity data is also acquired. Combining the two datasets allows the target response to be isolated from the gravitational effects of palaeotopography – we call this residual gravity field the 'Excess Mass'. The method allows large areas to be screened quickly and effectively, with low environmental impact.

This paper describes the journey from understanding the exploration problem, finding a solution, and the successful implementation of the new approach.

Key words: Refraction, Gravity, Palaeochannel, Detrital Iron

INTRODUCTION

Mineral deposits under cover are generally difficult to target effectively, and this has been the case with the Koodaideri detrital iron deposits in the Fortescue valley of the Pilbara, Western Australia. The initial exploration concept was tested by widely spaced drill traverses across the featureless expanse of the valley. Many geophysical techniques were subsequently applied with varying degrees of success – none were direct ore finders. The advent of new seismic sources and their introduction to the mineral exploration industry was the spark that led to the development of a novel approach utilising the seismic method at its most minimalistic, comprising a single source and single receiver at a fixed offset. We named the method "Sparse Refraction". The advantage of such a minimal set up is speed. It allows large distances to be covered quickly, almost as quickly as conventional gravity surveys, and with minimal environmental impact. Coupled with complimentary gravity measurements, the approach enables large areas of ground to be quickly and effectively screened for concentrations of Fe ore within the cover sequence, by first defining the basement topography under cover, and then removing its effect from the gravity field, resulting in a residual gravity response that is dominated by density variations in the cover sequence. We called this residual the "Excess Mass" response, and it is this product, in this particular environment, that is a true ore-finding tool.

The successful development and implementation of this technique is the result of the right elements coming together at the right time. There was a vision of what we were trying to achieve, an immediate need for the tool, key technical hurdles were identified and understood, we had access to seismic professionals with a mandate to work with the minerals industry, enthusiastic professional partners to build and operate the acquisition system, in house expertise to develop the appropriate survey approach and data processing stream, and a solid financial framework.

The technique has potential for application anywhere that gravity has inherent value as a tool, but is compromised by the effects of variably thick overburden or regolith on a dense basement.

METHOD AND RESULTS

Understanding the problem

The Koodaideri detrital Fe deposits lie concealed along the southern margin of the Fortescue Valley flanking Rio Tinto's Koodaideri bedded Fe deposits of the Hamersley Ranges (Figure 1). These were discovered in 1987 by reconnaissance drilling along widely spaced traverses. Subsequent drilling has delineated resources over a very large area (>1000km2). The deposits were formed through the erosion of hematite rich bedded Fe deposits, and the subsequent deposition of this material into topographic depressions in the basement by fluvial processes. The deposits are all concealed by BIF rich gravels deposited through the continuing processes of

erosion of the Hamersley Ranges. The area is almost devoid of outcrop. It is a generally flat, featureless plain with Mulga shrubs and spinifex grass.
The lack of outcrop has meant geophysics played a significant role in exploration from the outset. Magnetic, EM, and Gravity techniques have been applied and assisted in drill targeting with some success – but also failures.

Each method provides some value but each is also flawed. Magnetics maps magnetic material, which in this case is the post-mineral BIF gravel cover. Magnetic highs can correspond to the underlying basement depressions – but this is not universally true. It is at best a qualitative basement depression hunter. EM maps conductivity, which can allow the top of basement to be mapped in places (as a resistor where basement is dolomite or as a conductor where basement is shale). However, these basement maps are patchy and somewhat interpretative/subjective. Groundwater salinity is an important factor allowing the identification of palaeochannels in some areas but not their depth extents.

Gravity is an obvious tool in the exploration for a dense target. Positive gravity anomalies might be expected to correspond to Fe concentrations in the cover sequence. However, the target in this case is preferentially hosted in depressions in the basement which generally renders it transparent to the technique. Moreover, because the density contrast between the cover and basement topography is large, basement topography tends to dominate the signal and thus gravity highs often correspond to basement highs.

Over time our understanding of the controls on mineralisation improved but our ability to successfully target drilling remained a frustration. A means of defining the basement topography was identified as the key to further discovery. This would not only define areas where mineralisation may have accumulated, but more importantly, in conjunction with gravity data we would be able to isolate specific gravity anomalies due to mineralisation. The best technique to do this is of course seismic, but this is far too expensive to be viable if run in a conventional way.
We needed a cheap and fast method of mapping basement topography, and so we started to look for adaptations to the seismic method, and in particular at seismic refraction. Small systems for mapping gravels have been utilised ever since the technique was developed. What was required was something bigger – and a little different.

Pulling together the threads of a solution

In 2006 the Centre for High Definition Geophysics (CHDG) was initiated at Curtin University, with the goal of applying seismic to solve problems in mineral exploration. Rio Tinto Exploration and Curtin University engaged in a number of collaborative ventures from this time.
CHDG put a number of seismic sources through trials. These included an accelerated weight drop for a 2D seismic reflection survey and 3D experiment over the Koodaideri Central Detritals prospect in 2006, and a second visit in 2007 with a much bigger seismic source to conduct a fully-fledged 3D seismic survey. The location of these surveys is shown in Figure 2. The 2006 2D reflection survey mapped the basement depression or 'channel' quite well, (Figure 3) but in terms of refracted arrivals the 80kg accelerated weight drop proved too weak a source in the unconsolidated gravels. First break refracted waves were not recoverable beyond 100m from the source.
The source used in the August 2007 survey was a bobcat mounted 500kg weight drop, which provided far better results. In places good signal was recovered at offsets of >1km. Automatic picking algorithms on the first break refracted arrivals across all source-receiver pairs from this survey provided a database comprising 175000 data points. Their analysis (Figure 4) provided extremely robust average velocity values for the basement and cover in the survey area, confirming a very strong velocity contrast between cover (1430m/s) and basement (7000m/s).

The success of the 500kg weight drop source and the knowledge of actual p-wave velocities provided the catalyst to develop a new approach to exploring with seismic. The concept of 'sparse refraction' took shape. Simply measuring first break times for a single source-receiver pair (with a fixed offset) progressively along a traverse would provide a facsimile of the subsurface basement topography – the longer the time, the thicker the cover. By plugging in actual velocity values, the depth of the interface is resolved. In the world of seismics, where massive data redundancy is the norm, this minimalistic approach may be viewed as heresy – but it looked like it would meet the requirements for this particular circumstance

We know from drilling that the top of basement surface extends from a few tens of metres to a maximum of 180m below surface in the area. Analysis of the data across a range of source-receiver distances confirmed simple calculation based on the known velocities, namely that a minimum source – receiver offset of 400m was required. This fell within the proven performance of the new seismic source.

Removal of the modelled gravitational effect of the basement topography from standard Bouguer gravity data results in a residual positive gravity response in the Central Detrital prospect corresponding to the known mineralisation. We named this residual product 'excess mass' (Figure 5). It is essentially the gravity field resulting from density heterogeneity in the basement and in the cover. The basement comprises near-horizontally bedded dolomite and shale and is therefore quite homogeneous. The dominant 'excess mass' contribution therefore comes from the cover sequence itself. And density highs in the cover are caused by concentrations of high grade Fe ore. We had the makings of a ore-finding tool!

Building the System:

RTX and Atlas Geophysics resolved to design, build, and implement a data acquisition system to acquire sparse refraction seismic data in conjunction with gravity data. The basic requirements of the system were to cover large areas quickly, cheaply, effectively, and with minimal environmental impact. A commercial framework was agreed which enabled Atlas to make the necessary investment in time, equipment, and software. The incentive was a guarantee of a significant body of work for a system that met the required specifications.

Building on the expertise at Curtin University, Atlas engineered a seismic source comprising a 600kg weight drop and bash plate, fitted to a small track-mounted bobcat. A later modification to the system included elastic straps to accelerate the weight-drop for increased energy. The bobcat was fitted with a real time kinematic GNSS navigation system, and radio trigger link which sent the shot time (t_0) and source coordinate to the receiver(s).

The receivers comprise a single geophone connected to a six channel seismic acquisition box running custom firmware, with receiver locations positioned by real time kinematic (RTK) GNSS. A radio link was used to receive the trigger signal (t_0). For each shot point, the source coordinate, receiver coordinate, trace data and first break pick were recorded to a field laptop. All instrumentation was carried in a light weight, low impact Kubota Utility Terrain Vehicle (UTV). The vehicle also carried a Scintrex CG5 gravity meter, and a gravity reading was taken at each seismic receiver station. Figure 7

Atlas designed software tools to allow data picking in real time in the field and 'post mission' software to generate located raw files for delivery to RTX

RTX designed the software tools to read in the field data, QA/QC the data, compute basement interface depths generate basement models, and compute the gravity fields, and finally generate the excess mass product.
A field acquisition work flow was designed to determine local velocities of cover and basement at appropriate intervals, and the optimal setup to maximise production. A survey configuration of 3 receivers was utilised:- one leading (or trailing) the source, and one orthogonal either side of the source (Figure 8). This only requires 4 operators in the field, with all equipment easily transported to site via a single off road truck and Landcruiser LV.

The system was built and tested over a period of 4 months, and was implemented in the field in August of 2008.

Implementation:

The acquisition system proved robust, and met the expected deliverables in terms of data quality and production rates, which improved further with modifications to equipment and survey procedures.

Data coverage depends on the ease of access and the speed of acquiring the data. In the format adopted at Koodaideri the station interval was 50m and source – receiver offset was 400m. At each location at least 2 readings were taken. On average 200 stations per day (70 per receiver) were read, which corresponded to 2km2 per day at a plot point density of 50m x 200m.

The data processing was all run in house using a combination of off the shelf software including Oasis Montaj and Modelvision.

A portion of the survey results are presented in Figure 9. The contribution of the basement topography to the Bouguer gravity signal is starkly demonstrated, and there is almost no correspondence between the 'Excess Mass' product and the Bouguer gravity data. The optimum density contrast employed in computing the effect of the basement topography resulted in the lowest correlation between the 'Excess Mass' product and the basement topography – an adaptation of the famous Nettleton Method (a density contrast of 0.8gcm-3 was used in this case). Consequently, in the absence of density heterogeneities in the cover and basement we should end up with a flat gravity field. Happily, we see anomalies, and some are strong and discrete.

Every anomaly in the 'Excess Mass' panel in Figure 9 relates to significant concentrations of Fe, and their amplitudes and lateral extents are consistent with drilling results.

The success of the method relies on selecting a source-receiver separation that is tuned to the basement topography and velocity contrasts. In the case of Koodaideri, a maximum basement depth of 180m is at the limits of being resolvable with a 400m offset. By opening the aperture of the source-receiver offset you can increase the depth of investigation, but at a loss in spatial resolution and equally importantly, at a loss in signal strength.

CONCLUSIONS

A novel minimalistic seismic method has been conceived, developed, and field tested, and shown to be an effective tool when combined with gravity data in the exploration of concealed detrital Fe ores in the Koodaideri setting. Both data sets can be collected simultaneously, with low environmental impact, and quickly – allowing large areas to be effectively screened for targets.

The surveys run at Koodaideri successfully identified all the known significant accumulations of high grade mineralisation and mapped their extents. New targets were identified which have since been tested and verified as detrital Fe deposits. The excess mass product also allows targets to be ranked based on potential size and thickness (or actual 'excess mass') and in theory could provide a constraint on ore reserve calculations (once the local rules have been established with respect to density being proportional to Fe grade).

The development of the tool is an example of successful innovation. Many factors played a role in this instance. In sharing our experience we hope others will also see success.

ACKNOWLEDGMENTS

Many individuals were instrumental in facilitating the development of this method. First and foremost, Leon and the team at Atlas Geophysics that built, tested, and successfully deployed the Sparse Refraction data acquisition system from a concept to a working solution in less than 1 year is a credit to the profession. Milovan Urosevic and Anton Kepic at Curtin University CHDG deserve special mention in making seismic more accessible to mineral exploration, and providing ongoing advice on technical matters. Rio Tinto Exploration provided enthusiastic management support including the enabling commercial framework that underwrote the project, and provided the personnel resources required to develop the processing streams. Rio Tinto Iron Ore provided ongoing support by commissioning much of the work that was undertaken using the techniques described above. Both are thanked for permission to publish this paper.

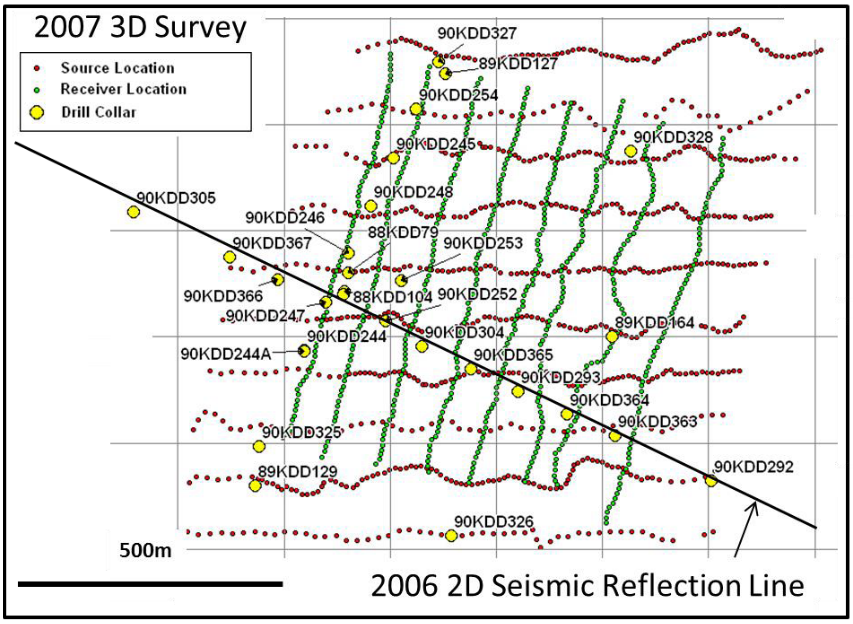


Figure 2: Seismic Trials at Koodaideri Central Detritals Prospect
2006 2D Seismic Reflection Line and 2007 3D Seismic Survey (Source and receiver location Plan)

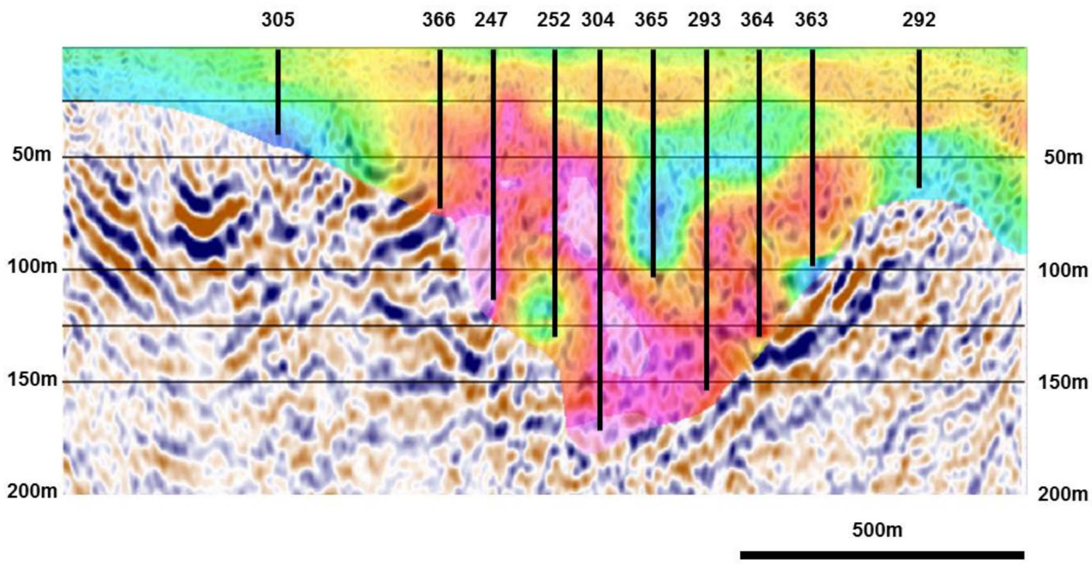


Figure 3: 2006 2D Seismic section across the Central Detritals Channel.
With superimposed colour image of Fe grades from RC drilling assays, and drillhole traces

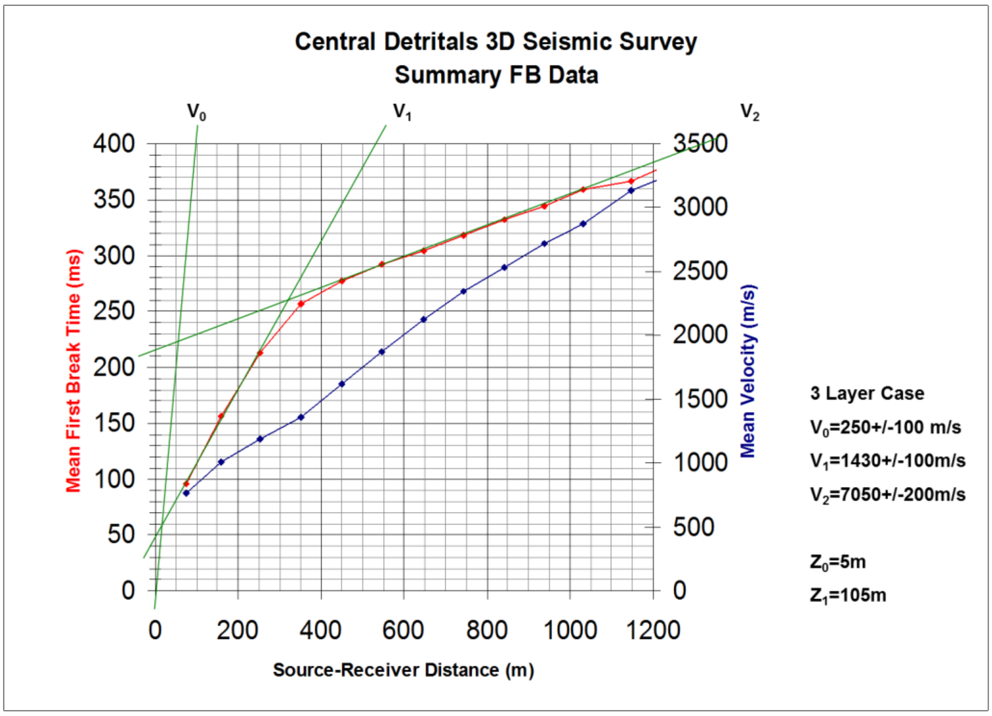
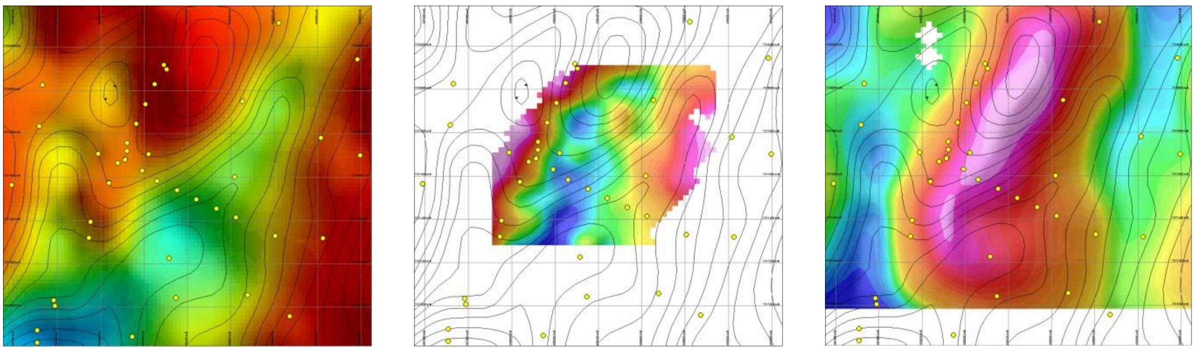


Figure 4: Time Distance Plots for the first break picks from the 2007 Koodaideri 3D Seismic Trial. 175000 data points were binned into 100m source-receiver distance increments. The surface unconsolidated layer is thin (a few m) and very poorly constrained, the velocity of the consolidated cover and especially the basement is very well resolved.
Note: Mean velocity increases as source-receiver distance increases, in proportion to the distance the seismic energy is travelling in the faster basement relative to the slower cover. In a 2 layer case velocity is inversely proportional to cover thickness.



a) b) c)

Figure 5: a) Bouguer gravity image b) Seismic velocity image derived from 400m source-receiver pairs. Low velocity (blue) corresponds to thick cover, high velocity (red) to thin cover c) 'Excess Mass' product derived by calculating and subtracting the modelled gravitational response of the basement topography (derived from the seismic data) from Bouguer gravity data
Common to a), b), and c) are Bouguer gravity contours at 0.1mGal and drill collars

Figure 6: The Atlas Accelerated Weight Drop Seismic Source mounted on Caterpillar 257B

Figure 7: The Atlas Receiver Set Up on Kubota RTV900

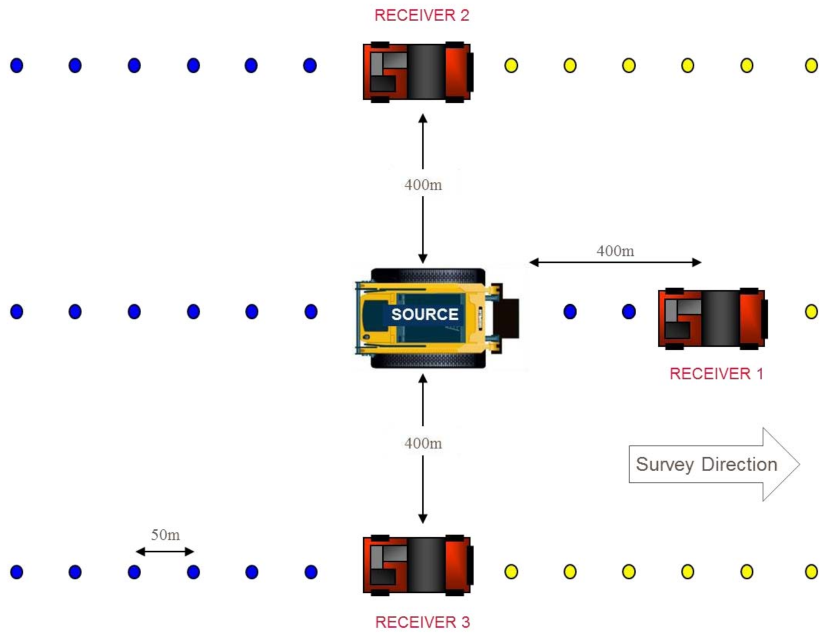


Figure 8: Schematic representation of Sparse Refraction Survey Configuration utilised at Koodaideri

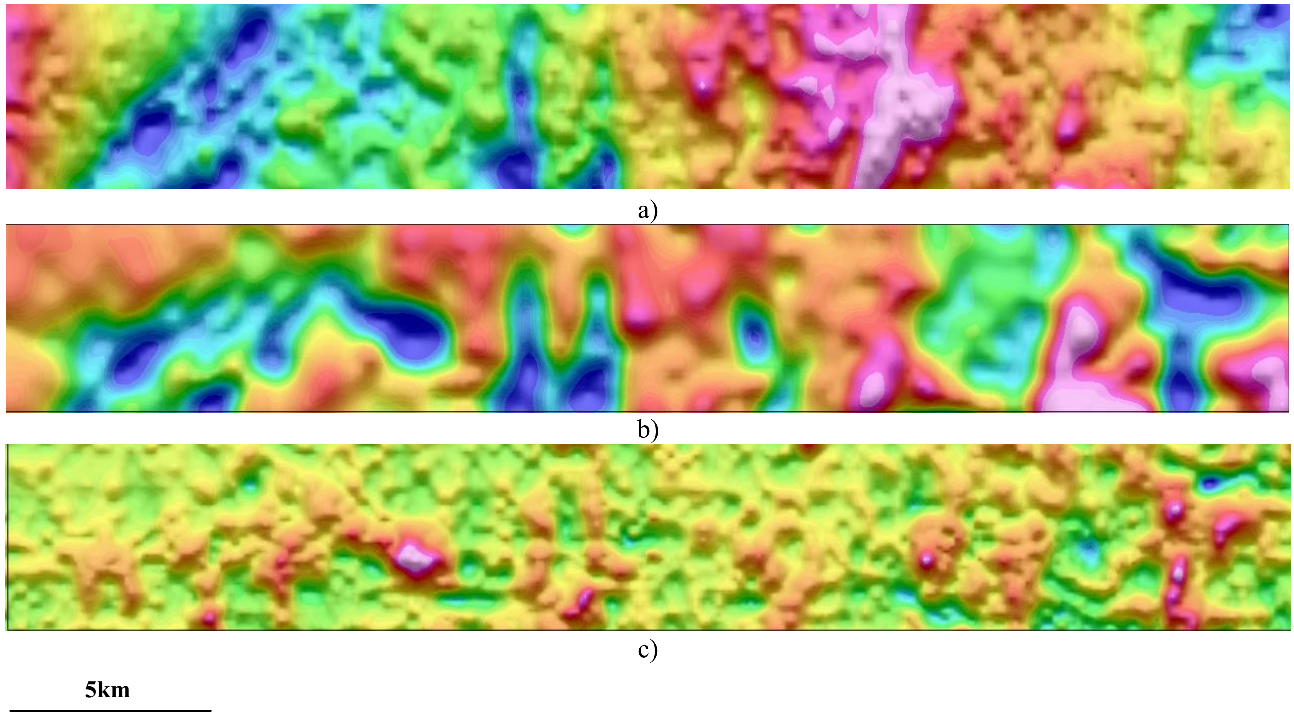


Figure 9: Results from the 2008/09 Koodaideri Sparse Refraction Survey:
- **a) Bouguer Gravity Image – Linear Trend Removed**
- **b) Top of Basement RL**
- **c) Excess Mass (Residual Gravity Image)**