GRAVITY AND GRANITES

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Geological data is almost never reliable enough to quantify the shape of granitic plutons at depth. For this reason, geophysical surveys are conducted to obtain further information of the sub-surface. Gravity investigation is an effective method of measuring the extent of granitic plutons due to the fact that acid intrusive rocks typically have a lower density than their surrounding country rocks. Utilising the gravity method we can measure negative gravity anomalies over granitic plutons and from these anomalies, the subsurface three-dimensional shape of the plutons can be modelled.

The availability of the Global Positioning System (GPS) for the determination of accurate (cm) real time elevations allows ground gravity data to be acquired at rates sufficient to attain datasets that let gravity images of plutons be produced rather than simply obtaining gravity profiles across the plutons. If the acquired gravity data is a profile, then 2D modelling of the sub-surface shape of plutons and contact relationships can be attempted. If the gravity data is sufficient, then those results can be used to form the basis of comprehensive 3D models of plutons. Before modelling can be attempted, average densities are required to be assigned to the rock units that are to be modelled. It is preferred that the densities selected for the pluton and country rocks are the average of the samples taken in the field, although this may be difficult due to weathering and outcrop availability. The attitude of the contacts of outcropping granites can usually be determined from gravity surveying. Even though the precise dip angle cannot be determined due to regional gravity effects, variations in densities, and variations in the displaced mass, the inward and outward dip property of contacts can usually be determined.

To illustrate the value in acquiring and modelling gravity data to investigate the sub-surface shape of granites we will look at the gravity response of two bodies, one with a negative gravity anomaly and the other with a positive gravity anomaly.

Moonbi and Bendemeer Adamellites

The Moonbi and Bendemeer Adamellites are located at the southern end of the New England Batholith, northeast of Tamworth, New South Wales. The Permian aged I-type plutons intrude the Tamworth Belt, the Woolomin Beds, and part of the S-type plutons of the Bundarra Batholith. Gravity surveying was conducted over the Moonbi and Bendemeer Adamellites, as well as their surrounding plutons and country rock, to improve the gravity field resolution of the area, and to also construct a three-dimensional model of the subsurface.

The Moonbi Adamellite shows a fairly clear low anomaly, while the Bendemeer Adamellite does not produce a very distinct anomaly. Extensive computational modelling revealed information about the subsurface shape of the plutons, and the density variation with depth of the surrounding country rock. From modelling integrated gravity and magnetic data, it was found that the contacts of the Bendemeer and Moonbi Adamellites predominantly dip outwards. The 3D model of the subsurface constructed using the gravity data revealed that the Moonbi Adamellite is on average 2-6km thick, and that the Bendemeer Adamellite is a thinner pluton, typically extending to a depth of 2-4km (Fig. 1). The Moonbi Adamellite contains a NEE trending granitoid root system, which extends to a depth of approximately 11km, when modelled within a layered country rock that increases in density with depth. The Bendemeer Adamellite contains no root system.

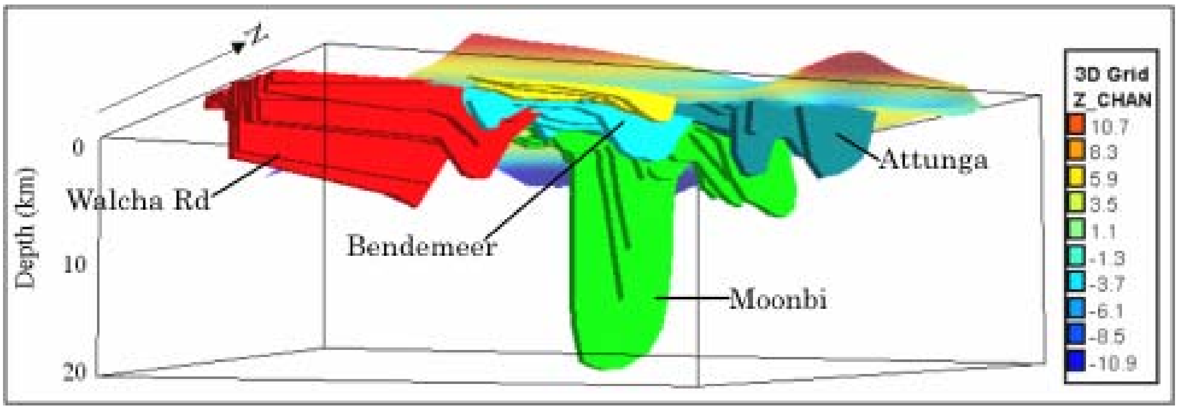

Figure 1. A 3D model for the Moonbi and Bendemeer Adamellites, viewing southwest at an inclination of -5^{o}, the density of the country rock is homogeneous. If the density of the country rock increases with depth, then the root for the Moonbi Adamellite will extend to 11km rather than the unrealistic 20km.

Yeoval Batholith

The Yeoval Batholith is a large Devonian intrusive complex located in central NSW, approximately 400 km to the west of Sydney. Within the Yeoval Batholith there are two different complexes and five individual plutons, with the Nallawa Complex occupying the western side of the batholith and the Yeoval Complex, which makes up almost half the area of the batholith the eastern side. The gravity data for the batholith shows a gravity high, which suggest larger volumes of dense, mafic material than is not seen on the surface. A detailed gravity survey was conducted over the Yeoval Complex of the batholith to examine the density structure and sub-surface shape of the complex. The survey consisted of two detailed profiles, which were used for modelling of the rocks at depth, as well as infilling of the regional gravity data. Samples of intrusive and host rocks were taken to provide information about surface density contrasts that were needed for modelling.

Modelling revealed several important facts about the sub-surface of the Yeoval Batholith. The models reveal that densities found on the surface of the felsic phase of the Yeoval Complex cannot extend to depth (Fig. 2). A rock with a higher density is required beneath this unit to produce the gravity anomaly measured (Fig. 3). The near-surface shape and the density distribution within the felsic phase have been determined, indicating the felsic phase does have a density increase with depth. It is denser around its contact with the host rocks at depth and typically has steep sided contacts near the surface. However, there are ambiguities regarding the thickness of this unit caused by the decreasing resolution of gravity data with depth. A similar density distribution and shape has been modelled for the main unit of the Nallawa Complex. Modelling of the thinner, mafic phase of the Yeoval Complex (Naringla Granodiorite) has revealed a flat basal contact and a depth estimate of 850 m has been made.

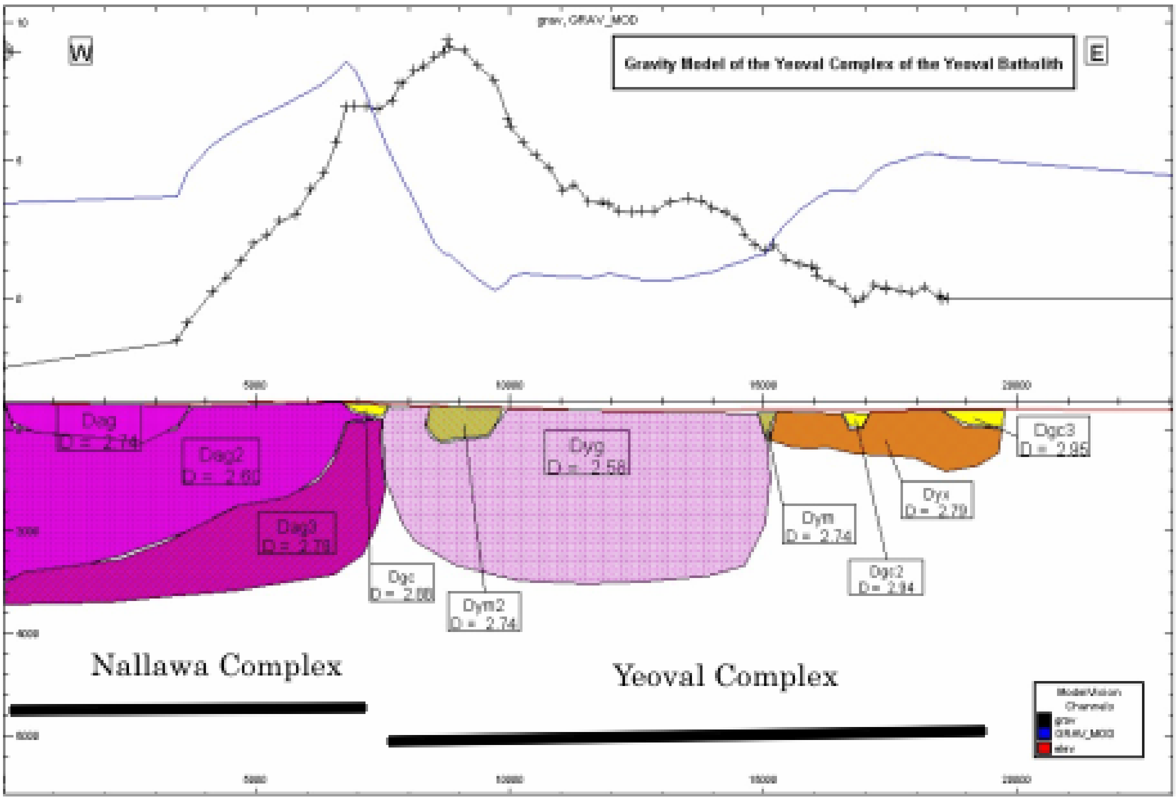

Figure 2. Gravity model for the main profile using the preferred model shape and surface densities at depth for unit Dyg of the Yeoval Complex. The modelled data does not match the measured response, although manipulating the density of Dag (Nallawa Complex) and the thickness of the Dyg unit gives a better but not a good fit.

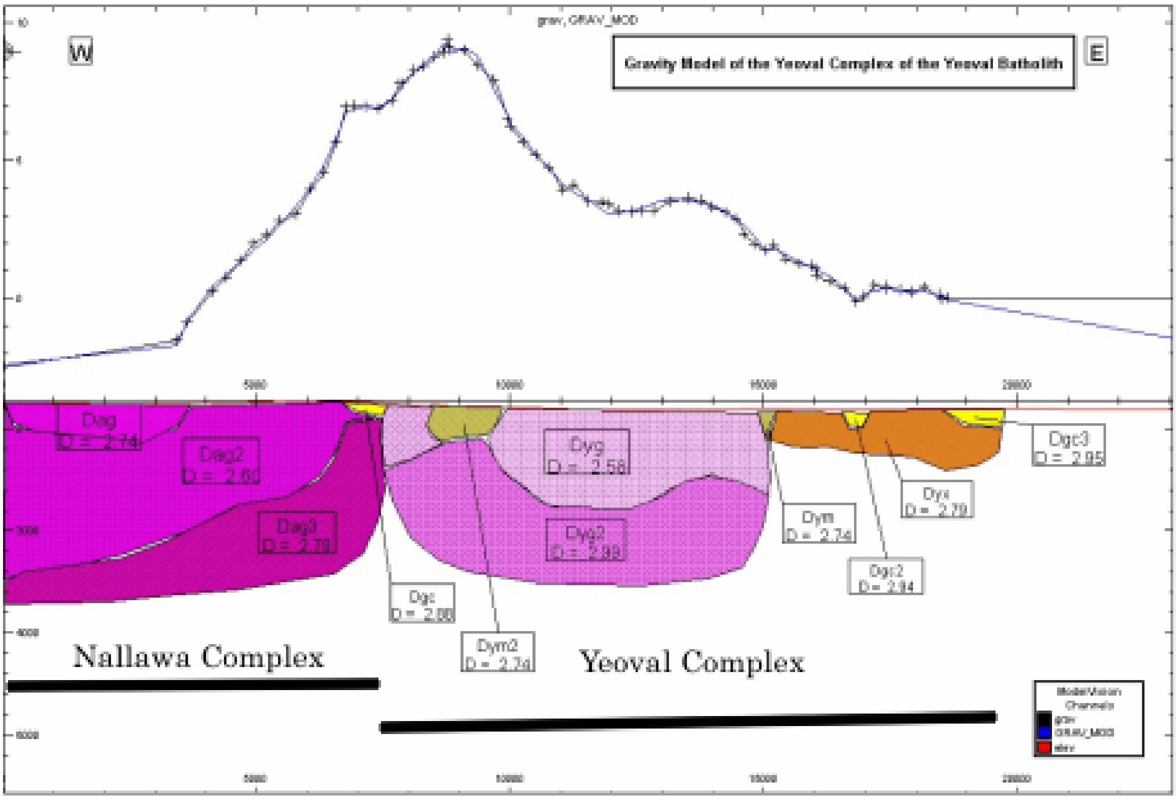

Figure 3. Preferred gravity model for the main profile across the Yeoval Batholith.

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GEMOC

Gravity

Acid intrusive rocks typically have a lower density than their surrounding country rocks.

Can measure negative gravity anomalies over granitic plutons.

Depending on the coverage of the gravity data, the 2D or 3D shape of the sub-surface can be modelled.

Density

Need to be able to assign densities to the rock units to be modelled.

Densities should be the average of samples taken in the field.

This can be difficult due to weathering and outcrop availability.

Rash assumptions about how homogeneous the density of the pluton is with depth.

Modelling

Attitude of contacts can usually be determined.

Precise dips, depend on coverage of gravity data and is usually better if magnetic data is also available.

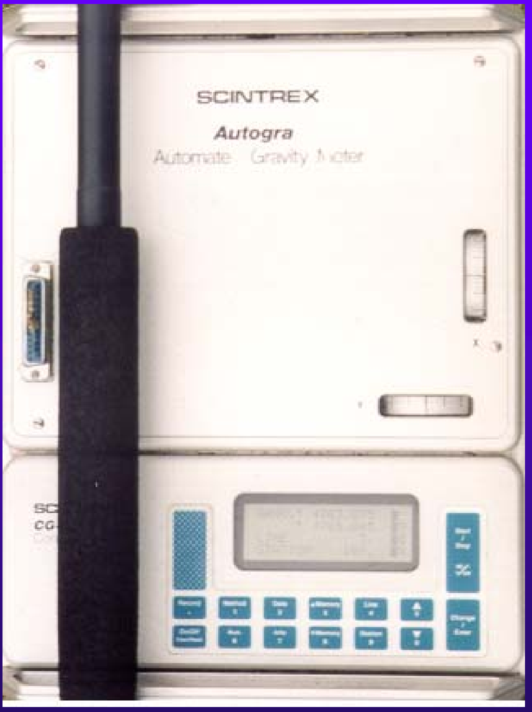
Depth to base of a pluton cannot be determined uniquely but bounds can usually be given, especially if other data is available.

Assumptions about density.

Equipment

- Gravimeter (action shot)
- Global Positioning System (GPS)
- Density Determination Kit

SCINTREX Autograv Automated Gravity Meter



Magellan Differential GPS with Antenna

Moonbi and Bendemeer

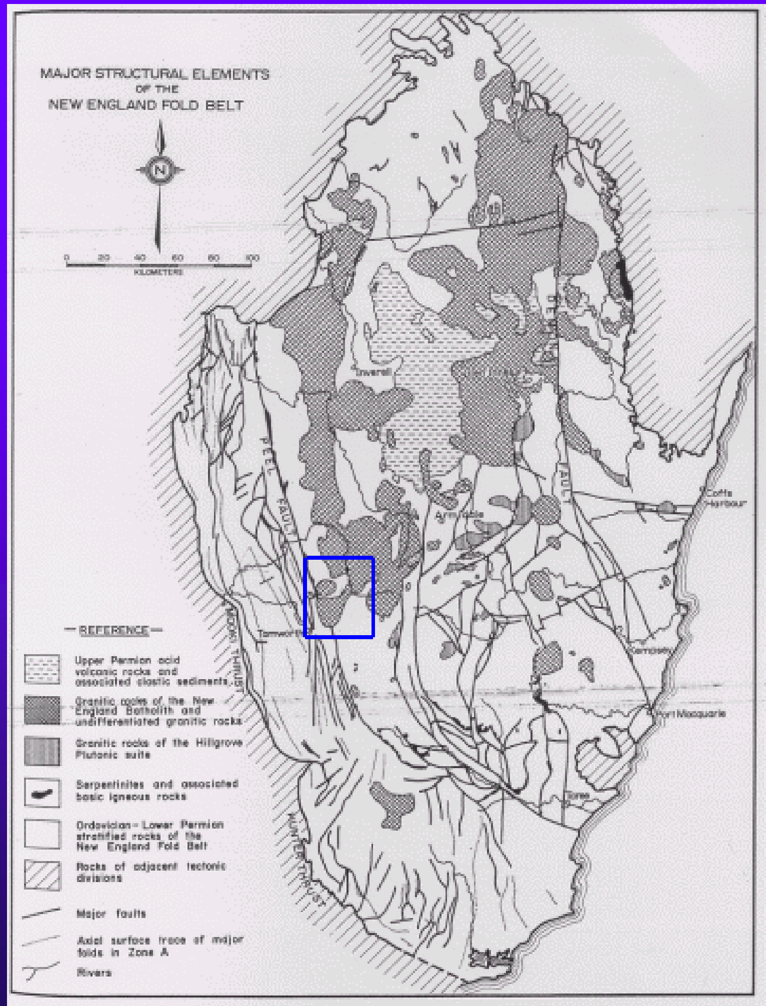
Introduction

- The Moonbi and Bendemeer Adamellites are located at the southern end of the New-England Batholith in New South Wales, just north of Tamworth. (where?)

- A total of 156 gravity stations have been established in the Tamworth – Moonbi District.

New England Fold

The southern part of the New England Fold Belt showing the associated rock types and major structural features.

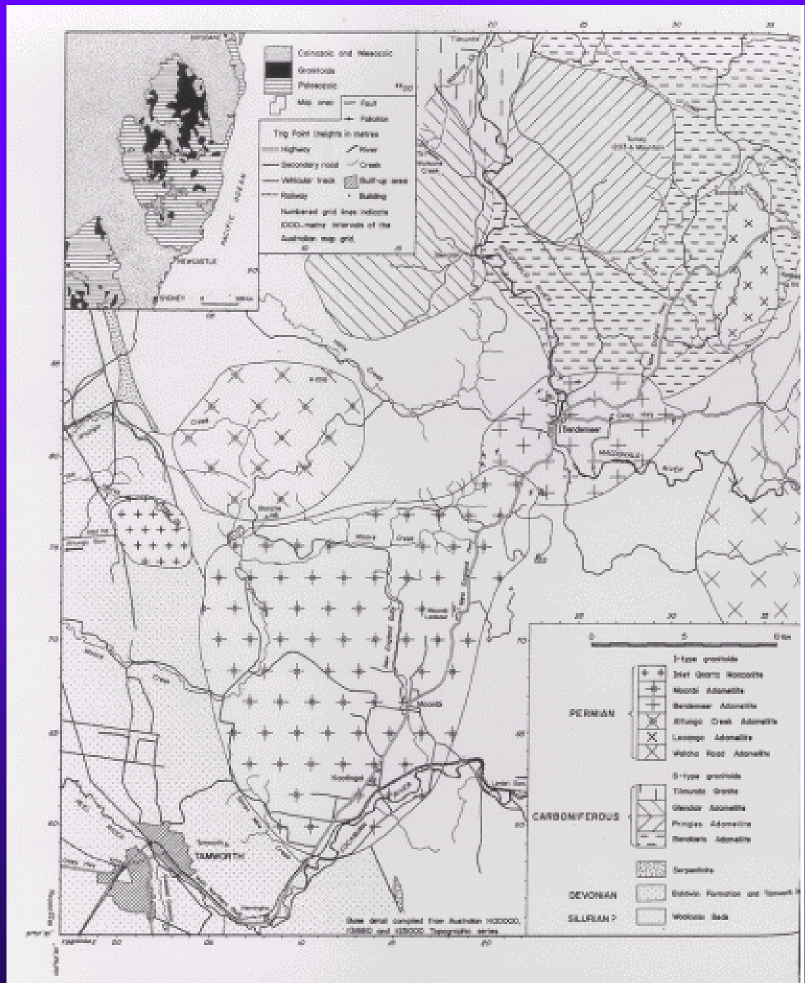


From Leitch (1974)

Geology

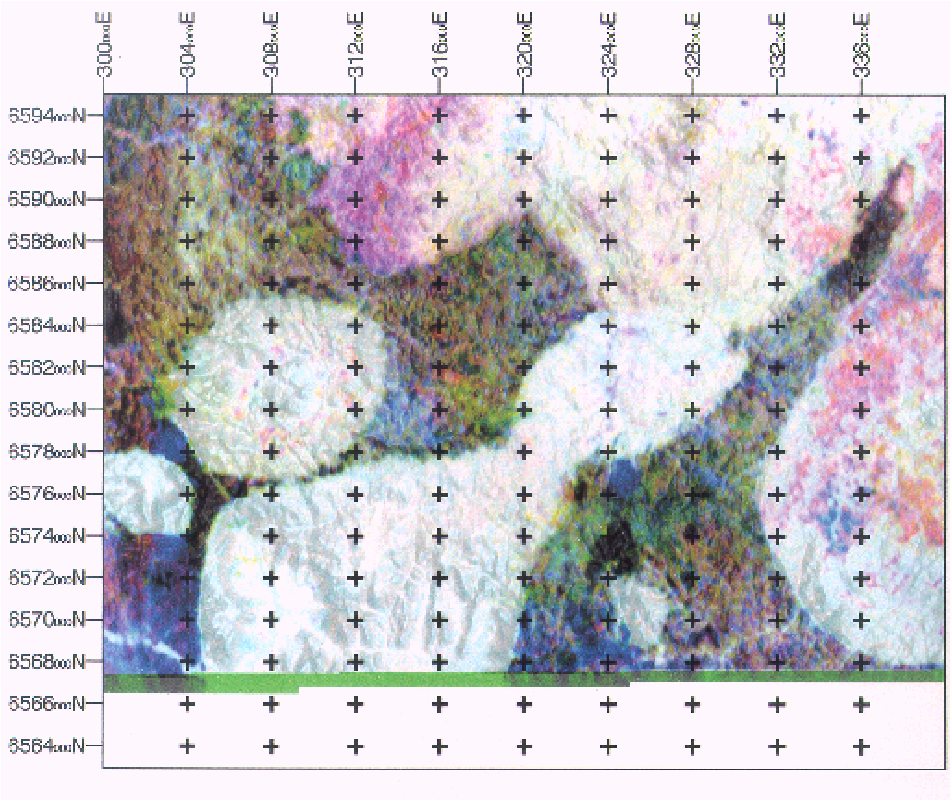
- A total of 10 plutons within the New England Batholith have been mapped in the Moonbi District. (fuzzy image)
- The Sedimentary Rocks in the region are divided into 2 groups separated by the Peel Fault System:
  - –The Tamworth Belt in the West.
  - –The Woolomin Beds in the East.

Geological map of the study area



From Chappell (1978)

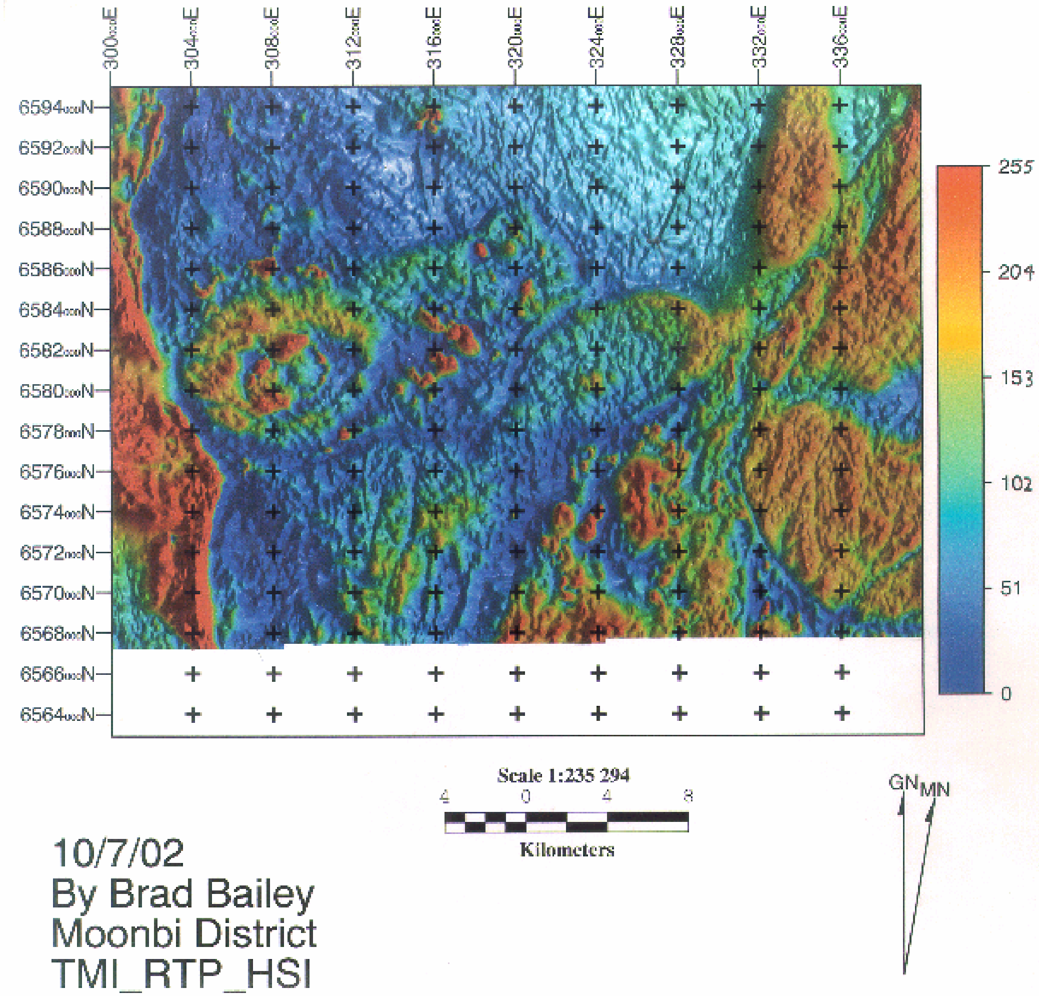
Local Ternary Radiometrics Image



Courtesy of NSW Department of Mineral Resources.

- This ternary radiometrics map overlaying a digital terrain model delineates the contacts of the plutons very well.
- The Inlet Quartz Monzonite, the Limbri Leucoadamellite, the Moonbi and Bendemeer Adamellites are all radiometrically similar.
- Possible zoning can be seen within the Attunga Ck Adamellite.

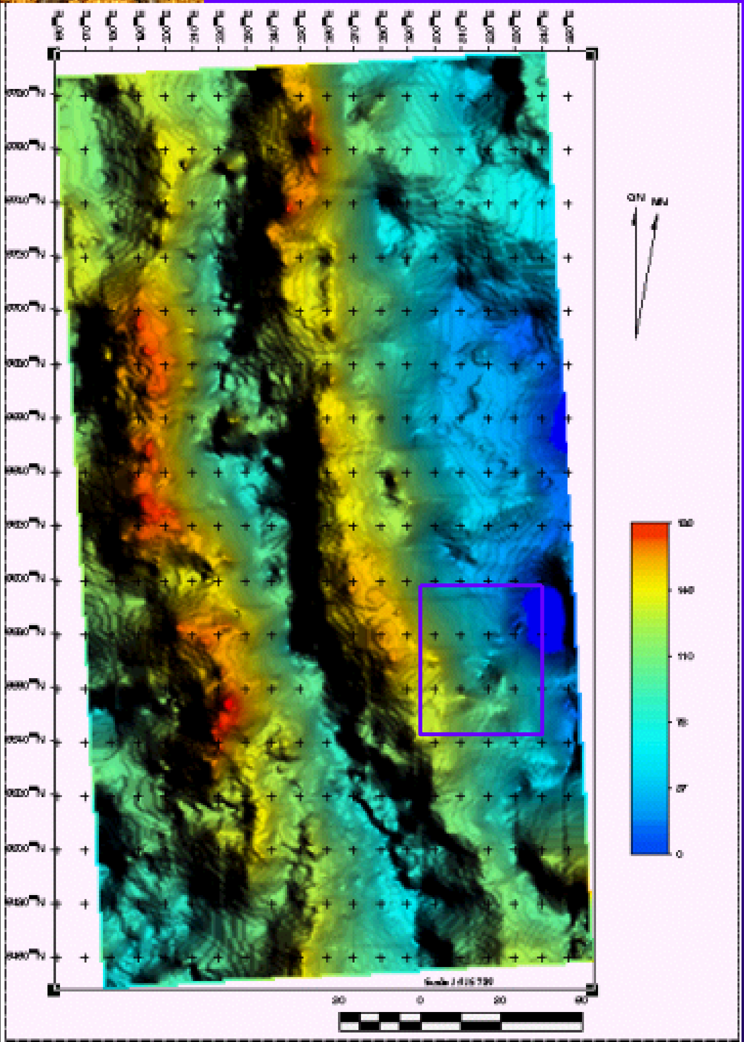
Local Magnetic Intensity Image



- The S-type adamellites are uniformly low in magnetics, ie. The Banalasta and Glenclair Adamellites.
- The Bendemeer is relatively magnetic at its northern and eastern margins.
- The Moonbi is relatively non-magnetic, except for parts in its centre that correlate with rugged topography.
- Mod/high hornfels east of Peel Fault and between the Moonbi and Walcha Rd Adamellite.
- Zonation within the Attunga Ck Adamellite.
- Walcha Rd and the Pringles Adamellites are relatively magnetic.
- The Limbri Leucoadamellite is relatively low.

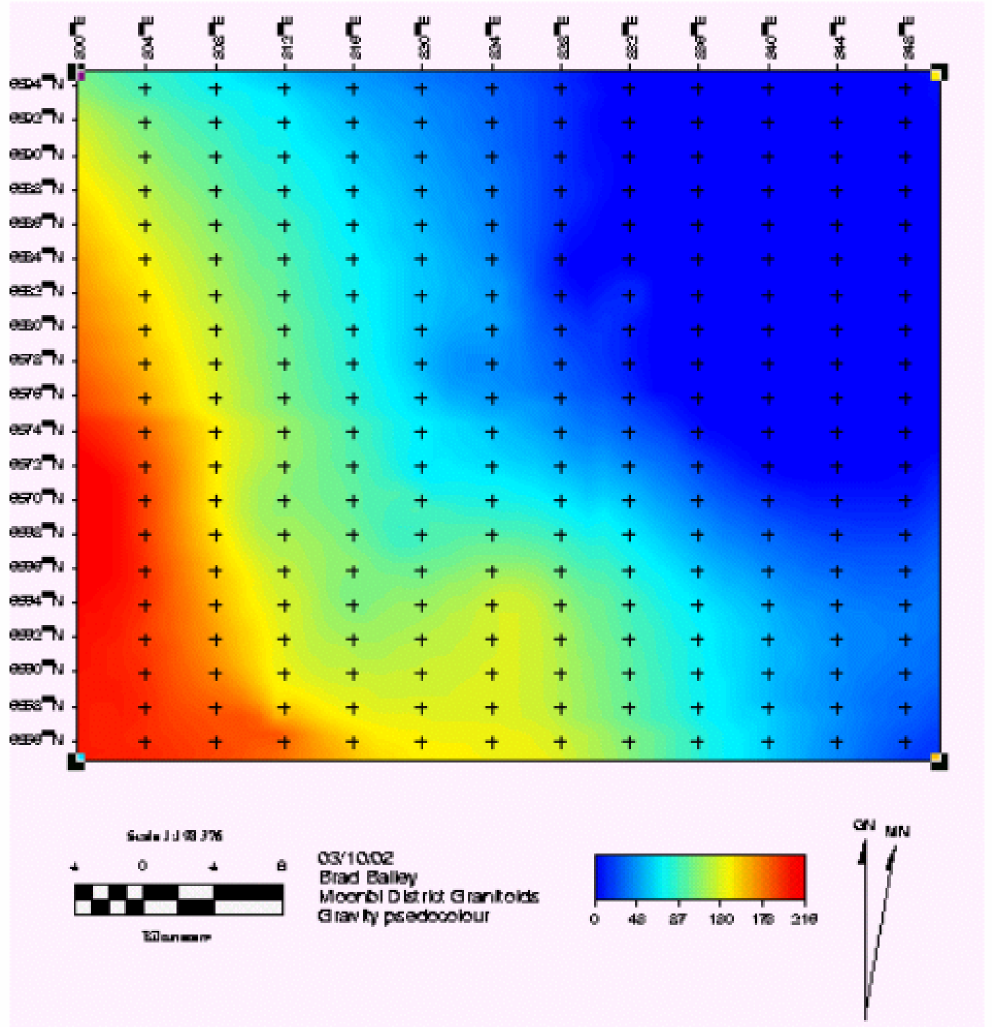
Courtesy of NSW Department of Mineral Resources.

Regional Gravity Image


Courtesy of NSW Department of Geoscience Australia.

- The Woolomin Beds are represented as a low anomaly.
- The regions associated with granitic intrusions are the lowest anomalies within the Woolomin Beds.
- Both the Peel Fault and Hunter-Mooki Fault are produce high linear anomalies.
- The Tamworth Belt is situated between the to high regions as a relatively lo anomaly belt.

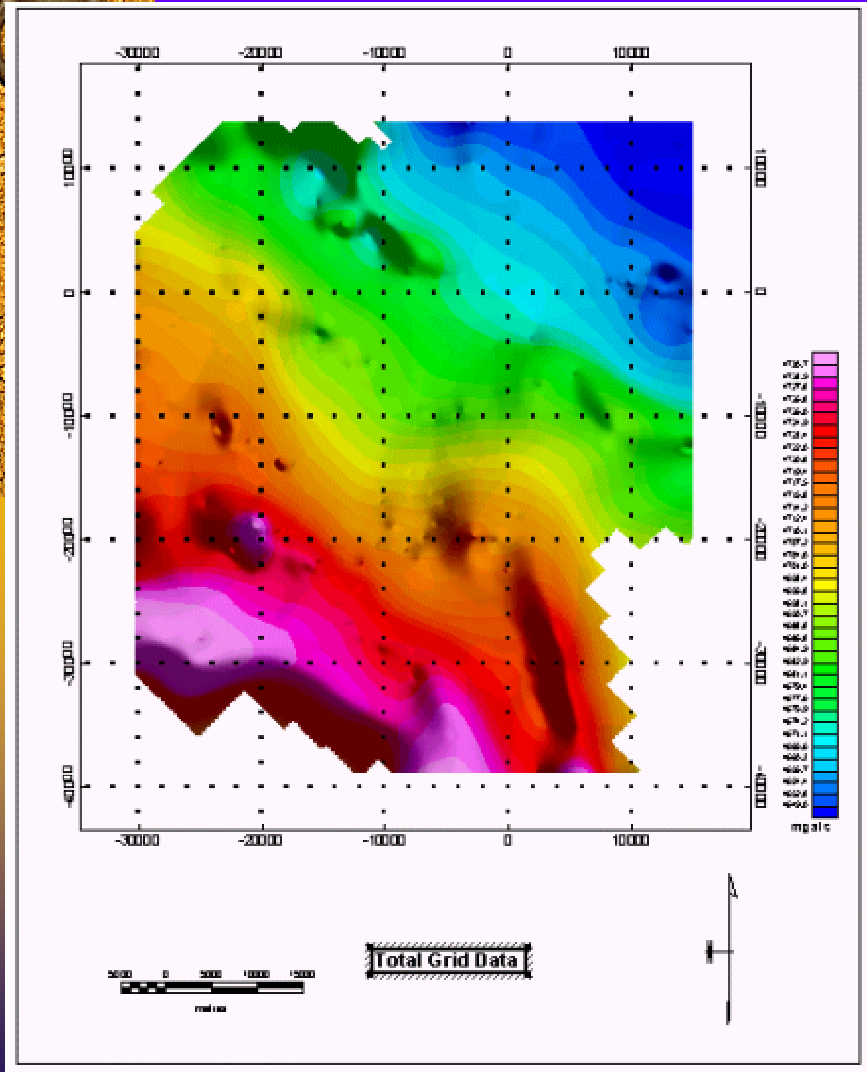
Local Gravity Image



Courtesy of NSW Department of Geoscience Australia.

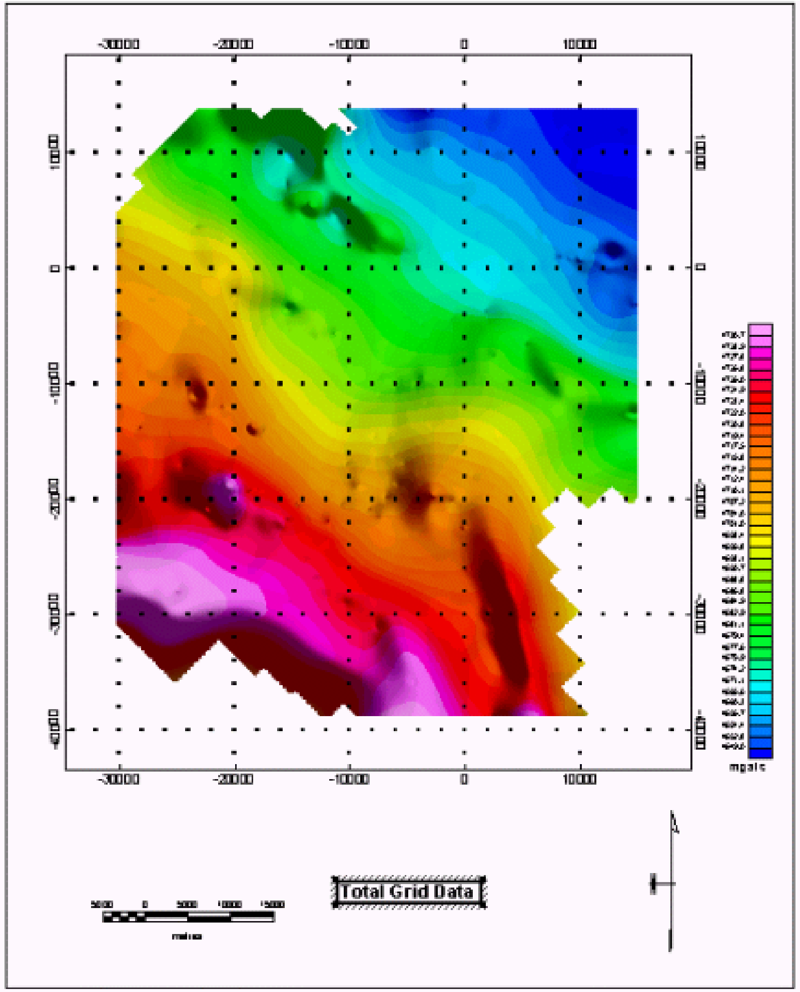
- The regional gravity trend is very evident, Tamworth Belt in the west, and the Woolomin Beds and Batholith in the north-east.
- The response from the Moonbi and Bendemeer Adamellites is evident but very subtle.

Total Grid Data Before Removal of Regional

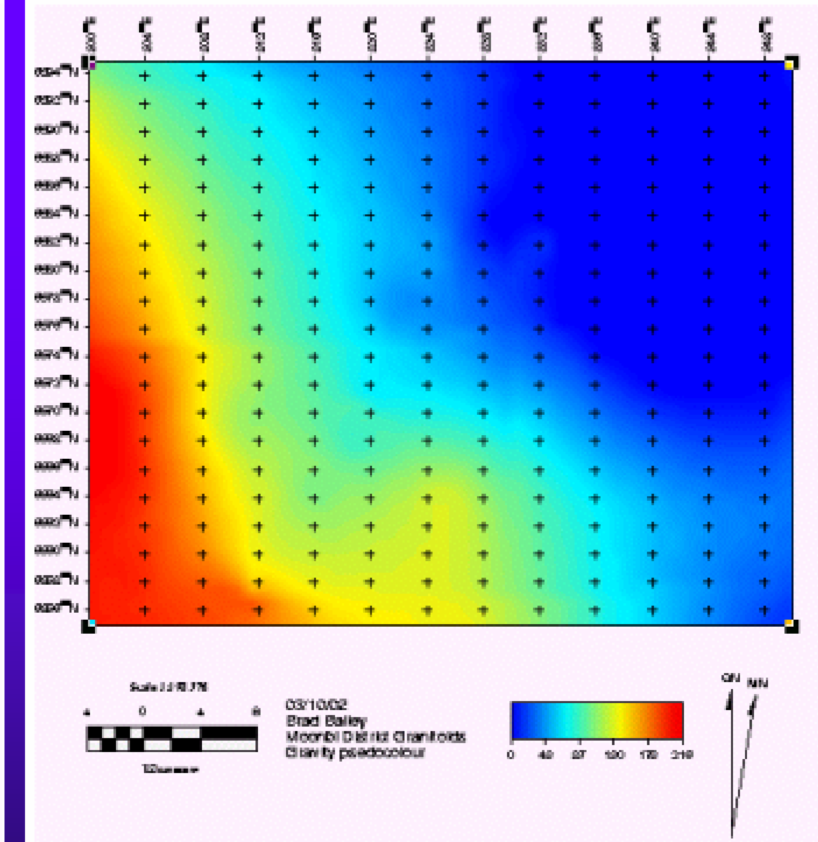


- Image created in Geosoft – Oasis Montaj.
- Strong regional trend due to the transition from the Peel Fault in the SW, to the Woolomin Beds and New England Batholith in the East to NE.

Detailed vs Regional Data

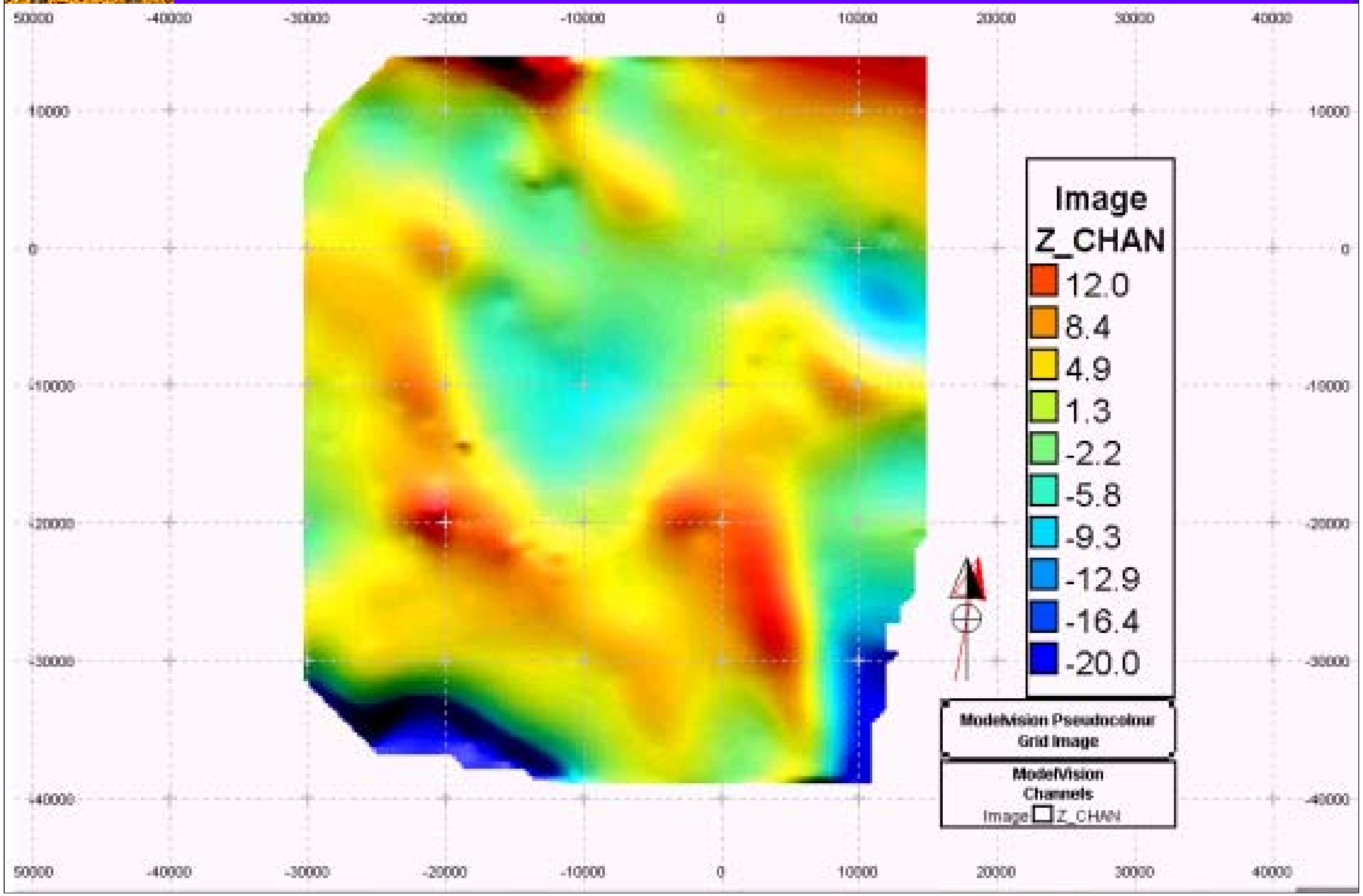


Courtesy of Geoscience Australia.

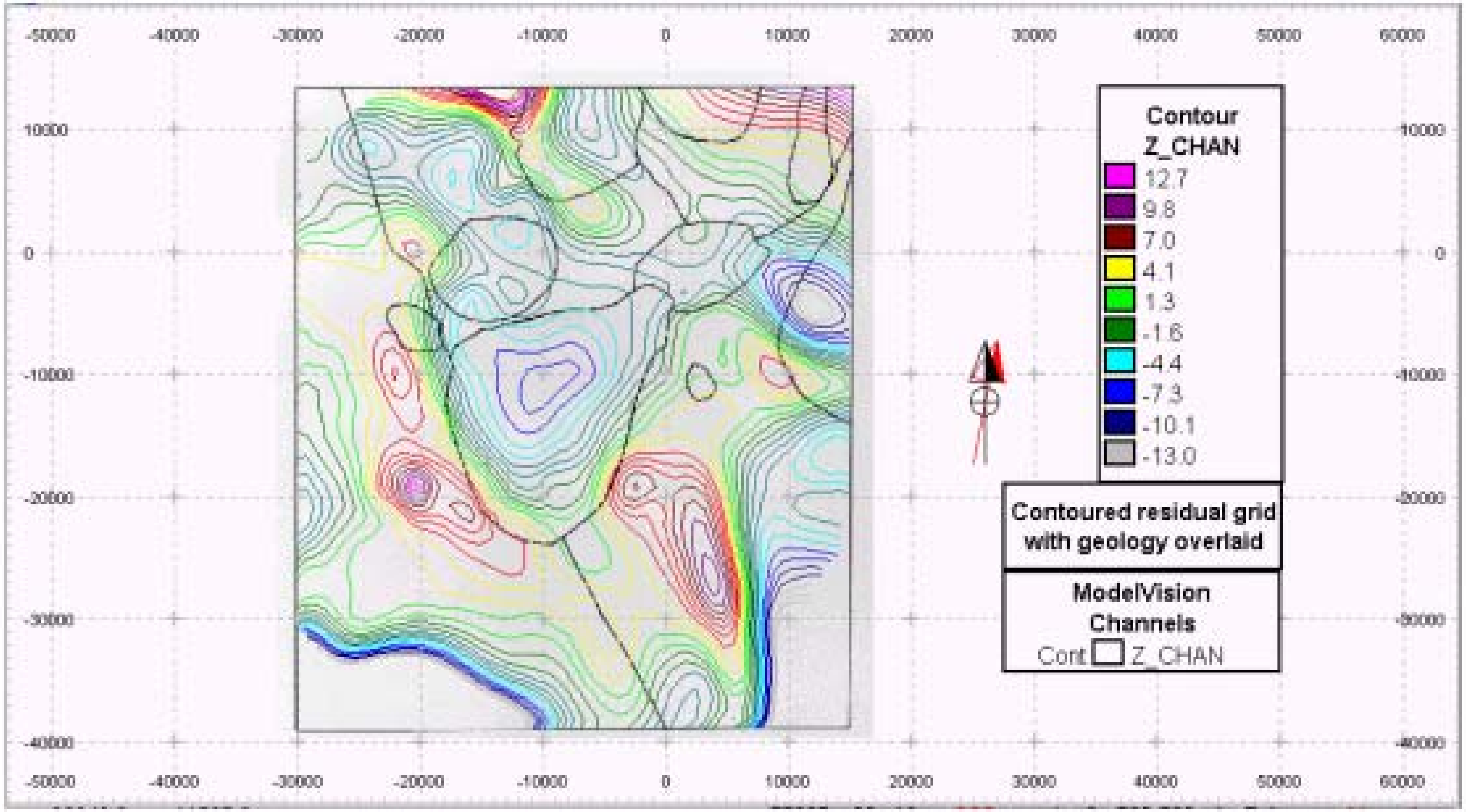


Courtesy of Geoscience Australia.

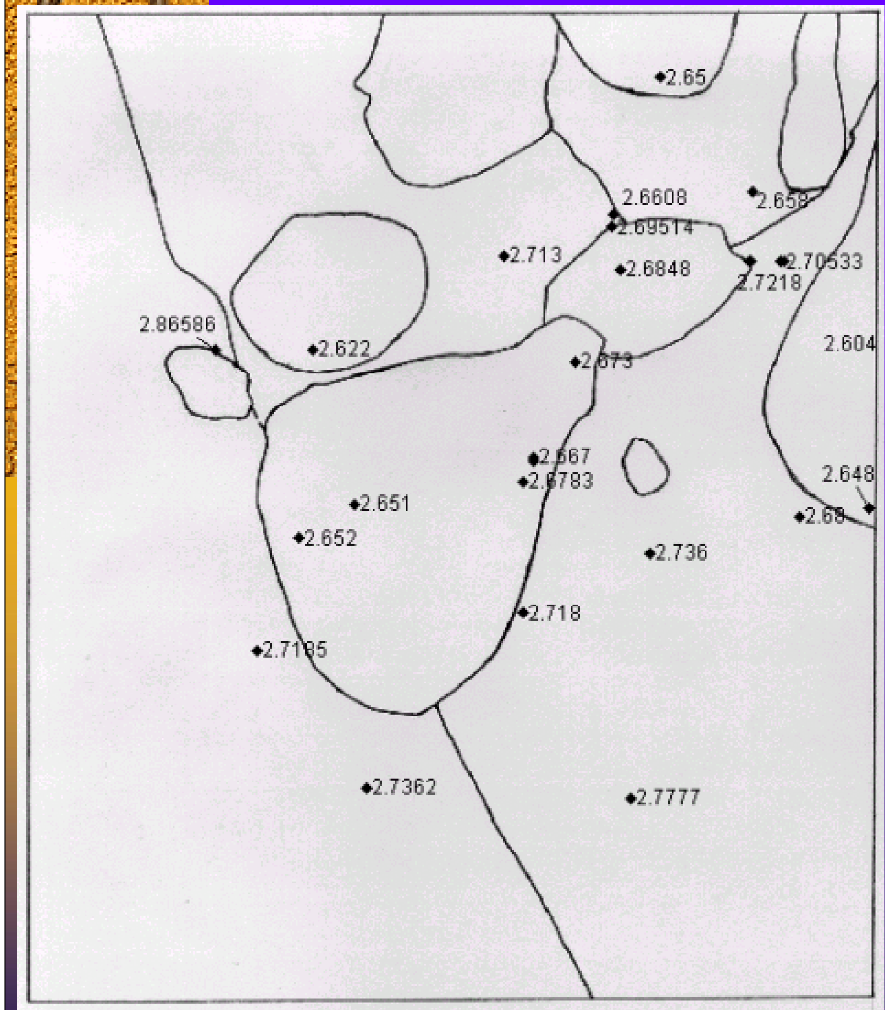
Pseudocolour Residual Grid Data



Residual Grid Data with Geology Overlaid



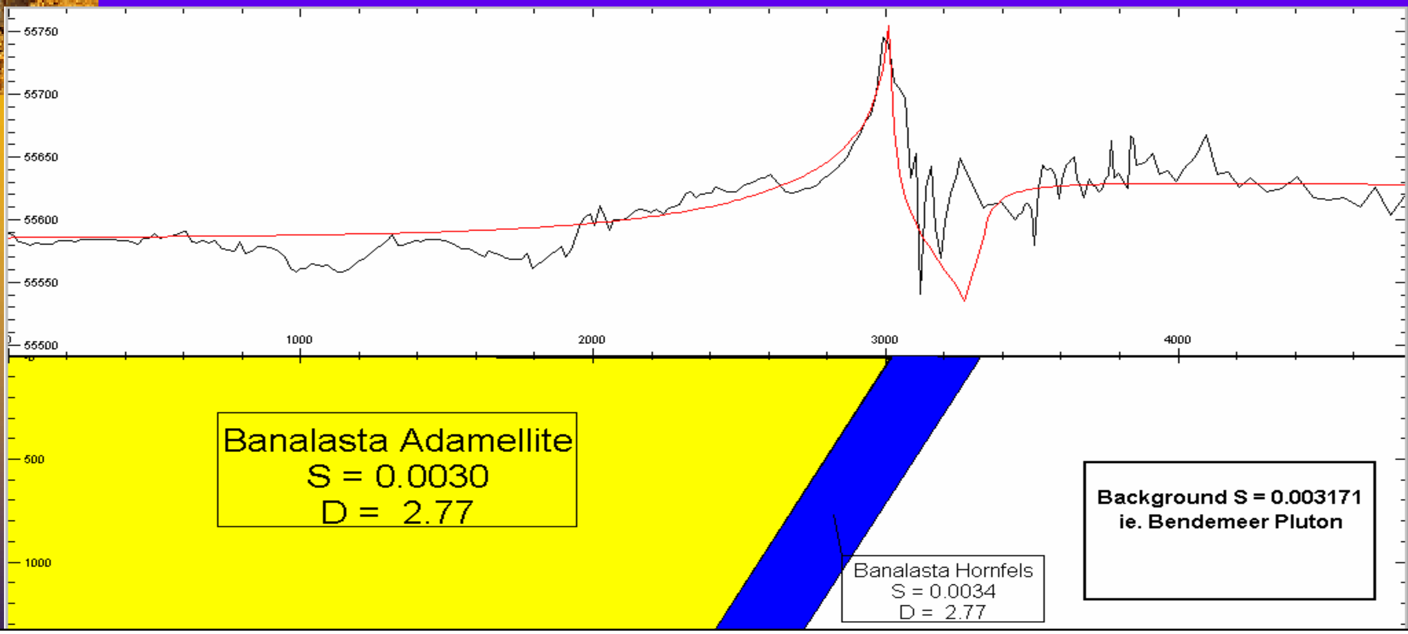
Density Samples



- A total of 39 rock samples were collected for at various outcrop locations density samples.
- Averages were calculated and used for modelling.

Magnetics

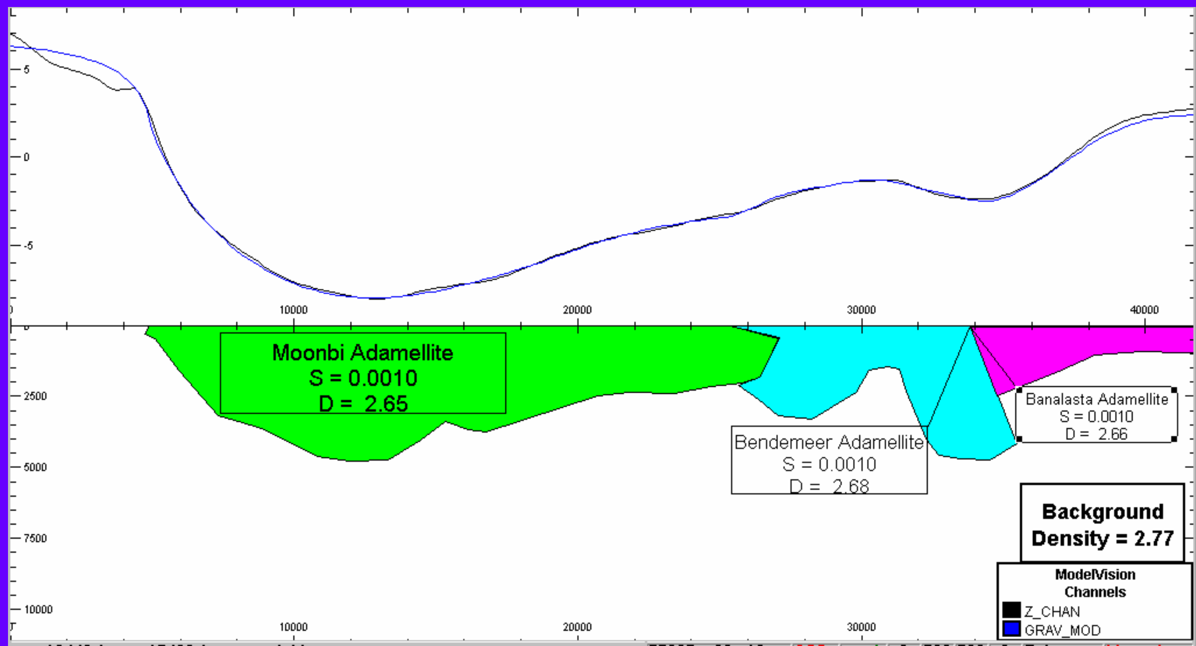
A metamorphic aureole of 1.5 km wide has a magnetic susceptibility value of 0.0034 CGS, to obtain a better fitting model with a steeper dipping contact close 70°.



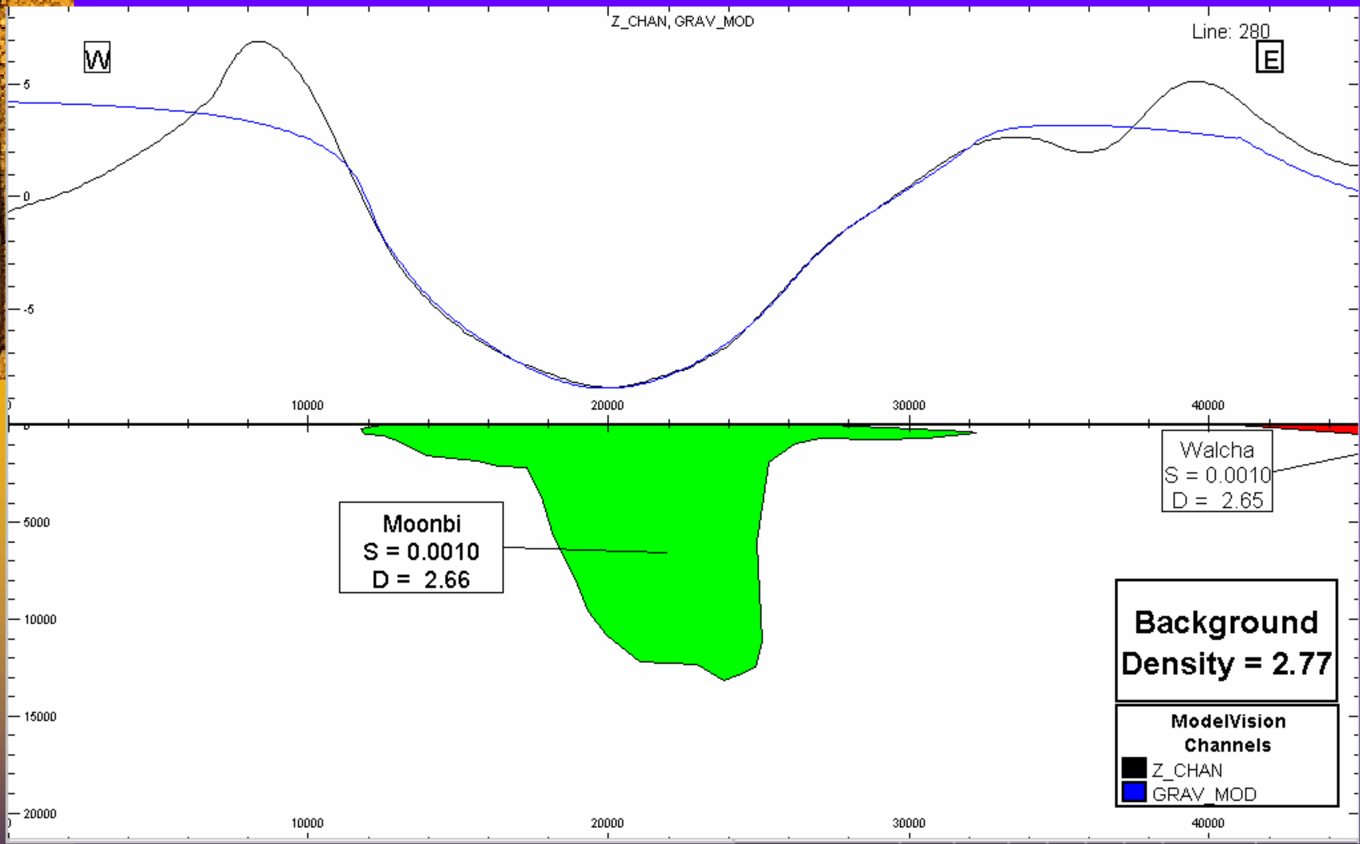
With no outcrop within the immediate contact metamorphism zone, no samples could be taken to test for higher magnetic susceptibility readings. Here, I have assumed that a metamorphic aureole of 1.5 km wide has a magnetic susceptibility value of 0.0034 CGA.

Modelling/Interpretation

•Preliminary profiles were initially modelled to obtain an idea of the sub-surface shape of the plutons, and also the contact relationship of neighbouring plutons.



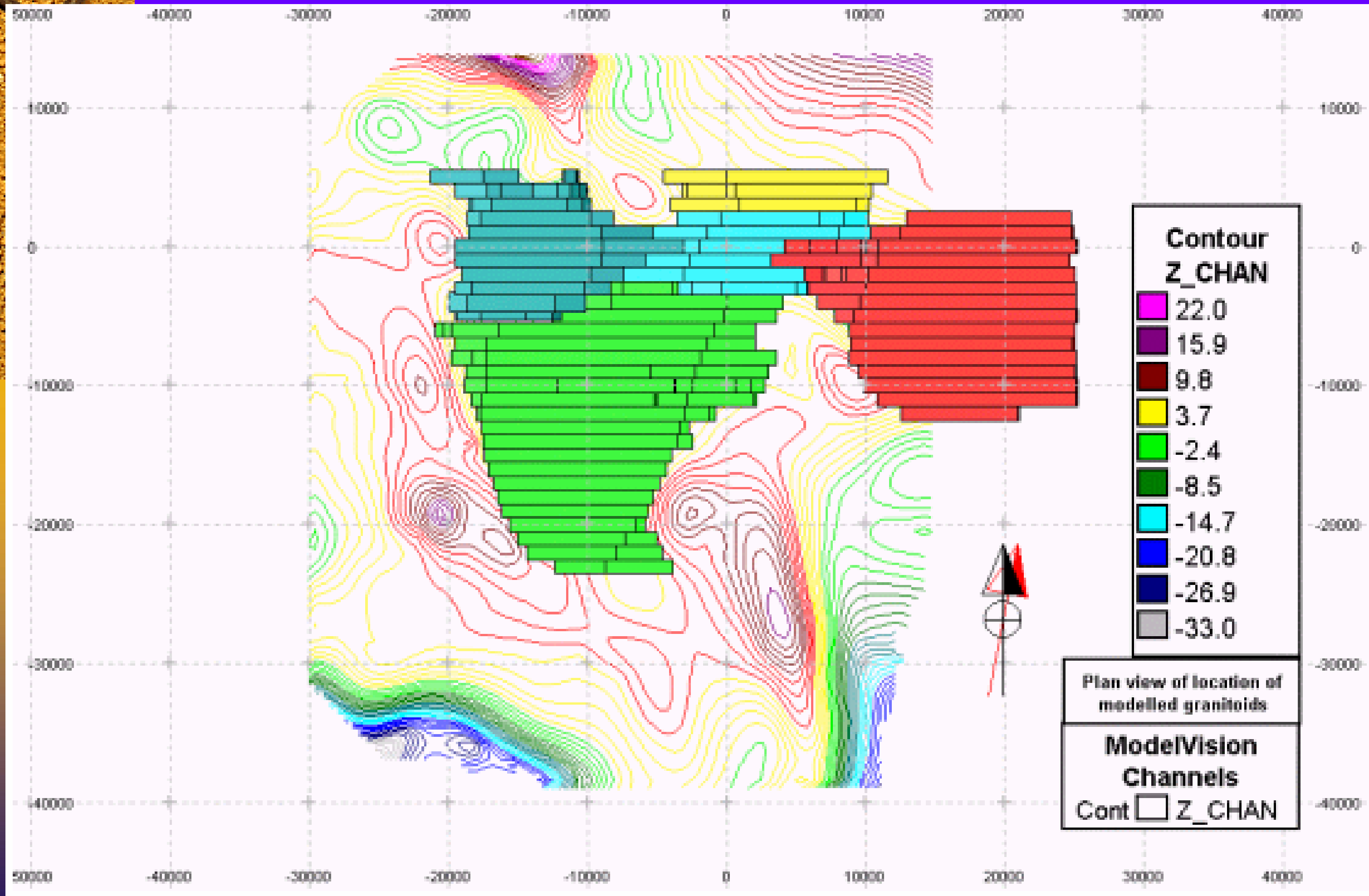
A East- West Profile Through the Moonbi Adamellite

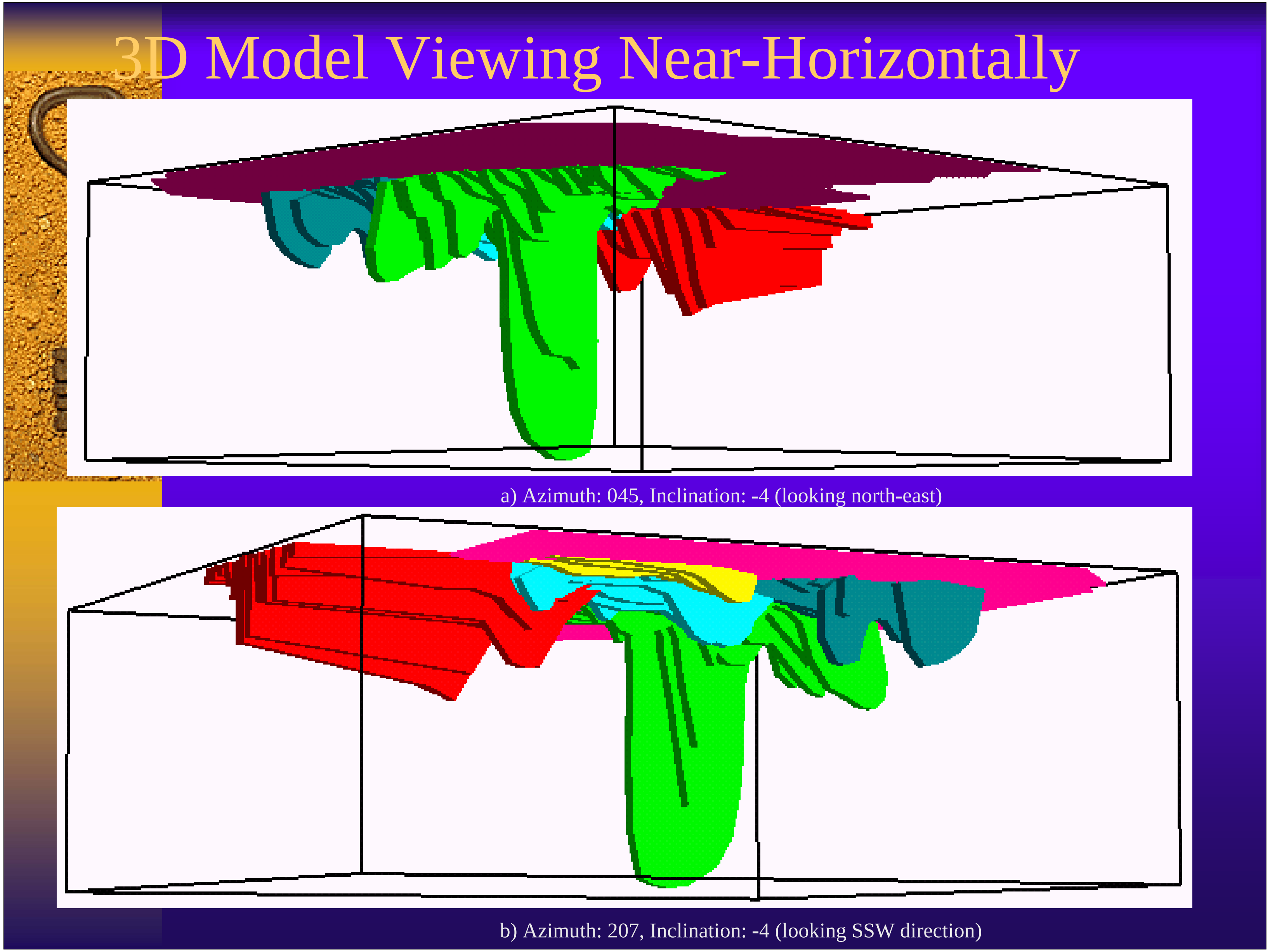


3D Modelling

- The 3D modelling technique that was used is called section modelling.
- Used 1km thick, vertical sections.
- Densities used in modelling:
  - Moonbi Adamellite – 2.665
  - Bendemeer Adamellite – 2.685
  - Attunga Creek Adamellite – 2.622
  - Banalasta Adamellite – 2.658
  - Walcha Road Adamellite – 2.648
  - Tamworth Belt/Woolomin Beds – 2.677
- Assumption: Density is homogeneous with depth of both the plutons and the country rock.

Plan View of 3D Model

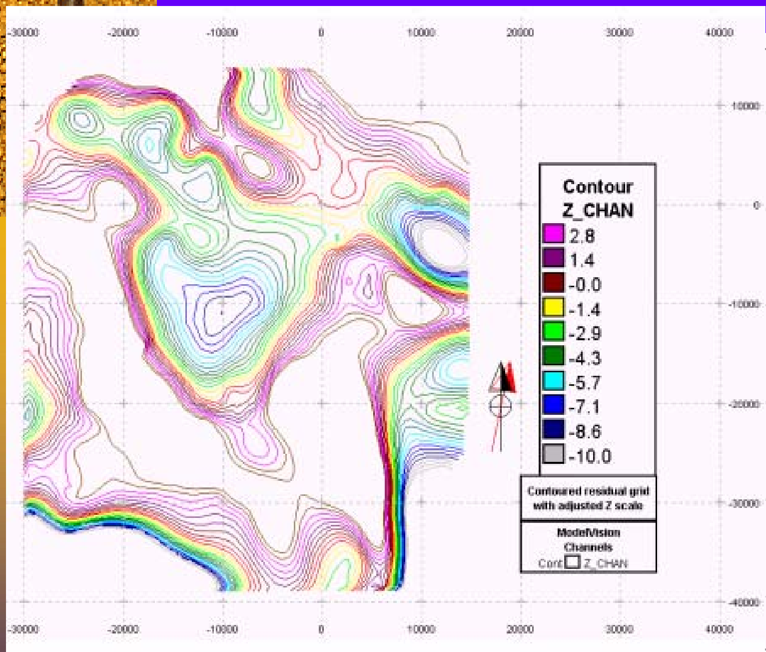


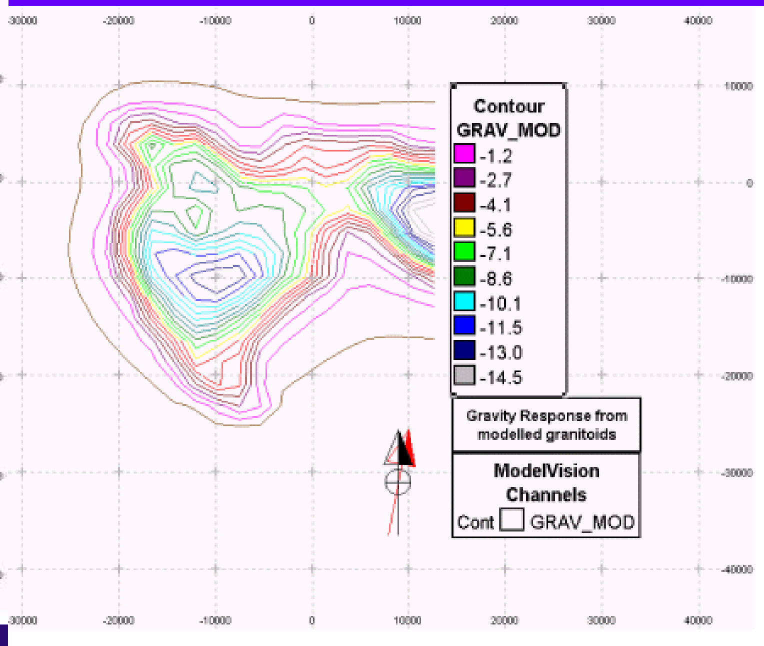


a) Azimuth: 045, Inclination: -4 (looking north-east)

b) Azimuth: 207, Inclination: -4 (looking SSW direction)

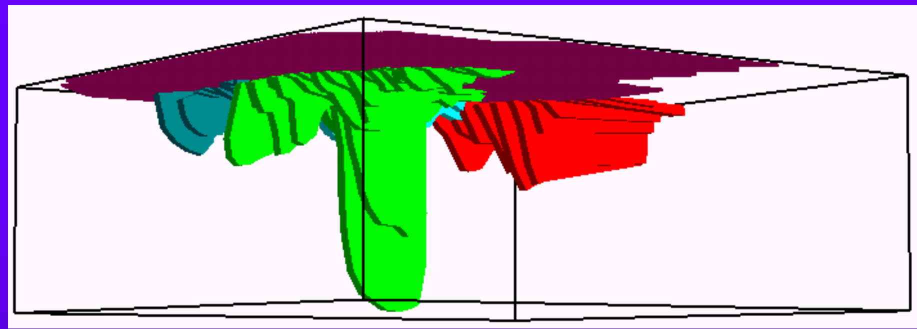
Scaled Grid Data vs Model Gravity Response



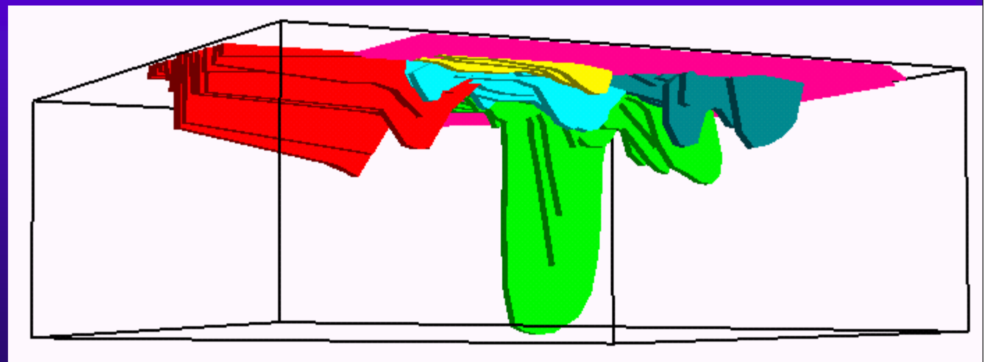


Observations of the 3D Model Assuming Density is Constant with Depth

- Moonbi Adamellite:
  - Contains a major root extending to approximately 20kms.
  - Predominantly outward dipping contacts.
  - The majority of the pluton is 2-6kms deep.

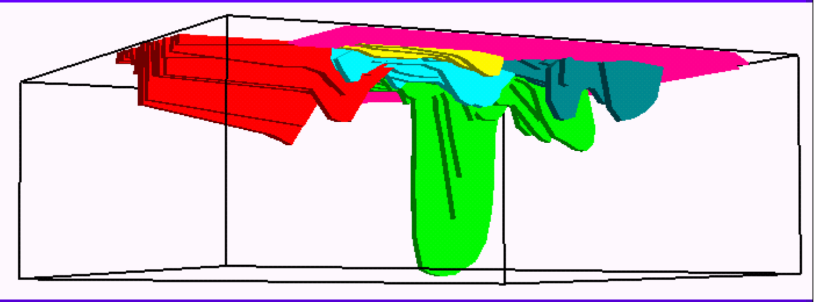


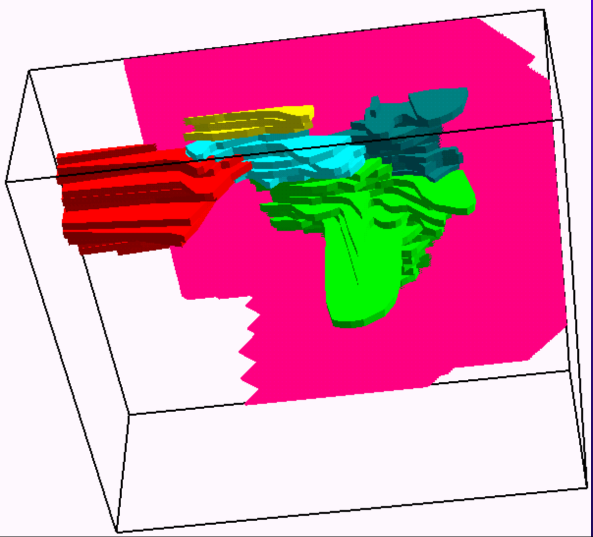
- Bendemeer Adamellite:
  - No root evident.
  - Outward dipping contacts.
  - Predominantly 2-4km deep.



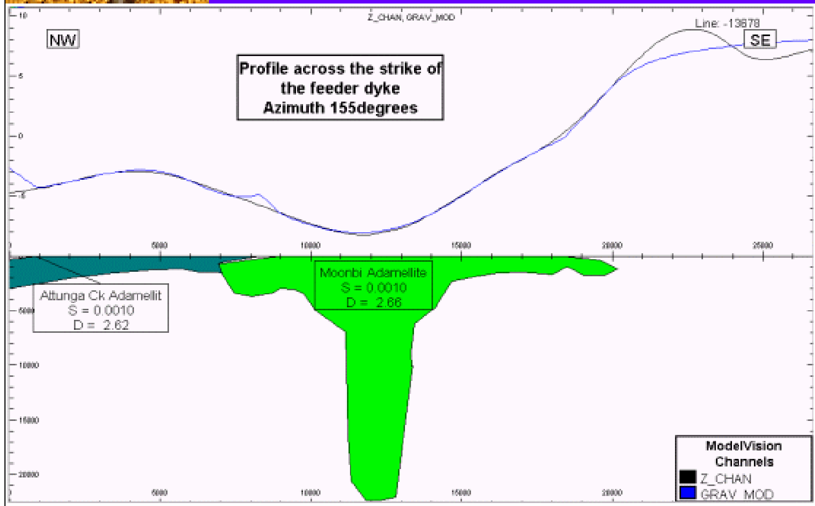
Observations of the 3D Model Assuming Density is Constant with Depth

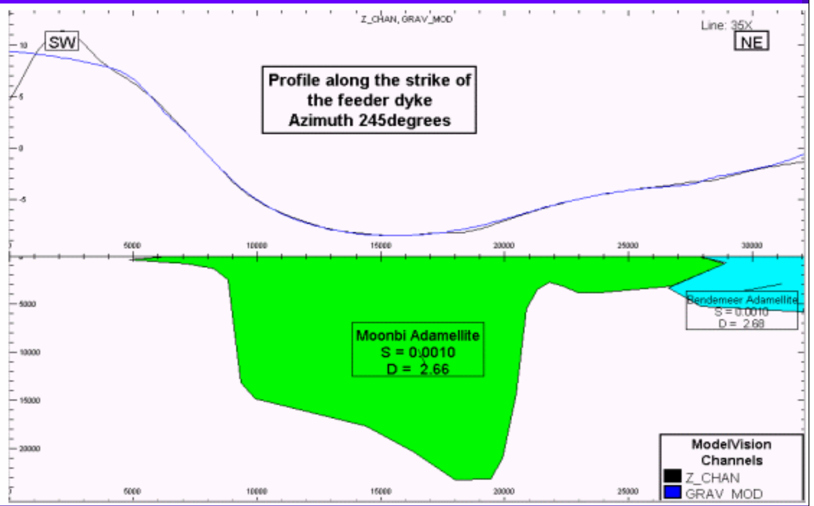
- Attunga Creek Adamellite
  - Possible root at northern end of pluton.
  - Predominantly 2-4km deep.
- Banalasta Adamellite
  - Appears to be very shallow, but this is partly an artifact due to the regional trend removal process.
- Walcha Road Adamellite
  - Predominantly 4-7km deep.
  - Gentle outward dipping western contact.





Modelled Profiles across and along strike of the Moonbi Adamellite Root

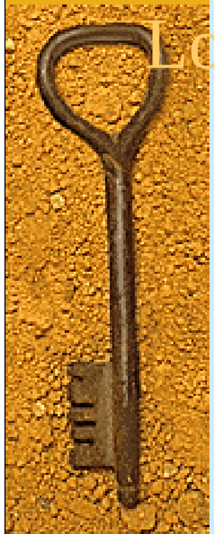




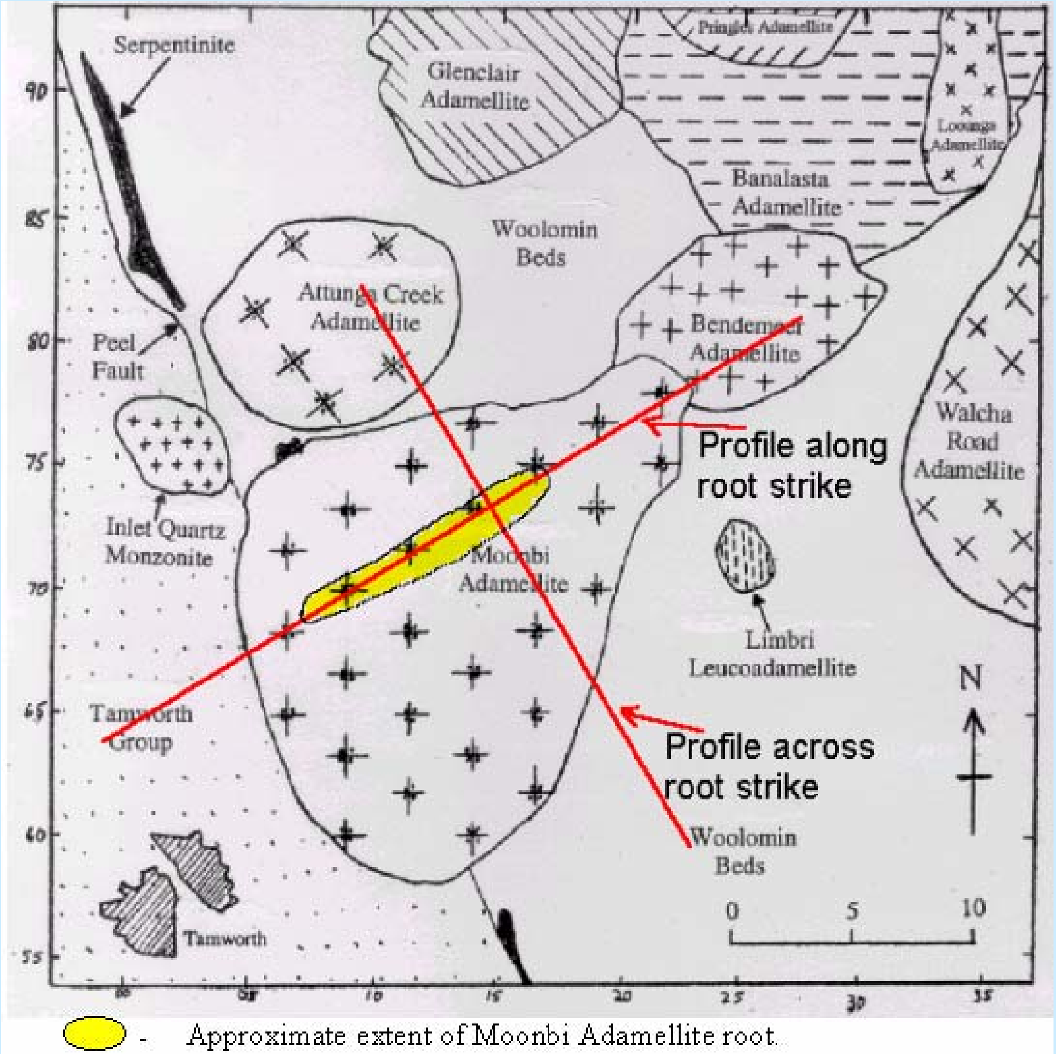
a) Cross-section across the strike of the root, Azimuth 155°.

b) Cross-section along the strike of the root, Azimuth 245°.

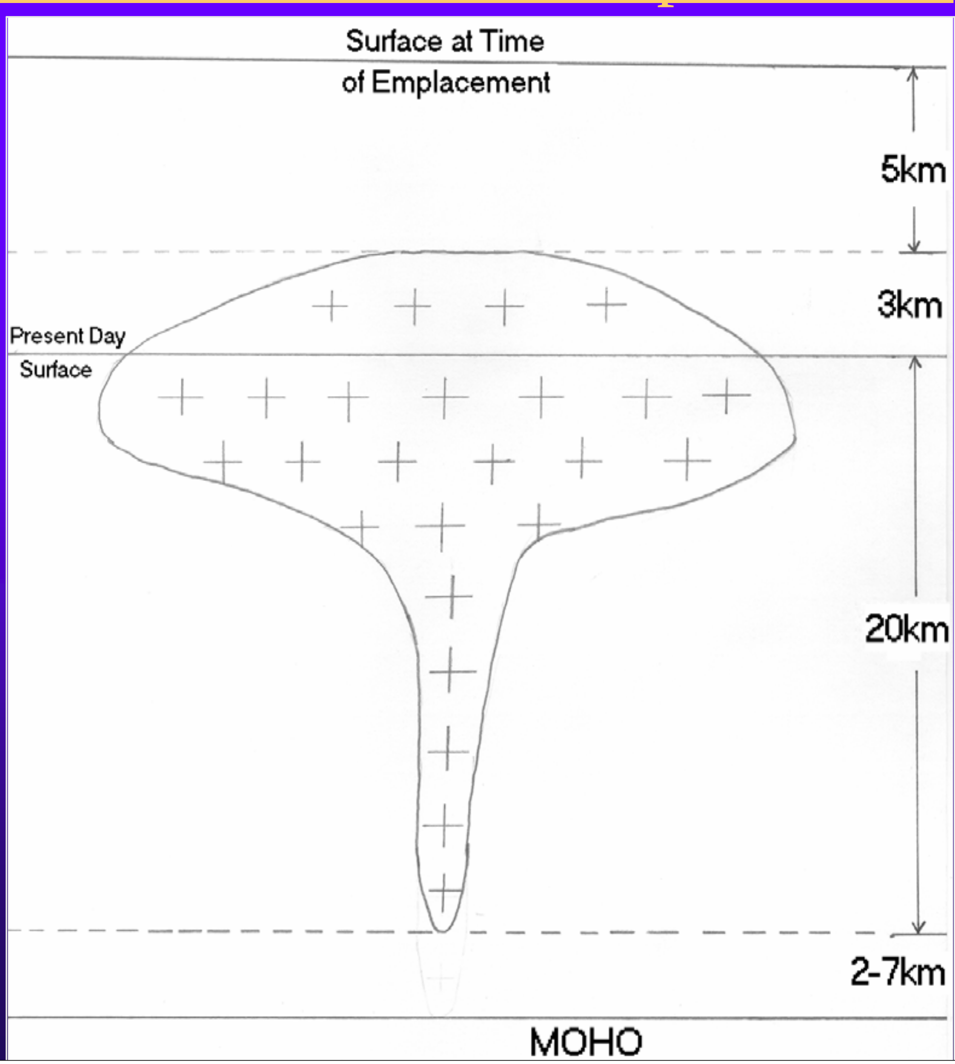
- Result: The thinnest cross-sectional when modelled was found to be 2km and was found at an angle of 155°, thus the approximate strike of the root is approximately 245°.



Geology Map showing the Approximate Size, Location and Strike of the Root



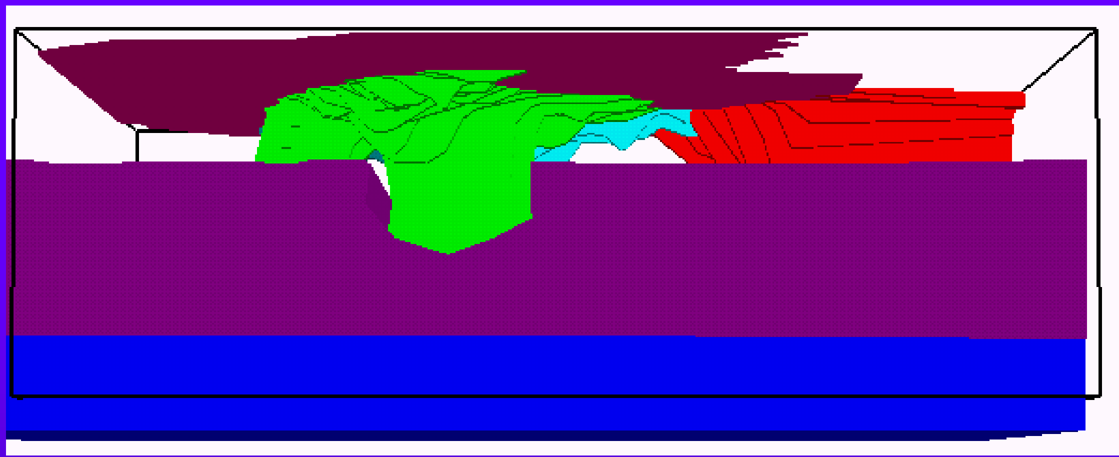
Generalised Diagram showing Unrealistic Depth of Root at Time of Emplacement



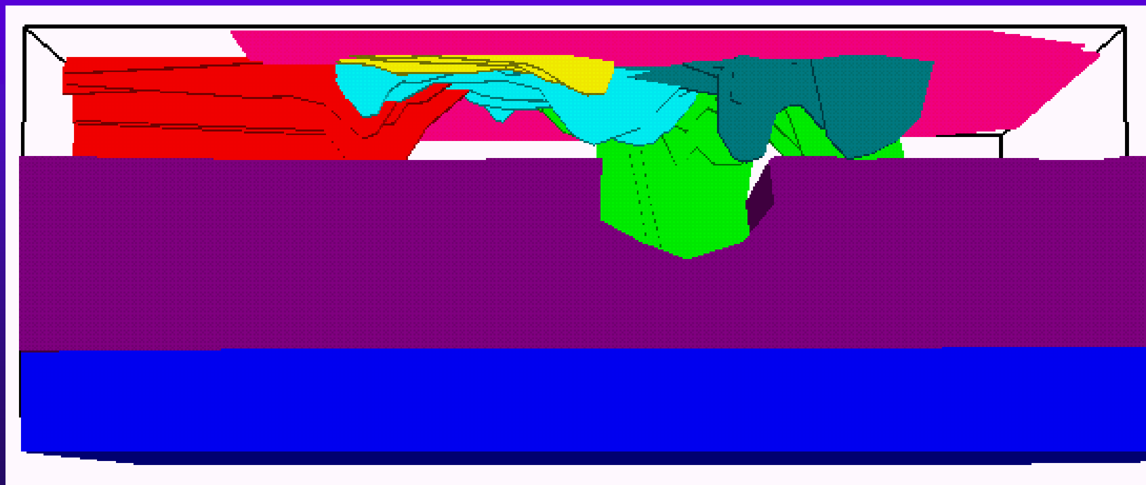
Proposed Solution - Country Rock Density Variation with Depth

- It is likely that the density of the pluton root is fairly homogeneous with depth, compared to the increase in density with depth of the country rocks.
- Can construct another 3D model with the country rock densities increasing with depth, based on the calculations of Masters and Shearer(1995).
- An upper layer of 2.77 g/cm^3 extends to a depth of 6.5 kms, the next layer has a density of 2.85 g/cm^3 and extends to 16 kms, and a base layer has a density of 2.9 g/cm^3.
- The top 4-5kms of the plutons are virtually unchanged in shape.
- The new depth of the root is approximately 11 kms.

3 Layer 3D Model

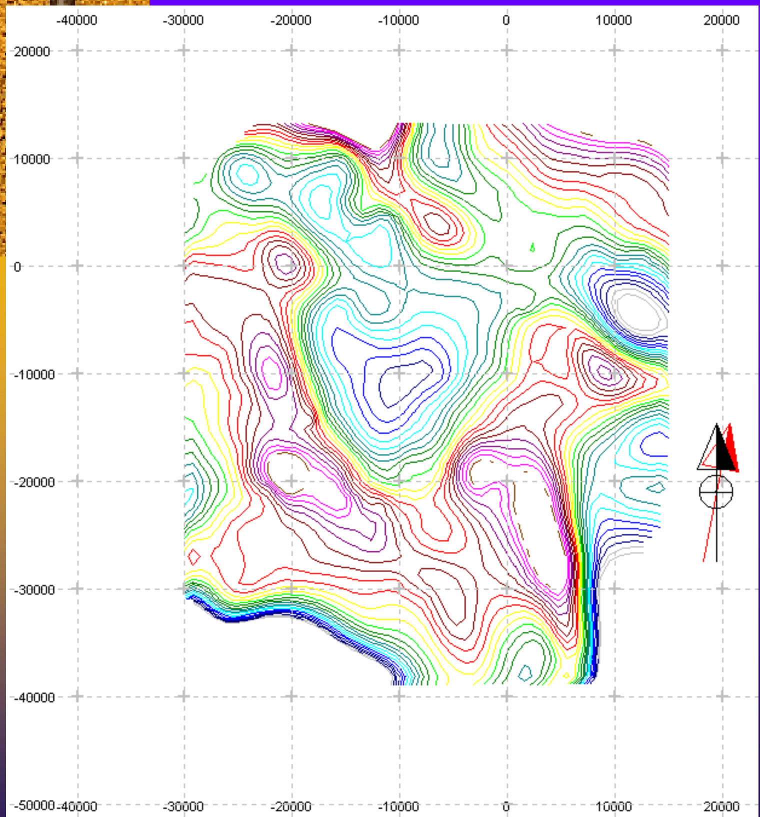


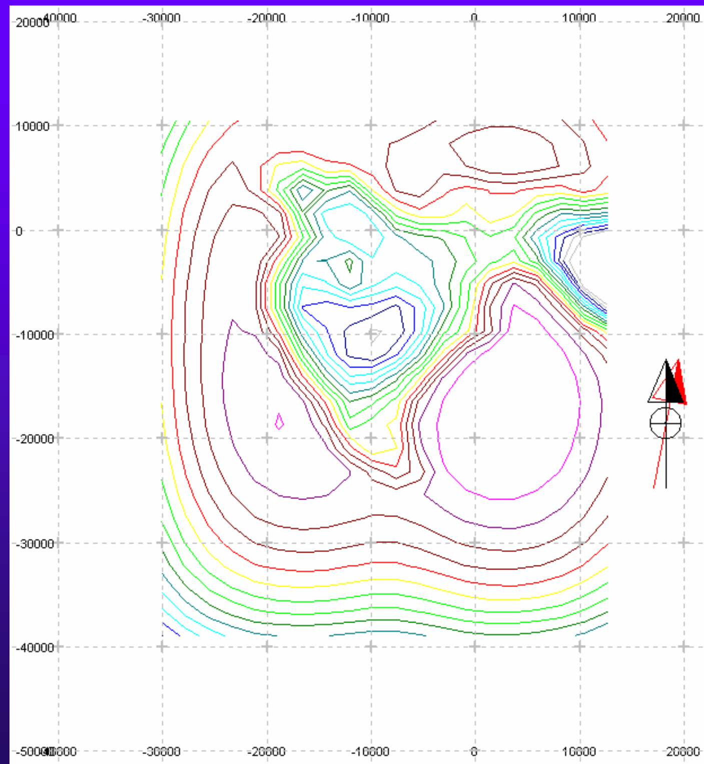
a) Azimuth 000, Inclination 4. (ie. Looking north)



b) Azimuth 180, Inclination 4. (ie. Looking south)

Residual Grid vs 3 Layer Model Response



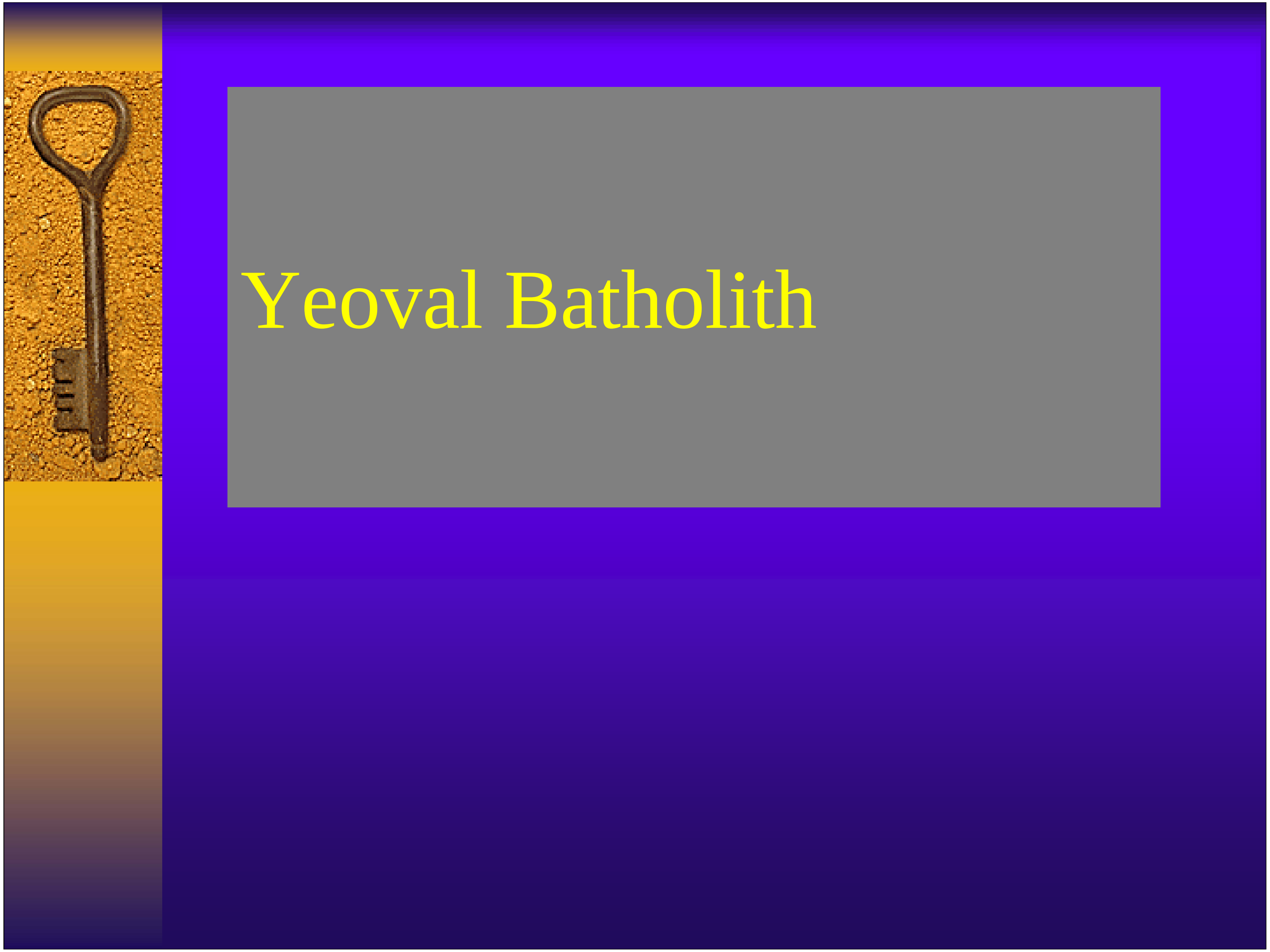


Conclusions

- The Moonbi Adamellite:
  - Has outward dipping contacts, hence the upper portion of the pluton is exposed at the surface.
  - Has a root approximately 2km wide with a strike of 245°.
  - The root can be modelled to a depth of approximately 20km when the density of the country rock is assumed to be constant.
  - The depth of the root can be modelled to a depth of approximately 11km within a layered medium, of density increasing with depth.

Conclusions

- The Bendemeer Adamellite:
  - Does not give a considerable gravity anomaly due to its shallow depth and small density contrast with the surrounding Woolomin Beds.
  - Outward dipping contacts.
  - Relatively shallow with no root evident.

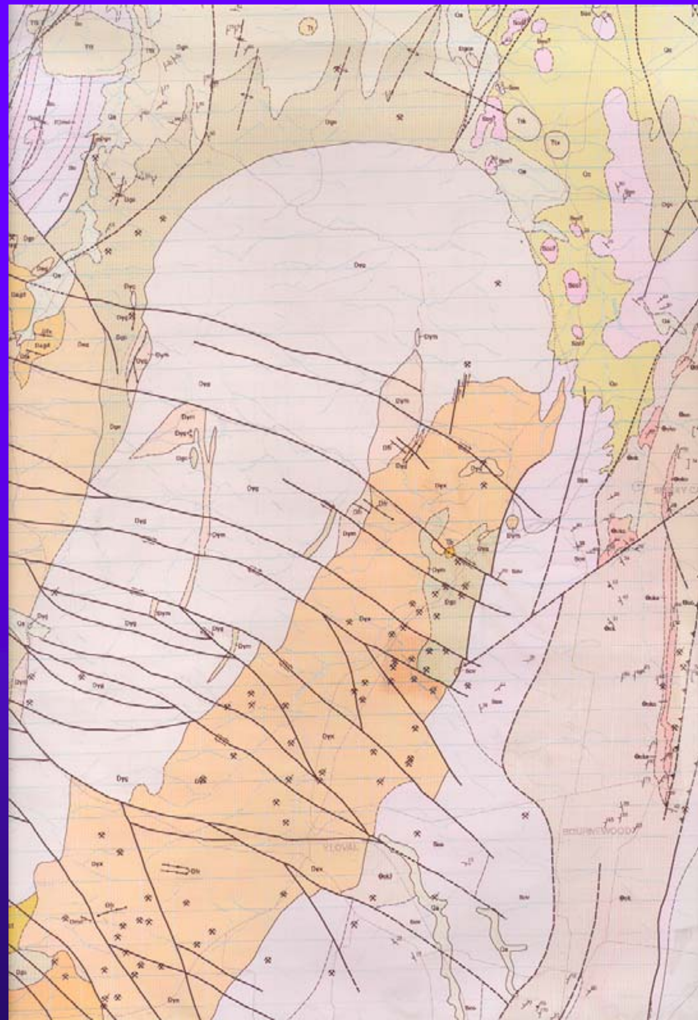

Yeoval Batholith

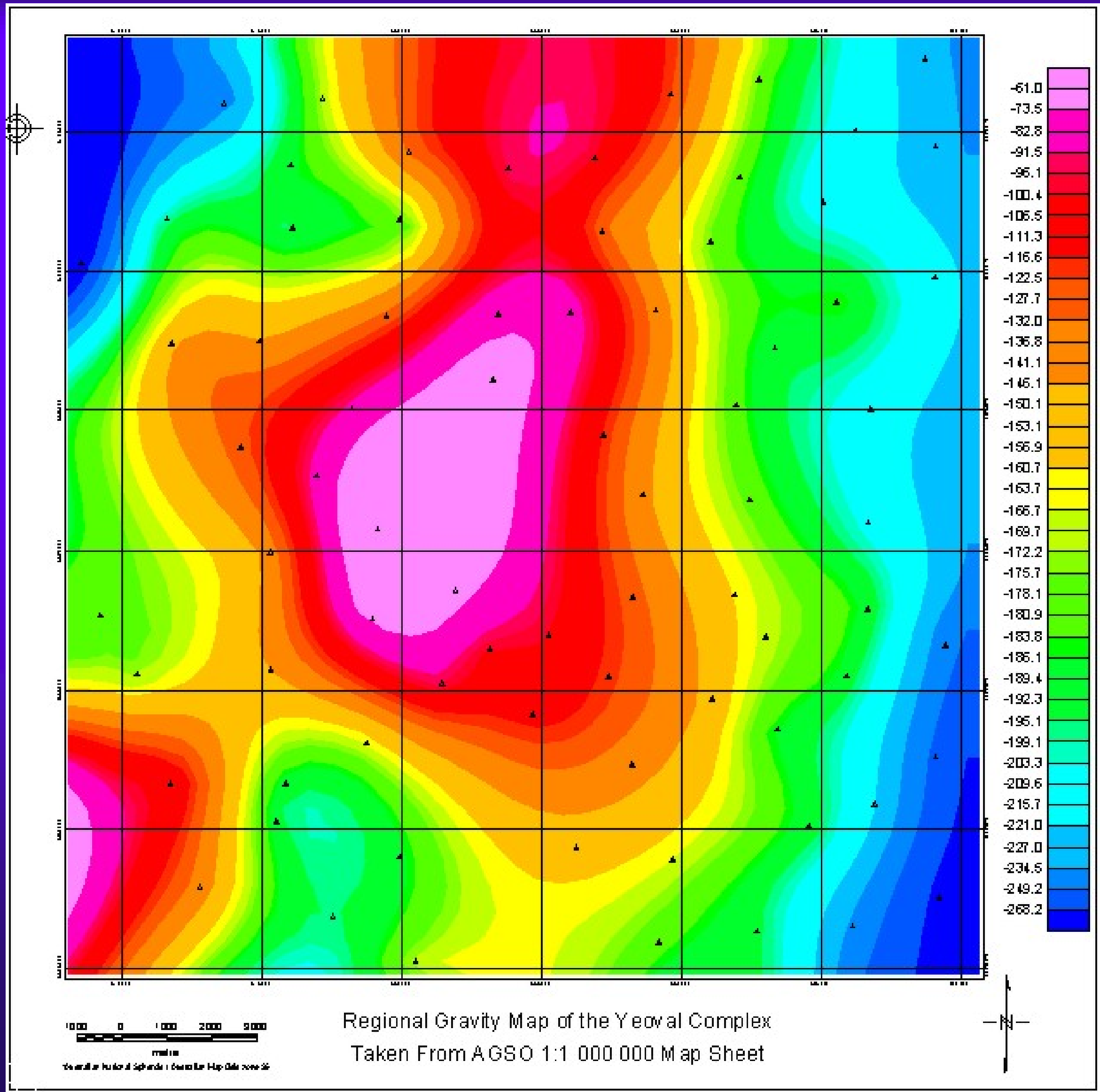
Introduction

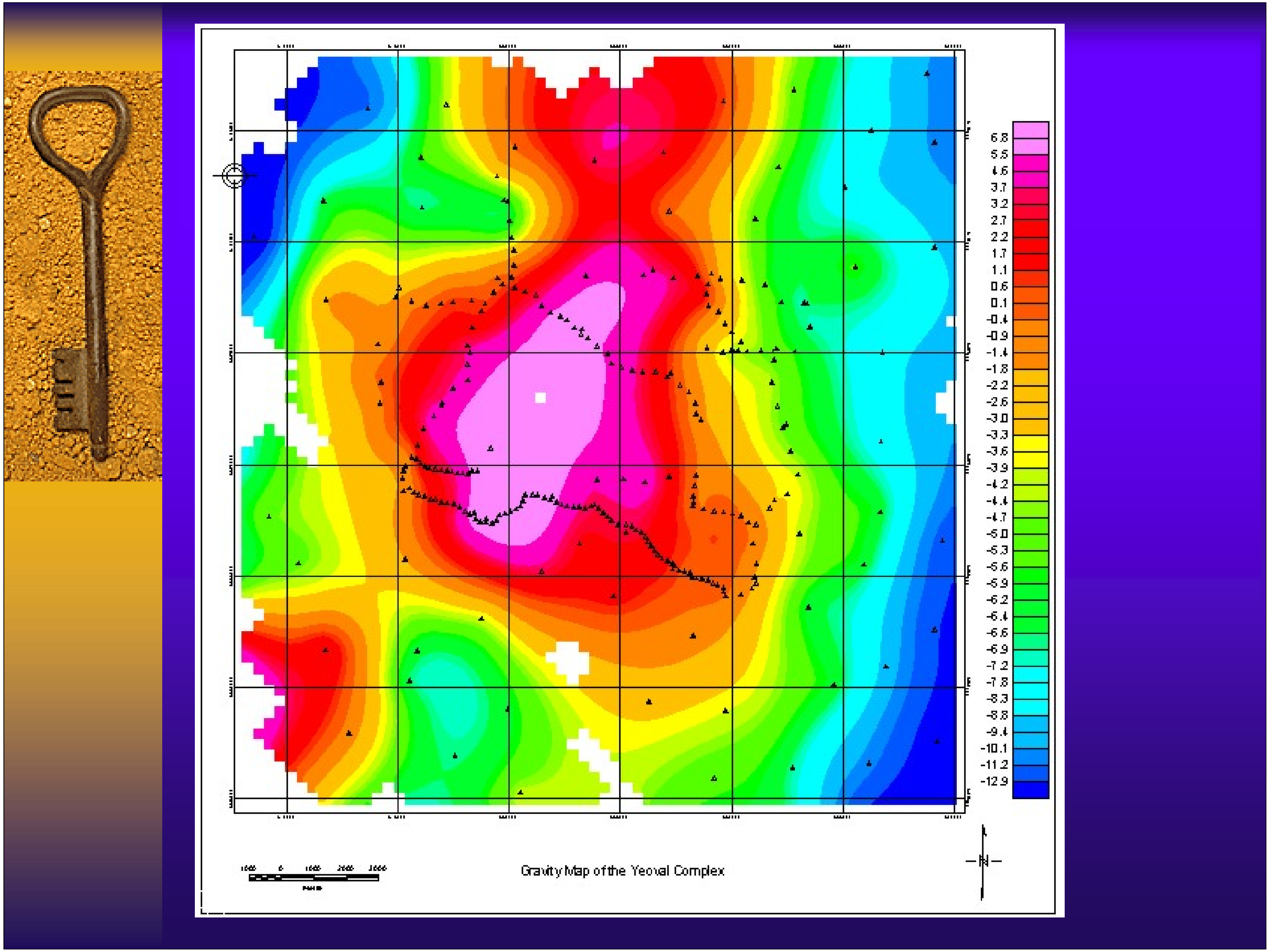
- The Yeoval Batholith extends for some 20 km to the north and south and 15 km to the west of the town of Yeoval in central NSW. The batholith is composed of mainly felsic and intermediate Devonian intrusives from several different phases.
- The Yeoval Complex is the largest phase of the batholith and contains three main rock units ranging from granite to diorite.
- The Yeoval complex of the Yeoval batholith displays a gravity high.

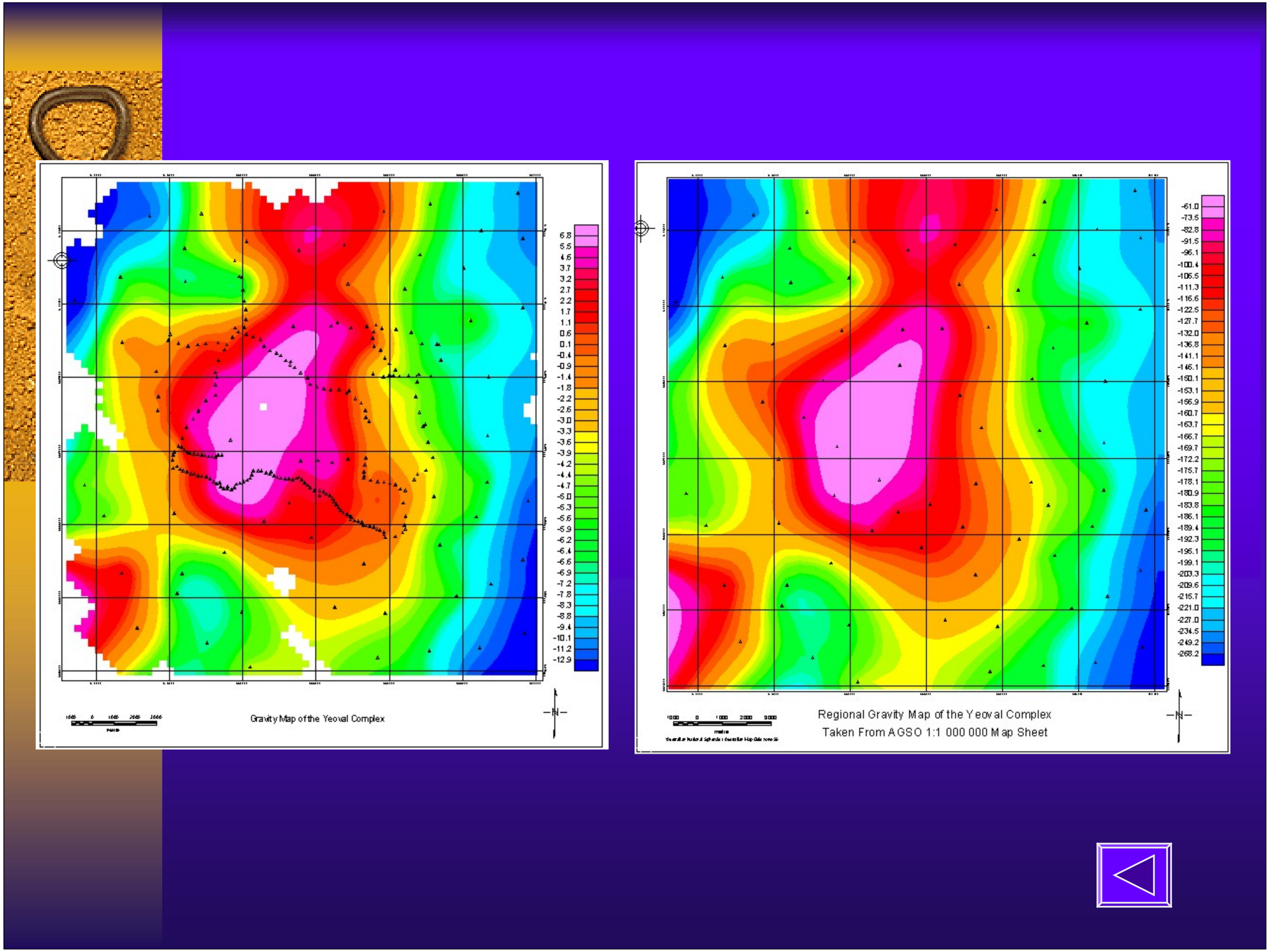
Yeoval Complex

- Largest component of the Yeoval Batholith .
- Four main rock units – Dyg, Dyq Dym and Dyx (Naringla Granodiorite).
- Intrudes the Cuga Burga Volcanics, Canowindra Volcanics, Hanover Formation and Nallawa complex.




-61.0
-73.5
-82.8
-91.5
-96.1
-100.4
-106.5
-111.3
-116.6
-122.5
-127.7
-132.0
-136.8
-141.1
-146.1
-150.1
-153.1
-156.9
-160.7
-163.7
-166.7
-169.7
-172.2
-175.7
-178.1
-180.9
-183.8
-186.1
-189.4
-192.3
-195.1
-199.1
-203.3
-209.6
-215.7
-221.0
-227.0
-234.5
-249.2
-268.2
1000 0 1000 2000 3000
metres
Regional Gravity Map of the Yeoval Complex
Taken From AGSO 1:1 000 000 Map Sheet
N

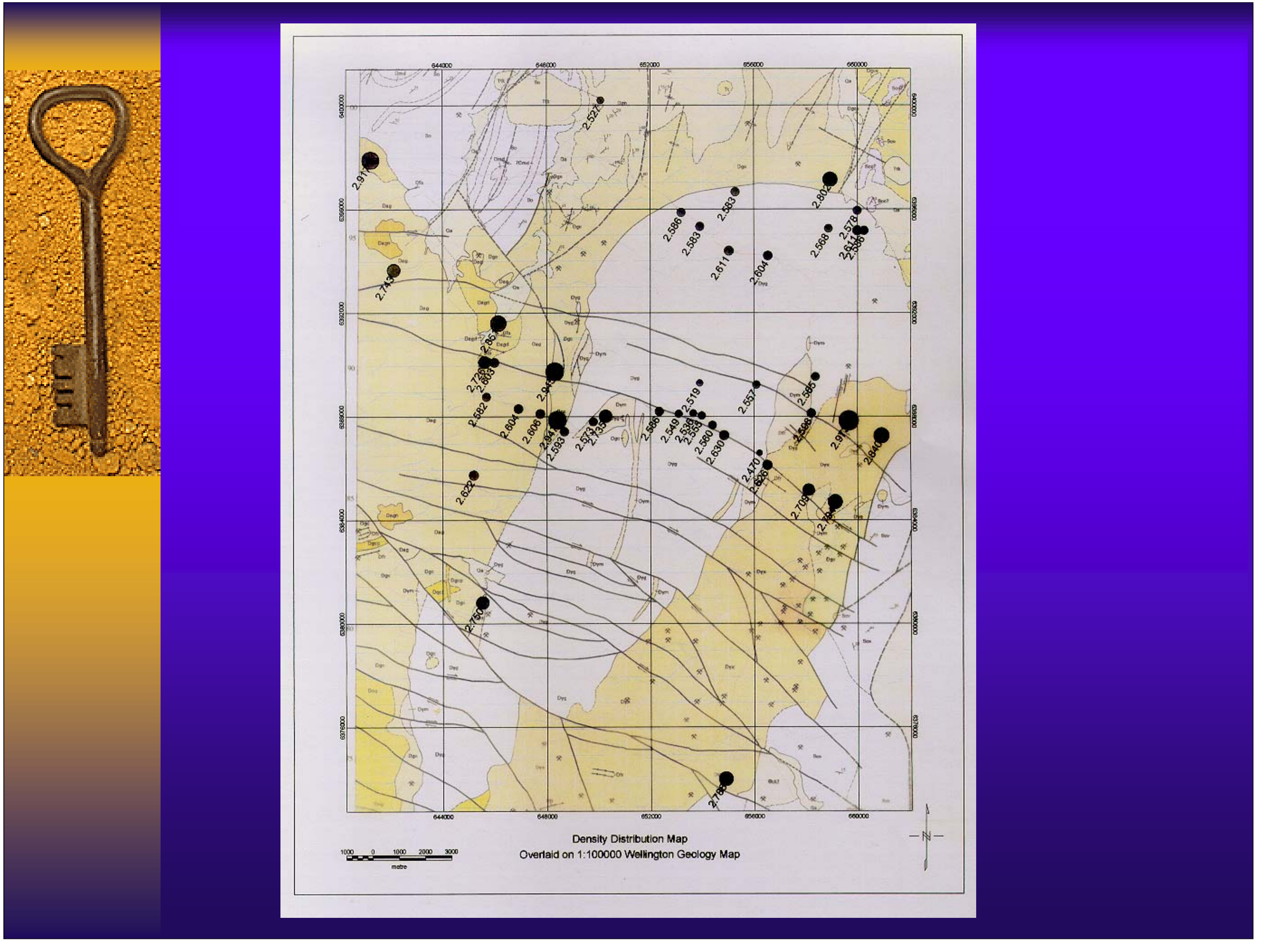

6.8
5.5
4.6
3.7
3.2
2.7
2.2
1.7
1.1
0.6
0.1
-0.4
-0.9
-1.4
-1.8
-2.2
-2.6
-3.0
-3.3
-3.6
-3.9
-4.2
-4.4
-4.7
-5.0
-5.3
-5.6
-5.9
-6.2
-6.4
-6.6
-6.9
-7.2
-7.8
-8.3
-8.8
-9.4
-10.1
-11.2
-12.9
Gravity Map of the Yeoval Complex
N

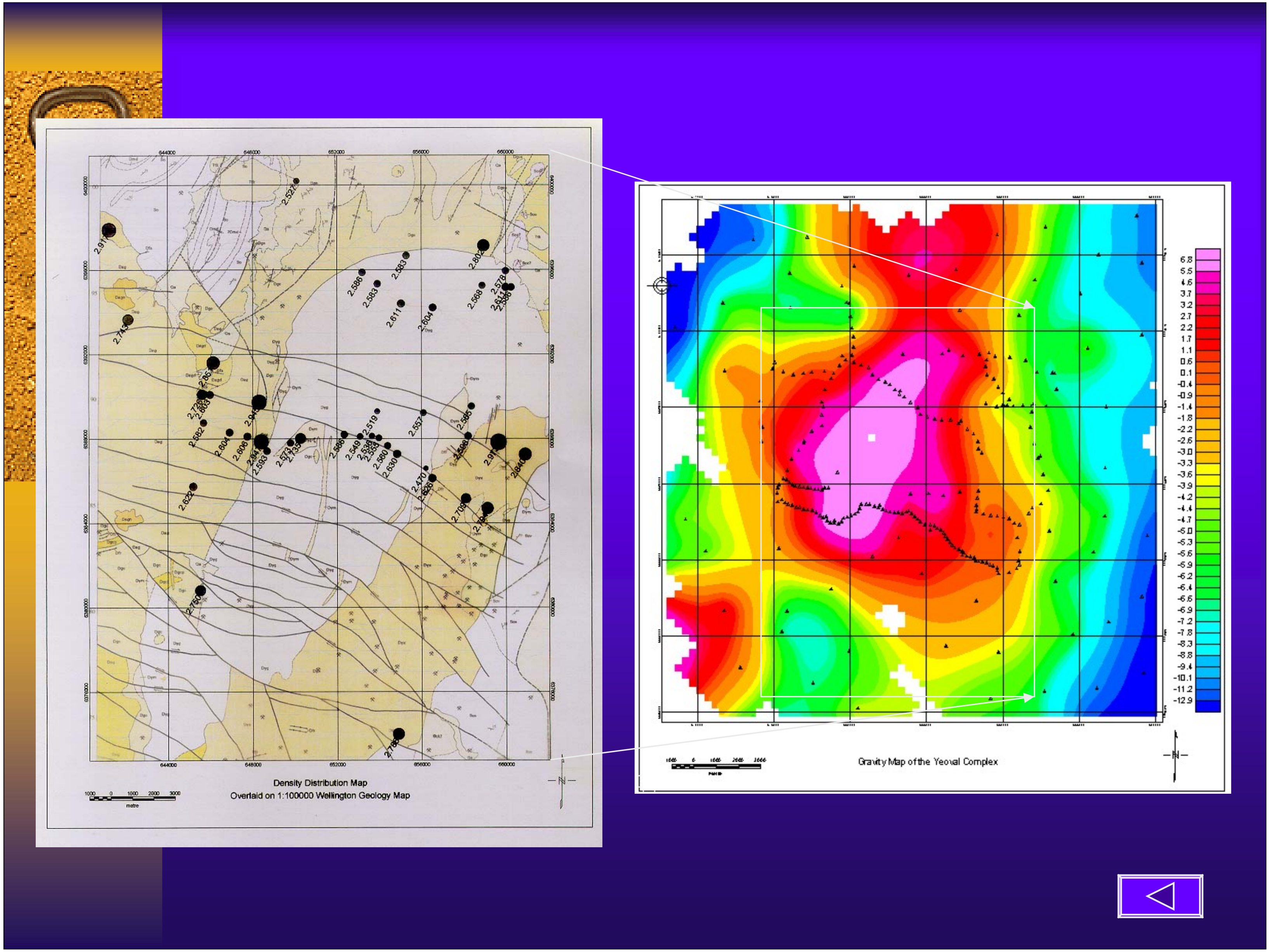

Gravity Map of the Yeoval Complex
Regional Gravity Map of the Yeoval Complex
Taken From AGSO 1:1 000 000 Map Sheet

Modelling

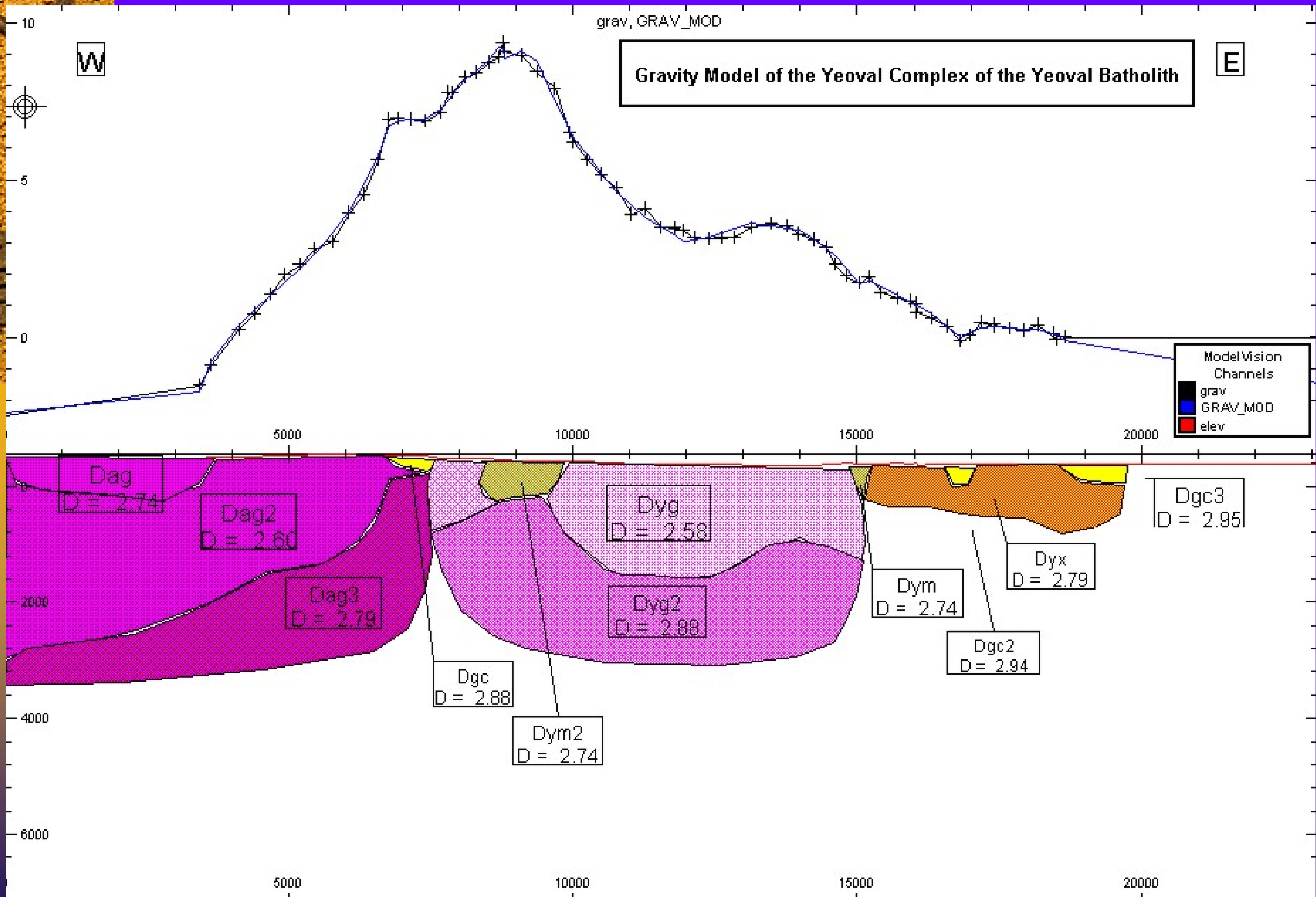
- All modelling was done on the two detailed profiles across the main granite using ModelVision Pro.
- Direct Method of modelling.
- A background density of 2.65 has been used for most models.
- Measured surface densities have been used on the surface of the preferred models.
- To the Models.

This gives way to a wide variety of possible models as only two of these values are known……

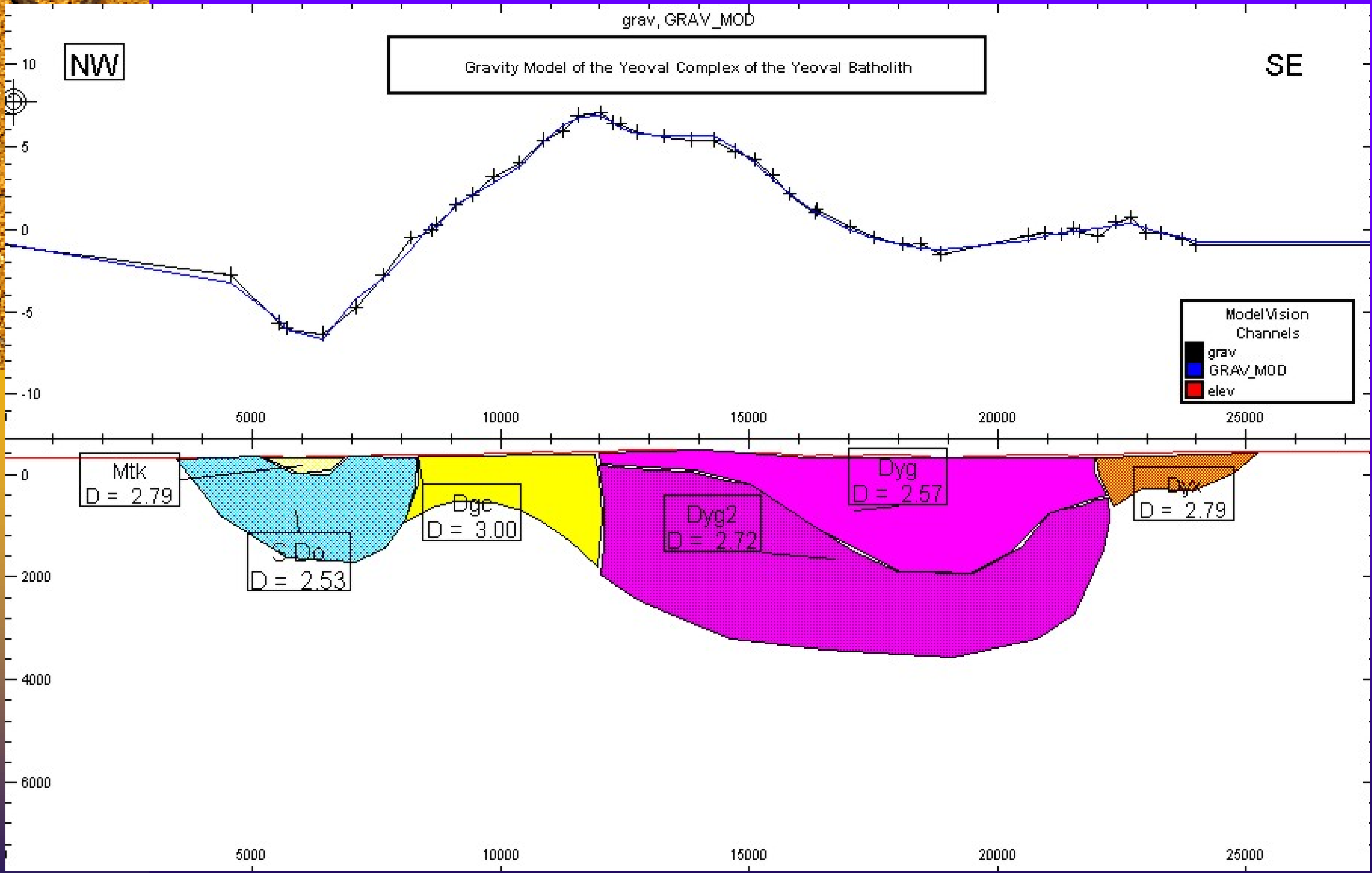

Density Distribution Map
Overlaid on 1:100000 Wellington Geology Map


Density Distribution Map
Overlaid on 1:100000 Wellington Geology Map
Gravity Map of the Yeoval Complex

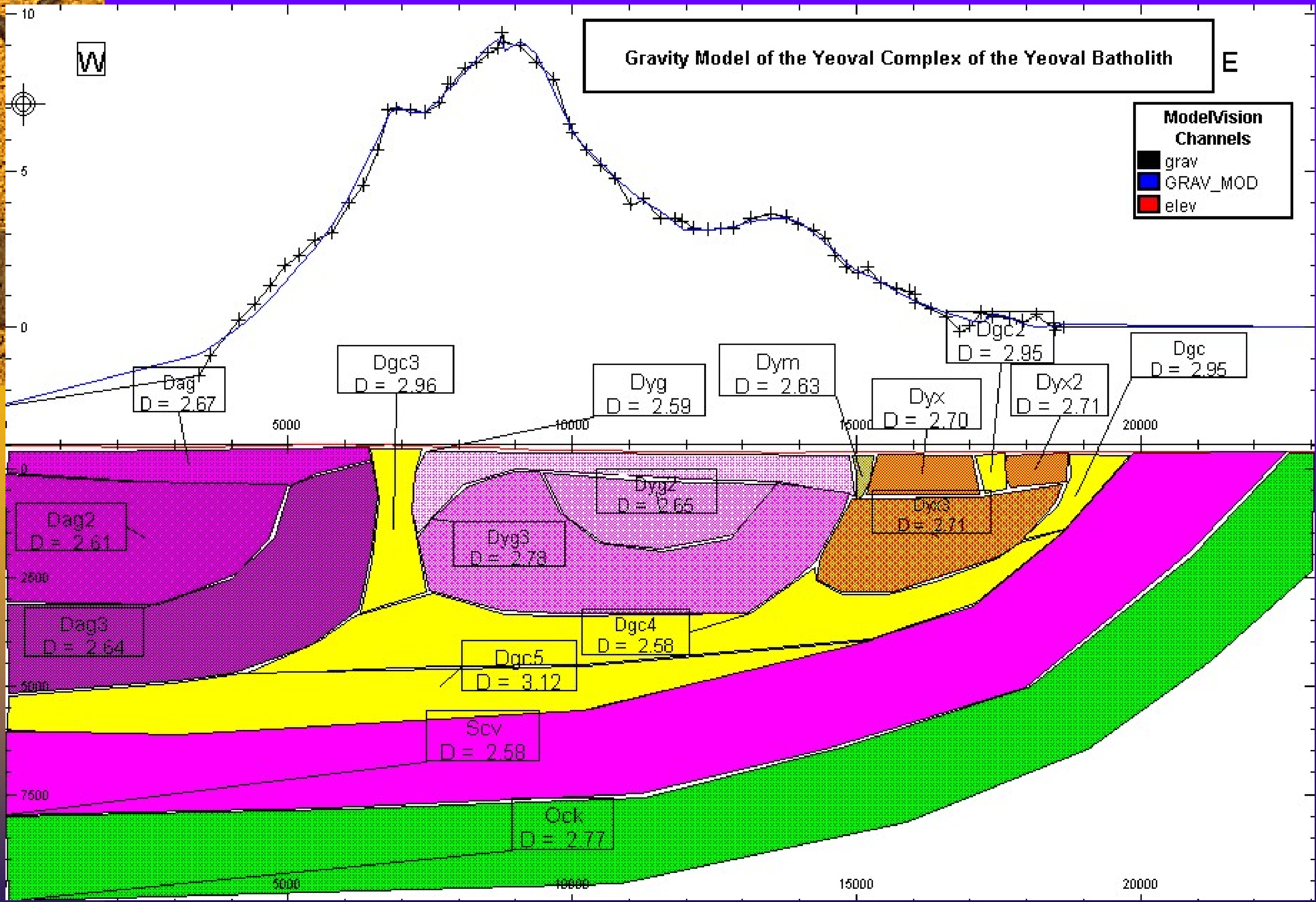
Preferred Model – Main E-W Profile



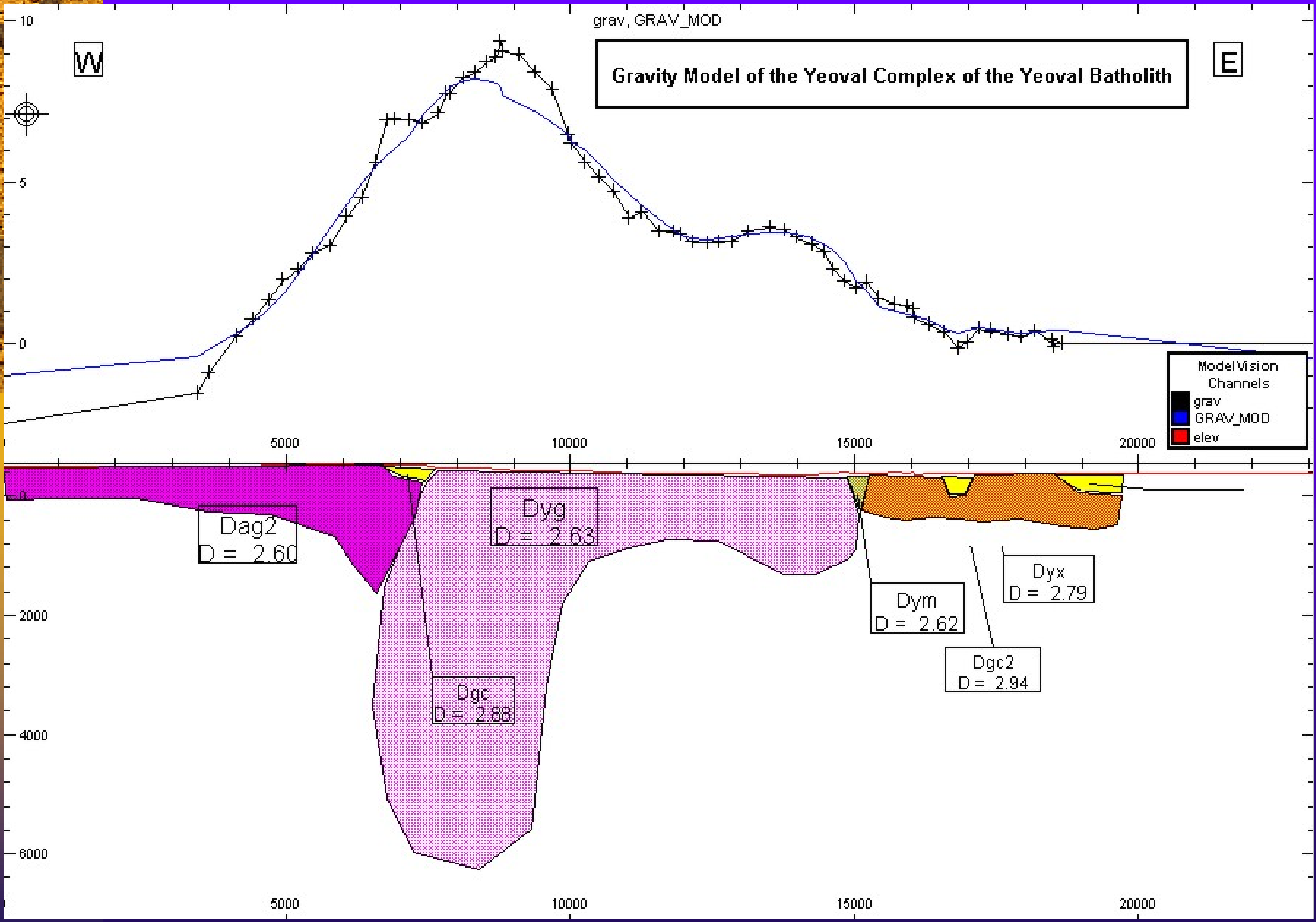
Preferred Model – Secondary Profile



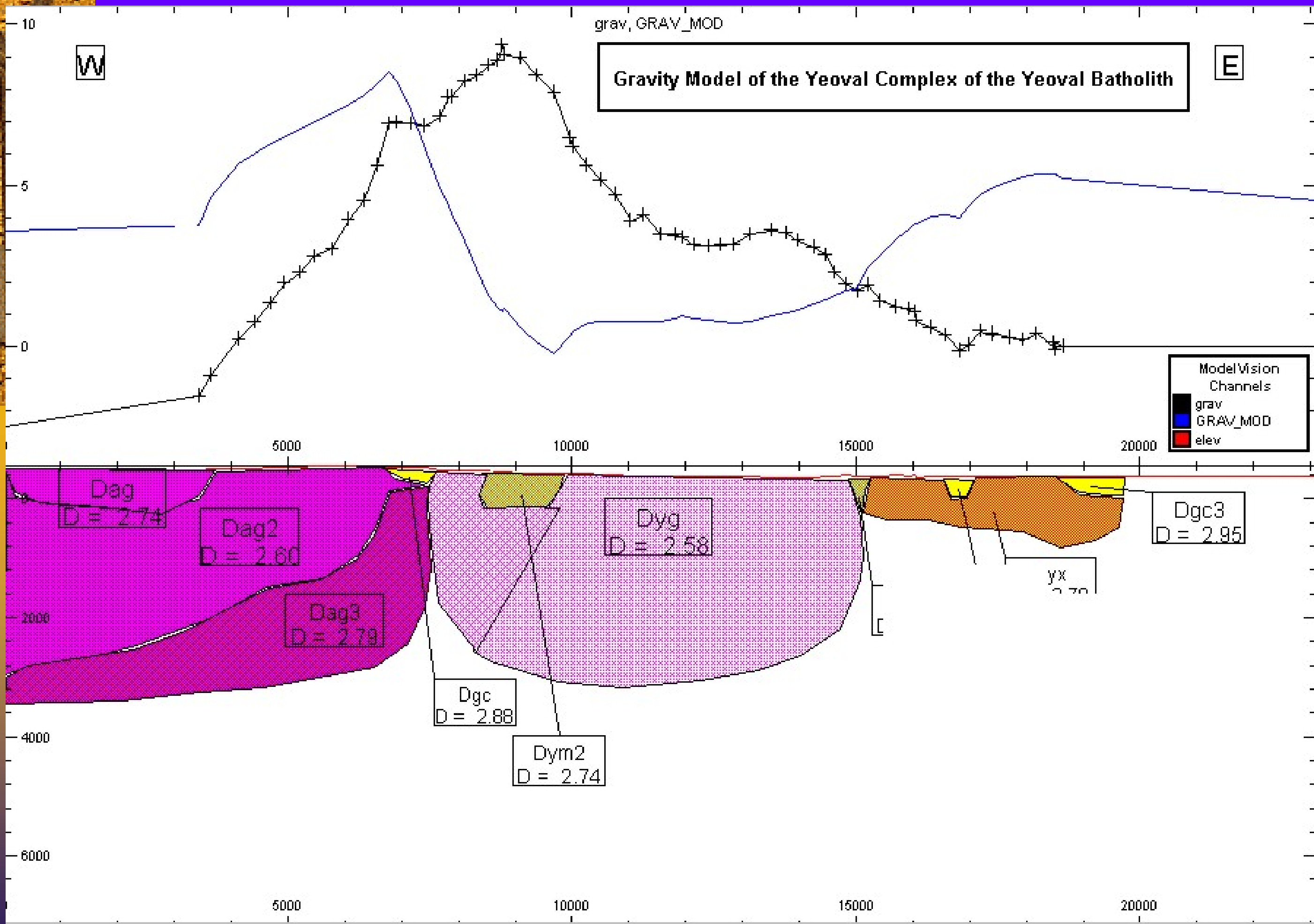
Model – Main E-W Profile

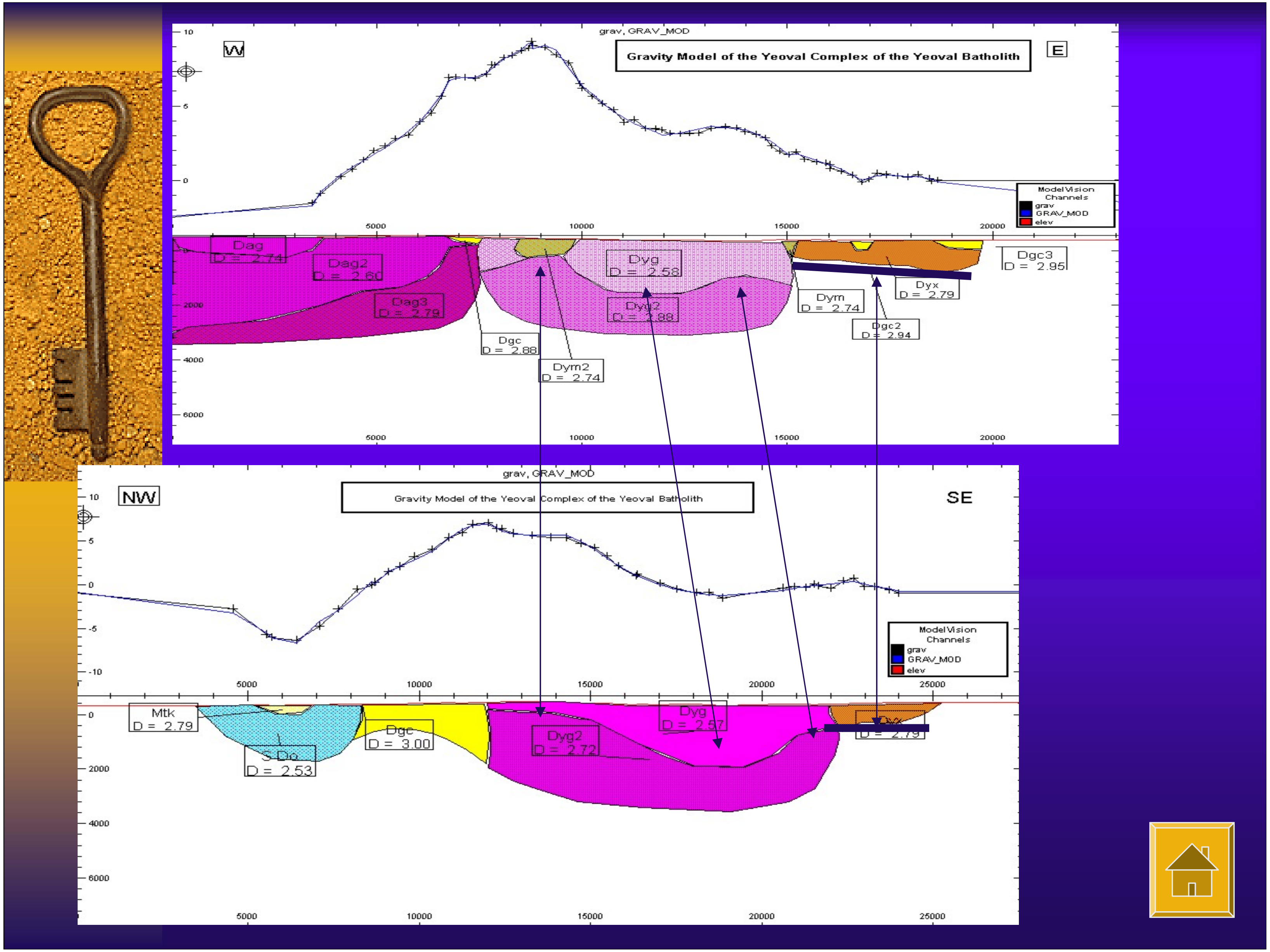


Model – Main E-W Profile



Model – Main E-W Profile




grav, GRAV_MOD
W
E
Gravity Model of the Yeoval Complex of the Yeoval Batholith
ModelVision Channels
grav
GRAV_MOD
elev
Dag D = 2.74
Dag2 D = 2.60
Dag3 D = 2.79
Dyg D = 2.58
Dyg2 D = 2.88
Dgc D = 2.88
Dym2 D = 2.74
Dym D = 2.74
Dyx D = 2.79
Dgc2 D = 2.94
Dgc3 D = 2.95
grav, GRAV_MOD
NW
SE
Gravity Model of the Yeoval Complex of the Yeoval Batholith
ModelVision Channels
grav
GRAV_MOD
elev
Mtk D = 2.79
S Do D = 2.53
Dgc D = 3.00
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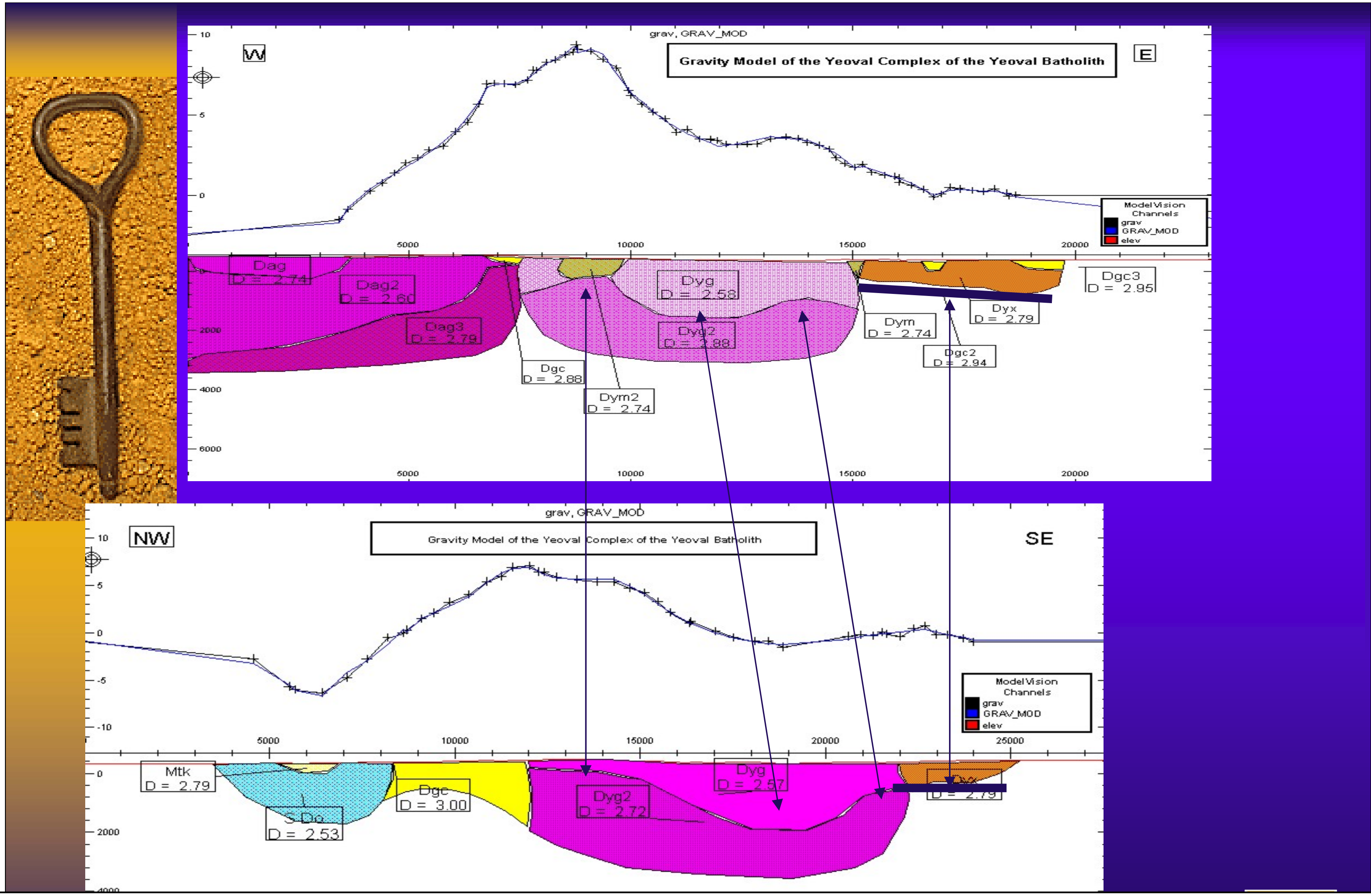

Approx 1500 m is the deepest Dyx has been modeled at and produced a good fit.

Any deeper produces a gravity high……

The best model fits are achieved when the base of the intrusion are at around 3.2 km. However an increased or decrease in depth can be offset with an increase or decrease in density at depth.

Conclusions

- The fine grained pink granite (Dyg) cannot extend to depth and produce a gravity high.
- The Naringla Granodiorite has a approx. max. depth of 850 m.
- A minimum density of approx. 2.76 g/cm^3 is required at depth for the model to match the measured gravity.
- The depth of Unit Dyg is not well constrained.
- Volume of Unit Dym is not clear.
- Vertical or sub vertical sided intrusions produce the best model fits.